REVISED DIOXIN AND FURAN HEALTH RISK ASSESSMENT OF EMISSIONS FROM A PROPOSED WASTE TREATMENT AND TRANSFER FACILITY

GRUNDON WASTE MANAGEMENT LIMITED
ZINC ROAD, AVONMOUTH

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Executive Summary

Grundon Waste Management Limited (Grundon) proposes to redevelop an existing low Carbon energy facility located on Zinc Road in the Avonmouth industrial area. The facility previously processed refuse derived fuel, although is believed to have ceased operation in 2016. Grundon has now acquired the site and intends to replace key plant with an alternative, smaller scale waste treatment and transfer facility (the Facility).

The new scheme includes a high temperature treatment process and detailed atmospheric dispersion modelling has been undertaken to consider the potential impact of the emissions to atmosphere from the Facility. Emissions from the treatment process will include small quantities of Dioxins and Furans released to air from the 36.5-metre-high stack associated with the Facility.

An initial health risk assessment was undertaken in support of the planning application and this revised assessment is produced at the point of application for a variation to the site Environmental Permit. This latest assessment benefits from the detailed design data now available and applied the process contributions of Dioxins and Furans predicted by the modelling to occur in the local area, to assess the potential impact on the health of people living and working in the vicinity of the installation. The Lakes Environmental IRAP-h View software package has been used to apply the US EPA Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (HHRAP) in assessing the impact of emissions of Dioxins and Furans on the local area. This revised assessment supersedes the original Dioxin and Furan Health Risk Assessment (May 2022) prepared for and presented with the planning application.

Detailed atmospheric dispersion modelling of emissions from the 36.5-metre-high stack was undertaken using the ADMS Version 6 model to predict increases in pollutant concentrations at nearby sensitive receptors such as residential properties, and at neighbouring commercial premises. The latest assessment, which was reported in the 'Detailed Air Quality Assessment for a Proposed Waste Treatment and Transfer Facility at an Existing Site'; Issue 4, October 2023, involved a comparison of model-predicted process contributions against health-based Air Quality Standards (AQS) and Environmental Assessment Levels (EALs) recommended by the Environment Agency.

In the absence of any relevant AQS / EALs for the impacts of Dioxin and Furan releases, the US EPA HHRAP has been applied here to assess the potential risk to the health of people living and working in the locality of the Facility due to emissions of Dioxins and Furans, and Dioxin-like PCBs. The assessment applied the results from the Air Quality Assessment and considered the potential human health risks associated with the intake of Dioxins and Furans from inhalation and the consumption of potentially contaminated foodstuffs due to emissions to atmosphere from the stack of the Facility. All assumptions used within the assessment were conservative and as such, the study was undertaken on a worst-case basis. It is also noted that the Facility will replace an already consented, built and historically operated thermal treatment plant which itself would have discharged levels of Dioxins, Furans and PCBs, but which ceased operation in 2016.

The assessment indicates that the risk to health of the local population due to exposure to Dioxins and Furans in emissions from the Facility is likely to be low, remaining well within 1 % of the Tolerable Daily Intake (TDI) of 2 pg kg^{-1} for both adults and children. The addition of Dioxin-like PCBs to the assessment naturally results in a marginal increase in the reported process contributions, but overall remains a very small proportion (less than 1 %) of the 2 pg kg^{-1} TDI.

In conclusion, the results from the assessment confirm that there is no significant health risk associated with potential exposure to emissions of pollutants from the Facility now proposed by Grundon Waste Management Limited, to be developed in Avonmouth.

Contents

Issue and Revision Record

Issue	Date	Author	Review / Authorise	Description
DRAFT	25/10/2023	Amanda Owen	ENVISAGE	Initial draft for Client comment
1	09/11/2023	Amanda Owen	ENVISAGE	Issue of Revised HRA for Permitting
2 DRAFT	26/04/2024	Amanda Owen	ENVISAGE	Including corrections and amendments to incorporate HMIP congener split and consideration of 2022 TEFs
2	30/05/2024	Amanda Owen	ENVISAGE	Issue 2

1. Introduction

Environmental Visage Limited (Envisage) was commissioned by Grundon Waste Management Limited to undertake a Dioxin and Furan human health risk assessment in support of an application to vary the Environmental Permit for their waste treatment and transfer facility located on Zinc Road, Avonmouth.

An Environmental Permit (EP) was granted by the Environment Agency (EA) to New Earth Energy (West) Operations Limited for the operation of the Avonmouth Energy Facility in January 2013. The EP includes for the operation of a Schedule 1, Section 5.1 (A1) (c) activity:

The incineration of non-hazardous waste in a pyrolysis and gasifier plant with a capacity of 1 tonne or more per hour.

The EP was subsequently transferred to Avonmouth Bio Power Limited in October 2015.

Whilst the gasification plant was constructed and commissioned, it did not operate as it was intended. The gasification plant was eventually mothballed by Avonmouth Bio Power Limited in 2016. Grundon Waste Management Limited (Grundon) subsequently acquired the site from Avonmouth Bio Power Limited in February 2021 and now intends to replace key plant with an alternative, smaller scale waste treatment and transfer facility.

Grundon has removed all of the gasification process equipment, including the waste feed and flue gas treatment systems. Grundon is currently installing a new waste incineration combustion technology, and associated waste and flue gas treatment systems to process a mix of non-hazardous, clinical and hazardous wastes which require high temperature incineration, herein referred to as the Facility.

Grundon is applying for a Variation to the EP to allow for the high temperature incineration of hazardous and non-hazardous wastes.

This assessment considers the release of Dioxins and Furans and Dioxin-like Poly-Chlorinated Biphenyls (PCBs) from the Facility, with other human health impacts being assessed in a Detailed Air Quality Assessment for a Proposed Waste Treatment and Transfer Facility at an Existing Site[1] (AQA). Small quantities of pollutants, including Dioxins, Furans and PCBs will be released to atmosphere through the associated 36.5-metre-high stack, and this report presents an assessment of the likely health impact of those releases.

Air Quality Standards (AQS) have been established primarily to protect the health of the general population and the detailed atmospheric dispersion modelling reported in the AQA confirmed that there will be no off-site exceedances of any AQS objective value or Environmental Assessment Level. Accordingly, it is expected that the operation of the Facility is unlikely to pose a significant risk to the health of the local population living in the surrounding area. However, no such standards exist for the consideration of the impact of Dioxins and Furans and, in order to quantify the potential impact of these airborne pollutants on the health of surrounding communities, this Health Risk Assessment (HRA) has been prepared.

The assessment applies the modelled predicted increases in ambient pollutant concentrations arising from the operation of the Facility to calculate the potential health impact of releases of Dioxins, Furans and PCBs. As such, it should be read in conjunction with the associated air quality assessment report.

This document presents the results from the HRA studies undertaken on the basis of model predictions, and assuming that the plant operates continually throughout the year.

1.1 Health Issues Associated with Emissions from the Facility

The primary source of Dioxin, Furan and Dioxin-like PCB emissions from the Facility will be emissions from the high temperature waste thermal treatment process. Exhaust gases from the process are routed to discharge through a 36.5-metre-high stack situated at the south-eastern corner of the main process building.

Health effects resulting from exposure to pollutants are generally associated with either acute effects (noticeable effects soon after exposure), or chronic effects (noticeable effects after prolonged exposure).

The pollutants considered within the detailed AQA fall into the following categories:

Acute Effects

- Oxides of Nitrogen (NO_x) including Nitrogen Dioxide (NO_2);
- Sulphur Dioxide (SO_2);
- Particulates;
- Carbon Monoxide (CO);
- Hydrogen Chloride (HCl);
- Hydrogen Fluoride (HF).

Each of the pollutants above has associated Air Quality Standards (AQS) or Environmental Assessment Levels (EALs) and was compared to their respective assessment level within the AQA report.

Chronic Effects

- Volatile Organic Compounds (VOCs);
- Heavy Metals;
- Dioxins and Furans;
- Polynuclear Aromatic Hydrocarbons (PAH); and,
- Poly-Chlorinated Biphenyls (PCBs).

The process contributions of VOCs, heavy metals, PAH (as Benzo[a]Pyrene – B[a]P) and PCBs were also compared against their respective assessment levels within the detailed AQA. However, there are no similar assessment levels for emissions of Dioxins and Furans and hence, further assessment and consideration must be provided.

This HRA considers the direct health risks associated with the inhalation and consumption of Dioxins and Furans, and Dioxin-like substances (PCBs) released from the stack of the Facility. The assessment quantifies the potential impact of emissions of pollutants on the health of local people living or working in the vicinity of the Facility through the application of the US EPA Human Health Risk Assessment Protocol (HHRAP) for Dioxins and Furans, and Dioxin-like PCBs[2].

1.2 Assessment Methodology

A Dioxin and Furan health risk assessment has been undertaken using the US EPA HHRAP calculation procedures to estimate intake of Dioxins and Furans via the dietary and inhalation routes in the vicinity of the Facility. The Lakes Environmental Software Industrial Risk Assessment Programme – Human Health (IRAP-h View Version 5.1.1) was applied to perform the HHRAP calculations.

IRAP-h has been developed to enable the production of comprehensive, multi-pathway human health risk assessments based on the US EPA HHRAP, and can calculate risk values for multiple chemicals, from multiple sources, at multiple exposure locations. The software includes the extensive HHRAP chemicals database, including information on the transport and fate parameters for each species.

The input data for the assessment has its base in predictive modelling that was undertaken using the ADMS atmospheric dispersion model to estimate likely ground level concentrations and deposition rates for Dioxins and Furans as a result of emissions to atmosphere from the Facility. Recognised requirements of the HHRAP methodology were taken into account when preparing the modelling for the assessment, including:

- The unitisation of the Dioxin and Furan release (1 g s^{-1}), with subsequent consideration of the actual release of each relevant congener based on the actual mass release and appropriate fractionation of particle and particle bound emissions;
- Consideration of the airborne concentration of vapour, particle and particle bound substances emitted from the discharge stack;
- The wet deposition rate of particle and particle bound substances;
- The dry deposition rate of vapour, particle and particle bound substances;
- Incorporating plume depletion into the modelling exercise.

The assessment is based upon the incremental increase in Dioxin and Furan concentrations due to emissions from the stack of the Facility and does not take account of any existing contamination by Dioxins and Furans at the location of the specific receptors.

The modelling also considers Dioxins and Furans as a single compound. However, reference to Dioxins and Furans denote two groups of compounds that are similar in structure and are based on two benzene rings fused to either a central Dioxin or a Furan ring. Each individual Dioxin and Furan species is referred to as a ‘congener’ and each has different physical properties and toxicity levels that will affect their atmospheric behaviour. The HHRAP methodology is therefore designed to consider the fate and transport of each congener on its own specific properties, based on the varying volatility of the congeners and their different toxicities.

The HHRAP is therefore designed to calculate the likely exposure of a receptor in the vicinity of a process to a Chemical of Potential Concern (COPCs) from that process, before characterising the risk and hazard associated with the potential exposure.

The risk from exposure to combustion emissions is the probability that a human receptor will develop cancer, based on a unique set of exposure, model, and toxicity assumptions.

In contrast, the hazard is the potential for developing non-cancer health effects as a result of exposure to COPCs. A hazard is not a probability but, rather, a comparison (calculated as a ratio) of a receptor’s potential exposure relative to a standard exposure level.

2. Process Contribution of Dioxins and Furans

A detailed dispersion modelling assessment was undertaken applying the requirements of the HHRAP methodology such as those specified in Section 1.2. With the exception of the specific requirements of the HHRAP, model inputs were identical to those applied in the original AQA, including the discharge characteristics, stack and building dimensions etc.

Modelled contributions of vapour and solid phase pollutants were calculated from the unitised release, as were relevant contributions to both dry and wet deposition.

In order to conservatively estimate the exposure of receptors to emissions from the Facility, the assessment assumed a continuous mass release of Dioxins and Furans from the Facility at the daily emission limit value (0.04 ng Nm^{-3}), and this was applied to the unitised results, fractionated by COPC type, in order that the overall contribution of each species would be considered.

It is important to note that the emission limit value is stated with full consideration of the toxicity of the individual Dioxin and Furan congeners. However, there are various Toxic Equivalency Factors (TEFs) available, and the permitted ELV applies a different set of TEFs (NATO I-TEFs) than is applied by the Dioxin and Furan assessment level (WHO TEFs). The WHO TEFs dated from 2005 until recently, but were revised in 2022. For completeness, both sets of WHO TEFs have been applied in this report and Table 1 demonstrates the difference in the congener splits.

Table 1 Toxic Equivalence Factors for Dioxins and Furans

Congener	NATO I-TEFs	WHO 2005 TEFs	WHO 2022 TEFs
2,3,7,8-TCDD	1	1	1
1,2,3,7,8-PeCDD	0.5	1	0.4
1,2,3,4,7,8-HxCDD	0.1	0.1	0.09
1,2,3,6,7,8-HxCDD	0.1	0.1	0.07
1,2,3,7,8,9-HxCDD	0.1	0.1	0.05
1,2,3,4,6,7,8-HpCDD	0.01	0.01	0.05
OCDD	0.001	0.0003	0.001
2,3,7,8-TCDF	0.1	0.1	0.07
1,2,3,7,8-PeCDF	0.05	0.03	0.01
2,3,4,7,8-PeCDF	0.5	0.3	0.1
1,2,3,4,7,8-HxCDF	0.1	0.1	0.3
1,2,3,6,7,8-HxCDF	0.1	0.1	0.09
1,2,3,7,8,9-HxCDF	0.1	0.1	0.2
2,3,4,6,7,8-HxCDF	0.1	0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01	0.01	0.02
1,2,3,4,7,8,9-HpCDF	0.01	0.01	0.1
OCDF	0.001	0.0003	0.002

The purpose of the TEFs is to consider and compare the toxicity of different combinations of Dioxins, Furans and Dioxin-like compounds. The TEFs are the calculated ratio of the toxicity of an individual Dioxin or Furan congener, against the most toxic compound (2,3,7,8-TetraChloroDibenzo-p-Dioxin) and are used to calculate the Toxic Equivalence (TEQ) by multiplying the actual mass release of each compound by its corresponding TEF, e.g. 10 grams x 0.1 TEF = 1 gram TEQ, and then summing the results for the specific mixture of congeners. The result of this toxicity assessment is that, for any given actual mass release, the mass as toxic equivalent will vary depending on the combination of congeners in the emission.

With no measured partitioning of the relevant Dioxin and Furan congeners, or particle fractionation, the assumptions detailed in the following report sections were made.

2.1 Partitioning Emissions of COPCs

In order to undertake a detailed assessment of the risk and hazard associated with the release of Dioxins and Furans from the process, it is therefore necessary to calculate the individual Dioxin and Furan congener emission rates.

Two congener profiles are available for use in identifying the likely combination of Dioxin and Furan species emitted from incineration processes, being a 1996 UK study from Her Majesty's Inspectorate of Pollution (HMIP)[3] and an emissions profile specified by the US Environmental Protection Agency (US EPA) in their November 2006 study[4]. Although the US EPA data provides more up-to-date partitioning of the COPCs from incineration processes, the values are lower than the HMIP figures, and would result in a lower overall impact if applied. Therefore, data from the HMIP 1996 municipal waste incineration (MWI) study was used as the basis of this assessment.

From the data in the HMIP study, the individual Dioxin and Furan congener emission rates were calculated as detailed in Table 2, converting the maximum emission (0.04 ng Nm^{-3} on the basis of the NATO I-TEQ) to an actual mass release based on the HMIP congener split, for input into the IRAP-h View model. It is noted that the results from the IRAP-h View calculations subsequently require conversion to the WHO TEQs, multiplying the individual congener results by the WHO TEFs, for comparison with the assessment level, and this step is performed before reporting.

An alternative approach could be to include the inputs converted from the NATO I-TEQ, first to an actual mass release and then back to the WHO TEQ, all prior to undertaking the IRAP-h View calculations. Either method of calculation would be acceptable, resulting in negligible differences to the end-result of Dioxin and Furan intakes. However, a sensitivity analysis would demonstrate very small variations in the results, simply due to rounding the results from each calculation stage. Therefore, whilst such differences result in a negligible overall impact on the final result of the assessment, the two-stage approach to the calculations, inputting the emissions as an actual release and subsequently converting to the WHO TEQ for comparison with the assessment level, is applied here in order to provide the marginally worst-case result.

Finally, despite the Environment Agency anticipating that the 2005 TEFs are likely more conservative that the impact proposed when applying the 2022 WHO TEFs, a sensitivity analysis with results corrected to the 2022 TEFs has been provided in this report.

Table 2 provides details of the calculated inputs into the IRAP-h View model.

Table 2 Mass Release of Congeners Applied to the Assessment

Congener	HMIP MWI Study 1996[A] (ng Nm^{-3})	HMIP MWI Split Applied to ELV[B] (ng Nm^{-3})	Factored Mass Release for Input[C] (g s^{-1})
2,3,7,8-TCDD	0.031	0.0012	1.19E-11
1,2,3,7,8-PeCDD	0.245	0.0098	9.43E-11
1,2,3,4,7,8-HxCDD	0.287	0.0115	1.10E-10
1,2,3,6,7,8-HxCDD	0.258	0.0103	9.93E-11
1,2,3,7,8,9-HxCDD	0.205	0.0082	7.89E-11
1,2,3,4,6,7,8-HpCDD	1.704	0.0682	6.56E-10
OCDD	4.042	0.1617	1.56E-09
2,3,7,8-TCDF	0.277	0.0111	1.07E-10
1,2,3,7,8-PeCDF	0.277	0.0111	1.07E-10
2,3,4,7,8-PeCDF	0.535	0.0214	2.06E-10
1,2,3,4,7,8-HxCDF	2.179	0.0872	8.38E-10
1,2,3,6,7,8-HxCDF	0.807	0.0323	3.11E-10
1,2,3,7,8,9-HxCDF	0.042	0.0017	1.62E-11
2,3,4,6,7,8-HxCDF	0.871	0.0348	3.35E-10
1,2,3,4,6,7,8-HpCDF	4.395	0.1758	1.69E-09
1,2,3,4,7,8,9-HpCDF	0.429	0.0172	1.65E-10
OCDF	3.566	0.1426	1.37E-09

A: Risk Assessment of Dioxin Releases from Municipal Waste Incineration Processes, HMIP, 1996 (Table 7.2a). The concentrations indicated are based on an ELV of 1 ng Nm^{-3} before correction to any toxic equivalent i.e. as an actual mass release of Dioxins and Furans
B: HMIP MWI congener split applied to 0.04 ng Nm^{-3} ELV on the basis of the NATO I-TEQ (I-TEQ)
C: Congener split concentrations multiplied by the normalised flow rate (9.62 Nm^3 s^{-1}) to give a mass release for each congener when discharging at the Dioxin and Furan ELV of 0.04 ng Nm^{-3} (I-TEQ)

2.2 Particle Fractionation

In the absence of any detailed characterisation of the particulate that will likely be emitted from the stack, it was assumed that the discharge will include particulate size fractions of 1, 2.5 and 10 microns (µm). Data on the mass and area of these particulate sizes were calculated using the fractionation methodology specified in the HHRAP and resulted in the following fractions:

Table 3 Particle Fractionation Applied in the Assessment

Particle Diameter (µm)	Particle Density (g cm^{-1})	Mass Fraction[A]	Area Fraction[B]
1	1	0.25	0.625
2.5	1	0.25	0.25
10	1	0.5	0.125

A: Assumed mass fraction
B: Calculated area fraction for particle bound emissions, based on the proportion of the available surface area

The calculated process contributions of Dioxins and Furans in their vapour, particulate and deposited state were then input into the IRAP-h View software in order to calculate the uptake of the emitted substances by humans coming into contact with the affected media through inhalation or ingestion of food, water, and soils.

When presented with modelling data, IRAP-h View extracts various air parameters from the dispersion modelling plot-files and applies them into the assessment. Air parameters generated by IRAP-h View include hourly air concentrations of vapour phase, particle phase and particle bound emission; annual average dry deposition from the particle phase, particle bound and vapour phase and annual average wet deposition from the particle phase, particle bound and vapour phase.

2.3 Modelled Receptors and Their Exposure Scenarios

The contribution of Dioxins and Furans across the local area can impact on sensitive receptors in the vicinity such as farmland, allotments and residential areas. The IRAP-h View software enables the assessment of the potential risk to receptors, resulting from the contribution of pollutants.

Land use in the immediate vicinity of the development site is commercial in its nature with some, although limited, sensitive residential receptor and allotment locations identified.

Thirteen specific receptors were included in the health risk assessment representing nearby locations, where members of the general public may be present for significant periods of time. People living and working in the vicinity of the development site may be exposed to emissions of Dioxins and Furans from the Facility via the inhalation route, and those growing crops or raising animals on land in the vicinity may be further exposed, although the Grundon Facility will not be the only source of airborne Dioxins and Furans in the wider area.

The characterisation of the exposure setting identifies the human receptors, their land uses and activities, which might be impacted by exposure to emissions from the Facility being assessed. The US EPA HHRAP suggests consideration of both current and reasonably potential future land use, as risk assessments typically evaluate the potential risks from facilities over long periods of time.

The US EPA HHRAP suggests consideration of the following exposure scenarios for each type of receptor:

Table 4 HHRAP Suggested Scenarios

Pathway	Recommended Scenario (combined for each receptor as appropriate)						
	Adult Resident	**Resident's Child**	**Adult Farmer**	**Farmer's Child**	**Adult Fisher**	**Fisher's Child**	**Acute Receptor**
Inhalation of vapour and particulate							
Ingestion of soil							N/A
Drinking water							N/A
Homegrown produce							N/A
Home reared beef	N/A	N/A			N/A	N/A	N/A
Home produced milk	N/A	N/A			N/A	N/A	N/A
Home reared chicken	Potential	Potential			Potential	Potential	N/A
Home produced eggs	Potential	Potential			Potential	Potential	N/A
Home reared pork	N/A	N/A			N/A	N/A	N/A
Ingestion of fish	Potential	Potential	Potential	Potential			N/A
Ingestion of breast milk	Additional	N/A	Additional	N/A	Additional	N/A	N/A

'N/A' denotes that the pathway is not applicable;
'Potential' suggests that site specific exposure setting characteristics may warrant adding this exposure pathway (e.g. the presence of ponds on farms or the presence of small-holdings);
'Additional' denotes the need to consider infant exposure to Dioxins and Furans through ingestion of their mother's milk, as a separate assessment, specific to the infant.

The fisher exposure scenario is made up of the exposure pathways through which a receptor may be exposed in an urban or non-farm rural setting where fish is the main source of protein in the receptor diet. Therefore, where locally caught sources of fish may constitute the main source of protein, the fisher scenario can be applied, although dietary consumption of meat and eggs should be discounted at these receptors.

The thirteen modelled receptors are detailed in Table 5, colour coded to denote the specific scenarios that were considered for each.

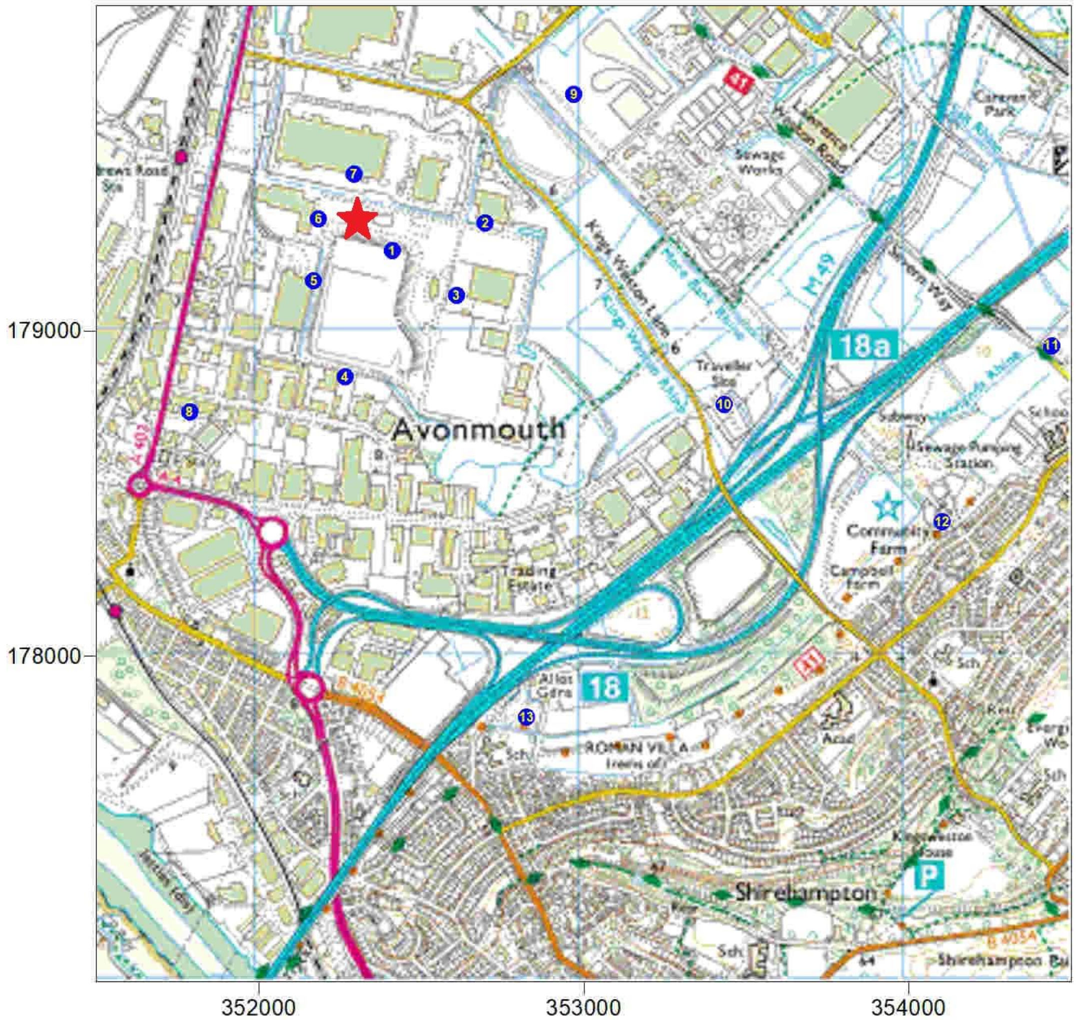
Table 5 Receptors Considered Within the Dioxin and Furan Health Risk Assessment

Number in IRAP-h	No. in AQA	Name	Metres from Site	Description	Scenarios		
1	1	Open space off Zinc Road	105	Open space / leisure: ‘Resident’ and ‘Farmer’			
2	2	Business to the E	358	Business: ‘Resident’			
3	3	Business to the SE	343	Business: ‘Resident’			
4	4	Business to the S	470	Business: ‘Resident’			
5	5	Business to the SW	240	Business: ‘Resident’			
6	6	Business to the W	157	Business: ‘Resident’			
7	7	Business to the NW	165	Business: ‘Resident’			
8	8	Business to SW	794	Business: ‘Resident’			
9	9	The Mere Bank and Hoar Gout	749	Business / ecological: ‘Resident’			
10	10	Kings Weston Lane Travellers Site	1,223	Residential: ‘Resident’ and ‘Farmer’			
11	16	Atwood Drive Allotments	2,133	Allotments: ‘Farmer’			
12	19	Lawrence Weston Community Farm	1,984	Community Farm: ‘Farmer’			
13	24	Barracks Lane Allotments	1,586	Allotments: ‘Farmer’			

In addition, the consumption of breast milk by the infants of adults that are resident at each receptor was considered.

Figure 1 over page identifies the location of the receptors, with the Facility marked with a red star.

Figure 1 Receptor Locations



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It is noted that, although termed resident and / or farmer scenarios, the majority of the receptor locations represent open space and / or businesses within the Avonmouth industrial area.

Receptor number 1 is considered as both a residential and farm scenario, in order to confirm the potential impact at the most local receptor to the installation, although this land would not be used for agricultural purposes. Receptor 10 has also been assessed as a residential and farm setting, in order to consider the keeping and eating of any livestock by the travellers' resident at the site, although in reality, this will likely represent a significant over-estimate of the potential impact with vegetable produce, poultry and eggs likely being the most significant home-grown food sources.

The Lawrence Weston Community Farm has been considered as this site is used to provide people with the opportunity to experience daily farming, gardening and interaction with animals. This site and the two allotment sites have been included as farm settings, effectively assuming that these are commercial scale, agricultural areas, managed by individuals that consume all of their food from their own supplies. This too will result in a significant over-estimate of the potential impact at these receptors.

For all of the exposure scenarios, being at the location of exposure for less than 100 % of the time or obtaining less than 100 % of the total consumption of relevant food, would reduce proportionately any exposure to potential emissions of Dioxins and Furans from the Facility. Accordingly, the estimates of exposure resulting from this assessment are likely to over-estimate considerably, those likely to be experienced by local residents when the Facility is operational.

3. Exposure Pathways

3.1 Potential Pathways for Exposure

The following pathways were considered as part of the health risk assessment:

- Inhalation;
- Ingestion of soil;
- Consumption of fruit and vegetables;
- Consumption of milk by the general population and breast milk consumption by infants;
- Consumption of meat (beef, pork and poultry) and eggs - farmers only; and
- Drinking water.

Members of the local population are only likely to be substantially exposed to effects associated with emissions of Dioxins and Furans from the Facility if:

- They spend significant periods of time at locations where and when emissions from the Facility increase the concentration of Dioxins and Furans above the existing background;
- They consume food grown at locations where emissions from the Facility increase the concentration of Dioxins and Furans above the concentration normally present in food from those locations;
- They undertake activities likely to lead to the ingestion of soil at locations where emissions from the Facility have increased the concentration of Dioxins and Furans in the soil above those normally present; and
- They drink water from sources exposed to increased concentrations of Dioxins and Furans above the levels normally present.

The extent of exposure that any person may experience will depend directly on the degree to which they engage in any or all of the above activities, and by how much existing background concentrations of Dioxins and Furans increase as a result of the operation of the Facility. The drinking water exposure route is considered to be highly unlikely as very few people are likely to collect and drink rainwater in the vicinity of the development site, and as such, it is discussed below, but is readily discounted.

3.2 Pathways Relevant to the Facility

Inhalation

People living in the vicinity of the Facility may be exposed to marginally higher levels of Dioxins and Furans as a result of the operation of the Facility for the proportion of the time that they spend there.

Accordingly, this pathway was considered relevant to the current assessment, and the default values recommended by the US EPA were used as the basis for assessment.

Ingestion of Soil

People working on the land in close proximity to the Facility, for example in agricultural fields, allotments or in their gardens, may be exposed to marginally higher levels of Dioxins and Furans as a result of the operation of the Facility for the proportion of the time that they work there. The potential for exposure by soil ingestion is likely to affect only a few local residents who may tend allotments or plots in their home gardens, and then for only limited periods of the year. Dioxin and Furan intake via the ingestion of soil was included in the assessment.

Consumption of Fruit and Vegetables

The majority of the general population purchase their fruit and vegetables from commercial outlets that are likely to source their produce from outside the locality. Unless a substantial proportion of fruit and vegetables sold are produced locally, the overwhelming majority of the local population's exposure to Dioxins and Furans due to consumption of fruit and vegetables will not be affected significantly by the operation of the Facility.

People who consume fruit and vegetables grown within the vicinity of the Facility may be exposed to marginally higher levels of Dioxins and Furans as a result of the operation of the process, although any increase is likely to be small. The likelihood of individuals obtaining almost all of their fruit and vegetables from gardens or allotments in the vicinity of the development site is likely to be low, especially considering the urban nature of the locality. Nevertheless, Dioxin and Furan intake via the consumption of fruit and vegetables is included in the assessment for all receptor points, despite the majority of these being business locations rather than residential or agricultural areas.

Consumption of Local Dairy Produce

The Facility is located in an urban area and there is, therefore, limited potential for grazing animals to forage on pasture land in the vicinity of the development. However, in order to provide a worst-case basis for assessment, Dioxin and Furan intake via the consumption of locally sourced dairy produce was included in the assessment when considering locations 1 and 10 - 13 in order to provide a worst-case assessment at the nearest receptor point (1) and those which might include home production of milk and milk products (10 – 13) due to farming activities or similar self-sufficiency measures.

A separate assessment is made of the potential for infants up to 1-year old to be exposed to Dioxins and Furans through the consumption of breast milk. The consumption of breast milk by infants may be a potentially significant pathway for the dietary intake of Dioxins and Furans due to absorption from contaminated foodstuffs by the mother's lactate system. However, where an infant is consuming breast milk it is unlikely that it will also be consuming cow's milk or other significant food stuffs. As such, the assessment for potential exposure to Dioxins and Furans via breast milk is reported separately in Section 4.2.2.

Consumption of Meat and Eggs

Free-range animals and poultry may be exposed to Dioxins and Furans through consuming forage or grain, or soil ingested with food picked up from the ground. Exposure of poultry could also impact the level of contamination in eggs. Although the area in the immediate vicinity of the site is largely industrial, it is not known if the rearing of meat or poultry occurs to a significant level in the wider area close to the development site. However, the assessment assumes that the consumption of locally sourced meat and eggs does occur for all locations that were considered under the farmer scenario.

The calculations consider the rearing and consumption of beef, pork and poultry and, as a worst case, it is assumed that all three meat types will be consumed each day.

Drinking Water

The likelihood of contamination of groundwater aquifers occurring due to the deposition of Dioxins and Furans associated with emissions from the Facility is considered highly unlikely given the very low solubility of Dioxins and Furans in water.

Bristol Water draws raw water from a number of boreholes and owns three major reservoirs: Chew (16.6 km away from the site); Blagdon (18.7 km distant); and Cheddar (26.3 km away). However, nearly half the water used in the area is understood to come from rivers outside the area of supply including the River Severn.

Furthermore, the likelihood of local residents collecting rainwater for drinking purposes is also thought to be low and has been discounted. Accordingly, no further consideration has been given to drinking water as a potential pathway.

Limitation of Exposure

As noted in Section 2.3, being at the location of exposure for less than 100 % of the time or obtaining less than 100 % of the total consumption of relevant food, would reduce proportionately any exposure to potential emissions of Dioxins and Furans from the Facility. Accordingly, the estimates of exposure resulting from this assessment are likely to overestimate considerably, those likely to be experienced by local residents when the Facility is operational.

3.3 Exposure Factors

Exposure factors were obtained from literature sources for rates of breathing and ingestion of soil and foodstuffs.

Inhalation Rates

For a 70 kg adult the daily respiration volume was taken as 20 m^3 day^{-1} which is in line with US EPA recommendations. This corresponds to an average value of about 0.833 m^3 hr^{-1}. The corresponding value for a child weighing about 20 kg was 7.2 m^3 day^{-1}, or about 0.3 m^3 hr^{-1}.

Consumption of Meat and Eggs

Information on the UK intake of meat and eggs was obtained from the National Diet and Nutrition Survey (NDNS) on the gov.uk website[5] and is summarised in the following table.

Table 6 UK Official Figures for the Consumption of Meat and Eggs (g day^{-1})

Food Category	UK Adult Mean (g day^{-1})	UK Child Mean (g day^{-1})
Beef	43.7	21.1
Pork	12.2	4.5
Poultry meat	73	40
Eggs	24.5	10.8

The above figures are based upon the average consumption values for men and women aged 19 – 64, and girls and boys between 4 and 10 years' old, including non-consumers, to give an overall average for an adult or child member of the population. The values relate to the average daily consumption of meat and eggs.

However, where information within the HHRAP database suggested a significantly higher consumption rate, these figures were applied to the adult farmer scenario as a worst-case, as follows:

Food Category	HHRAP Adult Farmer (g day^{-1})
Beef	85.4
Pork	38.5
Eggs	52.5

For home-reared or allotment-reared eggs and poultry meat, it is unlikely that meat consumption rates would be as high as those for eggs, as the birds are the source of the eggs in preference to a meat source. Accordingly, the assumption that poultry meat consumed in the vicinity all comes from sources produced within the potential zone of exposure of the emissions from the Facility will likely overestimate considerably the potential impact of poultry meat consumption. Consideration of intake from poultry and meat sources was therefore limited to receptor numbers 1 and 10 – 13.

Consumption of Fruit and Vegetables

Values for the consumption of fruit and vegetables are provided in the US EPA HHRAP methodology as follows:

Table 7 US EPA HHRAP Estimates for the Consumption of Fruit and Vegetables

Food Category	Ingestion Rate (kg kg-day^{-1} DW)			
	Farmer	Farmer Child	Resident	Resident Child
Exposed above ground fruit and vegetables	0.00047	0.00113	0.00032	0.00077
Protected above ground fruit and vegetables	0.00064	0.00157	0.00061	0.00150
Below ground produce	0.00017	0.00028	0.00014	0.00023

As can be seen the values for the case of the "Farmer" and "Farmer Child" indicate a higher level of consumption due to the increased likelihood of consuming home-produced fruit and vegetables.

Consumption of Milk

Information on the intake of milk was obtained from the NDNS on the gov.uk website and is summarised in the following table.

Table 8 UK Official Figures for the Consumption of Milk (grams day^{-1})

Milk Category	UK Adult Mean (g day^{-1})	UK Child Mean (g day^{-1})
Whole milk	24	73.7
All liquid milk and cream	150	200

The above figures are based upon the average consumption values for men and women aged 19 – 64, and girls and boys between 4 and 10 years' old, including non-consumers, to give an overall average for an adult or child member of the population.

Although the HHRAP methodology assumes a milk fat content of 4 % for the Biotransfer factor for milk, which is representative of the fat content of whole milk, the consumption rates of whole milk in the UK are only a proportion of total liquid milk which also includes skimmed and semi-skimmed products, and cream. As such, and in order to produce a worst-case assessment, it would be appropriate to assume the consumption of all liquid milk and cream products, despite some containing a lower fat content than assumed by the assessment calculations.

Additionally, information from the HHRAP database suggests a significantly higher consumption rate of milk products and, as an overly conservative, worst-case assessment, these figures were applied to the adult farmer and farmer's child scenarios as follows:

Food Category	HHRAP Adult Farmer (g day^{-1})	HHRAP Farmer's Child (g day-1)
Milk	957	454

It has been assumed that all of the milk consumed, at rates specified in the HHRAP database, has been produced on pastures in the vicinity of the development site, and these combined assumptions will result in an overly conservative, worst-case assessment of the potential impact of milk consumption for the local farming population, assumed to be located at receptor numbers 1 and 10 - 13.

The consumption of breast milk by infants to the age of 1-year applies the US EPA HHRAP ingestion rate of 0.688 kg day^{-1}.

Ingestion of Soil

Values for the ingestion of soil are provided in the US EPA HHRAP methodology as follows:

Table 9 US EPA HHRAP Estimates for Soil Ingestion (kg day^{-1})

Soil Intake	Adult (kg day^{-1})	Child (kg day^{-1})
Soil intake rate	0.0001	0.0002

The higher value for a child reflects the greater likelihood of soil ingestion by children playing outdoors.

3.4 Emissions Scenario

The Facility will be subject to regulation by the Environment Agency in line with the Emission Limit Values (ELVs) for Dioxins and Furans for incineration plant as defined by the EU Industrial Emissions Directive (IED) and the associated BAT-Conclusions document. Accordingly, atmospheric dispersion modelling was undertaken on the basis of normal operation with emissions of Dioxins and Furans at the 0.04 ng Nm^{-3} ELV specified in the BAT-Conclusions, which is the design point and performance guarantee for the Facility.

Exposure via the dietary route was assessed by modelling Dioxin and Furan deposition in both the gaseous and particulate phases. Partitioning of Dioxins and Furans between the vapour phase and the particulate phase was assumed to be in the proportions 66.4:33.6 as provided by HHRAP guidance[6], and the modelling results were adjusted accordingly.

The atmospheric dispersion modelling exercise was prepared to consider the dispersion of emissions and resultant contribution of Dioxins and Furans in the local area. Five-years' worth of meteorological conditions were originally modelled and the results from modelling weather data from 2018 generally resulted in the maximum contribution of pollution to the receptor locations As such, data from 2018 were carried forward into this Dioxin and Furan health risk assessment.

The results from deposition modelling were input into the IRAP-h View software tool in order to apply the US EPA Human Health Risk Assessment Protocol for Hazardous Waste Combustion for calculating the intake of Dioxins and Furans. The results were compared against the Tolerable Daily Intake (TDI) value of 2 pg WHO TEQ kg^{-1} day^{-1} recommended by the UK Committee on Toxicity[7]. Both the 2005 and 2022 WHO TEFs have been applied to the results.

4. Methodology

Health risk estimates are directly affected by several factors which include:

- The location of the receptor in relation to the stack of the Facility;
- The proportion of time spent by the receptor at locations where Dioxin and Furan concentrations may increase as a result of emissions from the process;
- The proportions of the types of food consumed that are produced at locations where Dioxin and Furan concentrations may increase as a result of emissions from the process; and
- The emissions scenario.

The results from the health risk assessment reported here represent the maximum potential incremental increase as a result of emissions from the Facility for each of the pathways included, based upon continuous emissions of Dioxins and Furans at the anticipated ELV of 0.04 ng Nm^{-3}, which is the design point and performance guarantee for the proposed technology.

Intake of Dioxins and Furans was estimated on the basis of the maximum daily intake due to inhalation and the consumption of soil and vegetable products in areas defined as residential exposure points, with the addition of meat, eggs and milk consumption in areas defined as farming receptors. The combined results at each receptor were then compared against the 2 pg kg^{-1} Tolerable Daily Intake (TDI) reference value to determine whether there is likely to be a significant risk to health as a result of potential exposure to Dioxins and Furans released from the Facility.

4.1 Summary of the Calculation Methodology

4.1.1 Exposure via Inhalation

The following equation is taken from the US EPA HHRAP and was used in the calculation of the Maximum Daily Intake due to inhalation of Dioxins and Furans at each receptor location as a result of exposure to emissions from the Facility:

Equation 1 Maximum Daily Intake Due to Inhalation

$$ADI = \frac{C_a \cdot IR \cdot ET \cdot EF \cdot ED \cdot 0.001 \ mg/\mu g}{BW \cdot AT \cdot 365 \ day/yr}$$

Where:

- ADI = Average daily intake via inhalation (mg kg^{-1} day^{-1});
- Ca = Total air concentration (Daily Average) – derived from ADMS output;
- IR (Adult) = 0.833; Inhalation Rate (m^3 hr^{-1}) - (US EPA HHRAP value);
- IR (Child) = 0.300; Inhalation Rate (m^3 hr^{-1}) - (US EPA HHRAP value);
- ET = 24; Exposure time (hrs day^{-1}) - (US EPA HHRAP value);
- EF = 350; Exposure frequency (days $year^{-1}$) - (US EPA HHRAP value);
- ED = Exposure duration (years) - US EPA HHRAP values of 6 years for children, 30 years for adult residents and 40 years for adult farmers;
- BW (Adult) = 70; Body Weight (kg) - (US EPA HHRAP value);
- BW (Child) = 20; Body Weight (kg) - UK Toxicological assessment report
- AT = 70; Averaging time - (US EPA HHRAP value);
- 0.001 = Units conversion – mg μg^{-1}
- 365 = Units conversion – days $year^{-1}$

4.1.2 Potential Increase in Concentration of Dioxins and Furans in Soil Due To Emissions from the Facility

Any increase in Dioxin and Furan concentration in the soil has the potential to transfer into the food chain and to add to the daily intake via the dietary pathway. An assessment was made of the potential increase of Dioxins and Furan concentrations in the soil at each receptor location as a result of deposition due to emissions from the Facility.

Deposition modelling of Dioxins and Furans in the particulate and gaseous phases, was carried out using ADMS Version 6. The likelihood is that the majority of Dioxins and Furans released from the Facility would be associated with the particulates in the emission to atmosphere and, due to the application of abatement technologies, the size of the majority of particles released is likely to be very small. However, as detailed in Section 2.1 it was assumed that the total discharge will include particulate size fractions of 1, 2.5 and 10 microns (µm). Accordingly, the model predictions for Dioxin deposition associated with each of these size fractions has been applied and is assumed to represent an appropriate assessment of Dioxin and Furan deposition to soils in the vicinity of the Facility.

Little of the deposited Dioxins and Furans are likely to penetrate far into the ground due to their low solubility in water. Absorption of Dioxins and Furans by the soil is also likely to decrease their mobility. The US EPA HHRAP database quotes a value of 0.19 ng litre^{-1} for the solubility of Dioxins in water.

Increase in Soil Concentration

The increase in Dioxin and Furan loading of soils as a result of deposition was estimated using the equations in Table B-3-1 in Appendix B of the US EPA HHRAP for Hazardous Waste Combustion Facilities.

Equation 2 The Increase in Dioxin and Furan Concentration in the Soil Due to Deposition

$$Cs = \frac{\left(\frac{Ds \cdot tD - Cs_{tD}}{ks}\right) + \left(\frac{Cs_{tD}}{ks} \cdot \left[1 - \exp\left(-ks \cdot \left(T_2 - tD\right)\right)\right]\right)}{\left(T_2 - T_1\right)};$$

$$Cs_{tD} = \frac{Ds \cdot \left[1 - \exp\left(-ks \cdot tD\right)\right]}{ks}; and$$

$$Ds = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot \left[F_v \cdot \left(Dydv + Dywv\right) + \left(Dydp + Dywp\right) \cdot \left(1 - F_v\right)\right]$$

Where:

- Cs = Maximum average incremental increase in soil concentration over exposure duration;
- Cs_{tD} = Soil concentration at time tD - calculated;
- Ds = Deposition Term – mg kg soil^{-1} yr^{-1};
- tD = Time period over which deposition occurs – 30 years;
- ks = Dioxin and Furan soil loss constant due to all mechanisms – calculated;
- T_2 = Length of exposure duration - US EPA HHRAP values of 6 years for children, 30 years for adult residents and 40 years for adult farmers;
- T_1 = Time period at the beginning of combustion – 0;
- 100 = Conversion Factor;
- Q = Dioxin and Furan emission rate (g s^{-1});
- Z_s = Soil Mixing Zone depth – 2 cm (representing untilled land);
- BD = Soil Bulk Density – 1.5 kg m^3;
- F_v = Fraction of Dioxin and Furan concentration in air, in the vapour phase – 0.664 (US EPA HHRAP value);

- Dydv = Unitised annual average dry deposition from vapour phase – derived from ADMS output;
- Dywv = Unitised annual average wet deposition from vapour phase – derived from ADMS output;
- Dydp = Unitised annual average dry deposition from particulate phase – derived from ADMS output;
- Dywp = Unitised annual average dry deposition from particulate phase – derived from ADMS output.

4.1.3 Exposure from Dietary Intake Due to Ingestion of Soil

The formula in Table C-1-1 in Appendix C of the US EPA HHRAP was used to estimate the potential intake of Dioxins and Furans due to ingestion of soil in the locality of the Facility:

Equation 3 The Intake of Dioxins and Furans Due to Ingestion of Soil

$$I_{Soil} = \frac{Cs \times CR_{Soil} \times F_{Soil}}{BW}$$

Where:

- I_{Soil} = Daily intake of Dioxins and Furans via soil ingestion;
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- CR_{Soil} = Consumption rate of soil (US EPA HHRAP Values);
- F_{Soil} = Fraction of soil contaminated by Dioxins and Furans – US EPA HHRAP recommends the use of 1.0;
- BW = Body weight.

4.1.4 Exposure from Dioxin and Furan Intake Due to the Consumption of Fruit and Vegetables

An assessment for exposure to Dioxins and Furans has been undertaken for the consumption of fruit and vegetables in order to represent a scenario where local residents are obtaining their dietary intake of fruit and vegetables from plants grown in soil that could potentially be contaminated by Dioxins and Furans in the emissions from the Facility. It is noted however, that the majority of the nearby receptors are open sites or business premises within the industrial area. Hence, in reality, these are not locations which might be used to grow fruit and vegetables for consumption, and as such, their assessment provides results on an overly conservative, worst-case basis.

The equation in Table C-1-2 in Appendix C of the HHRAP methodology was used to estimate the daily intake of Dioxins and Furans via the consumption of fruit and vegetables:

Equation 4 The Intake of Dioxin and Furan in Produce Due to Increase in Concentration in the Soil

$$I_{ag} = \left[\left(\left(Pd \times Pv \times \mathrm{Pr}_{ag}\right) \times CR_{ag}\right) + \left(\mathrm{Pr} \times CR_{pp}\right) + \left(\mathrm{Pr}_{bg} \times CR_{bg}\right)\right] \times F_{ag}$$

Where:

- I_{ag} = Daily intake of Dioxins and Furans from the consumption of fruit and vegetables;
- Pd = Above ground exposed fruit and vegetables concentration due to direct deposition onto plant surfaces – calculated using Equation B-2-7 in Appendix B of HHRAP methodology;
- Pv = Above ground exposed fruit and vegetables concentration due to air-to-plant transfer – calculated using Equation B-2-8 in Appendix B of HHRAP methodology;
- Pr_{ag} = Above ground exposed and protected fruit and vegetables concentration due to root intake – calculated using Equation B-2-9 in Appendix B of HHRAP methodology;
- Pr_{bg} = Below ground exposed and protected fruit and vegetables concentration due to root intake – calculated using Equation B-2-10 in Appendix B of HHRAP methodology;
- CR_{ag} = Consumption rate of aboveground fruit and vegetables (US EPA HHRAP Value);
- CR_{pp} = Consumption rate of protected aboveground fruit and vegetables (US EPA HHRAP Value);
- CR_{bg} = Consumption rate of belowground fruit and vegetables (US EPA HHRAP Value);

- F_{ag} = Fraction of fruit and vegetables that is contaminated – assumed to be 1.0.

Calculation of P_d

Equation B-2-7 in Appendix B of the US EPA HHRAP methodology was used for the calculation of P_d and is as follows:

Equation 5 The Increase in Dioxin and Furan Concentration in Aboveground Produce Due to Deposition

$$Pd = \frac{1000 \times Q \times (1 - F_v) \times [Dydp + (Fw \times Dywp)] \times Rp \times [1.0 - e^{(kp \times Tp)}]}{Yp \times kp}$$

Where:

- Pd = Concentration of Dioxins and Furans in aboveground fruit and vegetables due to direct deposition;
- Q = Dioxin and Furan emission rate;
- F_v = Fraction of Dioxin and Furan in the vapour phase – US EPA HHRAP value for Dioxins and Furans = 0.664;
- Dydp = Unitised yearly average dry deposition from particulate phase – ADMS modelling;
- Fw = Fraction of Dioxin and Furan that adheres to plant surfaces – US EPA HHRAP value = 0.6 for organics;
- Dywp = Unitised yearly average wet deposition from particulate phase – ADMS modelling;
- Rp = Interception fraction of the edible portion of the plant – US EPA HHRAP value = 0.39;
- Kp = Plant surface loss coefficient – US EPA HHRAP value = 18;
- To = Length of plant exposure to deposition per harvest of edible portion of plant – US EPA HHRAP value = 0.16;
- Yield of standing crop biomass of the edible portion of the plant (productivity) – US EPA HHRAP value = 2.24.

Calculation of P_v

Equation B-2-8 in Appendix B of the US EPA HHRAP methodology was used for the calculation of P_v and is as follows:

Equation 6 The Increase in Dioxin and Furan Concentration in Above ground Produce Due to Air-Plant Transfer

$$Pv = Q \times F_v \times \frac{Cyv \times Bv_{ag} \times Vg_{ag}}{\rho_a}$$

Where:

- Pv = Concentration of Dioxins and Furans in aboveground fruit and vegetables due to air-to-plant transfer;
- Q = Dioxin and Furan emission rate;
- F_v = Fraction of Dioxin and Furan in the vapour phase – US EPA HHRAP value for Dioxins and Furans = 0.664;
- Cyv = Unitised annual average atmospheric concentration – ADMS modelling;
- Bv_{ag} = Dioxin and Furan air-to-plant bio-transfer factor for above ground fruit and vegetables – US EPA HHRAP value = 6.55×10^{-4};
- Vg_{ag} = Empirical correction factor for above ground fruit and vegetables – US EPA HHRAP value = 0.01;
- P_a = Density of air (1,225 g m^{-3} at 15 ^oC).

Calculation of Pr_{ag}

Equation B-2-9 in Appendix B of the US EPA HHRAP methodology was used for the calculation of Pr_{ag} and is as follows:

Equation 7 The Increase in Dioxin and Furan Concentration in Above ground Produce Due to Root Intake

$$\mathrm{Pr}_{ag} = Cs \times Br_{ag}$$

Where:

- Pr_{ag} = Concentration of Dioxins and Furans in above ground fruit and vegetables due to root intake;
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period – calculated from ADMS model outputs (mg kg^{-1} soil);
- Br_{ag} = Plant-soil bio-concentration factor for above ground fruit and vegetables – US EPA HHRAP value for Dioxins and Furans = 0.00455.

Calculation of Pr_{bg}

Equation B-2-10 in Appendix B of the US EPA HHRAP methodology was used for the calculation of Pr_{bg} and is as follows:

Equation 8 The Increase in Dioxin and Furan Concentration in Below ground Produce Due to Deposition

$$\mathrm{Pr}_{bg} = Cs \times Br_{rootveg} \times Vg_{rootveg}$$

Where:

- Pr_{bg} = Concentration of Dioxins and Furans in belowground fruit and vegetables due to root intake;
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period – calculated from ADMS model outputs (mg kg^{-1} soil);
- $Br_{rootveg}$ = Plant-soil bio-concentration factor for below ground fruit and vegetables – US EPA HHRAP value for Dioxins and Furans = 1.03;
- $Vg_{rootveg}$ = Empirical correction factor for below ground fruit and vegetables – US EPA HHRAP value = 0.01.

Calculation of Dioxin and Furan Intake from the Consumption of Fruit and Vegetables

Equation C-1-2 in Appendix C of the US EPA HHRAP methodology was used to calculate the overall intake of Dioxins and Furans due to the consumption of fruit and vegetables:

Equation 9 The Daily Intake of Dioxins and Furans Due to the Consumption of Fruit and Vegetables

$$I_{ag} = \left[\left((Pd \times Pv \times \mathrm{Pr}_{ag}) \times CR_{ag}\right) + (\mathrm{Pr} \times CR_{pp}) + (\mathrm{Pr}_{bg} \times CR_{bg})\right] \times F_{ag}$$

Where:

- I_{ag} = Daily intake of Dioxins and Furans from the consumption of fruit and vegetables;
- P_d = Above ground exposed fruit and vegetables concentration due to direct deposition onto plant surfaces – calculated using Equation B-2-7 in Appendix B of HHRAP methodology (as above);

- P_v = Above ground exposed fruit and vegetables concentration due to air-to-plant transfer – calculated using Equation B-2-8 in Appendix B of HHRAP methodology (as above);
- Pr_{ag} = Above ground exposed and protected fruit and vegetables concentration due to root intake – calculated using Equation B-2-9 in Appendix B of HHRAP methodology (as above);
- Pr_{bg} = Below ground exposed and protected fruit and vegetables concentration due to root intake – calculated using Equation B-2-10 in Appendix B of HHRAP methodology (as above);
- CR_{ag} = Consumption rate of above ground fruit and vegetables (US EPA HHRAP Value) = 0.00047 kg kg^{-1} day^{-1} DW for adults and 0.00113 kg kg^{-1} day^{-1} DW for children;
- CR_{pp} = Consumption rate of protected above ground fruit and vegetables (US EPA HHRAP Value) = 0.00064 kg kg^{-1} day^{-1} DW for adults and 0.00157 kg kg^{-1} day^{-1} DW for children;
- CR_{bg} = Consumption rate of below ground fruit and vegetables (US EPA HHRAP Value) = 0.00017 kg kg^{-1} day^{-1} DW for adults and 0.00028 kg kg^{-1} day^{-1} DW for children;
- F_{ag} = Fraction of fruit and vegetables that is contaminated – assumed to be 1.0

4.1.5 Exposure from Dietary Intake of Meat and Eggs – Farm Scenario Only

The potential link between human receptors and the consumption of locally reared meat or eggs is not known but is likely to be small, especially due to the urban nature of the local environment. However, as the consumption of locally sourced meat and eggs could be a potential exposure pathway these sources could provide a key pathway for Dioxin and Furan exposure and as such it is appropriate that they should be investigated.

Accordingly, an assessment for exposure to Dioxins and Furans has been undertaken for intake via the consumption of beef, pork, chicken and eggs at the nearest modelled receptor and at those where there is any potential for meat of eggs to be produced and consumed. Despite being unlikely that farmers would consume full portions of all three meats each day, in order to provide a worst-case assessment, the calculation assumes this to be the case. It is however noted that the contribution of Dioxins and Furans to the total daily intake are significantly higher from beef consumption than from either pork or chicken, either in isolation or combined.

The US EPA HHRAP for Hazardous Waste Combustion Facilities methodology was used to assess the potential exposure to Dioxins and Furans arising from emissions from the Facility. The equations in Table B-3-10 and Table B-3-12 in Appendix B of the HHRAP were used to determine the concentration of Dioxins and Furans in beef and pork respectively at farming locations in the vicinity of the development site. The equation in Table B-3-13 in Appendix B of the HHRAP was used to determine the concentration of Dioxins and Furans in eggs and the equation in Table B-3-14 was used to determine the corresponding concentration of Dioxins and Furans in poultry meat.

Dioxin and Furan Concentration in Beef

The following formula was used to estimate the potential Dioxin and Furan concentration consumed by cattle through the ingestion of contaminated plant-based feed items and soil:

Equation 10 The Intake of Dioxins and Furans by Cattle Foraging on Contaminated Feed and Soil

$$A_{beef} = \left(\Sigma(F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs\right) \cdot Ba_{beef} \cdot MF$$

Where:

- A_{beef} = Concentration of Dioxins and Furans in beef (mg kg^{-1} FW tissue);
- F_i = Fraction of plant type i grown on contaminated soil and ingested by the cattle (unitless);
- Qp_i = Quantity of plant type i eaten by the cattle per day (kg DW plant day^{-1});
- P_i = Concentration of Dioxins and Furans in each plant type i eaten by the cattle (mg kg^{-1} DW);
- Q_s = Quantity of soil eaten by the cattle each day (kg day^{-1});
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- B_s = Soil bio-availability factor (unitless);
- Ba_{beef} = COPC bio-transfer factor for beef (day kg^{-1} FW tissue);

- MF = Metabolism factor (unitless).

The value of P_i was derived from the sum of the equations in Tables B-3-7, B-3-8 (above ground contributions to forage and silage) and B-3-9 (root uptake) of Appendix B of the HHRAP which therefore take account of the overall concentration in fresh matter and silage which will have been exposed to pollutants through direct deposition, air to plant transfer and root uptake, and grain which absorbs pollution through root uptake.

Dioxin and Furan Concentration in Pork

The following formula was used to estimate the potential Dioxin and Furan concentration consumed by pigs through the ingestion of contaminated plant-based feed items and soil:

Equation 11 The Intake of Dioxins and Furans by Pigs Foraging on Contaminated Feed and Soil

$$A_{pork} = \left(\sum(F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs\right) \cdot Ba_{pork} \cdot MF$$

Where:

- A_{pork} = Concentration of Dioxins and Furans in pork (mg kg^{-1} FW tissue);
- F_i = Fraction of plant type i grown on contaminated soil and ingested by the pig (unitless);
- Qp_i = Quantity of plant type i eaten by the pig each day (kg DW plant day^{-1});
- P_i = Concentration of Dioxins and Furans in plant type i eaten by the pig (mg kg^{-1} DW);
- Q_s = Quantity of soil eaten by the pig (kg day^{-1});
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- B_s = Soil bio-availability factor (unitless);
- Ba_{pork} = COPC bio-transfer factor for pork (day kg^{-1} FW tissue);
- MF = Metabolism factor (unitless).

The value of P_i was derived from the sum of the equations in Tables B-3-7, B-3-8 (above ground contributions to plants that become silage) and B-3-9 (root uptake) of Appendix B of the HHRAP which therefore take account of the overall concentration in silage which will have been exposed to pollutants through direct deposition, air to plant transfer and root uptake, and grain which absorbs pollution through root uptake.

Dioxin and Furan Concentration in Eggs

The following formula was used to estimate the potential Dioxin and Furan concentration in eggs due to ingestion of soil and grain by free-range chickens reared in the locality:

Equation 12 The Intake of Dioxins and Furans in Eggs Due to Chickens Foraging on Contaminated Soil

$$A_{egg} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Q_s \cdot C_s \cdot B_s\right) Ba_{egg}$$

Where:

- A_{egg} = Concentration of Dioxins and Furans in egg;
- F_i = Fraction of grain grown on contaminated soil and ingested by chickens – assumed to be 1.0;
- Qp_i = Quantity of grain ingested by chickens – assumed to be 0.2 (US EPA HHRAP value);
- P_i = Concentration of Dioxins and Furans in grain – derived from separate equation below;
- Q_s = Quantity of soil ingested by chicken – assumed to be 0.022 kg day^{-1} (US EPA HHRAP value);
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- B_s = Soil bio-availability factor – assumed to be 1.0 (US EPA HHRAP value);
- Ba_{egg} = COPC bio-transfer factor for chickens (day kg^{-1} FW tissue).

Pi is calculated as follows:

Equation 13 The Intake of Dioxin and Furan in Grain Due to Increase in Soil Concentration

$$P_i = C_s \cdot Br_{forage}$$

Where:

- P_i = Concentration of Dioxins and Furans in forage as grain;
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- Br_{forage} = Plant-soil bio-concentration factor for grain (US EPA HHRAP Database).

Dioxin and Furan Concentration in Chicken Meat

The following formula was used to estimate the potential Dioxin and Furan concentration in chicken meat due to ingestion of soil and grain by free-range chickens reared in the locality:

Equation 14 The Intake of Dioxins and Furans in Chicken Meat Due to Foraging on Contaminated Soil

$$A_{Chicken} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Q_s \cdot C_s \cdot B_s\right) Ba_{Chicken}$$

Where:

- $A_{Chicken}$ = Concentration of Dioxins and Furans in chicken meat;
- F_i = Fraction of grain grown on contaminated soil and ingested by chickens – assumed as 1.0;
- Qp_i = Quantity of grain ingested by chickens – assumed to be 0.2 (US EPA HHRAP value);
- P_i = Concentration of Dioxins and Furans in grain – derived from the equation above;
- Q_s = Quantity of soil ingested by chickens – assumed to be 0.022 kg day^{-1} (US EPA HHRAP value);
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- B_s = Soil bio-availability factor – assumed to be 1.0 (US EPA HHRAP value);
- Ba_{egg} = Bio-transfer factor for chicken carcase (US EPA HHRAP Database).

Dietary Intake Due to the Combined Consumption of Meat and Eggs

Data published by Public Health England (PHE) and the UK Food Standards Agency (FSA) on the gov.uk website was presented in Table 5 and provides the dietary intakes of meat and eggs for adults and children in the UK. The data are based upon the average values for men and women, and boys and girls, to give an overall average for an adult or child member of the population. The values relate to the average daily consumption of meat and eggs normalised to include non-consumers, to give an overall average for an adult or child member of the population.

However, where information within the HHRAP database suggested a significantly higher consumption rate, these figures were applied to the adult farmer scenario as a worst-case. Calculated concentrations of Dioxins and Furans in foodstuffs are multiplied by the daily average consumption rate for each food type in order to predict the daily intake through consumption.

It is noted that the calculated process contributions above actually occur at locations within the industrial estate, allotments and a local community farm, rather than at commercial scale agricultural sites. As such, it is unlikely that the receptor sites will be used for the production of significant quantities of meat or eggs, and hence consideration of the calculated intake represents a significantly conservative approach.

4.1.6 Exposure from Dietary Intake of Milk – Farm Scenario Only

The potential link between human receptors in the vicinity of the Facility and the consumption of locally produced milk is not known, especially considering the urban nature of the local environment. Nevertheless, to provide a worst-case basis for assessment, exposure to Dioxins and Furans via the consumption of milk has been undertaken.

The US EPA HHRAP for Hazardous Waste Combustion Facilities methodology was used to assess the potential exposure to Dioxins and Furans arising from emissions from the Facility. The equation in Table B-3-11 in Appendix B of the HHRAP was used to determine the concentration of Dioxins and Furans in milk at locations in the vicinity of the Facility.

Dioxin and Furan Concentration in Milk

The following formula was used to estimate the potential Dioxin and Furan concentration in milk due to ingestion of soil and grass by cows reared in the locality:

Equation 15 The Intake of Dioxins and Furans in Milk Due to Grazing on Contaminated Soil

$$A_{milk} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Q_s \cdot C_s \cdot B_s\right) \cdot Ba_{milk} \cdot MF$$

Where:

- A_{milk} = Concentration of Dioxins and Furans in milk;
- F_i = Fraction of plant type i grown on contaminated soil and ingested by the cattle (unitless);
- Qp_i = Quantity of plant type i eaten by the cattle per day (kg DW plant day^{-1});
- P_i = Concentration of Dioxins and Furans in each plant type i eaten by the dairy cows (mg kg^{-1} DW);
- Q_s = Quantity of soil ingested by cows – assumed to be 0.04 kg day^{-1} (US EPA HHRAP value);
- C_s = Incremental increase in Dioxin and Furan concentration in the soil over exposure period;
- B_s = Soil bioavailability factor – assumed to be 1.0 (US EPA HHRAP value);
- Ba_{milk} = Biotransfer factor for milk (US EPA HHRAP Database).

The value of P_i was derived from the sum of the equations in Tables B-3-7, B-3-8 (above ground contributions to forage and silage) and B-3-9 (root uptake) of Appendix B of the HHRAP which therefore take account of the overall concentration in fresh matter and silage which will have been exposed to pollutants through direct deposition, air to plant transfer and root uptake, and grain which absorbs pollution through root uptake.

Dietary Intake Due to the Consumption of Milk

Data published by Public Health England (PHE) and the UK Food Standards Agency (FSA) on the gov.uk website was presented in Table 8 and provides the dietary intakes of milk for adults and children in the UK. The data are based upon the average values for men and women, and boys and girls, to give an overall average for an adult or child member of the population. The values relate to the average daily consumption of milk normalised to include non-consumers, to give an overall average for an adult or child member of the population.

However, where information within the HHRAP database suggested a significantly higher consumption rate, these figures were applied to the adult farmer scenario as a worst-case. Calculated concentrations of Dioxins and Furans in foodstuffs are multiplied by the daily average consumption rate for each food type in order to predict the daily intake through consumption.

It is noted that the calculated process contributions above actually occur at locations within the industrial estate, allotments and a local community farm, rather than at commercial scale agricultural sites. As such, it is unlikely that the receptor sites will be used for the production of significant quantities of meat or eggs, and hence consideration of the calculated intake represents a significantly conservative approach.

Dietary Intake of Infants Due to the Consumption of Breast Milk

An assessment was made of the potential for infants up to 1-year old to be exposed to Dioxins and Furans through the consumption of breast milk, as this would represent a potentially significant pathway for the dietary intake of Dioxins and Furans for very young children. However, where an infant is consuming breast milk it is unlikely that it will also be consuming cow's milk or other significant food stuffs and as such, this assessment is reported as a simple, worst-case assessment and is not subsequently included in the total which otherwise represents the potential impact on older children and adults.

The following formulae were used to estimate the potential Dioxin and Furan concentration in breast milk due to ingestion by the mother (Equation 16 below taken from Table C-3-1 of Appendix C of the HHRAP), and then the uptake of Dioxins and Furans by the feeding infant (Equation 17, taken from Table C-3-2 of Appendix C of the HHRAP):

Equation 16 The Concentration of Dioxins and Furans in Breast Milk Due to Maternal Ingestion

$$C_{milkfat} = \frac{m \cdot 1\times10^{9} \cdot h \cdot f_1}{0.693 \cdot f_2}$$

Where:

- C milk/fat = Concentration of Dioxins and Furans in breast milk (pg kg^{-1} of milk fat);
- m = 1.25 x 10^{-11} - the calculated average maternal Dioxin and Furan intake via the total dietary route (mg kg^{-1} BW day^{-1});
- 1 x 10^{9} = Conversion factor (pg mg^{-1});
- H = 2,555 - the half-life of Dioxins in adults (days) – (US EPA HHRAP value);
- f_1 = 0.9 - Fraction of ingested Dioxins stored in fat – (US EPA HHRAP value);
- f_2 = 0.3 - Fraction of mother's weight that is fat – (US EPA HHRAP value).

Equation 17 The Uptake of Dioxins and Furans by the Feeding Child

$$ADD_{infant} = \frac{C_{milkfat} \cdot f_3 \cdot f_4 \cdot IR_{milk} \cdot ED}{BW_{infant} \cdot AT}$$

Where:

- ADD infant = Average daily dose for infant exposed to contaminated breast milk;
- C milk/fat = Concentration of Dioxins and Furans in breast milk as calculated (pg kg^{-1} of milk fat);
- f_3 = 0.04 - Fraction of mother's milk that is fat – (US EPA HHRAP value);
- f_4 = 0.9 - Fraction of Dioxin and Furan that is absorbed – (US EPA HHRAP value);
- IR milk = 0.688 - Ingestion rate of breast milk by infant (kg day^{-1}) – (US EPA HHRAP value);
- ED = 1 - Exposure duration (years) – (US EPA HHRAP value);
- BW infant = 9.4 - Body weight of infant (kg) – (US EPA HHRAP value);
- AT= 1 - Averaging time (years) – (US EPA HHRAP value).

5 Results and Discussion

IRAP-h View applies the calculation procedures detailed above in Section 4 enabling consideration of multiple COPCs, in this case the separate Dioxin and Furan congeners, in order to calculate the total intake from inhalation and dietary sources at each receptor location from the estimated composition of the Dioxin and Furan release. The software includes the extensive HHRAP chemicals database, including information on the transport and fate parameters for each species. From the total intake element, the software also calculates cancer risk values for each location, based on the unique set of exposure, model, and toxicity assumptions.

5.1 Quantitative Results

When the detailed results from the above calculation procedures were converted to dietary and inhalation intake values (pg kg^{-1} BW day^{-1}) for Dioxins and Furans, the following results were obtained for a farmer and their child at receptor number 1:

Table 10 Process Contribution to Dioxin and Furan Intake by Farmer Scenario at Receptor 1

Uptake From	Adult Farmer		Farmer's Child	
	pg kg^{-1} day^{-1}	% of the TDI	pg kg^{-1} day^{-1}	% of the TDI
Above ground vegetables	2.99E-05	0.0015%	7.12E-05	0.0036%
Beef	1.88E-03	0.094%	1.62E-03	0.0812%
Chicken	1.11E-07	0.000006%	1.89E-07	0.000009%
Eggs	4.57E-08	0.000002%	2.93E-08	0.000001%
Milk	6.72E-03	0.336%	1.11E-02	0.557%
Pork	7.27E-05	0.0036%	8.04E-05	0.0040%
Soil	3.55E-07	0.00002%	2.21E-06	0.0001%
Inhalation	2.40E-05	0.0012%	3.02E-05	0.0015%

The farmer scenario for receptor number 1 reports the highest contributions across each of the receptor locations and scenarios modelled. It is noted that the location of receptor number 1 does not actually represent any residence or agricultural area, being open space off Zinc Road, and hence the assumption that uptake from foodstuffs or soils consumed through farming activities from this location provides an overly conservative and highly unlikely assessment.

However, even when considering this conservative approach, the individual contributions to the tolerable daily intake are so small as to be insignificant. Table 11 over page details the total contributions at receptor number 1 and at all other modelled scenarios.

The Mean Daily Intake (MDI) concentrations applied in Table 11 were drawn from the Environment Agency toxicological reports for contaminants in soil[8 and 9] and represent the assumed MDI from ingestion and inhalation at any given location in England, as follows:

Mean Daily Intake (Adults) = 0.7 pg kg^{-1} day^{-1} (35.14 % of the TDI)
Calculated Mean Daily Intake (Children) = 1.8 pg kg^{-1} day^{-1} (91.02 % of the TDI)

The MDI for children assumes a correction factor of 0.74[9].

The vast majority of the MDI is received from ingestion rather than inhalation, and the factors were included as the background levels of intake at each of the receptors in Table 11.

The IRAP-h View model does not report results for child inhalation, as the model only considers intake by inhalation for the purpose of calculating the uptake of Dioxins and Furans by infants in breast milk. However, the inhalation of children at any specific location can be pro-rated from the adult intake, factoring the air intake of the child from that of the adult in m^3 kg^{-1} day^{-1}, resulting in a multiplication factor of 1.26. This has been applied to the adult inhalation rate, to report inhalation intake by children.

Table 11 Total Dioxin and Furan Intake by All Receptors

Receptor	Scenario	Intake - Indirect Sources (pg kg^{-1} day^{-1})	Percentage of the TDI	Percentage of TDI including MDI	Intake – Inhalation (pg kg^{-1} day^{-1})	Percentage of the TDI	Percentage of TDI including MDI	Total Intake - Percentage of TDI (WHO TEQ 2005)	Total Intake - Percentage of TDI (WHO TEQ 2022)
1	**Farmer (F)**	**8.70E-03**	**0.435%**	**35.43%**	**2.40E-05**	**0.00120%**	**0.144%**	**0.436%**	0.325%
	F. Child	**1.29E-02**	**0.646%**	**91.30%**	**3.02E-05**	**0.00151%**	**0.372%**	**0.647%**	0.484%
	Resident (R)	2.08E-05	0.001%	35.001%	1.80E-05	0.00090%	0.1438%	0.0019%	0.0009%
	R. Child	5.13E-05	0.003%	90.653%	2.27E-05	0.00113%	0.3711%	0.0037%	0.0023%
2	Resident (R)	1.63E-05	0.001%	35.001%	1.25E-05	0.00063%	0.1435%	0.0014%	0.0007%
	R. Child	4.11E-05	0.002%	90.652%	1.58E-05	0.00079%	0.3708%	0.0028%	0.0019%
3	Resident (R)	6.73E-06	0.0003%	35.000%	5.90E-06	0.00030%	0.1432%	0.0006%	0.0003%
	R. Child	1.66E-05	0.0008%	90.651%	7.44E-06	0.00037%	0.3704%	0.0012%	0.0007%
4	Resident (R)	5.37E-06	0.0003%	35.000%	4.09E-06	0.00020%	0.1431%	0.0005%	0.0002%
	R. Child	1.35E-05	0.0007%	90.651%	5.16E-06	0.00026%	0.3703%	0.0009%	0.0006%
5	Resident (R)	1.75E-05	0.0009%	35.001%	1.20E-05	0.00060%	0.1435%	0.0015%	0.0008%
	R. Child	4.47E-05	0.0022%	90.652%	1.52E-05	0.00076%	0.3708%	0.0030%	0.0021%
6	Resident (R)	3.51E-06	0.0002%	35.000%	2.24E-06	0.00011%	0.1430%	0.0003%	0.0002%
	R. Child	9.03E-06	0.0005%	90.650%	2.82E-06	0.00014%	0.3701%	0.0006%	0.0004%
7	Resident (R)	2.85E-06	0.0001%	35.000%	1.35E-06	0.00007%	0.1429%	0.0002%	0.0001%
	R. Child	7.58E-06	0.0004%	90.650%	1.70E-06	0.00009%	0.3701%	0.0005%	0.0004%
8	Resident (R)	6.01E-06	0.0003%	35.000%	4.14E-06	0.00021%	0.1431%	0.0005%	0.0003%
	R. Child	1.53E-05	0.0008%	90.651%	5.22E-06	0.00026%	0.3703%	0.0010%	0.0007%
9	Resident (R)	6.25E-06	0.0003%	35.000%	4.63E-06	0.00023%	0.1431%	0.0005%	0.0003%
	R. Child	1.58E-05	0.0008%	90.651%	5.84E-06	0.00029%	0.3703%	0.0011%	0.0007%
10	Farmer (F)	6.27E-04	0.031%	35.031%	1.74E-06	0.00009%	0.1429%	0.0314%	0.0234%
	F. Child	9.31E-04	0.047%	90.697%	2.20E-06	0.00011%	0.3701%	0.0467%	0.0348%
	Resident (R)	1.47E-06	0.000%	35.000%	1.31E-06	0.00007%	0.1429%	0.0001%	0.0001%
	R. Child	3.62E-06	0.000%	90.650%	1.65E-06	0.00008%	0.3701%	0.0003%	0.0002%
11	Farmer (F)	4.98E-04	0.025%	35.025%	1.40E-06	0.00007%	0.1429%	0.0249%	0.0186%
	F. Child	7.39E-04	0.037%	90.687%	1.77E-06	0.00009%	0.3701%	0.0370%	0.0277%
12	Farmer (F)	3.22E-04	0.016%	35.016%	8.92E-07	0.00004%	0.1429%	0.0162%	0.0121%
	F. Child	4.79E-04	0.024%	90.674%	1.12E-06	0.00006%	0.3701%	0.0240%	0.0179%
13	Farmer (F)	2.18E-04	0.011%	35.011%	6.16E-07	0.00003%	0.1429%	0.0109%	0.0082%
	F. Child	3.23E-04	0.016%	90.666%	7.76E-07	0.00004%	0.3700%	0.0162%	0.0121%

The results in Table 11 demonstrate that the farmer scenario (adult and child) at receptor number 1 report the highest levels of intake of each of the receptor locations. These results are highlighted in bold text. It could be anticipated that the receptor nearest to the emissions source might receive the highest process contribution, and as noted in Section 5.1, the assumption that this location is farmed land provides an overly conservative and highly unlikely assessment, as the area represents open space off Zinc Road, rather than a farm or other area likely used for growing crops or rearing animals.

Process contributions to the levels of Dioxin and Furan intake at receptor number 1 equate to 0.436 % of the TDI for the farmer and 0.647 % of the TDI for a child of the farmer, based on the 2005 WHO TEQs. With a process contribution of less than 1 % for both adults and children, the impact of Dioxin and Furan emissions from the Facility is immediately screened as insignificant, and the addition of these insignificant contributions to the existing MDIs do not result in any exceedance of the TDI.

The final column in Table 11 presents the results of the assessment factored to the 2022 WHO TEQs and confirms that the 2005 WHO TEQs present the worst case. As such, the assessment continues on that basis, with only the 2005 WHO TEQ results being considered from this point.

5.2 Risk and Hazard Results

The risk of developing cancer over the course of a lifetime from daily exposure to Dioxins and Furans due to the operation of the Facility are calculated by multiplying the intake rate by the total exposure period during the operational lifetime of the plant (assumed to be 30 years) and an oral cancer slope factor as calculated by the US EPA and specified in the HHRAP, before dividing the total by 70 years to represent a lifetime. The result is a unitless cancer risk figure, the inverse of which describes the population exposure for each cancer case.

Table 12 Total Cancer Risk Potential from the Emission of Dioxins and Furans

Receptor	Scenario	Cancer Risk	Potential Population Exposure (1 in:)
1	**Farmer (F)**	**3.688E-07**	**2,711,773**
	F. Child	**8.215E-08**	**12,172,363**
	Resident (R)	6.017E-10	1,662,056,219
	R. Child	2.942E-10	3,399,544,772
2	Resident (R)	2.659E-08	37,603,192
	R. Child	5.925E-09	168,789,718
3	Resident (R)	4.285E-11	23,335,005,568
	R. Child	2.091E-11	47,820,203,999
4	Resident (R)	2.108E-08	47,448,774
	R. Child	4.695E-09	212,987,584
5	Resident (R)	1.368E-08	73,119,780
	R. Child	3.047E-09	328,198,161
6	Resident (R)	9.203E-09	108,662,263
	R. Child	2.050E-09	487,748,989
7	Resident (R)	4.498E-10	2,223,377,089
	R. Child	2.228E-10	4,488,023,939
8	Resident (R)	1.955E-10	5,116,091,046
	R. Child	9.543E-11	10,478,400,340
9	Resident (R)	1.473E-10	6,787,805,567
	R. Child	7.300E-11	13,697,701,922
10	Farmer (F)	4.667E-10	2,142,718,624
	F. Child	2.332E-10	4,287,949,031
	Resident (R)	9.223E-11	10,842,513,776
	R. Child	4.654E-11	21,484,584,943
11	Farmer (F)	7.030E-11	14,225,143,261
	F. Child	3.652E-11	27,380,075,745
12	Farmer (F)	1.605E-10	6,229,408,070
	F. Child	8.013E-11	12,480,477,200
13	Farmer (F)	1.702E-10	5,874,750,385
	F. Child	8.460E-11	11,819,959,390

When considering the significance or otherwise of the calculated cancer risk, the accepted position in the UK at present is that a risk level of 1 x 10^{-05} is considered to be appropriate for use as the basis for assessment for carcinogenic contaminants such as Dioxins and Furans[10,11]. Accordingly, as the risk at each location is significantly lower than this for both adults and children, the results can be screened as insignificant.

Target levels are risk management based rather than providing an indication of an observed adverse effect. Therefore, if a risk estimate falls below a target level, it is reasonable to conclude, without any further investigation, that the proposal does not present an unacceptable risk. However, a risk estimate that exceeds a target would not, in itself, necessarily indicate that the proposal presents an unacceptable risk. Rather, a risk estimate that exceeds a target value triggers further careful consideration of the underlying scientific basis for the calculation.

It should be noted that the above results are based upon a series of worst case, conservative assumptions as follows:

1. Emissions of Dioxins and Furans are continuously discharged at the ELV of 0.04 ng Nm^{-3} for waste incineration plants.
2. It is assumed that all of the food consumed by adult farmers and their children is grown at receptor numbers 1 or 10 - 13, which is unlikely in any event, but also assumes that these are farming locations, including receptor number 1, which is actually representative of open land in the otherwise industrial area; and
3. All of the milk consumed by farmers and their children is produced by cows grazing at or receiving silage or grain from the specific receptor location for the entire year, which is also highly unlikely.

Accordingly, the above results are considered to provide a worst-case and an overly conservative assessment of the effects of potential exposure to Dioxins and Furans in the vicinity of the Facility.

To put the cancer risk data into perspective, in 2022, the UK reported the fourth lowest road death rate across 32 European countries. With 1,766 deaths this equates to approximately 26 deaths per million population in the UK[12], or approximately 1 person in every 38,460. An adult cancer risk of 3.688 x 10^{-07} (0.0000003688) calculated on the assumption that receptor number 1 is a farming environment, equates to one death in every 2,711,773 people, or a potential risk which is approximately 71 times less likely than dying in a road traffic accident.

5.3 Dioxin-Like PCBs

Having assessed the risk and hazard associated with the anticipated release of Dioxins and Furans from the Facility consideration can also be given to the potential process contribution of Poly-Chlorinated Biphenyls (PCBs) to the local area.

PCBs are synthetic organic compounds made up of Carbon, Hydrogen and Chlorine. There are 209 different PCB compounds with up to 10 Chlorine atoms attached to a two ring, Biphenyl group. They are sometimes referred to as Aroclor compounds with different numbering configurations. For example, Aroclor 1254 refers to a 12-Carbon atom compound containing 54 % Chlorine by mass. However, Aroclor is a brand name and refers to historically marketed PCB mixtures, rather than individual PCB species, and although TEFs for PCB species are available from the World Health Organisation there is no standard emissions profile for Dioxin-like PCBs from the process or any similar reference plant. Furthermore, the HHRAP COPC Database of compounds that can be modelled in IRAP-h View includes Aroclor 1016 and Aroclor 1254 as the only Dioxin-like PCB species.

The Waste Incineration BREF[13] does not specify an individual achievable emission level for PCBs, instead specifying that the combined emissions of Dioxins, Furans and Dioxin-like PCBs from waste incineration plant should remain within 0.06 ng Nm^{-3}, or 1.5 times the Dioxin and Furan ELV.

As a result of the limited available data on PCB emissions, the options for assessing the intake of Dioxin-like PCBs was limited to considering an assumed contribution from the overall Dioxin, Furan and Dioxin-like PCB emission, with the PCB fraction assessed as Aroclor 1016 and / or Aroclor 1254, or simply assuming that the total effect of the 0.06 ng Nm^{-3} release would result in an intake that was 1.5 times that of Dioxins and Furans as already calculated.

A sensitivity analysis was therefore undertaken to consider the results of each scenario at receptor number 1. The total intake results for an adult farmer at receptor 1 are presented below and show that assuming an additional emission of Dioxins and Furans of 0.02 ng Nm^{-3} to represent Dioxin-like PCBs results in a higher intake level than when modelling PCBs independently as either Aroclor 1016 or Aroclor 1254. Therefore, assuming a total release of 0.06 ng Nm^{-3} as Dioxins and Furans would present a worst-case approach to the inclusion of Dioxin-like PCBs in light of the lack of detail associated with the PCB inputs. It is noted that, although Table 13 only presents the data for the farmer, the results for the farmer's child, and adult or child residents at receptor number 1 showed a similar pattern, with the application of the Dioxin and Furan intake x 1.5 to represent the potential effect of total Dioxin, Furan and Dioxin-like PCB emissions, providing the most conservative assessment of the combined emissions.

Table 13 Sensitivity Analysis of PCB Emission Modelling

Total Indirect Intake (no inhalation) mg kg^{-1} day^{-1}	**PCDD / DF Split**	**Aroclor 1016**	**Aroclor 1254**
	4.35E-12	1.17E-13	4.74E-13

The results of the sensitivity assessment confirmed that the application of the total Dioxin, Furan and Dioxin-like PCB emission (0.06 ng Nm^{-3}) as Dioxins and Furans provides the most conservative approach to the consideration of these species and the resultant effect on the overall intake of these species at receptor number 1 is detailed in Table 14.

Table 14 Total Intake of Dioxins and Furans; and Dioxins, Furans and PCBs at the Receptor Locations

Total Intake (including inhalation) pg kg^{-1} day^{-1}	**Adult Farmer**	**Farmer's Child**
Total Dioxin and Furan Loading	8.72E-03	1.29E-02
As a Percentage of 2 pg kg^{-1} day^{-1}	0.44 %	0.65 %
Total Dioxin, Furan and PCB Loading (x 1.5)	1.31E-02	1.94E-02
As a Percentage of 2 pg kg^{-1} day^{-1}	0.65 %	0.97 %
Intake of Dioxins and Furans from Breast Milk	1.57E-01	N/A
As a Percentage of 2 pg kg^{-1} day^{-1}	7.86 %	

The results presented in Table 14 for the total Dioxin and Furan loading represent a worst-case estimate, based upon Dioxin and Furan deposition rates from continuous emissions at the ELV of 0.04 ng Nm^{-3}, at a location identified as a potential receptor but which actually occurs within the industrial area, and therefore will almost certainly not be used for agricultural purposes. It also assumes that total dietary intake of meat, eggs, milk, and fruit and vegetables is derived from produce grown at that specific location, which is clearly a significantly conservative assessment.

Nevertheless, the results show that the potential impact of Dioxin and Furan release from the Facility on Dioxin and Furan concentrations in the soil, and on the associated increase in dietary intake through the consumption of meat, eggs, fruit and vegetables, as well as via the ingestion of soil through the working of the land, and through inhalation, is likely to be less than 1 % the recommended Tolerable Daily Intake of 2 pg kg^{-1} day^{-1} for either an adult farmer or their child.

The overall potential intake of Dioxins and Furans for adults represents about 0.44 % of the TDI, with that for children equating to approximately 0.65 % of the TDI.

When multiplied by 1.5, in order to represent the potential loading of Dioxins, Furans and Dioxin-like PCBs, the intake values naturally increase, but remain within 1 % of the TDI for both adult and child exposure, and are therefore screened as insignificant, despite the conservative nature of the assessment.

The intake by infants feeding on mother's milk equates to an incremental increase in daily Dioxin and Furan uptake by the infant of 0.157 pg kg^{-1}, due to the operation of the Facility. This equates to a daily dietary intake by infants from the consumption of breast milk, of approximately 7.86 % of the Tolerable Daily Intake.

While still a very low contribution to the total daily intake this percentage increase may not necessarily be considered to be insignificant against the TDI assessment level. However, the concentration can also be considered in relation to the levels of Dioxin, Furan and PCB that are found in breast milk.[14]

World Health Organisation (WHO) field studies in the 1990's showed differences between the Dioxin, Furan and PCB contamination of breast milk, with higher mean levels in industrialised areas (10-35 pg I-TEQ/g milk fat) and lower mean levels in developing countries (< 10 pg I-TEQ/g milk fat). The suggested addition of 0.000157 pg g^{-1} milk fat (0.157 pg kg^{-1}) equates to an increase of 0.00045 – 0.0016 % on these measured levels of Dioxins and Furans in breast milk, although that study did note that in the preceding 10 years there had been clear evidence of a decrease in Dioxin levels in human milk in almost every region for which suitable data existed. It could be assumed that this reduction has continued and therefore the proposed increase might result in a slightly higher contribution to the background levels of Dioxins in breast milk, although this cannot be quantified here, and the overall addition would still be expected to be a fraction of 1 %.

Additionally however, the relevance of assessing short-term exposure against the TDI should also be considered.

The Tolerable Daily Intake range identified by the WHO in their 1998 report and that which has effectively been adopted by the UK Committee on Toxicity (COT), has its starting point in the lowest-observable-adverse-effect-level (LOAEL) for the most sensitive adverse responses reported in experimental animals, and were associated with body burdens from which a range of long-term human daily intakes of 14 - 37 pg kg^{-1} day^{-1} were estimated. By applying an uncertainty factor of 10 to this range a TDI range of 1 - 4 TEQ pg kg^{-1} BW day^{-1} (rounded figures) was established for Dioxins and Dioxin-like compounds. However, it is emphasised that *the TDI represents a tolerable daily intake for lifetime exposure and that occasional short-term excursions above the TDI would have no health consequences provided that the averaged intake over long periods is not exceeded.*

The report goes on to note that:

Breast-fed infants are exposed to higher intakes of these compounds on a body weight basis, although for a small proportion of their lifespan. However, the consultation noted that in studies of infants, breast feeding was associated with beneficial effects, in spite of the contaminants present. The subtle effects noted in the studies were found to be associated with transplacental, rather than lactational, exposure. The consultation therefore reiterated conclusions of previous WHO meetings on the health significance of contamination of breast milk with dioxin-like compounds; namely that the current evidence does not support an alteration of WHO recommendations which promote and support breast feeding.

This continued support for breast-feeding was also reflected in a UK COT report of 2004[15] which notes that the period of breast-feeding is short compared with the time needed to accumulate Dioxin and Furan compounds in the body and there are known benefits to breast-feeding. The report concluded that, amongst other things:

49. The TDI is set to protect against the most sensitive effects of dioxins and dioxin-like PCBs, which occur in the male fetus as a result of the mother's accumulated body burden. There is uncertainty with respect to whether similar effects would arise from post-natal exposure, but there is currently no basis for assuming that the young infant is at increased risk.

50. Taking into account that the TDI is now set to protect against reproductive effects and the evidence that concentrations of dioxins and dioxin-like PCBs in breast milk are declining, the new data do not suggest any reason to alter Government advice that breast-feeding should continue to be encouraged on the basis of convincing evidence of the benefits of human milk to the overall health and development of the infant.

Therefore, when considering a suggested increase in the daily dietary intake by infants from the consumption of breast milk over a relatively short period, of approximately 7.86 % of the Tolerable Daily Intake, the implications of these higher levels are expected to have no health consequences provided that the averaged intake over long periods is not exceeded.

It should also be noted that in defining a TDI of 2 pg kg^{-1} for Dioxins and Furans, the UK COT acknowledged the uncertainties associated with the approach:

We concluded that the available human data did not provide a sufficiently rigorous basis for establishment of a tolerable intake. This was because:

- *the epidemiological studies do not reflect the most sensitive population identified by animal studies;*
- *there are considerable uncertainties in the exposure assessments and inadequate allowance for confounding factors;*
- *the patterns of exposure did not reflect exposures experienced in the general UK population, which are mainly from diet.*

We therefore found it necessary to base our evaluation on the data from studies conducted in experimental animals.

Accordingly, the results from this assessment, which are based upon a series of overly pessimistic assumptions relating to emissions of Dioxins and Furans and their associated deposition, should be viewed within the context that they are low relative to an inexact assessment level. This is particularly the case with regard to the predictions for the consumption of milk. These values reflect the fact that Dioxins and Furans tend to concentrate in fats and fatty tissues and pass through into an animal's lactate system. However, despite the uncertainties associated with the UK COT assessment level, the application of a worst-case and significantly overly conservative approach when considering the potential for exposure at receptor locations using the US EPA HHRAP methodology, confirms that the risks and hazards associated with the proposed releases from the Facility on Zinc Road in Avonmouth, will be insignificant.

6. Conclusions

A health risk assessment has been undertaken to assess the potential impact to the health of people living and working in the vicinity of the Facility, located within the main Avonmouth industrial area. Detailed atmospheric dispersion modelling of emissions from the 36.5-metre-high stack that will be associated with the Facility was undertaken using the ADMS Version 6 model to predict increases in pollutant concentrations at nearby sensitive receptors such as allotments and the local community farm, as well as local businesses which are the nearest potential points of exposure. The air quality assessment (AQA) produced to report the dispersion modelling work included detailed consideration of model-predicted process contributions against health-based Air Quality Standards and relevant Environmental Assessment Levels recommended by the Environment Agency.

In addition to the AQA, this report has applied the US EPA Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities to assess the potential risk to health of people living and working in the locality of the Facility due to emissions of Dioxins and Furans, and Dioxin-like PCBs. The assessment considered the potential health risks associated with the intake of Dioxins and Furans from the consumption of potentially contaminated foodstuffs due to emissions to atmosphere from the stack of the Facility. The assumptions used within the assessment are conservative and therefore the study is considered to represent a worst-case.

The assessment indicates that the risk to health of the local population due to exposure to Dioxins and Furans in emissions from the Facility is likely to be low, remaining well within 1 % of the Tolerable Daily Intake (TDI) of 2 pg kg^{-1} for both adults and children when considering the worst-case, farmer scenario. The inclusion of Dioxin-like PCBs into the assessment resulted in a marginal increase in the resulting process contributions but remained less than 1 % of the 2 pg kg^{-1} TDI.

In conclusion, the results from the health risk assessment confirms that there is no significant health risk associated with potential exposure to emissions of Dioxins, Furans and PCBs from the Facility which Grundon Waste Management Limited proposes to develop at their site on the Avonmouth industrial estate.

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