8. Hazard Assessment

8.1 Introduction

8.1.1 Background

8.1.1.1 This section of the EIA presents the Hazard Assessment for the Route 16 Alternative Alignment. The Alternative Alignment passes within the Consultation Zones of Tai Po Road Water Treatment Works (WTW), Shek Lei Pui WTW and Sha Tin WTW, all of which are classified as Potentially Hazardous Installations (PHIs) due to the use of liquid chlorine in 1 tonne containers. The alignment also passes near to two bulk LPG installations at Carado Gardens, Tai Wai and the Lai Chi Kok Reception Centre.

8.1.1.2 The Alternative Alignment is identical to the Conforming Alignment in respect of the Sha Tin end of Route 16. The Sha Tin Section does not require further consideration in this assessment. In respect of the LPG installation at Carado Gardens, the Gas Standards Office of EMSD have advised that a Quantitative Risk Assessment (QRA) is not required, as Route 16 lies well outside the fireball radius. This section of the EIA therefore presents Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs (*Section 8.2*) as well as the LPG installation at the Lai Chi Kok Reception Centre (*Section 8.3*).

8.1.2 Scope and Objectives

8.1.2.1 A Hazard Assessment is required to demonstrate that the risk to construction workers and road users complies with the requirements of the Risk Guidelines in Annex 4 of the EIAO-TM.

8.1.2.2 The objectives of the Hazard Assessment are as follows:

- identification of all hazardous scenarios associated with transport, storage and processing of hazardous materials (including chlorine) taking into account equipment failures and human error;
- 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; and
- identification and assessment of practicable, cost-effective risk mitigation measures to demonstrate the compliance with Hong Kong Risk Guidelines.

8.1.2.3 The Hazard Assessment covers both the construction and operation phases of Route 16.

8.2 Hazard Assessment for Tai Po Road and Shek Lei Pui WTWs

8.2.1 Overall Approach

8.2.1.1 A Preliminary Environmental Review was previously carried out by the Consultants in July 1998 for the Alternative Alignment of Route 16. This study identified that the risk for Route 16 due to Tai Po Road and Shek Lei Pui WTWs may lie in the upper 'ALARP' (As Low as Reasonably Practicable) or unacceptable region of the Hong Kong Risk Guidelines, necessitating consideration of significant mitigation measures. Various measures were suggested, including modifications to the WTWs as well as to Route 16. Of these measures, enclosure of Route 16 in the vicinity of the WTWs was considered feasible. Furthermore, WSD have indicated that modification of Tai Po Road WTW to facilitate using 50kg cylinders is feasible (subject to the availability of a suitable site for construction of a new building within the boundary of the WTW).

8.2.1.2 Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs were carried out by the Consultants in 1995 as part of the *CE48/93, Hazard Assessment for 5 Small WTWs*. These studies assessed the risks to the overall population in the vicinity of the WTWs, including the Route 16 Conforming Alignment. The conclusion of these studies was that the risks due to the two WTWs could be reduced to ALARP levels by implementation of a package of mitigation measures.

8.2.1.3 This package of mitigation measures comprised:

- improvements to the access road;
- installation of door alarms;
- provision of a means of immobilising the truck during unloading;
- improved QA checks on chlorine containers;
- improved truck unloading procedures;
- improved fire safety provisions;
- provision of a portable scrubber;
- formulation of on-site and off-site emergency plans; and
- conduct of emergency exercises;

8.2.1.4 WSD are in the process of implementing these measures, including provision of permanent scrubbers at each WTW.

8.2.1.5 The overall approach to this Hazard Assessment is as follows:

i) assess the risk to Route 16 without enclosure for the WTWs with the modifications as recommended in the 1995 Hazard Assessment (the 'base case');

ii) determine the length of road enclosure required to comply with the Risk Guidelines (assuming no further modifications are made to the WTWs);

iii) examine various mitigation options for the WTWs, including modification to facilitate using chlorine in 50kg cylinders; and

iv) re-assess the required length of road enclosure assuming implementation of the mitigation options as per iii.

8.2.1.6 The methodology for the Hazard Assessment follows that of the 1995 Hazard Assessment.

8.2.2 Background Information on Tai Po Road and Shek Lei Pui WTWs

Location

Tai Po Road WTW

8.2.2.1 Tai Po Road WTW is located to the south of the Kowloon Byewash Reservoir and to the west side of Pipers' Hill close to Tai Po Road. The site location is shown in *Figure 8.2a* with the chlorine store location marked by '**x**'. The site is accessed from Tai Po Road. The access road is about 400m long and forms part of the Monkey Trail. The road to the site is narrow and winding. The site is at 100m above Principal Datum. To the south of the site the ground falls towards Ching Cheung Road. To the north, Kam Shan forms a natural barrier to the passage of dense chlorine clouds.

Shek Lei Pui WTW

8.2.2.2 Shek Lei Pui WTW is located close to the Kowloon Reception Reservoir on the southern edge of the Kam Shan Country Park. The site location is shown in *Figure 8.2a* with the chlorine store location marked by '**x**'. The site is accessed from Tai Po Road. The access road is some 800m long and passes over the Monkey Trail and the dam at the end of Kowloon Byewash Reservoir. The road to the site is narrow and winding, although not steep.

Operations

Tai Po Road WTW

8.2.2.3 Tai Po Road WTW normally stores 4 x 1 tonne drums, including the drums at the two gas draw-off units, one of which is for post-chlorination and the other for pre-chlorination. There is no standby or auto changeover system. The need to manually changeover a drum is signalled by a low pressure alarm. The operator can also check the drum weigh scale to ascertain the need to change a drum.

8.2.2.4 Each of the two gas draw-off units is connected to two chlorinators via a manifold. An electrically operated gas isolating valve, installed upstream of the chlorinator, is fitted with a pressure reducing unit to avoid chlorine passing at full pressure to the regulator.

8.2.2.5 The storage room adjoining the draw-off room has 3 x 1-tonne drum storage positions. The doors between the two rooms are normally closed and only open during changeover of drums. During the Consultants' site visit in January 1999, construction work was in progress to install a chlorine scrubbing system and underfloor ventilation extract ducts within the chlorine store. The construction work also includes a door seal and provision of an alarm on the main doors.

8.2.2.6 Drums are unloaded from the truck outside the store using the hoist on the truck. The drums are lowered onto a wood platform positioned just inside the store. The drums are then manhandled into a position where they can be picked up by the store overhead hoist, which is manually operated. Stock is used in order of receipt in order to minimise the storage period of a particular drum. If the works shuts down, or runs at low capacity for any significant length of time, it is normal for stocks to be reduced to minimum levels to avoid long storage times.

8.2.2.7 Three chlorine leak detectors are provided in the store. Upon chlorine leak detection (detectors set at 3ppm), the alarm is raised and the low and high level motorised louvres shut and the ventilation fans stop automatically.

8.2.2.8 The throughput and chlorine consumption of Tai Po Road WTW are listed in *Table 8.2a* below.

Shek Lei Pui WTW

8.2.2.9 Shek Lei Pui WTW uses chlorine in 1 tonne drums and has a storage capacity of up to 9 tonnes of chlorine, including the duty and standby drums. The conversion from a gas draw-off system to a liquid draw-off system with evaporators was completed in 1998. The works is expected to operate continuously throughout the year. *Table 8.2a* below shows the throughput and chlorine consumption at Shek Lei Pui WTW.

8.2.2.10 Drums are unloaded from the truck outside the store using the hoist on the truck. The drums are then manhandled into a position where they can be picked up by the electrically-operated store overhead crane. Full and empty drums are clearly labelled in the store.

8.2.2.11 The changeover between duty and standby drums is initiated automatically by a low pressure alarm. The gas produced by the evaporators, which have a capacity of 2720 kg/day, is fed to the chlorinators. There are three chlorinators, two of 1350 kg/day capacity for pre-chlorination and common standby purposes and one of 450 kg/day capacity for post-chlorination.

8.2.2.12 Chlorine detectors are provided in the storeroom. On chlorine leak detection (set at 3ppm), the alarm is raised and the low and high level motorised louvres shut and the ventilation fans stop. At the time of the Consultants' visit to Shek Lei Pui WTW in January 1999, a chlorine scrubbing system was being installed.

Table 8.2a Plant Operating Data

Works	Tai Po Road	Shek Lei Pui
Chlorine storage (tonnes)	4	9
Average throughput (Ml/d)	32	76
Average dosing rate (mg/l)	4	4
Maximum pre-chlorination dosing rate (mg/l)	10	15
Maximum post-chlorination dosing rate (mg/l)	3	3
Annual consumption of chlorine (tonnes)	46.72	111
Average tonnes/delivery	2	2
Average number of deliveries/year	24	60
Type of container (tonnes)	1	1
Volume of store (m^3)	100	200

Local Topography

Tai Po Road WTW

8.2.2.13 Tai Po Road WTW is located in a basin, around 50m deep but with an opening to the south west. There are steep but well maintained cut slopes to the east of the building and to the east of the access road. Kam Shan to the north of the WTW, as well as the high ground to the east of Tai Po Road, form a natural barrier to the passage of dense chlorine clouds.

8.2.2.14 The proposed Route 16 Alternative Alignment is immediately adjacent to the north-west boundary of the Tai Po Road WTW site at an elevation 30m below the level of the chlorine store. The topography surrounding Tai Po Road WTW may cause chlorine releases to effectively 'channel' along the Route 16 alignment, rather than disperse in the direction of the wind. A suitably conservative approach to the modelling of the effects of chlorine releases on Route 16 has therefore been adopted for this study, ie use of flat terrain chlorine dispersion estimates from the 1995 Hazard Assessment Study (generally conservative when applied to real terrain) and consideration of chlorine channeling into the tunnel (see *Section 8.2.5* below).

Shek Lei Pui WTW

8.2.2.15 Shek Lei Pui WTW is at 135m above Principal Datum and is located in a basin formed around the service reservoir by tree-covered ridges some 10-20m in height. To the SSW of the WTW there is an opening in the ridges leading to a steep valley also running SSW (see *Figure 8.2a*).

Weather

8.2.2.16 The meteorological data for this study is as per the Consultants' 1995 Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs (*Table 8.2b* below).

Table 8.2b Weather Class - Wind Direction Probabilities at Cheung Sha Wan Weather Station

Probability	Wind speed and stability class					
Wind direction	2.5B	1D	3.5\D	7D	3E	1F
N	1.36%	0.49%	2.13%	0.48%	1.10%	2.87%
NNE	1.02%	0.62%	3.23%	0.18%	1.29%	2.82%
NE	0.88%	0.55%	1.78%	0.06%	1.04%	3.10%
ENE	1.60%	0.71%	5.35%	0.29%	3.15%	4.30%
E	2.96%	0.69%	4.48%	0.06%	2.38%	5.55%
ESE	1.32%	0.26%	1.35%	0.00%	0.40%	1.79%
SE	0.33%	0.02%	0.12%	0.00%	0.05%	0.48%
SSE	0.47%	0.07%	0.42%	0.05%	0.23%	1.16%
S	1.13%	0.27%	0.86%	0.02%	0.28%	1.82%
SSW	3.91%	0.77%	3.37%	0.50%	0.69%	2.44%
SW	2.27%	0.42%	0.96%	0.01%	0.09%	2.06%
WSW	1.30%	0.54%	0.16%	0.00%	0.02%	2.72%
W	0.87%	0.55%	0.27%	0.01%	0.24%	3.17%
WNW	0.04%	0.04%	0.01%	0.00%	0.01%	0.27%
NW	0.10%	0.09%	0.04%	0.00%	0.00%	0.66%
NNW	0.24%	0.23%	0.11%	0.02%	0.12%	1.26%

8.2.3 Route 16

8.2.3.1 The proposed Alternative Alignment of Route 16 is shown in *Figure 8.2a*. The Route will connect the Lai Wan Interchange in West Kowloon to the future Trunk Road T3 and Che Kung Miu Road in Sha Tin. At the West Kowloon end, the main alignment starts at Lai Wan Interchange with connections to the primary distributor P1 on the West Kowloon Reclamation. The Route passes over Wai Man Tsuen and continues through Butterfly Valley. After crossing over Ching Cheung Road, the Route passes the Eagle's Nest Tunnel and the Sha Tin Heights Tunnel before meeting the Trunk Road T3. At its closest approach, Route 16 passes 30m to the north of Tai Po Road WTW. The southern portal of the Eagle's Nest tunnel lies approximately 70m west of the chlorine store at Tai Po Road WTW. Shek Lei Pui WTW is about 350m north-west of Route 16 (closest approach), whilst the chlorine store at Shek Lei Pui WTW lies 65m above the elevation of the nearest section of Route 16. The total above-ground length of Route 16 lying within the Consultation Zones of Tai Po Road and Shek Lei Pui WTWs is 1 km. Details of the ventilation arrangements for the Eagle's Nest tunnel are presented in *Annex 8A*.

8.2.3.2 *Table 8.2c* below summarises the traffic data (peak hour vehicle flows predicted for year 2019) used as the basis for this Hazard Assessment. *Tables 8.2d* and *8.2e* summarise the assumptions made on off-peak vehicle flows and vehicle occupancy, based on data in the 1996 Annual Traffic Census. The average traffic speed is 35 km/hr.

Table 8.2c Peak Hour Vehicle Flows on Route 16 for 2019

Vehicle type	Peak hour flows (AM peak) (No. vehicles)	
	North bound	South bound
Motorcycle	100	200
Private Car	1230	2390
Taxi	230	440
Passenger Van	40	80
Light Goods Vehicle (LGV)	870	810
Medium Goods Vehicle (MGV)	510	480
Heavy Goods Vehicle (HGV)	510	480
Bus	130	120
Special Public Bus (SPB)	40	80

Table 8.2d Off Peak Vehicle Flows (estimated from Annual Traffic Census, 1996)

Time period	Off-peak vehicle flow (as % of peak flow)
Peak	100%
Working Day	80%
Weekend Day	70%
Night	10%

Table 8.2e Vehicle Occupancy (based on Annual Traffic Census, 1996)

Vehicle type	Occupancy (Number of people per vehicle) (Note 1)
Motorcycle	1.1
Private Car	1.1
Taxi	2.4
Passenger Van	3.2
Light Goods Vehicle (LGV)	1.7
Medium Goods Vehicle (MGV)	1.7
Heavy Goods Vehicle (HGV)	2.0
Bus	80
Special Public Bus (SPB)	25

Note 1: Data refers to vehicle occupancy at peak hours - off-peak occupancy is 68% of peak occupancy (overall) based on sampling of 1996 ATC data for various roads

8.2.4 Methodology

Overview

8.2.4.1 The methodology for the Hazard Assessment follows that of the Consultant's previous Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs, undertaken as part of the *CE48/93, Hazard Assessment for 5 Small WTWs.*

8.2.4.2 The assessment of the impact of chlorine releases on the transient population of Route 16 is based on the latest research undertaken on behalf of the UK Health and Safety Executive contained in the document *The implications of major hazards sites in close proximity to major transport routes, Contract Research Report 163/1998.* The methodology for this assessment is described further below.

Assessment of Impact of Chlorine Releases on Route 16

8.2.4.3 One of the key considerations in assessing the impact of chlorine releases on major highways is the extent to which gas could infiltrate into moving vehicles so as to impair driving ability. If this happens then vehicles may slow down, or road accidents could occur, causing backing-up of traffic and increasing both the number of people exposed to the chlorine release and their exposure duration.

8.2.4.4 *The HSE Contract Research Report (CRR) 163/1998* suggests an approach for determining whether traffic build-up could occur, based on whether the toxic load experienced by the driver could exceed the HSE's Dangerous Toxic Load (DTL) criteria. Applying this approach, *HSE CRR 163/1998* concludes that for chlorine facilities (in this case bulk facilities) located approximately 100 metres from a major highway, releases of the order of 1 kg/s would be unlikely to cause an accident, whilst releases of the order of 10 kg/s could cause traffic to come to a standstill.

8.2.4.5 For this study the same approach has been applied. This leads to the conclusion that, for the road without enclosure (nearest open section of road approximately 70 metres from Tai Po Road WTW), instantaneous chlorine releases of 1 tonne or more, and large continuous releases (7 kg/s or more, eg due to large leaks (20mm hole) from 3 or more containers on the truck), could impair driving ability and cause traffic to build-up.

8.2.4.6 The overall approach to the assessment of the impact of chlorine releases on Route 16 is summarised below:

Protection afforded by vehicle

8.2.4.7 Road users are treated effectively as an outdoors population, since there would be little protection afforded by being within a vehicle due to the high air change rate associated with the movement of the vehicle and/or the use of air conditioning (this also recognises the uncertainty of human response to this type of incident, which could be to leave the vehicle).

Impairment of driving ability

8.2.4.8 As noted above, certain large chlorine releases are considered capable of impairing driving ability. In these cases it is assumed that traffic is brought to a standstill, bumper-to-bumper on both carriageways. An exception is made in the case of chlorine releases caused by earthquakes. In this case it is assumed the direct effects of the earthquake would be to cause traffic to come to a standstill, but without backing-up of traffic (Modified Mercali VIII earthquakes, which are of relevance to this study, would affect the steering of motor vehicles).

Peak hour traffic congestion

8.2.4.9 For all chlorine release scenarios it is assumed that the traffic on Route 16 is at a standstill, at peak times (i.e. bumper-to-bumper on one carriageway), which leads to an upper bound estimate of the risk to Route 16.

Escape from the chlorine cloud

8.2.4.10 Account is taken of escape from the chlorine cloud with the probability of escape dependent on the chlorine cloud concentration, following the methodology of the 1995 Hazard Assessment Study, which is the approach used by the UK Health and Safety Executive.

Tunnel population

8.2.4.11 The population associated with the Eagle's Nest Tunnel is treated as effectively an indoor population with a toxic dose equivalent to 1/10th of that received by road users on the open road sections at the equivalent distance from the WTW. The population associated with vehicles in the tunnel is represented as a point receptor located at the southern portal of the tunnel.

8.2.5 Risk Results

Government Risk Guidelines

8.2.5.1 The HKPSG, Chapter 11 require that development proposals within the Consultation Zone of a PHI should be assessed against the Hong Kong Risk Guidelines to ensure that risks to the public are confined to within acceptable limits. The Risk Guidelines are also specified in EIAO TM Annex 4. Acceptable risk levels are defined below.

8.2.5.2 *Individual Risk*: The maximum involuntary individual risk of death associated with accidents arising at PHIs should not exceed 1 chance in 100,000 per year (10^{-5}/yr).

8.2.5.3 *Societal Risk*: The societal risk associated with a PHI should comply with the F-N diagram in Annex 4 of the EIAO-TM. Three areas of risk are shown:

- Acceptable where risks are so low that no action is necessary.
- Unacceptable where risks are so high that they should usually be reduced regardless of the cost or else the hazardous activity should not proceed.
- ALARP (As Low As Reasonably Practicable) where the risks associated with each probable hazardous event at the PHI should be reduced to a level 'as low as reasonably practicable', usually measured as a trade off between the risk reduction afforded and the cost of that reduction. Risk mitigation measures may take the form of engineered measures at the PHI or development (ie population) controls in the vicinity of the PHI.

8.2.5.4 In the case of a new development within the Consultation Zone of an existing PHI the onus is on the developer to implement such measures as are necessary to ensure that risk levels at the development site are ALARP.

Societal Risk Results: Operation Phase

Base Case Risk Results

8.2.5.5 The base case risk results for Route 16 are presented in *Table 8.2f* (Potential Loss of Life values) and *Figure 8.2b* ('FN' curves). The base case refers to the road without enclosure and the WTWs with the package of mitigation measures recommended in the Consultants

1995 Hazard Assessment study. The risks have been calculated using the Consultants *RISKPLOT* risk integration software, using the same data (as the 1995 study but with the mitigation measures included) above and methodology as the 1995 Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs. *Annex 8B* contains the detailed input and output data for the Tai Po Road WTW 'base case' risk assessment.

Table 8.2f ***Base Case Risk Results for Route 16***

WTW	PLL (Route 16) (per year)	PLL (all other populations) (ie 'Background' risk) (per year) (Note 1)
Tai Po Road	1.18E-3	8.65E-5
Shek Lei Pui	4.99E-5	2.58E-4

Note 1: PLL values from 1995 Hazard Assessment Study (mitigated cases)

8.2.5.6 *Figure 8.2b* shows that the 'FN' curve for the risk to Route 16 due to Tai Po Road WTW lies in the high ALARP region of the Risk Guidelines and exceeds the 1000 fatalities 'cut-off'. This necessitates consideration of measures firstly to reduce the risk to 'not unacceptable' levels and secondly to a level which is 'as low as reasonably practicable'.

8.2.5.7 The dominant contributor to risk for Tai Po Road WTW is a 1 tonne drum rupture within the chlorine store assumed to cause collapse of the store due to its small internal volume. This event would cause traffic disruption, with the 90% fatality contour extending approximately 200 metres down the length of Route 16 for the worst case wind direction.

8.2.5.8 For Shek Lei Pui WTW, *Figure 8.2b* shows that the societal risk to Route 16 lies in the low ALARP region. *Table 8.2f* shows that, for both Tai Po Road and Shek Lei Pui WTWs, the risk due to Route 16 adds significantly to the background level of risk (in the case of Tai Po Road WTW, dominating the background risk).

Risk Mitigation Measures for Tai Po Road WTW

8.2.5.9 On the basis of the calculated risk to Route 16 due to Tai Po Road WTW (PLL - 1.18E-3 per year), a simple calculation may be undertaken to gauge the level of expenditure which is justifiable on risk mitigation measures, as follows:

Maximum level of justifiable expenditure = PLL value (per year) x value of life (HK$)
x operating lifetime of Route 16 (years)
x aversion factor

8.2.5.10 A value of life of HK$24M has typically be used to date in Hazard Assessments in Hong Kong and this is adjusted to HK$33M in line with inflation, following the Consultants Methodology Report for the *Reassessment of Chlorine Hazards for Eight Existing Water Treatment Works, CE14/96*. An aversion factor of 20 is applied following the 1995 Hazard Assessment. An operating lifetime for Route 16 of 50 years is assumed. Therefore

Maximum level of justifiable expenditure = 1.18E-3 x 33E6 x 50 x 20 = HK$39M

8.2.5.11 This calculation indicates that significant expenditure on risk mitigation measures is justified. To guide the analysis of the mitigation measures, Table 8.2g below identifies the dominant

contributors to the risk for Tai Po Road WTW. Various candidate measures have been considered as shown in *Table 8.2h* below.

Table 8.2g Dominant Contributors to Risk - Tai Po Road WTW

Contributors to Risk	% contribution	
	Route 16	Route 16 + all other populations
i. Loadshedding	2.6	5.3
ii. Spontaneous vehicle fire	0.6	0.63
iii. Earthquake	2.3	7.65
iv. Driveaway	-	0.19
v. Spontaneous container failure	94.1	85.73
vi. Rollover	0.4	0.5
Total	100.0	100.0

Table 8.2h Candidate Risk Mitigation Measures (Operation Phase)

Candidate risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in assessment ? (Y/N)
Mitigation Measures at Route 16		
1. Enclosure of Route 16 to the south of the southern portal of the Eagle's Nest Tunnel	An enclosure would provide an effective mitigation measure for Route 16 in the vicinity of the WTWs. It would effectively place the southern portal of the Eagle's Nest tunnel further away from the WTWs. Provision of an enclosure is however a relatively expensive measure (HK$150K per metre of enclosure, as advised by the Route 16 design consultants).	Y
2. Further re-alignment of Route 16	The controlling factor for switching from the Conforming Alignment to the Alternative Alignment was due to the traffic need rather than on economic grounds. The cost saving in the construction of the Alternative Alignment compared with that for the Conforming Alignment is therefore only a secondary factor which should however be measured against the increased societal risk arising from the closer proximity of the Alternative Alignment to the WTW PHIs. The cost saving for the Alternative Alignment is around HK$600M, which far exceeds the justifiable expenditure on risk mitigation measures (HK$39M) calculated above. Therefore it can be seen that the Alternative Alignment is justified on the basis of a societal risk cost-benefit analysis	N

Candidate risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in assessment ? (Y/N)
3. Provision of gas detectors on Route 16 linked to a means of stopping traffic	Emergency measures to stop traffic on Route 16 in the event of a major chlorine release from Tai Po Road WTW are recommended as a matter of good practice (*Section 8.2.7*). Provision of gas detectors at Route 16 would not be effective for traffic already stationary or which is initially within the affected zone of the chlorine release, therefore is not considered as a prime means of risk mitigation.	N
Mitigation Measures at Tai Po Road WTW		
4. Modification to facilitate using chlorine in 50kg cylinders	This is an effective means of reducing risk and is being implemented by WSD at other WTWs. This measure was considered (although rejected) in the Consultants 1995 Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs.	Y
5. Provision of a new building (to provide indoor unloading and the ability to withstand the effects of an internal, instantaneous 1 tonne release) at the existing location at Tai Po Road WTW.	This is an effective measure for reducing risk and was considered (although rejected) in the Consultants 1995 Hazard Assessments for Tai Po Road and Shek Lei Pui WTWs.	Y
6. Closure or relocation of Tai Po Road WTW	This would eliminate the risk to Route 16 due to Tai Po Road WTW. However WSD have advised that closure of Tai Po Road WTW is not feasible, therefore this option has not been considered further.	N
7. Use of an alternative disinfection agent.	This measure has been considered on a territory-wide basis in the Chlorine Transport Risk study. It is unlikely to prove cost-effective for modification of a small, relatively old WTW such as Tai Po Road WTW and is therefore not considered further.	N
8. Reduction of chlorine stock levels	This measure, in isolation, would not provide the significant reduction in risk required to bring the risk from Tai Po Road WTW within the acceptable region of the Risk Guidelines. Furthermore it may not be practical to reduce chlorine stock levels and usage given the required dosing rates and considerations of security of supply.	N

8.2.5.12 From *Table 8.2h* above the following measures are taken forward for further consideration in the risk mitigation analysis:

Option A: Enclosure of the road (enclosure lengths of 200m and 400m have been considered);

Option B: Modification of Tai Po Road WTW to facilitate using 50kg cylinders; and

Option C: Provision of a new chlorine building at Tai Po Road WTW.

8.2.5.13 It is noted that modification to facilitate using 50kg cylinders would require additional storage space, therefore *Options B and C* are considered in combination as well as individually. Also WSD advise that it is not feasible to construct a new building (with indoor unloading bay) for 50kg cylinders at the existing location. Therefore the analysis (below) considers an alternative location for the building (further from Route 16) as a means of reducing the required length of, or need for, road enclosure.

Mitigated Risk Results for Tai Po Road WTW

8.2.5.14 The risk results for *Options A - C* are presented in *Table 8.2i* (PLL values) and *Figure 8.2c* ('FN' curves). *Annex 8C* contains details of the modeling assumptions for each mitigation option.

Table 8.2i Risk Results for Mitigation Options

Mitigation option	PLL (Route 16) per year	% reduction (compared to base case)
A1 (200 m road enclosure)	1.94E-4	83.6%
A2 (400m road enclosure)	1.22E-5	99.0%
B (Modification of Tai Po Road WTW to facilitate using 50kg cylinders)	1.40E-4	88.1%
C (Provision of a new chlorine building at Tai Po Road WTW)	6.28E-5	94.7%

8.2.5.15 *Figure 8.2c* shows that all three options significantly reduce the risks to Route 16. However only *Option A2* reduces the risks to acceptable levels, whilst for *Options B and C*, involving modifications to the WTW, it may still be necessary to consider some length of road enclosure.

8.2.5.16 In order to determine which of the above measures should be implemented (either singly or in combination), it is useful to calculate the Implied Cost of Averting a Fatality (ICAF) for each mitigation option. The ICAF is the cost of implementation of a measure divided by the risk reduction achieved, ie equivalent to cost per life saved. It is useful for determining whether risks have been reduced to ALARP levels and to determine which mitigation measures are the most cost-effective to implement. The formula for calculation of the ICAF is as follows:

ICAF = Cost of mitigation measure/(reduction in PLL x operating lifetime)

8.2.5.17 The smaller the ICAF value the more cost-effective the measure is to implement. The ICAF may be compared to the value of life figure, which, incorporating the aversion factor of 20, is HK$660M. Mitigation measures whose ICAF is in excess of HK$660M may generally be regarded as not reasonably practicable, whilst measures whose ICAF value is below HK$660M should be implemented.

8.2.5.18 The calculations of ICAF value for the various mitigation options considered, including combinations thereof, is presented in *Table 8.2j* below. The calculations take into account not only the risk reduction at Route 16 but also the reduction in overall risk (for mitigation measures at the WTW) based on the Consultants' 1995 Hazard Assessment study.

Table 8.2j ***Assessment of Risk Mitigation Options (Operation Phase)***

Mitigation option	Cost (HK$M)	PLL reduction (Route 16) (per year)	PLL reduction (all other populations) (per year)	Total PLL reduction (per year)	ICAF (HK$M) (Note 5)
A1	30 (Note 1)	9.86E-4	-	9.86E-4	609
A2	60	1.17E-3	-	1.17E-3	1026
B	5 (Note 2)	1.04E-3	6.25E-5 (Note 4)	1.10E-3	91
C	5 (Note 3)	1.12E-3	5.91E-5 (Note 4)	1.18E-3	85
A1 + B	35	1.16E-3	6.25E-5	1.22E-3	574
A1 + C	35	1.17E-3	5.91E-5	1.23E-3	569
B + C	15 (Note 6)	1.12E-3	6.61E-5	1.19E-3	252
A1 + B + C	45	1.18E-3 (Note 7)	6.61E-5	1.25E-3	722
B + C + 100m enclosure	30	1.15E-3	6.61E-5	1.22E-3	492

Note 1: Based on a cost for the enclosure of HK$150,000 per metre (data provided by Route 16 design consultants).

Note 2: Estimated cost.

Note 3: Estimated cost.

Note 4: From Consultants 1995 Hazard Assessment Study.

Note 5: ICAF = Cost/(ΔPLL_{total} x T)

where

ΔPLL_{total} = total reduction in PLL

T = operating lifetime (assumed 50 years for Route 16 as well as for the WTW).

Note 6: Cost estimate taking into account provision of a new chlorine building at a new location (ie including HK$5M for site preparation, re-routing of pipelines etc) (see below)

Note 7: Assumes risk to Route16 can be reduced to zero

8.2.5.19 The calculations in *Table 8.2j* indicate that:

- the ICAF value for provision of 200m of enclosure (HK$609M) is below the value of life figure of HK$660M (including aversion factor) and therefore is reasonably practicable to implement;
- provision of a 400m length of enclosure (ICAF HK$1026M) is not justified on ALARP grounds;
- modifications to the WTW are the most cost-effective means of reducing the risk and there is a case for either modification of Tai Po Road WTW to facilitate using 50kg cylinders or provision of a new chlorine building, as well as provision of a 200m road enclosure (ie the ICAF values for *Options A1 + B* and *A1 + C* are below *HK$660M*);
- The combination of measures which achieves the greatest reduction in risk, whilst having an ICAF value below HK$660M, is *Option A1 + C* (ie a 200m enclosure + provision of a new building); and

- provision of 200m enclosure with modification of Tai Po Road WTW to facilitate using 50kg cylinders and provision of a new building (ie options A1 + B + C) would not be reasonably practicable (ICAF is HK$722M).

8.2.5.20 *Figure 8.2d* shows the 'FN' curves for the case of a 200 metre road enclosure with either modification of Tai Po Road WTW to facilitate using 50kg cylinders or provision of a new chlorine building. In each case the 'FN' curve lies in the acceptable region of the Risk Guidelines.

8.2.5.21 Also shown in *Figure 8.2d* is the case of modification of Tai Po Road WTW to facilitate using 50 kg chlorine cylinders and provision of a new building. Whilst this produces a similar reduction in risk to the other two cases it can be seen that the 'FN' curve for Route 16 still remains partly within the ALARP region, close to the 1000 fatalities cut-off, and therefore this option is not preferred.

8.2.5.22 Highways Department have advised that an enclosure of greater than 100 metres may have implications for road safety as the crossover required to be located at the southern portal of the Eagle's Nest tunnel would lie within the enclosure. Therefore a further mitigation case of *Options B and C* plus a 100 metre enclosure has been considered. This provides a reduction in PLL of 1.22E-3 per year at reduced cost compared to either *Option A1 + B* or *Option A1 + C*. The ICAF value is HK$492M. The 'FN' curve for this case lies marginally within the ALARP region (*Figure 8.2d*). The advantage of this option is that it provides the greatest reduction of risk at source which will benefit the other populations near the WTW including any future development. Also by modifying the WTW to facilitate using 50kg cylinders, Tai Po Road WTW will no longer be a PHI.

8.2.5.23 As noted above, WSD have advised that it is not feasible to construct a new chlorine building (with indoor unloading bay) for 50kg cylinders at the existing location. However a possible site exists 110m to the east north-east (*Figure 8.2j*). Relocation of the chlorine building to this new location avoids the need for a 100m road enclosure. This is because the relative distance between the chlorine building and the nearest open section of road (the key factor in the risk assessment) remains the same, ie 180m. In this analysis the road enclosure is considered as simply an extension of the Eagle's Nest Tunnel.

8.2.5.24 Another way to look at this aspect of the risk assessment is to consider the population within the road enclosure. Removing the enclosure increases the risk to this population (by a factor of 10). However relocation of the chlorine building 110m further away from the road means that chlorine concentrations at Route 16 are reduced and less of the road is affected. This achieves a corresponding reduction in the number of fatalities as demonstrated below.

8.2.5.25 For 'N' people per 100m of road:

Removal of 100m enclosure: Number of fatalities increases by 10*0.09*N = 0.9N (this considers the enclosure to lie within the LD90 contour, which is equivalent to 9% fatality for people 'indoors' in the enclosure)

Relocation of chlorine building 100m further from road (along the same axis as road): Number of fatalities reduces by (0.9 - 0.5)*N + (0.5 - 0.03)*N (ie the reductions in fatalities between the LD90/LD50 and LD50/LD03 contours) = 0.87N

8.2.5.26 The key factor here is that the chlorine store is relocated further from the road but along the *same axis* as the road. This is achieved for the proposed relocation site, which is 110m ENE of the current store and 100m in the NE direction (ie the direction of the road within the Butterfly valley).

8.2.5.27 The above analysis does not take into account the fact that moving the chlorine building 110m ENE moves it closer to other populations, eg Tai Po Road. However a sensitivity analysis has been undertaken which shows that the change in background risk due to relocation of the chlorine building is negligible (3% change in PLL value). As a result of the relocation of the store its distance from Tai Po Road and Caldecott Road will be 65m and 275m respectively. It is also noted that Tai Po Road WTW lies 50m above the level of the chlorine store at its new location. However, there is a net reduction in risk when considering Route 16 population as well and the improvements which will be made at the WTW.

8.2.5.28 Taking into account the above, the preferred combination of mitigation measures, therefore, is provision of a new chlorine building (with indoor unloading bay and 50kg cylinders) at a new location 110m ENE of the existing store.

Risk Mitigation Measures for Shek Lei Pui WTW

8.2.5.29 The 'FN' curve for Shek Lei Pui WTW lies partly in the low ALARP region of the Risk Guidelines (*Figure 8.2b*), whilst the PLL is 4.99E-5 per year, representing a 20% increase above background. This necessitates consideration of risk mitigation measures.

8.2.5.30 The analysis of risk mitigation measures considers two aspects:

i. analysis of *new* mitigation measures in respect of the *additional* risk arising from the presence of Route 16; and

ii. re-evaluation of mitigation measures previously considered (but rejected) in the 1995 Hazard Assessment Study, but which may now be justified due to the increased risk level. [There are two mitigation measures in this category: provision of a new chlorine building/scrubber and modification of the WTW to facilitate using chlorine in 50kg cylinders].

To guide the analysis of mitigation measures, *Table 8.2k* below identifies the dominant contributors to risk for Shek Lei Pui WTW.

Table 8.2k Dominant Contributors to Risk - Shek Lei Pui WTW

Contributors to Risk	% contribution	
	Route 16	Route 16 + all other populations
i. Loadshedding	33.4	67.9
ii. Spontaneous vehicle fire	2.3	5.1
iii. Earthquake	40.0	22.4
iv. Driveaway	2.4	-
v. Dropped container	7.5	-
vi. Spontaneous container failure	1.2	-
vii. Accident while positioning to unload	4.8	-
viii. Rollover	1.6	2.4
ix. Other	6.8	2.2
Total	100.0	100.0

8.2.5.31 Simple calculations may be undertaken to determine the maximum justifiable expenditure on mitigation measures. In respect of the *additional* risk arising from the presence of Route 16, the maximum justifiable expenditure on *new* mitigation measures is:

Maximum justifiable expenditure = 4.99E-5 x 33E6 x 50 x 20 = HK$1.7M

In respect of the revised overall societal risk for Shek Lei Pui WTW, the maximum justifiable expenditure for re-evaluation of previously-identified mitigation measures is:

Maximum justifiable expenditure = (2.58E-4 + 4.99E-5) x 33E6 x 50 x 20 = HK$10.2M

The analysis of mitigation measures is presented in *Table 8.2l* below.

Table 8.2l Assessment of Risk Mitigation Measures for Shek Lei Pui WTW

Candidate Risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in Assessment ? (Y/N)
Mitigation Measures at Route 16		
1. Enclosure of Route 16	An enclosure would provide an effective mitigation measure for Route 16 in the vicinity of the WTWs. It would effectively place the southern portal of the Eagle's Nest tunnel further away from the WTWs. Provision of an enclosure is however a relatively expensive measure. This option will be considered in the cost benefit analysis.	Y
2. Enhanced emergency response measures	Emergency measures to stop traffic on Route 16 in the event of a major chlorine release from Shek Lei Pui WTW are recommended as a matter of good practice (*Section 8.2.6)*	Recommended as good practice (for Shek Lei Pui and Tai Po Road)
Mitigation Measures at Shek Lei Pui WTW		
3. Measures to reduce the chance of loadshedding (eg improved securing of the drums on the truck or improvements to the condition of the access road)	The chlorine drums are already secured onto the truck by two means - end clamps and straps (a recommendation from the Chlorine Transport Study, DNV, 1990). Also, the1995 Hazard Assessment recommended improvements to the Shek Lei Pui WTW access road (signage, road widening etc) which have now been implemented. Further mitigation measures are therefore not considered necessary. Furthermore, according to current assessment methodology (Chlorine Transport Risk Study, DNV 1996) the frequency of loadshedding is a factor of 50 below that assessed in the 1995 study. Therefore loadshedding accidents are not a significant factor in current assessments.	N

Candidate Risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in Assessment ? (Y/N)
4. Improvements to the normal ventilation extract fans	At Shek Lei Pui WTW (as for Tai Po Road WTW) the ventilation extract fans are located at low level in the chlorine storage area, providing an extract direct to the outside of the building. The extracts are located close to the chlorine drums and pipework and therefore it is vital that the fan intake louvres close quickly in the event of a chlorine release to prevent any escape of chlorine to atmosphere. However if the ventilation extracts at Shek Lei Pui WTW are the same as those at Tai Po Road WTW (where the louvres observed to close slowly) then they should be modified to include faster-closing louvres. This is recommended as a matter of good practice.	Recommended as good practice (for Shek Lei Pui and Tai Po Road)
5. Improvements to the door alarm	The 1995 Hazard Assessment study recommended installation of an alarm to ensure that the main access door to the chlorine store is kept closed when not in use. This has been installed, however it was observed that the operators could easily override the alarm by standing on the door sill and holding down the alarm activation switch. The problem lies with the 'timer' on the alarm which sounds without giving sufficient time for operators to complete the drum unloading operation. It is therefore recommended that the door alarm installations at Shek Lei Pui WTW be reviewed, and modified as necessary, such that the alarm 'timer' allows sufficient time for the chlorine unloading operation to take place (ie unloading of one full drum into the store and removal of one empty drum) but that, once sounding, the alarm cannot be de-activated without closing the doors and re-setting the alarm. This recommendation is also made for Tai Po Road WTW, where an alarm system was about to be installed at the time of the Consultants site visit in January 1999.	Recommended as good practice (for Shek Lei Pui and Tai Po Road)

Candidate Risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in Assessment ? (Y/N)
6. Provision of a barrier, and an enclosure in front of the chlorine store, to mitigate the spread of chlorine towards Route 16	Physical barriers can be an effective means of mitigating the effects of a hazardous, dense gas release. Barriers of this nature are normally 3-12m in height and provide for a reduction in near field concentration of a factor of 2-9, depending on the barrier design, release location, weather conditions etc. Barriers are normally provided to protect particular (nearby) populations from specific leak sources. This measure would reduce risks from smaller releases at the chlorine store/unloading area, but would probably not be that effective against larger releases. A 3m high solid fence will provide a 180 degree protection for chlorine releases due to unloading and some seismic events. The fence will extend to about 100m till the 2 traffic barriers on the access road. A small low cost (part) enclosure in front of the chlorine store to provide a similar kind of protection as the fence is also recommended in conjunction with the fence.	Y
7. Provision of a new building with scrubber (This mitigation measure was previously considered in the 1995 Hazard Assessment)	A new building would provide indoor unloading and could also provide improved earthquake-resistance and/or reduced damage to drums in the event of an earthquake-induced roof collapse. This would mitigate the risk from events iii, iv and v in *Table 8.2k* above. Space for a new chlorine building at Shek Lei Pui WTW (with scrubber and truck manoeuvring area) is limited. Therefore the provision of such a facility is assumed to require some site formation work and diversion of existing pipelines.	Y
8. Modification of Shek Lei Pui WTW to facilitate using 50kg cylinders (This mitigation measure was previously considered in the 1995 Hazard Assessment)	Modification to facilitate using 50kg cylinders will require more space for storage of the equivalent quantity of chlorine as well as for the gas draw-off units. This would require a new building, the cost effectiveness of which will be evaluated.	Y

8.2.5.32 From the analysis in *Table 8.2l* it can be seen that a number of improvement measures are recommended for good practice with a number of measures also recommended for consideration in the Cost Benefit Analysis. The measures that are recommended as good practice are carried forward to the recommendations section (*Section 8.2.7*). The calculations in Table *8.2m* indicate that:

- The ICAF value for provision of 200m enclosure (HK$14492M) is far above the value of life figure of HK$660M (including aversion factor) and is hence not reasonably practicable to implement.
- Construction of a 3m fence and a low cost part enclosure outside the chlorine store is demonstrated as a cost effective measure and should be implemented. The maximum

justifiable cost for this measure is around HK$1M. This amount can be used for the construction and subsequent maintenance of the mitigation measure.

- A new chlorine store (ICAF HK$3226M) is not reasonably practicable to implement.
- The conversion to 50kg cylinders with a new building (ICAF HK$738M) also is not reasonably practicable to implement.

Table 8.2m Assessment of Risk Mitigation Options (Operation Phase) for Shek Lei Pui

Mitigation option	Cost (HK$M)	Total PLL reduction (per year)	ICAF (HK$M)
200m Enclosure of Route 16	30 (Note 1)	4.14E-5	14492
3m solid fence and low cost enclosure in front of store	0.1	3.1E-5	64.5
New Building (with scrubber) for Chlorine Store	10 (Note 2)	6.2E-5	3226
Conversion to 50kg cylinders (which would require a new building)	10 (Note 3)	2.71E-4	738

Note 1: Based on a cost for the enclosure of HK$ 150,000 per metre
Note 2: Estimated Cost taking into account site formation and diversion of existing pipelines.
Note 3: Estimated Cost with the inclusion of a new building required to house the 50kg cylinders.

Cumulative Operation Phase Risks

8.2.5.33 *Figure 8.2e* presents the cumulative societal risks for the Route 16 operation phase, which is a summation of the risks for both Tai Po Road WTW and Shek Lei Pui WTW. The case considered for Tai Po Road WTW is the provision of a new chlorine building (with indoor unloading bay and 50kg cylinders) at a new location 110m ENE of the existing store. For Shek Lei Pui WTW the case considered is the 'base case' risk assessment.

8.2.5.34 From *Figure 8.2e* it can be seen that the cumulative 'FN' curve lies in the low ALARP region of the Risk Guidelines. Mitigation measures were therefore recommended for Shek Lei Pui WTW (providing a 10% reduction in PLL for this WTW) to demonstrate ALARP (See Tables 8.2l & 8.2m above. From the preceding analysis of mitigation measures for the two WTWs, it is considered that the risks are as low as reasonably practicable (with all of the recommended mitigation measures implemented) and therefore compliant with the Risk Guidelines in Annex 4 of the EIAO-TM.

Societal Risk Results: Construction Phase

Base Case Risk Results

8.2.5.35 WSD have advised that it is not possible to close Tai Po Road WTW, even on a temporary basis. Furthermore a period of two years may be required to implement mitigation measures of the nature discussed in the preceding section (eg provision of new chlorine building with 50kg cylinders). This may leave a period of about one year in which the Route 16 construction work is proceeding alongside the operation of the existing WTW. This section therefore examines the significance of the construction phase risk levels (for both Tai Po

Road and Shek Lei Pui WTWs) in relation to the Risk Guidelines and identifies possible mitigation measures.

8.2.5.36 The EIA for the Conforming Alignment of Route 16, previously undertaken by the Consultants, assumes a construction workforce of up to 350 persons for the entire alignment of Route 16, present 24 hours per day. For the purpose of this Hazard Assessment it has been assumed that up to 50 workers may be present in the immediate vicinity of Tai Po Road WTW at some point during the construction period. It has been assumed that these workers are all outdoors, present during the day only and distributed throughout the 150 metre 'cut and cover' section of the alignment immediately adjacent the chlorine store at Tai Po Road WTW. To represent the construction workforce associated with the remainder of Route 16, it is assumed that there are a further 100 workers distributed along the remaining 1km length of Route 16 lying within the Consultation Zones of Tai Po Road and Shek Lei Pui WTWs (ie 10 per 100m).

8.2.5.37 The risk results for the construction phase of Route 16 are shown in *Figure 8.2f*. The assessment assumes no modification to Tai Po Road WTW prior to the commencement of Route 16 construction.

8.2.5.38 From *Figure 8.2f* it can be seen that the construction phase risks for Tai Po Road WTW are significant. The 'FN' curve lies in the ALARP region, necessitating consideration of measures to reduce risk to as low as reasonably practicable The PLL value is 2.12E-4 per year. The construction phase risks associated with Shek Lei Pui WTW are acceptable (PLL = 2.52E-5 per year).

8.2.5.39 The reason why the construction phase risks are significant for Tai Po Road WTW is the close proximity of the Route 16 alignment (the alignment passes within 30 metres of the chlorine store) and the vulnerability of the outdoor workers. The dominant contributor to risk is a 1 tonne drum rupture within the chlorine store (55% of the PLL) assumed to cause collapse of the store, similar to the 'base case' operation phase risk for Tai Po Road WTW. Other significant contributors to risk are large and small leaks external to the chlorine store (12% and 7% respectively) arising, in part, from accidents during truck manoeuvring and unloading.

Risk Mitigation Measures for Tai Po Road WTW

8.2.5.40 Candidate risk mitigation measures for the construction phase of Route 16 are listed in *Table 8.2n* below, together with an assessment of their practicality for implementation and likely cost-effectiveness.

Table 8.2n Candidate Risk Mitigation Measures (Construction Phase)

Candidate risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in assessment ? (Y/N)
Mitigation Measures at Route 16		
1. Limitation of working hours, numbers of workers etc in vicinity of the WTW	This measure would directly reduce societal risk levels, but may have implications for the Route 16 construction programme. In this analysis it is considered as the 'last resort' mitigation measure.	Y
2. Suspension of construction work during chlorine deliveries	The risk associated with chorine delivery is a significant factor in the base case risk assessment. Furthermore this measures would not be too onerous to implement as deliveries are relatively infrequent (currently less than once per fortnight). 'Suspension' of construction activities in this context means evacuation of workers, either to a specified minimum distance from the WTW or to a place of safety indoors during movement of truck along the access road and drum unloading.	Y
3. Construction of a chlorine barrier between the chlorine store at Tai Po Road WTW and the Route 16 construction site	This measure would provide a degree of protection for the Route 16 construction site, depending on such factors as the release scenario, release location, weather conditions and barrier height and configuration. However it should be noted that chlorine would still be carried over the barrier by the wind and may also migrate around the sides of the barrier. Barriers of this nature are normally 3m to 12m in height and primarily provide for a reduction in near-field concentration by factors of 2 to 9 (*Guidelines for Post-Release Mitigation Technology in the Chemical Process Industry, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1997*).	Y
4. Provision of a water spray curtain around the WTW	Water spray curtains are a common post-release mitigation measure for toxic as well as flammable substances. They comprise a series of spray nozzles located around a hazardous facility which generate a fine spray of water which mitigates the hazardous release by a combination of increased air entrainment and and/or absorption of the hazardous material in the water. For chlorine, however, NFPA advise that water should not be applied directly to a leak due to the enhancement of vapourisation of liquid chlorine and the formation of hydrochloric acid which may enlarge the leak due to corrosion. This measure is therefore not considered further.	N
5. Enhanced emergency response arrangements, eg provision of audible alarms, toxic refuge, training etc	Provision of toxic refuges on the Route 16 construction site, together with a means of alerting construction workers to a release of chlorine would provide an effective mitigation measure. This is therefore included in the cost-benefit analysis in conjunction with measure 3. above.	Y
Mitigation Measures at Tai Po Road WTW		

Candidate risk mitigation measure	Assessment of practicality and likely cost-effectiveness of measure	Include in assessment ? (Y/N)
6. Modification of Tai Po Road WTW	*Modification to facilitate using 50kg cylinders and/or provision of a new building* These measures may be effective, as for the operational phase of Route 16. However WSD advise that modifications to the existing chlorine building (or provision of a new building) may take two years to complete and therefore would not be ready at the start of Route 16 construction.	N
	Provision of a temporary enclosure over the truck manoeuvring and unloading area This is a feasible measure which would not affect the operation of the existing WTW. However the risks associated with drum unloading are not a significant factor in the base case risk assessment	Y
	Modification of the store ventilation extracts Tai Po Road WTW has normal ventilation extracts (3) at low level on the side of the chlorine building facing the Route 16 alignment. These extracts are adjacent to the drum storage locations. It was observed during a site visit that the motorised louvres provided at the extracts are relatively slow-acting (in response to detection of a chlorine leak). These could be replaced by faster-acting louvres and the ventilation extracts could also be re-located to discharge away from Route 16. This measure is recommended as a matter of good practice.	Recommend as good practice.
7. Closure of WTW for period of construction work	This measure would effectively eliminate the risk posed by Tai Po Road WTW during the Route 16 construction period. However as WSD advise that Tai Po Road WTW cannot be closed for operational reasons, it has not been considered further.	N
8. Reduction in drum stock during period of construction work and adoption of 'just in time' delivery	The event which contributes primarily to risk is directly related to number of drums in stock, hence this measure would provide effective risk mitigation. WSD advise that the minimum practical stock level is 3 drums (ie two duty and one standby drum). A 'just in time' delivery policy could also be adopted, particularly during periods of low chlorine consumption to avoid prolonged stocking of chlorine.	Y

8.2.5.41 From *Table 8.2m* the following measures are taken forward for further consideration in the risk mitigation analysis:

Option A - Operational Restrictions at the WTW: Limitation of the drum stock at Tai Po Road WTW to 3 drums (2 duty and 1 standby) and adoption of 'just in time' delivery;

Option B - Mitigation of Truck Delivery and Unloading Risks: Temporary enclosure of the truck manoeuvring/unloading area at Tai Po Road WTW (*Option B1*) or suspension of

construction activities and evacuation of workers during truck delivery and unloading *(Option B2)*; and

Option C - Post-Release Mitigation: Provision of a chlorine barrier to mitigate the effects of a chlorine release on the Route 16 construction site. Also considered in this option is the provision of an off-site alarm (ie an alarm that can be heard on the Route 16 construction site) as well as provision of toxic refuges on the Route 16 construction site and breathing apparatus (escape sets) for workers unable to easily access the toxic refuges.

Option D - Restriction on Route 16 Construction Work: restriction on the number of construction workers in the vicinity of Tai Po Road WTW and/or the working hours (last resort).

Mitigated Risk Results for Tai Po Road WTW

8.2.5.42 The results of the analysis of mitigation measures (*Options A-D*) are presented in *Figure 8.2g and Table 8.2o* below.

Table 8.2o Assessment of Risk Mitigation Options (Construction Phase)

Mitigation option	PLL reduction (Route 16) (per year)	Justifiable cost of mitigation measure (HK$) (Note 1)	Assessment of whether reasonably practicable (Y/N)	Notes
A	4.80E-5	32,000	Y	Reduction in drum stock at WTW to 3 drums and adoption of 'just in time' delivery will not incur any additional cost.
B1	2.60E-5	17,200	N	Temporary enclosure of the truck manoeuvring/unloading area would cost significantly more than HK$17,200. Therefore this measure is rejected as not reasonably practicable.
B2	5.30E-5	35,000	Y	Suspension of construction activities during the delivery and unloading of chlorine is practicable given that deliveries will be less than once per week (1 drum at a time).
C	1.41E-4	93,100	Marginal	The cost of a chlorine barrier, together with an off-site alarm, toxic refuges and breathing apparatus is likely to exceed HK$93,000. However these measures provide a simple, effective means of mitigating the risk to the Route 16 construction site and are therefore recommended as a matter of good practice. It is also noted that the Route 16 construction area ('cut and cover' section) is 30m below the level of the chlorine store at Tai Po Road WTW and therefore chlorine, if released, would tend to flow into the construction area, which should therefore be protected. The chlorine barrier has been modeled by assuming that it provides for a reduction in near-field chlorine concentration of a factor of 5 (ie within the range given in *Table 8.2m*

Mitigation option	PLL reduction (Route 16) (per year)	Justifiable cost of mitigation measure (HK$) (Note 1)	Assessment of whether reasonably practicable (Y/N)	Notes
				above). A barrier of height 7m is estimated to be sufficient to achieve this reduction in concentration, based on limited modeling of near-field chlorine dispersion modeling undertaken by the Consultants (Note 2). It is noted that the provision of a barrier would cause chlorine to persist in high concentrations near the source of the release, which may not permit emergency access by WSD personnel. However WSD advise that all key plant controls, such as the ventilation system manual stop and the emergency scrubber manual start will be provided in the main control room. Therefore this is not considered a problem. It is not envisaged that there will be any adverse affect on the operation of the WTW as a result of the presence of the barrier.
D	6.20E-5	40,900	Marginal	Even after implementation of mitigation measures A, B2 and C it can be seen (*Figure 8.2g*) that the F-N curve for the Route 16 construction phase still lies in the ALARP region. To bring the F-N curve into the acceptable region the number of construction workers within 100m of the chlorine store at Tai Po Road WTW would need to be reduced from 50 to 30 (or a corresponding reduction made in the construction working hours). It is recognised that implementation of this mitigation measure may have cost/programme implications. However it is recommended that the construction work is planned on the basis of restricting the number of workers to 30 (or equivalent), if necessary by bringing the start date of key construction activities forward. The analysis considers construction workers to be present within the cut and cover section of Route 16 immediately adjacent to Tai Po Road WTW. However workers may be present anywhere within the site clearance area (see blue line in *Figure 8.2a)*, part of which lies within 100m of the access road for Shek Lei Pui WTW. It is therefore considered that the restriction of 30 workers should apply to this area as well. It is noted that there is currently no works planned for the parts of the site clearance lying near to the Shek Lei Pui WTW access road.

Mitigation option	PLL reduction (Route 16) (per year)	Justifiable cost of mitigation measure (HK$) (Note 1)	Assessment of whether reasonably practicable (Y/N)	Notes

Note 1: Justifiable cost = PLL reduction x cost of life (HK$33M) x aversion factor (20) x period of construction work (1 year)

Note 2: The estimate of the required barrier height is based on limited modeling of near-field dispersion of chlorine jet releases undertaken by the Consultants under the contract *CE14/96, Reassessment of Chlorine Hazard for Eight Existing Water Treatment Works*. Chlorine jet releases are of concern as, due to their momentum, they may be carried directly over a barrier without significant dilution. The modeling undertaken indicates that the maximum height of a chlorine cloud in the near-field (ie the height at the end of the jet dispersion phase) would be around 6m for the release scenarios of interest in this study.

Cumulative Construction Phase Risks

8.2.5.43 *Figure 8.2h* presents the cumulative societal risks for the Route 16 construction phase, which is a summation of the risks for both Tai Po Road WTW and Shek Lei Pui WTW. The case considered is Tai Po Road WTW (with implementation of mitigation options A, B2, C and D) and Shek Lei Pui WTW (with account taken of mitigation option D).

8.2.5.44 It can be seen that the cumulative 'FN' curve lies in the low ALARP region of the Risk Guidelines. However, from the preceding analysis of mitigation measures for Tai Po Road WTW, it is considered that the risks are as low as reasonably practicable and therefore compliant with the Risk Guidelines in Annex 4 of the EIAO-TM.

Individual Risk Results

8.2.5.45 The Consultants 1995 Hazard Assessment studies for Tai Po Road and Shek Lei Pui WTWs showed that off-site individual risks do not exceed the Hong Kong Risk Guidelines (10^{-5} per year) (*Figure 8.2i*). In the 1995 studies individual risks were assessed on the basis of a hypothetical individual spending 100% of their time in the vicinity of the WTW, 90% of the time indoors and 10% outdoors.

8.2.5.46 In this study the Route 16 road users and the construction workers have been considered as 100% outdoors populations. This increases individual risk compared to the case considered in the 1995 Hazard Assessment by approximately a factor of 5 (based on an indoor fatality probability one tenth of that for a person outdoors). However account can also be taken of occupancy (ie the fraction of time an individual is at risk). For road users (even a regular commuter) this would be expected to be a low value, eg a person spending, at most, 1 hour per day in a traffic jam adjacent to Tai Po Road WTW would still only have an occupancy of 4%. Therefore individual risk to Route 16 road users remains within the Risk Guidelines.

8.2.5.47 For construction workers the occupancy will be 2000/8760 = 0.23 based on 2000 working hours per year. Therefore the inclusion of the occupancy factor does not off-set the increase in risk due to being outdoors 100% of the time. However the mitigation measures recommended for Tai Po Road WTW, in particular the reduction in drum stock from 4 drums to 3 drums, the suspension of construction work during chlorine deliveries and the provision of a chlorine barrier, off-site alarm, toxic refuges and breathing apparatus will reduce individual risk below 10^{-5} per year.

8.2.6 Conclusions

8.2.6.1 The Hazard Assessment which has been undertaken shows that, although the risks to Route 16 due to Tai Po Road and Shek Lei Pui WTWs are significant (for both the construction and operation phases) there are cost-effective mitigation measures which can be implemented to reduce risks to 'as low as reasonably practicable' in compliance with the Risk Guidelines in Annex 4 of the EIAO-TM. The recommended risk mitigation measures are presented in *Section 8.2.7* below.

8.2.7 Recommendations

8.2.7.1 The following recommendations are made to ensure that the risks associated with the construction and operation phases of Route 16 comply with Annex 4 of the EIAO-TM.

Operation Phase

1. The existing chlorine building at Tai Po Road WTW should be replaced by a new chlorine building (with indoor unloading bay and using chlorine in 50kg cylinders) at a new location as shown *Figure 8.2j*.

2. The on-site and off-site emergency plans for Tai Po Road WTW and Shek Lei Pui WTW should be updated to include provision for direct warning of a hazardous chlorine release by WSD staff at the WTWs to the Route 16 Tunnel Operator so that the following action can be taken by the Route 16 Tunnel Operator:

    i. Route 16 southbound traffic should be stopped at the toll plaza at the Sha Tin end of the Eagle's Nest Tunnel;

    ii. Route 16 northbound traffic should be prevented from entering the Consultation Zones of Tai Po Road WTW and Shek Lei Pui WTW by activation of signage which should be located on the slip road from Ching Cheung Road (eastbound) onto Route 16 (northbound) and on the Lai Chi Kok viaduct (northbound) section of Route 16 (Route 16 will be supported by a Traffic Control and Surveillance System). Indicative locations for the signage on Ching Cheung Road are shown in *Figure 8.2a*.

    iii. The Eagle's Nest Tunnel ventilation fans should be shut down (and preferably reversed to blow air out of the tunnel) to minimise ingress of chlorine into the tunnel; and

    iv. Any tunnel operating staff who may be present at the south portal (the south ventilation building will not normally be occupied) should:

        - go indoors and close all windows, doors and other openings;
        - remain indoors until instructed by the emergency services (ie FSD/Police) that it is safe to leave the building; and
        - upon instruction to go outdoors, ventilate the building by opening all windows and doors.

3. An emergency plan, which forms part of the tunnel operating manual, should be developed during the detailed design of Route 16 in accordance with items 2 (i)-(iv) above, which should dovetail with those of WSD and the emergency services.

4. The store ventilation extracts at Shek Lei Pui and Tai Po Road WTW should be modified to include faster-closing louvres.

5. The door alarm installation at Shek Lei Pui WTW should be reviewed, and modified as necessary, such that the alarm 'timer' allows sufficient time for the chlorine unloading operation to take place (ie unloading of one full drum into the store and removal of one empty drum) but that, once sounding, the alarm cannot be de-activated without closing the doors and re-setting the alarm. The recommendation is also made for Tai Po Road WTW where an alarm system was about to be installed at the time of the Consultants' site visit in January 1999.

6. A 3m high solid fence around the chlorine store along with a low-cost part enclosure in front of it is recommended for Shek Lei Pui WTW. This will provide a 180 degree protection for small chlorine releases within the store, leaks due to loading/unloading activities and will also provide protection for releases due to some seismic events. The fence will be approximately 100m long and will extend to the two traffic barriers on the access road. The fence and enclosure are shown in *Figure8.2j.*

Construction Phase

7. The drum stock at Tai Po Road WTW should be reduced to 3 drums (2 duty and 1 standby) and deliveries of chlorine should be made on a 'just in time' basis during the period of construction of Route 16.

8. The store ventilation extracts at Tai Po Road WTW should be modified to include faster-closing louvres.

9. The door alarm installation at Tai Po Road WTW should be reviewed, and modified as necessary, such that the alarm 'timer' allows sufficient time for the chlorine unloading operation to take place (ie unloading of one full drum into the store and removal of one empty drum) but that, once sounding, the alarm cannot be de-activated without closing the doors and re-setting the alarm.

10. A chlorine barrier should be provided at Tai Po Road WTW to block travel of chlorine towards the Route 16 construction site. The required height of the barrier is estimated to be 7m, whilst the location of the barrier is indicated in *Figure 8.2j.* The barrier should be constructed of a material capable of resisting corrosive attack by chlorine (for a design life of two years).

11. Construction activities should be suspended during delivery and unloading of chlorine at Tai Po Road WTW, ie construction workers should be evacuated to a minimum distance of 500m from the chlorine store (if outdoors) or to a place of safety indoors (ie a toxic refuge - see item 13 below) during the movement of the chlorine truck along the access road at Tai Po Road WTW and during the drum loading/unloading operation.

12. Construction activities within 100 metres of the chlorine store at Tai Po Road WTW (including activities within the Eagle's Nest tunnel up to a distance of 200m from the portal and activities within 200m of the access road to Shek Lei Pui WTW) should be restricted to day-time only (7am-7pm) with a maximum of 30 workers. Increased numbers of workers could be tolerated at correspondingly reduced working hours, eg 60 workers for 6 hours each day. Construction activities within 500m of the chorine store at Tai Po Road WTW should also be restricted to day-time only with a maximum of 70 workers (or equivalent at reduced working hours). Facilities such as workshops, offices etc should be located beyond 500m from the chlorine store at Tai Po Road WTW, as far as reasonably practicable.

13. The following emergency measures should be implemented, in line with best practice:

    - construction workers within 500m of Tai Po Road and Shek Lei Pui WTWs (the extent of the 50% fatality contour for a 1 tonne instantaneous release) should

receive information and training in relation to the hazards posed by the WTWs and what action they should take in the event of an emergency;

- toxic refuges should be provided at the construction site, ie well-sealed buildings, with a bottled air supply capable of maintaining the interior of the building at a positive pressure with respect to the outside so as to maintain safe conditions within the refuge for a period of at least 1 hour (ie chlorine concentrations below 3ppm, which is the US ERPG-2(1) level). The toxic refuges should have sufficient capacity for the number of workers who may need to use them, ie capacity for at least 30 workers within 100m of the chlorine store at Tai Po Road WTW and a further 40 workers within 500m (noting however that increased capacity should be provided if reduced working hours are to be adopted, as item 11. above). The toxic refuges should be equipped with self-contained breathing apparatus (SCBA), ie escape sets, sufficient for the number of workers who may need to use the refuge (as above). The toxic refuges should contain equipment to facilitate communication with external parties.

- construction workers out of easy reach of a toxic refuge (eg in the Eagle's Nest Tunnel) should have ready access to SCBA at their work locations;

- construction workers should receive information, instruction and training in the use of SCBA.

- in the event of a chlorine release, any temporary ventilation intakes for the Eagle's Nest Tunnel should be shutdown rapidly (or preferably reversed) to minimise ingress of chlorine into the tunnel from the south portal;

- a means of providing a rapid, direct warning to construction workers in the event of a hazardous chlorine release at Tai Po Road or Shek Lei Pui WTW should be provided (eg a siren audible within 500m);

- chlorine gas alarm(s) should be provided at construction areas within 100m of the chlorine store at Tai Po Road WTW to provide an additional direct warning to construction workers of a chlorine release;

- the access road to the Route16 construction areas should be adequate for access by the emergency services and should be maintained clear;

- the emergency services should familiarise themselves with the emergency arrangements for the Route 16 construction site, including the locations of the toxic refuges, site access arrangements etc.

- the Route 16 contractor should develop an emergency plan in accordance with the recommendations above, which should dovetail with those of WSD and the external emergency services.

(1) American Industrial Hygiene Association, Emergency Response Panning Guidelines - Level 2. This is the level at which 'nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action'.

14. In view of the close proximity of the Route 16 construction site to Tai Po Road WTW (ie within 30m), a hazard review should be undertaken prior to the commencement of construction to address any hazards which the construction activities may pose to the safe operation of the WTW, eg relating to fire, slope failure, dropped objects etc.

8.3 Hazard Assessment for LPG Installation

8.3.1 Introduction

8.3.1.1 This section of the Hazard Assessment assesses the risk associated with the LPG installation at the Lai Chi Kok (LCK) Reception Centre. The purpose of this assessment is to determine what (if any) constraint the presence of the LPG installation poses on Route 16.

8.3.2 Description of the LPG Installation

8.3.2.1 The LPG installation at the LCK Reception centre comprises a single 5.2kl (3.1 tonne) above-ground LPG storage vessel, a vapouriser, pressure regulators and LPG distribution pipework.

8.3.2.2 LPG is supplied to the facility three times per week by China Resources Petrochems (Group) Co. Ltd, using bulk road tankers of either 19kl (11.2 tonnes) or 11.5kl (6.8 tonnes) capacity . The delivery quantity is approximately 2.5kl (1.5 tonnes) per trip.

8.3.2.3 The LPG vessel is situated towards the northern boundary of the LCK Reception Centre, 45m from the proposed LCK viaduct. The viaduct will be dual-3 carriageway approximately 30m above ground level and there will be a 5m noise/security barrier along the side of the viaduct facing the LCK Reception Centre. Between the LPG vessel and the LCK viaduct there are two buildings, of 10 and 9 storeys height, which block all bar a 5m section of the viaduct from the direct view of the LPG vessel.

8.3.2.4 For this study, detailed information was obtained from China Resources Petrochems on the LPG delivery equipment and procedures. Also the Gas Standards Office of EMSD provided a schematic of the LPG piping. However no details were available of the LPG vessel, the valving on the LPG supply lines or the layout of the LPG installation. The assessment has therefore been undertaken on a pessimistic basis with regard to the safety features of the LPG installation.

8.3.3 Hazards Posed by the LPG Installation

8.3.3.1 Small bulk LPG installations of this nature pose a hazard to nearby populations, due to the potential for a leak of LPG which, if ignited, would lead to a fire or, possibly, an explosion. Fatal effects may extend beyond 100m from the LPG vessel, although the likelihood of such incidents is low.

8.3.3.2 Based on previous Quantitative Risk Assessments (QRAs) undertaken by the Consultants, the types of incident which are usually of significance in terms of the risk to the public are those listed in *Table 8.3a* below.

Table 8.3a LPG Release Scenarios

No	Scenario description	Release type (Note 1)	Hole size	Phase	Hazardous outcomes
1	Cold catastrophic failure of storage vessel	I	-	Liquid	Fireball (Note 2) Flash fire (Note 2)
2	Cold partial failure of storage vessel	C	25mm	Liquid	Flash fire BLEVE (Note 3)
3	Cold catastrophic failure of road tanker	I	-	Liquid	Fireball Flash fire

No	Scenario description	Release type (Note 1)	Hole size	Phase	Hazardous outcomes
4	Cold partial failure of road tanker	C	25mm	Liquid	Flash fire BLEVE
5	Guillotine failure of liquid filling line to storage vessel	C	Pipe full bore	2-phase or liquid	Flash fire BLEVE
6	Guillotine failure of liquid supply line to vapouriser	C	Pipe full bore	2-phase or liquid	Flash fire BLEVE
7	Guillotine failure of liquid filling line to flexible hose	C	Pipe full bore	2-phase or liquid	Flash fire BLEVE
8	Vapouriser failure	C	Pipe full bore	2-phase	Flash fire
9	Guillotine failure of flexible hose	C	Pipe full bore	2-phase or liquid	Flash fire BLEVE

Note 1: I - Instantaneous or C - Continuous

Note 2: Fireball due to immediate ignition of a catastrophic LPG release, flash fire due to delayed ignition of an LPG release

Note 3: Boiling Liquid Expanding Vapour Explosion (arising from prolonged jet flame impingement on the storage vessel (or road tanker)

8.3.3.3 Although a vapour cloud explosion (VCE) is a possible outcome of an LPG release, previous LPG QRA studies undertaken by the Consultants in Hong Kong have indicated that there is insufficient obstacles or confined spaces outdoors for such explosions to occur.

8.3.4 Risk Assessment

Consequence Analysis

8.3.4.1 Based on previous studies undertaken by the Consultants the effect zones for the scenarios identified above are summarised in *Tables 8.3b and c* below.

Table 8.3b Consequence Analysis - LPG Fireball/BLEVE

No.	Description	Release quantity (tonnes)	Fireball radius (max) (Note 1) (m)	Fireball height (max) (Note 1) (m)	Probability of fatality at viaduct (Note 1)	
					Person outdoors	Person within vehicle
1, 2, 4-7, 9	Fireball/BLEVE of storage vessel	3.1	44	101	0.86	0.10
2, 3, 4-7, 9	Fireball/BLEVE of road tanker	11.2	68	156	1.0	0.90

Note 1: Fireball dimensions and associated probabilities of fatality determined using Society of Fire Protection Engineers (SFPE) 3D fireball model.

Table 8.3c Consequence Analysis - LPG Flash Fire

No.	Description	Cloud dimensions (m) (Note 1)				Probability of fatality within cloud	
		D3.5		E1		Person outdoors	Person within vehicle
		d	c	d	c		
1	Catastrophic failure of storage vessel	90	47	127	94	1.0	0.1
3	Catastrophic failure of road tanker	153	85	206	161	1.0	0.1
2, 4	Partial failure of storage vessel or road tanker	73	11	115	88	1.0	0.1
5-9	Guillotine failure of LPG pipework or flexible hose (Note 2)	28	3	59	25	1.0	0.1

Note 1: Cloud dimensions are given for 'D3.5' and 'E1' weather conditions. 'D' and 'E' refer to neutral and stable atmospheric conditions respectively with associated wind speeds of 3.5 m/s and 1 m/s. 'd' and 'c' refer to downwind and cross wind distance to Lower Flammable Limit (LFL) at ground level.

Note 2: Results given for typical 1 kg/s release.

8.3.4.2 From the consequence analysis in *Tables 8.3b and Table 8.3c* it can be seen that the scenarios of primary concern with regard to the risk to Route 16 are fireball/BLEVE incidents involving either the LPG storage vessel or the road tanker and flash fires due to partial/catastrophic failure of either the LPG vessel or road tanker (flash fires arising from failure of LPG pipework are not significant). The following paragraphs consider the number of fatalities which could arise at Route 16 from these scenarios

8.3.4.3 *Fireball/BLEVE of LPG Vessel or LPG Road Tanker*: From *Table 8.3b* it can be seen that a fireball/BLEVE of the LPG vessel would not quite reach the LCK viaduct, although the thermal radiation levels for a person inside a vehicle (assumed stationary) could give rise to a level of fatality of around 10%. The calculation is pessimistic in ignoring the shielding effect of the intervening buildings, the viaduct barrier and the roof of the vehicle. For a BLEVE of the road tanker the fireball could engulf the LCK viaduct and the probability of fatality would be expected to be high (assumed to be 90%). The number of fatalities at the LCK viaduct can now be estimated for these scenarios, as shown in *Table 8.3d* below.

Table 8.3d Estimation of Number of Fatalities - LPG Fireball/BLEVE

Scenario	Length of road affected (m)	Number of fatalities (Note 3)	
		Traffic stationary in one direction	Traffic moving
Storage vessel fireball/BLEVE	25 (Note 1)	4	2
Road tanker fireball/BLEVE	100 (Note 2)	134	65

Scenario	Length of road affected (m)	Number of fatalities (Note 3)

Note 1: 25m of road assumed to be affected most severely, noting that thermal radiation levels outside fireball diminish significantly with distance.

Note 2: 100m of road assumed affected most severely based on distance of road from fireball centre.

Note 3: Number of fatalities calculated for two cases: traffic stationary in one direction (8m vehicle spacing, 3 persons per vehicle) and traffic moving in both directions (25m vehicle spacing, 3 persons per vehicle) with same probabilities of fatality in each case.

Flash fire due to catastrophic or partial failure of either the LPG vessel or road tanker: From *Table 8.3c* it can be seen that the maximum downwind extent of the LFL for a major release from the LPG installation is of the order of 100-200m. However, as LPG vapour is heavier than air and the LCK viaduct is 30m above ground level, it is unlikely that significant concentrations of LPG (ie concentrations above the LFL) could occur on the viaduct, unless the release is vertically-orientated. For the purposes of this assessment it is assumed that a stretch of up 150m of the viaduct could be engulfed by the flash fire (for catastrophic failure of the road tanker), with an associated probability of fatality for persons within vehicles of 10% (following previous QRA studies). Therefore the number of fatalities for the flash fire scenarios are as shown in *Table 8.3e* below:

Table 8.3e Estimation of Number of Fatalities - LPG Flash Fire

Scenario	Length of road affected (m)	Number of fatalities	
		Traffic stationary in one direction	Traffic moving
Flash fire due to: cold partial/catastrophic failure of storage vessel cold partial failure of road tanker	50	7	4
Flash fire due to: cold catastrophic failure of road tanker	150	22	11

Frequency Estimation

8.3.4.4 The next step in the risk assessment is to estimate the frequency of the events which have been identified above as posing a significant hazard to the LCK viaduct. This is undertaken based on the generic data and methodology of previous QRA studies undertaken by the Consultants.

8.3.4.5 It is assumed that the LPG installation contains an emergency isolation system for the storage vessel. However no credit is given in the analysis for any fire protection measures. It is assumed that the vessel is 10% radiographed, but not necessarily stress-relieved.

8.3.4.6 The estimated scenario frequencies are shown in *Table 8.3f* below:

Table 8.3f Scenario Frequencies

No.	Scenario description	Frequency (per year)
1	Cold catastrophic failure of storage vessel (fireball)	4.5E-6
2	Cold partial failure of storage vessel (BLEVE of storage vessel)	1.2E-7
9	Guillotine failure of flexible hose (BLEVE of storage vessel)	6.7E-8
	Total (Fireball/BLEVE of storage vessel)	**4.7E-6**
3	Cold catastrophic failure of road tanker (fireball)	9.0E-8
9	Guillotine failure of flexible hose or loading arm (BLEVE of road tanker)	6.7E-9
	Total (Fireball/BLEVE of road tanker)	**9.7E-8**
1	Cold catastrophic failure of storage vessel (flash fire)	5.0E-7
2	Cold partial failure of storage vessel (flash fire)	5.0E-7
3	Cold catastrophic failure of road tanker (flash fire)	1.0E-8
4	Cold partial failure of road tanker (flash fire)	2.5E-8
	Total (Flash fire due to catastrophic or partial failure of either the LPG vessel or road tanker)	**1.0E-6**

Risk Assessment

8.3.4.7 The data generated above for the frequency and consequences of hazardous events affecting the LCK viaduct may be used to construct an 'FN' curve. In undertaking the risk assessment it is assumed that there is a 10% chance that traffic is stationary on Route 16 at the time of the incident. A further 10% factor is applied for the flash fires scenarios to account for the probability of the wind blowing towards the nearest section of the LCK viaduct.

8.3.4.8 The FN curve is shown in *Figure 8.3a.* It can be seen that the FN curve lies within the acceptable region of the Risk Guidelines.

8.3.5 Conclusions

8.3.5.1 From the analysis undertaken in *Section 8.3.4* it is concluded that the risk to Route 16 due to the presence of the LPG installation is acceptable. There on no constraints placed on the alignment or design of Route 16 as a result of the presence of the LPG installation.

FIGURE 8.2a

SITE LOCATION

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DATE: 22/06/99

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Figure 8.2b Route 16 Operational Phase (Base Case)

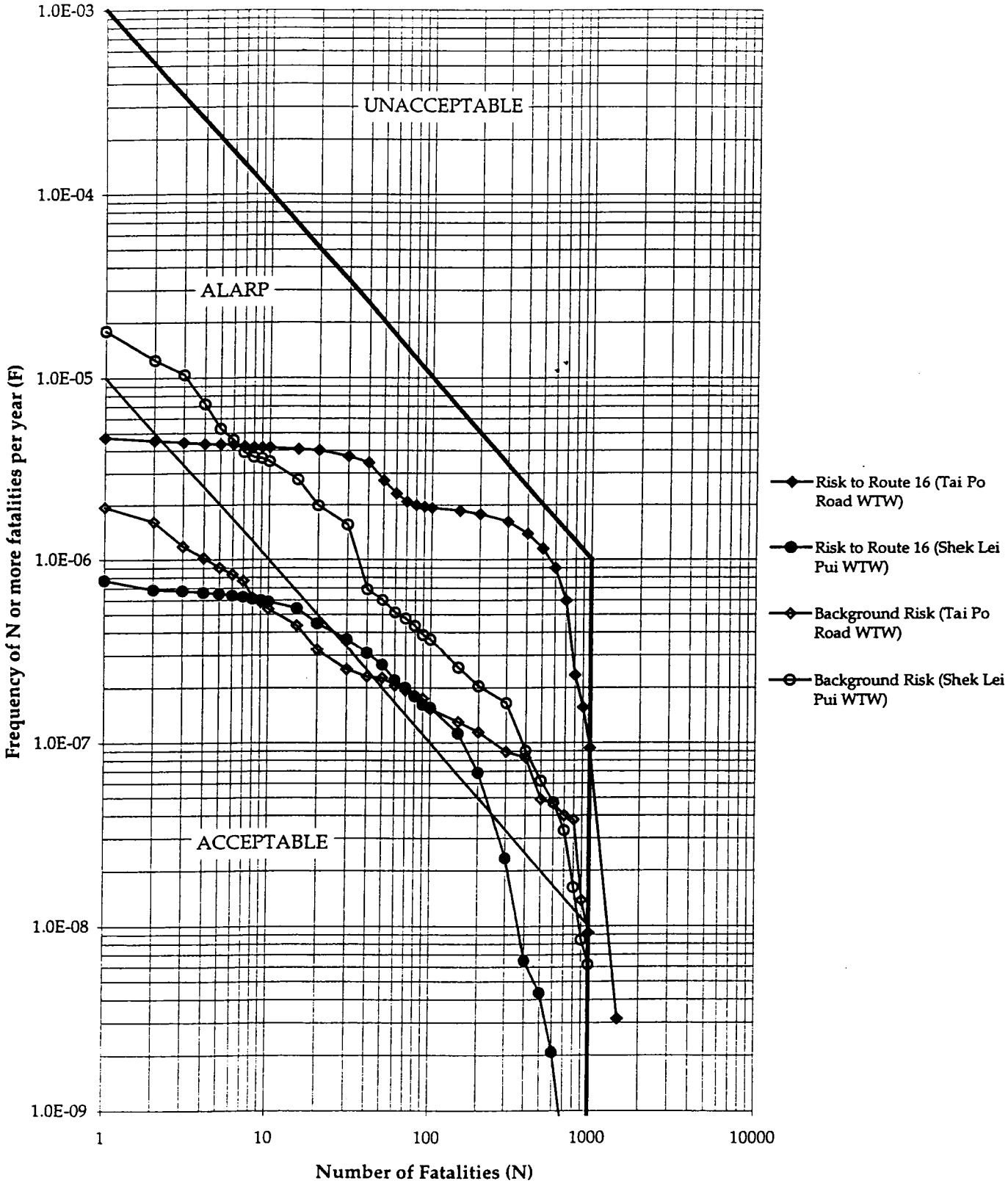


Figure 8.2c Route 16 Operational Phase (Mitigation Options)

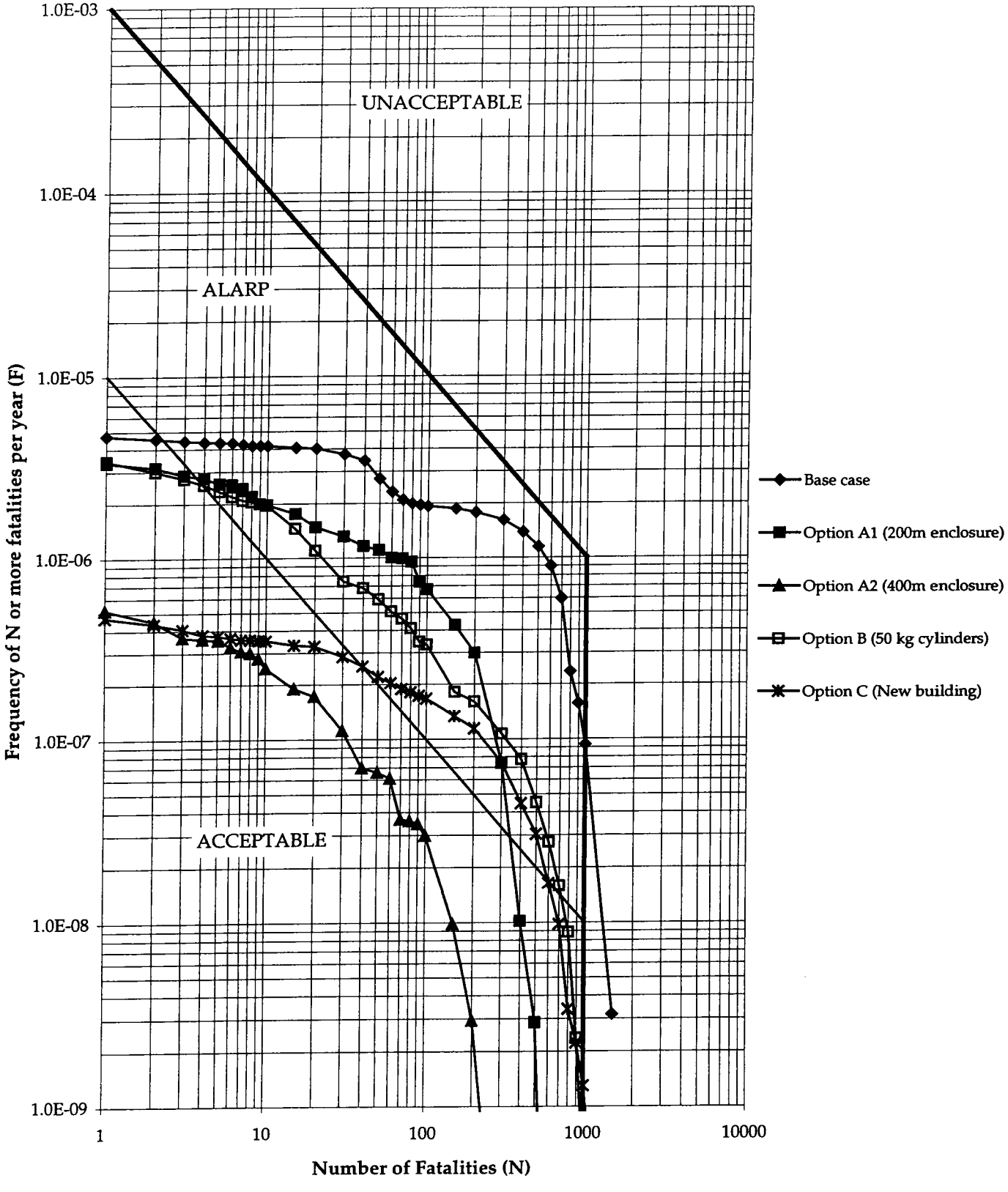


Figure 8.2d Route 16 Operational Phase (Combined Mitigation Options)

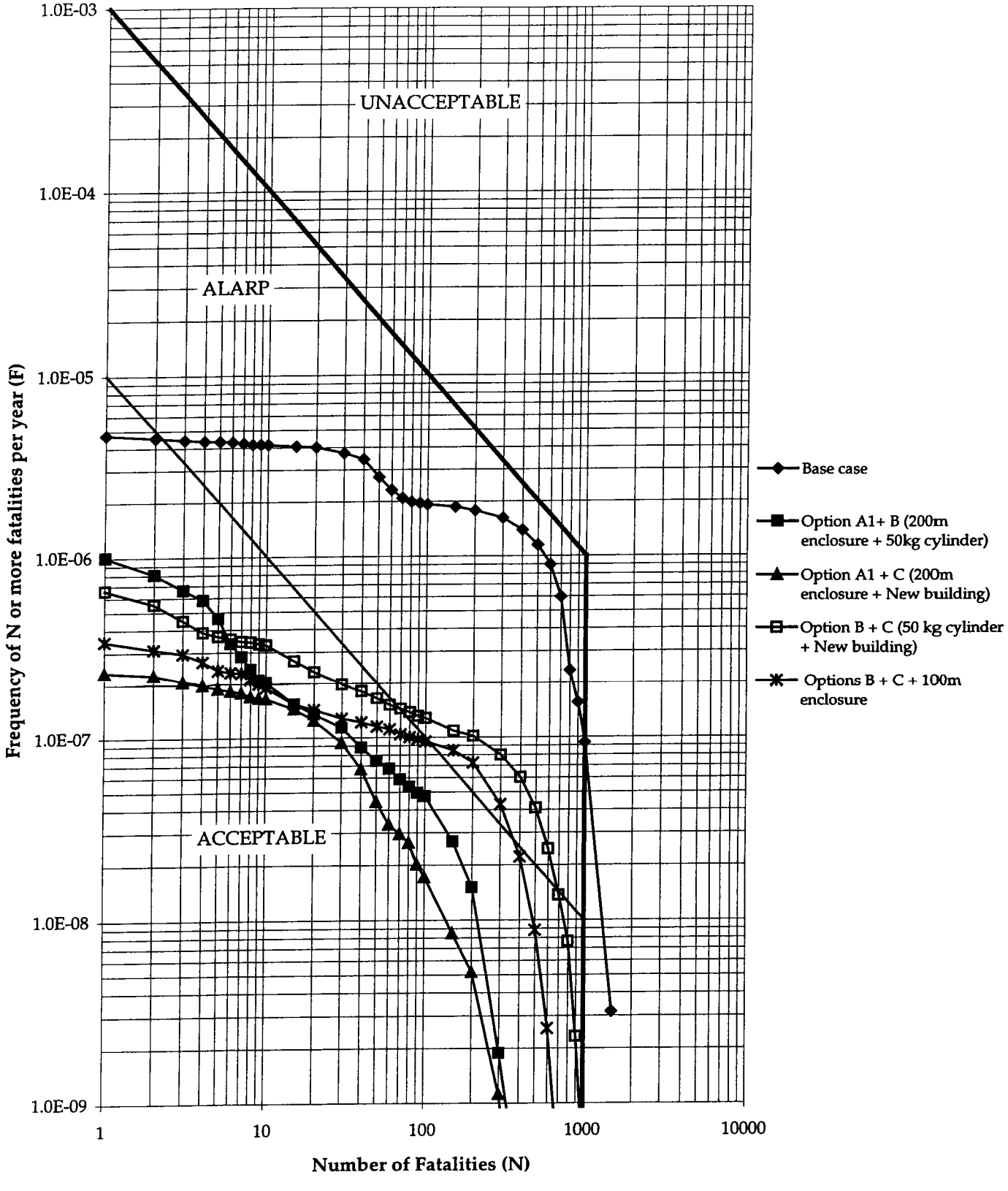


Figure 8.2e Cumulative Risk for Operation Phase of Route 16

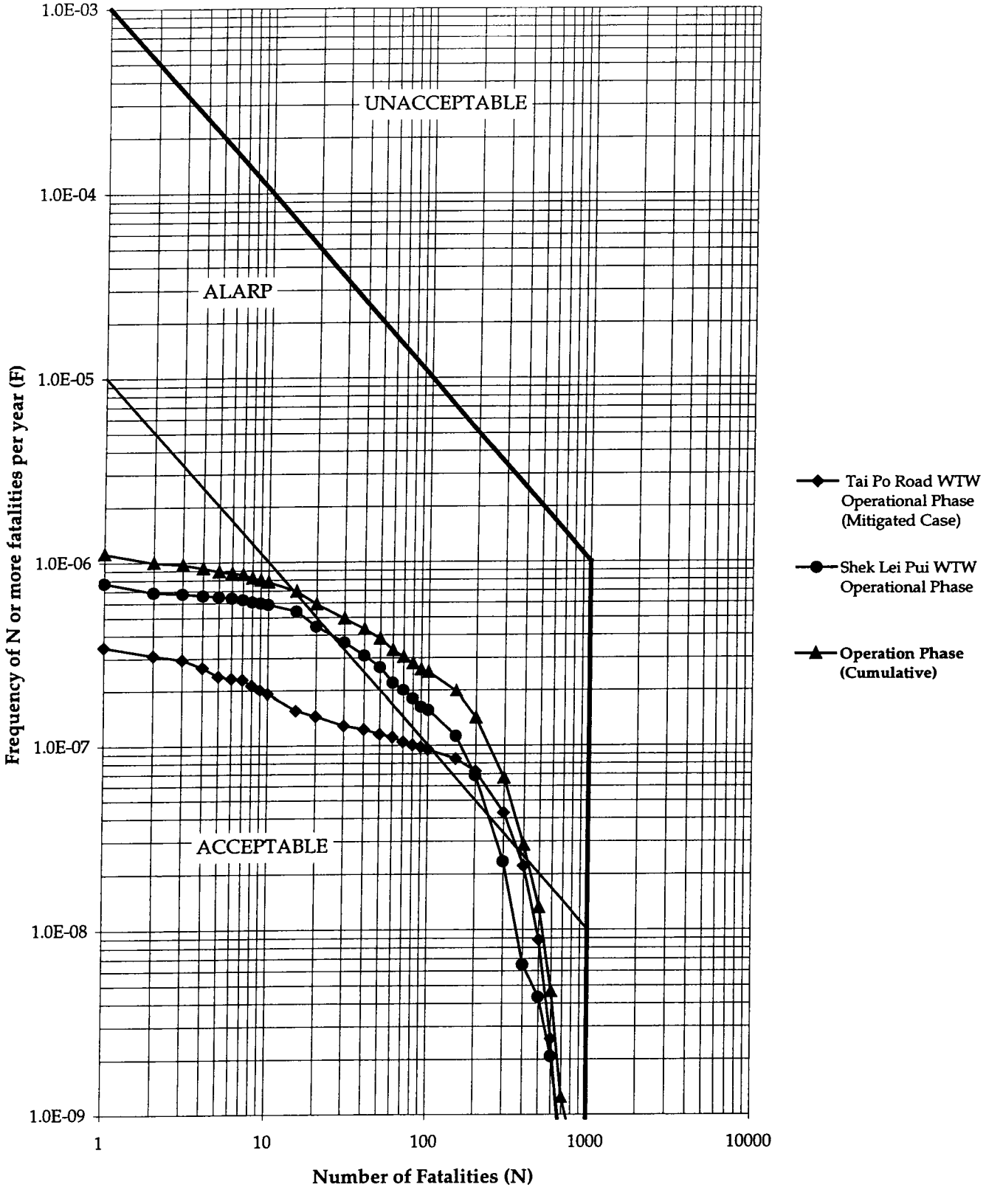


Figure 8.2f Route 16 Construction Phase (Base Case)

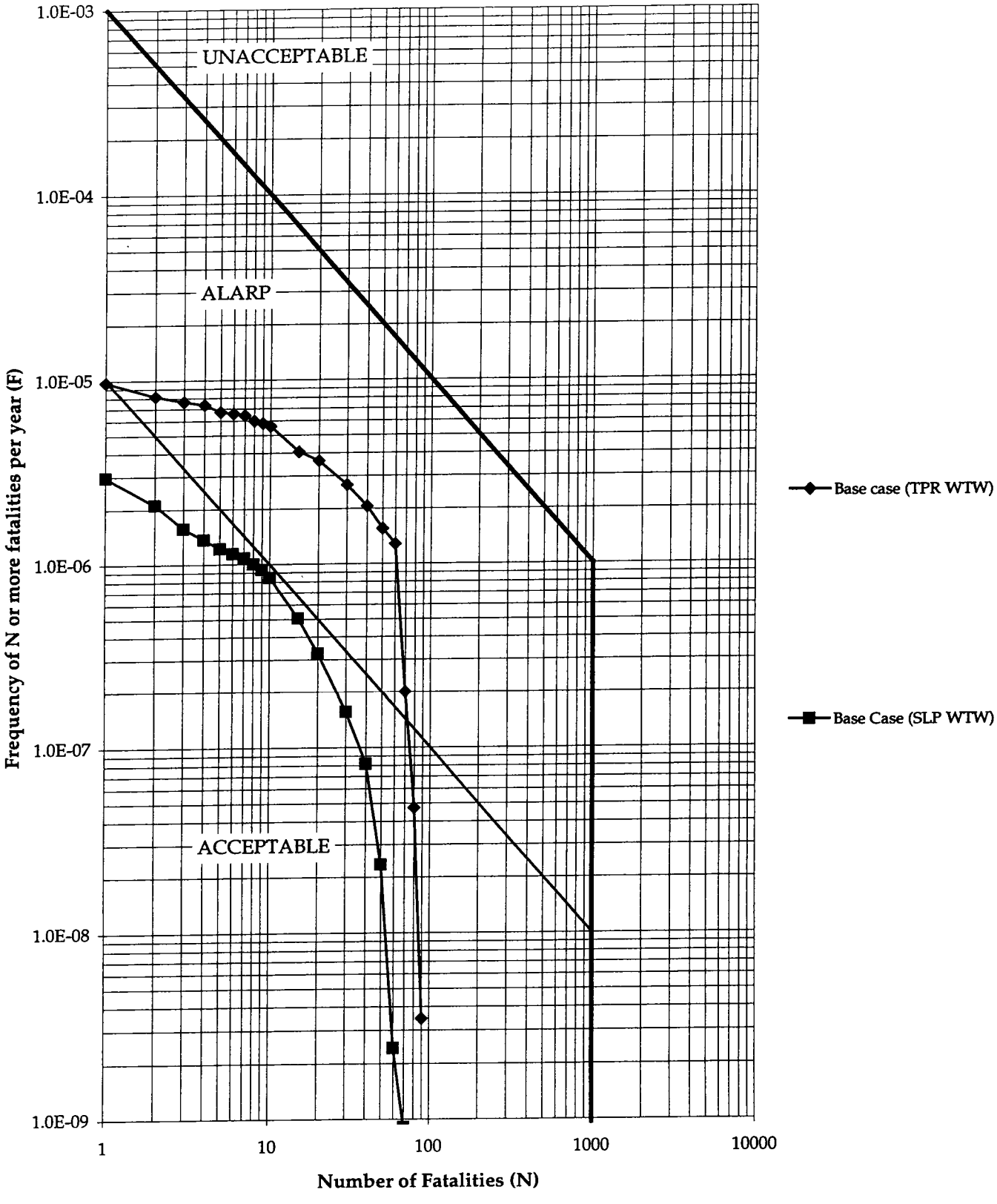


Figure 8.2g Route 16 Construction Phase (Mitigation Options)

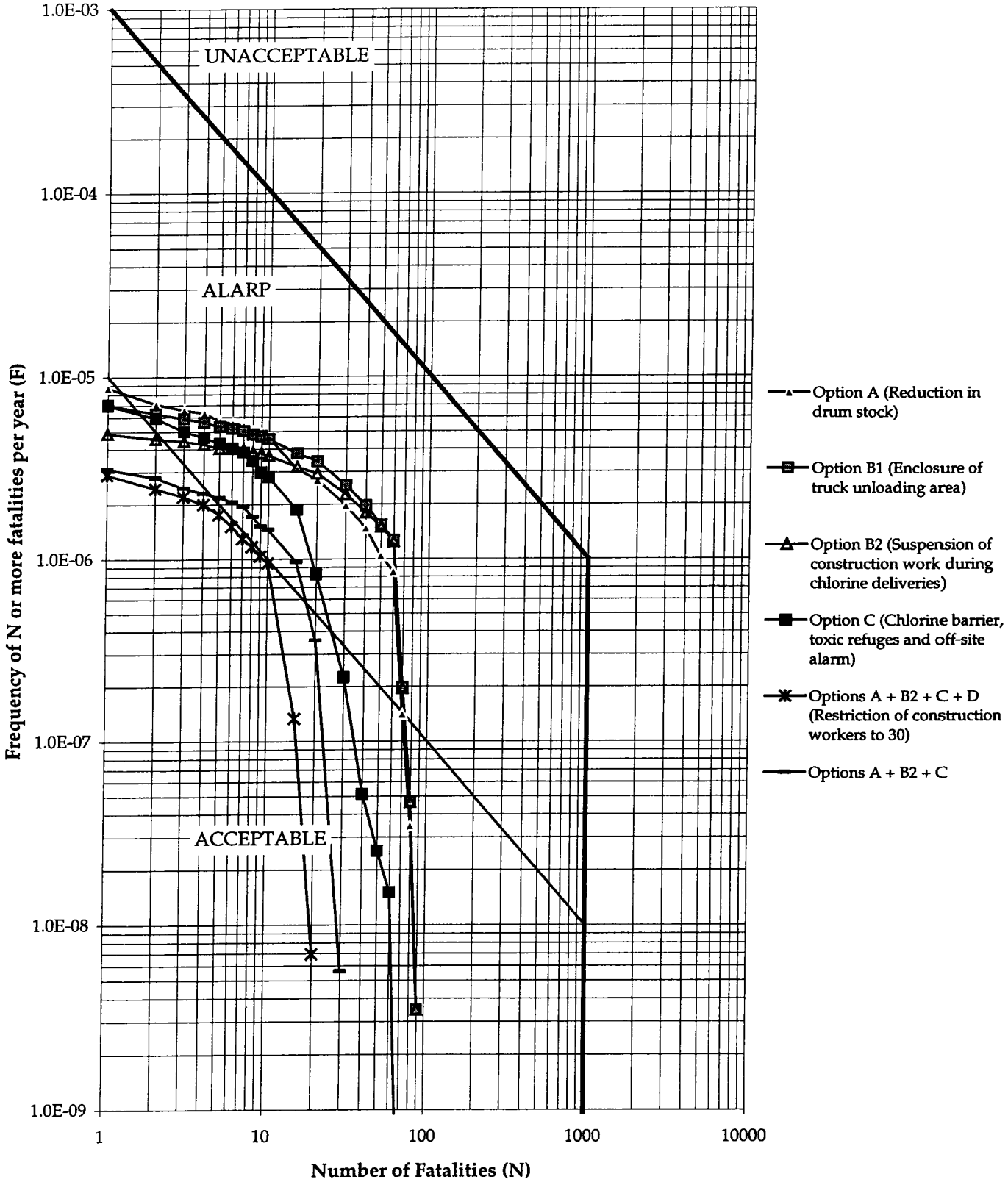
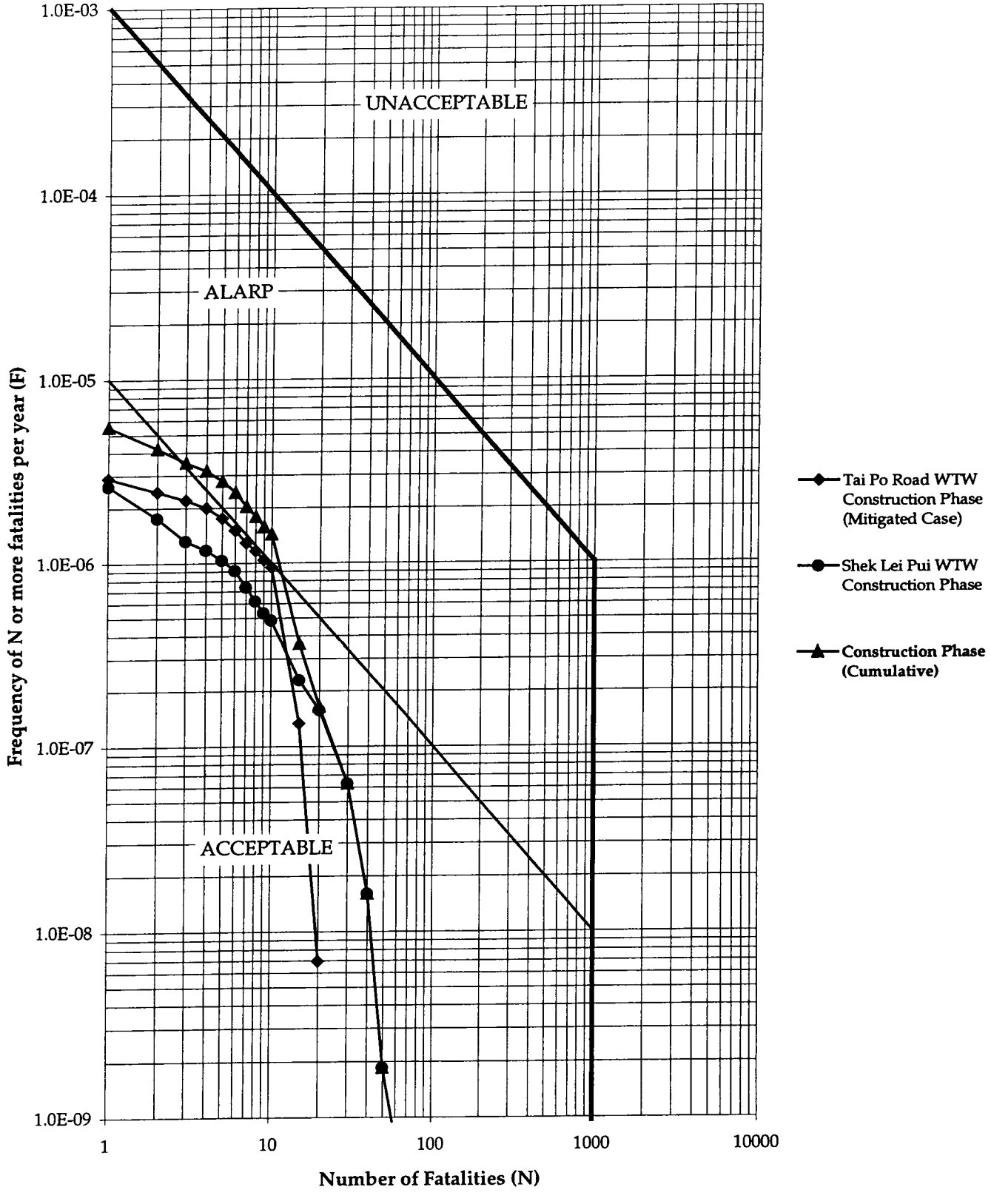


Figure 8.2h Cumulative Risk for Construction Phase of Route 16



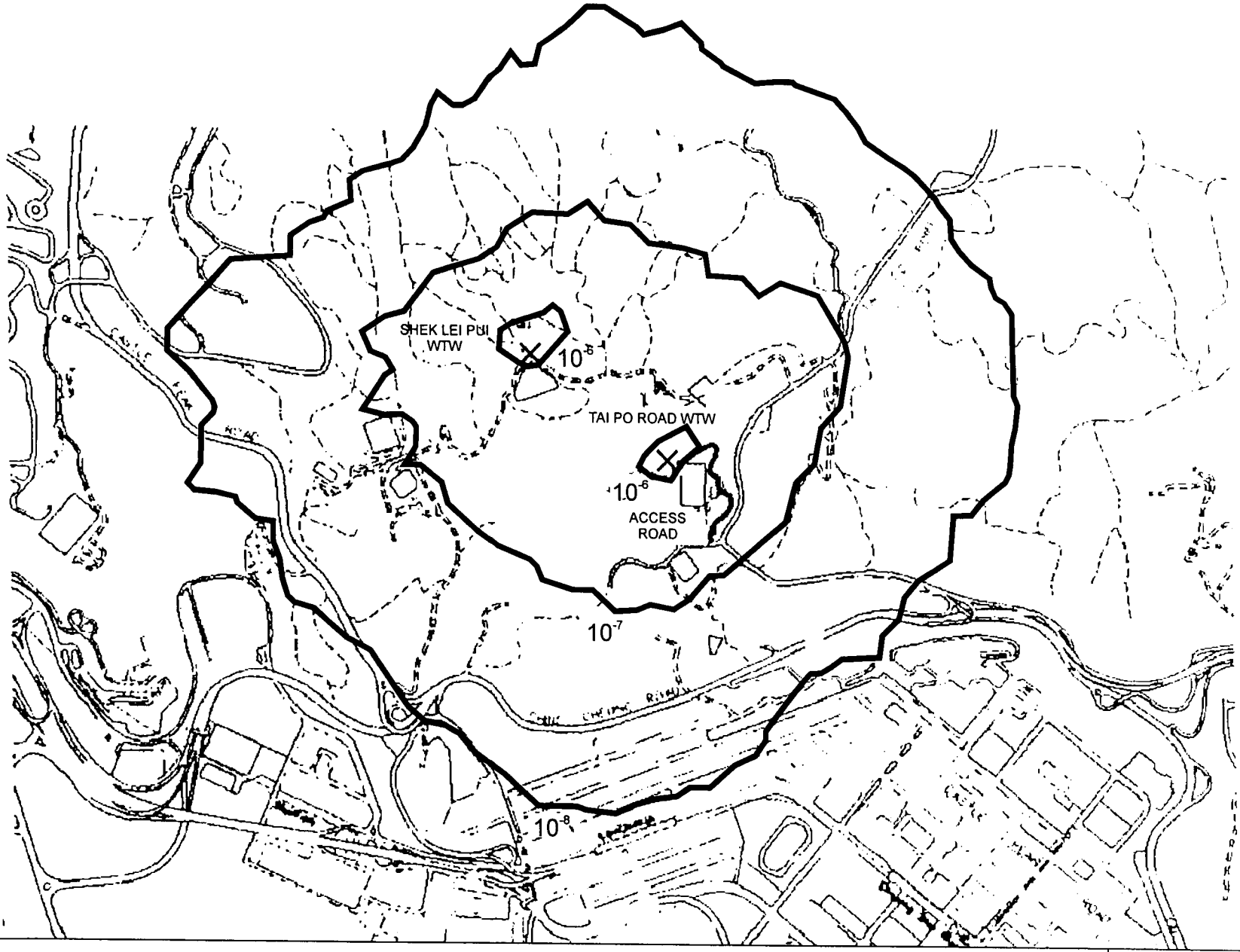


FIGURE 8.2i

INDIVIDUAL RISK CONTOURS FOR SHEK LEI PUI AND TAI PO ROAD WTW MITIGATED CASES
(FROM 1995 HAZARD ASSESSMENT STUDY)

FILE: C1884g
DATE: 27/05/99

Environmental
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Management

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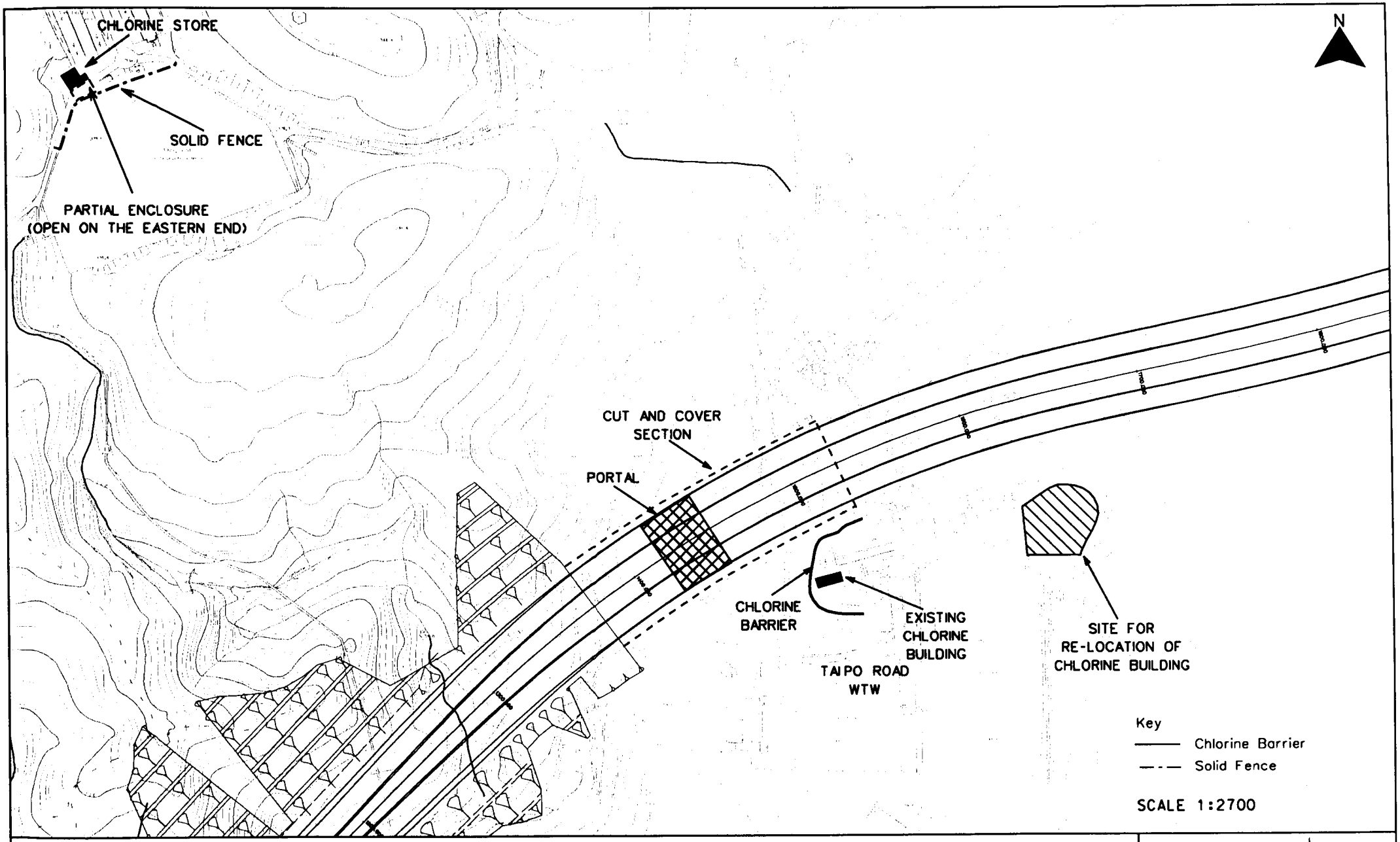

FIGURE 8.2j-1

PLAN SHOWING CHLORINE BARRIER AND SITE FOR NEW CHLORINE BUILDING AT TAI PO ROAD WTW

Environmental Resources Management

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USTN FILE: C1884_48
DATE: 16/06/99

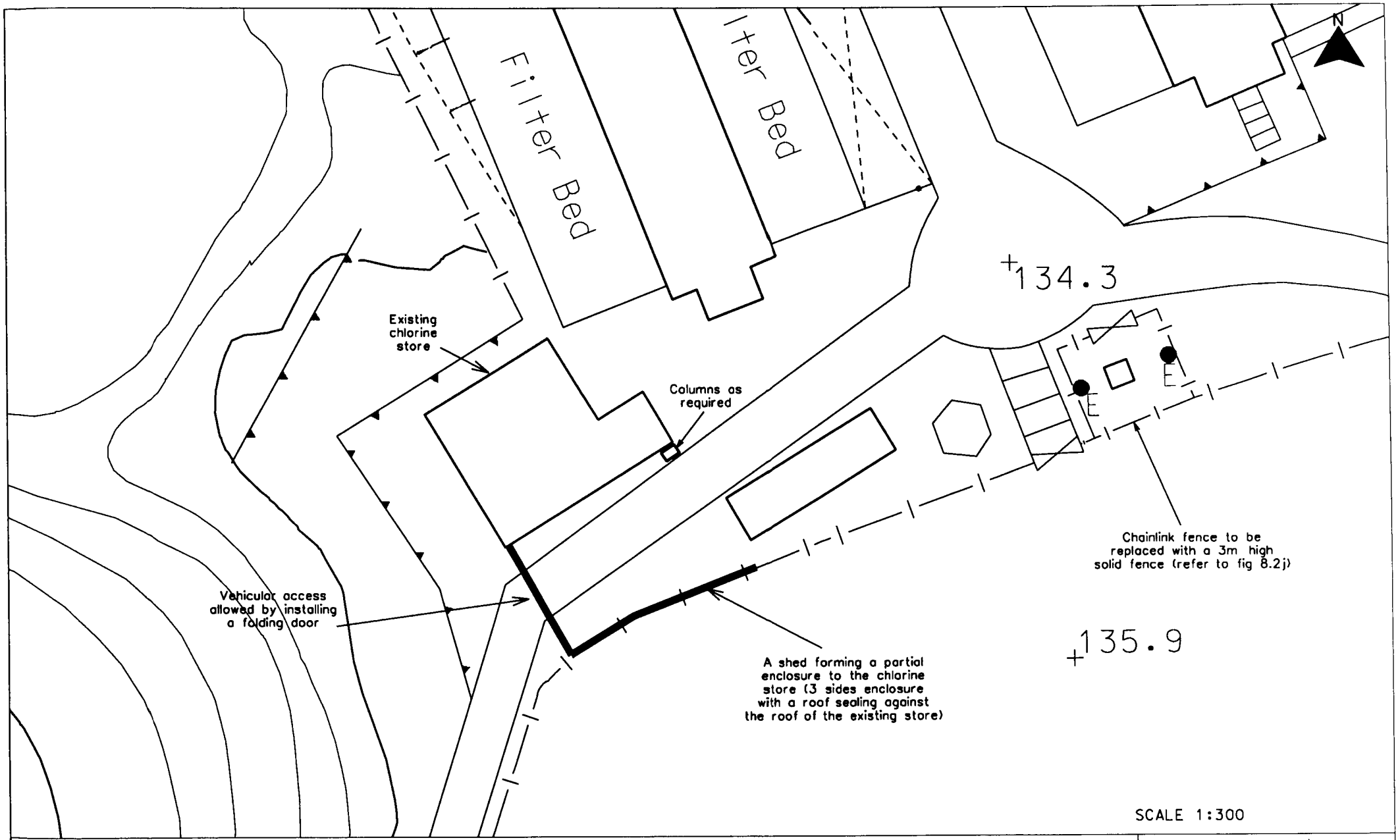

FIGURE 8.2 j-2

PLAN OF THE PART ENCLOSURE

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DATE: 19/08/99

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Figure 8.3a FN Curve for Risk to Route 16 due to the Lai Chi Kok Reception Centre LPG Installation