SLR

Trident Park Energy from Waste and Recycling Facility Cardiff

Human Health Risk Assessment

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WASTE MANAGEMENT

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APPENDICES

1.0 INTRODUCTION

1.1 Background

Guidance on 'Developing Health Impact Assessment in Wales' (National Assembly for Wales, 2000) emphasises the importance of assessing potential health impacts during policy and planning decisions. Health Impact Assessment (HIA) enables a judgement to be made as to whether a policy or development project has significant effects on the health of the potentially impacted population and also seeks to quantify the extent of predicted outcomes. SLR has undertaken a 'prospective HIA' to predict the potential consequences of the proposed Energy from Waste (EfW) facility at Trident Park, Cardiff using the best available tools and UK technical guidance.

HIA is a multi-faceted process and is described as comprising 5 main steps (National Assembly for Wales, 2000):

- *Screening* that determines whether a project is worth subjecting to HIA
- *Scoping* that identifies potential hazards (or benefits) and sets the terms of reference for the assessment process.
- *Risk Assessment* that involves characterising the nature and magnitude of health risks associated with a project
- *Decision making* involves considering the outcome of the risk assessment and the various options going forward.
- *Implementation and monitoring* involves actions to implement the decision(s) and to observe their consequences.

This exercise is concerned with the risk assessment stage and is dedicated to considering the nature and magnitude of potential health effects arising from the trace levels of persistent chemicals associated with particulate matter in stack emissions from the proposed Trident Park EfW.

1.2 Human Health Risk Assessment for Trident Park EfW

A Human Health Risk Assessment (HHRA) was undertaken in order to estimate the potential level of risk posed to health by emissions generated by operation of the proposed Trident Park EfW plant.

The objective of this assessment was to evaluate the potential risk for populations that may be exposed to emissions from the proposed EfW facility. The dominant source of emissions is assumed to be the discharge of residual combustion products from the stack. Compounds released in stack emissions are divided into two classes, these are:

1. Compounds that exist predominantly in the gaseous phase, e.g. SOx, NOx and other acid gases. The health effects of these compounds are due to exposure via the inhalation pathway and are most likely to be of an acute nature. Concentrations of these compounds in air are assessed by comparison to air quality standards. Fine particulate matter (i.e. particles with a mean aerodynamic diameter of <10 µm, i.e. PM_{10}) also induces health effects following inhalation and is assessed against an air quality standard.

2. Compounds that exist associated with the particulate phase, e.g. metals and non-volatile organic compounds such as dioxins. Exposure to these persistent

compounds will predominantly arise from indirect pathways following deposition of particles from the air; such pathways include ingestion of soil, dust and food grown in contaminated soil and to a lesser extent ingestion of foods, such as meat or milk, derived from animals that have grazed on pastures or fodder that has been contaminated by aerial deposition of dust containing pollutants.

Predominantly gaseous phase contaminants are considered in Technical Appendix 16 and this section of the report details a HHRA of the persistent contaminants predominantly associated with the particulate phase that may accumulate in the environment and therefore result in long term exposure. Potential exposure to these contaminants is evaluated for indirect pathways such as ingestion of soil and soil-derived dust and incorporation into the food chain.

This primary focus of this assessment of persistent contaminants is a screening exercise based on available UK guidance and models adapted to the purpose of a Human Health Risk Assessment (HHRA) for an EfW facility. The methodology is based on a worst-case scenario approach, using the maximum predicted contaminant concentrations in soil following deposition and assessing these levels against soil criteria that are protective of the most sensitive receptors within exposed populations.

2.0 METHODOLOGY

The principles of the assessment have largely been developed from environmental impact assessment (National Assembly for Wales, 2000). The human health risk assessment of Trident Park EfW has therefore been undertaken following the UK Risk Assessment Framework specified in the DETR (2000) publication 'Guidelines for Environmental Risk Assessment and Management' which is recommended for use in all public domain risk assessments. The UK Risk Assessment Framework is based on a tiered approach, where the level of complexity and effort/cost generally increases with each tier as conservatism and uncertainty decrease.

The common Risk Assessment Framework is summarised below

- Tier 1: Risk Screening - This is concerned with the development of an outline conceptual model and establishing whether there is any potential for unacceptable risks and a need for further assessment.
- Tier 2: Generic Quantitative Risk Assessment (GQRA) - This Tier uses the conceptual model and generic assessment criteria (GAC), if available, to identify potentially unacceptable risks.
- Tier 3: Detailed Quantitative Risk Assessment (DQRA) - This Tier involves site-specific risk assessment and more detailed consideration of receptor characteristics. This generally requires more complex risk modelling tools and the generation of more detailed data to characterise the site and receptors under consideration

A staged approach to HHRA for an EfW facility following this framework is presented below.

2.1 Tier 1: Risk Screening and Development of Conceptual Model

The risk assessment process utilises the source-pathway-receptor concept in the development of a conceptual site model and identifies sources of potential contaminants, receptors that could be at risk and the contaminant transport and exposure pathways that might result in direct or indirect exposure. A potential 'pollutant linkage', requiring further assessment, is identified where all three components are present. Information on a generic EfW scenario pertinent to qualitative risk assessment and the development of a conceptual site model is detailed below:

2.1.1 Source of hazard

The source of the hazard is the incineration of municipal solid waste, which results in combustion emissions from the EfW plant being released via a stack. The constituents of the stack emissions vary due to the composition of waste incinerated and the combustion process (residence time / temperature etc). Emission levels are defined by the Waste Incineration Directive (WID) which prescribes methodologies and standards in order to minimise effects on the environment and health; specifications include the following:

- operating conditions, including gas temperatures and residence times (e.g. 850ºC / 2 seconds);
- emission limit values for a range of substance to air and water including dioxins; and

- emission monitoring requirements.

2.1.2 Hazard

Stack emissions are potentially hazardous due to the discharge and dispersion of both gaseous phase and particulate contaminants that have properties hazardous to health, i.e. acid gases (NOx and SOx) that have acute respiratory effects and persistent pollutants such as metals and dioxins that have a range of chronic toxicological effects. Particulate contaminants of concern are those that are can enter into the lungs, and their classifications are based on their degree of penetration. Consequently air quality limits exist for particulate with a diameter of less than 10 microns known as PM_{10}, and a separate classification is also made for those particles with a diameter of less than 2.5 micrometers known as $PM_{2.5.}$

2.1.3 Transport mechanisms

The WID sets out emission limit values for emissions to air as detailed in Table 1; these emission limits would be set as Environmental Permit conditions by the Environment Agency as part of the permitting process.

Table 1
WID Emission Limit Values

Pollutant	Emission Limits (mg/Nm^3) [(a)]		
	Daily average values	Half hourly averages	
		100th Percentile	97th Percentile
Particles	10	30	10
TOC	10	20	10
HCl	10	60	10
HF	1	4	2
SO_2	50	200	50
NOx	200	400	200
CO (b)	50	150	100
Group 1 metals (c)	0.05		
Group 2 metals (d)	0.05		
Group 3 metals (e)	0.5		
Dioxins and furans	0.0000001 (f)		

Notes:

(a) Concentrations referenced to temperature 273 K, pressure 101.3 kPa, 11% oxygen, dry gas.

(b) 150 mg/Nm^3 of combustion gas for at least 95% of all measurements determined as 10 minute averages or 100 mg/Nm^3 of combustion gas of all measurements determined as half-hourly average values taken in any 24 hour period.

(c) Cadmium (Cd) and thallium (Tl)

(d) Mercury (Hg)

(e) Antimony (Sb), arsenic (As), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni), and vanadium (V).

(f). The emission limit value refers to the total concentration of dioxins and furans calculated using the concept of toxic equivalence (TEQ).

The transport of pollutants from the EfW stack into the surrounding environment occurs as a result of the dispersion and dilution of the stack plume as a result of meteorological conditions. The most important meteorological parameters governing the atmospheric dispersion of pollutants are as follows:

- wind direction determines the broad transport of the emission and the sector of the compass into which the emission is dispersed;
- wind speed will affect ground level concentrations of emissions by increasing the initial dilution of pollutants in the emission; and
- atmospheric stability, which is a measure of the turbulence, particularly of the vertical motions present. Advanced dispersion models use Monin-Obukhov lengths - a more advanced method of determining stability[1] than Pasquill.

2.1.4 Pathways

Atmospheric transport of gases and particulates is the main potential pathway for identified hazards reaching a nearby human receptor. Exposure to gaseous contaminants will occur by direct inhalation. Exposure to particulate phase contaminants will primarily occur via indirect pathways following deposition to soil; these pathways include ingestion of soil and soil-derived dust and uptake of contaminants from soil into the food-chain (via home-grown produce and crops).

2.1.5 Targets/receptors and exposure

License and discharge conditions for ERfWs are summarised in Table 1 previously. Down wind ‘receptor locations’ may include residential areas, schools, businesses, allotments and farms. The most sensitive human receptors are generally considered to be young children in residential areas and at school who may be exposed over long periods of time to low levels of combustion gases and particulates. This exposure is quantified in subsequent tiers of the risk assessment process.

2.1.6 Contaminants of concern

Emissions of dioxins, furans and metals are governed under the Waste Incineration Directive, which sets emission concentrations for 3 groups of metals and for total dioxin/furan releases. Classes of pollutants and individual contaminants specified by the WID are listed below:

[1] Defined as: ‘*the height over the ground, where mechanically produced (by vertical shear) turbulence is in balance with the dissipative effect of negative buoyancy, thus where Richardson number equals to 1*.’ Essentially it is a more quantitative method of estimating stability than the previously used Pasquill Stability Classes. It requires two quantities not routinely measured by national meteorological networks: the friction velocity *u* and flux of sensible heat *H*.

Table 2
Persistent Pollutants

Class	Pollutant
Group I metals	Cadmium
	Thallium
Group II metals	Mercury
Group III metals	Antimony
	Arsenic
	Chromium
	Cobalt
	Copper
	Lead
	Manganese
	Nickel
	Vanadium
Dioxins (PCDDs)	2,3,7,8-TCDD
	1,2,3,7,8-PeCDD
	1,2,3,4,7,8-HxCDD
	1,2,3,7,8,9-HxCDD
	1,2,3,6,7,8-HxCDD
	1,2,3,4,6,7,8-HpCDD
	OCDD
Furans (PCDFs)	2,3,7,8-TCDF
	1,2,3,7,8-PeCDF
	2,3,4,7,8-PeCDF
	1,2,3,4,7,8-HxCDF
	1,2,3,7,8,9-HxCDF
	1,2,3,6,7,8-HxCDF
	2,3,4,6,7,8-HxCDF
	1,2,3,4,6,7,8-HpCDF
	1,2,3,4,7,8,9-HpCDD
	OCDF

All contaminants from the list above are included in HHRA for EfW emissions with the exception of antimony, cobalt and manganese which are not considered by quantitative risk assessment due to their absence from the list of priority contaminants for land contamination published by Defra and the Environment Agency (2002c). Antimony and manganese are considered to possess only moderate toxicity while cobalt is thought to be of low toxicity. A toxicity equivalence (TEQ) approach was applied to the individual dioxins and furans which relates their toxicity to that of the most toxic and best studied compound, 2,3,7,8-TCDD.

Further details of the TEQ approach for dioxins and the de novo derivation of assessment criteria are provided in Appendix A.

2.2 Tier 2: Generic Quantitative Risk Assessment

Atmospheric concentrations of gaseous phase contaminants and particulate are assessed against published air quality objectives and standards (contained within the Air Quality Standard Regulations 2007). There is no specific UK technical guidance for the assessment of indirect exposure to particulate emissions from combustion processes or a modelling tool capable of assessing this scenario in compliance with UK approaches to human health risk assessment. The HHRA has therefore been undertaken using air dispersion modelling, the calculation of resultant soil concentrations following deposition of particulates over an extended time period and comparison of these concentrations to generic assessment criteria (GACs) based of the principles of the Contaminated Land Regime and associated technical guidance.

The Contaminated Land Regime has been developed to assess the health risks associated with different levels of contaminants in soil in order to make quantified assessment. Quantification is achieved using the CLEA model which has been produced by the Environment Agency to estimate exposure to contaminants in soil. CLEA has been used to derive the published soil guideline values (SGVs) that are available for a limited number of contaminants and the model can also be used to derive de novo assessment criteria that can also be used in generic quantitative risk assessment.

2.3 Tier 3: Detailed Quantitative Risk Assessment

Where the screening exercise indicates that exposure exceeds 50% of the assessment criteria, site-specific assessment is undertaken for specific receptor locations. DQRA entails the utilisation of more detailed data on contaminant transport and receptor characteristics. In addition to refinement of some of the assumptions used in deriving GACs it may also be necessary to use more complex exposure models that incorporate additional exposure pathways such as incorporation of persistent contaminants into the food chain.

3.0 HUMAN HEALTH RISK ASSESSMENT

As described above, HHRA for persistent contaminants in stack emissions from the proposed Trident Park EfW facility follows the UK Risk Assessment Framework and GQRA will compare predicted concentrations of contaminants in soil, following deposition of particulate matter and semi-volatile contaminants, to generic assessment criteria used in the health risk assessment of contaminated land. This assessment of indirect exposure following deposition of persistent contaminants is based on the methodology detailed by Macleod et al (2006) for modelling indirect human exposure to airborne air pollution control (APC) residues[2] released from landfills. The approach detailed by Macloed et al employs air dispersion modelling to estimate dust emissions and predict deposition at selected receptor locations.

3.1 Risk Screening and Development of Conceptual Model

The development of a conceptual site model (CSM) is the first stage of the risk assessment. The CSM identifies the potential sources, critical pathways and receptors relevant to HHRA for the Trident Park EfW.

For the purpose of the HHRA exhaust gases from the stack are assumed to be the only source of emission. Contaminants of concern are those described previously in Section 2.1.6.

The potential impact of the proposed plant was assessed over an area of 20km x 20km (SW corner NGR 310250, 165300) at a resolution of 250m. A more detailed 6km x 7km grid (SW corner NGR 316200, 173000) with a resolution of 100m was also located over Cardiff city. In addition discrete receptors e.g. schools and hospitals within 5km were also identified. The identified discrete receptors are listed in Technical Appendix 4-2 Table 4.18 and shown in Drawing 4/2

Sources, types of receptors, relevant pathways of exposure and their potential significance are detailed in Table 3 below.

Table 3
Conceptual Site Model

Sources	Gaseous and particulates emitted in exhaust gases from Trident Park EfW stack Acid gases, e.g. NOx and SOx Particulates (as $PM_{2.5}$ and PM_{10}) Persistent contaminants in vapour and particulate phase, e.g. metals and dioxins		
Receptors	**Receptor**	**Location**	**Risk**
	Resident	Children and adults in downwind residential properties	High
	Commercial	Workers in downwind commercial properties.	Medium
	Schools	Children and teachers in downwind schools	Medium-High
	Farmer	Downwind farms	Medium

[2] APC residues are the by-products from the cleaning up of flue gases from high temperature installations such as EfW plants; they comprise fine ash, lime and finely divided carbon used to clean exhaust gases.

Pathways	Pathway	Description	Risk
	Inhalation	Inhalation of gaseous contaminants	High
		Inhalation of vapour phase contaminants	
		Inhalation of particulates	
		Inhalation of airborne soil/dust following deposition	Low-Medium
	Incidental ingestion of soil/dust	Ingestion of soil and soil-derived dust, particularly by children	Medium-High
	Consumption of contaminated produce	Residents and allotment owners consuming produce grown in soil contaminated by wet and dry deposition. Assumes high proportion of food is home-grown	Medium
		Consumption of local fruit and vegetable crops affected by wet and dry deposition. This will be a variable proportion of diet	Low-Medium
	Consumption of contaminated meat and dairy products	Consumption of locally produced eggs, dairy and meat products following bioaccumulation, particularly of dioxins, in local food chain.	Medium-High
	Ingestion of maternal breast milk	Ingestion of breast milk by local babies of mothers exposed to dioxins via ingestion of soil and local/home-grown produce.	High
Pollutant linkages	Inhalation	Inhalation of exhaust gases and particulates is a direct pathway and will pose a greater risk closer to the facility. It is of most concern for the very young and old and those suffering from respiratory conditions. However, scrubbing and filtration measures in the stack will remove a significant proportion of the acid gases and particulates.	
	Ingestion of soil/dust	Ingestion of soil and soil-derived dust is an indirect pathway of particular concern for children who ingest the largest amounts. This pathway will be of greatest significance at the location of deposition hot-spots.	
	Consumption of contaminated produce	Ingestion of fruit and vegetable (home-grown and local produce) affected by deposition is a potentially significant indirect pathway but will be mitigated to some extent by rainfall and washing produce. CLEA UK model assumes root vegetables are unpeeled	
	Maternal breast milk	Indirect pathway of potential concern for local breast fed babies. Compounds such as dioxins can be stored in the fatty tissue of the mother following local exposure and released in breast milk. However, mother's exposure due to the EfW facility is likely to be insignificant compared to background intake from diet	
Overall risk assessment	**MEDIUM-HIGH**		

Dermal exposure through skin contact with contaminated soil is considered to be of low significance but is included in the risk assessment as it is an exposure pathway considered by the CLEA UK model. Dietary exposure from the consumption of home-grown plants that have taken up contaminants from soil is considered by the CLEA model based on soil:plant concentration factors for below and above ground crops (i.e. root vegetables and leafy vegetables). Plant uptake following wet and dry deposition to plant foliage is not considered by the CLEA UK model, nor are uptake of contaminants into herd animals following consumption of foliage affected by deposition and exposure of babies via breast milk. However, a number of conservative assumptions are built into the quantitative risk assessment, which will provide an indication of the relative magnitude of the risk posed by emissions from the EfW facility and DQRA will be triggered if predicted soil concentrations exceed 50% of GAC.

The approach detailed by Macloed et al (2006) employs air dispersion modelling to estimate dust emissions and predict deposition at selected receptor locations.

Similar to the assessment of particulates emitted from an EfW facility, key pollutant linkages identified by Macloed et al. were as follows:

i) Inhalation of airborne dust (containing metals and dioxins) by local residents and workers (characterised as potentially high risk)

ii) Incidental ingestion of soil/dust (containing metals and dioxins) by local residents and particularly children (characterised as potentially high risk)

iii) Ingestion of maternal breast milk (containing dioxins) by local breast-fed babies (characterised as potentially high risk)

iv) Consumption of contaminated produce (containing dioxins and metals) by local residents consuming home-grown produce such as fruit and vegetables (characterised as potentially medium risk)

v) Consumption of contaminated dairy and meat products (containing dioxins) by consumers of locally produced dairy and meat products (characterised as potentially high risk)

3.2 Generic Quantitative Risk Assessment

3.2.1 Methodology

GQRA for Trident Park EfW entails the comparison of predicted concentrations of contaminants in soil, following deposition of particulate matter and semi-volatile contaminants, to generic assessment criteria used in the health risk assessment of contaminated land.

GQRA for the Trident Park EfW follows the methodology described by Macloed et al (2006) in that soil concentrations resulting from wet and dry deposition of particulates and vapour are compared to generic assessment criteria for soil generated using the CLEA UK model. A number of assumptions in the methodology of Macleod et al (2006), which are also utilised in this assessment are summarised below:

i) It is assumed that particulate deposition occurs at a constant annual rate and that deposited dust is mixed evenly into the top 0.1m of soil;

ii) A 6-year deposition period is assumed with the concentration at the end of the sixth year being assumed to have been present from the start. This is a conservative assumption and consistent with the exposure duration used in the CLEA model to assess risks to children from exposure to soil contamination;

iii) Local onward mobilisation of contaminated dusts is assumed to be negligible compared to the primary flux to the receptor location and the relative contribution from other exposure pathways such as ingestion;

iv) The most sensitive receptor and standard land-use is considered to be a female child aged 0-6 in a residential setting with private garden and where the family consumes its own homegrown produce.

The 'CLEA' model used by Macloed et al. was replaced by the Environment Agency with the updated 'CLEA UK' model in October 2005. CLEA UK incorporated a number of modifications to CLEA but the two models are broadly similar and the basic principles are summarised below.

3.2.2 The CLEA UK Model

The CLEA UK model estimates the intake of contaminants from soil humans from various exposure pathways (Environment Agency, 2005). This is achieved by combining information about contaminant properties, soil, site and building characteristics, modelling approaches for predicting fate and transport of contaminants and information about receptor characteristics and behaviour. The estimated intake of a contaminant (average daily exposure or ADE) is compared with appropriate toxicological benchmarks (health criteria values or HCVs[3]) which are considered to be either tolerable or representative of minimal risk.

CLEA UK is a probabilistic model in that certain input parameters (such as bodyweight and amount of vegetables that are consumed) are represented by a range rather than a single value. UK policy is that the 95th percentile of the ADE is compared to the HCV as a basis for establishing generic assessment criteria (GAC).

GAC are derived for a set of standard of assumptions relating to land-use, receptor behaviour, site, building and soil characteristics and are used to assess whether the soil concentration of a particular contaminant poses a significant risk to human health resulting from a particular land use (e.g. 'residential' or 'commercial'). These values represent 'intervention values', which indicate to an assessor that soil contaminant concentrations above this level could pose an unacceptable risk to the health of site users and that further investigation and/or remediation is required.

Generic assessment criteria have been published by the Environment Agency and Defra for selected contaminants and these are known as soil guideline values (SGVs). SGVs combine both authoritative science and policy judgements. With the exception of lead, which uses another model, the published SGVs have been derived using the CLEA UK model.

For those contaminants for which published SGVs are not available SLR has generated GAC following the approaches recommended in CLR reports 9 & 10 (Defra & Environment Agency, 2002a,b) and associated material (e.g. CLEA briefing notes 1-4). Physico-chemical input parameters used to populate the CLEA UK model were selected from Environment Agency/Defra publications, where available, and authoritative data sources[4].

It should be noted that a number of exposure pathways relevant to this HIA cannot be assessed using the CLEA UK model; these include:

[3] For threshold effect contaminants a 'tolerable daily soil intake' (TDSI) is derived by subtracting 'mean daily intake' (MDI) derived from background intake from the prescribed 'tolerable daily intake' (TDI). For non-threshold effect contaminants an 'index dose' (ID) is specified that represents an acceptable level of lifetime risk from a specific source of exposure, i.e. background exposure is not taken into account.

[4] E.g. CRC Handbook of Chemistry and Physics, IUPAC-NIST Solubility Series and US Environmental Protection Agency.

- deposition of particulates on the leaves of fruit and vegetables
- secondary uptake into the food chain
- ingestion of breast milk by breast-fed babies

These pathways are potentially significant but would only be considered by DQRA if generic risk assessment indicated a potential risk from any of the contaminants (i.e. soil concentrations were greater than 50% of GAC).

Wet, dry and vapour deposition of contaminatns to soil is estimated using AEROMOD, a USEPA air dispersion model designed to predict pollutant concentrations from continuous point and area sources. This enables the concentrations of windblown particulates and contaminant concentrations at nearby human receptor locations to be estimated.

3.2.3 Site specific AEROMOD dispersion of particulates & semi-volatile contaminants

The methodology for the prediction of deposition rates for particulates and semi-volatile contaminants is presented in Section 3.2 of Technical Appendix 4-1. A summary of the calculated deposition rates in downwind receptor locations is provided below.

Table 4
Deposition rates predicted for Trident Park EfW

Class	Pollutant	Deposition (5 yr, µg/m2)		
		Average	Min	Max
Group I	Cadmium	1.9	0.060	15
	Thallium	1.9	0.060	15
Group II	Mercury (total)	26	5.3	470
	Hg(2+) vap	25	5.2	470
	Hg(0) vap	1.1×10^{-4}	3.0×10^{-5}	0.015
	Hg(0) partic	0.71	0.026	5.5
Group III	Antimony	4.5	0.17	34
	Arsenic	4.1	0.14	31
	Chromium	4.6	0.18	34
	Cobalt	4.1	0.14	31
	Copper	4.1	0.14	31
	Lead	4.1	0.14	31
	Manganese	4.8	0.23	35
	Nickel	4.5	0.17	34
	Vanadium	4.5	0.17	34
		Deposition (5 yr, pg TEQ/m^2)		
Dioxins	Dioxins (total)	6.6	0.57	52
	particulate	6.2	0.56	49
	2378 TCDD gas	0.46	0.0073	3.2
	2378 TCDF gas	0.0022	6.0×10^{-4}	0.42

Air dispersion modelling for predicted emissions from the Trident Park EfW indicates a variable rate of deposition for the downwind receptor locations that have been assessed due to variations in the meteorological data set over the 5 years used. A single value, the maximum deposition rate, is used in GQRA as a conservative worst case scenario. Deposition over a 6-year period was calculated for each contaminant for use in the HHRA as this is the exposure duration used in CLEA UK to assess risks to children from exposure to soil contamination. Calculation of worst case deposition over a six-year period is detailed below in Table 5.

Table 5.
Calculation of 6-year deposition rate

		Max Deposition (5 yr, µg/m2)	Deposition Rate (µg/m2/yr)	Max Deposition (6 yr, µg/m2)
Group I	Cadmium	14	2.9	17
	Thallium	14	2.9	17
Group II	Mercury (total)	470	94	560
Group III	Antimony	34	6.8	41
	Arsenic	31	6.2	37
	Chromium	34	6.8	41
	Cobalt	31	6.2	37
	Copper	31	6.2	37
	Lead	31	6.2	37
	Manganese	35	7	42
	Nickel	34	6.8	41
	Vanadium	34	6.8	41
Dioxins	Dioxins (total TEQ)	4.9×10^{-5}	9.8×10^{-6}	5.9×10^{-5}

3.3 Risk Characterisation

GQRA was undertaken by comparing the calculated soil concentration at the most impacted receptor location to generic assessment criteria (GAC) comprised of SGVs and in-house screening criteria derived by SLR using CLEA UK. For the purpose of a 'worst case scenario' HHRA the maximum deposition rate calculated for any specific receptor was selected for each contaminant.

Soil concentrations after 6 years were calculated by assuming that deposited particulate matter would be mixed evenly in the top 0.1m of the soil (density 1600 kg/m^3) and that there was no onward mobilisation of contaminated dusts or degradation of organic contaminants such as dioxins.

As described previously, for a worst case scenario, the critical receptor at the most impacted location is assumed to a female child aged 0-6 years of age; this is the most sensitive receptor specified for the HHRA of contaminated land in CLR 10 (Defra and Environment Agency, 2002b). Generic assessment criteria for soil that are protective of this receptor are compared to worst case soil concentration calculated for the most impacted location. Results of the generic risk assessment are presented in Table 6.

Table 6
Generic Quantitative Risk Assessment

Contaminant	Max Deposition (6 yr, µg/m2)	Conc in top 0.1m (mg/kg)	SGV/GAC (mg/kg)	Hazard quotient	Time to exceedance (year)
Cadmium	17	1.1×10^{-4}	1 (SGV 3)	1.1×10^{-4}	55,000
Thallium	17	1.1×10^{-4}	0.85 (SLR)	1.3×10^{-4}	50,000
Mercury (total)	564	3.5×10^{-3}	8 (SGV 5)	4.4×10^{-4}	14,000
Arsenic	37	2.3×10^{-4}	20 (SGV 1)	1.2×10^{-5}	520,000
Chromium	41	2.6×10^{-4}	130 (SGV 4)	2.0×10^{-6}	3,100,000
Copper	37	2.3×10^{-4}	220 (SLR)	1.1×10^{-6}	5,700,000
Lead	37	2.3×10^{-4}	450 (SGV 10)	5.2×10^{-7}	12,000,000
Nickel	41	2.6×10^{-4}	50 (SGV 7)	5.1×10^{-6}	1,200,000
Vanadium	41	2.6×10^{-4}	250 (SLR)	1.0×10^{-6}	5,900,000
Dioxins (total)	5.9×10^{-5} µg TEQ	3.7×10^{-10} mg TEQ/kg	2.6×10^{-5} (SLR)	1.4×10^{-5}	420,000

All predicted soil concentrations for the metals are extremely low and for all metals except mercury the calculated soil concentration is less than 1 µg/kg. These concentrations are considerably less than UK soil background concentrations (e.g. 10-30 mg/kg lead[5], 10 mg/kg arsenic[6], 0.12 mg/kg mercury[7]).

All estimated worst case concentrations of metals in soil resulting from the deposition of particulates in emissions from operation of the EfW facility are negligible in comparison with the relevant GAC, with hazard quotients (HQ = soil conc / GAC) ranging from 5.2×10^{-7} to 4.4×10^{-4}. These results indicate an absence of risk to human health from the deposition of metal contaminants and even based on the conservative assumptions in this risk assessment methodology it would be thousands of years before GAC were exceeded at the most impacted receptor location, much longer than the anticipated operational lifetime of the facility.

The dioxin concentration in soil at the receptor location with the highest deposition rate was calculated as 3.7×10^{-4} nq TEQ/kg which is considerably lower than typical concentrations of 1 to 100 nq TEQ/kg that have been measured in soil across Europe (EC/DETR, 1999). The maximum estimated concentration of dioxins in soil resulting from the deposition of particulates in emissions from operation of the EfW facility is also negligible in comparison with the GAC derived for 2,3,7,8-TCDD (HQ = 1.4×10^{-5}) which indicates an absence of health risk from this class of contaminants also.

[5] Macloed et al (2006)
[6] Defra and Environment Agency (2002d)
[7] SSLRC (2000)

4.0 CONCLUSIONS

A conceptual site model was constructed for the Trident Park Energy from Waste and Recycling Facility that identified the potential sources of pollution, receptors and relevant pathways of exposure. Exposure to persistent pollutants such as heavy metals and dioxins/furans was estimated from particulate phase and vapour deposition to soil.

A conservative worst scenario was developed for a screening exercise in which it was assumed that the most sensitive receptor, a young female child, was present at the site location receiving the highest deposition rates of the persistent contaminants. Predicted soil concentrations were compared to generic assessment criteria generated by the CLEA UK model, used to assess human health risks deriving from contaminated land

Results of quantitative risk assessment indicate that indirect, long-term exposure to all persistent contaminants emitted from the proposed EfW facility and subsequently deposited to soil does not pose a health risk to downwind receptors. This conclusion is deemed to be robust as it is based on a worst case scenario and there is a large margin of safety (>2000) between the highest predicted soil concentrations and soil assessment criteria that are protective of the most sensitive human receptors.

References

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Defra and Environment Agency (2002c) Potential Contaminants for the Assessment of Land. R&D Publication CLR 8.

Defra and Environment Agency (2002d) Soil Guideline Values for Arsenic Contamination, R&D Publication SGV1

Defra and Environment Agency (2002e) Soil Guideline Values for Cadmium Contamination, R&D Publication SGV3

Defra and Environment Agency (2002f) Soil Guideline Values for Chromium Contamination, R&D Publication SGV4

Defra and Environment Agency (2002g) Soil Guideline Values for Inorganic Mercury Contamination, R&D Publication SGV5

Defra and Environment Agency (2002h) Soil Guideline Values for Nickel Contamination, R&D Publication SGV7

Defra and Environment Agency (2002i) Soil Guideline Values for Lead Contamination, R&D Publication SGV10

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European Commission DG Environment and UK Department of the Environment,Transport and the Regions (1999) Compilation of EU Dioxin Exposure and Health Data: Task 2 – Environmental Levels. Ref. 97/322/3040/DEB/E1. Report produced for European Commission DG Environment and UK Department of the Environment, Transport and the Regions (DETR), October 1999

Macloed C, Duarte-Davidson R, Fisher B, Ng B, Wiley D, Shi JP, Martin I, Drew G, Pollard S (2006) Modeling human exposures to air pollution control (APC) residues released from landfills in England and Wales. Environment International, 32, 500-509

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SSLRC (2000) Comparison of Original and Re-sampled National Soil Inventory Data, Defra R&D Project SP0506, Final Report

APPENDIX A

Technical Data for HHRA Generic Assessment Criteria

VIRIDOR Trident Park Energy from Waste Project

APPENDIX A

Contaminants of Concern – Derivation of Generic Assessment Criteria

Where a published Soil Guideline Value (SGV) is not available for the contaminants of concern SLR has derived de novo Generic Assessment Criteria (GACs) to assess the risk from deposited particulate material. GACs have been derived using the beta version of the CLEA UK model (released by the Environment Agency in November 2005).

SLR GACs have been generated following the approaches recommended in CLR reports 9 & 10 (EA/Defra, 2002a,b) and associated material (CLEA briefing notes and CLEA UK Handbook) and are therefore based on health criteria values (HCVs) selected following the hierarchy of preferred sources described in CLR 9, detailed below:

1. Recommendations by authoritative bodies in the UK, e.g. reviews by the Committees on Toxicity, Mutagenicity and Carcinogencity of Chemicals in Food, Consumer Products and the Environment (COT, COM and COC)
2. Source documents produced by the European Commission's committees such as the Scientific Committee on Food (SCF) or Risk Assessment Reports (RARs) produced under Existing Substances Regulations
3. Guidelines such as tolerable daily intakes (TDIs) produced by international authoritative organisations such as the World Health Organisation's 'Guidelines for Drinking Water Quality'
4. Reports and guidelines prepared by other national organisations such as the USEPA's Integrated Risk Information System (IRIS)
5. Reports produced by authoritative organisations but for different purposes, e.g. oral TDIs or Index Doses may be derived using information obtained from air quality standards
6. Occupational exposure levels, considered on a case-by-case basis using expert judgement and appropriately extrapolated to protect the general public.

Physico-chemical input parameters for the CLEA UK model were selected from Environment Agency/Defra publications, where available, and authoritative data sources[1].

Generation of GACs for individual contaminants of concern and selection of the source data input to the CLEA model are detailed below. CLEA UK record sheets detailing the model input and output for calculation of the GACs are presented in Appendix B.

[1] For example, CRC Handbook of Chemistry and Physics, IUPAC-NIST Solubility Series and US Environmental Protection Agency databases.

1.0 THALLIUM

Thallium is an acute poison that can be lethal at low doses with effects on the gastrointestinal tract, cardiovascular and nervous systems. Long-term low dose exposure leads to similar but milder symptoms. The reproductive system appears to be susceptible to the toxic effects of thallium. Human toxicological data following long term low-level exposure are scarce as there are very few data on the effects of chronic occupational exposure to thallium.

The selected HCV for oral exposure (TDI_{oral}) is based on the USEPA oral reference dose (RfD) for thallium sulphate reported in IRIS[2]. The RfD is based on a 90-day study in rats which determined a no observed adverse effect level (NOAEL) of 0.25 mg/kg bw/day for increases in the incidence of alopecia, lacrimation and exophthalmos, together with increased serum aspartate aminotransferase, lactate dehydrogenase and sodium levels and decreased glucose levels. The RfD was derived by application of an uncertainty factor of 3000 (including 10 for subchronic to chronic extrapolation, 10 for intraspecies extrapolation, and 10 to account for species variability) plus a factor of 3 to account for lack of reproductive and chronic toxicity data. This gives an oral RfD of 8 $\times 10^{-5}$ mg/kg bw/day for thallium sulphate which is corrected to 6.5 $\times 10^{-5}$ mg/kg bw/day thallium as it assumed that thallium is responsible for the compound's observed toxicity.

The selected HCV for inhalation exposure (TDI_{inh}) is based on 1% of the Workplace Exposure Limit (WEL) of 0.1 mg/m^3 detailed in the 2007 Edition of HSE's EH40 document[3]. A TDI_{inh} of 3.0 x10^{-4} mg/kg bw/day is derived based on the assumption that a 70 kg adult inhales 20m^3 of air daily (Defra and Environment Agency, 2002a).

The main route of exposure to thallium is from food and an estimated mean daily intake (MDI) of thallium from food of 2 ug/day is reported in the HSDB profile of thallium compounds[4]. The same source reports an estimated daily thallium intake from air for a 70 kg adult of 3.4 ng.

HCVs, MDI and physico-chemical data input to the CLEA-UK model for thallium are detailed in Table 1 below with reference to the source of the data.

Table 1
CLEA UK input data – Thallium

Parameter	Value	Reference
TDI_{oral}	0.065 µg/kg bw/d	USEPA IRIS
TDI_{inh}	0.3 µg/kg bw/d	1% WEL (EH40, HSE 2007)
MDI_{oral}	2 µg/d	HSDB
MDI_{inh}	3.4 x10^{-3} µg/d	HSDB
Aqueous solubility	3.9 x10^{4} mg/L	WHO EHC 182[5]
Kd	19 L/kg	ATSDR, 1992[6]

[2] IRIS *Integrated risk assessment system, thallium sulfate*, US Environmental Protection Agency. Available [June 2008] at http://www.epa.gov/iris/subst/0111.htm

[3] http://www.hse.gov.uk/coshh/table1.pdf

[4] Hazardous Substances Data Bank [Thallium compounds] available June 2008 at http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB

[5] IPCS (1996) Thallium. Environmental Health Criteria Document No 182. International Programme on Chemical Safety, WHO, Geneva.

Parameter	Value	Reference
Dermal absorption factor	0.1	CLEA Briefing Note 1[7]
Soil:plant CF (leafy)	0.004	Baes et al. 1984[8]
Soil:plant CF (root)	0.004	Baes et al. 1984

The CLEA UK model calculates a generic assessment criteria of 0.85 mg/kg thallium in soil for a 'residential with plant uptake' exposure scenario. CLEA record sheets for calculation of the thallium GAC are provided in Appendix B.

[6] Kd for clay mineral. ATSDR (1992) Toxicological profile for thallium. Agency for Toxic Substances and Disease Registry, Atlanta

[7] CLEA Briefing Note 1. Update on the Dermal Exposure Pathway. Environment Agency, March 2004

[8] Baes CF III, Sharp RD, Sjoreen AL & Shor RW (1984) A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. ORNL-5786. Oak Ridge National Laboratory, Tennessee

2.0 COPPER

Copper is an essential element for humans and is considered to be only moderately toxic following oral exposure with the main effect being gastrointestinal disturbance. Copper may also induce allergic contact dermatitis in susceptible individuals following dermal contact.

The selected TDI_{oral} of 160 µg/kg bw/d is based on the 'safe upper level for daily consumption over a lifetime' recommended by the FSA Expert Group on Vitamins and Minerals (EVM, 2003)[9]. This was based on a 13 week rat study which observed a NOAEL of 16 mg/kg bw/day for damage to the fore-stomach, kidney and liver. An overall uncertainty factor of 100 was applied (10 each for both inter- and intra-species variability). The EVM stated that this was consistent with small scale human studies where up to 10 mg/day were without adverse effects.

The TDI_{inh} is based on 1% of the Workplace Exposure Limit (WEL) of 1 mg/m^3 (8 hr TWA for copper dust) detailed in the 2007 Edition of EH40[10]. A TDI_{inh} of 2.9 $x10^{-3}$ mg/kg bw/day is derived based on the assumption that a 70 kg adult inhales $20m^3$ of air daily.

MDI_{oral} of 3.4 mg/day is based on average exposure from food (1.4 md/day) and water (2 mg/day) described by the EVM and UK Drinking Water Inspectorate, respectively. An MDI_{inh} of 3.8 µg/d is based on an average suburban air level of 190 ng/m^3 in the USA in the 1970s detailed in HSDB[11], assuming that an adult inhales $20m^3$ of air daily.

HCVs, MDI and physico-chemical data input to the CLEA-UK model for copper are detailed in Table 2 below with reference to the source of the data.

Table 2
CLEA UK input data – Copper

Parameter	Value	Reference
TDI_{oral}	160 µg/kg bw/d	EVM, 2003
TDI_{inh}	2.9 µg/kg bw/d	1% WEL (EH40, HSE 2007)
MDI_{oral}	3400 µg/d	EVM (2003) & DWi (2007[12])
MDI_{inh}	3.8 µg/d	HSDB
Aqueous solubility	1.27 $x10^5$ mg/L	WHO[13] ($CuSO_4$ solubility)
Kd	2120 L/kg	RIVM 711701023[14]

[9] EVM (2003) Expert Group on Vitamins and Minerals, "Safe Upper Levels for Vitamins and Minerals", Food Standards Agency, May 2003, ISBN 1 904 026 11 7.

[10] http://www.hse.gov.uk/coshh/table1.pdf

[11] Hazardous Substances Data Bank [Copper compounds] available June 2008 at http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~aoLttv:2

[12] DWI (2008) Drinking Water 2007, The Drinking Water Inspectorate 17th Annual Report, http://www.dwi.gov.uk/pubs/annrep07/CIR07%20Drinking%20water%20in%20England%20and%20Wales.pdf

[13] WHO Guidelines for Drinking Water Quality (2004) Background document for copper, http://www.who.int/water_sanitation_health/dwq/chemicals/copper.pdf

[14] RIVM (2001) Technical Evaluation of the Intervention Values for Soil/Sediment and Groundwater. Netherlands National Institute of Public Health and the Environment. RIVM Report 711701 23

Parameter	Value	Reference
Dermal absorption factor	0.1	CLEA Briefing Note 1
Soil:plant CF (leafy)	0.4	Baes et al. 1984
Soil:plant CF (root)	0.4	Baes et al. 1984

The CLEA UK model calculates a generic assessment criteria of 220 mg/kg copper in soil for a ‘residential with plant uptake’ exposure scenario. CLEA record sheets for calculation of the copper GAC are provided in Appendix B.

3.0 VANADIUM

The key features of vanadium's hazard profile are respiratory toxicity following inhalation (in humans and animals) and bronchiolar/alveolar tumours following chronic exposure in rodents. Vanadium is less toxic by the oral route, with gastrointestinal disturbance reported in humans, and equivocal data on adverse effects on kidneys, spleen, lungs and blood pressure and reproductive/developmental toxicity in rats and mice. The evidence from the carcinogenicity and mutagenicity data suggests that if vanadium were regarded as a suspected human carcinogen, then it would be via a non-genotoxic mechanism and thus likely to have a threshold. It is therefore appropriate to set tolerable daily intakes (TDIs) for vanadium.

The selected TDI_{oral} for vanadium is based on the USEPA[15] RfD of 9 µg/kg bw/day for vanadium pentoxide (equivalent to 5 µg/kg bw/day vanadium). The RfD is based on the unpublished work of Stokinger *et al* (1953)[16] which established a NOAEL of 0.89 mg/kg bw/day for decreased hair cystine in rats. An uncertainty factor of 100 was applied (10 each for both intra- and inter-species variability) to derive the RfD of 9 µg/kg bw/day vanadium pentoxide. It should be noted that the USEPA has expressed low confidence in the RfD due to the lack of details in the reference study and the scarcity of data available on vanadium pentoxide. However, this is the only currently available guideline for long-term oral exposure to vanadium and is supported by the EFSA (2004) [17] observation that the lowest dose reported to cause adverse effects in humans is approximately 200 µg vanadium /kg bw/day.

The selected TDI_{inh} is derived from the air quality guideline of 1 µg/m^3 recommended by the WHO (2000)[18]. This air quality guideline is based upon consideration of long-term human occupational data that indicate a LOAEL of 20 µg/m^3 for chronic upper respiratory tract symptoms. As minimal adverse effects were observed on the upper respiratory tract at this level, a protection factor of 20 was chosen for environmental exposure. It was thought that exposure to vanadium at levels below 1 µg/m^3 was unlikely to have adverse health effects. Assuming that a 70 kg adult inhales about 20 m^3 of air daily, the WHO air quality guideline value equates to a TDI_{inh} of 0.3 µg/kg bw/day.

The EFSA (2004) stated that the intake of vanadium from normal food is estimated to be of the order of 10-20 µg/day and the upper value from this range (20 µg/day) is taken here as the mean daily intake from food in the UK. The IPCS (1988)[19] noted that vanadium concentrations in drinking water were generally less than 10 µg/L with an average of about 5 µg/L. An adult drinking 2 L daily would therefore ingest about 10

[15] USEPA (1996). Vanadium Pentoxide. United States Environmental Protection Agency. IRIS Database - Integrated Risk Information System. Viewed on-line at http://www.epa.gov/iris/subst/0125.htm [July 2008]

[16] Stokinger HE, Wagner WD, Mountain JT, Stocksill FR, Dobrogorski OJ and Keenan RG (1953). Unpublished results. Division of Occupational Health, Cincinnati, OH. (Cited in: Patty's Industrial Hygiene and Toxicology, 3rd ed., 1981, and described in USEPA, 1996).

[17] EFSA (2004) European Food Safety Authority. Opinion of the Scientific Panel on Dietetic Products, Nutrition and Allergies on a request from the Commission related to the Tolerable Upper Intake Level of Vanadium. The EFSA Journal **33** 1-22

[18] WHO (2000). World Health Organization. Air quality guidelines for Europe, Second Edition. WHO Regional Publications, European Series No.91. Copenhagen: WHO Regional Office for Europe.

[19] IPCS (1988) International Programme on Chemical Safety. Vanadium, Environmental Health Criteria 81. World Health Organization, Geneva.

μg of vanadium via drinking water. The mean daily intake for an adult from food and water combined is therefore about 30 μg.

Recent air quality results for the UK indicate that values in central London have fallen from 20 ng/m^3 in 1980/81 to 4 ng/m^3 in 2002 (Defra, 2004)[20]; levels in other UK cities range from 1-3 ng/m^3. A 70 kg adult inhaling 20 m^3 daily at the current level in central London would therefore have a daily inhalation intake of vanadium of about 80 ng.

HCVs, MDI and physico-chemical data input to the CLEA-UK model for vanadium are detailed in Table 3 below with references to the source of the data.

Table 3
CLEA UK input data – Vanadium

Parameter	Value	Reference
TDI_{oral}	5 µg/kg bw/d	USEPA IRIS
TDI_{inh}	0.29 µg/kg bw/d	WHO (2000)
MDI_{oral}	30 µg/d	EFSA (2004) & IPCS (1988)
MDI_{inh}	0.08 µg/d	Defra (2004)
Aqueous solubility	8.82 $x10^5$ mg/L	IPCS CICAD[21]
Kd	1000 L/kg	USEPA EcoSSL[22]
Dermal absorption factor	0.1	CLEA Briefing Note 1
Soil:plant CF (leafy)	0.00485	USEPA EcoSSL
Soil:plant CF (root)	0.00485	USEPA EcoSSL

The CLEA UK model calculates a generic assessment criteria of 250 mg/kg vanadium in soil for a 'residential with plant uptake' exposure scenario. CLEA record sheets for calculation of the vanadium GAC are provided in Appendix B.

[20] Defra (2004). Department for Environment, Food and Rural Affairs. E-Digest of Environmental Statistics. Available on-line at http://www.defra.gov.uk/environment/statistics/index.htm, September 2004.

[21] IPCS (2001) Vanadium Pentoxide and Other Inorganic Vanadium Compounds (Concise International Chemical Assessment Document 29), World Health Organisation, Geneva, Switzerland

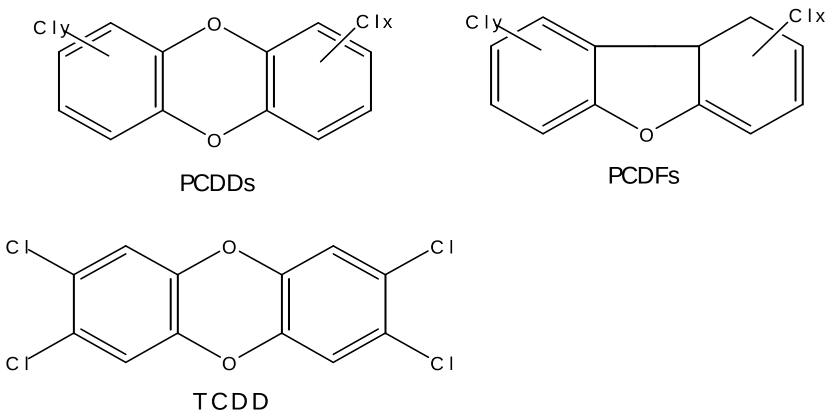
[22] USEPA (2007) Guidance for Developing Ecological Soil Screening Levels (Eco-SSLs), Attachment 4-1.Viewed at http://www.epa.gov/ecotox/ecossl/pdf/ecossl_attachment_4-1.pdf July 2008

4.0 DIOXINS

Dioxins are chlorinated compounds generated as by-products of waste combustion and as trace contaminants during the synthesis of many organochlorine compounds. The compounds referred to here as dioxins are restricted to those having a structure and toxicity related to that of the parent compound, 2,3,7,8-tetrachloro-para-dibenzodioxin (TCDD), which is commonly known as dioxin. Polychloro-p-dibenzodioxins (PCDDs), such as TCDD, have the structure of two oxygen atoms combined with two chlorobenzene rings or a chlorobenzene and a benzene ring. Polychlorodibenzofurans (PCDFs, commonly known as furans) are related compounds and have one oxygen atom combined with two benzene rings. The presence of four chlorine atoms at positions, 2,3,7 and 8 appears to be responsible for the observed dioxin-like toxicity.

The structural formula of TCDD and representative structures of PCDDs and PCDFs are shown in Figure 1.

Figure 1. Representative structures of PCDDs and PCDFs and the structural formula of TCDD.



Dioxins have been demonstrated to accumulate and be very persistent in the human body, with measured half-lives of up to 11 years. Extensive research has demonstrated that dioxin and dioxin-like compounds can cause a diverse array of toxic effects in animal systems, including disruption of the reproductive and immune systems, developmental effects such as birth defects and altered sexual development and cancer. Although many of these effects have not been seen in humans, it appears that dioxins do increase the risk of cancer in exposed individuals, but much remains unknown about the health effects of these compounds.

The TEF approach

Studies in animals have indicated that the effects of dioxin and dioxin-like compounds are mediated by a specific cytoplasmic receptor protein, the Ah receptor. The 2,3,7,8-TCDD or dioxin molecule has the greatest affinity for the Ah receptor and is therefore considered to be the most potent synthetic Ah receptor ligand. All other dioxin-like compounds with effects mediated by the same receptor protein, albeit with lower potency, are considered to be functionally equivalent to dioxin hence the term 'dioxin-like'; their potencies relative to TCDD can be characterised by Toxic Equivalency Factors (TEFs).

The TEF values calculated for a single congener can vary by several orders of magnitude depending on species, tissue, and the model chosen. Nevertheless, because of the potential value of the TEF approach in simplifying calculations of the risk associated with measured concentrations of these compounds in the environment and in human tissue, the WHO European Centre for Environment and Health and the International Program on Chemical Safety have developed a set of criteria for TEF calculations for the relevant PCDD, PCDF and PCB congeners (Van den Berg *et al*., 2006)[23]. These TEFs have been endorsed by most international bodies concerned with environmental health and safety and are recommended for use by the UK Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT). The potential dioxin-like activity contributed by each congener is determined by multiplying the concentration of the congener by its WHO-designated TEF to yield the dioxin toxic equivalent (TEQ) for that congener. The net TEQ is the sum of the individual TEQs for each dioxin or dioxin-like compound.

WHO TEFs for dioxins and furans are detailed in Table 4 below.

Table 4
WHO TEFs for Dioxins (Van den Berg et al, 2006)

	Congener	WHO TEF
Dioxins (PCDDs)	2,3,7,8-TCDD	1
	1,2,3,7,8-PeCDD	1
	1,2,3,4,7,8-HxCDD	0.1
	1,2,3,7,8,9-HxCDD	0.1
	1,2,3,6,7,8-HxCDD	0.1
	1,2,3,4,6,7,8-HpCDD	0.01
	OCDD	0.0003
Furans (PCDFs)	2,3,7,8-TCDF	0.1
	1,2,3,7,8-PeCDF	0.03
	2,3,4,7,8-PeCDF	0.3
	1,2,3,4,7,8-HxCDF	0.1
	1,2,3,7,8,9-HxCDF	0.1
	1,2,3,6,7,8-HxCDF	0.1
	2,3,4,6,7,8-HxCDF	0.1
	1,2,3,4,6,7,8-HpCDF	0.01
	1,2,3,4,7,8,9-HpCDD	0.01
	OCDF	0.0003

The published Defra/EA toxicological report for contaminated land assessment (TOX 12, Defra/EA 2003)[24] contains recommendations for oral daily intake of dioxins and

[23] Van den Berg M et al (2006) The 2005 World Health Organization Re-evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Toxicological Sciences Advance Access, July 2006.

[24] Defra and Environment Agency (2003) Contaminants in Soil: Collation of Toxicological Data and Intake Values for Humans. Dioxins, Furans and Dioxin-like PCBs. R&D Publication TOX12

dioxin-like compounds and these are: TDI_{oral} 2 pg/kg bw/day; MDI_{oral} 126 pg/day. Intake via inhalation is assumed to be negligible in comparison to oral intake and no expert group has derived an inhalation or dermal TDI for dioxins or dioxin-like compounds.

HCVs, MDI and physico-chemical data input to the CLEA-UK model for derivation of a GAC for 2,3,7,8-TCDD (TEF = 1 and therefore applicable to overall dioxin TEQ concentrations) are detailed in Table 5 below with reference to the source of the data.

Table 5
CLEA UK input data – 2,3,7,8 TCDD

Parameter	Value	Reference
TDI_{oral}	2.0 $\times 10^{-6}$ µg/kg bw/d	TOX 12 (Defra/EA, 2003)
TDI_{inh}	-	
MDI_{oral}	1.26 $\times 10^{-4}$ µg/d	TOX 12 (Defra/EA, 2003)
MDI_{inh}	-	
Henrys Law constant	1.35 $\times 10^{-3}$	Lancaster Uni Database[25]
Air diffusion coefficient	1.0 $\times 10^{-6}$ m^2/s	Generic low value
Water diffusion coefficient	1.0 $\times 10^{-10}$ m^2/s	Generic low value
Vapour pressure	2.5 $\times 10^{-7}$ Pa	Lancaster Uni Database
Aqueous solubility	2.0 $\times 10^{-4}$ mg/L	SRC PhysProp Database[26]
Koc	6.66	Lancaster Uni Database
Kd	6.8	Lancaster Uni Database
Relative molecular mass	322	SRC PhysProp Database
Dermal absorption factor	0.1	CLEA Briefing Note 1
Soil:plant CF (leafy)	2.7 $\times 10^{-3}$	PCDD/Fs, Rideout & Teschke (2004)[27]
Soil:plant CF (root)	4.2 $\times 10^{-3}$	PCDD/Fs, Rideout & Teschke (2004)

The CLEA UK model calculates a generic assessment criteria of 2.6 $\times 10^{-5}$ mg/kg dioxin TEQ in soil for a 'residential with plant uptake' exposure scenario. CLEA record sheets for calculation of the dioxin GAC are provided in Appendix B.

[25] Lancaster University Research Database. Polychlorinated Dibenzo Dioxins and Furans (PCDD/Fs). Viewed online at http://www.lec.lancs.ac.uk/ccm/research/database/4.html July 2008

[26] SRC PhysProp Database[2,3,7,8-Tetrachlorodibenzo-p-dioxin] Viewed online at http://esc.syrres.com/interkow/webprop.exe?CAS=1746-01-6 July 2008

[27] Rideout K & Teschke K (2004) Potential for increased human food-borne exposure to PCDD/F when recycling sewage sludge on agricultural land. Environmental Health Perspectives 2004;112:959-969

APPENDIX B

CLEA UK Record Sheets

CLEA UK MODEL 2005 VERSION Version 1.0

Simulation Date:	05/08/2008
Type of simulation:	Generic

Company Name:	SLR Consulting
Person running Simulation:	ES
Contact Number:	01484 860521
Site Name:	HIA GACs
Site Address:	Generic

Chemical	HCV_{oral} compared with which exposure route/s?			HCV_{inhal} compared with which exposure route/s?			Assessment Criteria (mg.kg^{-1})					Site Specific Soil Concentration (mg.kg^{-1} dry weight soil)	ADE/HCV (dimensionless)	
	oral	dermal	inhal	oral	dermal	inhal	oral & dermal (using HCV_{oral})	20% rule applied?	inhalation (using $HCV_{inhalation}$)	20% rule applied?	integrated		oral & dermal	inhalation
2,3,7,8-TCDD	Yes	Yes	No	No	No	No	2.62E-05	Yes		Yes			1.00E+00	
Copper_SLR	Yes	Yes	No	No	No	Yes	2.16E+02	Yes	4.57E+05	Yes	2.16E+02		1.00E+00	1.00E+00
Thallium_SLR	Yes	Yes	No	No	No	Yes	8.51E-01	Yes	2.83E+05	Yes	8.51E-01		1.00E+00	1.00E+00
Vanadium_SLR	Yes	Yes	No	No	No	Yes	2.56E+02	No	2.27E+05	No	2.56E+02		1.00E+00	1.00E+00

Land-use selected:	residential with plant uptake

	Land-use Parameters	Age Class 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Exposure Frequency ($day.yr^{-1}$)	direct soil and dust ingestion	1.80E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02												
	consumption of home grown produce	2.50E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02												
	consumption of soil attached to home grown produce	2.50E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02												
	skin contact, indoors	1.80E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02												
	skin contact, outdoors	6.50E+01	1.30E+02	1.30E+02	1.30E+02	1.30E+02	1.30E+02												
	inhalation of dust and vapours, indoors	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02												
	inhalation of dust and vapours, outdoors	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02	3.65E+02												
Respiration Frequency ($hr.day^{-1}$)	active, indoors	2.00E+00	3.00E+00	3.00E+00	3.00E+00	3.00E+00	2.00E+00												
	active, outdoors	1.00E+00	2.00E+00	2.00E+00	3.00E+00	3.00E+00	2.00E+00												
	passive, indoors	2.00E+01	1.80E+01	1.80E+01	1.80E+01	1.80E+01	1.60E+01												
	passive, outdoors	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00												
Soil Ingestion Rate (mg.day-1)	soil ingestion rate	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated												
Soil-skin adherence factor ($mg.cm^{2}$)	indoor	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02												
	outdoor	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00												
Exposed skin fraction (dimensionless)	indoor maximum exposed skin fraction	3.20E-01	3.30E-01	3.20E-01	3.50E-01	3.50E-01	3.30E-01												
	outdoor maximum exposed skin fraction	2.60E-01	2.60E-01	2.50E-01	2.80E-01	2.80E-01	2.60E-01												

Receptor selected:	female (UK)

Start Age Class	End Age Class	Exposure duration (years)	Averaging Time (years)
1	6	6	6

BUILDING PARAMETERS

Building type selected:	Residential - typical house

Building Parameters	Units	Input Value
height of living/working space above ground	cm	4.80E+02
height of cellar space below ground	cm	0.00E+00
enclosed space floor length	cm	6.40E+02
enclosed space floor width	cm	6.40E+02
foundation or slab thickness	cm	1.50E+01
living/working space air exchange rate	hr^{-1}	5.00E-01
pressure differential between soil and enclosed space	$g.cm^{-2}$	3.00E+01
floor-wall seam crack width	cm	2.00E-01
fixed crack to total area ratio	unitless	1.25E-03
volumetric flow rate of soil gas entering the building	$cm3.s^{-1}$	3.95E+01
volumetric building ventilation rate from indoor to outdoor air	cm3.s-1	2.73E+04

SOIL CHARACTERISTICS

Soil type selected:	sandy - UK

Soil parameter	Units	Input value
grainsize	cm	5.00E-02
total porosity	cm^3 cm^{-3}	4.60E-01
air-filled porosity	cm^3 cm^{-3}	3.10E-01
water-filled porosity	cm^3 cm^{-3}	1.50E-01
dry bulk density	g cm^{-3}	1.60E+00
enrichment factor	dimensionless	6.00E+00
soil pH	dimensionless	7.00E+00
fraction of organic carbon	dimensionless	5.80E-03
van Genuchten shape parameter	dimensionless	3.47E-01
residual water content	cm^3 cm^{-3}	3.00E-02
saturated hydraulic conductivity	$cm.s^{-1}$	6.47E-03
ambient soil/water temperature	K	2.83E+02
intrinsic soil permeability	cm^2	8.63E-08

SITE PARAMETERS

Site Parameter	Units	Input Value
Area of source-zone	cm^2	2.25E+06
Depth below ground to source zone	cm	1.15E+02
Equivalent threshold wind speed (7m)	$m.s^{-1}$	1.13E+01
Fraction of soil in building dust	dimensionless	7.50E-01
Fraction of the site with hard or vegetative cover	dimensionless	5.00E-01
Mean annual windspeed (10m)	$m.s^{-1}$	4.69E+00
Normalised annual average concentration of dust particles	$kg.m^{-3}$ per $g.m^{-2}.s^{-1}$	1.10E-02
Tracked back soil adjustment factor	dimensionless	1.00E+00
Width of contaminated zone in direction of prevailing wind	cm	1.50E+03
Wind speed distribution function	dimensionless	1.94E-01
Wind speed in mixing zone (1-2m)	$m.s^{-1}$	3.00E+00

Exposure Pathways

	Oral						Dermal				Inhalation														background exposure (oral)	background exposure (inhalation)
	direct soil and soil derived indoor dust Ingestion		consumption of site-grown vegetables		consumption of soil attached to site-grown vegetables		skin contact with soil-derived indoor dust		skin contact with soil		inhalation of soil derived indoor dust		inhalation of soil dust		inhalation of vapours indoors		inhalation of vapours outdoors		vapour model calculated values		dispersion factor for ambient air				
Chemical	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	ADE % Contribution	ADE Mean (ug.kg-1 bw.day-1)	soil air diffusion coefficient (cm2.s-1)	soil-vapour to indoor air attenuation coefficient (dimensionless)	young child (cm.s-1)	older child (cm.s-1)	adult (cm.s-1)	ADE Mean (ug.kg-1 bw.day-1)	ADE Mean (ug.kg-1 bw.day-1)
2,3,7,8-TCDD	7.05E+01	1.76E-07	8.51E+00	2.13E-08	5.91E+00	1.48E-08	2.07E+00	5.18E-09	1.30E+01	3.26E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.63E-04	1.31E-04	8.10E+00	N/A	N/A	0.00E+00	0.00E+00
Copper_SLR	7.40E+00	1.45E+00	9.04E+01	1.77E+01	6.20E-01	1.22E-01	2.18E-01	4.27E-02	1.37E+00	2.68E-01	1.04E-03	2.05E-04	3.53E-04	6.92E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.10E+00	N/A	N/A	0.00E+00	0.00E+00
Thallium_SLR	7.04E+01	5.73E-03	8.60E+00	6.99E-04	5.90E+00	4.80E-04	2.07E+00	1.68E-04	1.30E+01	1.06E-03	1.66E-03	1.35E-07	5.60E-04	4.55E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.10E+00	N/A	N/A	0.00E+00	0.00E+00
Vanadium_SLR	6.91E+01	1.72E+00	1.02E+01	2.55E-01	5.79E+00	1.44E-01	2.03E+00	5.06E-02	1.28E+01	3.18E-01	9.75E-03	2.43E-04	3.30E-03	8.20E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.10E+00	N/A	N/A	1.04E+00	1.99E-03

HEALTH CRITERIA VALUES

Chemical	TDI (ug.kg-1 bw.day-1)		ID (ug.kg-1 bw.day-1)		MDI (µg day-1)	
	oral	inhalation	oral	inhalation	oral	inhalation
2,3,7,8-TCDD	4.00E-07	2.00E-01	none	none	0.00E+00	0.00E+00
Copper_SLR	3.20E+01	5.80E-01	none	none	0.00E+00	0.00E+00
Thallium_SLR	1.30E-02	6.00E-02	none	none	0.00E+00	0.00E+00
Vanadium_SLR	5.00E+00	2.90E-01	none	none	3.00E+01	8.00E-02

PHYSICO-CHEMICAL PROPERTIES

Chemical	Henry's Law Constant (dimensionless)	Reference Temperature (K)	Henry's Law Constant (atm.m3.mol^{-1})	Reference Temperature (K)	Henry's Law Constant at ambient temperature (dimensionless)	Enthalpy of vaporisation at boiling point (cal.mol^{-1})	Boiling Point (K)	Critical Temperature (K)	Air diffusion coefficient (m2.s^{-1})	Water diffusion coefficient (m2.s^{-1})	Relative atomic (molecular) mass (g - mol)	Vapour pressure at 10°C (Pa)	Aqueous solubility at 10°C (mg.L^{-1})	organic carbon - water distribution coefficient, log K_{oc} (log(cm^3-water.g^{-1} oc)	octanol-water distribution coefficient log, log K_{ow} (dimensionless)	soil-water distribution coefficient, K_d (cm^3 - water.g^{-1} - soil)	Total soil concentration to pore water concentration ratio (cm^3-water.g-soil)	dermal absorption fraction (dimensionless)	Type of soil-to-plant concentration factor, dry or fresh weight? (leafy) (dimensionless)	Type of soil-to-plant concentration factor, dry or fresh weight? (root) (dimensionless)	soil-to-plant concentration factor (leafy) (ug.g^{-1} FW plant over ug.cm^3 soil solution)	soil-to-plant concentration factor (root) (ug.g^{-1} FW plant over ug.cm^3 soil solution)	dust Enrichment Factors used?
2,3,7,8-TCDD	3.34E+00	2.98E+02	3.34E+00	2.98E+02	1.35E-03	N/A	7.20E+02	N/A	1.00E-06	1.00E-10	3.22E+02	2.50E-07	2.00E-04	6.66E+00	6.80E+00	2.65E+04	2.65E+04	1.00E-01	dw	dw	2.70E-03	4.20E-03	Yes
Copper_SLR	N/A	N/A	N/A	N/A	0.00E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.27E+05	N/A	N/A	2.12E+03	2.12E+03	1.00E-01	dw	dw	4.00E-01	4.00E-01	Yes
Thallium_SLR	N/A	N/A	N/A	N/A	0.00E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.94E+04	N/A	N/A	1.90E+01	1.90E+01	1.00E-01	dw	dw	4.00E-03	4.00E-03	No
Vanadium_SLR	N/A	N/A	N/A	N/A	0.00E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.82E+04	N/A	N/A	1.00E+03	1.00E+03	1.00E-01	dw	dw	4.85E-03	4.85E-03	Yes

MEDIA CONCENTRATIONS

	Distribution of chemical in soil							Distribution in Non-soil Media												Boundary Limits					
	$mg.g^{-1}$				%			mg.m-3 - air						mg.g-1 FW plant matter						$mg.L^{-1}$	$mg.L^{-1}$		$mg.m^{-3}$	$mg.m^{-3}$	
Chemical	total soil concentration	sorbed concentration	dissolved concentration	vapour concentration	sorbed concentration	dissolved concentration	vapour concentration	indoor vapour air concentration	outdoor vapour air concentration for Young Child	outdoor vapour air concentration for Older Child	outdoor vapour air concentration for Adults	outdoor dust air concentration	indoor dust air concentration	concentration in Brussels sprouts	concentration in cabbage	concentration in carrot	concentration in leafy salad	concentration in onion, leek, shallots	concentration in potatoes	pore water concentration	maximum aqueous solubility	% max	ambient source vapour concentration	saturated source vapour concentration	% max
2,3,7,8-TCDD	2.62E-08	2.62E-08	9.26E-14	2.58E-16	1.00E+02	3.54E-04	9.87E-07	1.75E-13	1.23E-15	N/A	N/A	1.99E-14	1.49E-14	6.72E-12	8.91E-12	1.07E-11	2.83E-12	1.72E-11	2.31E-11	9.88E-10	2.00E-04	4.94E-04	1.33E-09	3.42E-05	3.90E-03
Copper_SLR	2.16E-01	2.16E-01	9.54E-06	0.00E+00	1.00E+02	4.42E-03	0.00E+00	0.00E+00	0.00E+00	N/A	N/A	1.64E-07	1.23E-07	8.19E-03	1.09E-02	8.37E-03	3.45E-03	1.35E-02	1.81E-02	1.02E-01	1.27E+05	8.01E-05	0.00E+00	0.00E+00	N/A
Thallium_SLR	8.51E-04	8.51E-04	4.20E-06	0.00E+00	1.00E+02	4.93E-01	0.00E+00	0.00E+00	0.00E+00	N/A	N/A	6.46E-10	4.84E-10	3.23E-07	4.29E-07	3.30E-07	1.36E-07	5.31E-07	7.15E-07	4.48E-02	3.94E+04	1.14E-04	0.00E+00	0.00E+00	N/A
Vanadium_SLR	2.56E-01	2.56E-01	2.40E-05	0.00E+00	1.00E+02	9.38E-03	0.00E+00	0.00E+00	0.00E+00	N/A	N/A	1.94E-07	1.45E-07	1.18E-04	1.56E-04	1.20E-04	4.96E-05	1.93E-04	2.60E-04	2.56E-01	8.82E+04	2.90E-04	0.00E+00	0.00E+00	N/A