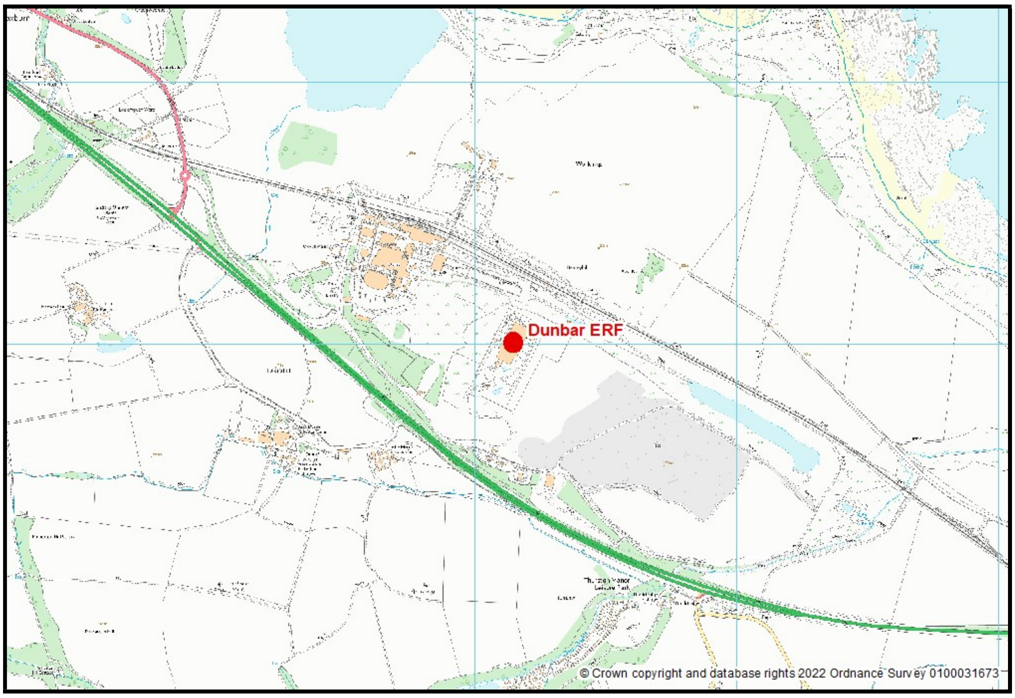
Viridor

Dunbar Energy Recovery Facility

Human Health Risk Assessment



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AIR

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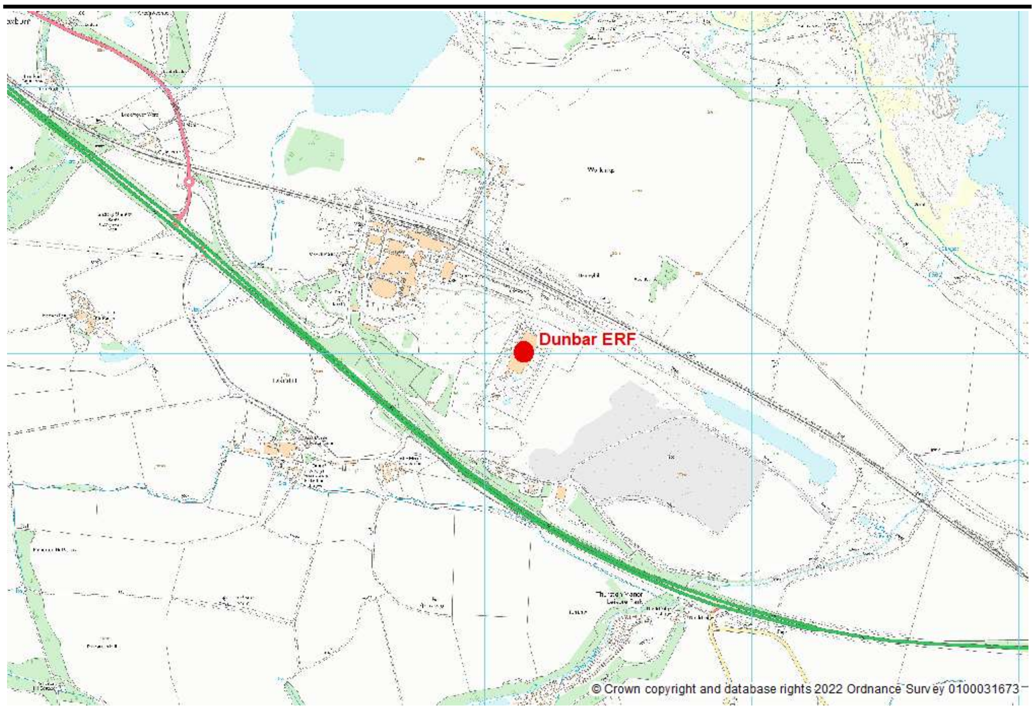
1 INTRODUCTION

1.1 BACKGROUND

Gair Consulting Ltd has been commissioned, on behalf of Viridor Dunbar Waste Services Limited (Viridor), by RPS to undertake an assessment to consider the effects on human exposure from emissions to air from the Dunbar Energy Recovery Facility (ERF) to the southeast of Dunbar in Scotland. The location of the ERF is presented in *Figure 1.1*.

FIGURE 1.1 LOCATION OF THE DUNBAR ERF



Viridor is seeking to increase the plant performance, which will increase the flue gas flow rate. This report details the revised human health risk assessment (HHRA) taking into account the relevant changes due to the increased plant performance.

This HHRA supplements the air quality assessment provided for the proposed changes at the ERF. The HHRA only considers emissions to air as human exposure to any harmful pollutants discharged directly to the aquatic environment and from solid waste disposal is considered to be negligible.

The area surrounding the installation is dominated by agricultural land to the south, the Tarmac Cement Works to the northwest and mineral workings to the north and east. The nearest densely populated area is the south-eastern edge of Dunbar to the northwest of the installation.

An air quality assessment of emissions from the installation has been provided by RPS [1]. The air quality assessment provides a comparison of predicted concentrations of pollutants at off-site locations with background air quality and air quality standards and guidelines for the protection of human health.

The emissions from the ERF would contain a number of substances that cannot be evaluated in terms of their effects on human health simply by reference to ambient air quality standards. Health effects could occur through exposure routes other than purely inhalation. As such, an assessment needs to be made of the overall human *exposure* to the substances by the local population and then the *risk* that this exposure causes.

1.2 PURPOSE OF THE ASSESSMENT

This assessment has been undertaken to support an application to vary the Pollution Prevention and Control (PPC) permit for the ERF. It is a human health risk assessment of emissions from the installation using a scope and methodology for the assessment that has been agreed with the Scottish Environmental Protection Agency (SEPA). As a consequence, the following have been included in the assessment.

- Exposure to dioxins, furans and dioxin-like polychlorinated biphenyls (PCBs).
- Predicted concentrations of arsenic (As), nickel (Ni) and cadmium (Cd) in soil with a comparison of concentrations with soil guideline values (SGVs).
- Direct and indirect exposure to antimony (Sb), arsenic, cadmium, chromium (Cr), lead (Pb), mercury (Hg), nickel, benzene and benzo(a)pyrene (BaP).
- A sensitivity analysis using the US EPA AERMOD model for comparison with the UK ADMS model results.
- Cumulative impacts with the adjacent Tarmac Cement Works.

Human exposure to dioxins and furans has been compared against the Committee of Toxicity (COT) Tolerable Daily Intake (TDI) of 2 pg/kg per day. An assessment of exposure to dioxin-like PCBs has also been included. It should be noted that the former Her Majesty's Inspectorate of Pollution (HMIP) method does not have the capability to consider dioxin-like PCBs and the US EPA HHRAP method is limited in this respect. The HHRAP method does not contain physical properties or exposure parameters for individual dioxin-like PCBs but does provide information for two dioxin-like PCB mixtures (Aroclor 1016 and Aroclor 1254). Therefore, for these two substances typical emissions for dioxin-like PCBs have been included in the Industrial Risk Assessment

1 Air Quality Assessment, Dunbar Energy from Waste Facility for Viridor Waste Management Limited (21st February 2022)

Program (IRAP) model and these have been assumed to comprise entirely of Aroclor 1016 or Aroclor 1254 depending on which substance gives rise to the highest exposure.

For benzene, BaP and the trace metals, the IRAP model is used to determine exposure via ingestion and inhalation. Where the substance has a threshold level for toxicity, the exposure is compared to a TDI for that substance. Where there is no threshold for toxicity, an Index Dose (ID) is defined which is a level of exposure associated with negligible risk to human health. Details of the TDIs and IDs defined for these substances is provided in *Section 3.3.2*.

1.3 SCOPE OF THE ASSESSMENT

The emissions from the ERF during the modelled operational scenario would contain a number of substances that cannot be evaluated in terms of their effects on human health simply by reference to ambient air quality standards. Health effects could occur through exposure routes other than purely inhalation. As such, an assessment needs to be made of the overall human *exposure* to the substances by the local population and then the *risk* that this exposure causes.

The assessment presented here considers the potential impact of substances released by the installation on the health of the local population at the point of maximum exposure. These substances are those that are 'persistent' in the environment and/or have several pathways from the point of release to the human receptor. Essentially, these are dioxins/furans and dioxin-like polychlorinated biphenyls (PCBs), trace metals, benzene and BaP. Dioxins and furans and are present in extremely small quantities and are typically measured in mass units of nanograms (ng = 10^{-9} g), picograms (pg = 10^{-12} g) and femtograms (fg = 10^{-15} g).

Unlike substances such as nitrogen dioxide, which have short term, acute effects on the respiratory system, the substances considered have the potential to cause effects through long term, cumulative exposure. A lifetime is the conventional period over which such effects are evaluated. A lifetime is taken to be 70 years.

The exposure scenarios used here represent highly unrealistic situations in which all exposure assumptions are chosen to represent a worst case and should be treated as an extreme view of the risks to health. While individual high-end exposure estimates may represent actual exposure possibilities (albeit at very low frequency), the possibility of all high-end exposure assumptions accumulating in one individual is, for practical purposes, never realised. Therefore, intakes presented here should be regarded as an extreme upper estimate of the actual exposure that would be experienced by the real population in the locality.

1.4 APPROACH TO THE ASSESSMENT

The risk assessment process is based on the application of the US EPA Human Health Risk Assessment Protocol (HHRAP) [2]. This protocol has been assembled into a commercially available model, Industrial Risk Assessment Program (IRAP, Version 5.1.0) and marketed by Lakes Environmental of Ontario.

The approach seeks to quantify the *hazard* faced by the receptor, the *exposure* of the receptor to the substances identified as being a potential hazard and then to assess the *risk* of the exposure, as follows.

- *Quantification of the exposure*: an exposure evaluation determines the dose and intake of key indicator chemicals for an exposed person. The dose is defined as the amount of a substance contacting body boundaries (in the case of inhalation, the lungs) and intake is the amount of the substance absorbed into the body. The evaluation is based upon worst-case, conservative scenarios, with respect to the following:
  - location of the exposed individual and duration of exposure;
  - exposure rate;
  - emission rate from the source.
- *Risk characterisation*: following the above steps, the risk is characterised by examining the toxicity of the chemicals to which the individual has been exposed, and evaluating the significance of the calculated dose by a comparison of intakes with the TDI or ID.

2 US EPA Office of Solid Waste (September 2005) Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities

2 METHODOLOGY FOR ESTIMATING EXPOSURE TO EMISSIONS

2.1 INTRODUCTION

An exposure assessment for the purposes of characterising the health impact of the ERF emissions requires the following steps:

(1) Measurement or estimation of emissions from the source.

(2) Modelling the fate and transport of the emitted substances through the atmosphere and through soil, water and biota following deposition onto land. Concentrations of the emitted chemicals in the environmental media are estimated at the point of exposure, which may be through inhalation or ingestion.

(3) Calculation of the uptake of the emitted chemicals into humans coming into contact with the affected media and the subsequent distribution in the body.

With regard to Step (3), the exposure assessment considers the uptake of polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans (PCDD/Fs, often abbreviated to 'dioxins/furans') and dioxin-like PCBs, benzene, BaP and trace metals by various categories of human receptors.

2.2 POTENTIAL EXPOSURE PATHWAYS

There are two primary exposure 'routes' where humans may come into contact with chemicals that may be of concern:

- direct, via inhalation; or
- indirect, via ingestion of water, soil, vegetation and animals and animal products that become contaminated through the food chain.

There are four other potential exposure pathways of concern following the introduction of substances into the atmosphere:

- ingestion of drinking water;
- dermal (skin) contact with soil;
- incidental ingestion of soil; and
- dermal (skin) contact with water.

2.3 Exposure Pathways Considered in the Assessment

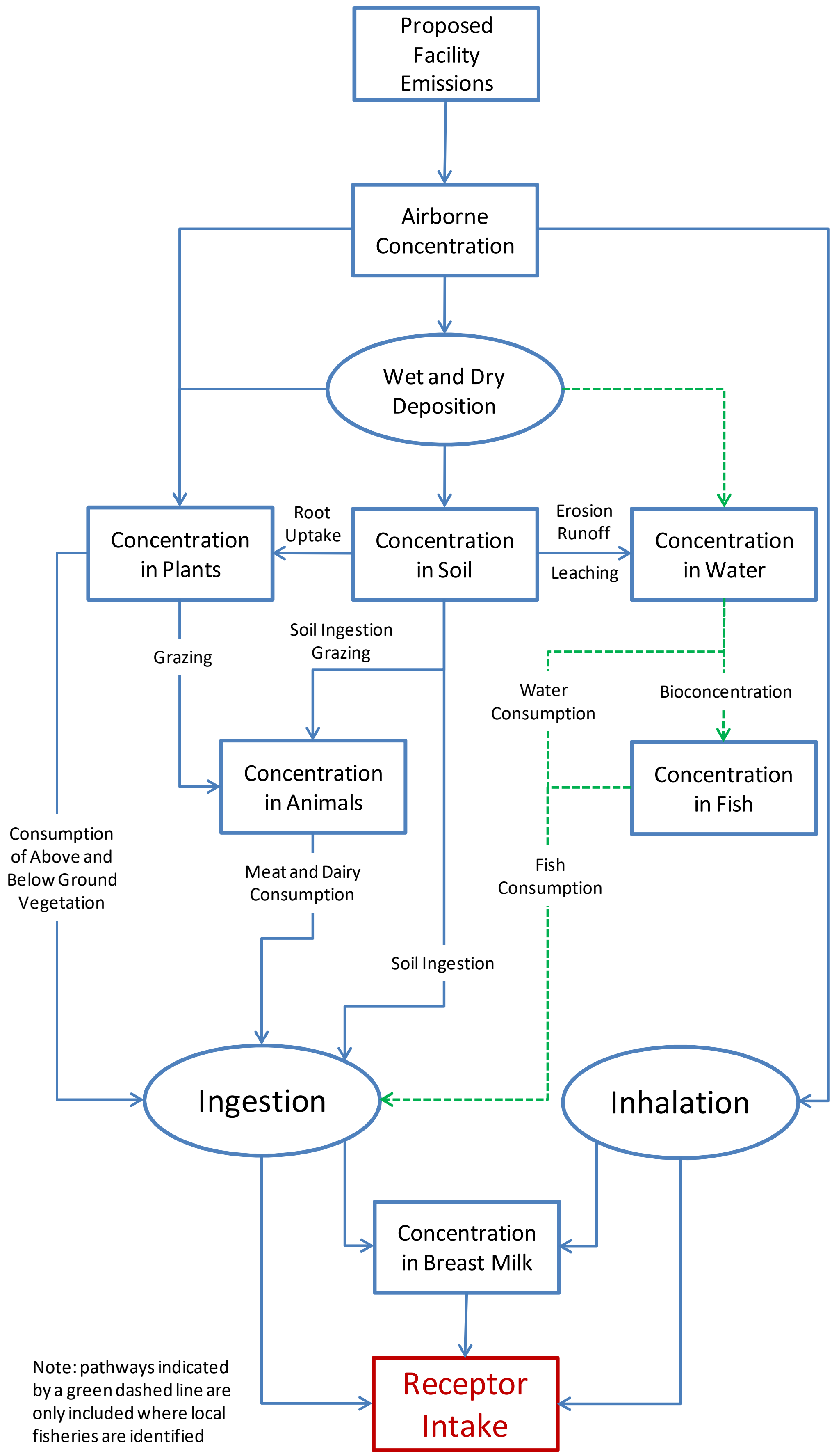
The possible exposure pathways included in the IRAP model are shown in *Figure 2.1*. Dermal contact with soil is an insignificant exposure pathway on the basis of the infrequent and sporadic nature of the events and the very low dermal absorption factors for this exposure route, coupled with the low plausible total dose that may be experienced (when considered over the lifetime of an individual). Health risk assessments of similar emissions (Pasternach (1989) *The Risk Assessment of Environmental and Human Health Hazards*, John Wiley, New York) have concluded that dermal absorption of soil is at least one order of magnitude less efficient than lung absorption.

Similar arguments are relevant with respect to the elimination of aquatic pathways from consideration; swimming, fishing and other recreational activities are also sporadic and unlikely to lead to significant exposures or uptake of any contamination into the human body via dermal contact with water.

Exposure via drinking water requires contamination of surface drinking water sources local to the point of consumption. The likelihood of contamination reaching a level of concern in the local water sources and ground water supplies is extremely low, particularly where there is no large-scale storage (e.g. reservoirs) or catchment areas for local water supplies. However, the US EPA's HHRAP does include the ingestion of drinking water from surface water sources as a potential exposure pathway where water bodies and water sheds have been defined within the exposure scenario. The ingestion of groundwater as a source of local drinking water is not considered by the HHRAP as it is considered to be an insignificant exposure pathway for emissions derived from combustion processes.

The ingestion of drinking water from surface water sources is only considered a potential exposure pathway where there is a local surface water body which provides local drinking water. However, it is our experience that drinking water from a reservoir located close to this type of facility makes a very small contribution to the total exposure. Therefore, exposure via drinking water is generally only considered where there is the potential for exposure via the ingestion of fish and the presence of edible fish farms (e.g. trout or salmon farms). There are no edible fish farms identified within 5 km of the ERF. The nearest trout fishery (Markle Trout Fishery) is located to the west of Dunbar at a distance of 13 km west of the ERF.

FIGURE 2.1 EXPOSURE PATHWAYS FOR RECEPTORS



On the basis of the assessment of the potential significance of the exposure pathways, the key exposure pathways which are relevant to the assessment and, hence, subject to examination in detail are as follows:

- inhalation;
- ingestion of food; and
- ingestion of soil.

Therefore, the exposures arising from ingestion are assessed with reference to the following:

- milk from home-reared cows;
- eggs from home-reared chickens;
- home-reared beef;
- home-reared pork;
- home-reared chicken;
- home-grown vegetable and fruit produce;
- breastmilk; and
- soil (incidental).

The inclusion of all food groups in the assessment conservatively assumes that both arable and pasture land are present in the vicinity of the predicted maximum annual average ground level concentration. This is, in reality, a highly unlikely scenario, but it has been included as a means of building a high degree of conservatism into the assessment and, hence, reducing the risk of exposures being underestimated. However, it should be noted that not all exposure scenarios will result in the ingestion of home-reared meat and animal products and these food products are only considered by the HHRAP for farmers and the families of farmers.

Similarly, the ingestion of fish is only considered where there is a local water body that is used for fishing and where the diet of the fisher (and family) may be regularly supplemented by fish caught from these local water sources. As discussed previously, there are no edible fish farms identified within 5 km of the ERF.

Therefore, the ingestion of locally caught edible fish from an inland closed water source has not been considered as consumption rates are likely to be very small.

2.4 EMISSIONS AND DISPERSION MODELLING INPUT DATA – DUNBAR ERF

2.4.1 Compounds of Potential Concern (COPCs)

The substances which have been considered in the assessment are referred to as the Compounds of Potential Concern (COPCs) and include the seventeen PCDD/F congeners that are known to be toxic (refer *Section 2.4.3*). In addition, the IRAP model includes two dioxin-like PCBs (Aroclor 1016 and Aroclor 1254). These comprise a mixture of congeners with one to four chlorine atoms for Aroclor 1016 with a chlorine content of 41% by mass (average of three chlorine atoms). Similarly, Aroclor 1254 has between four and seven chlorine atoms and a chlorine content of 54% by mass (average of five chlorine atoms).

Of the twelve trace metals that have regulated emissions from the ERF, seven are included in the IRAP model and have been included in the assessment. These are Sb, As, Cd, Cr, Pb, Hg and Ni. As requested by SEPA, emissions of benzene and BaP have also been included in the assessment.

2.4.2 Emission Parameters

Emissions from the ERF are via two flues within a common stack. Emission parameters assumed for the assessment are consistent with those used for the air quality assessment as follows:

- stack height of 80 m (metres) above ground level;
- effective stack diameter of 2.4 m;
- emission temperature of 145°C (degrees celcius) or 418 K (kelvin).
- emission velocity of 17.6 m s^{-1} (metres per second); and
- normalised flow rate of 59.6 Nm^3 s^{-1} (normal cubic metres per second at 273 K, dry and 11% O_2).

2.4.3 Emission Concentrations for the COPCs

Dioxins, Furans and Dioxin-like PCBs

The general term dioxins denotes a family of compounds, with each compound composed of two benzene rings interconnected with two oxygen atoms. There are 75 individual dioxins, with each distinguished by the position of chlorine or other halogen atoms positioned on the benzene rings. Furans are similar in structure to dioxins, but have a carbon bond instead of one of the two oxygen atoms connecting the two benzene rings. There are 135 individual furan compounds. Each individual furan or dioxin compound is referred to as a congener and each has a different toxicity and physical properties with regard to its atmospheric behaviour. It is important, therefore, that the exposure methodology determines the fate and transport of PCDD/Fs on a congener specific basis. It does this by accounting for the varying volatility of the congeners and their different toxicities. Consequently, information regarding the PCDD/F annual mean ground level concentrations on a congener specific basis is required.

For the purposes of the exposure assessment, the congener profile for the ERF has been based on measured concentrations for extractive monitoring tests undertaken between May 2020 and January 2020. Details of the measured concentrations are provided in *Annex C* and summarised in *Table 2.1.* The international toxic equivalency factors are given and used to derive the toxic equivalent emission (I-TEQ). It is assumed that PCDD/F emissions are 0.1 ng I-TEQ Nm^{-3} (reference conditions 273K, dry and 11% O_2). The assumed emission concentration is a factor of ten higher than the maximum measured concentration of 0.0088 ng I-TEQ Nm^{-3}.

TABLE 2.1 PCDD/F CONGENER PROFILE FOR THE DUNBAR ERF

Congener	Annual Mean Emission Concentration (ng Nm^{-3})	I-TEF toxic equivalent factors)	Annual Mean Emission Concentration (a)(b) (ng I-TEQ Nm^{-3})
2,3,7,8-TCDD	0.00033	1.0	0.00033
1,2,3,7,8-PeCDD	0.0042	0.5	0.0021
1,2,3,4,7,8-HxCDD	0.022	0.1	0.0022
1,2,3,7,8,9-HxCDD	0.031	0.1	0.0031
1,2,3,6,7,8-HxCDD	0.064	0.1	0.0064
1,2,3,4,6,7,8-HpCDD	3.3	0.01	0.033
OCDD	28.4	0.001	0.028
2,3,7,8-TCDF	0.016	0.1	0.0016
2,3,4,7,8-PeCDF	0.0089	0.5	0.0044
1,2,3,7,8-PeCDF	0.030	0.05	0.0015
1,2,3,4,7,8-HxCDF	0.019	0.1	0.0019
1,2,3,7,8,9-HxCDF	0.0026	0.1	0.00026
1,2,3,6,7,8-HxCDF	0.024	0.1	0.0024
2,3,4,6,7,8-HxCDF	0.037	0.1	0.0037
1,2,3,4,6,7,8-HpCDF	0.48	0.01	0.0048
1,2,3,4,7,8,9-HpCDF	0.080	0.01	0.00080
OCDF	3.0	0.001	0.0030
Total (ng I-TEQ m^{-3})			**0.1**

(a) Congener profile from extractive monitoring between May 2020 and January 2022, pro-rated to give 0.1 ng I-TEQ Nm^{-3}

(b) Reference conditions of 273K, 1 atmosphere, dry and 11% O_2

Information on dioxin-like PCB emissions has been obtained from the Defra report WR 0608 [3]. Based on the information provided, a maximum emission concentration of 3.6×10^{-9} mg m^{-3} is assumed. It is not stated in the Defra report

3 WR 0608 Emissions from Waste Management Facilities, ERM Report on Behalf of Defra (July 2011)

whether this is total PCBs or dioxin-like PCBs. Therefore, as a worst-case it is assumed to comprise entirely of dioxin-like PCBs. Furthermore, it is assumed that this is the total PCB emission and that these data are presented as the toxic equivalent concentration (i.e. 3.6 x 10^{-9} mg TEQ Nm^{-3}, equivalent to 0.0036 ng I-TEQ Nm^{-3}). For the dioxin-like PCBs, a toxic equivalent factor (TEF) of 0.1 has been used to provide an actual emission concentration (i.e. 3.6 x 10^{-8} mg Nm^{-3}). The same equivalence factor has been used to convert the total actual dose back to the total toxic equivalent dose. Dioxin-like PCBs are not routinely monitoring but total PCBs are. Between May 2020 and January 2022 maximum measured concentrations were 0.00092 ng TEQ Nm^{-3} (equivalent to 9.2 x 10^{-10} mg TEQ Nm^{-3}), a factor of four less than assumed for the assessment.

For the ERF, the emission rates for the dioxins, furans and dioxin-like PCBs as input to the IRAP model are provided in *Table 2.2*.

TABLE 2.2 PCDD/F EMISSION RATES USED IN THE IRAP MODEL – DUNBAR ERF

Congener	Emission Concentration (mg Nm^{-3})	Emission Rate (g s^{-1})
2,3,7,8-TCDD	0.00033 x 10^{-6}	2.0 x 10^{-11}
1,2,3,7,8-PeCDD	0.0042 x 10^{-6}	2.5 x 10^{-10}
1,2,3,4,7,8-HxCDD	0.022 x 10^{-6}	1.3 x 10^{-9}
1,2,3,7,8,9-HxCDD	0.031 x 10^{-6}	1.9 x 10^{-9}
1,2,3,6,7,8-HxCDD	0.064 x 10^{-6}	3.8 x 10^{-9}
1,2,3,4,6,7,8-HpCDD	3.3 x 10^{-6}	2.0 x 10^{-7}
OCDD	28.4 x 10^{-6}	1.7 x 10^{-6}
2,3,7,8-TCDF	0.016 x 10^{-6}	9.8 x 10^{-10}
2,3,4,7,8-PeCDF	0.0089 x 10^{-6}	5.3 x 10^{-10}
1,2,3,7,8-PeCDF	0.030 x 10^{-6}	1.8 x 10^{-9}
1,2,3,4,7,8-HxCDF	0.019 x 10^{-6}	1.1 x 10^{-9}
1,2,3,7,8,9-HxCDF	0.0026 x 10^{-6}	1.6 x 10^{-10}
1,2,3,6,7,8-HxCDF	0.024 x 10^{-6}	1.4 x 10^{-9}
2,3,4,6,7,8-HxCDF	0.037 x 10^{-6}	2.2 x 10^{-9}
1,2,3,4,6,7,8-HpCDF	0.48 x 10^{-6}	2.9 x 10^{-8}
1,2,3,4,7,8,9-HpCDF	0.080 x 10^{-6}	4.7 x 10^{-9}
OCDF	3.0 x 10^{-6}	1.8 x 10^{-7}
Aroclor 1016/1254	0.036 x 10^{-6}	2.1 x 10^{-9}

Other Pollutant Emissions

For the metals considered for the health risk assessment, the individual emission concentrations are presented in *Table 2.3*. For the Group 1 metals (cadmium) and Group 2 metals (mercury) these have been derived as a fraction of the relevant emission limit values (50% for cadmium and 100% for mercury). For Group 3 metals, emissions have been derived from information provided by the Environment Agency [4].

An emission limit of 9 x 10^{-5} mg Nm^{-3} has been assumed for PAH (benzo(a)pyrene based on the Defra (WR0608)) report on emissions from waste management facilities[5]. Measured concentrations of BaP were all below the detection limit for the analysis for the extractive monitoring between May 2020 and January 2022. Assuming concentrations are at the detection limit, the maximum measured BaP concentration is 0.0076 µg Nm^{-3} (0.0000076 mg Nm^{-3}) and a factor of 12 lower than assumed for the assessment. Benzene is assumed to be 100% of the total organic compounds (TOC) emission limit value of 10 mg Nm^{-3}.

TABLE 2.3 OTHER EMISSION RATES USED IN THE IRAP MODEL – DUNBAR ERF

Pollutant	Percentage of Relevant Group	Emission Concentration (mg Nm^{-3})	Emission Rate (g s^{-1})
Antimony	2.3%	0.012	0.00069
Arsenic	5.0%	0.025	0.0015
Cadmium	50%	0.025	0.0015
Chromium III	18.4%	0.092	0.0055
Chromium VI	0.03%	0.00015	0.0000089
Lead	10.1%	0.051	0.0030
Mercury	100%	0.050	0.0030
Nickel	44.0%	0.22	0.013
Benzene	100%	10	0.60
Benzo(a)pyrene	-	0.00009	0.0000054

In accordance with the HHRAP methodology, it is important that loss of mercury to the global cycle is accounted for. For this purpose, the IRAP default values have been used and it is assumed that of the total mercury emitted 51.8% is lost to the global cycle, 48.0% is deposited as divalent mercury and 0.2% is emitted as elemental mercury. The model assumes that human exposure to elemental mercury occurs only through direct inhalation of the vapour phase elemental form. Human exposure to divalent mercury occurs through both indirect and direct inhalation pathways in the form of vapour and particle-bound mercuric chloride.

4 Releases from Municipal Waste Incinerators, Guidance to Applicants on Impact Assessment for Group 3 Metals, Environment Agency (September 2012)

5 WR 0608 Emissions from Waste Management Facilities, ERM Report on Behalf of Defra (July 2011)

Therefore, the following emission rates for mercury have been assumed:

- elemental mercury at 6.0×10^{-6} g s^{-1}; and
- mercuric chloride at 1.4×10^{-3} g s^{-1}.

2.5 EMISSIONS AND DISPERSION MODELLING INPUT DATA – TARMAC CEMENT

2.5.1 Emission Parameters

Emissions from the cement kiln (A10) at the Tarmac Cement facility are via a single stack. Emission parameters assumed for the assessment are consistent with those used for the air quality assessment as follows:

- stack height of 105 m;
- stack diameter of 3 m;
- emission temperature of 55°C or 328 K;
- emission velocity of 27.2 m s^{-1}; and
- normalised flow rate of 100.0 Nm^3 s^{-1}.

2.5.2 Emission Concentrations for the COPCs

Dioxins, Furans and Dioxin-like PCBs

The congener profile for the Tarmac cement kiln has been based on measured concentrations for extractive monitoring tests undertaken between February 2019 and February 2021. Details of the measured concentrations are provided in *Annex D* and summarised in *Table 2.4*. It is assumed that PCDD/F emission concentration is 0.1 ng I-TEQ Nm^{-3}. The assumed emission concentration is a factor of more than ten higher than the maximum measured concentration of 0.0074 ng I-TEQ Nm^{-3}.

TABLE 2.4 PCDD/F CONGENER PROFILE FOR THE TARMAC CEMENT KILN

Congener	Annual Mean Emission Concentration (ng Nm^{-3})	I-TEF toxic equivalent factors)	Annual Mean Emission Concentration (a)(b) (ng I-TEQ Nm^{-3})
2,3,7,8-TCDD	0.0098	1.0	0.0098
1,2,3,7,8-PeCDD	0.019	0.5	0.0096
1,2,3,4,7,8-HxCDD	0.013	0.1	0.0013
1,2,3,7,8,9-HxCDD	0.028	0.1	0.0028
1,2,3,6,7,8-HxCDD	0.056	0.1	0.0056
1,2,3,4,6,7,8-HpCDD	1.0	0.01	0.010
OCDD	1.1	0.001	0.0011
2,3,7,8-TCDF	0.10	0.1	0.010
2,3,4,7,8-PeCDF	0.058	0.5	0.029

TABLE 2.4 PCDD/F CONGENER PROFILE FOR THE TARMAC CEMENT KILN

Congener	Annual Mean Emission Concentration (ng Nm^{-3})	I-TEF toxic equivalent factors)	Annual Mean Emission Concentration (a)(b) (ng I-TEQ Nm^{-3})
1,2,3,7,8-PeCDF	0.040	0.05	0.0020
1,2,3,4,7,8-HxCDF	0.0	0.1	0.0048
1,2,3,7,8,9-HxCDF	0.016	0.1	0.0016
1,2,3,6,7,8-HxCDF	0.047	0.1	0.0047
2,3,4,6,7,8-HxCDF	0.051	0.1	0.0051
1,2,3,4,6,7,8-HpCDF	0.20	0.01	0.0020
1,2,3,4,7,8,9-HpCDF	0.022	0.01	0.00022
OCDF	0.18	0.001	0.00018
Total (ng I-TEQ m^{-3})			**0.1**

(a) Congener profile from extractive monitoring between February 2019 and February 2021, pro-rated to give 0.1 ng I-TEQ Nm^{-3}

(b) Reference conditions of 273K, 1 atmosphere, dry and 10% O_2

As for Dunbar ERF, a maximum emission concentration of 3.6 x 10^{-9} mg Nm^{-3} is assumed for dioxin-like PCBs. Between February 2019 and February 2021 maximum measured total PCB concentrations were 0.0021 ng TEQ Nm^{-3} (equivalent to 2.1 x 10^{-9} mg TEQ Nm^{-3}), less than assumed for the assessment despite concentrations being at the detection limit of the analysis.

For the Tarmac cement kiln, the emission rates for the dioxins, furans and dioxin-like PCBs as input to the IRAP model are provided in *Table 2.5.*

TABLE 2.5 PCDD/F EMISSION RATES USED IN THE IRAP MODEL

Congener	Emission Concentration (mg Nm^{-3})	Emission Rate (g s^{-1})
2,3,7,8-TCDD	0.0098 x 10^{-6}	9.8 x 10^{-10}
1,2,3,7,8-PeCDD	0.019 x 10^{-6}	1.9 x 10^{-9}
1,2,3,4,7,8-HxCDD	0.013 x 10^{-6}	1.3 x 10^{-9}
1,2,3,7,8,9-HxCDD	0.028 x 10^{-6}	2.8 x 10^{-9}
1,2,3,6,7,8-HxCDD	0.056 x 10^{-6}	5.6 x 10^{-9}
1,2,3,4,6,7,8-HpCDD	1.0 x 10^{-6}	1.0 x 10^{-7}
OCDD	1.1 x 10^{-6}	1.1 x 10^{-7}
2,3,7,8-TCDF	0.10 x 10^{-6}	1.0 x 10^{-8}
2,3,4,7,8-PeCDF	0.058 x 10^{-6}	5.8 x 10^{-9}
1,2,3,7,8-PeCDF	0.040 x 10^{-6}	4.0 x 10^{-9}
1,2,3,4,7,8-HxCDF	0.048 x 10^{-6}	4.8 x 10^{-9}
1,2,3,7,8,9-HxCDF	0.016 x 10^{-6}	1.6 x 10^{-9}

TABLE 2.5 PCDD/F EMISSION RATES USED IN THE IRAP MODEL

Congener	Emission Concentration (mg Nm^{-3})	Emission Rate (g s^{-1})
1,2,3,6,7,8-HxCDF	0.047×10^{-6}	4.7×10^{-9}
2,3,4,6,7,8-HxCDF	0.051×10^{-6}	5.1×10^{-9}
1,2,3,4,6,7,8-HpCDF	0.20×10^{-6}	2.0×10^{-8}
1,2,3,4,7,8,9-HpCDF	0.022×10^{-6}	2.2×10^{-9}
OCDF	0.18×10^{-6}	1.8×10^{-8}
Aroclor 1016/1254	0.036×10^{-6}	3.6×10^{-9}

Other Pollutant Emissions

For the metals considered for the health risk assessment, the individual emission concentrations are presented in *Table 2.6*. As for the Dunbar ERF, the Group 1 metals (cadmium) and Group 2 metals (mercury) these have been derived as a fraction of the relevant emission limit values (50% for cadmium and 100% for mercury). For Group 3 metals, emissions have been derived from information provided by the Environment Agency.

TABLE 2.6 OTHER EMISSION RATES USED IN THE IRAP MODEL – TARMAC CEMENT KILN

Pollutant	Percentage of Relevant Group	Emission Concentration (mg Nm^{-3})	Emission Rate (g s^{-1})
Antimony	2.3%	0.012	0.0012
Arsenic	5.0%	0.025	0.0025
Cadmium	50%	0.025	0.0025
Chromium III	18.4%	0.092	0.0092
Chromium VI	0.03%	0.00015	0.000015
Lead	10.1%	0.051	0.0051
Mercury	100%	0.050	0.0050
Nickel	44.0%	0.22	0.022
Benzene	100%	10	1.0
Benzo(a)pyrene	-	0.00009	0.0000090

An emission limit of 9×10^{-5} mg Nm^{-3} has also been assumed for BaP based on the Defra (WR0608)) report on emissions from waste management facilities. Measured concentrations of BaP were all below the detection limit for the analysis for the extractive monitoring. Assuming concentrations are at the detection limit, the maximum measured BaP concentration is 0.0053 µg Nm^{-3} (0.0000053 mg Nm^{-3})[6] and a factor of 17 lower than assumed for the assessment.

6 Excludes data for February 2019 and March 2019 which had particularly high detection levels for the analysis

Benzene is assumed to be 100% of the total organic compounds (TOC) emission limit value of 10 mg Nm^{-3}.

In accordance with the HHRAP methodology, the following emission rates for mercury have been assumed:

- elemental mercury at 1.0×10^{-5} g s^{-1}; and
- mercuric chloride at 2.4×10^{-3} g s^{-1}.

2.6 DISPERSION MODELLING ASSUMPTIONS

The air quality assessment has relied upon the use of ADMS to estimate ground level concentrations of pollutants. The HHRA model has been designed to accept output files from the US EPA ISC or AERMOD dispersion models, reflecting its North American origins and its need to follow the US EPA risk assessment protocol. The use of ADMS is consistent with the air quality assessment undertaken for the ERF and the emissions data and model set up are identical to that carried out for the air quality assessment [1].

Therefore, to maintain consistency with the air quality assessment, it has been possible to use output from the ADMS model with IRAP using the following procedure:

- generation of ISC input files and output files for the study area;
- generation of ADMS output data using the approach outlined in the US EPA risk assessment protocol;
- ADMS deposition rates are converted from µg m^{-2} s^{-1} to g m^{-2} a^{-1} (as required by IRAP) by multiplying by 3600, 24 and 365 and dividing by 1,000,000; and
- inserting the ADMS results into the ISC output files.

For the modelling, all emission properties, building heights, and other relevant factors were retained from the air quality assessment provided for the installation. As the health risk assessment requires information on the deposition of substances to surfaces as well as airborne concentrations of substances, the ADMS dispersion model has also been used to predict the following:

- the airborne concentration of vapour, particle and particle bound substances emitted;
- the wet deposition rate of particle and particle bound substances; and
- the dry deposition rate of vapour, particle and particle bound substances.

For dry deposition of particles and particle bound contaminants a fixed deposition velocity of 0.01 m s^{-1} has been used. The Dunbar ERF and Tarmac cement kiln are equipped with filters for particle removal and the emitted particles are likely to be less than 1 -2 µm in diameter. For particles of this size, deposition velocities are likely to be of the order of 0.001 to 0.01 m s^{-1}. Therefore, as a worst-case, for the ADMS modelling a value of 0.01 m s^{-1} has been adopted. A gas dry deposition velocity of 0.005 m s^{-1} is used for the gas phase. For wet deposition, the following washout coefficients are used:

- Gas phase – washout coefficient A at 0.00016 and washout coefficient B of 0.64;
- Particle phase – washout coefficient A at 0.00028 and washout coefficient B of 0.64; and
- Particle bound phase – washout coefficient A at 0.00010 and washout coefficient B of 0.64.

2.7 DISPERSION MODELLING RESULTS

A summary of the key results from the ADMS dispersion model is presented in *Table 2.7.* for the Dunbar ERF and the Tarmac Cement facility. These have been predicted using the 2017 Edinburgh Gogarbank meteorological data set. This year was selected, as out of the five years considered (2016 to 2020), it was the year that provided highest predicted annual mean concentrations and deposition rates.

TABLE 2.7 MAXIMUM ANNUAL AVERAGE PARTICLE PHASE CONCENTRATIONS AND PARTICLE PHASE DEPOSITION RATES

Pollutant	Max Annual Average Concentration		Max Annual Average Deposition Rate	
PCDD/Fs	($fg\ m^{-3}$) (a)		($ng\ m^{-2}\ year^{-1}$) (b)	
	Dunbar ERF	Tarmac Cement Kiln	Dunbar ERF	Tarmac Cement Kiln
2,3,7,8-TCDD	0.0020	0.031	0.026	4.4
1,2,3,7,8-PeCDD	0.025	0.062	0.33	8.5
1,2,3,4,7,8-HxCDD	0.13	0.042	1.7	5.8
1,2,3,7,8,9-HxCDD	0.19	0.091	2.5	12.6
1,2,3,6,7,8-HxCDD	0.38	0.18	5.0	24.8
1,2,3,4,6,7,8-HpCDD	19.7	3.2	258.1	446.4
OCDD	169.6	3.7	2224.5	507.8
2,3,7,8-TCDF	0.098	0.33	1.3	45.4
2,3,4,7,8-PeCDF	0.053	0.18	0.70	25.5
1,2,3,7,8-PeCDF	0.18	0.13	2.3	17.9
1,2,3,4,7,8-HxCDF	0.11	0.16	1.5	21.5
1,2,3,7,8,9-HxCDF	0.016	0.053	0.21	7.3
1,2,3,6,7,8-HxCDF	0.14	0.15	1.9	20.7
2,3,4,6,7,8-HxCDF	0.22	0.16	2.9	22.7
1,2,3,4,6,7,8-HpCDF	2.9	0.63	37.5	87.0
1,2,3,4,7,8,9-HpCDF	0.47	0.071	6.2	9.9
OCDF	17.8	0.57	233.6	79.1
Aroclor 1016/1254	0.21	0.12	2.8	16.0
Other Pollutants	($ng\ m^{-3}$)		($mg\ m^{-2}\ year^{-1}$)	
	Dunbar ERF	Tarmac Cement Kiln	Dunbar ERF	Tarmac Cement Kiln
Antimony	0.069	0.037	0.90	5.1
Arsenic	0.15	0.080	2.0	11.1
Cadmium	0.15	0.080	2.0	11.1
Chromium (total)	0.55	0.30	7.2	40.8
Chromium (hexavalent)	0.00090	0.00048	0.012	0.067
Lead	0.30	0.16	4.0	22.4
Total mercury	0.30	0.16	3.9	22.2
Nickel	1.3	0.71	17.2	97.6
Benzo(a)pyrene	0.00054	0.00029	0.0070	0.040
Benzene	59.7	32.1	783.1	4438.0

(a) Where 1 $fg\ m^{-3}$ is equal to $1 \times 10^{-15}\ g\ m^{-3}$

(b) Where 1 $ng\ m^{-2}\ year^{-1}$ is equal to $1 \times 10^{-9}\ g\ m^{-2}\ year^{-1}$

3 INPUT PARAMETERS FOR THE IRAP MODEL

3.1 INTRODUCTION

Exposure of an individual to a chemical may occur either by inhalation or ingestion (including food, water and soil). Of interest is the total dose of the chemical received by the individual through the combination of possible routes, and the IRAP model has been developed to estimate the dose received by the human body, often referred to as the external dose.

Exposure to COPCs is a function of the estimated concentration of the substance in the environmental media with which individuals may come into contact (i.e. exposure point concentrations) and the duration of contact. The concentration at the point of contact is itself a function of the transfer through air, soil, water, plants and animals that form part of the overall pathway. Exposure equations have been developed which combine exposure factors (e.g. exposure duration, frequency and medium intake rate) and exposure point concentrations. The dose equations therefore facilitate estimation of the received dose and account for the properties of the route of exposure, i.e. ingestion and inhalation.

For those substances that bio-accumulate, i.e. become more concentrated higher up the food chain, especially in body fats, the exposure to contaminated meat products and milk is of particular significance.

The IRAP model user has the facility to adjust some of the key exposure factors. An example is the diet of the receptor and the proportion of which is local produce, which may be contaminated. Obviously, if a nearby resident eats no food grown locally, then that person's diet cannot be contaminated by the emissions from the source, in this case the proposed facility. It is conventional to investigate two types of receptor, a farmer and a resident. It is assumed that a farmer eats proportionately more locally grown food than a resident. Where the potential exists for the consumption of locally caught fish a fisher receptor may also be considered. As discussed in *Section 2.3*, a fisher receptor does not apply here.

The receptor types can also be divided into adults and children. Children are important receptors because they tend to ingest soil and dusts directly and have lower body weights, so that the effect of the same dose is greater in the child than in the adult.

The IRAP model is designed to accept output files of airborne concentrations and deposition rates. From these, it proceeds to calculate the concentrations of the pollutants of concern in the environmental media, foodstuffs and the human receptor.

The model requires a wide range of input parameters to be defined, these include:

- physical and chemical properties of the COPCs;
- site information, including site specific data; and
- receptor information – for each receptor type (e.g. adult or child, resident or farmer or fisher).

The HHRAP default values, which are incorporated into the IRAP model, have been used for the majority of these input values. These data are provided in the following sections.

3.2 INPUT PARAMETERS FOR THE COPCS

The IRAP model contains a database of physical and chemical parameters for each of the 206 COPCs. This database is based on default values provided by the HHRAP and all default values have been used for this assessment.

These parameters are used to determine how each of the COPCs behave in the environment and their presence and accumulation in various food products (meat, fish, animal products, vegetation, soil and water). For cadmium and 2,3,7,8-TCDD (the most toxic of the PCDD/Fs), the default parameters are provided in *Table 3.1.*

TABLE 3.1 IRAP INPUT PARAMETERS FOR CADMIUM AND 2, 3, 7, 8-TCDD

Parameter Description	Symbol	Units	Cadmium	2,3,7,8-TCDD
Chemical abstract service number	CAS No.	-	7440-43-9	1746-01-6
Molecular weight	MW	g $mole^{-1}$	112.4	322.0
Melting point of chemical	T_m	K	593.2	578.7
Vapour pressure	V_p	atm	5.5×10^{-12}	1.97×10^{-12}
Aqueous solubility	S	mg L^{-1}	123000	1.93×10^{-5}
Henry's Law constant	H	atm-m^3 mol^{-1}	0.031	3.29×10^{-5}
Diffusivity of COPC in air	D_a	cm^2 s^{-1}	0.0772	0.104
Diffusivity of COPC in water	Dw	cm^2 s^{-1}	9.6×10^{-6}	5.6×10^{-6}
Octanol-water partition coefficient	K_ow	-	0.85	6,309,573
Organic carbon-water partition coefficient	K_oc	mL g^{-1}	0	3,890,451
Soil-water partition coefficient	Kd_s	mL g^{-1}	75	38,904
Suspended sediments/surface water partition coefficient	Kd_sw	L kg^{-1}	75	291,784
Bed sediment/sediment pore water partition coefficient	Kd_bs	mL g^{-1}	75	155,618
COPC loss constant due to biotic and abiotic degradation	K_sg	a^{-1}	0	0.03

TABLE 3.1 IRAP INPUT PARAMETERS FOR CADMIUM AND 2, 3, 7, 8-TCDD

Parameter Description	Symbol	Units	Cadmium	2,3,7,8-TCDD
Fraction of COPC air concentration in vapour phase	f_v		0.009	0.664
Root concentration factor	RCF	mL g^{-1}	0	39,999
Plant-soil bioconcentration factor for below ground produce	br_root_veg	-	0.064	1.03
Plant-soil bioconcentration factor for leafy vegetables	br_leafy_veg	-	0.125	0.00455
Plant-soil bioconcentration factor for forage	br_forage	-	0.364	0.00455
COPC air-to-plant biotransfer factor for leafy vegetables	bv_leafy_veg	-	0	65,500
COPC air-to-plant biotransfer factor for forage	bv_forage	-	0	65,500
COPC biotransfer factor for milk	ba_milk	day kg^{-1}	6.5×10^{-6}	0.0055
COPC biotransfer factor for beef	ba_beef	day kg^{-1}	1.2×10^{-4}	0.026
COPC biotransfer factor for pork	ba_pork	day kg^{-1}	1.9×10^{-4}	0.032
Bioconcentration factor for COPC in eggs	Bcf_egg	-	0.0025	0.060
Bioconcentration factor for COPC in chicken	Bcf_chicken	-	0	3.32
Fish bioconcentration factor	BCF_fish	L kg^{-1}	907	34,400
Fish bioaccumulation factor	BAF_fish	L kg^{-1}	0	0
Biota-sediment accumulation factor	BSAF_fish	-	0	0.09
Plant-soil bioconcentration factor for grain	br_grain	-	0.062	0.00455
Plant-soil bioconcentration factor for eggs	br_egg	-	0.0025	0.011
COPC biotransfer factor for chicken	ba_chicken	day kg^{-1}	0.11	0.019

3.3 ASSESSMENT CRITERIA FOR THE COPCS

3.3.1 Tolerable Daily Intake for PCDD/Fs

Total human exposure (inhalation and ingestion) to dioxins and furans and dioxin-like PCBs has been compared against the COT TDI of 2 pg/kg per day.

3.3.2 Toxicity Factors – Other COPCs

Toxicity factors (e.g. reference doses, unit risk factors) are included within the IRAP model and are provided in *Table 3.2* for the COPCs other than dioxins/furans. These can be used to determine the carcinogenic risk or hazard associated with exposure to each COPC via inhalation or ingestion exposure pathways.

TABLE 3.2 TOXICITY FACTORS INCLUDED WITHIN THE IRAP MODEL FOR THE OTHER COPCS CONSIDERED FOR THE ASSESSMENT

COPC	Inhalation Reference Concentration	Ingestion Reference Dose	Inhalation Unit Risk Factor	Ingestion Carcinogenic Slope Factor
Symbol	**RfC**	**RfD**	**Inh_URF**	**Ing_csf**
Units	**(mg m^{-3})**	**(mg kg^{-1} d^{-1})**	**(µg m^{-3})$^{-1}$**	**(mg kg^{-1} d^{-1})$^{-1}$**
Antimony	0.0014	0.0004	0	0
Arsenic	3.0×10^{-5}	0.0003	0.0043	1.5
Cadmium	0.0002	0.0004	0.0018	0.38
Chromium III	5.3	1.5	0	0
Chromium VI	8.0×10^{-6}	0.0030	0.012	0
Lead	0.0015	0.000429	1.2×10^{-5}	0.0085
Nickel	0.0002	0.02	0.00024	0
Elemental mercury	0.0003	8.57×10^{-5}	0	0
Mercuric chloride	0.0011	0.0003	0	0
Methyl mercury	0.00035	0.0001	0	0
Benzo(a)pyrene	0	0	0.0011	7.3
Benzene	0.03	0.004	7.8×10^{-6}	0.055

For the other COPCs considered, information on Tolerable Daily Intakes and Index Doses (ID) have been provided in a series of toxicological reports by the Environment Agency [7] and supplemented by more recent data from the European Food Safety Authority (EFSA) for some COPCs. The UK/EFSA adopted TDIs and IDs for other COPC emissions are provided in *Table 3.3*.

TABLE 3.3 TOLERABLE DAILY INTAKES AND INDEX DOSES FOR OTHER COPCS

COPC	TDI/ID Inhalation (µg kg^{-1} d^{-1})	TDI/ID Ingestion (µg kg^{-1} d^{-1})
Arsenic	ID = 0.002	ID = 0.3
Cadmium	TDI = 0.0014	TDI = 0.36
Total chromium	-	TDI = 3
Chromium VI	ID = 0.001	-
Methyl mercury	TDI = 0.23	TDI = 0.19 (a)(b)
Mercuric chloride	TDI = 0.06	TDI = 0.6 (a)(c)
Nickel	TDI = 0.006	TDI = 1.1 (a)
Benzo(a)pyrene	ID = 0.00007	ID = 0.02
Benzene	ID = 1.4	ID = 0.29

(a) EFSA TDI
(b) Derived from a Tolerable Weekly Intake of 1.3 µg kg^{-1} week^{-1}
(c) Derived from a Tolerable Weekly Intake of 4 µg kg^{-1} week^{-1}

7 Contaminants in Soil: Updated Collation of Toxicology Data and Intake Values for Humans

The UK/EFSA ingestion TDIs are representative of the IRAP RfD and can be used directly in the model. The UK TDIs for inhalation can be converted to RfC units of mg m^{-3} assuming a bodyweight of 70 kg and an inhalation rate of 20 m^3 d^{-1} for use in the IRAP model.

To derive unit risk factors and carcinogenic slope factors, the following equation is used:

URF or CSF = 1/ID * Risk Level

The IRAP model provides the risk as a lifetime risk. It is the convention to use an annual risk of 1 x 10^{-6} (1 in 1 million) as being acceptable for industrial regulation in the UK [8]. This would be equivalent to a lifetime risk of 7 x 10^{-5} (assuming a lifetime of 70 years). The inhalation ID also requires conversion to units of µg m^{-3} by multiplying by 70 (kilogram) and dividing by 20 (m^3 d^{-1}) for use in the IRAP model. A summary of the derived UK/EFSA RfC, RfD, URF and CSF are provided in *Table 3.4*.

TABLE 3.4 DERIVED UK/EFSA TOXICITY FACTORS FOR THE IRAP MODEL

COPC	Inhalation Reference Concentration	Ingestion Reference Dose	Inhalation Unit Risk Factor	Ingestion Carcinogenic Slope Factor
Symbol	**RfC**	**RfD**	**Inh_URF**	**Ing_csf**
Units	**(mg m^{-3})**	**(mg kg^{-1} d^{-1})**	**(µg m^{-3})$^{-1}$**	**(mg kg^{-1} d^{-1})$^{-1}$**
Arsenic	-	-	0.010	0.23
Cadmium	4.9 x 10^{-6}	0.00036	-	-
Total chromium	-	0.003	-	-
Chromium VI	-	-	0.020	-
Nickel	2.1 x 10^{-5}	0.0011	-	-
Mercuric chloride	0.00021	0.0006	-	-
Methyl mercury	0.00081	0.00019	-	-
Benzo(a)pyrene	-	-	0.29	3.5
Benzene	-	-	1.4 x 10^{-5}	0.24

The most stringent of the IRAP and derived UK/EFSA toxicity factors are used for the assessment. These include all of the factors provided in *Table 3.2* except where the UK values are higher which include the following:

- RfC for cadmium, nickel and mercuric chloride;
- RfD for cadmium, chromium and nickel;
- Inhalation URF for arsenic, hexavalent chromium, BaP and benzene;
- Ingestion CSF for benzene.

8 Risk Assessment for Environmental Professionals, CIWEM Publication (December 2001)

3.4 SITE AND SITE SPECIFIC PARAMETERS

The IRAP health risk assessment model requires information relating to the location and its surroundings. The parameters required include the following.

- The fraction of animal feed (grain, silage and forage) grown on contaminated soils and quantity of animal feed and soil consumed by the various animal species considered.
- The interception fraction for above ground vegetation, forage and silage and length of vegetation exposure to deposition. The yield/standing crop biomass is also required.
- Input data for assessing the risks associated with exposure to breast milk, including:
  - body weight of infant;
  - exposure duration;
  - proportion of ingested COPC stored in fat;
  - proportion of mother's weight that is fat;
  - fraction of fat in breast milk;
  - fraction of ingested contaminant that is absorbed; and
  - half-life of dioxins in adults and ingestion rate of breast milk.
- Other physical parameters (e.g. soil dry bulk density, density of air, soil mixing zone depth).

For all of these parameters the IRAP/EPA HHRAP default values have been used and these are presented in *Annex A*. Other site-specific parameters are also required which are not provided by the IRAP model. These parameters were specified for the facility as follows:

- Annual average evapotranspiration rate of 52.9 cm a^{-1} (assumed to be 70% of total precipitation);
- Annual average precipitation of 75.6 cm a^{-1} (based on the average for the five year data set for the 2016 to 2020 meteorological data);
- Annual average irrigation of 0 cm a^{-1} since manual irrigation of crops in the UK is not generally required due to natural irrigation;
- Annual average runoff of 7.6 cm a^{-1} (assumed to be 10% of total precipitation);
- An annual average wind velocity of 4.3 m s^{-1} (average for the five years); and
- A time period over which deposition occurs of 30 years (the HHRAP default value).

3.5 Receptor Information

Within the IRAP model there are three receptor types; Resident, Farmer and Fisher. Information relating to each receptor type (adult and/or child) is required by the model where these receptor types are used. The information required includes the following:

- Food (meat, dairy products, fish and vegetables), water and soil consumption rates for each receptor type. However, only Fishers are assumed to consume fish and only Farmers are assumed to consume locally reared animals and animal products.
- Fraction of contaminated food, water and soil which is consumed by each receptor type.
- Input data for the inhalation exposure including: inhalation exposure duration, inhalation exposure frequency, inhalation exposure time; and inhalation rate.
- Input data for the ingestion exposure including: exposure duration, exposure frequency, exposure time; and body weight of receptor.

For the purposes of this assessment the default IRAP/HHRAP parameters have been used mainly to define the characteristics of the receptors. The default input data are presented in *Annex B*. The only variation to this is the assumed body weight of a child receptor. The IRAP/HHRAP default value is 15 kg whereas in the UK a value of 20 kg is typically used. Therefore, a value of 20 kg has been used.

4 EXPOSURE ASSESSMENT – DUNBAR ERF

4.1 SELECTION OF RECEPTORS

In addition to defining specific locations for assessment, IRAP can be used to determine the location of the maximum impact over an area based on the results of the dispersion model. For each defined land-use area, IRAP selects the locations which represent the maximum predicted concentrations or deposition rates for the area selected. The locations of these various maxima are often co-located resulting in the selection of one to nine receptor locations per defined area. This approach is adopted by IRAP since the maximum receptor impact may occur at any one of the maximum concentration or deposition locations identified.

The nearest residential areas are at Pinkerton to the southwest and Innerwick to the south-southeast. There is also an extensive Leisure Park (Thurston Manor) to the south of the facility which is also assumed to be representative of residential exposure. Five areas where residential exposure may occur have been defined.

The site is surrounded by agricultural land to the south and north and has a land use that is dominated by farming activities and occasional isolated residential properties. Three areas where the potential for farming exists have been defined. These include areas to the east (E), north (N) and west (W).

In addition to the residential and farming receptors, a sensitivity analysis has been carried out that considers the maximum impact of the emissions irrespective of the land use (i.e. the maximum predicted impact anywhere within the model domain).

For each type of receptor up to nine locations are selected based on the maximum predicted airborne concentration, maximum predicted wet deposition rate and maximum dry deposition rate for the gas phase, particle phase and particle bound phase. For the assessment, six Farmer receptors and nine Residential receptors have been assessed. It is considered that the likelihood of locally caught fish being consumed is low and fisher receptors have not been included in the assessment. For all of the receptor types, adult and child receptors have been considered. The locations of the Resident and Farmer receptors are described in *Table 4.1* and presented in *Figure 4.1*.

At other locations not specifically considered in the assessment, the predicted hazards and risks will be lower than predicted for the discrete receptors considered.

FIGURE 4.1 LOCATION OF THE RESIDENT AND FARMER RECEPTORS

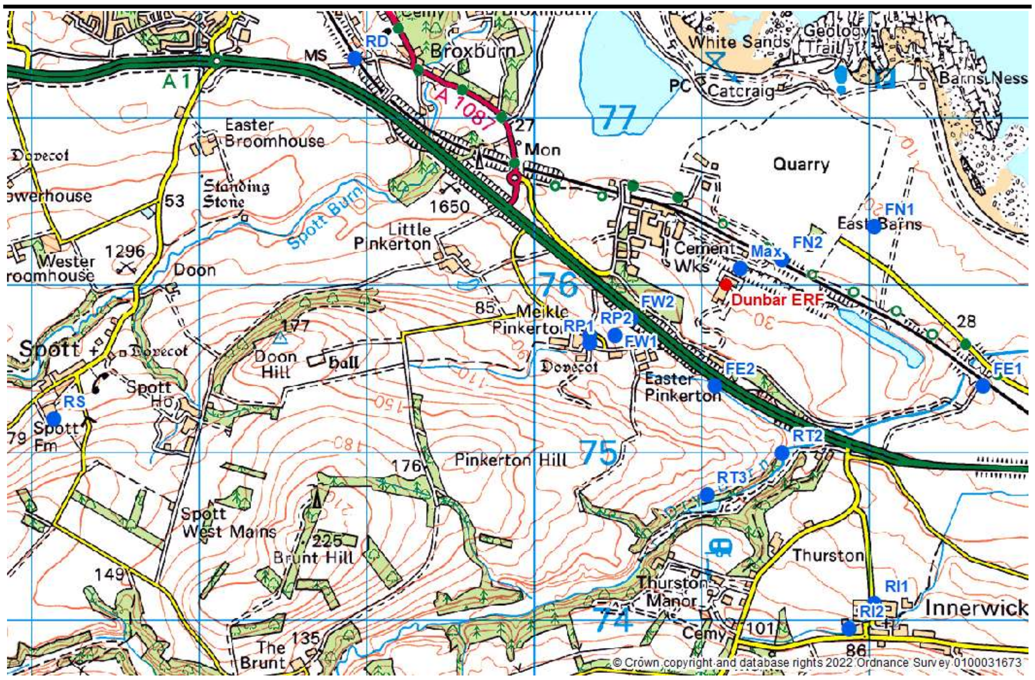


TABLE 4.1 DESCRIPTION OF RESIDENT AND FARMER RECEPTORS

Ref.	Name	Type	Easting	Northing
Max	Maximum	None	371230	676100
FE1	Farmer East 1	Farmer	372680	675400
FE2	Farmer East 2	Farmer	371080	675400
FN1	Farmer North 1	Farmer	372030	676350
FN2	Farmer North 2	Farmer	371480	676150
FW1	Farmer West 1	Farmer	370480	675700
FW2	Farmer West 2	Farmer	370580	675800
RD	Resident Dunbar	Resident	368930	677350
RI1	Resident Innerwick 1	Resident	372030	674100
RI2	Resident Innerwick 2	Resident	371880	673950
RP1	Resident Pinkerton 1	Resident	370330	675650
RP2	Resident Pinkerton 2	Resident	370330	675700
RS	Resident Spott	Resident	367130	675200
RT1	Resident Thurston Manor 1	Resident	371680	675100
RT2	Resident Thurston Manor 2	Resident	371480	675000
RT3	Resident Thurston Manor 3	Resident	371030	674750

The maximum predicted impact occurs to the immediate north of the site to the south of the railway. There would be no relevant public exposure at this location.

4.2 ASSESSMENT OF NON-CARCINOGENIC AND CARCINOGENIC RISK

4.2.1 Exposure to Dioxins, Furans and Dioxin-like PCBs

The ingestion intake is calculated as the Average Daily Dose (ADD) from all ingestion exposure routes (e.g. soil, above ground vegetables, meat and dairy products) where for example:

$$ADD_{Ing,\,TCDD} = \frac{I_{Ing,\,TCDD} \bullet ED \bullet EF}{AT \bullet 365}$$

Where: $ADD_{Ing,\ TCDD}$ = total ingestion dose for TCDD; ED is the exposure duration (dependent on the receptor type); EF is the exposure frequency (350 days per year); and AT is the averaging time, and for determining the TDI, is assumed to be equal to the ED. The total dose is the sum of the dose for each of the individual congeners.

For inhalation, the ADD from inhalation exposure is calculated as follows:

$$ADD_{Inh,\,TCDD} = \frac{C_a \bullet IR \bullet ED \bullet EF}{AT \bullet 365}$$

Where: $ADD_{Inh,\ TCDD}$ is the total inhalation does for TCDD, C_a is the concentration of TCDD in air and IR is the daily inhalation rate. The total dose is the sum of the dose for each of the individual congeners.

4.2.2 Non-carcinogenic Risk

The non-carcinogenic effect of the emissions on human health can be assessed in terms of the *Hazard Quotient* (HQ). For ingestion, the HQ is calculated as the Average Daily Dose (ADD) divided by the reference dose (RfD). For example, the HQ for ingestion exposure for cadmium (Cd) is calculated as follows:

$$HQ_{Ing,\,Cd} = \frac{ADD_{Ing,\,Cd}}{RfD_{Ing,\,Cd}}$$

Where:

$$ADD_{Ing,\,Cd} = \frac{I_{Ing,\,Cd} \bullet ED \bullet EF}{AT \bullet 365}$$

Where: $ADD_{Ing,\ Cd}$ = ingestion dose for cadmium; and AT is the averaging time (equal to ED for non-carcinogenic effects and 70 years for carcinogenic risks).

For inhalation, the HQ is calculated as the exposure concentration divided by the reference concentration (RfC). For example, the HQ for inhalation exposure for cadmium (Cd) is calculated as follows:

$$HQ_{Inh,\,Cd} = \frac{EC_{Cd} \bullet 0.001}{RfC_{Inh,\,Cd}}$$

Where:

$$EC_{Cd} = \frac{C_a \bullet ED \bullet EF}{AT \bullet 365}$$

Where: EC_{Cd} is the exposure concentration (µg m^{-3}), $RfC_{Inh,\,Cd}$ is the reference concentration for cadmium (mg m^{-3}) and C_a is the concentration of cadmium in air.

The Reference Dose and Reference Concentration for each COPC and exposure pathway are provided in *Section 3.3*. The RfDs and RfCs are set conservatively, that is they are protective of health and doses at or greater than the RfD or RfC indicate the potential for effect, rather than clear and certain indication of an effect. For example, should the maximum daily intake for a source, in this case the facility, be equal to the RfD, then the HQ would be equal to 1.0 and this would indicate the potential for a health effect. On the other hand, a hazard quotient of less than unity (1.0) implies that such an exposure would not create an adverse non-carcinogenic health effect.

The *Hazard Index* (HI) is the sum of the individual COPC/pathway HQs and assumes that there are no synergistic or antagonist health effects arising from the release. The smaller the HI, the less risk to human health is implied.

4.2.3 Carcinogenic Risk

The risk of interest in this context is the extra lifetime risk associated with the total dose resulting from exposure to the facility emissions. For each COPC, the US EPA has calculated a carcinogenic slope factor (CSF). These are calculated for ingestion exposure whereas for inhalation exposure, a unit risk factor (URF) has been adopted. A summary of the factors used for this assessment is provided in *Section* 3.2 and supplemented with UK data where appropriate. Where the CSF or URF is zero, this indicates that the COPC is non-carcinogenic via that exposure route. The IRAP model uses these values to calculate a cancer risk for each pollutant and for each pathway for exposure, so that the results can be expressed in a high degree of detail.

For example, the risk associated with the ingestion exposure (food, water and soil) to cadmium is calculated as follows:

$$Risk_{Ing,\,Cd} = ADD_{Ing,\,Cd} \bullet CSF_{Ing,\,Cd}$$

Where $ADD_{Ing,\ Cd}$ is the sum of the average daily dose from all ingestion exposure routes.

The risk associated with the inhalation of cadmium is calculated as follows:

$$Risk_{Inh,\,Cd} = EC_{Cd} \bullet URF_{Inh,\,Cd}$$

4.3 EXPOSURE TO DIOXINS AND FURANS

4.3.1 Facility Contribution to Intake

The World Health Organization (WHO) recommends a tolerable daily intake for dioxins/furans of 1 to 4 pg I-TEQ kg-BW^{-1} d^{-1} (picogrammes as the International Toxic Equivalent per kilogram bodyweight per day) [9]. The TDI represents the tolerable daily intake for lifetime exposure and short-term excursions above the TDI would have no consequence provided that the average intake over long periods is not exceeded. The average (lifetime) daily intake of dioxins/furans for the receptors considered is presented in *Table 4.2* (highest values for each receptor type are picked out in bold type). These are also compared to the Committee on Toxicity (COT) TDI for dioxins and dioxin-like PCBs of 2 pg I-TEQ kg-BW^{-1} d^{-1}.

The maximum contribution of the facility to the COT TDI is 2.9% for the Farmer North 2 child receptor and 1.9% for the Farmer North 2 adult receptor. This assumes as a worst-case that these receptors produce their own home reared and home-grown food at the location of maximum impact for the area and represents an extreme worst-case. Furthermore, this assumes that both arable land and pastureland are available at this location. Therefore, it is considered that the predicted impacts for this receptor and for other farmer receptors represent an extreme worst-case.

For the residential receptors, the maximum contribution of the facility to the COT TDI is 0.1% for Resident Pinkerton 2 receptor.

Therefore, taking into consideration the worst-case assumptions adopted for the assessment, the contribution of the facility to the intake of dioxins/furans and dioxin-like PCBs is negligible.

9 Assessment of the Health Risk of Dioxins: Re-evaluation of the Tolerable Daily Intake (TD), WHO Consultation, May 25-29 1998, Geneva, Switzerland

TABLE 4.2 COMPARISON OF AVERAGE DAILY INTAKES WITH THE UK COT AND WHO'S TDI FOR DIOXINS/FURANS (pg I-TEQ kg-BW^{-1} d^{-1}) – DUNBAR ERF

Receptor Name	Adult	Child
Farmer East 1	0.0040	0.0061
Farmer East 2	0.0070	0.011
Farmer North 1	0.034	0.051
Farmer North 2	**0.038**	**0.058**
Farmer West 1	0.015	0.023
Farmer West 2	0.016	0.025
Resident Dunbar	0.000053	0.00016
Resident Innerwick 1	0.000069	0.00021
Resident Innerwick 2	0.000072	0.00022
Resident Pinkerton 1	0.00089	0.0027
Resident Pinkerton 2	**0.00090**	**0.0028**
Resident Spott	0.00017	0.00053
Resident Thurston Manor 1	0.00013	0.00041
Resident Thurston Manor 2	0.00017	0.00052
Resident Thurston Manor 3	0.00024	0.00076
WHO TDI	*1 to 4 pg I-TEQ kg-BW^{-1} d^{-1}*	
Committee on Toxicity (COT) TDI	*2 pg I-TEQ kg-BW^{-1} d^{-1}*	

4.3.2 Total Intake

The contribution of the facility to total intake is provided as follows:

- predicted incremental intake due to emissions from the facility;
- average daily background intake (i.e. that arising from other sources), referred to as the mean daily intake (MDI);
- the total intake (i.e. the sum of the predicted incremental intake and the MDI);
- a comparison of the total intake with the TDI for dioxin/furans.

For the key receptors (i.e. those which represent the predicted highest exposure for the receptor types considered) the results are presented in *Table 4.3*. Results are presented for both adult and child receptors.

The MDI is derived from data provided by the Environment Agency [10] and a value of 49 pg WHO-TEQ d^{-1}. The MDI for an adult receptor and child receptor is calculated as follows:

- for an adult receptor a MDI of 0.7 pg I-TEQ kg^{-1} d^{-1} [11] is derived by dividing the Environment Agency MDI by a bodyweight of 70 kg;
- for a child receptor a MDI of 1.8 pg I-TEQ kg^{-1} d^{-1} is derived by dividing the Environment Agency MDI by a bodyweight of 20 kg and applying an adult to child correction factor of 0.74.

A comparison of predicted intakes with the MDI and TDI is presented in *Table 4.3*. Results are presented for Farmer North 2 and Resident Pinkerton 2 where highest farmer and resident exposures are predicted.

TABLE 4.3 COMPARISON OF TOTAL INTAKE WITH THE COT TDI – DUNBAR ERF

Receptor	Total Intake from the Facility (pg I-TEQ kg^{-1} d^{-1})	Total Intake Facility + MDI (pg I-TEQ kg^{-1} d^{-1})	Facility as %age of TDI	Total Intake as %age of TDI
Farmer North 2 Adult	0.038	0.74	1.9%	36.9%
Farmer North 2 Child	0.058	1.86	2.9%	92.9%
Resident Pinkerton 2 Adult	0.00090	0.70	<0.1%	35.0%
Resident Pinkerton 2 Child	0.0028	1.80	0.1%	90.1%
COT TDI	*2*	*2*	-	-

For inhalation and oral intake of PCDD/Fs for adults, total intake is well below the TDI. Background exposure represents approximately 35% of total exposure. At worst, the facility contributes 1.9% to the TDI for adults.

For inhalation and oral intake of PCDD/Fs for children, the background intake is relatively high at 90% of the TDI. At worst, the additional contribution from the facility for a child is 0.058 pg TEQ kg^{-1} d^{-1} (2.9% of the COT TDI). Combined with the background exposure for a 20 kg child (1.8 pg TEQ kg^{-1} d^{-1}) the total intake would be below the TDI (92.9%). However, it should be noted that the TDI for PCCD/Fs is set for the purposes of assessing lifetime exposure and these elevated background exposures for children are not representative of long-term exposure. Therefore, taking into account the extreme worst-case

10 Soil Guideline Values for dioxins, furans and dioxin-like PCBs in soil, Environment Agency, Science Report SC050021/Dioxins SGV, September 2009

11 No correction is provided between the WHO-TEF and the I-TEF but a sensitivity analysis indicates that correcting between the two systems would have negligible impact on the results

assumptions adopted for farmer receptors, it is concluded that the contribution of the facility to total intake would be not significant.

4.3.3 Infant Breast Milk Exposure to Dioxins and Furans

Another exposure pathway of interest is infant exposure to dioxins and furans via the ingestion of their mother's breast milk. This is because the potential for contamination of breast milk is particularly high for dioxin-like compounds such as these, as they are extremely lipophilic (fat soluble) and hence likely to accumulate in breast milk. Further, the infant body weight is smaller and it could be argued that the effect is proportionately greater than in an adult.

This exposure is measured by the Average Daily Dose (ADD) on the basis of an averaging time of 1 year. In the US, a threshold value of 50 pg kg^{-1} d^{-1} of 2,3,7,8-TCDD TEQ is cited as being potentially harmful. The IRAP model calculates the ADD that would result from an adult receptor breast feeding an infant. It should be noted that the ADD from breast feeding calculated by IRAP does not consider dioxin-like PCBs. However, the dioxin-like PCB emission is a small fraction of the total emission and the inclusion of dioxin-like PCBs would not result in a significant increase in the ADD from breast feeding. A summary of the ADD for each of the infants of adult receptors considered for the assessment is presented in *Table 4.4.*

TABLE 4.4 ASSESSMENT OF THE AVERAGE DAILY DOSE FOR A BREAST-FED INFANT OF AN ADULT RECEPTOR – DUNBAR ERF

Receptor Name	Average Daily Dose from Breast Feeding (pg kg^{-1} d^{-1} of 2,3,7,8-TCDD)
Farmer East 1	0.016
Farmer East 2	0.027
Farmer North 1	**0.14**
Farmer North 2	**0.14**
Farmer West 1	0.062
Farmer West 2	0.065
Resident Dunbar	0.00013
Resident Innerwick 1	0.00017
Resident Innerwick 2	0.00018
Resident Pinkerton 1	0.0022
Resident Pinkerton 2	**0.0023**
Resident Spott	0.00043
Resident Thurston Manor 1	0.00033
Resident Thurston Manor 2	0.00043
Resident Thurston Manor 3	0.00063
US EPA Criterion	*50*
WHO criterion	*1 to 4*
UK criterion (COT)	2

The highest ADDs are calculated for the infants of farmer receptors and represent at worst less than 0.3% of the US EPA criterion of 50 pg kg^{-1} d^{-1} of 2,3,7,8-TCDD. The calculated ADDs for residential receptors are lower compared to the farmer since the most significant exposure to dioxins/furans is via the food chain, particularly animals and animal products. The farmer receptors are assumed to consume contaminated meat and dairy products. However, residential receptors are only assumed to consume vegetable products which are less significant with regard to exposure to dioxins/furans.

As a worst case, the ADD for the highest exposure for the infants of farmers (Farmer North 2) is 7% of the COT TDI. For these receptors it is assumed, as a worst-case, that all of the food consumed by their mother is reared and grown locally at the location of maximum impact in their area. However, this represents an extreme worst-case. Furthermore, the duration of exposure is short and the average daily intake over the lifetime of the individual would be substantially less.

The WHO recognises that breast-fed infants will be exposed to higher intakes for a short duration, but also that breast feeding itself provides associated benefits.

4.4 ASSESSMENT OF NON-CARCINOGENIC EFFECTS

4.4.1 Hazard Index

The Hazard Index (HI) calculated by IRAP for emissions from the facility for each of the receptors (adult and child) is presented in *Table 4.5* (highest values for each receptor type are picked out in bold type). These are the HIs for all COPCs where the HQ for dioxins, furans and dioxin-like PCBs has been calculated by dividing the total intake (as provided in *Table 4.2*) by the TDI.

TABLE 4.5 HAZARD INDEX FOR RESIDENT AND FARMER RECEPTORS – DUNBAR ERF

Receptor Name	**Hazard Index (HI)**	
	Adult	**Child**
Farmer East 1	0.015	0.018
Farmer East 2	0.018	0.024
Farmer North 1	**0.14**	**0.17**
Farmer North 2	0.059	0.091
Farmer West 1	0.058	0.071
Farmer West 2	0.057	0.070
Resident Dunbar	0.0025	0.0028
Resident Innerwick 1	0.0033	0.0036
Resident Innerwick 2	0.0031	0.0034
Resident Pinkerton 1	**0.039**	**0.043**
Resident Pinkerton 2	0.038	0.042
Resident Spott	0.0080	0.0088
Resident Thurston Manor 1	0.0063	0.0069
Resident Thurston Manor 2	0.0064	0.0071
Resident Thurston Manor 3	0.0057	0.0067
Criterion	*1.0*	

The HIs are well below unity (1.0) and so it is highly unlikely that emissions of COPCs from the facility would cause an adverse non-carcinogenic health risk. The highest HI is predicted for the Farmer North 1 Child this is a factor of around six less than unity. The maximum residential HI is 0.043 for Resident Pinkerton 1 (child) and is a factor of 23 less than unity. Therefore, it is concluded that the non-carcinogenic hazard for resident and farmer receptors is negligible.

4.4.2 COPC Contribution to the Hazard Index

Emissions of dioxins/furans (and dioxin-like PCBs), antimony, arsenic, benzene, cadmium, chromium, hexavalent chromium, lead, mercuric chloride, methyl mercury and nickel will contribute to the HI. For the Farmer North 1 and Resident Pinkerton 1 receptors, the contribution of each to the HI is presented in *Table 4.6*.

TABLE 4.6 COPC CONTRIBUTION TO THE HAZARD INDEX – DUNBAR ERF

COPC	HQ – Farmer North 1 Adult	HQ – Farmer North 1 Child	HQ – Resident Pinkerton 1 Adult	HQ – Resident Pinkerton 1 Child
Dioxins/furans	0.017	0.026	0.00044	0.0014
Antimony	0.000047	0.000048	0.000018	0.000018
Arsenic	0.0065	0.0078	0.0021	0.0024
Benzene	0.0019	0.0020	0.00075	0.00076
Cadmium	0.030	0.031	0.011	0.012
Chromium	0.0038	0.0061	0.00014	0.00039
Chromium VI	0.00011	0.00012	0.00004	0.000041
Lead	0.0033	0.0062	0.00044	0.00097
Mercuric chloride	0.0032	0.0059	0.00041	0.0010
Methyl mercury	0.00040	0.00079	0.000071	0.00017
Nickel	0.075	0.084	0.023	0.024
Hazard Index	0.14	0.17	0.039	0.043
Criterion	*1*			

Highest contributions arise from emissions of cadmium and nickel and combined represent around 70% of the HI for farmers and 85% for residents. Cadmium is assumed to be emitted at 50% of the Group 1 emission limit value (0.025 mg Nm^{-3}) but maximum measured concentrations of cadmium emitted from the ERF between May 2020 and January 2022 were 0.00070 mg Nm^{-3}, a factor of 36 times lower than assumed for the assessment. Similarly, nickel was assumed to be 44% of the Group 3 emission limit value of 0.5 mg Nm^{-3} (0.22 mg Nm^{-3}), this is a factor of more than 10 higher than the maximum measured concentration of nickel of 0.018 mg Nm^{-3}. Therefore, the results presented are representative of an absolute worst-case scenario.

4.5 ASSESSMENT OF CARCINOGENIC EFFECTS

4.5.1 Total Annual Risk

The total annual risk calculated by IRAP for emissions from the facility for each of the receptors (adult and child) is presented in *Table 4.7.* These are presented as the annual risk which has been derived by dividing the predicted lifetime risk by a factor of 70 (assuming a lifetime of 70 years).

The highest carcinogenic risk is predicted for Farmer North 1 (adult) and Resident Pinkerton 1 (adult). The additional, total annual risks to these receptors are 0.066×10^{-6}, (1 in 15,151,500) and 0.0083×10^{-6} (1 in 120,481,900), respectively. Such risks are well within an annual risk of 1×10^{-6} (1 in 1 million), conventionally considered to be acceptable for industrial regulation in the UK [12].

12 Risk Assessment for Environmental Professionals, CIWEM Publication (December 2001)

TABLE 4.7 TOTAL ANNUAL RISK FOR FARMER AND RESIDENT RECEPTORS – DUNBAR ERF

Receptor Name	Annual Risk	
	Adult	Child
Farmer East 1	0.0072×10^{-6}	0.0014×10^{-6}
Farmer East 2	0.010×10^{-6}	0.0021×10^{-6}
Farmer North 1	**0.066×10^{-6}**	**0.013×10^{-6}**
Farmer North 2	0.042×10^{-6}	0.0096×10^{-6}
Farmer West 1	0.028×10^{-6}	0.0056×10^{-6}
Farmer West 2	0.028×10^{-6}	0.0057×10^{-6}
Resident Dunbar	0.00054×10^{-6}	0.00013×10^{-6}
Resident Innerwick 1	0.00068×10^{-6}	0.00017×10^{-6}
Resident Innerwick 2	0.00065×10^{-6}	0.00016×10^{-6}
Resident Pinkerton 1	**0.0083×10^{-6}**	**0.0021×10^{-6}**
Resident Pinkerton 2	0.0082×10^{-6}	0.0021×10^{-6}
Resident Spott	0.0017×10^{-6}	0.00043×10^{-6}
Resident Thurston Manor 1	0.0013×10^{-6}	0.00033×10^{-6}
Resident Thurston Manor 2	0.0014×10^{-6}	0.00035×10^{-6}
Resident Thurston Manor 3	0.0013×10^{-6}	0.00037×10^{-6}
Criterion	*1.0×10^{-6}*	

4.5.2 COPC Contribution to the Annual Risk

Emissions of dioxins/furans (and dioxin-like PCBs), arsenic, benzene, BaP, cadmium, hexavalent chromium, lead, and nickel will contribute to the carcinogenic risk. For the Farmer North 1 and Resident Pinkerton 1 receptors, the contribution of each to the annual risk is presented in *Table 4.8*.

Highest contributions arise from emissions of dioxins/furans and arsenic for farmer receptors and arsenic for residents. Combined dioxins/furans and arsenic represent around 70% of the annual risk for farmers. Arsenic contributes around 50% to the annual risk for residents. Dioxins/furans are assumed to be emitted at the emission limit value of 0.1 ng TEQ Nm^{-3} but maximum measured concentrations emitted from the ERF between May 2020 and January 2022 were 0.0088 ng TEQ Nm^{-3}, a factor of more than ten lower. Arsenic is assumed to be emitted at 5% of the Group 3 emission limit value (0.025 mg Nm^{-3}) but maximum measured concentrations of arsenic between May 2020 and January 2022 were 0.00050 mg Nm^{-3}, a factor of 50 times lower than assumed for the assessment. Therefore, the results presented are representative of an absolute worst-case scenario.

TABLE 4.6 COPC CONTRIBUTION TO THE ANNUAL RISK – DUNBAR ERF

COPC	Annual Risk Farmer North 1 Adult	Annual Risk Farmer North 1 Child	Annual Risk Resident Pinkerton 1 Adult	Annual Risk Resident Pinkerton 1 Child
Dioxins/furans	0.029×10^{-6}	0.0064×10^{-6}	0.00038×10^{-6}	0.00023×10^{-6}
Arsenic	0.018×10^{-6}	0.0035×10^{-6}	0.0041×10^{-6}	0.0010×10^{-6}
Benzene	0.0067×10^{-6}	0.0010×10^{-6}	0.0020×10^{-6}	0.00040×10^{-6}
Benzo(a)pyrene	0.0056×10^{-6}	0.0011×10^{-6}	0.00037×10^{-6}	0.000078×10^{-6}
Cadmium	0.0030×10^{-6}	0.00065×10^{-6}	0.00078×10^{-6}	0.00021×10^{-6}
Chromium VI	0.00014×10^{-6}	0.000021×10^{-6}	0.000039×10^{-6}	0.0000079×10^{-6}
Lead	0.00012×10^{-6}	0.000031×10^{-6}	0.000016×10^{-6}	0.0000056×10^{-6}
Nickel	0.0024×10^{-6}	0.00036×10^{-6}	0.00069×10^{-6}	0.00014×10^{-6}
Total Annual Risk	0.066×10^{-6}	0.013×10^{-6}	0.0083×10^{-6}	0.0021×10^{-6}
Criteria	*1.0×10^{-6}*			

4.6 METAL CONCENTRATIONS IN SOIL

The IRAP model has been used to estimate the maximum predicted concentration (anywhere within the model domain) of cadmium, arsenic and nickel in soil. The results are compared to the Soil Quality Criteria (SQC) as follows:

- Arsenic – maximum concentration of 6.1×10^{-7} mg kg^{-1} (less than 0.1% of the SQC of 50 mg kg^{-1}).
- Cadmium – maximum concentration of 3.9×10^{-5} mg kg^{-1} (less than 0.1% of the SQC of 3 mg kg^{-1}).
- Nickel – maximum concentration of 3.6×10^{-4} mg kg^{-1} (less than 0.1% of the SQC of 50 mg kg^{-1}).

Therefore, the ERF will have a negligible impact on trace metal concentrations in soils.

4.7 SENSITIVITY ANALYSIS

4.7.1 Maximum Predicted Impact

SEPA has requested that the maximum impact anywhere within the model domain to be predicted. The maximum impact occurs to the immediate northeast of the Dunbar ERF (refer *Figure 4.1*). The maximum impact is compared against the highest farmer receptor and highest residential receptor in *Table 4.7* for dioxins/furans, *Table 4.8* for non-carcinogenic impacts and *Table 4.9* for carcinogenic risk.

TABLE 4.7 COMPARISON OF AVERAGE DAILY INTAKES WITH THE UK COT AND WHO'S TDI FOR DIOXINS/FURANS (pg I-TEQ kg-BW^{-1} d^{-1}) – DUNBAR ERF

Receptor Name	Adult	Child
Maximum Farmer	0.20	0.30
Farmer North 2	0.038	0.058
Maximum Resident	0.015	0.048
Resident Pinkerton 2	0.00090	0.0028

Even for the very worst-case scenario of a farmer located at the maximum impact, predicted intakes are well below the TDI of 2 pg I-TEQ kg-BW^{-1} d^{-1}. Highest impacts are predicted for the farmer child receptor and are 15% of the TDI. For a resident at this location the predicted intake is 2.4% of the TDI.

TABLE 4.8 HAZARD INDEX FOR RESIDENT AND FARMER RECEPTORS – DUNBAR ERF

Receptor Name	Hazard Index (HI)	
	Adult	Child
Maximum Farmer	0.27	0.44
Farmer North 1	0.14	0.17
Maximum Resident	0.039	0.10
Resident Pinkerton 1	0.039	0.043

The predicted HIs for the location of maximum impact are well below unity. For the maximum farmer receptor, the predicted HIs are around a factor of two higher than predicted for Farmer North 1.

TABLE 4.9 TOTAL ANNUAL RISK FOR FARMER AND RESIDENT RECEPTORS – DUNBAR ERF

Receptor Name	Annual Risk	
	Adult	Child
Maximum Farmer	0.21×10^{-6}	0.048×10^{-6}
Farmer North 1	0.066×10^{-6}	0.013×10^{-6}
Maximum Resident	0.021×10^{-6}	0.011×10^{-6}
Resident Pinkerton 1	0.0083×10^{-6}	0.0021×10^{-6}

The predicted annual risk for the location of the maximum impact is well below 1×10^{-6} considered acceptable in the UK. For the farmer receptor, maximum exposure is around three times that predicted for the Farmer North receptor.

4.7.2 Use of AERMOD

It is not possible to run AERMOD through the ADMS model for the HHRA since the AERMOD module within ADMS does not allow for the calculation of wet deposition.

The HHRA assessment carried out in March 2008 for the Dunbar ERF indicated that predicted exposures were 2.3 (resident) to 3.2 (farmer) times higher with AERMOD compared to ADMS. Applying these factors to the Farmer North and Resident Pinkerton receptors would still result in acceptable non-carcinogenic hazards and carcinogenic risks.

4.7.3 Waste Calorific Value

The air quality assessment presents a sensitivity analysis for waste with different calorific values compared to the calorific value (CV) of 10 MJ kg^{-1} assumed for the results presented in *Sections* 4.3 to *4.5*. Maximum annual mean concentrations are predicted for waste with a CV of 8.5 MJ kg^{-1}. Therefore, a sensitivity analysis is provided here for waste with the lower CV.

For the key receptors (the maximum predicted, maximum farmer and maximum resident) results are presented in *Table 4.10* for dioxins/furans, *Table 4.11* for non-carcinogenic impacts and *Table 4.12* for carcinogenic risk. These can be compared to predicted concentrations for the higher CV in *Tables 4.7* to *4.9*.

TABLE 4.10 COMPARISON OF AVERAGE DAILY INTAKES WITH THE UK COT AND WHO'S TDI FOR DIOXINS/FURANS (pg I-TEQ kg-BW^{-1} d^{-1}) – CV OF 8.5 MJ/KG

Receptor Name	Adult	Child
Maximum Farmer	0.21	0.32
Farmer North 2	0.040	0.061
Maximum Resident	0.016	0.051
Resident Pinkerton 2	0.00093	0.0029

Even for the very worst-case scenario of a farmer located at the maximum impact, predicted intakes are well below the TDI of 2 pg I-TEQ kg-BW^{-1} d^{-1}.

TABLE 4.11 HAZARD INDEX FOR RESIDENT AND FARMER RECEPTORS – CV OF 8.5 MJ/KG

Receptor Name	Hazard Index (HI)	
	Adult	Child
Maximum Farmer	0.29	0.47
Farmer North 1	0.14	0.17
Maximum Resident	0.042	0.11
Resident Pinkerton 1	0.039	0.043

The predicted HIs for the lower CV are well below unity.

TABLE 4.12 TOTAL ANNUAL RISK FOR FARMER AND RESIDENT RECEPTORS – CV OF 8.5 MJ/KG

Receptor Name	Annual Risk	
	Adult	Child
Maximum Farmer	0.22×10^{-6}	0.051×10^{-6}
Farmer North 1	0.066×10^{-6}	0.013×10^{-6}
Maximum Resident	0.022×10^{-6}	0.011×10^{-6}
Resident Pinkerton 1	0.0084×10^{-6}	0.0021×10^{-6}

The predicted annual risk for the location of the maximum impact for the lower CV is well below 1×10^{-6} considered acceptable in the UK.

4.8 COMPARISON TO 2008 ESTIMATED EXPOSURES

A comparison of the HI for the 2008 HHRA with the exposures presented here is provided in *Table 4.13*. The exposures for the 2008 assessment are predicted using the AERMOD dispersion model. Predicted exposures for this (2022) assessment are a factor of between 2 and 5 lower than predicted in 2008 and are most likely due to the difference between AERMOD and ADMS.

TABLE 4.13 HAZARD INDEX FOR RESIDENT AND FARMER RECEPTORS

Receptor Name	Hazard Index (HI)	
	Child 2008	Child 2022
Maximum Farmer Receptor	0.325	0.17
Maximum Resident Receptor	0.20	0.043

A comparison of the annual carcinogenic risk for the 2008 HHRA with the exposures presented here is provided in *Table 4.14*. The exposures for the 2008 assessment are predicted using the AERMOD dispersion model and have been converted to an annual risk by dividing by 70. Predicted exposures for this (2022) assessment are factor of between 15 and 115 lower than predicted in 2008.

TABLE 4.14 ANNUAL RISK FOR RESIDENT AND FARMER RECEPTORS

Receptor Name	Annual Risk	
	Child 2008	Child 2022
Maximum Farmer Receptor	0.19×10^{-6}	0.013×10^{-6}
Maximum Resident Receptor	0.24×10^{-6}	0.0021×10^{-6}

5 CUMULATIVE IMPACTS WITH THE TARMAC FACILITY

5.1 INTRODUCTION

For the receptors identified in *Section 4*, the combined impact of the Dunbar ERF and Tarmac Cement Kiln have been assessed.

5.2 EXPOSURE TO DIOXINS AND FURANS

5.2.1 Facility Contribution to Intake

The average (lifetime) daily intake of dioxins/furans for the receptors considered is presented in *Table 5.1* for adult receptors and *Table 5.2* for child receptors (highest values for each receptor type are picked out in bold type).

TABLE 5.1 COMPARISON OF AVERAGE DAILY INTAKES WITH THE UK COT AND WHO'S TDI FOR DIOXINS/FURANS (pg I-TEQ kg-BW^{-1} d^{-1}) – ADULT RECEPTORS

Receptor Name	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.0040	0.0087	0.013
Farmer East 2	0.0070	0.0073	0.014
Farmer North 1	0.034	**0.042**	**0.076**
Farmer North 2	**0.038**	0.030	0.068
Farmer West 1	0.015	0.024	0.039
Farmer West 2	0.016	0.026	0.043
Resident Dunbar	0.000053	0.00012	0.00017
Resident Innerwick 1	0.000069	0.00011	0.00018
Resident Innerwick 2	0.000072	0.00011	0.00018
Resident Pinkerton 1	0.00089	**0.0013**	**0.0022**
Resident Pinkerton 2	**0.00090**	**0.0013**	**0.0022**
Resident Spott	0.00017	0.00041	0.00058
Resident Thurston Manor 1	0.00013	0.00020	0.00033
Resident Thurston Manor 2	0.00017	0.00019	0.00036
Resident Thurston Manor 3	0.00024	0.00028	0.00053
WHO TDI	*1 to 4 pg I-TEQ kg-BW^{-1} d^{-1}*		
Committee on Toxicity (COT) TDI	*2 pg I-TEQ kg-BW^{-1} d^{-1}*		

TABLE 5.2 COMPARISON OF AVERAGE DAILY INTAKES WITH THE UK COT AND WHO'S TDI FOR DIOXINS/FURANS (pg I-TEQ kg-BW^{-1} d^{-1}) – CHILD RECEPTORS

Receptor Name	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.0061	0.013	0.019
Farmer East 2	0.011	0.011	0.021
Farmer North 1	0.051	**0.062**	**0.11**
Farmer North 2	**0.058**	0.044	0.10
Farmer West 1	0.023	0.035	0.058
Farmer West 2	0.025	0.039	0.063
Resident Dunbar	0.00016	0.00033	0.00050
Resident Innerwick 1	0.00021	0.00032	0.00053
Resident Innerwick 2	0.00022	0.00031	0.00053
Resident Pinkerton 1	0.0027	0.0037	0.0065
Resident Pinkerton 2	**0.0028**	**0.0039**	**0.0066**
Resident Spott	0.00053	0.0012	0.0017
Resident Thurston Manor 1	0.00041	0.00056	0.00097
Resident Thurston Manor 2	0.00052	0.00055	0.0011
Resident Thurston Manor 3	0.00076	0.00082	0.0016
WHO TDI	*1 to 4 pg I-TEQ kg-BW^{-1} d^{-1}*		
Committee on Toxicity (COT) TDI	*2 pg I-TEQ kg-BW^{-1} d^{-1}*		

For the majority of adult and child receptors, the contribution from Tarmac Cement is higher than for the Dunbar ERF. Tarmac Cement contributes around 60% of the total and Dunbar around 40%.

The maximum combined contribution to the COT TDI is 5.7% for the Farmer North 1 child receptor and 3.8% for the Farmer North 2 adult receptor. This assumes as a worst-case that these receptors produce their own home reared and home-grown food at the location of maximum impact for the area and represents an extreme worst-case.

For the residential receptors, the maximum contribution of the facility to the COT TDI is 0.3% for Resident Pinkerton 2 receptor.

Therefore, taking into consideration the worst-case assumptions adopted for the assessment, the combined contribution to the intake of dioxins/furans and dioxin-like PCBs is negligible.

5.2.2 Infant Breast Milk Exposure to Dioxins and Furans

A summary of the ADD for each of the infants of adult receptors considered for the assessment is presented in *Table 5.3* for the Dunbar ERF, Tarmac Cement and the two sources combined.

TABLE 5.3 ASSESSMENT OF THE AVERAGE DAILY DOSE (pg kg^{-1} d^{-1} of 2,3,7,8-TCDD) FOR A BREAST-FED INFANT OF ADULT RECEPTORS

Receptor Name	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.016	0.11	0.12
Farmer East 2	0.027	0.089	0.12
Farmer North 1	**0.14**	0.52	0.66
Farmer North 2	**0.14**	0.35	0.49
Farmer West 1	0.062	0.29	0.35
Farmer West 2	0.065	0.31	0.38
Resident Dunbar	0.00013	0.0012	0.0013
Resident Innerwick 1	0.00017	0.0012	0.0013
Resident Innerwick 2	0.00018	0.0011	0.0013
Resident Pinkerton 1	0.0022	0.013	0.016
Resident Pinkerton 2	**0.0023**	0.014	0.016
Resident Spott	0.00043	0.0042	0.0046
Resident Thurston Manor 1	0.00033	0.0020	0.0024
Resident Thurston Manor 2	0.00043	0.0020	0.0024
Resident Thurston Manor 3	0.00063	0.0029	0.0036
US EPA Criterion	*50*		
UK criterion (COT)	*2*		

Tarmac Cement contributes around 80% of the total combined impact. The highest ADDs for the combined emissions are calculated for the infants of farmer receptors and represent at worst less than 1.3% of the US EPA criterion of 50 pg kg^{-1} d^{-1} of 2,3,7,8-TCDD. The calculated ADDs for residential infants are less than 0.1% of the US EPA criterion.

As a worst case, the ADD for the highest exposure for the infants of farmers (Farmer North 1) is 33% of the COT TDI. This comprises 7% from the Dunbar ERF and 26% from Tarmac Cement. For these receptors it is assumed, as a worst-case, that all of the food consumed by their mother is reared and grown locally at the location of maximum impact in their area. However, this represents an extreme worst-case. Furthermore, the duration of exposure is short and the average daily intake over the lifetime of the individual would be substantially less.

Therefore, taking into consideration the worst-case assessment provided, it is concluded that the predicted impact from exposure to dioxins and furans for breast-fed infants would be negligible. Furthermore, the WHO recognises that breast-fed infants will be exposed to higher intakes for a short duration, but also that breast feeding itself provides associated benefits.

5.3 ASSESSMENT OF NON-CARCINOGENIC EFFECTS

The Hazard Index (HI) calculated by IRAP for emissions from Dunbar ERF, Tarmac Cement and the two sources combined are presented in *Table 5.4* for adult receptors and *Table 5.5* for child receptors (highest values for each receptor type are picked out in bold type).

TABLE 5.4 HAZARD INDEX FOR RESIDENT AND FARMER RECEPTORS – ADULTS

Receptor Name	Hazard Index (HI)		
	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.015	0.018	0.033
Farmer East 2	0.018	0.015	0.033
Farmer North 1	**0.14**	**0.088**	**0.23**
Farmer North 2	0.059	0.045	0.10
Farmer West 1	0.058	0.039	0.097
Farmer West 2	0.057	0.037	0.094
Resident Dunbar	0.0025	0.0036	0.0061
Resident Innerwick 1	0.0033	0.0046	0.0078
Resident Innerwick 2	0.0031	0.0043	0.0074
Resident Pinkerton 1	**0.039**	0.026	0.064
Resident Pinkerton 2	0.038	**0.027**	**0.065**
Resident Spott	0.0080	0.014	0.022
Resident Thurston Manor 1	0.0063	0.0076	0.014
Resident Thurston Manor 2	0.0064	0.0073	0.014
Resident Thurston Manor 3	0.0057	0.0067	0.012
Criterion	*1.0*		

Combined, the HIs are well below unity (1.0) and it is unlikely that the combined emissions would cause an adverse non-carcinogenic health risk. The highest combined HI is predicted for the Farmer North 1 Child this is a factor of around four less than unity. The maximum residential HI is 0.073 for Resident Pinkerton 2 (child) and is a factor of 14 less than unity.

The contribution of each to the combined HI is similar with higher contributions from the Dunbar ERF at some receptors and higher contributions from Tarmac Cement for others.

TABLE 5.5 HAZARD INDEX FOR RESIDENT AND FARMER RECEPTORS – CHILDREN

Receptor Name	Hazard Index (HI)		
	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.018	0.023	0.041
Farmer East 2	0.024	0.019	0.043
Farmer North 1	**0.17**	**0.11**	**0.28**
Farmer North 2	0.091	0.060	0.15
Farmer West 1	0.071	0.051	0.12
Farmer West 2	0.070	0.050	0.12
Resident Dunbar	0.0028	0.0039	0.0067
Resident Innerwick 1	0.0036	0.0049	0.0085
Resident Innerwick 2	0.0034	0.0046	0.0080
Resident Pinkerton 1	**0.043**	0.029	0.072
Resident Pinkerton 2	0.042	**0.031**	**0.073**
Resident Spott	0.0088	0.015	0.024
Resident Thurston Manor 1	0.0069	0.0082	0.015
Resident Thurston Manor 2	0.0071	0.0079	0.015
Resident Thurston Manor 3	0.0067	0.0074	0.014
Criterion	*1.0*		

5.4 ASSESSMENT OF CARCINOGENIC EFFECTS

The total annual risks calculated by IRAP for the combined emissions are presented in *Table 5.6* for the adult receptors and *Table 5.7* for the child receptors. These are presented as the annual risk which have been derived by dividing the predicted lifetime risk by a factor of 70 (assuming a lifetime of 70 years).

The highest combined carcinogenic risk is predicted for Farmer North 1 (adult) and Resident Pinkerton 2 (adult). The additional, total combined annual risks to these receptors are 0.13×10^{-6}, (1 in 7,692,300) and 0.015×10^{-6} (1 in 66,666,700), respectively.

For children, the highest combined carcinogenic risk is predicted for Farmer North 1 and Resident Pinkerton 2. The additional, total combined annual risks to these receptors are 0.027×10^{-6}, (1 in 37,037,000) and 0.0039×10^{-6} (1 in 256,410,300), respectively.

The predicted risks for adults and children are well within an annual risk of 1×10^{-6} (1 in 1 million), conventionally considered to be acceptable for industrial regulation in the UK.

TABLE 5.6 TOTAL ANNUAL RISK FOR FARMER AND RESIDENT RECEPTORS – ADULTS

Receptor Name	Annual Risk		
	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.0072×10^{-6}	0.014×10^{-6}	0.021×10^{-6}
Farmer East 2	0.010×10^{-6}	0.011×10^{-6}	0.021×10^{-6}
Farmer North 1	**0.066×10^{-6}**	**0.066×10^{-6}**	**0.13×10^{-6}**
Farmer North 2	0.042×10^{-6}	0.041×10^{-6}	0.083×10^{-6}
Farmer West 1	0.028×10^{-6}	0.034×10^{-6}	0.062×10^{-6}
Farmer West 2	0.028×10^{-6}	0.035×10^{-6}	0.063×10^{-6}
Resident Dunbar	0.00054×10^{-6}	0.00078×10^{-6}	0.0013×10^{-6}
Resident Innerwick 1	0.00068×10^{-6}	0.00097×10^{-6}	0.0017×10^{-6}
Resident Innerwick 2	0.00065×10^{-6}	0.00092×10^{-6}	0.0016×10^{-6}
Resident Pinkerton 1	**0.0083×10^{-6}**	0.0060×10^{-6}	0.014×10^{-6}
Resident Pinkerton 2	0.0082×10^{-6}	**0.0064×10^{-6}**	**0.015×10^{-6}**
Resident Spott	0.0017×10^{-6}	0.0030×10^{-6}	0.0047×10^{-6}
Resident Thurston Manor 1	0.0013×10^{-6}	0.0016×10^{-6}	0.0029×10^{-6}
Resident Thurston Manor 2	0.0014×10^{-6}	0.0016×10^{-6}	0.0030×10^{-6}
Resident Thurston Manor 3	0.0013×10^{-6}	0.0015×10^{-6}	0.0028×10^{-6}
Criterion	*1.0×10^{-6}*		

TABLE 5.7 TOTAL ANNUAL RISK FOR FARMER AND RESIDENT RECEPTORS – CHILDREN

Receptor Name	Annual Risk		
	Dunbar ERF	Tarmac Cement	Combined
Farmer East 1	0.0014×10^{-6}	0.0028×10^{-6}	0.0042×10^{-6}
Farmer East 2	0.0021×10^{-6}	0.0023×10^{-6}	0.0044×10^{-6}
Farmer North 1	**0.013×10^{-6}**	**0.014×10^{-6}**	**0.027×10^{-6}**
Farmer North 2	0.0096×10^{-6}	0.0086×10^{-6}	0.018×10^{-6}
Farmer West 1	0.0056×10^{-6}	0.0070×10^{-6}	0.013×10^{-6}
Farmer West 2	0.0057×10^{-6}	0.0074×10^{-6}	0.013×10^{-6}
Resident Dunbar	0.00013×10^{-6}	0.00021×10^{-6}	0.00034×10^{-6}
Resident Innerwick 1	0.00017×10^{-6}	0.00024×10^{-6}	0.00041×10^{-6}
Resident Innerwick 2	0.00016×10^{-6}	0.00023×10^{-6}	0.00039×10^{-6}
Resident Pinkerton 1	0.0021×10^{-6}	0.0017×10^{-6}	0.0038×10^{-6}
Resident Pinkerton 2	**0.0021×10^{-6}**	**0.0018×10^{-6}**	**0.0039×10^{-6}**
Resident Spott	0.00043×10^{-6}	0.00078×10^{-6}	0.0012×10^{-6}
Resident Thurston Manor 1	0.00033×10^{-6}	0.00041×10^{-6}	0.00074×10^{-6}
Resident Thurston Manor 2	0.00035×10^{-6}	0.00040×10^{-6}	0.00075×10^{-6}
Resident Thurston Manor 3	0.00037×10^{-6}	0.00042×10^{-6}	0.00079×10^{-6}
Criterion	*1.0×10^{-6}*		

6 SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The possible impacts on human health arising from emissions from the Dunbar ERF have been assessed for the proposed changes to the plant performance. The assessment is for a worst-case scenario, namely that of an individual exposed for a lifetime to the effects of the highest airborne concentrations and consuming mostly locally grown food. This equates to a hypothetical farmer consuming food grown on the farm, situated at the closest proximity to the facility. Where there are no active farming areas in close proximity, a residential receptor is considered where it is assumed that the resident consumes locally grown vegetables.

The assessment has considered emissions of dioxins, furans, dioxin-like PCBs, trace metal emissions, benzene and benzo(a)pyrene. The impact of dioxin, furans and dioxin-like PCBs has been assessed by comparison of the predicted intake with the COT TDI. In addition, the carcinogenic risk of the emissions has been assessed as well as the non-carcinogenic hazard.

The assessment has identified and considered the most plausible pathways of exposure for the individuals considered (farmer and resident). Deposition and subsequent uptake of the compounds of potential concern (COPCs) into the food chain is likely to be the more numerically significant pathway over direct inhalation.

The maximum contribution of the Dunbar ERF to the COT TDI is 2.9% for the farmer receptors and 0.1% for the residential receptors. For the farmer this assumes as a worst-case that these receptors are located at the closest farming area to the facility and all of their food is reared and grown at this location and represents an extreme worst-case. Therefore, taking into account the extreme worst-case assumptions, the impact of dioxin, furan and dioxin-like PCB emissions on local sensitive receptors is considered to be not significant.

The non-carcinogenic hazard from exposure to dioxins, furans, dioxin-like PCBs, antimony, arsenic, benzene, cadmium, chromium, hexavalent chromium, lead, mercuric chloride, methyl mercury and nickel has been assessed. The total hazard index was predicted for farmer receptors and at 0.17 was well below a value of 1.0 which is considered as an acceptable exposure level.

The carcinogenic risk of exposure to dioxins, furans, arsenic, benzene, benzo(a)pyrene, cadmium, hexavalent chromium, lead and nickel has been assessed. The total annual risk was predicted for farmer receptors and at 0.066 x 10^{-6} (1 in 15,151,500) was well below a value of 1.0 x 10^{-6} (1 in 1,000,000) which is considered an acceptable risk in the UK.

A comparison of the non-carcinogenic hazard and carcinogenic risk with the previous assessment carried out in 2008 has been provided. There was some lack of transparency on the assumptions adopted previously and it is difficult to make a direct comparison between the two assessments. However, the predicted exposures for this assessment are lower than predicted previously.

The assessment has also considered the cumulative impact of emissions from the Dunbar ERF with emissions from the Tarmac Cement Kiln.

6.2 CONCLUSIONS

The risk assessment methodology used in this assessment has been structured so as to create worst case estimates of risk. A number of features in the methodology give rise to this degree of conservatism. It has been demonstrated that for the maximally exposed individual, exposure to emissions from the Dunbar ERF is not significant.

Therefore, taking into account the worst-case assumptions adopted for the assessment, it is concluded that the risk to health from changes to the ERF emissions would be negligible.

ANNEX A

SITE PARAMETERS

Annex A: Site Parameters Defined for the Health Risk Assessment

Parameter	Parameter Value	IRAP Symbol	Units
Soil dry bulk density	1.5	bd	g cm^{-3}
Forage fraction grown on contam. soil eaten by CATTLE	1.0	beef_fi_forage	--
Grain fraction grown on contam. soil eaten by CATTLE	1.0	beef_fi_grain	--
Silage fraction grown on contam. eaten by CATTLE	1.0	beef_fi_silage	--
Qty of forage eaten by CATTLE each day	8.8	beef_qp_forage	kg DW d^{-1}
Qty of grain eaten by CATTLE each day	0.47	beef_qp_grain	kg DW d^{-1}
Qty of silage eaten by CATTLE each day	2.5	beef_qp_silage	kg DW d^{-1}
Grain fraction grown on contam. soil eaten by CHICKEN	1.0	chick_fi_grain	--
Qty of grain eaten by CHICKEN each day	0.2	chick_qp_grain	kg DW d^{-1}
Fish lipid content	0.07	f_lipid	--
Fraction of CHICKEN's diet that is soil	0.1	fd_chicken	--
Universal gas constant	8.205e-5	gas_r	atm-m^3 mol^{-1} K^{-1}
Plant surface loss coefficient	18	kp	a^{-1}
Fraction of mercury emissions NOT lost to the global cycle	0.48	merc_q_corr	--
Fraction of mercury speciated into methyl mercury in produce	0.22	mercmethyl_ag	--
Fraction of mercury speciated into methyl mercury in soil	0.02	mercmethyl_sc	--
Forage fraction grown contam. soil, eaten by MILK CATTLE	1.0	milk_fi_forage	--
Grain fraction grown contam. soil, eaten by MILK CATTLE	1.0	milk_fi_grain	--
Silage fraction grown contam. soil, eaten by MILK CATTLE	1.0	milk_fi_silage	--
Qty of forage eaten by MILK CATTLE each day	13.2	milk_qp_forage	kg DW d^{-1}
Qty of grain eaten by MILK CATTLE each day	3.0	milk_qp_grain	kg DW d^{-1}
Qty of silage eaten by MILK CATTLE each day	4.1	milk_qp_silage	kg DW d^{-1}
Averaging time	1	milkfat_at	a
Body weight of infant	9.4	milfat_bw_infant	kg
Exposure duration of infant to breast milk	1	milkfat_ed	a
Proportion of ingested dioxin that is stored in fat	0.9	milkfat_f1	--
Proportion of mothers weight that is fat	0.3	milkfat_f2	--
Fraction of fat in breast milk	0.04	milkfat_f3	--
Fraction of ingested contaminant that is absorbed	0.9	milkfat_f4	--
Half-life of dioxin in adults	2555	milkfat_h	d
Ingestion rate of breast milk	0.688	milkfat_ir_milk	kg d^{-1}
Viscosity of air corresponding to air temp.	1.81e-04	mu_a	g cm^{-1} s^{-1}
Fraction of grain grown on contam. soil eaten by PIGS	1.0	pork_fi_grain	--
Fraction of silage grown on contam. soil and eaten by PIGS	1.0	pork_fi_silage	--
Qty of grain eaten by PIGS each day	3.3	pork_qp_grain	kg DW d^{-1}
Qty of silage eaten by PIGS each day	1.4	pork_qp_silage	kg DW d^{-1}
Qty of soil eaten by CATTLE	0.5	qs_beef	kg d^{-1}
Qty of soil eaten by CHICKEN	0.022	qs_chick	kg d^{-1}
Qty of soil eaten by DAIRY CATTLE	0.4	qs_milk	kg d^{-1}
Qty of soil eaten by PIGS	0.37	qs_pork	kg d^{-1}
Density of air	1.2e-3	rho_a	g cm^{-3}
Solids particle density	2.7	rho_s	g cm^{-3}
Interception fraction - edible portion ABOVEGROUND	0.39	rp	--
Interception fraction - edible portion FORAGE	0.5	rp_forage	--
Interception fraction - edible portion SILAGE	0.46	rp_silage	--
Ambient air temperature	298	t	K
Temperature correction factor	1.026	theta	--
Soil volumetric water content	0.2	theta_s	mL cm^{-3}
Length of plant expos. to depos. - ABOVEGROUND	0.16	tp	a
Length of plant expos. to depos. - FORAGE	0.12	tp_forage	a
Length of plant expos. to depos. - SILAGE	0.16	tp_silage	a
Average annual wind speed	3.9	u	m s^{-1}
Dry deposition velocity	0.5	vdv	cm s^{-1}
Dry deposition velocity for mercury	2.9	vdv_hg	cm s^{-1}
Wind velocity	3.9	w	m s^{-1}
Yield/standing crop biomass - edible portion ABOVEGROUND	2.24	yp	kg DW m^{-2}
Yield/standing crop biomass - edible portion FORAGE	0.24	yp_forage	kg DW m^{-2}
Yield/standing crop biomass - edible portion SILAGE	0.8	yp_silage	kg DW m^{-2}
Soil mixing zone depth	2.0	z	cm

ANNEX B

SCENARIO PARAMETERS

Annex B: Exposure Scenario Parameters

Parameter Description	Adult Resident	Child Resident	Adult Farmer	Child Farmer	Adult Fisher	Child Fisher	Units
Averaging time for carcinogens	70	70	70	70	70	70	a
Averaging time for noncarcinogens	30	6	40	6	30	6	a
Consumption rate of BEEF	0.0	0.0	0.00122	0.00075	0.0	0.0	kg kg^{-1} FW d^{-1}
Body weight	70	15	70	15	70	15	kg
Consumption rate of POULTRY	0.0	0.0	0.00066	0.00045	0.0	0.0	kg kg^{-1} FW d^{-1}
Consumption rate of ABOVEGROUND PRODUCE	0.00032	0.00077	0.00047	0.00113	0.00032	0.00077	kg kg^{-1} DW d^{-1}
Consumption rate of BELOWGROUND PRODUCE	0.00014	0.00023	0.00017	0.00028	0.00014	0.00023	kg kg^{-1} DW d^{-1}
Consumption rate of DRINKING WATER	1.4	0.67	1.4	0.67	1.4	0.67	L d^{-1}
Consumption rate of PROTECTED ABOVEGROUND PRODUCE	0.00061	0.0015	0.00064	0.00157	0.00061	0.0015	kg kg^{-1} DW d^{-1}
Consumption rate of SOIL	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002	kg d^{-1}
Exposure duration	30	6	40	6	30	6	yr
Exposure frequency	350	350	350	350	350	350	d a^{-1}
Consumption rate of EGGS	0.0	0.0	0.00075	0.00054	0.0	0.0	kg kg^{-1} FW d^{-1}
Fraction of contaminated ABOVEGROUND PRODUCE	1.0	1.0	1.0	1.0	1.0	1.0	--
Fraction of contaminated DRINKING WATER	1.0	1.0	1.0	1.0	1.0	1.0	--
Fraction contaminated SOIL	1.0	1.0	1.0	1.0	1.0	1.0	--
Consumption rate of FISH	0.0	0.0	0.0	0.0	0.00125	0.00088	kg kg^{-1} FW d^{-1}
Fraction of contaminated FISH	1.0	1.0	1.0	1.0	1.0	1.0	--
Inhalation exposure duration	30	6	40	6	30	6	a
Inhalation exposure frequency	350	350	350	350	350	350	d a^{-1}
Inhalation exposure time	24	24	24	24	24	24	h d^{-1}
Fraction of contaminated BEEF	1	1	1	1	1	1	--
Fraction of contaminated POULTRY	1	1	1	1	1	1	--
Fraction of contaminated EGGS	1	1	1	1	1	1	--
Fraction of contaminated MILK	1	1	1	1	1	1	--
Fraction of contaminated PORK	1	1	1	1	1	1	--
Inhalation rate	0.83	0.30	0.83	0.30	0.83	0.30	m^3 h^{-1}
Consumption rate of MILK	0.0	0.0	0.01367	0.02268	0.0	0.0	kg kg^{-1} FW d^{-1}
Consumption rate of PORK	0.0	0.0	0.00055	0.00042	0.0	0.0	kg kg^{-1} FW d^{-1}
Time period at the beginning of combustion	0	0	0	0	0	0	a
Length of exposure duration	30	6	40	6	30	6	a

ANNEX C

SUMMARY OF EXTRACTIVE MONITORING – DUNBAR ERF

Dunbar ERF - Extractive Monitoring

Below the limit of detection | Excluded from average | Where concentration below LoD, concentration assumed to be at the LoD

		A1	A1	A1	A1	A2	A2	A2	A2	Average	Maximum
		May-20	Oct-20	Feb-21	Jan-22	May-20	Nov-20	Feb-21	Jan-22		
Actual flow	Am3/s	42.86	45.72	43.86	41.63	47.23	46.02	47.66	40.95	44.5	47.7
Normalised flow	Nm3/s	31.48	33.15	29.70	32.61	32.79	32.93	30.90	32.10	32.0	33.2
Temperature	oC	151.1	157.1	152	144	150	157	153	144	151.1	
Moisture	%v/v	16.3	15.5	18.2	17.8	19.6	17.2	19.3	17.5	17.7	
Oxygen	%v/v dry	7.2	6.28	7.6	6.5	7.1	7.03	7.6	6.70	7.0	
Cd & Tl		0.0008	0.0009	0.00086	0.001	0.001	0.00068	0.00083	0.0008	0.00086	0.0010
Metals		0.009	0.013	0.018	0.01	0.015	0.029	0.052	0.007	0.019	0.052
Hg		0.0005	0.0004	0.00066	0.0008	0.00034	0.00058	0.00064	0.0007	0.00058	0.00080
Cd		0.0004	0.0005	0.0005	0.0007	0.0004	0.0004	0.0005	0.0004	0.00048	0.00070
Tl		0.0004	0.0004	0.0004	0.0003	0.0004	0.0003	0.0004	0.0003	0.00036	0.00040
Hg		0.0005	0.00044	0.00066	0.0008	0.00034	0.00058	0.00064	0.0007	0.00058	0.00080
As		0.0005	0.0005	0.0005	0.0004	0.0005	0.0004	0.0005	0.0004	0.00046	0.00050
Co		0.0004	0.0004	0.0005	0.0004	0.0004	0.0004	0.0005	0.0004	0.00043	0.00050
Cr		0.0035	0.0063	0.0112	0.001	0.0034	0.0026	0.0295	0.001	0.0073	0.030
Cu		0.0018	0.0011	0.0009	0.0008	0.0028	0.0017	0.0017	0.0009	0.0015	0.0028
Mn		0.0006	0.0023	0.0006	0.0008	0.0004	0.0012	0.0005	0.0007	0.00089	0.0023
Ni		0.0009	0.0005	0.0012	0.0043	0.0007	0.0179	0.0005	0.0021	0.0035	0.018
Pb		0.0008	0.0014	0.0026	0.002	0.0064	0.0044	0.0176	0.0008	0.0045	0.018
Sb		0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.00050	0.00050
V		0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0003	0.00031	0.00040
Dioxins (TEQ WHO Humans, LOD)	ng/Nm3	0.0021	0.0055	0.0088	0.0013	0.0029	0.0074	0.0065	0.0018	0.0045	0.0088
PCBs (TEQ WHO Humans LOD)	ng/Nm3	0.000226	0.00055	0.00092	0.000029	0.000343	0.00069	0.00087	0.000035	0.00046	0.00092
BaP	ug/Nm3	0.004	0.0037	0.0074	0.007209	0.003	0.0032	0.0076	0.007122	0.0060	0.0076
Total TOCs (as carbon)	mg/Nm3	0.29	0.52	0.27	0.32	0.49	0.27	1.3	0.15	0.47	1.3

Dioxins/Furans	ng	%age	ng	%age	ng	%age	ng	%age	ng	%age	ng	%age	ng	%age	ng	%age	Average %age
TetraCDD, 2,3,7,8-	0.0008	0.6%	0.0015	0.2%	0.0028	0.2%	0.0022	0.3%	0.0012	0.6%	0.0014	0.2%	0.0021	0.3%	0.001	0.0%	0.3%
PentaCDD, 1,2,3,7,8-	0.0049	3.6%	0.0121	1.5%	0.021	1.7%	0.0087	1.1%	0.0071	3.5%	0.0111	1.4%	0.0163	2.0%	0.0083	0.3%	2.1%
HexaCDD, 1,2,3,4,7,8-	0.003	2.2%	0.013	1.7%	0.0277	2.2%	0.0116	1.4%	0.0066	3.3%	0.0187	2.4%	0.0204	2.5%	0.0127	0.4%	2.2%
HexaCDD, 1,2,3,6,7,8-	0.0098	7.3%	0.0314	4.0%	0.0923	7.4%	0.0422	5.2%	0.0131	6.5%	0.05	6.4%	0.0645	7.8%	0.0489	1.5%	6.4%
HexaCDD, 1,2,3,7,8,9-	0.0047	3.5%	0.0194	2.5%	0.0462	3.7%	0.0196	2.4%	0.0061	3.0%	0.0258	3.3%	0.0303	3.7%	0.0256	0.8%	3.1%
HeptaCDD, 1,2,3,4,6,7,8-	0.0414	30.6%	0.217	27.6%	0.498	39.7%	0.244	29.8%	0.0588	29.3%	0.292	37.2%	0.301	36.4%	0.444	13.6%	33.0%
OctaCDD, 1,2,3,4,6,7,8,9-	0.0266	19.7%	0.335	42.7%	0.33	26.3%	0.285	34.9%	0.0435	21.7%	0.217	27.7%	0.215	26.0%	2.27	69.5%	28.4%
TetraCDF, 2,3,7,8-	0.0047	3.5%	0.0079	1.0%	0.0109	0.9%	0.0029	0.4%	0.0053	2.6%	0.0104	1.3%	0.0149	1.8%	0.0049	0.2%	1.6%
PentaCDF, 1,2,3,7,8-	0.0039	2.9%	0.007	0.9%	0.0148	1.2%	0.0067	0.8%	0.0045	2.2%	0.007	0.9%	0.0122	1.5%	0.0073	0.2%	1.5%
PentaCDF, 2,3,4,7,8-	0.0104	7.7%	0.0236	3.0%	0.044	3.5%	0.0144	1.8%	0.0139	6.9%	0.0306	3.9%	0.0359	4.3%	0.0194	0.6%	4.4%
HexaCDF, 1,2,3,4,7,8-	0.0037	2.7%	0.0094	1.2%	0.0186	1.5%	0.0111	1.4%	0.0062	3.1%	0.0157	2.0%	0.013	1.6%	0.0134	0.4%	1.9%
HexaCDF, 1,2,3,6,7,8-	0.0046	3.4%	0.0136	1.7%	0.0293	2.3%	0.0095	1.2%	0.0068	3.4%	0.0185	2.4%	0.0201	2.4%	0.0155	0.5%	2.4%
HexaCDF, 2,3,4,6,7,8-	0.0072	5.3%	0.0223	2.8%	0.0446	3.6%	0.0235	2.9%	0.0082	4.1%	0.0299	3.8%	0.0303	3.7%	0.0254	0.8%	3.7%
HexaCDF, 1,2,3,7,8,9-	0.0005	0.4%	0.0016	0.2%	0.0025	0.2%	0.0018	0.2%	0.0004	0.2%	0.003	0.4%	0.0022	0.3%	0.0027	0.1%	0.3%
HeptaCDF, 1,2,3,4,6,7,8-	0.0062	4.6%	0.0457	5.8%	0.0498	4.0%	0.035	4.3%	0.0134	6.7%	0.0318	4.1%	0.034	4.1%	0.128	3.9%	4.8%
HeptaCDF, 1,2,3,4,7,8,9-	1.20E-03	0.9%	0.0043	0.5%	0.0102	0.8%	0.0066	0.8%	0.0015	0.7%	0.0071	0.9%	0.0071	0.9%	0.014	0.4%	0.8%
OctaCDF, 1,2,3,4,6,7,8,9-	1.50E-03	1.1%	0.0206	2.6%	0.0115	0.9%	0.0927	11.3%	0.0043	2.1%	0.014	1.8%	0.008	1.0%	0.225	6.9%	3.0%

																	Averge
Total dioxins (ng)	0.0912	67.5%	0.6294	80.1%	1.0180	81.2%	0.6133	75.0%	0.1364	67.9%	0.6160	78.6%	0.6496	78.5%	2.8105	86.1%	
Total furans (ng)	0.0439	32.5%	0.1560	19.9%	0.2362	18.8%	0.2042	25.0%	0.0645	32.1%	0.1680	21.4%	0.1777	21.5%	0.4556	13.9%	
Total (ng)	0.1351	100.0%	0.7854	100.0%	1.2542	100.0%	0.8175	100.0%	0.2009	100.0%	0.7840	100.0%	0.8273	100.0%	3.2661	100.0%	

ANNEX D

SUMMARY OF EXTRACTIVE MONITORING – TARMAC CEMENT KILN

Tarmac Cement Works - Dunbar

Below the limit of detection | Excluded from average | Where concentration below LoD, concentration assumed to be at the LoD

		EP10	EP10	EP10	EP10	EP10	EP10	Average	Max
		Feb-19	Mar-19	Jul-19	Oct-19	Aug-20	Feb-21		
Actual flow	Am3/s	169.96	175.51	192.16	116.61	176.88	141.39	162.1	192.2
Normalised flow	Nm3/s	88.66	81.51	99.34	53.13	85.48	69.74	79.6	99.3
Temperature	oC	53	60	55	30.9	53	56	51.3	
Moisture	%v/v	15.5	16.6	19.99	13.8	13.6	14	15.6	
Oxygen	%v/v dry	13	13.6	12.4	13.9	12.8	13.4	13.2	
Cd & Tl	mg/Nm3	0.0038	0.004	0.0029	0.0025	0.002	0.0025	0.0030	0.0040
Metals	mg/Nm3	0.063	0.186	0.2659	0.15	0.039	0.12	0.14	0.27
Hg	mg/Nm3	0.00078	0.004	0.0011	0.00055	0.00053	0.00076	0.0013	0.0040
Cd	mg/Nm3	0.00062	0.00201	0.0018	0.00093	0.0007	0.0007	0.0011	0.0020
Tl	mg/Nm3	0.0032	0.00161	0.00106	0.0016	0.0013	0.0018	0.0018	0.0032
Hg	mg/Nm3	0.00078	0.004		0.00055	0.00053	0.00076	0.0013	0.0040
As	mg/Nm3	0.00068	0.00077	0.0014	0.0001	0.0007	0.0007	0.00073	0.0014
Co	mg/Nm3	0.00062	0.0006	0.0005	0.001	0.0007	0.0007	0.00069	0.0010
Cr	mg/Nm3	0.0053	0.00991	0.02869	0.0088	0.0078	0.0102	0.012	0.029
Cu	mg/Nm3	0.0034	0.09971	0.05419	0.035	0.0082	0.025	0.038	0.100
Mn	mg/Nm3	0.02	0.01871	0.0666	0.052	0.0141	0.028	0.033	0.067
Ni	mg/Nm3	0.025	0.00949	0.01193	0.035	0.004	0.0452	0.022	0.045
Pb	mg/Nm3	0.0062	0.00402	0.00669	0.015	0.0023	0.0088	0.0072	0.015
Sb	mg/Nm3	0.00073	0.0364	0.09154	0.0011	0.0009	0.001	0.022	0.092
V	mg/Nm3	0.001	0.00682	0.0044	0.0012	0.0007	0.0016	0.0026	0.0068
Dioxins (I-TEQ Humans, LOD)	ng/Nm3	0.00081	0.00046	0.0074	0.00078	0.00031	0.0014	0.0019	0.0074
PCBs (WHO-TEQ Humans LOD)	ng/Nm3	0.0021	-	-	0.000044	0.000025	0.000078	0.00056	0.0021
BaP	ug/Nm3	0.56	0.9077	-	0.0044	0.0043	0.0053	0.30	0.91
Benzene	mg/Nm3	8.7	-	-	0.25	11.6	1.0	5.4	11.6

Dioxins/Furans	TEQ	ng	ng TEQ	%age	ng	ng TEQ	%age	ng	ng TEQ	%age	ng	ng TEQ	%age	ng	ng TEQ	%age	ng	ng TEQ	%age	Average %age All	Average Last 4		Order for HHRA Spreadsheet
TetraCDD, 2,3,7,8-	1	0.0012	0.001200	27.2%	0.0004	0.000400	26.8%	0.0011	0.001100	5.1%	0.0002	0.000200	7.0%	0.0003	0.000300	24.9%	0.0001	0.000100	2.3%	15.5%	9.8%	TetraCDD, 2,3,7,8-	2,3,7,8-TCDD
PentaCDD, 1,2,3,7,8-	0.5	0.0012	0.000600	13.6%	0.0008	0.000400	26.8%	0.0041	0.002050	9.5%	0.0003	0.000150	5.2%	0.0003	0.000150	12.5%	0.0010	0.000500	11.3%	13.1%	9.6%	PentaCDD, 1,2,3,7,8-	1,2,3,7,8-PeCDD
HexaCDD, 1,2,3,4,7,8-	0.1	0.0013	0.000130	2.9%	0.0006	0.000060	4.0%	0.0036	0.000360	1.7%	0.0003	0.000030	1.0%	0.0002	0.000020	1.7%	0.0004	0.000040	0.9%	2.0%	1.3%	HexaCDD, 1,2,3,4,7,8-	1,2,3,4,7,8-HxCDD
HexaCDD, 1,2,3,6,7,8-	0.1	0.0013	0.000130	2.9%	0.0006	0.000060	4.0%	0.0273	0.002730	12.6%	0.0005	0.000050	1.7%	0.0008	0.000080	6.6%	0.0006	0.000060	1.4%	4.9%	5.6%	HexaCDD, 1,2,3,6,7,8-	1,2,3,7,8,9-HxCDD
HexaCDD, 1,2,3,7,8,9-	0.1	0.0016	0.000160	3.6%	0.0006	0.000060	4.0%	0.0132	0.001320	6.1%	0.0007	0.000070	2.4%	0.0002	0.000020	1.7%	0.0005	0.000050	1.1%	3.2%	2.8%	HexaCDD, 1,2,3,7,8,9-	1,2,3,6,7,8-HxCDD
HeptaCDD, 1,2,3,4,6,7,8-	0.01	0.0039	0.000039	0.9%	0.0005	0.000005	0.3%	0.127	0.001270	5.9%	0.073	0.000730	25.4%	0.0096	0.000096	8.0%	0.0045	0.000045	1.0%	6.9%	10.1%	HeptaCDD, 1,2,3,4,6,7,8-	1,2,3,4,6,7,8-HpCDD
OctaCDD, 1,2,3,4,6,7,8,9-	0.001	0.0028	0.000003	0.1%	0.00936	0.000009	0.6%	0.103	0.000103	0.5%	0.0164	0.000016	0.6%	0.0387	0.000039	3.2%	0.0140	0.000014	0.3%	0.9%	1.1%	OctaCDD, 1,2,3,4,6,7,8,9-	OCDD
TetraCDF, 2,3,7,8-	0.1	0.0014	0.000140	3.2%	0.0007	0.000070	4.7%	0.0096	0.000960	4.4%	0.0027	0.000270	9.4%	0.0019	0.000190	15.8%	0.0050	0.000500	11.3%	8.1%	10.2%	TetraCDF, 2,3,7,8-	2,3,7,8-TCDF
PentaCDF, 1,2,3,7,8-	0.05	0.0019	0.000095	2.2%	0.0004	0.000020	1.3%	0.0088	0.000440	2.0%	0.001	0.000050	1.7%	0.0003	0.000015	1.2%	0.0027	0.000135	3.1%	1.9%	2.0%	PentaCDF, 1,2,3,7,8-	2,3,4,7,8-PeCDF
PentaCDF, 2,3,4,7,8-	0.5	0.0018	0.000900	20.4%	0.0004	0.000200	13.4%	0.0151	0.007550	34.9%	0.0016	0.000800	27.8%	0.0002	0.000100	8.3%	0.0039	0.001950	44.1%	24.8%	28.8%	PentaCDF, 2,3,4,7,8-	1,2,3,7,8-PeCDF
HexaCDF, 1,2,3,4,7,8-	0.1	0.0023	0.000230	5.2%	0.0004	0.000040	2.7%	0.0089	0.000890	4.1%	0.0013	0.000130	4.5%	0.0005	0.000050	4.2%	0.0029	0.000290	6.6%	4.5%	4.8%	HexaCDF, 1,2,3,4,7,8-	1,2,3,4,7,8-HxCDF
HexaCDF, 1,2,3,6,7,8-	0.1	0.0023	0.000230	5.2%	0.0004	0.000040	2.7%	0.0111	0.001110	5.1%	0.0013	0.000130	4.5%	0.0003	0.000030	2.5%	0.0029	0.000290	6.6%	4.4%	4.7%	HexaCDF, 1,2,3,6,7,8-	1,2,3,7,8,9-HxCDF
HexaCDF, 2,3,4,6,7,8-	0.1	0.0025	0.000250	5.7%	0.0004	0.000040	2.7%	0.0127	0.001270	5.9%	0.0017	0.000170	5.9%	0.0002	0.000020	1.7%	0.0031	0.000310	7.0%	4.8%	5.1%	HexaCDF, 2,3,4,6,7,8-	1,2,3,6,7,8-HxCDF
HexaCDF, 1,2,3,7,8,9-	0.1	0.0028	0.000280	6.3%	0.0005	0.000050	3.3%	0.0021	0.000210	1.0%	0.0002	0.000020	0.7%	0.0004	0.000040	3.3%	0.0007	0.000070	1.6%	2.7%	1.6%	HexaCDF, 1,2,3,7,8,9-	2,3,4,6,7,8-HxCDF
HeptaCDF, 1,2,3,4,6,7,8-	0.01	0.0011	0.000011	0.2%	0.00333	0.000033	2.2%	0.02	0.000200	0.9%	0.0053	0.000053	1.8%	0.0045	0.000045	3.7%	0.0059	0.000059	1.3%	1.7%	2.0%	HeptaCDF, 1,2,3,4,6,7,8-	1,2,3,4,6,7,8-HpCDF
HeptaCDF, 1,2,3,4,7,8,9-	0.01	0.0014	0.000014	0.3%	0.00047	0.000005	0.3%	0.0059	0.000059	0.3%	0.0006	0.000006	0.2%	0.0003	0.000003	0.2%	0.0007	0.000007	0.2%	0.3%	0.2%	HeptaCDF, 1,2,3,4,7,8,9-	1,2,3,4,7,8,9-HpCDF
OctaCDF, 1,2,3,4,6,7,8,9-	0.001	0.0019	0.000002	0.0%	0.0015	0.000002	0.1%	0.0102	0.000010	0.0%	0.0021	0.000002	0.1%	0.0064	0.000006	0.5%	0.0027	0.000003	0.1%	0.1%	0.2%	OctaCDF, 1,2,3,4,6,7,8,9-	OCDF
																					Average		Total
Total dioxins (ng)		0.0133	0.0023	51%	0.0129	0.0010	67%	0.2793	0.0089	41%	0.0914	0.0012	43%	0.0501	0.0007	59%	0.0211	0.0008	18%				
Total furans (ng)		0.0194	0.0022	49%	0.0085	0.0005	33%	0.1044	0.0127	59%	0.0178	0.0016	57%	0.0150	0.0005	41%	0.0305	0.0036	82%				
Total (ng)		0.0327	0.0044	100%	0.0214	0.0015	100%	0.3837	0.0216	100%	0.1092	0.0029	100%	0.0651	0.0012	100%	0.0516	0.0044	100%				

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