9a. HEALTH IMPACT (TTAL SITE)

9a.1 Introduction

9a.1.1.1 This section presents the assessment of the potential health risk impact associated with the construction and operation phases of the IWMF located in Tsang Tsui Ash Lagoon (TTAL) site.

9a.1.1.2 With reference to the Section 3.4.8.1 of the EIA Study Brief No. ESB-184/2008 for this Project, the health risk assessment can be broadly grouped into the following tasks:

- Assess the potential health impacts of aerial emissions from the IWMF during operational phase;
- Assess the potential health impacts of biogas from sorting and recycling plant;
- Assess the potential health impacts of fugitive emissions during transportation, storage and handling of the waste and ash;
- Assess the potential health impacts of any radon emissions from pulverized fly ash (PFA) within the Tsang Tsui Ash Lagoon during construction and operation of the IWMF; and
- Assess any other potential accidental events.

9a.2 Potential Health Impacts of Aerial Emissions from the IWMF during Operational Phase

9a.2.1 Project Site

9a.2.1.1 The TTAL site are located in the northwest New Territories adjacent to the West New Territories (WENT) Landfill and the China Light and Power Company Ltd. (CLP) Black Point Power Station and the Castle Peak Power Station. The ash lagoons were constructed in the 1980s by CLP for the purpose of storing pulverized fuel ash (PFA). In addition to storing PFA, the lagoons are periodically mined of ash for commercial use.

9a.2.2 Hazard Identification

<u>General</u>

9a.2.2.1 Based on our desktop literature search, the conduct of full quantified health risk assessments has become fairly standard for incinerators, but there is generally no regulatory requirement, nor official guidance on how to conduct risk assessments for incinerators. For example, the WHO has general guidelines, but there are no specific quantitative recommendations on assumptions or equations that should be used. The risk assessment procedures used in the US for incinerators are state-of-the-science and are more detailed than any other country's guidelines. The proposed risk assessment methodology is therefore based on the Human Health Risk Assessment Protocol (HHRAP) USEPA, 2005.

9a.2.2.2 The purpose of the hazard identification step is to identify compounds of potential concern (COPC) for quantitative evaluation and to generate emissions estimates for short-term (acute) and long-term (chronic) exposures to the selected COPCs.

Compounds of Potential Concern

9a.2.2.3 An early step of the health risk assessment involved reviewing data for compounds potentially present in facility emissions (due to presence in the waste stream, presence in stack gas emissions as products of incomplete combustion, or as a result of emissions from fugitive sources associated with waste handling and the combustion process), and then identifying the most toxic, prevalent, mobile and persistent compounds. Based on this analysis, COPCs are selected for evaluation in the health risk assessment.

Identification of COPCs

9a.2.2.4 The IWMF thermal treatment facility is currently in the planning stages. As such, facility specific stack gas emissions data are not available. Therefore, to identify COPCs and their associated emission rates, it was necessary to evaluate information from a variety of different sources.

9a.2.2.5 Sources of information for selection of COPCs included regulatory air quality requirements or stack gas permit limits such as those provided in the Environmental Protection Department's (EPD) Guidance Note on the Best Practicable Means (BPM) for Incinerators (EPD, 2008). Additional consideration was given to identifying COPCs that may be considered Persistent, Bioaccumulative and Toxic (PBT) chemicals, often of particular concern through indirect (ingestion) exposure pathways.

COPCs

9a.2.2.6 The list of identified COPCs is provided below.

Trace Metals

- Antimony
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Lead
- Manganese
- Mercury
- Nickel
- Thallium
- Vanadium
- Zinc

Organic Compounds

- Polychlorinated biphenyls (PCBs)
- Polychlorinated dibenzodioxins and furans (dioxins/furans)
- Polynuclear aromatic hydrocarbons (PAHs)

Other Compounds

- Carbon monoxide
- Hydrochloric acid
- Hydrogen fluoride
- Nitrogen dioxide
- Particulate matter (respirable)
- Sulphur dioxide

9a.2.2.7 These COPCs are representative of MSW thermal treatment facilities in general and are expected to represent those compounds or groups of compounds for which regulatory permit limits may be applicable and those that may be the most toxic, prevalent, mobile and persistent compounds in MSW emissions. Most of the compounds listed above are subject to the target concentration limits set by the EPD. For those COPCs (i.e. Beryllium, Zinc, PCBs & PAHs) not listed on the BPM, the emission rates are made reference to the "Quantitative risk assessment of stack emissions from municipal waste combustors"[1].

Estimation of Emission Rates

9a.2.2.8 Long-term maximum stack emission rates (in grams per second) have been developed for each COPC identified. Because stack gas measurement data are not available for the planned MSW thermal treatment unit, emission factors upon which emission rates are based may be higher than actual emission rates. This is customary in permitting MSW thermal treatment units since (1) certain values (such as Target Emission Levels established as part of the EIA) may become permit limits; (2) emissions from MSW thermal treatment units are known to fluctuate as a result of variations in waste composition; and (3) it is prudent to take an approach that assures the emissions will not be understated. It is important to emphasize that the final design of the planned MSW thermal treatment unit will incorporate good engineering practices and air pollution control (APC) systems which will minimize actual emissions.

9a.2.2.9 Concentration limits have been established by the Hong Kong EPD (Guidance Note on the BPM for Incinerators (Municipal Waste Incineration), BPM 12/1 (08)) for most of the metals listed above as well as hydrogen chloride (HCl), nitrogen oxides (NOx), particulate matter and dioxins and furans. These concentration limits are proposed as the basis for estimating emission rates of those COPCs except NOx. For NOx, the target emission levels for the IWMF would be set as half of respective concentration limits stipulated in BPM 12/1 (08). The emission rates have been estimated by multiplying the target concentration limits and the stack gas flow rate, which were determined from preliminary design parameters for the combustion unit at the IWMF. For Be, Zn, PCBs & PAHs, the maximum emission rates stated in the "Quantitative risk assessment of stack emissions from municipal waste combustors" is for the combustion of 1500 tonnes of waste per day. Since the design capacity of the IWMF is 3000 tpd, therefore two times the maximum emission rates stated in the above paper have been adopted for the assessment. In accordance with the above paper, the anticipated normal emission rates for Be, Zn, PCBs & PAHs would only be 2% to 11% of their corresponding maximum emission rates, taking into consideration the waste composition and the incinerator design of the IWMF, the assumed emission rates for Be, Zn, PCBs & PAHs adopted in this assessment are indeed conservative.

[1] Stephen G. Zemba, Laura C Green, Edmund A. C. Crouch, Richard R. Lester, 1995, Quantitative risk assessment of stack emissions from municipal waste combustors

9a.2.3 Air Dispersion and Deposition Modelling

General

9a.2.3.1 Air dispersion and deposition of aerial emissions from the planned MSW thermal treatment units have been predicted from a combination of modelling efforts to support the health risk assessment.

Air Dispersion Modelling

9a.2.3.2 Potential cumulative impacts due to dispersion of aerial emissions from the IWMF have been predicted at existing and planned/committed Air Sensitive Receivers (ASRs) with the use of Industrial Source Complex (ISC) model (for the near field ASRs (i.e. TT1 to TT6)) and the Pollutants in the Atmosphere and their Transport over Hong Kong (PATH) Model. The proposed representative ASRs are listed in **Table 9a.1.** The detailed methodology for modelling air dispersion is presented in **Section 3** of this EIA Report.

Table 9a.1 Identified Air Sensitive Receivers for the TTAL Site

ASR	Description	Nature of ASR (1)	Building Height, m	Ground level, mPD	Distance to Project Boundary, m
TT1	Ha Pak Nai	R	9	3.4	1989
TT2	Sludge Treatment Facilities Site Office	I	-	5.0	205
TT3	EPD WENT Landfill Site Office	I	6	5.7	625
TT4	Tin Hau Temple	G/IC	3	4.7	88
TT5	Black Point Power Station (Office)	I	9	5.6	1130
TT6	Lung Kwu Sheung Tan	R	6	3.4	1871
TM1	Block F, Tuen Mun Hospital	G/IC	66	5.8	5627
TM2	Tuen Mun Town Plaza	R	104	4.5	6149
TM3	Kam Hing Building	R	89	5.8	5961
TM4	Hong Lai Garden	R	96	5.0	5770
TM5	Block 4, Tai Hing Gardens	R	102	16.0	5245
TM6	Leung King Estate	R	102	10.0	4261
TC1	Caribbean Coast Block 1	CDA	141	7.5	14291
TC2	Caribbean Coast Block 6	CDA	153	6.8	14508
TC3	Ling Liang Church Sau Tak primary School	G/IC	21	6.4	14590
TC4	Yu Tung Court - Hor Tung House	R	108	9.3	14954
TC5	Tung Chung Crescent Block 9	R	129	11.1	14664
TC6	Yat Tung Estate - Hong Yat House	R	105	9.7	15523
AP1	Chek Lap Kok Fire Station	C	9	7.5	13317
AP2	Gate Gourmet Catering Building	C	30	6.7	12890
AP3	DHL Central Asia Hub	C	30	5.4	13636
AP4	Regal Airport Hotel	C	90	5.3	11253
AP5	SkyCity Nine Eagles Golf Course	C	-	6.2	11496
AP6	SkyCity Nine Eagles Golf Course	C	-	6.2	11700

ASR	Description	Nature of ASR (1)	Building Height, m	Ground level, mPD	Distance to Project Boundary, m
AP7	Hong Kong SKyCity Marriott Hotel	C	45	6.2	11414
AP8	Terminal 2 Sky Plaza	G/IC	25	6.4	11573
SLW1	Sha Lo Wan House No.1	R	9	5.0	14195
SLW2	Tin Hau Temple at Sha Lo Wan	R	9	4.9	14556
SLW3	Tin Sum	R	9	5.7	14362
KT1	Block 6, Lai King Estate	R	42	40.1	22380
KT2	Block 7, Lai King Estate	R	66	40.1	22507
KT3	Lai King Home	R	12	40	22631
KT4	Hong Chi Winifred Mary Cheung Morninghope School		6	38.5	22867
KT5	Lai Hong House, Ching Lai Court	R	135	25	23526
KT6	Princess Margaret Hospital	G/IC	30	38.9	23523
KT7	Lai Chi Kok Park Stage III	G/IC	-	7.6	24502
KT8	Hoi Yin House, Hoi Lai Estate	R	108	5.9	24842

Note:
(1) R – Residential; C – Commercial; I – Industrial; G/IC –Government / Institution / Community; CDA - Comprehensive Development Area

<u>Deposition Modelling Analysis</u>

9a.2.3.3 Deposition of facility-related COPCs were used to evaluate potential cumulative indirect exposure through the food chain as a result of COPCs that are deposited onto soil and then taken up into the food chain. ISC model was used to predict deposition rates for particles and vapours emitted from the IWMF stack. ISC deposition modelling analysis have been conducted in accordance with USEPA recommendations for conducting modelling in support of health risk assessment as outlined in the HHRAP guidance (USEPA, 2005). The modelling procedures and input requirements required for modelling are discussed below.

Source Data

9a.2.3.4 The modelling has been performed with a unit (1 g/sec) emission rate. Pollutant-specific deposition rates have been determined within the Lakes Environmental Industrial Risk Assessment Program Human Health (IRAP-h-view) Version 3.3.1 by multiplying the normalized impacts by the emission rates in g/sec.

9a.2.3.5 In addition to the physical stack parameters and exhaust stack parameters, particle size data on stack emission are required to perform deposition modelling.

9a.2.3.6 Unit-specific particle size data were not available since the unit has not yet been built. Therefore, the aerodynamic size distribution of emitted particulate was based on published data for similar types of units, which can be found in the open literature. For example, USEPA's Technology Transfer Network Clearing House for Emission Inventories and Emission Factors (http://www.epa.gov/ttn/chief/ap42/) contains information on particle size distribution data and sized emission factors for selected sources, including municipal solid waste incinerators.

9a.2.3.7 In accordance with the HHRAP (USEPA, 2005), two different particle size distributions have been modelled. The distribution of particle mass was used to represent all metals except mercury when present. Semi-volatile organic species and some mercury species that tend to vaporize during combustion and condense on the surface of emitted flyash are represented by a surface area-weighted size distribution ("particle-bound"). Elemental mercury and a fraction of divalent mercury are modelled as vapours. This approach tends to produce more realistic deposition rates of these materials in the immediate vicinity of the source. The proposed particle distributions are shown in **Table 9a.2**.

Table 9a.2 Particle Size Distributions

Mean Particle Diameter (µm)(1)	Mass Fraction(1)	Surface Area Fraction(2)
0.11	0.237	0.878
0.61	0.0661	0.0442
1.00	0.0577	0.0235
1.70	0.0717	0.0172
2.93	0.0785	0.0109
4.53	0.114	0.0102
6.68	0.174	0.0106
10.23	0.0877	0.00349
25.16	0.114	0.00184
(1) Compliance test at the Covanta Hempstead EfW Facility (Radian, 1989) **(2) Calculated based on assumed spherical particle diameter and mass fraction**		

Meteorological Data

9a.2.3.8 The deposition modelling has been conducted based on the meteorological data extracted from the PATH model (i.e. MM5 hourly meteorological data).

Application of ISC

9a.2.3.9 ISC was applied to determine long-term averages (based on one year modelled) of wet, dry, and total deposition for vapours, particles, and particle-bound compounds. The modelling domain included an area in the vicinity of the facility (10km radius from stack) to cover the local sections of any nearby water bodies and watersheds. The following iterations have been conducted with ISC to obtain the modelled deposition rates required for input to the software, IRAP-h-view:

1) wet and dry deposition of particles, based on mass-weighted particle distribution including plume depletion;
2) wet and dry deposition of particles, based on area-weighted particle size distribution including plume depletion; and
3) wet and dry deposition of vaporous gases with plume depletion.

9a.2.4 Exposure Assessment

General

9a.2.4.1 In this step of the risk assessment process, hypothetical human receptors and potential exposure pathways through which such receptors may be exposed to facility-related COPCs were identified. Selection of such potential exposure scenarios was based on the characteristics of the facility and surrounding area, and activities that could take place in the vicinity of the facility. Dispersion of COPCs into the ambient air allows direct human exposure to COPCs through inhalation. COPCs that are deposited onto soil, water or plants (such as vegetables), are available for indirect exposure through the ingestion of soil, water, or produce. Additionally, the COPCs are potentially available to other secondary indirect pathways of exposure, including ingestion of locally raised agricultural products (beef, dairy, pork, and poultry products), or consumption of locally caught fish. The goal of the exposure assessment is to predict the magnitude of potential human exposure to COPCs in emissions from the facility through a variety of assumed exposure pathways.

9a.2.4.2 In the combustion risk assessment process, the air dispersion and deposition modelling, discussed in **Section 9a.2.3** above, provides the foundation for all other environmental concentration modelling efforts. The final air dispersion and deposition modelling results were entered into the Lakes Environmental Software model IRAP-h View (Version 3.3.1), which provides the basis for estimating exposure point concentrations in each environmental medium, the magnitude of potential exposures and ultimately the potential health risks for each of the potential exposure pathways discussed below. The IRAP-h View model was developed with the intent that it could, in default mode, exactly follow the risk assessment methodology recommended in the latest USEPA guidance (USEPA, 2005).

Exposure Scenarios

9a.2.4.3 The HHRAP (USEPA, 2005) suggests the evaluation of three pairs of potential receptors: a non-farming resident (child and adult), a subsistence farmer (child and adult), and a subsistence fisher (child and adult). However, the exact receptors to be evaluated were made site-specific based on land use and human activity patterns. Information on land use in the vicinity of the TTAL site was considered so that the receptor scenarios chosen for the health risk assessment would be appropriate for the Hong Kong situation.

9a.2.4.4 The TTAL site is not identified as having a large population of sensitive receptors in the vicinity. A more detailed discussion on land use, focused on a vicinity of the facility is presented below to ensure that the maximally impacted receptors were evaluated in the risk assessment.

Chronic Exposure Scenarios

9a.2.4.5 The locations of current exposure scenarios have been selected based on a combination of the air dispersion and deposition modelling results and actual land uses identified in the vicinity of each site. Inhalation exposure has been evaluated under each scenario. The locations of the ASRs as described in **Section 9a.2.3** above were evaluated in the context of the air modelling results to ensure that the locations of the maximum ambient concentrations were included in the evaluation. The indirect pathways have only been evaluated under the relevant scenarios (i.e., ingestion of fish is only be evaluated under the fisher scenario) and in relevant locations (i.e., areas capable of supporting the activity).

Residential

9a.2.4.6 A reasonable resident scenario was evaluated at the off-site location with the highest estimated soil (corresponding to the location of maximum total deposition) concentration to ensure that potential exposures for a resident are not underestimated.

9a.2.4.7 The Tsang Tsui Ash Lagoon is in an isolated location away from Hong Kong's main residential areas. Residents in Lung Kwu Tan and Pak Nai were evaluated in the health risk assessment.

Farming

9a.2.4.8 Most agricultural produce consumed in Hong Kong is imported from neighbouring mainland China. The average daily production of vegetable, live chicken and live pigs are 44 tons, 11,100 birds and 240 heads respectively. There is virtually no cattle farming in Hong Kong. In 2010, local production accounted for 2.5% of fresh vegetables, 56.2% of live poultry and 6.4% of live pigs consumed in the territory (http://www.afcd.gov.hk/english/agriculture/agr_hk/agr_hk.html).

9a.2.4.9 Local land use in the vicinity of the TTAL site with regards to agricultural production is described below in more detail.

9a.2.4.10 The TTAL site is located at the CLP ash lagoons and is adjacent to the existing WENT Landfill and its future extension. In accordance with the information available from the Agriculture, Fisheries, and Conservation Department (http://www.afcd.gov.hk/tc_chi/agriculture/agr_accfarm/agr_accfarm_num/agr_accfarm_num.html), several locally accredited farms are located in approximately 1.5km from the boundary of the TTAL site.

9a.2.4.11 As the vast majority of foodstuffs in Hong Kong are imported, the impact of waste facility emissions on any one individual's exposure is likely to be very limited. A subsistence farmer scenario has been evaluated in the health risk assessment for the TTAL site as a conservative measure.

Fishing

9a.2.4.12 Hong Kong's commercial fishing activities are conducted mainly in the waters of the adjacent continental shelf in the South and East China Seas. This area extends over a 160km wide section, between the Gulf of Tonkin and the East China Sea. Marine fish culture, pond fish culture and oyster culture are regulated industries within the Hong Kong territory. In 2010, production from local aquaculture including marine fish culture, pond fish culture and oyster culture was 2.2% in weight of the total fisheries production (http://www.afcd.gov.hk/english/fisheries/fish_aqu/fish_aqu_mpo/fish_aqu_mpo.html). Local surface water use in the vicinity of the TTAL site is evaluated to determine the potential for exposure to MSW thermal treatment unit emissions through consumption of locally harvested seafood products. As the vast majority of seafood is imported into Hong Kong, the potential IWMF emissions to significantly impact any individual's exposure through ingestion of fish is likely to be limited due to the relatively small proportion of fish consumed that is locally produced.

9a.2.4.13 The Shenzhen Bay in the Pearl River Estuary is rich in fish and oysters and supports commercial fishing and aquaculture. Since two residential communities namely Lung Kwu Tan and Pak Nai are located nearby Shenzhen Bay, a subsistence fisherman scenario have been evaluated in the TTAL health risk assessment. Maximum fish concentrations predicted in the Bay have been paired with maximum soil, produce, and vapour concentrations predicted for all receptors in evaluating the subsistence fisherman scenario.

9a.2.4.14 A compliance check of the maximum permitted concentration of certain metals present in foods due to the Project as stipulated in "Food Adulteration (Metallic Contamination) Regulations" by the Centre for Food Safety, was conducted based on the risk modelling results. Two schedules of the maximum permitted concentration of certain metals present in specified foods are listed below.

Table 9a.3 First Schedule – Maximum permitted concentration of certain metals naturally present in specified foods

Metal	Description of food	Maximum permitted concentration in parts per million
Arsenic (as As_2O_3)	Solids being fish and fish products	6
	Solids being shellfish and shellfish products	10

Table 9a.4 Second Schedule – Maximum permitted concentration of certain metals present in specified foods

Metal	Description of food	Maximum permitted concentration in parts per million
Antimony (Sb)	Cereals and vegetables	1
	Fish, crab-meat, oysters, prawns and shrimps	1
	Meat of animal and poultry	1
Arsenic (as As_20_3)	Solids other than- (i) fish and fish products; and (ii) shellfish and shellfish products	1.4
	All food in liquid form	0.14
Cadmium (Cd)	Cereals and vegetables	0.1
	Fish, crab-meat, oysters, prawns and shrimps	2
	Meat of animal and poultry	0.2
Chromium (Cr)	Cereals and vegetables	1
	Fish, crab-meat, oysters, prawns and shrimps	1
	Meat of animal and poultry	1
Lead (Pb)	All food in solid form All food in liquid form	6 1
Mercury (Hg)	All food in solid form All food in liquid form	0.5 0.5
Tin (Sn)	All food in solid form All food in liquid form	230 230

Acute Exposure Scenarios

9a.2.4.15 Acute exposure has been evaluated at the selected ASRs described in **Section 9a.2.3**.

Exposure Pathways

Chronic Residential Pathways

9a.2.4.16 Chronic exposure has been evaluated for adult and child residents via the following pathways:

- Inhalation of vapours and particulates
- Incidental ingestion of soil
- Ingestion of home-grown produce

9a.2.4.17 Fresh water is limited in Hong Kong, with approximately 70-80% of fresh water coming directly from Dongjiang (the East River) and 20-30% coming from local catchments. An agreement between the Hong Kong Government and the Guangdong authorities ensures the stability of the Dongjiang water supply to Hong Kong (http://www.gov.hk/en/residents/environment/water/drinkingwater.htm). It is very unlikely that surface water in the vicinity of the TTAL site would be used as a source of drinking water. For this reason and because drinking water exposure is typically not a significant source of risk in incinerator risk assessments, the drinking water pathway has not been evaluated in the health risk assessment.

Chronic Farmer Pathways

9a.2.4.18 According to the Agriculture, Fisheries, and Conservation Department of Hong Kong, at the end of 2008, land used in Hong Kong for vegetable, flower, field crop, and orchard were 297 ha, 153 ha, 20 ha, and 276 ha respectively (http://www.afcd.gov.hk/english/agriculture/agr_hk/agr_hk.html). Therefore, the amount of land dedicated to farming of produce that can be consumed is less than $3.4km^2$, which is less than 1% of the land in Hong Kong. However, as mentioned previously, several accredited farms are located in the vicinity of the TTAL site. Based on observations made during previous site visits, the farms in the vicinity of TTAL produce vegetables, chickens, and pigs. Therefore, exposure via the following pathways was evaluated for adult and child farmers:

- Inhalation of vapours and particles
- Incidental ingestion of soil
- Ingestion of home-grown produce
- Ingestion of home-reared chicken and eggs
- Ingestion of home-reared pork

Chronic Fisherman Pathways

9a.2.4.19 Exposure via the following pathways have been evaluated for adult and child fishers:

- Inhalation of vapours and particles
- Incidental ingestion of soil
- Ingestion of home-grown produce
- Ingestion of fish

Acute Pathways

9a.2.4.20 Acute exposure has been evaluated via the inhalation pathway at the selected ASRs described in **Section 9a.2.3**.

Exposure Assumptions

9a.2.4.21 Except where noted in this EIA Report, the equations and input parameters presented in the final HHRAP guidance (2005) were used to estimate chemical concentrations in media and food sources for the standard exposure scenarios (resident, farmer, fisher).

Body Weight

9a.2.4.22 The exposure dose is defined as the amount of COPC taken into the receptor and is expressed in units of milligrams of COPC per kilogram of body weight per day (mg/kg-day). Because exposure is normalized by body weight (is in the denominator of the intake equation), small differences in body weight can substantially increase or decrease estimated intakes. In general, Asians are smaller than Americans. Therefore, use of the body weight assumptions recommended in the HHRAP (USEPA, 2005) is not appropriate and a population-specific body weight is proposed for use in this assessment.

9a.2.4.23 The adult and child body weights used by the Hong Kong EPD to develop Risk-Based Remediation Goals (RBRGs) are 50kg and 15kg for adults and children, respectively (EPD, 2007a). These values are based on an average of 60kg for male adults and 50kg for female adults (Leung and Lui, 1989) (EPD, 2007b). The child body weight is based on USEPA default assumptions for children six years old and younger. These body weights have been adopted for use in this assessment.

Food Consumption Rates

9a.2.4.24 The WHO has implemented the Global Environment Monitoring System/Food Contamination Monitoring and Assessment Programme (GEMS/Food Regional Diets) to assess the levels and trends of potentially hazardous chemicals in food and their significance for human health and trade (WHO, 2003). As part of this dietary exposure assessment mandate, GEMS/Food Regional Diets has developed five regional diets which are currently used for predicting dietary intake of pesticide residues according to internationally accepted methodologies. The GEMS/Food Regional Diets are based on Food Balance Sheet (FBS) data compiled by the Food and Agriculture Organization of the United Nations (FAO) from selected countries to represent five regional dietary patterns. The regions covered are Middle Eastern, Far Eastern, African, Latin American, and European. Hong Kong is included in the Far East region along with Japan, Korea, Taiwan, Singapore, Indonesia, Thailand, Vietnam, and Malaysia.

9a.2.4.25 **Table 9a.5** summarizes consumption rates in grams per day (g/day) for relevant food items from the GEMS/Food Regional Diets (WHO, 2003; http://www.who.int/foodsafety/chem/en/gems_regional_diet.pdf). The GEMS/ Food Regional Diets only provide adult consumption rates. Therefore, child meat consumption rates are assumed to be 15% of the adult value and child vegetable consumption rates are assumed to be 30% of the adult value. The percentages used to adjust adult consumption rates for children are based on the ratio between adult and child food consumption rates for the U.S. population as reflected in the assumptions recommended in the HHRAP (USEPA, 2005). This is a fairly standard approach when children's consumption rates are unavailable (USEPA, 2007). In addition, with the exception of poultry products, the estimated values for children are in good agreement with estimates provided for children (0 – 6 years) in Tables 3-3, 3-6 and 3-10 (males and females) of the USEPA's Child-Specific Exposure Factors Handbook (USEPA, 2002a).

Table 9a.5 Food Consumption Rates

Individual Adult Consumption Rates from the GEMS/Food (2003) for the Far East and Estimated Child Consumption Rates (g/day)							
Total Vegetables		**Total Fish**		**Poultry Products**		**Pork**	
Adult	Child (a)	Adult	Child (b)	Adult	Child (b)	Adult	Child (b)
287	86.1	31.5	4.7	24.6	3.7	28.2	4.2

Notes:
(a) 30% of adult consumption rate.
(b) 15% of adult consumption rate.

9a.2.4.26 Based on detailed national surveys, average food consumption estimates based on FBS data are about 15% higher than actual average food consumption in the worst cases (e.g. certain fruits and other highly perishable products). This is partly because GEMS/Food Regional Diet values are given for the whole raw agricultural commodity. This approach is conservative because the production rate data are provided in tons/day, but include edible and non-edible parts of such as bone and shell. In addition, waste at the household or individual level is not taken into account, which also overestimates consumption.

9a.2.4.27 Two additional sources of fish consumption rates for Asian populations were located in the open scientific literature that quoted higher fish consumption rates. A paper entitled "Mercury and Organochlorine Exposure from Fish Consumption in Hong Kong" quotes an average Hong Kong fish consumption rate of 60kg/year, which is equivalent to 164g/day. The source of the 60kg/year consumption rate is Consumer Asia, Euromonitor Plc (1997) but the original source of the value could not be located. Another study, "Human Exposure to Dioxin-Like Compounds in Fish and Shellfish Consumed in South Korea (2007) cites fish consumption rates for more than 30 species developed from Korean FBS by the Korea Rural Economic Institute (KREI, 2002). A total fish consumption rate of 67g/day was derived by summing the individual consumptions rates. However, the original source of the fish consumption rates could not be located and is in Korean. Also, this concatenated value is not likely representative of any individual as no single individual is likely to consume all 30+ species of fish.

9a.2.4.28 Despite the higher fish consumption rates found in these two papers, the GEMS/Food Regional Diets (WHO, 2003) consumption rates were used in the health risk assessment for all food items for the following reasons:

- The consumption rates recommended in the GEMS/Food Regional Diet are already being used to predict dietary intake of pesticide residues by the WHO and are, therefore, internationally accepted for use in estimating chronic hazards and risks;
- The GEMS/Food Regional Diets provide data on all of the food commodities, making it possible to use one source for all consumption rates, thus avoiding the potential internal inconsistencies that could arise if multiple sources of food consumption rates were used; and
- Original sources for the literature values could not be located for verification.

Estimation of Chemical Concentrations in Environmental Media

9a.2.4.29 **Table 9a.6** summarizes the mechanisms by which environmental media can become contaminated as a result of incinerator emissions. The table also summarizes the inputs necessary for estimating those media concentrations. Equations and input parameters presented in the HHRAP guidance (USEPA, 2005) were used to estimate chemical concentrations in media and food sources. The HHRAP guidance provides standard conservative fate and transport and chemical-specific assumptions for each of the media and food sources of interest. The HHRAP guidance was developed for use in the U.S. Thus, the HHRAP reflects assumptions and modelling equations that are representative of potential human exposure scenarios in the U.S. For example, locally raised pigs and chickens are assumed to be exposed to facility emissions through ingestion of locally raised grain and silage or through grazing on locally impacted lands. However, given the small percentage of land that is used for farming in Hong Kong, it is highly unlikely that livestock would be fed on locally-produce silage or grazed on local pasture land.

9a.2.4.30 Where the results of the risk assessment indicate that a default assumption may be unrealistically influencing the results of the assessment, site-specific refinements to the health risk assessment have been made and documented accordingly.

9a.2.4.31 For those exposure scenarios for which default fate and transport modelling parameters are not available in the HHRAP guidance, site specific parameters have been derived, consistent with the recommendations of the HHRAP guidance. Examples of site-specific inputs would include the delineation of the extent of the watersheds and water body surface areas (in the vicinity of the facility). Estimated input parameters for the algorithms outlined in the HHRAP was based on knowledge of the site and its vicinity (e.g., soil types, watershed areas, land slopes, etc.) obtained from existing reports, topographic maps, and/or soil surveys. It should be noted that the HHRAP model for evaluating watershed and water body impacts is designed and intended for use in evaluating freshwater streams, rivers, ponds and lakes. Therefore, the local marine environment was treated as a lake in the HHRAP modelling.

Table 9a.6 Mechanisms for Environmental Media Contamination

Pathway	Mechanisms of Media Contamination	Input
Direct Inhalation	Air concentration of a pollutant based on air quality modelling run as described in **Section 3a**.	1. Vapour phase air concentration
Soil Ingestion	Soil may become contaminated by emissions through direct deposition onto the soil. The soil equation includes a loss term which accounts for the loss of contaminant from the soil after deposition by several mechanisms, including leaching, erosion, runoff, degradation, and volatilization.	2. Emission rates 3. Modelled vapour phase air concentration, wet deposition from vapour phase, dry deposition from particle phase, and wet deposition from particle phase 4. Soil concentration due to deposition
Consumption of aboveground produce	Produce may become contaminated by emissions through direct deposition onto the plant, direct uptake of vapour phase contaminant, and root uptake of contaminants deposited on the soil.	1. Emission rates 2. Modelled vapour phase air concentration, wet deposition from vapour phase, dry deposition from particle phase, and wet deposition from particle phase 3. Soil concentration due to deposition 4. Air-to-plant biotransfer factors
Consumption of Animal Products	Animal tissue may be contaminated through ingestion of contaminated forage, grain, silage, and soil by livestock or wildlife.	1. Emission rates 2. Modelled vapour phase air concentration, wet deposition from vapour phase, dry deposition from particle phase, and wet deposition from particle phase 3. Soil concentration due to deposition 4. Forage and silage concentrations 5. Beef concentration due to plant and soil ingestion by cattle 6. Milk concentration due to plant and soil ingestion by cows
Consumption of Drinking Water and Fish	Contaminant concentrations in a water body are partitioned between dissolved phase, suspended sediment, and benthic sediment. Contaminant concentrations in fish are calculated from the	1. Soil concentration averaged across the watershed 2. Total contaminant load to the water body due to runoff, soil erosion, and direct deposition 3. Dissolved water concentration 4. Total water column concentration 5. Sediment concentration 6. Bioconcentration and/or

Pathway	Mechanisms of Media Contamination	Input
	contaminant concentrations in the water body.	bioaccumulation factors 7. Biota-to-sediment accumulation factors

9a.2.4.32 **Table 9a.7** presents a summary of the water body and watershed parameters that have been identified for input to the risk assessment. Equations for evaluating exposure and risk are presented in **Appendix 9.1**.

Table 9a.7 Summary of General Water Body and Watershed Parameters

Parameter	Unit	Fate & Transport Variable
Average Annual Runoff	cm/year	220
Average Wind Speed	m/s	3.4
Water Body Surface Area	m^2	6×10^7
Total Watershed Area Receiving Pollutant	m^2	5×10^7
Average Volumetric Flow Rate	m^3/year	6.3×10^{11}
Depth of Water Column	m	7
USLE Rainfall Factor	per year	550

9a.2.5 Toxicity Assessment

General

9a.2.5.1 The purpose of the toxicity assessment is to identify the types of adverse health effects a COPC may potentially cause, and to define the relationship between the dose of a compound and the likelihood or magnitude of an adverse health effect (response). Adverse health effects are typically characterized in the health risk assessment as carcinogenic or non-carcinogenic for long-term exposure and acute hazard for short-term exposure.

Toxicity Criteria / Guidelines for Long-Term Exposure

9a.2.5.2 COPCs are classified as to whether they exhibit cancer and non-cancer health effects and whether health effects can result from ingestion or inhalation of the chemical.

9a.2.5.3 The toxicity of each COPC is based on toxicity factors developed by relevant studies. The toxicity factors are referred to as dose-response values, and are derived for both inhalation and oral routes of exposure. The dose-response values derived by evaluation of potential carcinogenic health effects resulting from long-term exposure to COPCs are called cancer slope factors [CSFs; expressed in units of $(mg/kg\text{-}day)^{-1}$] for oral exposure pathways, and unit risk factors [URFs; expressed in units of $(ug/m3)^{-1}$] for direct inhalation exposure pathways. The dose-response values derived for evaluation of potential non-carcinogenic health effects resulting from long-term exposure to COPC are called reference doses (RfDs) or tolerable daily intakes (TDI) expressed in units of mg/kg-day for oral exposure pathways and reference concentrations (RfCs) or tolerable concentrations in air (TCA) expressed in mg/m^3) for inhalation exposure pathways. For some COPCs, both cancer and non-cancer toxicity factors are available because the chemical has been associated with both cancer and non-cancer health effects. The health risk assessment includes an evaluation of both potentially carcinogenic and non-carcinogenic COPCs.

Classical COPCs of the HKAQO

9a.2.5.4 For the classical COPCs of the Hong Kong Air Quality Objectives (HKAQO) with potential chronic inhalation health effects, the contribution of the IWMF project to the predicted cumulative long-term (annual average) concentrations of these classical COPCs at the air sensitive receivers have been analysed as part of this health risk assessment and compared against the findings of relevant toxicology studies.

Other COPCs

9a.2.5.5 For the other COPCs, the following sources of information have been reviewed to determine the toxicity factors for use in evaluating exposure and risk through inhalation and other indirect pathways (i.e. ingestion of food, soil, water)

- Air Quality Guidelines (AQG) values by the World Health Organization (WHO)
- World Health Organization (WHO) documents
- USEPA's Integrated Risk Information System (IRIS)
- Publications of the USEPA's Superfund Technical Support Center (STSC) (only toxicological indices which have supporting documentation on their derivation)
- Other relevant international publications of toxicology studies

9a.2.5.6 For those COPCs with no available toxicity factors, adjustment of the UK Workplace Exposure Limits (WELs) were made to derive the chronic inhalation reference concentrations based on WEL/500.

9a.2.5.7 **Table 9a.8** contains all the toxicity criteria used in the risk assessment. For the sake of sensitivity test, the selected toxicity factors have been taken as the most conservative toxicity factors available from WHO and IRIS, or from other sources of information reviewed under **Section 9a.2.5.4** above if both WHO and IRIS factors are not available.

Table 9a.8 Toxicity Factors for the Risk Assessment

COPCs	Inhalation Unit Risk Factor $(\mu g/m^3)^{-1}$	Inhalation RfC $(\mu g/m^3)$	Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$	Oral RfD/TDI (mg/kg-day)
Sb	NA	1 HSE (2005)	NA	0.0004 IRIS
As	0.0043 IRIS	NA[a]	1.5 IRIS	0.0003[g] IRIS
Be	0.0024 IRIS	0.02 IRIS	NA	0.002 IRIS
Cd	0.0018 IRIS	NA[b]	NA	0.0005 (water) 0.001 (food) IRIS
Cr (VI)	0.04 WHO (2000)	0.1 (particulate) IRIS	NA	0.003 IRIS
Co	NA	0.2 HSE (2005)	NA	NA
Cu	NA	2 HSE (2005)	NA	NA
Dioxins	NA	NA[c]	150000 HEAST (1997)	2.3×10^{-9} WHO (2001)
HCl	NA	20 IRIS	NA	NA

COPCs	Inhalation Unit Risk Factor $(\mu g/m^3)^{-1}$	Inhalation RfC $(\mu g/m^3)$	Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$	Oral RfD/TDI (mg/kg-day)
HF	--	3 HSE (2005)	--	--
Pb	NA	0.5 WHO (2000)	NA	NA(h)
Mn	NA	0.05 IRIS	NA	0.06 WHO (2011)
Hg	NA	1 WHO (2000)	NA	0.002 WHO (2011)
Ni	0.0004 WHO (2000)	NA(d)	NA	0.012 WHO (2011)
PCBs	NA	NA(e)	2 IRIS	NA
PAHs	0.09 (B(a)P) WHO (2000)	3 (Naphthalene) IRIS	7.3 (B(a)P) IRIS	0.02 (Naphthalene) IRIS
Tl	NA	0.2 HSE (2005)	NA	0.00008 (chloride /carbonate) IRIS
V	NA	1 WHO (2000)	NA	NA
Zn	NA	NA(f)	NA	0.3 IRIS

Note

(a) Arsenic is a human carcinogen. Present risk estimates have been derived from studies in exposed human populations in Sweden and the United States. When assuming a linear dose–response relationship, a safe level for inhalation exposure cannot be recommended. (Reference: WHO Air Quality Guidelines – 2nd Edition)

(b) International Agency for Research on Cancer has classified cadmium and cadmium compounds as human carcinogens, having concluded that there was sufficient evidence that cadmium can produce lung cancers in humans and animals exposed by inhalation. Yet because of the identified and controversial influence of concomitant exposure to arsenic in the epidemiological study, however, no reliable unit risk can be derived to estimate the excess lifetime risk for lung cancer. (Reference: WHO Air Quality Guidelines – 2nd Edition)

(c) An air quality guideline for Dioxins is not proposed because direct inhalation exposures constitute only a small proportion of the total exposure, generally less than 5% of the daily intake from food. (Reference: WHO Air Quality Guidelines – 2nd Edition)

(d) Even if the dermatological effects of nickel are the most common, such effects are not considered to be critically linked to ambient air levels. Nickel compounds are human carcinogens by inhalation exposure. The present data are derived from studies in occupationally exposed human populations. Yet assuming a linear dose response, no safe level for nickel compounds can be recommended. (Reference: WHO Air Quality Guidelines – 2nd Edition)

(e) An air quality guideline for PCBs is not proposed because direct inhalation exposures constitute only a small proportion of the total exposure, in the order of 1-2% of the daily intake from food. (Reference: WHO Air Quality Guidelines – 2nd Edition)

(f) No information from WHO. With reference to IRIS, available data are not suitable for the derivation of an RfC for zinc. (Reference: http://www.epa.gov/iris/subst/0426.htm#refinhal)

(g) Joint FAO/WHO Expert Committee on Food Additives (JECFA) recently re-evaluated arsenic and concluded that the existing provisional tolerable weekly intake (PTWI) was very close to the lower confidence limit on the benchmark dose for a 0.5% response calculated from epidemiological studies and was therefore no longer appropriate. The PTWI was therefore withdrawn.

(h) Based on the dose–response analyses, JECFA estimated that the previously established PTWI of 25 µg/kg body weight is associated with a decrease of at least 3 intelligence quotient (IQ) points in children and an increase in systolic blood pressure of approximately 3 mmHg

(0.4 kPa) in adults. These changes are important when viewed as a shift in the distribution of IQ or blood pressure within a population. JECFA therefore concluded that the PTWI could no longer be considered health protective, and it was withdrawn.

(i) Sources of References:
WHO (1998): http://www.who.int/ipcs/publications/en/exe-sum-final.pdf
WHO (2000): http://www.euro.who.int/document/e71922.pdf
WHO (2001): http://www.who.int/ipcs/food/jecfa/summaries/en/summary_57.pdf
WHO (2011): http://www.who.int/water_sanitation_health/dwq/guidelines/en/index.html
USEPA (IRIS): http://www.epa.gov/iris/index.html
HSE (2005): Health and Safety Executive. EH40/2005 Workplace exposure limits
HEAST (1997): Health Effects Assessment Summary Tables (HEAST). Fiscal Year 1997 Update". Office of Solid Waste and Emergency Response. EPA-540-R-97-036. July 1997

9a.2.5.8 Discussed below are a few special cases for which the specification of toxicity criteria / guidelines is somewhat more complex.

Chromium (VI)

9a.2.5.9 For the purpose of health risk assessment, chromium and chromium compounds need to be speciated into trivalent and hexavalent chromium species with trivalent chromium or Cr(III) being non-toxic and hexavalent chromium or Cr(VI) is toxic. With reference to the 2005 National Emissions Inventory Data prepared by USEPA, the percentage of Cr (VI) in total Cr is 19% for emissions of large municipal waste combustors. Therefore, a 19% Cr(VI) speciation factor is applied to the total Cr emissions in this health risk assessment.

Lead

9a.2.5.10 USEPA has not derived RfDs for lead due to uncertainties about the health effects and dose-response associated with exposures to lead. Based on findings that neurobehavioral effects in young children occur at exposure levels below those that have caused cancer in laboratory animals, an Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children has been developed by USEPA (USEPA, 2002b). USEPA guidance (USEPA, 2005) has recommended the use of this IEUBK model in combustor health risk assessments.

9a.2.5.11 Several recent combustor facility risk studies have yielded extremely low incremental concentrations of lead in the modelled environmental media. Those concentrations are often so low that they are difficult to evaluate in the IEUBK model (due to threshold format restrictions).

Polycyclic Aromatic Hydrocarbons (PAHs)

9a.2.5.12 Consistent with USEPA guidance (USEPA, 2005), the health risk assessment has considered both potential carcinogenic effects and non-carcinogenic toxicity for the potential PAH constituents. Potentially carcinogenic polycyclic aromatic hydrocarbon (PAH) are ranked in order of potency in relation to benzo(a)pyrene. For those PAH compounds that are potentially carcinogenic, the risk analysis has used the USEPA-developed comparative potency factors to derive cancer slope factors representative of these compounds and their potential toxicity relative to benzo(a)pyrene (USEPA, 1993), which are mostly consistent with those endorsed by the WHO (WHO, 1998). The only differences are for benzo(k)fluoranthene (WHO value of 0.1 vs. U.S. EPA value of 0.01) and chrysene (no WHO potency factor vs. the U.S. EPA recommended 0.001). Potential non-carcinogenic effects of PAHs has been evaluated using the RfD for naphthalene recommended by USEPA if total PAHs are evaluated or individual PAH toxicity factors recommended by USEPA if emission rates for individual PAHs are located in the literature.

Dioxin and Furans

9a.2.5.13 Although there are hundreds of dioxin and furan compounds, those compounds for which potential human health impacts can be quantitatively evaluated are the dibenzodioxin, and dibenzofuran congeners which have four chlorine molecules attached in positions 2, 3, 7, and 8 on the central ring structure. A CSF has been developed only for 2,3,7,8-tetrachloro-dibenzo-p-dioxin (2,3,7,8-TCDD).

9a.2.5.14 The WHO has established (1998) and re-evaluated (2005) toxicity equivalency factors (TEFs) for dioxins and related compounds. Other congeners are assigned WHO TEFs that relate their toxicities to that of 2,3,7,8-TCDD (Van den Berg et al., 2005). This concept parallels that used for evaluating PAHs, as explained above.

9a.2.5.15 For this evaluation, since emission rates were based on the combined concentration limit for dioxins and furans, there was no need to apply the WHO TEFs (emissions were not estimated for individual congeners). Potential carcinogenic health risks associated with the dioxin and furans have been evaluated in accordance with the approach developed by USEPA, and recommended in the 2005 HHRAP as follows: Risks have been calculated for combined dioxin and furans using the cancer slope factor for 2,3,7,8-TCDD listed in HEAST (USEPA, 1997).

9a.2.5.16 Dioxin and furan congeners may also have some risk of non-carcinogenic toxicity associated with them; however, there are no established RfDs with which to evaluate this hazard.

Polychlorinated Biphenyls

9a.2.5.17 Moderately chlorinated PCB congeners can have dioxin-like effects. This sub-category includes PCB congeners with four or more chlorine atoms and few substitutions in the ortho positions (positions designated 2, 2', 6, or 6'). They are sometimes referred to as “coplanar” PCBs, because the rings can rotate into the same plane if not blocked from rotation by ortho-substituted chlorine atoms. In this configuration, the shape of the PCB molecule is very similar to that of a dioxin molecule. Studies have shown that these dioxin-like congeners can react with the aryl hydrocarbon receptor; the same reaction believed to initiate the adverse effects of dioxins and furans.

9a.2.5.18 A recent revision of the TEF scheme was undertaken by the WHO (Van den Berg et al, 2005) in connection with a review of the WHO recommended Tolerable Daily Intake. The proposed scheme included coplanar congeners of PCBs within the overall TEQ scheme, by defining TEFs for 12 coplanar PCBs on the basis that their mode of action and the responses elicited in biological systems parallel those of the 2,3,7,8-positional dioxins and furans. The WHO-TEQ of the sample would be represented by the summation of the products of the concentrations of 17 dioxin/furan congeners and 12 PCB congeners by their respective TEFs. Risks from coplanar PCBs have been estimated by computing a toxicity equivalency quotient (TEQ) for PCBs, and then applying the slope factor for 2,3,7,8-TCDD.

9a.2.5.19 In addition to the coplanar (dioxin-like) PCB congeners, the remaining PCBs have also been evaluated in the risk assessment. After considering the accumulated research on PCBs and a number of studies of the transport and bioaccumulation of various congeners, USEPA derived three new CSFs to replace the former single CSF for PCBs. The upper-bound CSF designated for use when evaluating food-chain exposures and ingestion of soil is used to evaluate cancer risk associated with the remaining PCBs (the non-dioxin-like PCBs) in the mixture as recommended by USEPA.

Toxicity Criteria / Guidelines for Short-Term Exposure

9a.2.5.20 As currently recommended in the HHRAP guidance, it is proposed that potential risks due to short-term inhalation exposure (such as irritant or respiratory health effects) be evaluated in addition to the more commonly evaluated chronic risks to human health discussed above. Therefore, a screening level evaluation of short-term health effects has been conducted by comparing predicted short-term (maximum 1-hour) air concentrations against the findings of relevant toxicology studies.

Classical COPCs of the HKAQO

9a.2.5.21 For the classical COPCs of the HKAQO with potential acute health effects, the contribution of the IWMF project to the predicted cumulative short-term (hourly average) concentrations of these classical COPCs at the air sensitive receivers are analysed as part of this health risk assessment and compared against the findings of relevant toxicology studies.

Other COPCs

9a.2.5.22 For other COPCs with potential acute health effects, for the purpose of this risk assessment, the following sources of information have been reviewed to determine the inhalation reference level for use in evaluating exposure and risk through inhalation:

- California EPA Acute Reference Exposure Levels (Cal/EPA, 2008);
- Acute inhalation exposure guidelines (AEGL-1) (USEPA, 2010);
- Level 1 emergency planning guidelines (ERPG-1; DoE, 2010);
- Temporary Emergency Exposure limits (TEEL-1; DoE, 2010); and
- AEGL-2 values (USEPA, 2010).

9a.2.5.23 If no AEGL-1 value is available, but an AEGL-2 value is available, the AEGL-2 value was selected only if it is a more protective value (lower in concentration) than an ERPG-1, or a TEEL-1 value if either of these values is available.

9a.2.5.24 The adopted exposure limits/reference levels for short term exposure of COPCs are presented in **Table 9a.9**.

Table 9a.9 Exposure Limits/Reference Levels for COPCs Acute Exposure

COPC	Exposure Limit/Reference Level ($\mu g/m^3$, 1-hr averaging time)	Source
Sb	1,500/10 = 150	TEEL-1
As	30 /10 = 3	TEEL-1
Cd	30/10 = 3	TEEL-1
Cr (VI)	30/10 = 3	TEEL-1
Co	3,000/10 = 300	TEEL-1
Cu	100	Cal/EPA Acute REL
Dioxins	No guideline	-
HCl	2,100	Cal/EPA Acute REL
HF	240	Cal/EPA Acute REL
Pb	150/10 = 15	TEEL-1
Mn	3,000/10 = 300	TEEL-1
Hg	0.6	Cal/EPA Acute REL
Ni	6.0	Cal/EPA Acute REL
Tl	300/10 = 30	TEEL-1
V	150/10 = 15	TEEL-1

9a.2.6 Risk Characterization

General

9a.2.6.1 In the risk characterization step, the potential human health risks associated with COPC emissions from the MSW thermal treatment unit have been estimated. The risk characterization step combined the results of both the exposure assessment and the dose-response assessment to estimate the incremental potential risks to human health.

Non-carcinogenic Hazard

Classical COPCs of the HKAQO

9a.2.6.2 The highest cumulative annual average SO_2 concentrations predicted at the hot spot areas (see **Section 3a**) based on territory-wide scale model results (PATH model) would range from 7 to 17 μg/m^3. The average contribution by the IWMF would range from 0.11 to 1.29%. Nevertheless, there is still considerable scientific uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse air effects or, rather a surrogate for particulate matters[2]. While it is not possible to totally rule out its adverse health effects, the potential additional health effects are likely to be small.

9a.2.6.3 For the RSP, the highest cumulative annual average RSP concentrations predicted at the hot spot areas based on territory-wide scale model results (PATH model) would range from 39 to 48 μg/m^3. The average contributions by the IWMF would be below 0.02%. As such, the associated additional risk for adverse health effects of RSP due to the IWMF are likely to be very small and are unlikely to be quantifiable[3].

9a.2.6.4 For NO_2, the highest cumulative annual average NO_2 concentrations predicted at the hot spot areas based on territory-wide scale model results (PATH model) would range from 13 to 40 μg/m^3. The average contribution by the IWMF would range from 0.01 to 0.37%. The associated additional risk for adverse health effects of NO_2 due to the IWMF are likely to be very small. As such, it is very unlikely that the NO_2 emitted by the IWMF will cause significant long-term adverse health effects.

9a.2.6.5 The detailed percentage contributions of SO_2, NO_2 and RSP by the IWMF are presented in **Appendix 9.3**.

Other COPCs

9a.2.6.6 The cumulative non-carcinogenic health impact due to chronic inhalation, includes the impact arising from the IWMF plus the background contribution (including contribution from the nearby Sludge Treatment Facilities) are presented in **Appendix 9.4**. Cumulative chronic health impact of the IWMF at all receptors are assessed and compared with the exposure limits/reference levels. It is concluded that the effect are insignificant when compared to the proposed exposure limits/reference levels. No adverse chronic inhalation health effects are expected and no risks due to long-term exposure are expected.

9a.2.6.7 The potential for chemicals to cause adverse non-carcinogenic health effects has been assessed by dividing estimated exposure doses (determined for the exposure scenarios described above) by appropriate dose-response values, such as reference doses (RfDs). The resulting ratio is referred to as the "chemical-specific risk ratio" or hazard quotient. For individual chemicals, hazard quotients have been added across exposure pathways

[2] *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, Summary of risk assessment*, World Health Organization
[3] *Fourth External Review Draft of Air Quality Criteria for Particulate Matter (June, 2003), Appendix 9A*, USEPA

to determine the total non-carcinogenic hazard index (HI) for each receptor potentially exposed to facility-related COPC in the environment.

9a.2.6.8 The USEPA has determined that exposure to a chemical is not expected to cause significant adverse health effects if this total risk ratio, or HI, for all exposure pathways has a total value of 1 or less. The most recent USEPA risk management guidance (USEPA, 1998) describing management decisions for combustion facilities recommends, however, that it be assumed that 75% of this value is reserved for exposures that may come from other background sources. Thus, the guidance indicates that the remaining HI = 0.25 should serve as an initial screening benchmark for exposures that may be associated with the subject facility operations.

9a.2.6.9 Since a total HI of less than or equal to 1.0 generally indicates no significant risk of adverse non-carcinogenic human health effects, the more conservative approach of 0.25 would also support such a conclusion. The USEPA further recommends that if the resulting summation exceeds 0.25, the HI analysis should be re-examined and refined, such that only those chemicals exhibiting the same or similar toxicity endpoints (i.e., they affect the same target organ) are summed. Since chemicals may display a variety of effects depending on concentration, the toxic endpoint is defined in this context as the most sensitive non-carcinogenic health effect used to derive the RfD.

9a.2.6.10 With reference to risk assessment results on non-carcinogenic hazard presented in **Appendix 9.5**, it can be concluded that the Hazard Index at all receptors falls under 0.25. The highest hazard quotient occurs at receptor SLW2 with a value of 0.01. Therefore, the exposure of the receptors for the TTAL site to the non-carcinogenic COPCs is not expected to cause significant adverse health effects.

Cancer Risk

9a.2.6.11 Potential incremental ("excess") lifetime cancer risks have been calculated for each receptor by multiplying the appropriate CSF by the site-specific exposure dose level determined for each of the exposure scenarios described above. The cancer risks from each carcinogenic COPC and from each exposure pathway have been added together to estimate the total cancer risk for each receptor. The equation for estimating cancer risk is presented below:

$$\text{Cancer Risk}_i = I \times ED \times EF \times CSF / AT \times 365$$

Where:

I	=	Intake (mg/kg-d)
ED	=	Exposure duration (years)
EF	=	Exposure frequency (days/year)
CSF	=	Cancer slope factor $(\text{mg/kg-day})^{-1}$
AT	=	Averaging time (days)
365	=	Days/year

9a.2.6.12 Total cancer risk are calculated as follows:

$$\text{Total Cancer Risk} = \Sigma_i \text{ Cancer risk}_i$$

9a.2.6.13 The USEPA risk management guidance[4] (USEPA, 1998) suggests a target risk level of $1x10^{-5}$ as an acceptable total for all contributions of carcinogenic risk at a designated individual receptor from the Project. In accordance with the USEPA risk management guidance, if a calculated risk falls within the target values, the authority may, without

[4] Region 6 Risk Management Addendum - Draft Human Health Risk Assessment Protocol for hazardous Waste Combustion Facilities.

further investigation, conclude that the proposed project does not present an unacceptable risk.

9a.2.6.14 The predicted total carcinogenic risk at the representative receptors are summarized in **Appendix 9.5**. The results indicated that the predicted total carcinogenic risk from the Project at all receptors are less than 1×10^{-5}. The highest total cancer risk occurs at receptor SLW2 with a value of 1.26×10^{-6}. Therefore, it is expected that the Project would not present an unacceptable risk.

9a.2.6.15 Since the assessment results meet the both cancer risk and non-cancer hazard index criteria, no further analysis is presumed to be necessary.

Risks Due to Short-Term Exposure

9a.2.6.16 In addition to the potential long-term risk to human health presented by COPCs emitted from the facility, short-term or acute risk has been evaluated for direct inhalation COPCs. Acute exposure has been estimated, based on maximum one-hour average air concentrations predicted from the atmospheric dispersion modelling described in **Section 3a**. To determine the likelihood of adverse acute effects, maximum predicted one-hour average air concentrations are compared with criteria for short-term inhalation exposures.

Classical COPCs of the HKAQO

9a.2.6.17 The average contribution of 1-hr SO_2 concentrations by the IWMF are predicted at the hot spot areas (see **Section 3a**) to be in the range of 0.06% to 1.14%. The highest cumulative 1-hr average SO_2 concentration with the operation of the IWMF would be 184µg/m^3 based on territory-wide scale model results (PATH model), which is below the short term exposure level with observable acute health effects in vulnerable groups[5]. Therefore, the associated acute health effect would be negligible.

9a.2.6.18 For CO, the average contribution of 1-hr CO concentrations by the IWMF are predicted at the hot spot areas to be less than 0.04%. The predicted highest cumulative 1-hr average CO concentration is 1712µg/m^3 based on territory-wide scale model results (PATH model) and is far below international safe levels[6]. Therefore, adverse health effect of CO contribution from the IWMF is negligible.

9a.2.6.19 For NO_2, the predicted highest cumulative 1-hr average NO_2 concentration is 275µg/m^3 based on territory-wide scale model results (PATH model). The predicted 1-hr average concentration is below the level with clear observable acute health effects in many short term experimental toxicology studies[7]. Nevertheless, the average contribution of 1-hr average NO_2 concentration at the hot spot areas by the IWMF is predicted to be in the range of 0.01% to 0.31%. Therefore, the acute adverse health effects of NO_2 due to the IWMF would be very small and are unlikely to be quantifiable.

9a.2.6.20 In summary, the IWMF would make only small additional contributions to local concentration of CO, SO_2 and NO_2. While it is not possible to rule out adverse health effects from the IWMF with complete certainty, the impact on health from small additional air pollutants is likely to be very small and unlikely to be quantifiable.

[5] *Toxicological Profile for Sulfur Dioxide*, US Department of Health and Human Services
[6] *Toxicological Profile for Carbon Monoxide*, US Department of Health and Human Services
[7] *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, Summary of risk assessment*, World Health Organization

Other COPCs

9a.2.6.21 The cumulative non-carcinogenic health impact due to direct inhalation, includes the impact arising from the IWMF plus the background contribution (including contribution from the nearby Sludge Treatment Facilities) are presented in **Appendix 9.6**. Cumulative acute health impact of the IWMF at all receptors are assessed and compared with the exposure limits/reference levels. It is concluded that the effect are insignificant when compared to the proposed exposure limits/reference levels. No adverse acute effects are expected.

9a.2.6.22 Maximum Permitted Concentration of Certain Metals present in Foods

9a.2.6.23 In order to determine the compliance of the maximum permitted concentration of certain metals present in foods due to the Project as stipulated in “Food Adulteration (Metallic Contamination) Regulations” by the Centre for Food Safety, a compliance check was conducted based on the risk modelling results. The concentrations of the metals listed in **Table 9a.3** and **Table 9a.4** at each receptor location were compared with the maximum permitted concentrations.

9a.2.6.24 Based on the assessment results presented in **Appendix 9.7**, it is concluded that food grown in the vicinity of all receptor locations would comply with the maximum permitted concentrations stipulated by the Centre for Food Safety. The concentrations of Antimony, Arsenic, Cadmium, Chromium, Lead and Mercury at all receptor locations fall under the maximum permitted concentrations listed in the first and second schedules in **Table 9a.3** and **Table 9a.4**.

<u>Uncertainty Analysis</u>

9a.2.6.25 Within any risk assessment process, a number of assumptions and simplifications are made in recognition of the lack of complete scientific knowledge and inherent variability in many of the parameters used in risk assessment models. In some cases, the values may vary widely between a conservative upper confidence limit and a mean value. In other cases, measurement data are too sparse to develop a statistically robust estimate of the mean. In those cases, judgments must be made in selecting an assumed value that is credible, but unlikely to be exceeded when future measurements become available.

9a.2.6.26 The health risk assessment is a complex process, requiring the integration of the followings:

- Release of COPCs into the environment;
- Transport of the COPCs by air dispersion, in a variety of different and variable environments;
- Potential for adverse health effects in human, as extrapolated from animal studies; and
- Probability of adverse effects in a human population that is highly variable genetically, and in age, activity level and lifestyle.

9a.2.6.27 Uncertainty can be introduced in the assessment at many steps of the process. The following paragraphs discuss the uncertainties associated with each stage of the assessment.

Hazard Identification

9a.2.6.28 COPCs are identified based on the air pollutants listed in EPD’s BPM12/1. This list of chemicals may not cover all the chemicals emitted from the stack of the IWMF which could pose a threat to human health, which may underestimate the risk. However, it is considered that although the COPCs identified may not be exhaustive, it appeared sufficiently comprehensive for the purpose of the assessment because BPM12/1 serves the purpose to prevent the air pollutant emissions from incinerator stack from harming the environment and human health or creating nuisance.

9a.2.6.29 The adopted emission factors of COPCs from the IWMF stack for air quality modelling are based on the target exhaust gas concentration limits proposed for the IWMF. It is considered that this assumption would overestimate the risk because COPC emission rate from the IWMF would not reach the allowed maximum rate all the time. Moreover, the emission factors for individual heavy metals (except Hg) are based on the “exhaust gas concentration for combined metal species”[8], this would further overestimate the risk.

Exposure Assessment

9a.2.6.30 In this stage of the assessment, air dispersion model is used to predict the COPC dispersion in air and the COPC concentrations at potential human receptors. As computer models are simplifications of reality requiring exclusion of some variables that influence predictions, of which would introduce uncertainty in the prediction of COPC concentration at potential human receptors and may in turn overestimate or underestimate the risk.

9a.2.6.31 Moreover, the air quality modelling results adopted for exposure assessment are modelled based on the worst case scenario which would not occur all the time. This conservative approach in air quality modelling would overestimate the risk.

9a.2.6.32 The characteristic parameter values for human receptors used in the HHRA are adopted from the default values suggested in USEPA (2005). The values adopted may not precisely reflect the conditions of potential human receptors identified, which may overestimate or underestimate the risk.

Dose-response Assessment

9a.2.6.33 The toxicity criteria / guidelines[9] adopted from agencies would introduce uncertainty to the HHRA. These toxicity criteria / guidelines are used as single-point estimates throughout the analysis with uncertainty and variability associated with them. Moreover, the arbitrary application of safety factor to occupational exposure limit for derivation of toxicity criteria / guidelines for long term COPC exposure is another source of uncertainty. This uncertainty may overestimate or underestimate the risk. However, it should be noted that much of the uncertainty and variability associated with the toxicity criteria / guidelines shall be accounted for in the process that the agencies setting verified toxicity criteria / guidelines.

9a.3 Potential Health Impacts of Biogas from Sorting and Recycling Plant

9a.3.1 Introduction

9a.3.1.1 This section reviewed the potential health impact associated with biogas in sorting and recycling plant (i.e. Mechanical Treatment) operations. Mechanical Treatment Plant includes the following components:

- Municipal Solid Waste (MSW) receiving, storage and feeding system
- Mechanical treatment system including shredding and sorting facilities

[8] 0.05mg/m^3 as the limit for total concentration of Cd and Tl; 0.5mg/m^3 as the limit for total concentration of Sb, As, Pb, Co, Cr, Mn, V and Ni.
[9] Unit risk factors, air quality standards/occupational exposure limit value for long term COC exposure as well as exposure limits and reference level for acute COC exposure.

- Products and by-products storage and handling system
- Odour control system
- Process control and monitoring system

9a.3.1.2 In a mechanical treatment process for mixed MSW treatment, mechanical part is used mainly to pre-treat the waste for the subsequent treatment process, and meanwhile recover the recyclable materials, such as metals, plastic and paper.

9a.3.2 Description of Potential Biogas Emissions

9a.3.2.1 The objectives of mechanical treatment process include preparation and sorting / separation of waste. Waste preparation is to split the refuse bags, remove bulky waste and shred and homogenise the waste into smaller particle sizes suitable for separation processes. The mechanical sorting processes then separate the prepared wastes into the following parts:

- Recyclable materials including metals, paper and plastics;
- Inappropriate constituents for subsequent treatment, including:
  - Over-size refuse such as textiles, wood and residual paper and plastics;
  - Under-size refuse such as glass, sands and residual metals.

9a.3.2.2 In the consideration of Hong Kong context, MSW would be source separated to reduce the waste disposal and increase waste recycling and recovery. At the refuse transfer stations (RTS), waste is compacted before transported to the treatment facilities. It is thus considered that the bulky waste (such as furniture, glass and plastic bottles and old clothing etc) in the MSW delivered to the IWMF would be very limited and the waste would not be fully enclosed by multiple layers of bags. Therefore, manual separation method is considered unnecessary for the IWMF in Hong Kong, considering the feedstock characteristics and staff healthy concerns.

9a.3.2.3 Since mechanical treatment will not generate the biogas, potential health impact to the staff due to biogas emission from mechanical treatment is not expected.

9a.3.3 Impact Evaluation

9a.3.3.1 In accordance with the description in **Section 9a.3.2** above, biogas will not be generated in the mechanical treatment process. Potential health impact to the staff and nearby sensitive receivers due to biogas from sorting and recycling plant is therefore not expected.

9a.4 Potential Health Impacts of Fugitive Emissions during Transportation, Storage and Handling of Waste and Ash

9a.4.1 Introduction

9a.4.1.1 This section reviewed the potential health impact associated with fugitive emissions during transportation, storage and handling of waste and ash during operation of the IWMF.

9a.4.2 Description of Operation Process

9a.4.2.1 For the artificial land near SKC, the mixed MSW would be delivered from various existing refuse transfer stations in Hong Kong to the site by marine vessels (probably from Island East (IETS), Island West (IWTS) and West Kowloon refuse transfer station (WKTS)). For the TTAL site, in addition to the mixed MSW that would be delivered from various existing refuse transfer stations in Hong Kong to the site by marine vessels, some of the mixed MSW originally planned to deliver to the WENT Landfill Extension by land transport might also be diverted to the IWMF for treatment. The MSW will be delivered to the waste reception hall of the incineration plant or the mechanical treatment plant.

9a.4.2.2 At the waste reception hall of the incineration plant, mixed MSW would be unloaded into the bunker. The waste is then transferred by overhead cranes into the combustion chamber for burning. Ash will be collected at the bottom of the combustion chamber and passes to the ash storage pit through an ash extractor and magnetic separator for ferrous metal recovery. These ashes, commonly known as bottom ash, would be delivered in containers to the landfill for final disposal or reuse.

9a.4.2.3 The hot flue gases from the combustion chambers would flow through the boiler, releasing thermal energy which turns the water in the boiler tubes into steam. The steam produced would be used to drive the turbine to generate electricity. The cooled flue gases would be treated by flue gas treatment system including scrubbers, activated carbon powder injection and fabric filter systems. The cleaned flue gases would then be released to the atmosphere via the stack. A relatively smaller amount of fly ash and residues would be collected from the boiler and flue gas equipments. The fly ash and residues would then be stabilized with cement or other suitable material before final disposal.

9a.4.2.4 As regards the MSW delivered to the mechanical treatment plant, they would be unloaded into a storage pit. The waste would then be shredded and separated by mechanical treatment systems for sorting of recyclable metals, recyclable plastics, oversize refuse and inert materials. The recyclables would be collected, stored for delivery to other recycling sites. The inert materials would be delivered to the landfill for disposal. The oversize sorting residues would be combusted in the incineration plant or disposed of at landfills.

9a.4.3 Hazard Identification

<u>Transportation</u>

9a.4.3.1 As described above, the existing transportation mode of MSW to landfills will be adopted for the future transportation of waste and ash to and from the IWMF.

<u>Storage and Handling</u>

9a.4.3.2 Potential fugitive emission from waste would be expected during unloading to waste storage pit and transferring waste by overhead cranes grab into the combustion chamber. Ash will be generated after combustion and it will be collected at the bottom of combustion chamber. The ash will be conveyed to the ash storage pit automatically through enclosed extractor. Closed grab will be used to grab the ash to ash hopper and then transfer the ash to enclosed-type container.

9a.4.4 Impact Evaluation

9a.4.4.1 With reference to existing experience of MSW transportation to landfills, potential fugitive emission during transportation of waste and ash is not expected. The potential health impacts associated with the transportation of waste to the IWMF would be similar to those that associated with the current transportation of waste to the landfill and are considered insignificant.

9a.4.4.2 With regards to the storage and handling of waste and ash, given that all the reception halls and ash storage pits will be fully enclosed with slightly negative air pressure and closed grab will be use to grab waste and ash, leakage of any fugitive emissions to the outdoor environment is not expected.

9a.4.4.3 In order to minimize the potential health impacts to the worker who worked inside the plant, the following health risk control measures will be implemented. With the implementation of the following measures, the potential health impacts associated with the transportation, storage and handling of waste and ash are considered to be insignificant.

- Provide signage for clear indication of the travelling route of waste/ash trucks;
- Monitor and control the traffic flow inside the reception hall of the plant;
- Vehicle cleaning system should be provided to clean the waste/ash trucks before they leave the plant;
- Apply good practice during unloading of MSW to waste storage pit including: provide signage to assist waste/ash truck drivers to stop at appropriate unloading position; provide sufficient training to waste/ash truck drivers;
- Detection device / alarm should be installed to prevent overfilling of waste and ash storage pit;
- In case manual handling of waste/ash is needed, the workers involved should wear personal protective equipment;
- The on-site workers responsible for maintenance and cleaning of equipment or vehicles contaminated with waste/ash should wear personal protective equipment; and
- Emergency plan should be established and implemented to handle the situation of accidental incineration units shut down.

9a.5 Potential Health Impacts of Radon Emissions from Pulverized Fly Ash

9a.5.1 Introduction

9a.5.1.1 Pulverized Fly Ash (PFA) has been used for a wide range of applications (e.g. fill for land formation and reclamation as well as raw material in concrete) locally and in overseas countries for a long period of time (more than 50 years in the UK). Health concerns due to radon emissions of PFA applications are not a new issue; they were raised more than 15 years ago. Studies assessing the potential health impacts associated with PFA have been conducted, which showed that PFA is an environmentally harmless material that can be safely used in bound and unbound applications.

9a.5.1.2 Based on the findings from various research projects and studies, which include local studies presented in **Section 9.5.4** below, it is appropriate to consider that the health impact associated with radon emissions from PFA during the construction and operation of the IWMF at the TTAL site would be insignificant. Therefore, this section aims to present the findings of the literature review rather than developing a risk assessment approach for the radon emissions from PFA.

9a.5.2 Health Hazard of Radon

9a.5.2.1 Radiation is a natural and ubiquitous phenomenon. The major natural radionuclides are potassium-40 and those in the decay series headed by thorium-232 and uranium-238.

9a.5.2.2 Radon-222 is an inert gas, which is the first radioactive decay product of Radium-226, which itself is a naturally-occurring radionuclide arising from the decay of uranium-238. The decay products of radon gas (radon-222) in their order of appearance are shown in **Figure 9.1**. They are called the "radon progeny". Each radioactive element on the list gives off either alpha or beta radiation and sometimes gamma radiation too, thereby transforming itself into the next element on the list. Lead-206, the last element on the list, is not radioactive. It does not decay, and therefore has no half-life.

9a.5.2.3 In living lung tissue, if the DNA in one of the cells adjacent to an inhaled radioactive particle is damaged by the emitted radiation, it may become a cancer cell later on, spreading rapidly through the lung, causing lung cancer. The relative risk model (Yu et al.), which takes into account various factors, such as age and sex, has been used to estimate the lung cancer deaths due to radon. It has been found that, around the year of 1988, about 300 (about 13%) of the lung cancer deaths each year are attributable to radon in Hong Kong.

9a.5.2.4 The risk estimate of International Commission on Radiological Protection (ICRP 1993) projected a lung cancer risk of 283×10^{-6} per WLM (working level month) posed by radon. Based on this risk factor, together with the total annual indoor exposure of 0.22 WLM for Hong Kong with a population of Hong Kong in 1986 of 5.5 million, the estimated number of Rn-induced lung cancer deaths per year would be 340, which agrees with that calculated from the relative risk model.

9a.5.2.5 From the relative risk model, the number of Rn-induced lung cancer deaths is expected to grow with the population, unless the indoor radon concentration is reduced.

9a.5.3 Radon Associated with PFA

9a.5.3.1 As radioactive substances are found throughout the earth’s crust, substances extracted from it, including sand, clay, flint, marble, granite and coal, also contain radioactive material. Upon burning of coal for power generation, some of the radioactive materials are left behind in the ash, which consequently has a raised concentration of radioactivity per unit mass. With an average ash content of coal of about 16%, the activity per unit mass of ash would be expected to be about six times greater than the original coal.

9a.5.3.2 A study on the radiological significance of utilization and disposal of coal ash from power stations was conducted by Green in 1986. The main objectives of the study were to assess the radiological significance of the utilization of PFA as building materials and activities of workers and the general public on disposal sites, under both indoor and outdoor environment. This was calculated based on actual field studies, laboratory studies and mathematical models.

9a.5.3.3 Field measurements were taken at three coal ash disposal sites in the United Kingdom (UK). Radionuclide content, porosity, radon emanating fraction and exhalation rates of building blocks containing PFA were analyzed. Mathematical models were used to estimate the exposure to gamma-ray dose rates and radon concentrations under the tested conditions:

- Exposures from building materials; and
- Exposures from disposal sites under indoor and outdoor conditions

9a.5.3.4 From the field studies conducted, it was concluded that there is an increase of radionuclide content from coal to PFA. This agreed with the results of the assessment of the specific activity of samples of PFA, FBA (fuel bottom ash) and coal from the Castle Peak Power Stations conducted by the EPD and Royal Observatory (RO) in co-operation with CLP in 1989. The results are extracted and shown in **Table 9a.10** below after conversion to radium equivalent activities. It indicates an increased activity from the un-burnt coal to PFA and FBA. A summary of the more recent measurements conducted by Lu et al (2006) is extracted and shown in **Table 9a.11**.

9a.5.3.5 Several observations were noted when predicting flux for various thicknesses of PFA and of soil cover in the field studies. It was noted that increasing the thickness of the PFA layer beyond 5m makes little impact on the surface radon flux. The flux would be reduced by a factor of 2 if 30cm of soil cover is provided on top of the PFA.

Table 9a.10 Radium Equivalent Activities of PFA, FBA and Coal from the Castle Peak Power Station

Coal Source	Date of Sample Collection	Radium equivalent activity (Bq/kg)		
		Coal	PFA	FBA
Columbia	22/02/1989		233	255
Australia	22/02/1989		373	347
Australia	02/03/1989		532	163
South Africa	07/03/1989		407	343
South Africa	08/03/1989			
South Africa	10/03/1989	72	423	382
South Africa	15/03/1989	66	443	335
Australia	19/03/1989	27	211	197
Sampled by RO	1987		377 [(a)]	
Source not specified	1987		378 [(a)]	

Remark: (a) Data from RO

Table 9a.11 Radium Equivalent Activities of PFA, FBA and Coal from Power Plant in other Countries

Power Plant	Radium equivalent activity (Bq/kg)		
	Coal	PFA	FBA
Baoji, China	86	350	298
Lodz, Poland	26-71	157-309	97-248
India	-	283	-
Hong Kong, China	47	375	260
Shanghai, China	94	408	307
Beijing, China	86	285	-

Reference: Natural radioactivity of coal and its by-products in the Baoji coal-fired power plant, China, Xinwei Lu, Xiaodan Jia and Fengling Wang, July 2006

9a.5.4 Health Impact Associated with PFA due to Radon Emissions

<u>Construction Phase</u>

9a.5.4.1 During construction phase of the Project, the ash will mostly remain in the lagoon and excavation of ash would take place for certain activities, such as piling or utility installation within the lagoon area. Extensive transport or disposal of ash would unlikely take place offsite.

9a.5.4.2 As the construction activities would be mainly conducted on top of the existing ash lagoon, which can be considered as working outdoors, the health risk associated with radon emission is considered to be insignificant, which is explained by the paragraphs below.

9a.5.4.3 The National Radiological Protection Board (NRPB) conducted a study on radiological significance of the utilization and disposal of coal ash from power stations (Green (1986)). The study assessed exposure from building materials and exposure above ash disposal sites when used for either leisure or for construction. The estimated annual effective dose for both the reference situation and those involving power station ashes are shown in **Table 9a.12**.

9a.5.4.4 In Green (1986), the dose assessments of radon were conducted on the basis of a radon concentration above active or restored sites of 4 Bqm^{-3}. It was estimated that the annual effective dose equivalent to a worker spending 2000 hours each year on an ash disposal site would be 60 μSv, a conversion factor of 10 mSv WLM^{-1} being used because of the breathing rate of workers.

Table 9a.12 Summary of Estimates of Annual Effective Dose

Situation	Normal Ground			PFA disposal site 50cm soil cover			PFA disposal site no soil cover		
	From gamma	From radon	Total	From gamma	From radon	Total	From gamma	From radon	Total
Indoors									
All-brick dwelling	0.740	0.260	1.000	0.750	0.360	1.110	0.760	0.780	1.540
Heavy block dwelling	0.700	0.290	0.990	0.710	0.400	1.110	0.720	0.820	1.540
Light block dwelling	0.530	0.340	0.870	0.540	0.440	0.980	0.560	0.860	1.420
Outdoors									
Workers such as farm or disposal site labour (2000 hrs in a year)	0.056	0.057	0.113	0.070	0.060	0.130	0.130	0.060	0.190
Members of the public (500 hrs in a year)	0.014	0.007	0.021	0.018	0.008	0.026	N/A	N/A	N/A

Situation	**Normal Ground**			**PFA disposal site 50cm soil cover**			**PFA disposal site no soil cover**		
	From gamma	**From radon**	**Total**	**From gamma**	**From radon**	**Total**	**From gamma**	**From radon**	**Total**
Inhalation of Re-suspended Dust									
(8,760 hrs in a year)			0.011			-			0.035

Notes: Values are rounded to three decimal places
N/A: Not applicable
All units in mSv

9a.5.4.5 The effective dose equivalent to the workers during the construction phase of the IWMF should be more or less similar to the estimation in Green (1986). The differences between the situations in Hong Kong and the UK mainly concern higher background radon level and longer working hours in Hong Kong.

9a.5.4.6 When comparing the differences of radiation dose between the UK situation and the current situation for the IWMF, the background radiation levels should not be considered since it is not related to the Project. Whereas, only the incremental risk due to the PFA on site shall be considered. Since the risk imposed on workers with direct radon exposure is not significant and there will be no off-site disposal of PFA in this Project, the risk on off-site air sensitive receivers will also be insignificant as well.

9a.5.4.7 Tso and Leung (1996) conducted a study to evaluate the radiological impact of coal ash from power plants in Hong Kong. The study involved collection of PFA samples from the two local electric companies and measurement of radon produced from the samples.

9a.5.4.8 The study indicated for situation that the PFA is not covered with soil (e.g. construction phase for the IWMF project), the radon concentration at locations above the uncovered PFA is only slightly higher than the ambient background radon concentration. Also, precaution could be undertaken to suppress re-suspension of ash particles for protection to people on-site. Hence, the health impact associated with PFA due to emissions in the IWMF construction stage would be insignificant.

Operation Phase

9a.5.4.9 The health risk due to radon emission from PFA in the operation phase would primarily involve the staff in the IWMF. As building structures would be constructed on the ash lagoon, it is expected that the ingress of radon into and subsequent accumulation inside the building structures may increase the radiation exposure when people stay within the buildings.

9a.5.4.10 Referring to **Table 9a.10** & **Table 9a.11**, a higher radium equivalent activity is shown for PFA over coal. However, Stranden (1988) indicated that a higher specific activity is not necessarily indicative of higher radiation release. This is particularly true for radon as it is gaseous at room temperature and pressure and tends to emanate from materials containing radium. Since the radon emanation takes place into interstitial pores of a material and the subsequent releases or exhalation of radon through the pores is a complex issue.

9a.5.4.11 Stranden (1983) cited an example regarding the use of PFA in cement. It was expected that there would be an increase in the radon exhalation, however, the results of studies showed this perception is not true. Several authors found that the added PFA caused a decrease in radon exhalation, others found no significant difference between ordinary and PFA concrete and, in only a few cases, PFA concrete was found to exhale more radon than ordinary concrete. It is believed that the discrepancies in these studies are probably caused by differences in Ra-226 concentration, porosity, surface structure and PFA content in concrete in different countries.

9a.5.4.12 Sutton (2001) studied radon emissions from a high volume coal fly ash structural fill site in Tennessee, USA. Radon was used as an indicator for measuring the potential for emissions of naturally occurring radioactive materials at the structural fill site. Radon levels were measured under ambient conditions and inside some structures with various treatments simulating different slab-on-grade conditions. Data were collected over a seven-year period.

9a.5.4.13 The results of this long-term study indicated that a large-scale fly ash structural fill did not increase the presence of Radon-222 or other alpha emitters in structures located above the fill. The study provided evidence that radon should not be a major concern when locating a structure on a properly designed and constructed pulverized fly ash fill site.

9a.5.4.14 In Sutton's (2001) study, it was found that fly ash may contain more radium but emitted less radon than local soils in the vicinity of Bull Run in Tennessee. The lower radon flux of fly ash, compaction of the fly ash fill, compacted soil surface cover, as well as isolation from underlying soils and bedrock contribute to a mitigation of environmental radon in the area of the fly ash structural fill site.

9a.5.4.15 The indoor radon concentration within the structure on ash disposal site was studied in Green's study (1986). As shown in **Table 9a.12**, three scenarios, including normal ground, PFA disposal site with 50cm soil cover and without soil cover, were studied. It was estimated that the annual effective dose contributed by radon at the PFA disposal site without soil cover was in the range of 2 to 3 times higher than the other two scenarios.

9a.5.4.16 As concluded by Green (1986), there may be a potential increase in the radiation exposure of occupants in the building structure over ash disposal sites due to the increased radon flux out of the ground. However, he commented that the increases were not of great radiological significance. Green suggested incorporating simple preventive measures at the planning stage of Projects involving PFA for the interest of keeping doses to levels as low as reasonably achievable.

9a.5.4.17 Also, in Tso and Leung (1996), radon exposure estimation based on the sample measurement results indicated that when the PFA in the ash lagoon is covered by soil, the radiological hazard due to the PFA underneath the soil will become negligible and the land covered with soil will be safe for use.

9a.5.4.18 In order to further reduce radiation impact, the limit on the radium-226, thorium-232 and potassium-40 contents (**Table 9a.13**) in building materials would be adopted. These limitations are aimed at reducing the external gamma radiation background in indoor and outdoor environment and the limit on radium-226 concentration is also aimed at reducing the source term of radon emanation.

Table 9a.13 Maximum Activity Concentration Limit

Standard	Maximum activity concentration (Bq/kg)		
	Radium-226	Thorium-232	Potassium-40
EU (Radiation Protection 112)	300	200	3000
China (GB 6566-2001)	370	260	4200

9a.5.4.19 WHO (2003) recommends that countries implement national programmes to reduce the population's risk from exposure to the national average radon concentration, as well as reducing the risk for individuals exposed to high radon levels. WHO recommends that building codes should be implemented to reduce radon levels in homes under construction. A national reference level of 100 Bq/m^3 is recommended. However, if this level cannot be reached under the prevailing country-specific conditions, the reference level should not exceed 300 Bq/m^3. In Hong Kong, in accordance with Appendix 2 of "Protocol of Radon Measurement for Non-residential Building" of EPD ProPECC Note PN 1/99 "Control of Radon Concentration in New Buildings", the average radon concentration for all confined areas inside a building, but excluding areas where full-time occupancy is not anticipated, should preferably be lower than the territory-wide mean concentration of 100 Bq/m^3 and in any case, any individual measurement must not exceed 200 Bq/m^3.

9a.5.5 Impact Evaluation

9a.5.5.1 As supported by the studies reviewed in this literature review, health risks for radon emissions from PFA due to construction and operation activities of the IWMF at the TTAL site would be considered insignificant.

9a.5.5.2 There is a potential for increased radiation exposure (compared to background level) to the staff in the IWMF from the radon flux out of the ground filled by PFA. However, the increase would likely not be of great radiological significance and can be readily minimized by proper preventive measures.

9a.5.6 Recommended Measures to Control Radon Health Risk

9a.5.6.1 As discussed in the above, there is no significant radiological hazard to the workers at the IWMF on an ash lagoon during construction and operation periods. However, recommended measures shall be considered during the design, construction and operation of the IWMF.

9a.5.6.2 Prevention of radon influx from the PFA to the IWMF buildings is preferred. A soil cover can be provided beneath the buildings on top of ash lagoon prior to construction works because it reduces the level of radon influx significantly. Slab-on-grade can be an option on foundation design. In addition, soil suction can also prevent radon from entering the building by drawing the radon from below the building and venting it through a pipe, or pipes, to the air above the building.

9a.5.6.3 Sufficient ventilation of the interior of the IWMF buildings should be provided. Forced and natural ventilation should be introduced properly to enhance air exchange rate in the IWMF buildings. Regarding basement areas, pressurization by using a fan to blow air into the basement areas from outdoors is suggested. This would create enough pressure at the lowest level indoors to prevent radon from entering into the IWMF buildings.

9a.5.6.4 Regular maintenance should be provided for the floor slabs and walls. Cracks and other openings in the foundation should be properly sealed to reduce radon ingress. Sealing the cracks limits the flow of radon into the building thereby making other radon reduction techniques more effective and cost-efficient. It also reduces the loss of conditioned air.

9a.5.6.5 Prior to the occupation of the IWMF buildings and quarterly during the first year of operation of the IWMF, radon concentration shall be measured by professional persons in accordance with EPD's ProPECC Note PN 1/99 Control of Radon Concentration in New Buildings Appendix 2, "Protocol of Radon Measurement for Non-residential Building" to ensure the radon concentration is in compliance with the guidance value.

9a.6 Health Impacts Associated with other Potential Accidental Events

9a.6.1.1 The IWMF will be designed and operated as a modern facility. The operator must also be well trained to avoid any accidental events. The possible accidental events associated with health impacts and their corresponding preventive measures are listed in **Table 9a.14**

Table 9a.14 Potential Accidental Events and Preventive Measures

Risks	**Preventive Measures**
Aerial emissions (emission discharge exceed the discharge limit)	➢ Use of best available techniques in emission stack design, implement continuous and regular emission monitoring
Transportation, storage and handling	➢ Implement good waste/ash transportation, storage and handling practices (see **Section 9.4**) ➢ Plan transport routes to avoid highly populated / sensitive areas ➢ Develop procedures for and deploy as necessary emergency response including spill response for accidents involving transport vehicles ➢ Enforce strict driver skill standards and implement driver / navigator and road / marine safety behaviour training
Chemical spillage and leakage	➢ Implement proper chemicals and chemical wastes handling and storage procedures ➢ Develop and implement spill prevention and response plan including provision of spill response equipment and trained personnel
Employee health and safety	➢ Implement industry best practice with reference to international standards and guidelines

9a.6.1.2 To further avoid or minimize the potential health impacts associated with other potential accidental events, an emergency response plan should be developed and properly implemented for the IWMF. It should be noted that the emergency response plan should be specific to the final design and operation of the IWMF. With the implementation of the preventive measures outlined in **Table 9a.14** above and an effective emergency response plan for the IWMF, the health impacts associated with any potential accidental events could be minimized if not avoided.

9a.7 Conclusion

9a.7.1.1 The cancer risk arising from exposure to compounds of potential concern (COPCs) associated with the emissions of the IWMF is evaluated in this section. The highest cancer risk arising from the IWMF is predicted to be 1.26×10^{-6} and it is considered that the Project would not present an unacceptable risk and no further analysis is necessary. The highest predicted total Hazard Index (HI) at all receptors are well below 0.25, which is derived from a conservative approach. Cumulative acute non-carcinogenic health impact of the IWMF imposed to the worst impacted human receptors were assessed and compared with local and overseas guideline levels. It was concluded that the levels of non-carcinogenic chemicals were found to be insignificant when compared to the adopted/derived reference levels. For the classical COPCs of the HKAQO, while it is not possible to rule out adverse health effects from the IWMF with complete certainty, the impact on health from small additional air pollutants is likely to be very small and unlikely to be quantifiable.

9a.7.1.2 The compliance check of the maximum permitted concentration of certain metals present in foods due to the Project as stipulated in "Food Adulteration (Metallic Contamination) Regulations" by the Centre for Food Safety, a compliance check was conducted. The concentrations of Antimony, Arsenic, Cadmium, Chromium, Lead and Mercury at all receptors fall under the maximum permitted concentrations listed in the first and second schedules of the Regulations.

9a.7.1.3 Biogas will not be generated in the mechanical treatment process of the mechanical treatment plant. Potential health impact to the staff and nearby sensitive receivers due to biogas from sorting and recycling plant is therefore not expected.

9a.7.1.4 The existing practices of waste transportation will be followed. With regards to the storage and handling of waste and ash, given that all the reception halls and ash storage pits will be fully enclosed with slightly negative air pressure and closed grab will be use to grab waste and ash, leakage of any fugitive emissions to the outdoor environment is not expected. With the implementation of the recommended health risk control measures, the potential health impacts associated with the transportation, storage and handling of waste and ash are considered to be insignificant.

9a.7.1.5 The potential health risk induced by radon emissions associated with PFA arising from the construction and operation was also evaluated. The estimation indicated that there would be no significant radiological hazard to workers working in the IWMF or in the restored/operating ash lagoon area adjacent to the IWMF.

9a.7.1.6 The IWMF will be designed and operated as a modern facility. The operator must also be well trained to avoid any accidental events. The possible accidental events associated with health impacts and their corresponding preventive measures are identified. To further avoid or minimize the potential health impacts associated with other potential accidental events, an emergency response plan should be developed and properly implemented for the IWMF. It should be noted that the emergency response plan should be specific to the final design and operation of the IWMF. With the implementation of the recommended preventive measures and an effective emergency response plan for the IWMF, the health impacts associated with any potential accidental events could be minimized if not avoided.

9a.8 Reference

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