Table 1.1 Uncertainty Analysis of Chlorine Release

Ref.	Key Parameter (or Assumption)	Uncertainty in Parameter (or Assumption)	Uncertainty Significant (Y/N)	Estimated Range of Uncertainty	Uncertainty in overall risk results
1	**POPULATION DATA**				
1.1	Population estimates	On-site hazard Population estimates have been obtained from a variety of sources, including Civil Engineering and Development Department (TKO Area 137 explosive pier), Planning Department (primary source), Social Welfare Department (for elderly persons homes), Education Department (for schools), Environmental Protection Department (SENT extension) and Transport Department (for roads) and etc. This has been supplemented by surveys by the Consultants including, where necessary, contact with individual establishments. It is not considered that there is a significant uncertainty in the population estimates. Off-site hazards Marine population is objectively estimated according to marine traffic surveys.	N	-	-
1.2	Percentage of people outdoors	On-site hazard The outdoors population is a critical factor in the QRA. This has been addressed through the site surveys undertaken by the Consultants, in which the number of people outdoors at different locations and different times of the day has been accurately recorded. The percentage of people outdoors will vary according to the time of day (i.e. less at night), but this is not modelled in the QRA. The approach adopted will overestimate the risk, but this will not be significant as the most important scenarios are those associated with the chlorine truck which delivers only during the day. Off-site hazards It is appropriate assuming marine population outdoor due to the fact that ventilation relies on either drawing fresh air at deck level for air conditioned cabin or natural airflow through opened windows and doors.	N	-	-
1.3	Spatial distribution	On-site hazard The Consultants risk integration software ERM GIS*Risk* enables populations to be represented as polygons of any shape. Population data within the LD03 contour (based on CFD modelling results) have been gathered for inclusion for the assessment, which provides an accurate representation of the spatial population distribution. High rise buildings are also explicitly accounted for in this study, such that only the lower stories are affected, according to the information on the height of the chlorine cloud provided by the dispersion modelling. Off-site hazards Marine population is assumed uniformly distributed over the sea as ships may pass the chlorine vessel in any directions.	N	-	-
1.4	Temporal distribution	On-site hazard The consultants have modelled five different time periods for this study (night, working day, weekend day, peak and 'jammed' peak) to enable accurate representation of the variation of population with time. Off-site hazards Chlorine is delivered during daytime over a relatively short period of time. Use of different time periods would not significantly affect the number of fatalities.	N	-	-
1.5	Sensitive populations	On-site hazard The QRA explicitly assessed the risk to sensitive populations such as primary schools. Therefore the risk to this component of the community has been accurately assessed. Off-site hazards Refer to on-site hazards	N	-	-
2	**WEATHER DATA**				

Ref.	Key Parameter (or Assumption)	Uncertainty in Parameter (or Assumption)	Uncertainty Significant (Y/N)	Estimated Range of Uncertainty	Uncertainty in overall risk results
2.1	Base weather data	<u>On-site hazard</u> The weather data used in the study is the data recorded by the Hong Kong Observatory for 10 years (2003 – 2012) from the nearest weather station (Kai Tak Weather Station). As data from 10 years has been used, it is not anticipated that this is a significant source of error. <u>Off-site hazards</u> Although equally distributed wind direction is adopted, the assumption has significant effect on neither chlorine dispersion nor number of fatalities due to the fact that - Topographical effect is not anticipated for dispersion over water surface; - Population on the sea is considered equally distributed in all directions.	N	-	-
2.2	Rationalisation of weather data	<u>On-site hazard</u> The base weather data recorded by the Hong Kong Observatory has been rationalised into discrete stability class/ wind speed combinations or 'weather states'. Day time conditions are represented by 4 weather states (B3, D2, D4.5 and F1.5), whilst night time conditions are represented by 3 weather states (D2, D4.5 and F1.5). This is a common approach in QRA studies and is not considered to introduce any significant error into the calculations (noting also that the chlorine hazard range has been found to have a relatively weak dependence on atmospheric stability - see below). <u>Off-site hazards</u> Chlorine is delivered during daytime. The adopted stability class D is based on the average wind speed and moderate solar radiation at daytime or completely overcast conditions, which could represent most of the atmospheric conditions in Hong Kong. Therefore, there is no significant uncertainty.	N	-	-
2.3	Representation of site-specific weather conditions	<u>On-site hazard</u> QRA studies do not commonly account for site-specific weather conditions. However in this study the CFD simulation allow the local topography and buildings to modify the wind speed and direction so as to account for such effects. <u>Off-site hazards</u> The assessment does not account for site specific weather condition as the transport route covers the whole territory. The use of non-site specific weather condition would not lead to significant uncertainty.	N	-	-

Ref.	Key Parameter (or Assumption)	Uncertainty in Parameter (or Assumption)	Uncertainty Significant (Y/N)	Estimated Range of Uncertainty	Uncertainty in overall risk results
2.4	Atmospheric stability	<u>On-site hazard</u> The key findings of the CFD modelling shows that atmospheric stability does not significantly influence the hazard range of either a 1.4 kg/s continuous release of chlorine or a 1 tonne instantaneous release of chlorine for the three weather conditions of most interest in this study (i.e. B – unstable conditions, D - neutral stability and F - stable conditions) for wind direction SE as shown in Annex B of the report. The results indicate that, in the presence of buildings inside the desalination plant, atmospheric stability is not a significant factor influencing the chlorine hazard range (certainly not as great as predicted by conventional flat terrain dispersion models). However, for B (unstable conditions) and F (stable conditions), the CFD results for the Desalination Plant indicate that, whilst the chlorine hazard range is not significantly affected by atmospheric stability, the shape of the cloud (i.e. impacted area) may be affected. D (neutral conditions) impacts relatively larger area than B (unstable conditions) and F (stable conditions) for LD03, LD50 and LD90 contours, i.e. a factor of 1.0 ~ 2.7 for 1.4kg/s continuous release and 1.0 ~ 1.2 for 1 tonne instantaneous release (by comparing impact area of D to F/B). Therefore, the results could be more conservative by adopting consequences of D (neutral conditions). Meanwhile, in the previous 8WTW study, (1) it is estimated that the average error may be typically +/- half an order of magnitude, in terms of the number of a fatalities due to the impacted area of the under D or F conditions; (2) The effect on the risk results will be less than this because F conditions typically only account for a third of the overall weather in Hong Kong. (3) Also this effect would only be expected to arise for certain wind directions, where there are particular topographic features. To be conservative, the uncertainty factor of 2 is retained in this study.	Y	± half order of magnitude	± a factor of 2
		<u>Off-site hazards</u> Dispersion of chlorine for off-site marine transport occurs over a rather flat and open area. The probability a cloud traveling in a particular direction or number of fatalities due to the cloud moving in a different direction would not be significantly affected by wind stability. Moreover, the adopted stability class D is based on the average wind speed and moderate solar radiation at daytime or completely overcast conditions, which could represent most of the atmospheric conditions in Hong Kong. Therefore, there is no significant uncertainty.	N	N	N
3	**CONSEQUENCE MODELLING**				
3.1	Source term definition	<u>On-site hazard</u> In previous 8 WTWs Reassessment Study, the source term was modelled by DRIFT and it has been discussed in Annex K of the 8 WTWs Reassessment Study that the uncertainty due to DRIFT model is negligible. It is assumed the same argument from DRIFT model applies to PHAST model. <u>Off-site hazards</u> Refer to on-site hazards	N	-	-
3.2	Isopleths generated by the CFD Simulations	<u>On-site hazard</u> *Isopleths Generated by the CFD Simulations* The uncertainties in the CFD simulations are discussed in HSL (1998) and include uncertainties in the turbulence model and grid resolution. To address these uncertainties, the CFD modelling (conducted by ANSYS CFX, which originates from AEA Technology CFX-4 adopted in the previous 8 WTWs Reassessment Study) uses higher order solution schemed wherever possible and computation grids if over 1,000,000 cells. To gauge the level of uncertainty, a sensitivity test was undertaken for one of the CFD simulations, in which the grid resolution was doubled to over 2,000,000 cells. This showed that predictions of the CFD modelling are substantially grid independent. <u>Off-site hazards</u> Not applicable	N	-	-

Ref.	Key Parameter (or Assumption)	Uncertainty in Parameter (or Assumption)	Uncertainty Significant (Y/N)	Estimated Range of Uncertainty	Uncertainty in overall risk results
3.3	Wind smoothing	<u>On-site hazard</u> The same method of wind smoothing is adopted from previous 8 WTWs Reassessment Study. It was concluded that the uncertainty for this parameter is negligible. Same conclusion is adopted in this study. <u>Off-site hazards</u> Refer to on-site hazards	N (Not in terms of risk to overall population)	-	-
3.4	Chlorine cloud height	<u>On-site hazard</u> The current study directly uses CFD simulation results which take into account the actual building layout and terrain to calculate the total dose during chlorine gas dispersion (i.e. integration of Probit via time). The maximum cloud height of LD03 is then determined accordingly. In the previous 8WTWs Reassessment Study, the cloud height was given by considering equivalent cloud height based on conversion of mass, scaling factors from DRIFT results and a relatively simple geometry. It is not considered that the estimation of chlorine cloud height, as outlined above, is a significant source of uncertainty in the analysis. <u>Off-site hazards</u> Due to the constraint of ALOHA model, the cloud heights are made reference to the well validated Reassessment Study. In the Reassessment Study, CFD and wind tunnel were used to estimate cloud heights which were compared with predicted cloud heights from the DRIFT flat terrain dispersion model. Therefore, significant uncertainty is not anticipated.	N	-	-
3.5	Seismic assessment - estimation of number of drums failing	<u>On-site hazard</u> This study has been conducted with reference to 8 WTWs Reassessment Study to assess the vulnerability of the chlorine stores to earthquake damage. It was concluded that the uncertainty for seismic assessment is negligible. Same conclusion is adopted in this study. <u>Off-site hazards</u> Not applicable	N	-	-
4	**TOXIC IMPACT ASSESSMENT**				
4.1	Chlorine toxicity relationship	<u>On-site hazard</u> Same Probit equation is adopted from previous 8 WTWs Reassessment Study. The uncertainty factor for this parameter is an overprediction of the number of fatalities by a factor of 5-15. The same uncertainty factor has been adopted in this study. <u>Off-site hazards</u> Refer to on-site hazards	Y	Overprediction of number of fatalities by a factor of 5-15	Overprediction of societal risk by a factor of 5-15
4.2	Probability of escape from chlorine cloud and time exposure	<u>On-site hazard</u> The same probability of escape from chlorine cloud and time exposure is adopted from previous 8 WTWs Reassessment Study. It was concluded that the uncertainty for this parameter is negligible. Same conclusion is adopted in this study. <u>Off-site hazards</u> Since people on a moving vessel are at speed faster than human escape speed, fatality probabilities and probability of escape derived from the 8WTWs Reassessment Study are adopted and considered reasonably conservative. The uncertainty is negligible.	N	-	-

Ref.	Key Parameter (or Assumption)	Uncertainty in Parameter (or Assumption)	Uncertainty Significant (Y/N)	Estimated Range of Uncertainty	Uncertainty in overall risk results
4.3	Assessment of direct probability of fatality due to earthquakes	On-site hazard The same direct probability of fatality due to earthquakes is adopted from previous 8 WTWs Reassessment Study. It was concluded that the uncertainty for this parameter is negligible. Same conclusion is adopted in this study. Off-site hazards Refer to on-site hazards	N	-	-
5	**FREQUENCY ESTIMATION**				
5.1	Base event frequencies	On-site hazard The same set of base event frequencies from 8 WTWs Reassessment Study has been adopted in this study. The uncertainty factor for this parameter is ± one order of magnitude. The same uncertainty factor has been adopted in this study. Off-site hazards Refer to on-site hazards	Y	± one order of magnitude	± one order of magnitude
5.2	Conditional probabilities	On-site hazard The same set of conditional probabilities from 8WTWs Reassessment Study has been applied to this study, as a result, the same margin of error (estimated to be ± half an order of magnitude) from 8WTWs Reassessment Study has been adopted. Off-site hazards Refer to on-site hazards	Y	± half an order of magnitude	± half an order of magnitude

Table 1.2 Uncertainty Analysis of Carbon Dioxide

Ref.	Key Parameter (or Assumption)	Uncertainty in Parameter (or Assumption)	Uncertainty Significant (Y/N)	Estimated Range of Uncertainty	Uncertainty in overall risk results
1	**POPULATION DATA**				
1.1	Population estimates	Population estimates have been obtained from a variety of sources, including Civil Engineering and Development Department (TKO Area 137 explosive pier), Planning Department (primary source), Social Welfare Department (for elderly persons homes), Education Department (for schools), Environmental Protection Department (SENT extension) and Transport Department (for roads) and etc. This has been supplemented by surveys by the Consultants including, where necessary, contact with individual establishments. It is not considered that there is a significant uncertainty in the population estimates.	N	-	-
1.2	Percentage of people outdoors	The same set of population data for TKO Area 137 and the percentage people outdoors from the PHI QRA are adopted. Referring to the PHI QRA, the percentage of people outdoors will vary according to the time of day (i.e. less at night), but this is not modelled in the QRA. The approach adopted will overestimate the risk, but this will not be significant as the most important scenarios are those associated with the CO2 road tanker which delivers only during the day.	N	-	-
1.3	Spatial distribution	Population areas are represented and are entered into the risk model as polygons. Population is uniformly distributed over the population areas. Locations of different population area are accounted for. Therefore, the uncertainty is not considered significant.	N	-	-
1.4	Temporal distribution	The consultants have modelled five different time periods for this study (night, working day, weekend day, peak and 'jammed' peak) to enable accurate representation of the variation of population with time.	N	-	-
2	**WEATHER DATA**				
2.1	Base weather data	The weather data used in the study is the data recorded by the Hong Kong Observatory for 10 years (2003 – 2012) from the nearest weather station (Kai Tak Weather Station). As data from 10 years has been used, it is not anticipated that this is a significant source of error.	N	-	-
2.2	Rationalisation of weather data	The base weather data recorded by the Hong Kong Observatory has been rationalised into discrete stability class/ wind speed combinations or 'weather states'. Day time conditions are represented by 4 weather states (B3, D2, D4.5 and F1.5), whilst night time conditions are represented by 3 weather states (D2, D4.5 and F1.5). This is a common approach in QRA studies and is not considered to introduce any significant error into the calculations	N	-	-
2.3	Representation of site-specific weather conditions	QRA studies do not commonly account for site-specific weather conditions.	N	-	-
2.4	Atmospheric stability	PHAST provide input of atmospheric stability class according to wind statistics. There is no significant uncertainty in this parameter.	N	-	-
3	**CONSEQUENCE MODELLING**				
3.1	Source term definition	In previous 8 WTWs Reassessment Study, the source term was modelled by DRIFT and it has been discussed in Annex K of the 8 WTWs Reassessment Study that the uncertainty due to DRIFT model is negligible. It is assumed the same argument from DRIFT model applies to PHAST model.	N	-	-
3.3	Wind smoothing	Number of wind directions can be specified in PHAST. The uncertainty for this parameter is negligible.	N	-	-
3.4	Cloud height	Toxic impact modelled in PHAST considers 2D footprint of cloud dispersion.	N	-	-
4	**IMPACT ASSESSMENT**				
4.1	Toxicity relationship	The most current Probit adopted from the HSE. The probit values are derived from Specified Level of Toxicity (SLOT) and Significant Likelihood of Death (SLOD) which are well adopted by HSE (UK) in the assessment on toxicity level.	N	-	-
5	**FREQUENCY ESTIMATION**				
5.1	Base event frequencies	Generic base failure data is adopted. Conservative assumptions are made in the fault tree analysis (e.g. failure of inner vessel due to road accident is assumed for rupture and leak failures). The worst case scenario is considered. The uncertainty factor for this parameter is - one order of magnitude.	Y	- one order of magnitude	- one order of magnitude
5.2	Conditional probabilities	The error in these conditional probabilities is generally less than the base frequency data., The error is estimated to be ± half an order of magnitude referring to 8WTWs Reassessment Study.	Y	± half an order of magnitude	± half an order of magnitude