Appendix 11.1 Some Information Extracted from the Reassessment Study

Table 3.2a from the Reassessment Study

Hazards Identified during HAZOP Study for Sheung Shui WTW

1. ACCESS ROAD	1.1 Fire on the truck leading to melting of the fusible plugs on one or more containers
	1.2 Fire on the roadside leading to melting of the fusible plugs on one or more containers
	1.3 Impact with object during truck manoeuvring
	1.4 Lorry over-turns
	1.5 Collision with another vehicle
	1.6 Loadshedding
	1.7 Spontaneous container failure
2. CONTAINER HANDLING	2.1 Dropped container
	2.2 Collision of container with another object
	2.3 Accidental impact of drum on pigtail during setdown at standby position
	2.4 Overextension during use of truck crane (not normally used)
3. CONTAINERS IN STORAGE	3.1 Leaking chlorine containers
	3.2 Overfilled containers leading to overpressurisation on thermal expansion
	3.3 Impurities in chlorine containers, in particular nitrogen trichloride (leading to explosion) or moisture (causing accelerated corrosion)
	3.4 Object falls onto chlorine containers
	3.5 Fire (external or internal)
	3.6 External explosion
	3.7 Lightning strike
	3.8 Extreme wind
	3.9 Flooding
	3.10 Construction activities
	3.11 Subsidence
	3.12 Landslide
	3.13 Earthquake
	3.14 Aircraft crash
	3.15 Sabotage
	3.16 Vehicle crash
	3.17 Electromagnetic interference
4. CONNECTION AND DISCONNECTION OF CHLORINE CONTAINERS	4.1 Human error or equipment failure during connection/disconnection of containers
5. CHLORINATION SYSTEM	5.1 Trapping of liquid chlorine between closed valves and subsequent thermal expansion leading to overpressurisation of pipework
	5.2 Pigtail failure
	5.3 Failure of fixed chlorine pipework
	5.4 Open end on pipework due to operator or maintenance error

	5.5 Corroded pipework
	5.6 Presence of nitrogen trichloride in evaporator leading to explosion
	5.7 Presence of moisture in evaporator leading to accelerated corrosion

Table 4.1b from the Reassessment Study

Effective Outdoors Probability of Fatality

Chlorine Concentration (ppm)	Probit Value for 10 min Exposure	Probability of Fatality (LD = Lethal Dose)
251	3.17	0.03 (LD03)
557	5.00	0.50 (LD50)
971	6.28	0.90 (LD90)

Table 5.1a from the Reassessment Study

Rationalisation of Chlorine Release Scenarios

Chlorine Release Scenario	Outcome	Hole Size	Phase	Chlorine Release Rate from Primary Source (kg/s)	Chlorine Release Quantity (tonnes)	Chlorine Release Rate (or Quantity) to Atmosphere	Significant Off-site Hazard ? (Y/N)	Event Ref[2]
1. ACCESS ROAD								
1.1 Truck fire	Considered to result in melting of the fusible plugs on up to three drums. Three cases are considered according to the number of 'old' and 'new' drums:							
	Case (i): 3 new drums, no old drums	3x6mm	liquid	2.4	3	2.4 kg/s[3]	Y	RU1TMML
	Case (ii): 2 new drums, 1 old drum	2x6mm (new drums) 6x6mm (old drums)	liquid	1.6 4.8	2 1	1.6 kg/s 4.8 kg/s[4]	Y	RU1TSRU
	Case (iii): No new drums, 3 old drums	18x6mm	liquid	14.4	3	14.4 kg/s[4]	Y	RU1TMRU
1.4 Rollover	Single drum - small leak	3mm	liquid	0.2	1	0.2 kg/s	N	-
	Single drum - medium leak	8mm	liquid	1.4	1	1.4 kg/s	Y	RU1TSML
	Three drums - medium leak	3x8mm	liquid	4.2	3	4.2 kg/s	Y	RU1TMML
	Fire (outcomes as item 1.1 above)							
1.5 Collision	Single drum - rupture Fire (outcomes as item 1.1 above)	-	liquid	-	1 (inst)	1 tonne	Y	RU1TSRU

Chlorine Release Scenario	Outcome	Hole Size	Phase	Chlorine Release Rate from Primary Source (kg/s)	Chlorine Release Quantity (tonnes)	Chlorine Release Rate (or Quantity) to Atmosphere	Significant Off-site Hazard ? (Y/N)	Event Ref[2]
1.6 Loadshedding	Single drum - small leak	3mm	liquid	0.2	1	0.2 kg/s	N	-
	Single drum - medium leak	8mm	liquid	1.4	1	1.4 kg/s	Y	RU1TSML
1.7 Spontaneous container failure	Single drum - medium leak	8mm	liquid	1.4	1	1.4 kg/s	Y	RU1TSML
	Single drum - large leak	20mm	Liquid	8.8	1	8.8 kg/s[4]	Y	RU1TSRU
	Single drum - rupture	-	liquid	-	1(inst)	1 tonne	Y	RU1TSRU
2. DRUM HANDLING								
2.1 Dropped drum	Single drum - medium leak	8mm	liquid	1.4	1	0.30 kg/s	N	-
	Single drum - large leak	20mm	liquid	8.8	1	0.56 kg/s	N	-
	Single drum - rupture	-	liquid	-	1 (inst)	57 kg	Y	IU1TSRU
2.3 Accidental impact of drum on pigtail during setdown at standby position	Pigtail - guillotine failure	4.5mm	two-phase	0.12	1	0.027 kg/s	N	-
3. CONTAINERS IN STORAGE								
3.1 Leaking chlorine drums	Single drum - medium leak	8mm	liquid	1.4	1	0.30 kg/s	N	-
	Single drum - large leak	20mm	liquid	8.8	1	0.56 kg/s	N	-
	Single drum – rupture	-	liquid	-	1 (inst)	57 kg	Y	IU1TSRU
3.2 Overfilled drums leading to overpressurisation on thermal expansion	As item 3.1 above							
3.3 Impurities in chlorine drum leading to explosion or leak	As item 3.1 above							
3.12 Earthquake	Roof collapse: multiple drum-rupture	-	liquid	-	14 (inst)	10 tonnes(1)	Y	EU1TMRU EU1TMRU1G
4. CONNECTION AND DISCONNECTION OF CHLORINE CONTAINERS								
4.1 Human error or equipment failure during connection/disconnection of drums	Pigtail - guillotine failure	4.5mm	two-phase	0.12	1	0.027 kg/s	N	-

Chlorine Release Scenario	Outcome	Hole Size	Phase	Chlorine Release Rate from Primary Source (kg/s)	Chlorine Release Quantity (tonnes)	Chlorine Release Rate (or Quantity) to Atmosphere	Significant Off-site Hazard ? (Y/N)	Event Ref[2]
5. CHLORINATION SYSTEM								
5.1 - 5.5 Failures associated with the chlorination system pipework	Liquid chlorine pipework - guillotine failure	4.5mm	two-phase	0.12	1.05	0.027 kg/s	N	-
5.6 - 5.7 Failure of Evaporator	Evaporator - leak or rupture	4.5mm	two-phase	0.12	1.05	0.027 kg/s	N	-

Note

(1) For large instantaneous releases, 70% of the chlorine is estimated to be released instantaneously to atmosphere as vapour and entrained aerosol. This comprises the initial vapour flash fraction (19%) plus the entrained aerosol (2 x 19%) plus the contribution from the evaporating chlorine pool over the first minute (around 10% depending on the pool size).

(2) Key to event ref

E	R (Road) or E (Earthquake) or A (Aircraft crash) or I (internal)
U	U (Unisolated) or I (Isolated)
1T	1T (1 tonne drums) or 50 (50 kg cylinders)
M	S (Single) or M (Multiple)
RU	RU (Rupture), LL (Large Leak), ML (Medium Leak) or SL (Small Leak)
H	Earthquake of higher ground acceleration

(3) This release (2.4 kg/s) treated as a multiple medium leak for simplification (conservative assumption).

(4) These releases treated as effectively instantaneous releases due to short release duration.

Table 5.2a from the Reassessment Study

Base Failure Rate Data

Item	Value	Units
1. Chlorine container		
1.1 (i) Spontaneous container failure frequency	1.5E-4	per year
(ii) Conditional probability of catastrophic failure	0.027	-
(iii) Conditional probability of medium leak	0.22	-
(iv) Conditional probability of large leak	0.081	-
1.2 (i) Probability of dropped container	7.7E-6	per lift
(ii) Conditional probability of catastrophic failure	1.0E-4	-
2. Chlorine delivery vehicle		
2.1 (i) Frequency of loadshedding	1.1E-7	per truck-km
(ii) Conditional probability of a medium leak	6.3E-2	-
2.2 (i) Frequency of rollover	1.9E-7	per truck-km
(ii) Conditional probability of a medium leak of a single drum	1.5E-1	-
(iii) Conditional probability of medium leak of Multiple drums	1.1E-2	-
2.3 (i) Frequency of vehicle impact	4.0E-7	per truck-km
(ii) Conditional probability of drum rupture	1.7E-2	-
2.4 (i) Frequency of spontaneous truck fire	4.0E-9	per truck-km
(ii) Probability of having 2 or 3 'old' drums among the 3 ruptured drums	0.061	-
(iii) Probability of having 1 'old' drum among the 3 ruptured drums	0.33	-
(iv) Probability of having nil 'old' drums among the 3 ruptured drums	0.61	-
3. External events		
3.1 (i) Frequency of earthquake of 0.5g ground acceleration(1)	3.3E-6	per year
(ii) Probability of roof collapse in an earthquake of 0.5g ground acceleration	0.1	-
3.2 (i) Frequency of earthquake of 0.8g ground acceleration(2)	1.4E-7	per year
(ii) Probability of roof collapse in an earthquake of 0.8g ground acceleration	0.5	-
3.3 Frequency of aircraft crash	1.2E-8	per landing

Note:

(1) Approximately equivalent to MMX.

(2) Approximately equivalent to MMXI-XII.

Table 5.2b from the Reassessment Study

Event Frequencies

Event Ref	Component Scenarios	Frequencies (per year)	Time Periods during which Event could Occur
IU1TSRU	Dropped drum	1.69E-6	All except Night
	Spontaneous drum failure	4.54E-4	All
	Total	4.55E-4	
RU1TSML	Rollover	1.04E-6	All except Night
	Loadshedding	2.54E-7	All except Night
	Spontaneous leak	1.03E-7	All except Night
	Total	1.40E-6	
RU1TMML	Rollover	7.65E-8	All except Night
	Truck fire	8.99E-8	All except Night
	Total	1.66E-7	
RU1TSRU	Truck impact	2.49E-7	All except Night
	Truck fire	4.76E-8	All except Night
	Spontaneous drum failure	5.08E-8	All except Night
	Total	3.47E-7	
RU1TMRU	Truck fire	8.89E-9	All except Night
EU1TMRU	Earthquake	3.30E-7	All
EU1TMRUH	Earthquake	7.00E-8	All

<u>Annex F2 from the Reassessment Study</u>

METHODOLOGY FOR ASSESSING RISKS TO TRANSIENT POPULATION

This annex presents an outline of the Consultants approach to modelling the effect of chlorine releases on transient populations, in particular road vehicles and trains. The approach adopted essentially follows that developed under research work undertaken on behalf of the UK Health and Safety Executive (HSE, 1998).

Effect of Chlorine Releases on Road Vehicles

Within the Consultation Zones of the eight WTWs under consideration in this study there are a wide variety of types of road ranging from single track access roads to multi-lane highways. In this study all roads carrying significant quantities of traffic have been modelled. Data on traffic flows and vehicle occupancy has been obtained from a variety of sources, including direct roadside surveys, the 1996 Annual Traffic Census (for existing major highways) and traffic forecasts (for future highways such as Route 16).

The analysis takes into account the variation in traffic flows and vehicle occupancy by modelling five separate time periods: night, working day, weekend day, peak hour and 'jammed peak', the last period representing conditions under which traffic is at standstill, eg due to an accident, lane restriction etc.

One of the key factors in modelling the effects of chlorine on road vehicles is assessing the extent to which chlorine builds up inside the vehicle and whether this could impair driving ability. HSE (1998) shows that vehicles generally afford little protection from toxic gas ingress and that for a major highway located 100m from a chlorine storage facility, releases of the order of 10 kg/s could give rise to concentrations sufficient to cause vehicles to come to a standstill. The hazards posed to road traffic toxic gas releases are evident from a number of past incidents (eg Youngstown, US, 1978 and Montana, US, 1996) in which motorists have become stranded resulting in injury or death.

In this study the population associated with road vehicles is modelled as effectively outdoors. The traffic is considered stationary to account for the presence of traffic lights, road junctions etc or the possibility that the chlorine itself may be of sufficient concentration to bring traffic to halt. As noted above, for major highways, consideration is also given to conditions under which the traffic is at a standstill, 'bumper to bumper' in one direction. As for other outdoors populations, allowance is made for the possibility of escape of exposed persons either directly out of the cloud or to a nearby building, although with a minimum exposure duration of 5 minutes.

Effect of Chlorine Releases on Trains

Kowloon-Canton Railway Corporation (KCRC) tracks pass through the Consultation Zones of a number of the WTWs. Many of the considerations outlined above for road vehicles apply equally to rail vehicles, except in this case the speed of travel of trains (and stopping distance) means that they are unlikely to come to a halt within a chlorine cloud. This means that the exposure of rail passengers to the released chlorine is limited to the duration for which the train is within the cloud plus the time for the chlorine to disperse from the carriages subsequently.

The following calculation assesses the probability of fatality of passengers on board a train passing through a chlorine cloud (this calculation was previously presented in response to comment no. 14-see *Annex M*, p4 of 15).

It is highly likely that a train will enter the cloud, as the service interval on East Rail is only 3 min (peak) and 5 min (off-peak). The methodology assumes that a train entering the cloud will continue to pass through, although at a speed below the normal line speed.

The dose to the train passengers is estimated as follows:

Exposure duration 1 minute (maximum)

(based on time for train to pass through chlorine cloud+ time for chlorine to disperse from train afterwards)

Air change rate 15 per hour (based on ACDS Report)

Dose calculation Dose= $(1/2 \times C_{max})^{2.3}$ x Exposure duration

(C_{max}= chlorine concentration in train after 30 seconds, calculated using a simple model of perfect mixing)

Estimate of probability of fatality TNO Green Book

Results are shown in *Table F5* below:

Table F5 Outdoor Fatality

Outdoor p(fatality)	C_{max}	p(fatality) in train
LD90 (C= 974 ppm)	115 ppm	<1%
LD50 (C= 559 ppm)	66 ppm	<1%
LD03 (C= 245 ppm)	29 ppm	<1%

On the basis of the above it will be assumed, as a conservative upper bound, that the probability of fatality of persons on-board a train will be 1% of the probability of fatality of a person outdoors. This takes into account that passengers on board the train will be exposed to the highest concentrations of chlorine entering the train via the roof level ventilation intakes.

In the QRAs for each WTW account is taken of the possibility of stationary trains being on the sections of line within the affected area. This includes trains present at stations or at signals. All calculations of the risk to rail passengers assume crush loading of trains at peak hours (300 persons per carriage on an East Rail train) and 50% loading at off-peak hours during the working day.

Methodology for Estimating Rail Populations

The population number for Pop Ref R in *Table 2.3a* of the Main Report represents the total number of exposed passengers assuming the whole rail track of 3.2km considered in the Hazard Assessment is fully occupied by trains, i.e.

$$\frac{\text{(12 cars/ train) x (300 people /car) x (3.2km of track)}}{\text{(300m/ train) x 10, reduction factor for limited exposure)}}$$

The total number of vulnerable population is derived by multiplying the above by the ratio of proportional length of track covered by the chlorine cloud of interest.

One-tenth Reduction Factor for Limited Exposure

Strictly speaking, this factor should be applied to the fatality probability instead of the exposed population. For simplicity, however, the software does not assign a particular fatality probability for a particular population group. This simplification has no effect on the final result.

However, it is noted that the trains cannot get closer than the minimum headway which is about 90s (roughly equivalent to a separation distance of about 600m to 1km). The above estimation is conservative.