FCC Environment Permit Variation

FCC Environment Permit Variation – Environmental Radioactivity {R9}

FCC Environment

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Introduction

This document is specific to the environmental radioactivity requirements of the Near-surface Guidance on Requirements for Authorisation (NS-GRA) of the FCC Lillyhall facility {R9}. Assessments relating to human radiological assessment during the period of authorisation {R5}; after the period of authorisation {R6}; and, associated with human intrusion {R7} are reported separately [FCC 2018a; FCC 2018b; and, FCC 2018c].

Executive Summary

This document is specific to the environmental assessment requirements of the Near-surface Guidance on Requirements for Authorisation (NS-GRA) during the period of authorisation of the FCC Lillyhall facility {R9}.

Based on the model radionuclide inventory (see Section 3 of the main report [FCC, 2018d]); estimated activity concentration data in leachate (see Section 2.12 of the main report [FCC, 2018d]) and in groundwater (see Section 2.12 of the main report [FCC, 2018d]) dose rates to non-human biota receptors have been assessed. The scenarios considered include:

- leachate processing off-site during the period of authorisation and exposure of marine biota to effluents discharged to the coast via pipeline from Whitehaven (Parton) Wastewater Treatment Works;
- radionuclide transport in groundwater to a small stream and exposure of freshwater biota during and after the period of authorisation; and,
- terrestrial biota intrusion into the waste in the period after authorisation.

The assessment has used several precautionary modelling approaches and data assumptions to give upper bounding (worst-case) estimates of biota dose rates with subsequent uncertainty analysis where estimated dose rates are at or in excess of relevant benchmarks. Dose rates estimated are compared against International Commission on Radiological Protection (ICRP) planned exposure reference points and the Environment Agency threshold below which population effects are unlikely to occur. Dose rates associated with intrusion into the waste after the period of authorisation are compared against the Environment Agency threshold and the ICRP derived consideration reference levels (DCRLs).

Dose assessment results relative to the dose criterion described above are shown below.

Exposure Pathway	Receptors	Maximum calculated Dose Rate (µGy/h)	Relevant Dose Rate threshold (µGy/h)
Period of Authorisation			
Leachate processing off-site	Marine biota	<0.001 (worst affected organism)	40
During and After Period of Authorisation			
Release to groundwater	Freshwater biota	<6 (gastropod mollusc)	40
After Period of Authorisation			
Biota intrusion	Terrestrial biota	83 (lichen & bryophyte)	40

Dose rates for the most exposed organism for both the leachate processing off-site and release to groundwater scenarios were below the relevant dose thresholds (Environment Agency threshold and relevant ICRP planned exposure reference points). The exposure of populations of non-human biota under these exposure scenarios are therefore unlikely to be of concern.

The maximum dose rate calculated for an intrusion scenario after the period of authorisation was a factor of 2 greater than the Environment Agency threshold and within the ICRP DCRL order of magnitude band of dose rate for small plants within which "*there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of Reference Animal or Plant"* [ICRP, 2008, para 195]. The area over which potential exposures could occur is, however, several orders of magnitude lower than a reference area for a population [IAEA, 2018a] and impacts across the population are therefore considered to be extremely unlikely. With the exception of the lichen and bryophyte reference organism for which the maximum dose rate was calculated, all other calculated dose rates were below the Environment Agency threshold. Calculated dose rates to populations of non-human biota are therefore considered to be of low concern.

1. Assessment Background

1.1. Regulatory Context

This document assesses the radiation effects of the facility on the accessible environment during the period of authorisation and afterward. It addresses NS-GRA Requirement 9 {R9} [Environment Agencies, 2009, para 6.3.70]:

"The developer/operator should carry out an assessment to investigate the radiological effects of a disposal facility on the accessible environment both during the period of authorisation and afterwards with a view to showing that all aspects of the accessible environment are adequately protected."

This requirement is addressed in the current report.

1.1.1. Environmental protection targets

Requirement 9 {R9} of the NS-GRA requires demonstration that all aspects of the accessible environment are protected through evaluation of effects on non-human species as well as consideration of more general environmental effects such as damage to habitat quality. In particular, demonstration that species and habitats are provided protection under national and international conservation legislation (e.g. through the EC Habitats Directive [EC, 1992]) is required.

The nearest designated site to Lillyhall is the River Derwent and Bassenthwaite Lake Special Area of Conservation (SAC). This includes the River Marron (a tributary of the River Derwent), which is also designated as a Site of Special Scientific Interest (SSSI). At its closest point, the River Marron is located around 2.5 km to the east of the site. The flow of groundwater at the site is from east to west. As such, there is no pathway by which leachate entering groundwater at the site could reach these designated receptors. These conservation sites have therefore been excluded from further assessment. The assessment therefore focuses on the exposure of representative species of fauna and flora that may inhabit the site or may be exposed to radionuclides as a result of their transport off-site both during and after the period of authorisation.

It is broadly accepted that the focus of protection for non-human species should not be on individuals (with the notable exception of endangered / protected species), but rather at higher levels of organisation such as populations, communities and ecosystems [ICRP, 2008, 2014; IAEA, 2014, 2018a; BIOPROTA, 2015]. In this regard, the International Atomic Energy Agency (IAEA) General Safety Guide for prospective radiological environmental impact assessment for facilities and activities (GSG-10 [IAEA, 2018a]) suggests the use of a reference area around a source that should be:

"*sufficiently large to ensure that mixing of the effluents within the environmental media occurs and that the number of individuals of the species considered in the assessment is suitably large*" [IAEA, 2018a, para I-18].

A reference area centred around an effluent release point of between 100 and 400 km^2 is suggested as appropriate for the averaging of activity concentrations for most normal operation exposure scenarios for facilities [IAEA, 2018a, para I-23].

1.1.2. Assessment criteria

In the absence of internationally established criteria against which radiological protection of the environment could be determined, the NS-GRA calls for the use of the best available information at the time of the assessment in drawing conclusions about the effect of a disposal facility on the accessible environment [Environment Agencies, 2009, para 6.3.74].

The Environment Agency has adopted a dose rate threshold level of 40 µGy/h for authorised discharges of radioactive substances [Allott et al., 2009]. This threshold has been applied in the current assessment. Consideration is also given to ICRP Derived Consideration Reference Levels (DCRLs), described below, and particularly the application of the DCRLs to planned exposure situations where these are more cautionary than the Environment Agency dose rate threshold.

The International Commission on Radiological Protection (ICRP) has developed a framework for protection of the environment, based around a small set of Reference Animals and Plants (RAPs), with associated DCRLs [ICRP, 2008], where DCRLs are defined as:

"a band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of Reference Animal or Plant" [ICRP, 2008, para 195].

The intended application of DCRLs to planned exposure situations is described in ICRP [2014]. Under this framework:

"*the lower boundary of the relevant DCRL band should be used as the appropriate reference point for protection of different types of biota within a given area during the planning of controls to be applied to a source*" [ICRP, 2014, para 33].

This is consistent with IAEA GSG-10 [IAEA, 2018a], which considers that dose rates below such reference points can be considered to have negligible impact on populations of flora and fauna and the level of protection may be considered adequate.

Planned exposure reference points (µGy/h) for ICRP RAPs in terrestrial and freshwater ecosystems are detailed in Table 1. The application of the reference points to other representative types of animal and plant that may be of relevance in assessments, as detailed in IAEA [2016, Table I-1], are also presented.

Table 1 Planned Exposure Situation Reference Points for ICRP RAPs and Representative Plants and Animals in Terrestrial and Freshwater Ecosystems (from IAEA [2018a, Table I-1])

Ecosystem	ICRP RAP	Representative animal / plant	ICRP Planned exposure reference point (µGy/h)
Terrestrial	Reference deer	Large mammal	4
	Reference rat	Small mammal	4
	Reference duck	Bird	4
	Reference frog	Amphibian	40
	Reference bee	Insect	400
	Reference earthworm	Annelid	400
	Reference wild grass	Small plant	40
	Reference pine tree	Large plant	4
Freshwater	Reference duck	Aquatic bird	4
	Reference trout	Fish	40
	Reference frog	Amphibian	40

The Reference points are intended to be applied in relation to dose rates calculated over a suitable spatial area, as discussed in Section 1.1.1 [ICRP, 2014, para 63].

1.2. Assessment Scenarios

In this document, the term "period of authorisation" covers the time when active management controls are maintained and the Environmental Permit remains in force and the term "after the period of authorisation" covers the time when active management controls have ceased and the Environmental Permitting Regulations (2016 as amended) Radioactive Substances Activities (EPR-RSA) environmental permit has been surrendered. The period of authorisation is assumed to last until 2090 in these assessments. The period after authorisation is therefore assumed to commence from 2091.

The potential exposure of populations of non-human biota associated with disposals at the site need to be assessed for a variety of hypothetical scenarios covering both the period of authorisation and after the period of authorisation. A variety of potential scenarios have therefore been identified Table 2.

Of the potential exposure scenarios identified for the period of authorisation, intrusion exposure was considered unlikely to occur due to active management of the site. During operations, continual disturbance of cells will prevent the establishment of resident biota populations although there may be some transitory exposure of individuals. The placement of a daily soil cover (10% by volume) over active cells will also minimise transitory exposure of individuals to emplaced wastes, which will be further mitigated through active pest control activities. A scenario of intrusion during the period of authorisation was not, therefore, taken forward to assessment.

Table 2 Hypothetical Exposure Scenarios for Populations of Fauna and Flora

Exposure Scenario	Description
Period of Authorisation	
Intrusion exposure	Biota that may have access into a disposal cell before it is finally capped
Leachate migration to groundwater	Biota exposed as a result of leachate entering groundwater
Leachate processing off-site	Biota exposed via the discharge of treated sewage effluent to sea
After the period of authorisation	
Intrusion exposure	Biota that may have access into a cell in a post-closure scenario after the cap has failed
Leachate migration to groundwater	Biota exposed via leachate entering groundwater

Leachate migration to groundwater was identified as an exposure scenario for both the period of authorisation and after the period of authorisation. A single cautious screening assessment has been undertaken, covering peak activity concentrations of radionuclides that may enter groundwater below a disposal cell, irrespective of the timing of release.

1.3. Primary Input Data

The assessment has been based on the primary input data as referenced in Table 3.

Table 3 Primary Input Data References

Exposure Pathway	Receptor	Reference
Leachate processing off-site	Marine biota	Calculated leachate concentrations and annual arising – see Section 2.12 of the main report [FCC, 2018d]
Release to groundwater	Freshwater biota	Calculated groundwater concentrations – see Section 2.12 of the main report [FCC, 2018d]
Waste intrusion	Terrestrial biota	Model inventory of waste – see Section 3 of the main report [FCC, 2018d]

2. Biota Dose Assessment

2.1. Leachate Processing Off-site During the Period of Authorisation

Screening calculations of dose rates to non-human biota were undertaken using the Environment Agency Initial Radiological Assessment Tool (IRAT) – Version 8 (May 2015) 'Release to Sewer' (338_04_SD_04) according to the methodology set out by the Environment Agency [2006a, 2006b].

The screening calculation was based on generic and site specific data and provides a highly precautionary estimate of the dose rate arising to non-human biota. IRAT assumes a default volume throughput at the sewage works of 60 m^3/d, which corresponds to a very small sewage works serving about 500 people. The Whitehaven (Parton) Wastewater Treatment Works (WwTW) has a typical throughput[1] of about 12,000 m^3/d (and a design capacity over twice this)[2], which means that radionuclide concentrations will be substantially more dilute than assumed in the default case. Equally, IRAT uses a default value for the average coastal/estuary exchange rate of 30 m^3/s. This is also extremely small. For instance, for the Whitehaven / Workington coast, a net exchange rate of 1,300m^3/s is recommended in Environment Agency [2011]. The assessment used calculated leachate activity concentration data (see Section 2.12 of the main report [FCC, 2018d]), an

[1] Personal communication 15.01.09, United Utilities to A. Borwick (Waste Recycling Group Ltd.)
[2] www.WaterProjectsOnline.com

assumed annual leachate arising of 6,500 m^3/y, a sewage sludge flow rate of 12,000 m^3/d and a coastal exchange rate of 1,300 m^3/s.

The estimated marine biota dose rate (to the worst affected organism) was less than 0.001 µGy/h. This is several orders of magnitude below any benchmark or screening value. Biota exposure via this route was not therefore considered further.

2.2. Leachate Migration to Groundwater During and After the Period of Authorisation

2.2.1. Environmental Setting

During the period of authorisation, leakage from the cells and migration of radioactivity into groundwater is considered to be from defects in the geomembrane liner which is underlain by a 2 m clay layer. The site is currently permitted for leachate levels of 3 m depth. For the sake of this assessment a constant head of leachate of 3 m has been assumed during the period of authorisation, to demonstrate whether or not the permitted leachate levels present a risk to man or the environment.

After the period of authorisation, leakage from the cells and migration of radioactivity into groundwater is considered to be from complete failure of the geomembrane liner which is underlain by a 2 m clay layer. This clay layer is assumed to remain intact throughout the assessment period in line with the approach recommended by the Health Protection Agency [HPA, 2007]. For the sake of this assessment a constant head of leachate of 3 m has been assumed after the period of authorisation, to demonstrate whether or not a fully saturated cell presents a risk to man or the environment.

The Lower Pennines Coal Measures (LCM) beneath the site is a fairly low permeability aquifer, it is classified by the Environment Agency as a Secondary A Aquifer which is capable of supporting water supplies at a local scale (i.e. a private water supply). Groundwater flow within the aquifer is in an east to west direction, towards the coast.

Some small streams / rivers are present between the site and the coast and the potential for upwelling of groundwater into a freshwater receptor cannot, therefore, be excluded. A precautionary assumption has therefore been made that radionuclides are transferred, via groundwater, to a small stream.

Distington Beck has not been specifically assessed since it is considered unlikely that groundwater underlying the proposed Cells would flow toward the Beck, and it is not thought that the Beck is in continuity with groundwater in the LCM. The selection of parameters to represent a small stream has been made to ensure that water flow rate is lower than that of Distington Beck to ensure exposures are no less precautionary than if discharge to the Beck itself had been assessed.

Calculation of radionuclide activity concentrations in groundwater beneath a cell is discussed in Section 2.12 of the main report [FCC, 2018d] and not are repeated here.

2.2.2. Assessment Context

Rainwater ingress into a cell containing radioactive waste will mobilise some of the radioactivity into the leachate. Both during the period of authorisation and after the period of authorisation there is the potential that some of this leachate will penetrate through the geomembrane liner and underlying clay and into groundwater.

Upwelling of groundwater to a small stream, located to the west of the site, is considered a bounding (worst-case) scenario compared with other exposure scenarios, such as upwelling of groundwater into a river or at the coast.

2.2.3. Assessment Methodology

The assessment of fauna and flora dose rates has been undertaken using Tier 2 of the ERICA assessment tool (version 1.2.1, 18 February 2016), with activity concentrations in a small stream being calculated using the built-in SRS-19 river dispersion model.

The stream was assumed to have a small flow rate (0.02 m^3/s) with the discharge point and receptor location being located on the same bank of the stream[3]. A receptor point of 10 m downstream of the discharge was assumed to allow for initial dilution. The assumed stream characteristics are provided in Appendix A.1.

Radionuclide discharge rates (Bq/s) were calculated using the activity concentrations in groundwater immediately below a cell and the groundwater flow rate (see Section 2.12 of main report [FCC, 2018d]). No credit has been taken for attenuation of radionuclides during groundwater transport from below the cell to the stream receptor. The radionuclide discharge rates are detailed in Appendix A.2.

The calculations presented assume that the following short-lived decay products are in secular equilibrium with the parent in the model inventory:

- Strontium-90 (Sr-90) / yttrium-90 (Y-90);
- Ruthenium-106 (Ru-106) / rhodium-106 (Rh-106);
- Caesium-137 (Cs-137) / barium-137 metastable (Ba-137m);
- Cerium-144 (Ce-144) / praseodymium-144 (Pr-144);
- Lead-210 (Pb-210) / bismuth-210 (Bi-210) / polonium-210 (Po-210);
- Radium-226 (Ra-226) / radon-222 (Rn-222) through to lead-210 (Pb-210);
- Thorium-234 (Th-234) / protactinium-234 metastable (Pa-234m) / protactinium-234 (Pa-234);
- Uranium-235 (U-235) / thorium-231 (Th-231); and,
- Uranium-238 (U-238) / thorium-234 (Th-234) / protactinium-234 metastable (Pa-234m) / protactinium-234 (Pa-234).

Note that the approach assumes that any U-238 is from the nuclear fuel cycle, has been chemically purified and hence only the initial short-lived decay products are present[4]. Dose rates calculated with the ERICA assessment tool include all short-lived daughters with a half-life of less than 10 days. Daughters with a half-life of more than 10 days have therefore been assessed separately, assuming secular equilibrium with the parent radionuclide. The following daughter radionuclides have therefore been evaluated independently of the parent:

- Ra-225 (Th-229 parent);
- Th-234 (U-238 parent); and,
- Pa-233 (Np-237 parent).

The ERICA assessment tool includes a wide range of radionuclides and supporting assessment parameter values (distribution coefficients (K_d) and concentration ratios (CR), both based on element data) for each of the thirteen default freshwater reference organisms. Parameter values to support the assessment of dose rates to freshwater biota were therefore available for the majority of radionuclides in the waste inventory. The exceptions were iron-55 (Fe-55), molybdenum-93 (Mo-93), tin-121 metastable (Sn-121m), promethium-147 (Pm-147) and samarium-151 (Sm-151) for which no default element parameter values were available. The K_d values applied in leachate calculations were applied for each of these radionuclides to address data gaps and, where available, CRs were obtained from the IAEA and International Union of Radioecologists (IUR) Wildlife Transfer Parameter Database[5] and specifically the 2015 IAEA summary tables for freshwater biota. Where data were unavailable for particular assessment organisms, the highest value available from the summary tables for each radionuclide was selected. No data were available for Pm-147 and default ERICA CR values for cerium (Ce) were therefore applied as analogues. The K_d and CR data applied for Fe-55, Mo-93, Sn-121m, Pm-147 and Sm-151 are presented in Appendix A.3 and A.4, respectively.

[3] This is considered to be a very precautionary assumption. Given the spatial extent of the site and the nature of the underlying geology, a realistic worst case would be seepage along about 400 m of stream bank.

[4] It takes roughly 2 billion years for full decay chain secular equilibrium to be achieved.

[5] http://www.wildlifetransferdatabase.org.

With the exception of reptile, for which there are no native freshwater species in the UK, all default reference organisms were included in the assessment.

Default radiation weighting factors of 10 for alpha radiation, 3 for low-energy beta radiation and 1 for beta/gamma radiation were applied to account for the relative biological effectiveness of the different types of radiation[6].

2.2.4. Initial Assessment Results

Estimated freshwater biota dose rates (μGy/h) are summarised in Table 4 and presented in detail in Appendix A.5.

Dose rates for all reference organisms are below the relevant ICRP planned exposure reference points and are around an order of magnitude below the Environment Agency threshold level. The highest dose rate (6 μGy/h) was calculated for gastropod molluscs. For the majority of reference organisms, C-14 was the main contributor to dose, but for vascular plant, U-238 and daughters were the primary contributors.

Results indicate that there will be no impact on populations of fauna and flora as a result of groundwater transport of radionuclides to a small surface stream and no further assessment is considered necessary.

Table 4 Calculated dose rates (μGy/h) for freshwater reference organisms

Reference organism	Total dose rate (μGy/h)	Primary dose contributors	
		C-14	U-238 series
Amphibian	3.0	>99%	
Benthic fish	3.1	>99%	
Bird	3.5	86%	12%
Bivalve mollusc	3.2	95%	
Crustacean	4.5	67%	32%
Gastropod mollusc	5.9	51%	47%
Insect larvae	3.1	>99%	
Mammal	3.2	92%	
Pelagic fish	3.1	100%	
Phytoplankton	0.1	94%	
Vascular plant	1.3	11%	85%
Zooplankton	2.9	>99%	

2.3. Intrusion Exposure After the Period of Authorisation

2.3.1. Environmental Setting

Waste disposal cells will be capped during the period of authorisation. The cap will be comprised of several layers (300 mm clean soil cover over the waste, a geomembrane layer, a geotextile layer and at least 1 m of clean restoration soil (increasing to 1.5 m in areas of shrub land and trees). After the period of authorisation, management of the site will cease and populations of non-human biota may become established, with the potential for waste intrusion by tree roots or from burrowing animals. Over time, erosional processes or human actions could result in the removal of the surface cap, allowing a broader range of non-human biota to become exposed to radionuclides in the disposed wastes.

2.3.2. Assessment Context

A bounding (worst case) scenario has been considered whereby complete removal of the cap is assumed to occur, allowing direct access of non-human biota to disposed wastes within a cell.

[6] This is consistent with ICRP draft guidance that is currently undergoing consultation.

2.3.3. Assessment methodology

Tier 2 of the ERICA assessment tool (version 1.2.1, 18 February 2016) was used as the basis for calculating potential exposures of terrestrial plants and animals. The tool was used to derive dose rate per unit concentration (DRPUC, µGy/h per Bq/kg soil) data for all radionuclides in the model inventory and the 13 default ERICA reference organisms (which encompass the ICRP RAPs). An additional user-defined organism was also included – a large burrowing mammal. Mammals are considered to be among the more radiosensitive organisms, as evidenced by the ICRP planned exposure reference point (see Table 1) and a large burrowing mammal inhabiting a den constructed within the wastes would have a high external exposure potential. A user-defined large burrowing mammal was therefore incorporated using the 'add organism' functionality of the ERICA assessment tool, assuming approximate dimensions and mass for a red fox. The parameters used in defining the large burrowing mammal are detailed in Appendix B.1.

The DRPUC data for each reference organism were calculated using default ERICA concentration ratios (CRs), that allow the calculation of internal radionuclide activity concentrations in organisms from those in soil[7]. Concentration ratios for a large burrowing mammal (given in Appendix B.2) were consistent with those for the other mammal reference organisms. Default concentration ratios were not available in ERICA for five of the radionuclides in the waste inventory, namely Fe-55, Mo-93, Sn-121m, Pm-147 and Sm-151. Where available, CRs for these radionuclides were obtained from the IAEA/IUR Wildlife Transfer Parameter Database[8], and specifically the 2015 IAEA summary tables for terrestrial biota. Where data were unavailable for particular reference organisms, the highest value available from the summary tables for each radionuclide was selected. No data were available for Pm-147 and default ERICA CRs for cerium were therefore applied as analogues. The CR data for each of these radionuclides as applied in the assessment are given in Appendix B.3.

The ERICA assessment tool includes all short-lived daughters with a half-life of less than 10 days. DRPUC data for daughters with a half-life of more than 10 days, namely Ra-225 (Th-229 parent), Th-234 (U-238 parent), and, Pa-233 (Np-237 parent), were therefore calculated separately, assuming secular equilibrium with the parent radionuclide. The parent and daughter DRPUC values were then summed to evaluate exposure from all radionuclides in the decay chain. The DRPUCs are detailed in Appendix B.4.

Default radiation weighting factors of 10 for alpha radiation, 3 for low beta radiation and 1 for beta/gamma radiation were applied to account for the relative biological effectiveness of the different types of radiation.

Estimated dose rates (µGy/h) for each of the reference organisms were derived by multiplying the DRPUCs with average activity concentrations (Bq/kg) associated with disposed wastes within a cell. The average activity concentration within the cell accounts for mixing of radioactive waste with non-radioactive waste and daily soil cover, as described in section 2.12 of the main report [FCC, 2018d]. It has been cautiously assumed that, with the exception of the most mobile radionuclides, i.e. tritium and C-14 that are assumed to be entirely leached from wastes during the period of authorisation (groundwater breakthrough time of 36 years), there has been no loss of radionuclides from the cell through leaching to groundwater or from active leachate management during the period of authorisation. The average activity concentrations used in the assessment are given in Appendix B.5.

2.3.4. Initial Assessment Results

Calculated terrestrial biota dose rates (µGy/h) and the primary contributory radionuclides to dose rates are summarised in Table 5 and presented in detail in Appendix B.6.

Table 5 Calculated Intrusion Dose Rates (µGy/h) for Terrestrial Biota

Reference organism	Total dose rate (µGy/h)	Primary dose contributors
Amphibian	6	Am-241 (31%), Co-60 (14%)
Annelid	7	Am-241 (33%), U-234 (18%)
Arthropod	5	Am-241 (28%), Co-60 (17%)
Bird	3	Sr-90 (25%), Ra-226 (19%)

[7] Waste materials are mixed with soil. Waste-related CR values do not exist, hence, soil values have been used in this assessment. This requires the assumption that radionuclides associated with wastes are in a bioavailable form.

[8] http://www.wildlifetransferdatabase.org/

Flying insect	4	Am-241 (36%), Ra-226 (17%)
Grasses & herbs	14	U-234 (36%), Ra-226 (18%)
Large burrowing mammal	5	Cs-137 (27%); Sr-90 (19%)
Lichen & bryophyte	83	U-234 (43%), U-238 (17%)
Mammal - large	6	Cs-137 (35%), Sr-90 (18%)
Mammal - small burrowing	6	Cs-137 (24%), Sr-90 (17%)
Mollusc - gastropod	7	Am-241 (28%), U-234 (19%)
Shrub	11	Ra-226 (43%), U-234 (23%)
Tree	3	Am-241 (14%), Pu-239 (14%)

With the exception of one reference organism (lichen and bryophyte), all calculated dose rates are below the Environment Agency threshold of 40 µGy/h. The calculated dose rate for lichen and bryophyte was 83 µGy/h with U-234 and U-238 being the main dose contributors.

2.3.5. Sensitivity Analysis

Many of the assumptions used within the assessment are precautionary (they aim to provide an upper bounding dose estimate). For example, it has been assumed that soil to biota CRs are applicable to radionuclides associated with disposed wastes and that the radionuclides are bioavailable. In the absence of site-specific data it is difficult to evaluate the implications of this assumption. A further precautionary assumption is that, with the exception of the most mobile radionuclides, which are assumed to be removed from disposal cells via leachate during the period of authorisation, there is no loss of inventory from disposal cells prior to intrusion by biota.

Whilst the dose rate for lichen and bryophyte exceeds the Environment Agency threshold, it falls within the lower range of the order of magnitude dose rate band of the ICRP DCRL for wild grass (40 to 400 µGy/h), which is also applicable to small plants [IAEA, 2018a]. As noted in Section 1.1.1, the intended protection target for biota is a population. To ensure assessments are commensurate with the protection of populations, IAEA [2018a] suggest an assessment area of between 100 and 400 km^2, with radionuclide activity concentrations being averaged across this area. The area of the cells that will receive radioactive wastes for disposal is around 0.073 km^2, which is several orders of magnitude lower than the suggested area for population-level assessments. Typical dose rates across the population would therefore be considerably lower than that calculated in this assessment.

The main contributors to dose rate for lichen and bryophyte are U-234 and U-238. There is considerable uncertainty regarding the transfer of uranium from soils to plants, with values spanning some five orders of magnitude[9]. Uranium is largely bioexcluded from plants [IAEA, 2018b] and literature data suggesting its apparent bioaccumulation may result from unremoved surface contamination [Ibrahim & Whicker, 1992; Sheppard & Evenden, 1988; Sheppard et al., 1989; Ham et al., 2001]. Were this to be the case, the dose rate calculated for lichen and bryophyte is likely to be a considerable over-estimate. Furthermore, with the absence of root systems, the overall appropriateness of a soil to organism CR for lichen and bryophyte can be questioned [Smith et al., 2010].

Taking into account the precautionary approach taken to assessment and the conservatisms discussed above, calculated dose rates are considered to be of low concern to populations of non-human biota and no further assessment has been undertaken.

[9] See 2015 IAEA summary tables for terrestrial biota within www.wildlifetransferdatabase.org.

4. Summary and Discussion

A precautionary assessment approach has been undertaken to evaluate potential exposures of non-human biota for three exposure scenarios. The assessment results are summarised in Table 6.

Table 6 Assessment Results Summary

Exposure Pathway	Receptors	Maximum calculated Dose Rate (µGy/h)	Relevant Dose threshold (µGy/h)
Period of Authorisation			
Leachate processing off-site	Marine biota	<0.001 (worst affected organism)	40
During and After Period of Authorisation			
Release to groundwater	Freshwater biota	<6 (gastropod mollusc)	40
After Period of Authorisation			
Biota intrusion	Terrestrial biota	83 (lichen & bryophyte)	40

Dose rates for the most exposed organism for both the leachate processing off-site and release to groundwater scenarios were below the relevant dose thresholds (Environment Agency threshold and relevant ICRP planned exposure reference points). The exposure of populations of non-human biota under these exposure scenarios are therefore unlikely to be of concern.

The maximum dose rate calculated for an intrusion scenario after the period of authorisation was a factor of 2 greater than the Environment Agency threshold and within the ICRP DCRL order of magnitude band of dose rate for small plants within which "*there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of Reference Animal or Plant"* [ICRP, 2008, para 195]. The area of which potential exposures could occur is, however, several orders of magnitude smaller than a reference area for a population [IAEA, 2018a] and impacts across the population are therefore considered to be extremely unlikely. With the exception the lichen and bryophyte reference organism for which the maximum dose rate was calculated, all other calculated dose rates were below the Environment Agency threshold. Calculated dose rates are therefore considered to be of low concern to populations of non-human biota.

5. References

Allott R, Copplestone D, Merrill P, Oliver S (2009). Habitats assessment for radioactive substances. Environment Agency Science report SC060083/SR1.

BIOPROTA (2015). Scales for post-closure assessment scenarios (SPACE). Addressing spatial and temporal scales for people and wildlife in ling-term safety assessments. BIOPROTA report, Version 2.0, August 2015. Available from www.bioprota.org.

Ham G J, Wilkins B T and Ewers L W (2001). ^{210}Pb, ^{210}Po, ^{226}Ra, U and Th in arable crops and ovine liver: variations in concentrations in the United Kingdom and resultant doses. Radiation Protection Dosimetry, 93(2), 151-159.

IAEA (2014). Modelling of biota dose effects: report of Working Group 6 biota Dose Effects Modelling of EMRAS II Topical Heading Reference Approaches for Biota Dose Assessment. IAEA TECDOC 1737, International Atomic Energy Agency, Vienna.

IAEA (2018a). Prospective radiological environmental impact assessment for facilities and activities. IAEA Safety Standards Series No. GSG-10. International Atomic Energy Agency, Vienna.

IAEA (2018b) The Environmental Behaviour of Uranium, International Atomic Energy Agency, Vienna, Austria, (In press).

Ibrahim, S.A., and Whicker F.W. (1992). Comparative plant uptake and environmental behaviour of U-series radionuclides at a uranium mine-mill. Journal of Radioanalytical and Nuclear Chemistry, Articles, 156(2): 253-267.

ICRP (2008). Environmental Protection: the Concept and Use of Reference Animals and Plants, ICRP Publication 108.

ICRP (2014). Protection of the Environment under Different Exposure Situations, ICRP Publication 124, Ann. ICRP 43(1).

Environment Agency (2006a). Allott, R.W., Lambers, B. and Titley, J.G., Initial Radiological Assessment Methodology – Part 1 User Report, Environment Agency Science Report SC030162/SR1, 2006.

Environment Agency (2006b). Lambers, B. and Thorne, M., Initial Radiological Assessment Methodology – Part 2 Methods and Input Data, Environment Agency Science Report SC030162/SR2, 2006.

Environment Agency (2011). Parameter values used in coastal dispersion modelling for radiological assessments. Report: SC060080/R3, 2011.

FCC (2018a). Human radiological assessment during the period of authorisation {R5}.

FCC (2018b). Risk Guidance Level after the period of authorisation {R6}.

FCC (2018c). Human intrusion after the period of authorisation {R7}.

FCC (2018d). Environmental Safety Case: Disposal of Low Activity Low Level Radioactive Waste (LA-LLW) at the Lillyhall Landfill Site, 2018.

Sheppard S C and Evenden W G (1988). Critical compilation and review of plant/soil concentration ratios for uranium, thorium and lead. Journal of Environmental Radioactivity, 8(3), 255-285.

Sheppard SC, Evenden WG and Pollock RJ (1989). Uptake of natural radionuclides by field and garden crops. Canadian Journal of Soil Science, 69: 751-767.

Smith K., Robinson C., Jackson D, de la Cruz I., Zinger I., Avila R. (2010). Non-human biota dose assessment: Sensitivity analysis and knowledge quality assessment. Posiva Working Report 2010-69.

Appendices

Appendix A. Groundwater Pathway

A.1. Stream Characteristics

Characteristic	Parameter value
Flow rate (m^3/s)	0.02
Depth (m)	0.2
Width (m)	0.75
Distance from release point to receptor (m)	10

A.2. Radionuclide Discharge Rates to Stream

Radionuclide	Discharge rate (Bq/s)	Radionuclide	Discharge rate (Bq/s)
H-3	2.4E+00	Eu-154	<1.0E-10
C-14	9.8E+00	Pb-210	<1.0E-10
Cl-36	6.2E-01	Po-210	0.0E+00
Ca-41	2.8E-01	Ra-226	<1.0E-10
Mn-54	<1.0E-10	Th-228	0.0E+00
Fe-55	0.0E+00	Th-229	<1.0E-10
Co-60	<1.0E-10	Ra-225	<1.0E-10
Ni-59	2.6E-03	Th-230	1.2E-07
Ni-63	<1.0E-10	Th-232	1.9E-06
Zn-65	<1.0E-10	Pa-231	1.2E-10
Sr-90	<1.0E-10	U-232	<1.0E-10
Nb-93m	<1.0E-10	U-233	1.1E-05
Nb-94	4.9E-09	U-234	1.3E-02
Mo-93	1.7E-04	U-235	5.6E-04
Tc-99	1.9E+00	U-236	9.7E-04
Ru-106	<1.0E-10	U-238	6.4E-03
Ag-108m	<1.0E-10	Th-234	6.4E-03
Ag-110m	<1.0E-10	Np-237	5.8E-04
Sn-121m	<1.0E-10	Pa-233	5.8E-04
Sb-125	<1.0E-10	Pu-238	<1.0E-10
I-129	7.5E-04	Pu-239	1.2E-05
Cs-134	<1.0E-10	Pu-240	1.9E-08
Cs-137	<1.0E-10	Pu-241	<1.0E-10
Ba-133	6.0E-05	Pu-242	1.0E-06
Ce-144	<1.0E-10	Am-241	<1.0E-10
Pm-147	<1.0E-10	Cm-242	0.0E+00
Sm-151	<1.0E-10	Cm-243	<1.0E-10
Eu-152	<1.0E-10	Cm-244	<1.0E-10

A.3. Freshwater Distribution Coefficients (K_d) for added Radionuclides

Radionuclide	K_d (L/kg)
Fe-55	8.8E+02
Mo-93	3.8E+01
Sn-121m	1.6E+03
Pm-147	4.5E+02
Sm-151	9.3E+02

A.4. Freshwater Concentration Ratios (Bq/kg per Bq/l) for added Radionuclides

Reference organism	Fe		Mo		Sn		Pm		Sm	
	CR	Source	CR	Source	CR	Source	CR	Source	CR	Source
Amphibian	4.4E+03	[1]	1.4E+03	[3]	4.8E+02	[4]	1.7E+02	[5]	1.4E+03	[6]
Bird	6.7E+02	[2]	1.4E+03	[2]	4.8E+02	[4]	4.4E+03	[5]	1.4E+03	[6]
Mollusc - gastropod	2.9E+03	[2]	2.0E+02	[2]	4.8E+02	[4]	1.0E+03	[5]	1.4E+03	[2]
Benthic fish	5.6E+02	[2]	2.2E+01	[2]	4.8E+02	[2]	1.7E+02	[5]	3.5E+02	[2]
Crustacean	4.4E+03	[1]	8.2E+01	[2]	3.9E+02	[2]	1.0E+03	[5]	1.4E+03	[6]
Insect larvae	4.4E+03	[1]	1.4E+03	[3]	4.8E+02	[4]	1.0E+03	[5]	1.4E+03	[6]
Mammal	4.4E+03	[1]	1.4E+03	[3]	4.8E+02	[4]	1.7E+02	[5]	1.4E+03	[6]
Mollusc - bivalve	2.9E+03	[2]	2.0E+02	[2]	4.8E+02	[4]	1.0E+03	[5]	1.4E+03	[2]
Pelagic fish	5.6E+02	[2]	2.2E+01	[2]	4.8E+02	[2]	1.7E+02	[5]	3.5E+02	[2]
Phytoplankton	4.4E+03	[2]	2.0E+01	[2]	1.9E+02	[2]	8.8E+03	[5]	1.4E+03	[6]
Vascular plant	6.6E+02	[2]	3.1E+02	[2]	5.5E+01	[2]	8.8E+02	[5]	6.1E+02	[2]
Zooplankton	4.4E+03	[1]	1.4E+03	[3]	4.8E+02	[4]	1.0E+03	[5]	1.4E+03	[6]

Data sources: [1] Highest available value (CR for phytoplankton); [2] Reference organism specific CR from Wildlife Transfer Database (WTD), IAEA Summary Data 2015-04-20; [3] Highest available value (CR for bird); [4] Highest available value (CR for fish); [5] CR data for Ce applied as analogue; [6] Highest available value (CR for mollusc).

A.5. Results - Freshwater Biota Dose Rates (µGy/h)

Radionuclide	Amphibian	Bird	Gastropod mollusc	Benthic fish	Crustacean	Insect larvae	Mammal	Bivalve mollusc	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton
H-3	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06	1.2E-06
C-14	3.0E+00	3.1E+00	3.0E+00	3.1E+00	3.0E+00	3.0E+00	3.1E+00	3.0E+00	3.1E+00	6.4E-02	1.4E-01	2.9E+00
Cl-36	7.4E-03	7.4E-03	6.9E-03	7.4E-03	5.1E-03	5.1E-03	7.4E-03	7.4E-03	7.4E-03	6.3E-04	1.1E-03	3.7E-03
Ca-41	8.7E-05	3.9E-05	5.2E-05	1.0E-04	4.7E-05	4.3E-06	2.8E-05	5.2E-05	1.0E-04	1.7E-05	1.8E-05	3.0E-06
Mn-54	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fe-55	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-60	1.4E-61	8.7E-61	4.0E-58	3.7E-58	4.0E-58	8.0E-58	4.0E-61	4.0E-58	2.6E-61	1.6E-61	4.0E-58	4.6E-61
Ni-59	2.8E-07	2.9E-07	1.0E-06	3.8E-07	5.3E-06	8.1E-06	2.9E-07	5.6E-07	2.9E-07	6.8E-07	3.4E-06	2.5E-06
Zn-65	4.2E-57	1.9E-56	1.9E-56	1.1E-55	6.5E-56	8.1E-56	3.0E-56	2.0E-56	9.2E-56	1.0E-56	1.8E-56	4.7E-56
Sr-90	5.1E-75	3.4E-75	2.7E-76	4.1E-76	4.5E-76	1.2E-75	5.6E-75	2.4E-76	4.0E-76	1.1E-77	3.0E-76	3.8E-76
Nb-93m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Nb-94	1.6E-10	2.8E-10	6.6E-11	3.3E-11	5.9E-11	9.5E-11	3.7E-10	7.4E-11	2.2E-12	6.8E-11	1.2E-10	2.0E-11
Mo-93	1.4E-07	1.6E-07	1.8E-08	2.7E-09	6.5E-09	9.4E-08	1.7E-07	2.1E-08	2.6E-09	1.3E-09	2.2E-08	9.0E-08
Tc-99	6.6E-04	6.6E-04	6.6E-04	6.6E-04	6.1E-04	6.2E-04	6.6E-04	6.6E-04	6.6E-04	2.2E-04	2.5E-04	5.7E-04
Ru-106	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ag-108m	7.6E-36	1.6E-35	3.8E-33	3.2E-33	3.9E-33	7.7E-33	2.3E-35	3.7E-33	4.1E-36	6.8E-37	3.8E-33	2.2E-35
Sb-125	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
I-129	7.0E-07	9.4E-08	4.2E-05	2.4E-05	4.8E-05	9.6E-05	8.0E-07	3.5E-05	7.5E-07	1.1E-07	4.8E-05	1.7E-07
Cs-134	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Radionuclide	Amphibian	Bird	Gastropod mollusc	Benthic fish	Crustacean	Insect larvae	Mammal	Bivalve mollusc	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton
Cs-137	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ba-133	3.4E-08	1.0E-06	2.0E-06	1.6E-06	2.1E-06	4.0E-06	6.5E-08	2.0E-06	4.9E-08	7.6E-09	2.0E-06	1.6E-07
Ce-144	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Eu-152	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Eu-154	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Pb-210	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Po-210	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ra-226	4.5E-23	4.8E-23	1.8E-22	1.7E-24	2.5E-24	1.8E-22	1.7E-27	1.8E-22	1.4E-24	4.1E-24	8.6E-24	1.8E-22
Th-228	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Th-229	1.1E-18	1.1E-18	9.5E-18	5.1E-18	6.8E-18	1.4E-17	1.1E-18	9.1E-18	2.4E-19	4.0E-18	4.0E-17	1.8E-19
Th-230	6.1E-07	6.1E-07	2.0E-06	1.5E-07	1.7E-07	5.9E-07	6.1E-07	2.0E-06	1.3E-07	2.2E-06	1.8E-05	1.0E-07
Th-232	8.2E-06	8.2E-06	2.7E-05	2.0E-06	2.3E-06	8.0E-06	8.2E-06	2.7E-05	1.8E-06	3.0E-05	2.5E-04	1.4E-06
Pa-231	6.8E-10	6.8E-10	3.9E-09	1.5E-09	2.1E-09	4.5E-09	6.8E-10	3.7E-09	1.8E-10	1.2E-09	2.3E-09	1.1E-10
U-232	4.8E-33	2.2E-33	2.3E-32	3.0E-33	8.2E-33	8.2E-33	4.8E-33	2.3E-32	3.0E-33	2.9E-33	1.5E-32	8.2E-33
U-233	2.2E-06	9.8E-07	1.0E-05	1.4E-06	3.7E-06	3.7E-06	2.2E-06	1.0E-05	1.4E-06	1.3E-06	6.9E-06	3.7E-06
U-234	2.5E-03	1.1E-03	1.2E-02	1.6E-03	4.3E-03	4.3E-03	2.5E-03	1.2E-02	1.6E-03	1.5E-03	8.0E-03	4.3E-03
U-235	1.0E-04	4.5E-05	4.8E-04	6.2E-05	1.7E-04	1.7E-04	9.9E-05	4.8E-04	6.2E-05	6.0E-05	3.2E-04	1.7E-04
U-236	1.8E-04	7.9E-05	8.4E-04	1.1E-04	3.0E-04	3.0E-04	1.8E-04	8.4E-04	1.1E-04	1.1E-04	5.6E-04	3.0E-04
U-238	1.1E-03	4.8E-04	5.1E-03	6.7E-04	1.8E-03	1.8E-03	1.1E-03	5.1E-03	6.7E-04	6.5E-04	3.4E-03	1.8E-03
Th-234	5.7E-04	6.2E-04	4.1E-01	1.1E-01	1.4E+00	2.8E+00	6.2E-04	1.9E-01	1.4E-04	4.1E-04	1.1E+00	2.4E-05
Np-237	1.1E-04	5.0E-05	5.3E-04	6.9E-05	1.9E-04	1.9E-04	1.1E-04	5.3E-04	6.9E-05	6.7E-05	2.1E-04	1.9E-04
Pu-238	1.4E-52	9.0E-53	1.7E-52	2.6E-53	1.9E-53	7.9E-53	1.4E-52	1.7E-52	2.6E-53	1.8E-52	3.3E-53	1.7E-53

Radionuclide	Amphibian	Bird	Gastropod mollusc	Benthic fish	Crustacean	Insect larvae	Mammal	Bivalve mollusc	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton
Pu-239	1.0E-04	6.5E-05	1.2E-04	1.8E-05	1.3E-05	5.6E-05	1.0E-04	1.2E-04	1.8E-05	1.3E-04	2.4E-05	1.2E-05
Pu-240	1.6E-07	1.0E-07	1.9E-07	2.9E-08	2.1E-08	8.8E-08	1.6E-07	1.9E-07	2.9E-08	2.0E-07	3.7E-08	1.9E-08
Pu-241	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Pu-242	8.0E-06	5.0E-06	9.5E-06	1.4E-06	1.1E-06	4.4E-06	8.0E-06	9.5E-06	1.4E-06	1.0E-05	1.9E-06	9.3E-07
Am-241	1.0E-27	1.0E-27	3.3E-27	2.7E-28	3.3E-27	6.5E-28	1.0E-27	3.3E-27	2.4E-28	4.3E-28	4.8E-28	5.5E-28
Cm-242	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cm-243	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cm-244	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ra-225	3.3E-17	3.3E-17	1.3E-16	9.8E-19	1.5E-18	1.3E-16	1.1E-21	1.3E-16	9.5E-19	2.9E-18	5.9E-18	1.3E-16
Pa-233	1.4E-05	1.6E-05	3.9E-02	3.3E-02	4.4E-02	8.7E-02	1.7E-05	3.7E-02	4.1E-06	2.0E-05	4.5E-02	1.9E-06
Ni-63	2.2E-17	2.2E-17	2.6E-17	2.2E-17	2.2E-16	2.3E-16	2.2E-17	2.5E-17	2.2E-17	5.7E-17	7.2E-17	2.0E-16
Ag-110m	9.6E-22	2.2E-21	6.2E-19	5.3E-19	6.1E-19	1.2E-18	3.1E-21	5.8E-19	5.6E-22	1.2E-22	6.1E-19	3.9E-21
Sn-121m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Pm-147	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sm-151	3.9E-62	3.9E-62	3.9E-62	9.9E-63	3.9E-62	3.9E-62	3.9E-62	3.9E-62	9.9E-63	3.9E-62	1.7E-62	3.9E-62
Total	**3.0E+00**	**3.1E+00**	**3.5E+00**	**3.2E+00**	**4.5E+00**	**5.9E+00**	**3.1E+00**	**3.2E+00**	**3.1E+00**	**6.8E-02**	**1.3E+00**	**2.9E+00**

Appendix B. Intrusion After the Period of Authorisation

B.1. Large Burrowing Mammal (Red Fox) Organism Parameters

Parameter	Value	Source
Mass	6.6 kg	Pröhl [2003], Table 2-6
Dimensions (height x length x width)	20 cm x 40 cm x 15 cm	Pröhl [2003], Table 2-6
Habitat occupancy factors	0.5 in soil, 0.5 on soil	Estimate

B.2. Concentration Ratios ($Bq/kg_{f.w.}$ per $Bq/kg\ soil_{d.w.}$) for a Large Burrowing Mammal

Element	CR	Source	Element	CR	Source
Ag	5.4E-01	[1]	Ru	1.2E-01	[1]
Sn	7.5E-03	[2]	Sb	3.5E-03	[1]
Pm	4.9E-03	[3]	I	4.0E-01	[1]
Sm	1.9E-02	[4]	Cs	3.4E+00	[1]
Pa	5.4E-01	[1]	Ba	2.8E-02	[1]
Fe	3.7E-03	[2]	Ce	4.9E-03	[1]
Mo	2.1E-01	[2]	Eu	3.4E-02	[1]
Cl	7.0E+00	[1]	Pb	3.7E-02	[1]
Ca	8.5E+00	[1]	Po	8.9E-02	[1]
Mn	2.5E-03	[1]	Ra	4.4E-02	[1]
Co	1.9E-01	[1]	Th	1.4E-04	[1]
Ni	1.1E-01	[1]	U	5.5E-03	[1]
Zn	3.0E+00	[1]	Np	5.4E-01	[1]
Sr	1.7E+00	[1]	Pu	1.4E-02	[1]
Nb	4.2E-02	[1]	Am	2.4E-02	[1]
Tc	3.9E-01	[1]	Cm	5.4E-01	[1]

Data sources: [1] default ERICA data for mammal; [2] Wildlife Transfer Parameter Database mammal CR; [3] Default Ce CR for mammal; [4] Highest Sm CR from Wildlife Transfer Parameter Database.

B.3. Terrestrial Concentration Ratios (Bq/kg (fresh weight) per Bq/kg soil (dry weight) for added Radionuclides

Reference organism	Fe		Mo		Sn		Pm		Sm	
	CR	Source	CR	Source	CR	Source	CR	Source	CR	Source
Amphibian	1.8E-02	[2]	1.6E+00	[3]	7.1E-01	[2]	4.9E-03	[4]	1.9E-02	[2]
Annelid	7.3E-03	[1]	2.6E-01	[1]	1.3E-02	[1]	4.8E-03	[4]	6.7E-03	[1]
Arthropod	4.1E-03	[1]	1.6E-01	[1]	1.2E-01	[1]	2.2E-03	[4]	3.2E-03	[1]
Bird	7.7E-03	[1]	1.6E+00	[1]	7.1E-01	[2]	6.9E-02	[4]	1.9E-02	[2]
Flying insect	1.8E-02	[2]	1.6E+00	[3]	7.1E-01	[2]	2.2E-03	[4]	1.9E-02	[2]
Grasses & herbs	1.5E-02	[1]	3.9E-01	[1]	1.0E-03	[1]	1.4E-02	[4]	1.2E-02	[1]
Lichen & bryophyte	1.8E-02	[1]	5.9E-01	[1]	7.1E-01	[1]	1.6E-02	[4]	1.9E-02	[1]
Mammal - large	3.7E-03	[1]	2.1E-01	[1]	7.5E-03	[1]	4.9E-03	[4]	1.9E-02	[2]
Mammal - small burrowing	3.7E-03	[1]	2.1E-01	[1]	7.5E-03	[2]	4.9E-03	[4]	1.9E-02	[2]
Mollusc - gastropod	1.8E-02	[2]	1.6E+00	[3]	7.1E-01	[2]	6.9E-02	[4]	1.9E-02	[2]
Reptile	1.8E-02	[2]	1.6E+00	[3]	7.1E-01	[2]	4.9E-03	[4]	1.9E-02	[2]
Shrub	2.4E-03	[1]	1.3E-01	[1]	4.7E-02	[1]	9.1E-03	[4]	2.6E-03	[1]
Tree	2.5E-03	[1]	6.3E-02	[1]	5.1E-03	[1]	1.7E-03	[4]	2.2E-03	[1]

Data sources: [1] Reference organism specific CR from Wildlife Transfer Database (WTD), IAEA Summary Data 2015-04-20; [2] Highest value (CR for lichens and bryophytes); [3] Highest value (CR for bird); [4] CR data for Ce applied as analogue.

B.4. Radionuclide Dose Rates (Gy/h) per Unit Concentration (Bq/kg soil)

Radionuclide	DRPUC (µGy/h per Bq/kg)						
	Amphibian	Annelid	Arthropod	Bird	Flying insect	Grasses & herbs	Lichen & bryophyte
H-3	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03
C-14	3.8E-02	1.2E-02	1.2E-02	4.0E-02	1.2E-02	2.5E-02	2.6E-02
Cl-36	1.1E-03	2.7E-05	4.3E-05	1.1E-03	4.3E-05	3.1E-03	1.2E-04
Ca-41	3.7E-05	8.1E-07	4.4E-07	2.4E-07	4.3E-07	1.3E-06	8.6E-06
Mn-54	4.4E-04	4.4E-04	4.5E-04	1.7E-04	1.7E-04	1.6E-04	1.8E-04
Fe-55	2.1E-07	1.2E-07	9.5E-08	6.3E-08	1.5E-07	2.0E-07	1.4E-07
Co-60	1.3E-03	1.3E-03	1.3E-03	4.9E-04	5.0E-04	4.8E-04	5.0E-04
Ni-59	1.1E-06	7.5E-07	2.5E-07	1.0E-06	1.5E-07	1.3E-06	2.1E-06
Ni-63	1.3E-06	8.8E-07	2.1E-07	1.3E-06	2.0E-07	1.6E-06	2.9E-06
Zn-65	3.7E-04	3.7E-04	3.2E-04	2.7E-04	1.3E-04	1.1E-04	1.2E-04
Sr-90/Y-90	7.8E-04	3.4E-05	1.2E-04	7.7E-04	1.4E-04	4.0E-04	1.5E-03
Nb-93m	9.8E-07	3.1E-06	2.0E-07	3.4E-06	3.6E-08	1.6E-07	5.4E-07
Nb-94	8.4E-04	8.6E-04	8.5E-04	3.6E-04	3.2E-04	3.1E-04	3.2E-04
Mo-93	1.6E-05	3.1E-06	2.1E-06	1.8E-05	1.2E-05	3.9E-06	4.1E-06
Tc-99	2.3E-05	2.3E-05	2.2E-05	9.7E-06	2.2E-05	8.0E-04	7.7E-04
Ru-106/ Rh-106	1.9E-04	1.1E-04	1.1E-04	1.4E-04	4.4E-05	5.1E-05	1.6E-03
Ag-108m	8.9E-04	8.9E-04	8.7E-04	4.0E-04	3.3E-04	4.6E-04	3.3E-04
Ag-110m	1.5E-03	1.5E-03	1.5E-03	6.9E-04	5.6E-04	7.1E-04	5.6E-04
Sn-121m/ Sn-121	5.7E-05	1.7E-06	9.8E-06	5.8E-05	5.6E-05	4.5E-07	5.3E-05
Sb-125	2.2E-04	2.2E-04	2.2E-04	8.5E-05	8.7E-05	8.8E-05	1.0E-04
I-129	2.3E-05	1.1E-05	1.8E-05	2.3E-05	1.5E-05	8.6E-06	7.7E-06
Cs-134	8.8E-04	8.4E-04	8.5E-04	4.3E-04	3.3E-04	4.2E-04	6.4E-04
Cs-137/ Ba-137m	3.7E-04	3.1E-04	3.2E-04	2.2E-04	1.3E-04	2.7E-04	5.6E-04
Ba-133	1.8E-04	1.8E-04	1.8E-04	1.1E-03	7.4E-05	7.6E-05	7.7E-05
Ce-144	2.6E-05	2.6E-05	2.4E-05	5.9E-05	9.9E-06	1.6E-05	1.4E-05
Pm-147	1.8E-07	1.8E-07	7.9E-08	2.5E-06	7.8E-08	5.0E-07	5.8E-07
Sm-151	2.6E-07	9.2E-08	4.5E-08	2.6E-07	2.6E-07	1.6E-07	2.6E-07
Eu-152	5.7E-04	5.8E-04	5.8E-04	3.1E-04	2.3E-04	2.2E-04	2.3E-04
Eu-154	6.4E-04	6.3E-04	6.4E-04	3.9E-04	2.5E-04	2.4E-04	2.5E-04
Pb-210/Bi-210	3.0E-05	1.2E-04	8.0E-05	1.6E-05	8.8E-05	2.8E-05	4.9E-04
Po-210	3.2E-03	3.1E-04	3.1E-04	3.2E-04	3.1E-04	8.7E-03	7.9E-02
Ra-226 to Po-214	6.9E-03	6.8E-03	6.8E-03	5.5E-03	6.2E-03	2.5E-02	9.9E-02
Th-228 to Tl-208	8.5E-04	2.5E-03	1.7E-03	3.6E-04	1.2E-03	3.0E-02	7.1E-02
Th-229 to Pb-209	2.0E-02	2.0E-02	1.9E-02	1.6E-02	1.9E-02	8.4E-02	3.2E-01
Th-230	1.1E-05	2.5E-04	1.4E-04	1.1E-05	1.4E-04	4.3E-03	1.0E-02
Th-232	9.1E-06	2.1E-04	1.2E-04	9.0E-06	1.2E-04	3.7E-03	8.8E-03
Pa-231	3.9E-03	5.1E-03	2.9E-03	9.0E-04	2.9E-03	4.8E-03	2.8E-02
Pa-233	1.1E-04	1.1E-04	1.0E-04	3.9E-05	5.0E-05	5.9E-05	1.5E-04
U-232	1.7E-04	1.0E-03	3.2E-04	3.9E-05	3.2E-04	3.9E-03	2.8E-02
U-233	1.5E-04	9.4E-04	2.9E-04	3.5E-05	2.9E-04	3.6E-03	2.5E-02
U-234	1.5E-04	9.4E-04	2.9E-04	3.5E-05	2.9E-04	3.6E-03	2.5E-02

Radionuclide	DRPUC (µGy/h per Bq/kg)						
	Amphibian	Annelid	Arthropod	Bird	Flying insect	Grasses & herbs	Lichen & bryophyte
U-235/Th-231	2.1E-04	9.4E-04	3.3E-04	6.1E-05	3.0E-04	3.3E-03	2.3E-02
U-236	1.4E-04	8.8E-04	2.7E-04	3.3E-05	2.7E-04	3.3E-03	2.4E-02
U-238/ Th-234/ Pa-234m	1.4E-04	8.2E-04	2.6E-04	3.5E-05	2.6E-04	3.1E-03	2.2E-02
Np-237/ Pa-233	3.8E-03	5.0E-03	2.9E-03	8.9E-04	2.8E-03	4.6E-03	2.7E-02
Pu-238	4.5E-04	9.8E-04	8.2E-04	7.3E-05	8.2E-04	5.2E-04	4.1E-03
Pu-239	4.2E-04	9.2E-04	7.7E-04	6.9E-05	7.7E-04	4.9E-04	3.9E-03
Pu-240	4.2E-04	9.2E-04	7.7E-04	6.9E-05	7.7E-04	4.9E-04	3.9E-03
Pu-241	1.1E-07	2.5E-07	2.1E-07	1.9E-08	2.0E-07	1.3E-07	1.1E-06
Pu-242	4.0E-04	8.6E-04	7.2E-04	6.4E-05	7.2E-04	4.6E-04	3.7E-03
Am-241	4.3E-03	5.6E-03	3.2E-03	9.9E-04	3.2E-03	3.2E-03	3.1E-02
Cm-242	4.7E-03	6.2E-03	4.8E-03	1.1E-03	4.8E-03	1.8E-05	3.5E-02
Cm-243	4.5E-03	6.0E-03	4.6E-03	1.0E-03	4.6E-03	4.0E-05	3.3E-02
Cm-244	4.4E-03	5.9E-03	4.5E-03	1.0E-03	4.5E-03	1.7E-05	3.3E-02

Radionuclide	DRPUC (µGy/h per Bq/kg)						
	Mammal - large	Mammal - small burrowing	Large burrowing mammal	Mollusc	Reptile	Shrub	Tree
H-3	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03
C-14	4.0E-02	4.0E-02	3.9E-02	1.2E-02	4.0E-02	2.5E-02	3.8E-02
Cl-36	1.1E-03	1.1E-03	1.1E-03	2.5E-05	1.1E-03	1.6E-04	2.3E-04
Ca-41	3.7E-05	3.7E-05	3.7E-05	2.0E-07	3.7E-05	7.9E-07	3.2E-06
Mn-54	8.5E-05	4.2E-04	2.3E-04	1.7E-04	4.0E-04	2.3E-04	1.5E-04
Fe-55	3.1E-08	8.0E-08	3.2E-08	1.5E-07	1.9E-07	2.5E-08	2.1E-08
Co-60	4.2E-04	1.2E-03	7.6E-04	5.0E-04	1.2E-03	4.5E-04	3.9E-04
Ni-59	9.9E-07	1.1E-06	1.0E-06	1.6E-07	2.9E-06	9.0E-07	2.0E-07
Ni-63	1.3E-06	1.3E-06	1.3E-06	2.2E-07	3.7E-06	1.2E-06	2.6E-07
Zn-65	6.6E-04	4.0E-04	4.1E-04	1.8E-04	2.8E-04	1.2E-04	1.1E-04
Sr-90/Y-90	1.1E-03	1.0E-03	1.1E-03	4.5E-05	2.4E-04	9.2E-05	3.1E-04
Nb-93m	8.4E-07	9.7E-07	8.4E-07	2.9E-06	9.4E-07	8.6E-08	2.5E-07
Nb-94	1.9E-04	8.0E-04	4.5E-04	3.4E-04	7.7E-04	2.9E-04	2.6E-04
Mo-93	2.6E-06	3.1E-06	2.6E-06	1.3E-05	1.8E-05	1.4E-06	8.1E-07
Tc-99	2.3E-05	2.3E-05	2.3E-05	2.2E-05	2.3E-05	6.7E-07	6.7E-07
Ru-106/ Rh-106	1.3E-04	1.9E-04	1.5E-04	4.5E-05	1.8E-04	2.5E-04	3.9E-04
Ag-108m	5.0E-04	8.8E-04	5.8E-04	3.6E-04	8.4E-04	3.1E-04	5.0E-04
Ag-110m	8.0E-04	1.5E-03	9.7E-04	6.0E-04	1.4E-03	5.1E-04	7.9E-04
Sn-121m/ Sn-121	7.0E-07	1.2E-06	7.9E-07	5.6E-05	5.8E-05	4.0E-06	5.6E-07
Sb-125	4.2E-05	2.1E-04	1.1E-04	8.9E-05	2.0E-04	8.3E-05	7.5E-05
I-129	2.4E-05	2.4E-05	2.3E-05	9.7E-06	2.3E-05	1.6E-06	9.3E-06
Cs-134	2.3E-03	1.4E-03	1.5E-03	3.2E-04	8.4E-04	4.9E-04	3.3E-04
Cs-137/ Ba-137m	1.2E-03	8.6E-04	9.1E-04	1.3E-04	3.7E-04	3.8E-04	1.3E-04
Ba-133	4.0E-05	1.7E-04	9.4E-05	7.6E-05	1.6E-04	9.3E-05	7.8E-05
Ce-144	8.2E-06	2.5E-05	1.6E-05	4.3E-05	2.4E-05	1.3E-05	8.6E-06
Pm-147	1.8E-07	1.8E-07	1.8E-07	2.5E-06	1.8E-07	3.3E-07	6.3E-08

Radionuclide	DRPUC (µGy/h per Bq/kg)						
	Mammal - large	Mammal - small burrowing	Large burrowing mammal	Mollusc	Reptile	Shrub	Tree
Sm-151	2.6E-07	2.6E-07	2.6E-07	2.6E-07	2.6E-07	3.6E-08	3.0E-08
Eu-152	1.3E-04	5.5E-04	3.1E-04	2.3E-04	5.3E-04	2.1E-04	1.8E-04
Eu-154	1.4E-04	6.1E-04	3.5E-04	2.5E-04	5.9E-04	2.2E-04	1.9E-04
Pb-210/ Bi-210	9.8E-06	9.8E-06	9.8E-06	2.0E-06	1.0E-05	7.3E-05	1.8E-05
Po-210	2.8E-03	2.8E-03	2.7E-03	3.1E-04	4.0E-03	1.0E-02	2.3E-03
Ra-226 to Po-214	6.3E-03	6.8E-03	6.6E-03	6.9E-03	6.8E-03	4.5E-02	1.9E-03
Th-228 to Tl-208	1.9E-04	7.6E-04	4.4E-04	2.0E-03	1.1E-03	1.2E-02	4.7E-04
Th-229 to Pb-209	2.0E-02	2.0E-02	2.0E-02	2.1E-02	2.0E-02	1.5E-01	5.2E-03
Th-230	3.7E-06	3.8E-06	3.7E-06	2.5E-04	5.9E-05	1.6E-03	3.4E-05
Th-232	3.1E-06	3.2E-06	3.2E-06	2.1E-04	5.0E-05	1.4E-03	2.9E-05
Pa-231	1.6E-02	1.6E-02	1.6E-02	1.6E-02	1.6E-02	6.5E-03	2.0E-04
Pa-233	1.3E-04	1.6E-04	1.3E-04	1.0E-04	1.5E-04	6.4E-05	3.2E-05
U-232	1.7E-04	1.7E-04	1.7E-04	1.0E-03	1.6E-04	1.9E-03	2.0E-04
U-233	1.5E-04	1.5E-04	1.5E-04	9.4E-04	1.4E-04	1.7E-03	1.8E-04
U-234	1.5E-04	1.5E-04	1.5E-04	9.4E-04	1.5E-04	1.7E-03	1.8E-04
U-235/Th-231	1.5E-04	2.0E-04	1.8E-04	9.0E-04	1.9E-04	1.6E-03	1.9E-04
U-236	1.4E-04	1.4E-04	1.4E-04	8.8E-04	1.3E-04	1.6E-03	1.7E-04
U-238/ Th-234/ Pa-234m	1.3E-04	1.4E-04	1.4E-04	8.2E-04	1.4E-04	1.5E-03	1.6E-04
Np-237/ Pa-233	1.5E-02	1.5E-02	1.5E-02	1.5E-02	1.5E-02	6.2E-03	2.2E-04
Pu-238	4.5E-04	4.5E-04	4.4E-04	3.8E-03	3.7E-04	2.2E-03	2.2E-03
Pu-239	4.2E-04	4.2E-04	4.2E-04	3.6E-03	3.5E-04	2.1E-03	2.1E-03
Pu-240	4.2E-04	4.2E-04	4.2E-04	3.6E-03	3.5E-04	2.1E-03	2.1E-03
Pu-241	1.1E-07	1.1E-07	1.1E-07	9.7E-07	9.3E-08	5.6E-07	5.6E-07
Pu-242	4.0E-04	4.0E-04	4.0E-04	3.4E-03	3.2E-04	2.0E-03	2.0E-03
Am-241	7.6E-04	7.7E-04	7.6E-04	4.6E-03	2.0E-03	8.6E-04	8.6E-04
Cm-242	1.9E-02	1.9E-02	1.9E-02	1.9E-02	1.9E-02	7.9E-03	3.3E-04
Cm-243	1.8E-02	1.8E-02	1.8E-02	1.8E-02	1.8E-02	7.5E-03	3.3E-04
Cm-244	1.8E-02	1.8E-02	1.8E-02	1.8E-02	1.8E-02	7.4E-03	3.1E-04

B.5. Average Radionuclide Activity Concentrations (Bq/kg) in Disposal Cells in the Period After Authorisation

Radionuclide	Activity concentration (Bq/kg)	Radionuclide	Activity concentration (Bq/kg)
H-3	0.00E+00	Eu-152	2.35E+02
C-14	0.00E+00	Eu-154	2.21E+01
Cl-36	1.72E+02	Pb-210/Bi-210	7.59E+00
Ca-41	1.12E+03	Po-210	2.92E-02
Mn-54	2.02E+02	Ra-226 to Po-214	1.02E+02
Fe-55	1.52E+03	Th-228 to Tl-208	2.67E+00
Co-60	6.31E+02	Th-229 to Pb-209	2.13E-06
Ni-59	8.26E+01	Th-230	2.41E+00
Ni-63	2.23E+03	Th-232	1.72E+00
Zn-65	1.61E+02	Pa-231	2.37E-03
Sr-90/Y-90	9.45E+02	Pa-233	1.42E-01
Nb-93m	1.53E+00	U-232	1.95E+01
Nb-94	4.76E+00	U-233	1.35E+00
Mo-93	1.26E+01	U-234	1.44E+03
Tc-99	5.36E+02	U-235/Th-231	5.43E+01
Ru-106/Rh-106	8.57E+01	U-236	9.47E+01
Ag-108m	4.67E+00	U-238/Th-234/Pa-234m	6.25E+02
Ag-110m	1.05E+01	Np-237/Pa-233	9.98E+00
Sn-121m/Sn-121	5.92E+00	Pu-238	6.85E+01
Sb-125	2.81E+01	Pu-239	1.79E+02
I-129	2.65E+00	Pu-240	9.64E+01
Cs-134	2.92E+01	Pu-241	1.77E+03
Cs-137/Ba-137m	1.60E+03	Pu-242	5.08E-01
Ba-133	4.69E+00	Am-241	4.37E+02
Ce-144	4.46E+01	Cm-242	4.97E+00
Pm-147	1.72E+02	Cm-243	1.42E+00
Sm-151	1.30E+02	Cm-244	7.83E+00

B.6. Results – Terrestrial Biota Dose Rates (µGy/h)

Radionuclide	Dose rate (µGy/h)						
	Amphibian	Annelid	Arthropod	Bird	Flying insect	Grasses & herbs	Lichen & bryophyte
Cl-36	1.9E-01	4.6E-03	7.4E-03	1.9E-01	7.4E-03	5.4E-01	2.1E-02
Ca-41	4.1E-02	9.1E-04	4.9E-04	2.7E-04	4.9E-04	1.4E-03	9.7E-03
Mn-54	8.9E-02	8.9E-02	9.1E-02	3.4E-02	3.5E-02	3.3E-02	3.6E-02
Fe-55	3.1E-04	1.8E-04	1.4E-04	9.6E-05	2.2E-04	3.0E-04	2.2E-04
Co-60	8.3E-01	8.2E-01	8.2E-01	3.1E-01	3.2E-01	3.0E-01	3.2E-01
Ni-59	8.9E-05	6.2E-05	2.1E-05	8.2E-05	1.3E-05	1.1E-04	1.7E-04
Ni-63	2.9E-03	2.0E-03	4.7E-04	2.9E-03	4.5E-04	3.6E-03	6.6E-03
Zn-65	5.9E-02	5.9E-02	5.1E-02	4.4E-02	2.1E-02	1.8E-02	2.0E-02
Sr-90/Y-90	7.3E-01	3.3E-02	1.1E-01	7.3E-01	1.4E-01	3.8E-01	1.4E+00
Nb-93m	1.5E-06	4.7E-06	3.1E-07	5.2E-06	5.5E-08	2.5E-07	8.2E-07
Nb-94	4.0E-03	4.1E-03	4.0E-03	1.7E-03	1.5E-03	1.5E-03	1.5E-03
Mo-93	2.1E-04	4.0E-05	2.7E-05	2.3E-04	1.5E-04	5.0E-05	5.2E-05
Tc-99	1.2E-02	1.2E-02	1.2E-02	5.2E-03	1.2E-02	4.3E-01	4.1E-01
Ru-106/Rh-106	1.7E-02	9.7E-03	9.6E-03	1.2E-02	3.8E-03	4.4E-03	1.3E-01
Ag-108m	4.2E-03	4.2E-03	4.1E-03	1.9E-03	1.6E-03	2.1E-03	1.6E-03
Ag-110m	1.5E-02	1.6E-02	1.6E-02	7.2E-03	5.9E-03	7.4E-03	5.8E-03
Sn-121m/Sn-121	3.4E-04	9.9E-06	5.8E-05	3.4E-04	3.3E-04	2.7E-06	3.2E-04
Sb-125	6.2E-03	6.3E-03	6.2E-03	2.4E-03	2.4E-03	2.5E-03	2.9E-03
I-129	6.1E-05	2.9E-05	4.7E-05	6.0E-05	4.0E-05	2.3E-05	2.0E-05
Cs-134	2.6E-02	2.4E-02	2.5E-02	1.3E-02	9.6E-03	1.2E-02	1.9E-02
Cs-137/Ba-137m	5.9E-01	5.0E-01	5.2E-01	3.5E-01	2.2E-01	4.3E-01	9.0E-01
Ba-133	8.3E-04	8.4E-04	8.4E-04	5.1E-03	3.5E-04	3.5E-04	3.6E-04
Ce-144	1.2E-03	1.1E-03	1.1E-03	2.6E-03	4.4E-04	7.2E-04	6.1E-04
Pm-147	3.1E-05	3.0E-05	1.4E-05	4.3E-04	1.3E-05	8.5E-05	1.0E-04
Sm-151	3.4E-05	1.2E-05	5.8E-06	3.4E-05	3.4E-05	2.1E-05	3.4E-05
Eu-152	1.3E-01	1.4E-01	1.4E-01	7.4E-02	5.4E-02	5.2E-02	5.3E-02
Eu-154	1.4E-02	1.4E-02	1.4E-02	8.7E-03	5.5E-03	5.4E-03	5.5E-03
Pb-210/Bi-210	2.3E-04	8.8E-04	6.0E-04	1.2E-04	6.6E-04	2.1E-04	3.8E-03
Po-210	9.2E-05	9.0E-06	9.0E-06	9.2E-06	9.0E-06	2.5E-04	2.3E-03
Ra-226 to Po-214	7.0E-01	6.9E-01	6.9E-01	5.6E-01	6.4E-01	2.5E+00	1.0E+01
Th-228 to Tl-208	2.3E-03	6.6E-03	4.6E-03	9.6E-04	3.3E-03	8.0E-02	1.9E-01
Th-229 to Pb-209	4.2E-08	4.2E-08	4.1E-08	3.4E-08	4.1E-08	1.8E-07	6.8E-07
Th-230	2.6E-05	6.0E-04	3.3E-04	2.5E-05	3.3E-04	1.0E-02	2.5E-02
Th-232	1.6E-05	3.6E-04	2.0E-04	1.5E-05	2.0E-04	6.3E-03	1.5E-02
Pa-231	9.2E-06	1.2E-05	6.9E-06	2.1E-06	6.8E-06	1.1E-05	6.7E-05
Pa-233	1.5E-05	1.6E-05	1.4E-05	5.5E-06	7.1E-06	8.4E-06	2.2E-05
U-232	3.3E-03	2.0E-02	6.2E-03	7.5E-04	6.2E-03	7.6E-02	5.4E-01
U-233	2.1E-04	1.3E-03	3.9E-04	4.7E-05	3.9E-04	4.8E-03	3.4E-02
U-234	2.2E-01	1.4E+00	4.2E-01	5.1E-02	4.2E-01	5.1E+00	3.6E+01
U-235/Th-231	1.1E-02	5.1E-02	1.8E-02	3.3E-03	1.6E-02	1.8E-01	1.3E+00
U-236	1.3E-02	8.3E-02	2.6E-02	3.1E-03	2.6E-02	3.1E-01	2.2E+00
U-238/Th-234/Pa-234m	8.9E-02	5.2E-01	1.6E-01	2.2E-02	1.6E-01	2.0E+00	1.4E+01
Np-237/Pa-233	3.8E-02	5.0E-02	2.9E-02	8.9E-03	2.8E-02	4.6E-02	2.7E-01
Pu-238	3.1E-02	6.7E-02	5.6E-02	5.0E-03	5.6E-02	3.6E-02	2.8E-01
Pu-239	7.5E-02	1.6E-01	1.4E-01	1.2E-02	1.4E-01	8.7E-02	6.9E-01
Pu-240	4.1E-02	8.9E-02	7.4E-02	6.6E-03	7.4E-02	4.7E-02	3.7E-01
Pu-241	2.0E-04	4.4E-04	3.7E-04	3.3E-05	3.5E-04	2.3E-04	1.9E-03
Pu-242	2.0E-04	4.4E-04	3.7E-04	3.3E-05	3.7E-04	2.3E-04	1.9E-03
Am-241	1.9E+00	2.5E+00	1.4E+00	4.3E-01	1.4E+00	1.4E+00	1.4E+01
Cm-242	2.3E-02	3.1E-02	2.4E-02	5.4E-03	2.4E-02	8.8E-05	1.7E-01
Cm-243	6.4E-03	8.5E-03	6.6E-03	1.5E-03	6.5E-03	5.6E-05	4.7E-02
Cm-244	3.5E-02	4.6E-02	3.6E-02	8.0E-03	3.6E-02	1.3E-04	2.6E-01
Total	**5.9E+00**	**7.4E+00**	**4.9E+00**	**2.9E+00**	**3.8E+00**	**1.4E+01**	**8.3E+01**

Radionuclide	Dose rate (µGy/h)						
	L. burrowing mammal	Mammal - large	S. burrowing mammal	Mollusc	Reptile	Shrub	Tree
Cl-36	1.9E-01	1.9E-01	1.9E-01	4.3E-03	1.9E-01	2.7E-02	3.9E-02
Ca-41	4.1E-02	4.1E-02	4.1E-02	2.3E-04	4.1E-02	8.9E-04	3.6E-03
Mn-54	4.7E-02	1.7E-02	8.5E-02	3.4E-02	8.1E-02	4.6E-02	3.0E-02
Fe-55	4.9E-05	4.6E-05	1.2E-04	2.2E-04	2.9E-04	3.8E-05	3.1E-05
Co-60	4.8E-01	2.7E-01	7.8E-01	3.2E-01	7.7E-01	2.8E-01	2.5E-01
Ni-59	8.2E-05	8.2E-05	8.9E-05	1.3E-05	2.4E-04	7.5E-05	1.6E-05
Ni-63	3.0E-03	2.9E-03	2.9E-03	4.9E-04	8.3E-03	2.7E-03	5.9E-04
Zn-65	6.5E-02	1.1E-01	6.4E-02	2.8E-02	4.6E-02	1.9E-02	1.8E-02
Sr-90/Y-90	1.0E+00	1.0E+00	9.8E-01	4.3E-02	2.3E-01	8.7E-02	2.9E-01
Nb-93m	1.3E-06	1.3E-06	1.5E-06	4.5E-06	1.4E-06	1.3E-07	3.8E-07
Nb-94	2.1E-03	8.9E-04	3.8E-03	1.6E-03	3.7E-03	1.4E-03	1.2E-03
Mo-93	3.2E-05	3.2E-05	3.9E-05	1.6E-04	2.3E-04	1.8E-05	1.0E-05
Tc-99	1.2E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02	3.6E-04	3.6E-04
Ru-106/Rh-106	1.3E-02	1.1E-02	1.6E-02	3.9E-03	1.6E-02	2.1E-02	3.4E-02
Ag-108m	2.7E-03	2.3E-03	4.1E-03	1.7E-03	3.9E-03	1.4E-03	2.3E-03
Ag-110m	1.0E-02	8.4E-03	1.6E-02	6.3E-03	1.5E-02	5.4E-03	8.3E-03
Sn-121m/Sn-121	4.7E-06	4.1E-06	6.8E-06	3.3E-04	3.4E-04	2.4E-05	3.3E-06
Sb-125	3.1E-03	1.2E-03	5.9E-03	2.5E-03	5.6E-03	2.3E-03	2.1E-03
I-129	6.2E-05	6.5E-05	6.3E-05	2.6E-05	6.1E-05	4.3E-06	2.5E-05
Cs-134	4.2E-02	6.7E-02	4.0E-02	9.4E-03	2.5E-02	1.4E-02	9.6E-03
Cs-137/Ba-137m	1.5E+00	2.0E+00	1.4E+00	2.0E-01	5.9E-01	6.2E-01	2.1E-01
Ba-133	4.4E-04	1.9E-04	7.9E-04	3.5E-04	7.6E-04	4.4E-04	3.7E-04
Ce-144	7.0E-04	3.7E-04	1.1E-03	1.9E-03	1.1E-03	6.0E-04	3.8E-04
Pm-147	3.1E-05	3.1E-05	3.1E-05	4.3E-04	3.1E-05	5.7E-05	1.1E-05
Sm-151	3.4E-05	3.4E-05	3.4E-05	3.4E-05	3.4E-05	4.6E-06	3.9E-06
Eu-152	7.4E-02	3.0E-02	1.3E-01	5.4E-02	1.3E-01	4.9E-02	4.3E-02
Eu-154	7.7E-03	3.1E-03	1.3E-02	5.6E-03	1.3E-02	4.9E-03	4.2E-03
Pb-210/Bi-210	7.4E-05	7.4E-05	7.5E-05	1.5E-05	7.8E-05	5.6E-04	1.4E-04
Po-210	7.9E-05	8.0E-05	8.0E-05	9.0E-06	1.2E-04	3.0E-04	6.6E-05
Ra-226 to Po-214	6.7E-01	6.5E-01	7.0E-01	7.0E-01	6.9E-01	4.6E+00	1.9E-01
Th-228 to Tl-208	1.2E-03	5.0E-04	2.0E-03	5.3E-03	3.0E-03	3.1E-02	1.3E-03
Th-229 to Pb-209	4.2E-08	4.1E-08	4.2E-08	4.5E-08	4.2E-08	3.1E-07	1.1E-08
Th-230	9.0E-06	8.9E-06	9.2E-06	6.0E-04	1.4E-04	4.0E-03	8.2E-05
Th-232	5.4E-06	5.4E-06	5.6E-06	3.6E-04	8.6E-05	2.4E-03	5.0E-05
Pa-231	3.7E-05	3.7E-05	3.7E-05	3.7E-05	3.7E-05	1.5E-05	4.6E-07
Pa-233	1.9E-05	1.8E-05	2.2E-05	1.5E-05	2.2E-05	9.1E-06	4.5E-06
U-232	3.3E-03	3.3E-03	3.3E-03	2.0E-02	3.1E-03	3.6E-02	3.9E-03
U-233	2.0E-04	2.0E-04	2.1E-04	1.3E-03	1.9E-04	2.3E-03	2.5E-04
U-234	2.2E-01	2.2E-01	2.2E-01	1.4E+00	2.1E-01	2.5E+00	2.7E-01
U-235/Th-231	9.5E-03	8.2E-03	1.1E-02	4.9E-02	1.1E-02	8.7E-02	1.0E-02
U-236	1.3E-02	1.3E-02	1.3E-02	8.3E-02	1.3E-02	1.5E-01	1.6E-02
U-238/Th-234/Pa-234m	8.6E-02	8.4E-02	8.9E-02	5.1E-01	8.5E-02	9.3E-01	1.0E-01
Np-237/Pa-233	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	6.2E-02	2.2E-03
Pu-238	3.0E-02	3.1E-02	3.1E-02	2.6E-01	2.5E-02	1.5E-01	1.5E-01
Pu-239	7.4E-02	7.5E-02	7.5E-02	6.4E-01	6.2E-02	3.8E-01	3.8E-01
Pu-240	4.0E-02	4.1E-02	4.1E-02	3.5E-01	3.3E-02	2.0E-01	2.0E-01
Pu-241	2.0E-04	2.0E-04	2.0E-04	1.7E-03	1.7E-04	1.0E-03	1.0E-03
Pu-242	2.0E-04	2.0E-04	2.0E-04	1.7E-03	1.6E-04	1.0E-03	1.0E-03
Am-241	3.3E-01	3.3E-01	3.4E-01	2.0E+00	8.9E-01	3.8E-01	3.8E-01
Cm-242	9.5E-02	9.4E-02	9.4E-02	9.4E-02	9.4E-02	3.9E-02	1.6E-03
Cm-243	2.6E-02	2.6E-02	2.5E-02	2.6E-02	2.5E-02	1.1E-02	4.7E-04
Cm-244	1.4E-01	1.4E-01	1.4E-01	1.4E-01	1.4E-01	5.8E-02	2.4E-03
Total	**5.3E+00**	**5.6E+00**	**5.7E+00**	**7.1E+00**	**4.6E+00**	**1.1E+01**	**2.7E+00**

SNC Lavalin

<contact info>