LLW Repository Ltd

LLWR Environmental Safety Case

Assessment of the Impacts on Non-human Biota for the LLWR 2011 ESC (Extended Disposal Area)

A report prepared by Serco for and on behalf of the Low Level Waste Repository Site Licence Company.

SERCO/TAS/003632/013 **Issue 2** **Date: April 2011**

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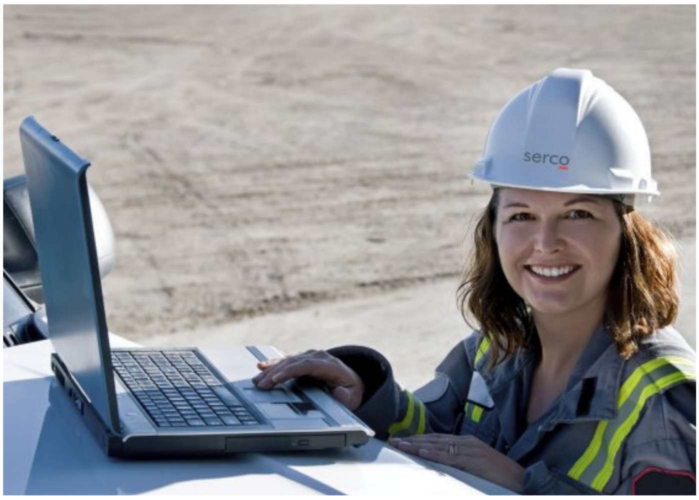

Prepared for	LLWR Lifetime Project
Prepared by	Serco
Your Reference	
Our Reference	Serco/TAS/003632/013 Issue 2
Classification	

25 April 2011

Design I Advise I Integrate I Deliver

Title	Assessment of the Impacts on Non-human Biota for the LLWR 2011 ESC (Extended Disposal Area)
Prepared for	LLWR
Your Reference	
Our Reference	Serco/TAS/E003632/013
Confidentiality, copyright and reproduction	

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Executive Summary

The Low Level Waste Repository (LLWR) is situated in west Cumbria adjacent to the Irish Sea coast, about 0.5 km inland, about 0.5 km from the Drigg village and 6 km to the south-east of the Sellafield Site. To the west and south the site is contiguous with or lies close to the Drigg Coast SSSI, which is designated both as an SSSI and a Special Area of Conservation (SAC).

This report is a supplement to a previous report relating to development and application of a methodology for assessing radiological impacts of potential releases of radionuclides from the LLWR on non-human biota. This information is required as an input to the Environmental Safety Case (ESC) for the LLWR to be submitted in May 2011. That report built on work reported in 2007, but utilised the new mathematical models that have been developed since that time to assess radiological impacts on humans due to potential releases of radionuclides from the LLWR by various pathways.

With development and closure of the facility, radionuclide contamination of the local environment would be expected initially to decrease. However, in the longer term (out to a few thousand years) radionuclides will be transported from the repository in groundwater and surface waters, and will be released as radioactive gases (notably C-14 labelled methane and carbon dioxide). In addition, the wastes will eventually become exposed at the cliff line due to coastal erosion and will be transported to the local marine environment across the beach and foreshore. All of these pathways of release have been studied in detail in other components of the ESC assessment related to the evaluation of radiological impacts on humans. These assessments necessarily provide radionuclide concentrations in environmental media (soils, sediments and waters) as intermediate results. These concentrations have been used as inputs to the ERICA Tool to evaluate the impacts on non-human biota.

The assessment described in this report updates the radiological impacts on non-human biota for the groundwater discharge, well abstraction release, gas release and coastal erosion pathways for a repository design in which future waste arisings are disposed in up to 13 vaults (i.e. the vaults are numbered from Vault 8 through to Vault 20). This Extended Disposal Area (EDA) repository design is in contrast to the Reference Disposal Area (RDA) repository design assumed for the ESC assessment calculations, in which the future vaults are assumed to end at Vault 14.

For the natural groundwater discharge pathways maximum dose rates for the EDA case are higher than for the RDA case for all discharge scenarios and biota types. However, all dose rates are over two orders of magnitude below the threshold of 10 $\mu Gy\ h^{-1}$. Thus, overall, radionuclide transport in groundwater is not identified as being of importance in determining radiological impacts on non-human biota.

For the coastal erosion pathway the maximum dose rates for the EDA case are only slightly higher than that for the RDA case. In view of these very small changes, all of the main conclusions in the ESC Non-human Biota Assessment report for the RDA case relating to the coastal erosion pathway are applicable also to the EDA assessment.

For the release of gaseous C-14 pathway the biota dose rates and conclusions that have been derived for the RDA case remain unchanged for the EDA case.

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1 Introduction

This report is a supplement to a previous report (Thorne and Schneider, 2011) relating to development and application of a methodology for assessing radiological impacts of potential releases of radionuclides from the Low Level Waste Repository (LLWR) on non-human biota. This information is required as an input to the Environmental Safety Case (ESC) for the LLWR to be submitted in May 2011. That report built on work reported previously (Eden and Barber, 2007), but utilised the new mathematical models that have been developed since that time to assess radiological impacts on humans due to potential releases of radionuclides from the LLWR by various pathways. These models necessarily calculate radionuclide concentrations in environmental media as an intermediate output and these concentrations are used as input to the ERICA Tool to evaluate their significance in terms of radiological impacts on non-human biota.

The assessment described in this report updates the radiological impacts on non-human biota for the groundwater discharge, well abstraction release, gas release and coastal erosion pathways for a repository design in which future waste arisings are disposed in up to 13 vaults (i.e. the vaults are numbered from Vault 8 through to Vault 20). This Extended Disposal Area (EDA) repository design is in contrast to the Reference Disposal Area (RDA) repository design assumed for the ESC assessment calculations, in which the future vaults are assumed to end at Vault 14.

Section 2 gives a brief geography of the LLWR site. Section 3 contains an overview description of the ERICA Tool and its use in the assessment process. Section 4 then describes the four potential pathways for which supplementary results are provided, i.e. migration in groundwater and discharge at the ground surface, migration in groundwater and well abstraction, release of gaseous C-14 and coastal erosion. The radionuclide concentrations projected to arise in the post-closure period are then evaluated in terms of radiological impacts on non-human biota using the ERICA Tool, as reported in Section 5. Conclusions are provided in Section 6 and references in Section 7.

2 Brief Geography of the LLWR Site

The LLWR is situated in west Cumbria adjacent to the Irish Sea coast, about 0.5 km inland, about 0.5 km from the Drigg village and 6 km to the south-east of the Sellafield Site. To the west and south the site is contiguous with or lies close to the Drigg Coast SSSI, which is designated both as an SSSI and a Special Area of Conservation (SAC).

The Drigg Stream flows through the site roughly parallel with the western site boundary. Towards the centre of the site the Drigg Stream is joined by the east-west stream which drains farmland to the north east and also takes surface water from the Whitehaven to Barrow-in-Furness railway drain. The Drigg Stream leaves the site to the south and discharges into the River Irt. The River Irt becomes a tidal estuary at its lower end as it flows into the sea. To the west, the site gently undulates towards a small cliff line marking the edge of the Drigg beach.

A much more detailed geographical description of the LLWR site plus its ecological context is given in the ESC Non-human Biota Assessment (Thorne and Schneider, 2011).

3 Use of the ERICA Tool for evaluating the Significance of Radionuclide Concentrations in Environmental Media

3.1 Overview Description of the ERICA Tool

The choice of the ERICA Tool to assess radiological impacts on non-human biota has been described in great detail in the ESC Non-human Biota Assessment report (Thorne and Schneider, 2011).

The ERICA Tool is a software system that has a structure based upon the tiered ERICA Integrated Approach to assessing the radiological risk to non-human biota. The Tool enables the necessary calculations to be performed to estimate risks to reference types of animals and plants in specific environments. The databases of the ERICA tool have been built around a number of reference organisms. Each reference organism has its own specified geometry (and default transfer data) and is representative of terrestrial, freshwater or marine ecosystems.

Tier 1 assessments are media concentration based and use pre-calculated environmental media concentration limits (EMCLs) to estimate risk quotients. Tier 2 calculates dose rates but allows the user to examine and edit most of the parameters used in the calculation including concentration ratios, distribution coefficients, percentage dry weight soil or sediment, dose conversion coefficients, radiation weighting factors and occupancy factors. The user can also input biota whole-body activity concentrations in Tier 2 if available rather than rely upon concentration ratios. Tier 3 offers the same flexibility as Tier 2 but allows the option to run the assessment probabilistically if the underling parameter probability distribution functions are defined.

In the evaluation reported in this report, all assessments have been carried out at Tier 2.

3.2 ERICA Tool Inputs and Selection of a Threshold Dose Rate

Apart from radionuclide concentrations in environmental media and organisms, which are calculated using the radionuclide transport models described in later sections of this report, the main additional data required for assessments using the ERICA Tool are DCCs (Dose Conversion Coefficients), occupancies of different parts of the habitat and threshold dose rates. Default data are provided for all these quantities.

For DCC values, there is no good reason to change the default values, since these are based on straightforward radiation transport calculations for the simple geometrical shapes (ellipsoids) used to represent reference organisms. Occupancies in or on soils and water bodies, and in air can be estimated by reference to the habits of the various species of interest. This matter is discussed further in the context of specific assessment calculations reported in later sections.

The selection of suitable threshold dose rates for screening purposes (whether at Tier 1 or Tier 2) has been described in great detail in the ESC Non-human Biota Assessment report (Thorne and Schneider, 2011). As discussed by Howard *et al.* (2010), whilst there are various numeric benchmarks being used by some national regulatory bodies, there are currently no internationally agreed numeric criteria or methodologies to derive thresholds for radiological purposes. The Environment Agency (EA) has, however, advised that evaluation against the generic screening threshold of 10 $\mu Gy\ h^{-1}$, which is more restrictive than the value that has previously been used in the UK (40 $\mu Gy\ h^{-1}$), will generally be sufficient (D Copplestone, personal communication, meeting between LLWR and EA, 23 June 2010).

4 Potential Discharges of Radionuclides from the LLWR in the Post-closure Period and Resulting Concentrations in Environmental Media

In this Section, a brief account is given of the approach used to estimate radionuclide concentrations in environmental media arising from the groundwater discharge and well abstraction release pathways considered. The account of methods is brief because the approaches used are described in full in the reports that discuss the evaluations of radiological impacts on humans (Kelly *et al.*, 2011, Towler *et al.*, 2011, Limer *et al.*, 2011).

The assessment described in this report updates the radiological impacts on non-human biota for the groundwater discharge, well abstraction, gas release and coastal erosion pathways for a repository design in which future waste arisings are disposed in up to 13 vaults (i.e. the vaults are numbered from Vault 8 through to Vault 20). This is in contrast to the repository design assumed for the ESC assessment calculations, in which the future vaults are assumed to end at Vault 14.

4.1 Migration in Groundwater and Discharge at the Surface

Radionuclides released in groundwater from the facility are transported either towards the coast or to the Drigg Stream.

In the current model, both the drift pathway and the sandstone pathway discharge into local coastal waters and the underling local coastal sediments. There is no discharge directly to the beach intertidal zone, but this zone becomes contaminated as a result of exchanges with local coastal waters.

Radionuclides are also discharged in surface waters to the Drigg Stream. Concentrations are calculated both in the water of the Stream and in the soils of the banks of the stream. Radionuclides that are discharged from the Drigg Stream enter the Lower Irt Estuary. This includes the water column and underlying sediments, together with pasture and salt marsh areas bordering the Estuary. Thus, for the Drigg stream and the Irt Estuary both freshwater and terrestrial organisms have to be taken into account.

Full details on the assessment method can be found in the radiological assessment report for groundwater pathways (Kelly *et al.*, 2011). For the EDA, radionuclide concentrations in the relevant environmental media are given in the corresponding radiological assessment report for groundwater pathways (Kelly and Carter, 2011), so they are not reproduced herein.

4.2 Migration in Groundwater and Well Abstraction

In this case, a groundwater plume is assumed to migrate to the west of the site. Abstraction of well water is taken to be both for domestic use and for irrigation of crops. It is the latter route that is of relevance here, as it leads to the contamination of soils with resultant exposure of agricultural crops, domesticated animals and other types of biota present in a predominantly cultivated environment, or invading such an environment after cultivation has lapsed.

Details of the assessment method can be found in the groundwater radiological assessment report (Kelly *et al.*, 2011) and the computations of concentrations are described and results given in the EDA radiological assessment report for groundwater pathways (Kelly and Carter, 2011), so they are not reproduced here.

4.3 Coastal Erosion

Current projections of future climate change and consequent coastal erosion in the vicinity of the LLWR indicate that disruption of the repository will begin on a timescale of hundreds to thousands of years.

Some large waste items may remain on the beach below the cliff for years to decades, but most contamination is associated with materials (such as corrosion products, degraded residues from organic wastes and mineral sands) that will be mixed with natural beach sediments and be dispersed into foreshore sediments. Contaminants will be released from the wastes and foreshore sediments into seawater; some will be sorbed on natural sediments. The six additional vaults for the EDA repository extend the ‘site frontage’ parallel to the coast by approximately by 220 m. This increases the length of beach that will in the future become contaminated with eroded wastes. The additional vaults are also deeper than some of the existing/earlier vaults. This increases the likelihood that the wastes will be directly eroded rather than undercut.

Details of the assessment method can be found in the coastal erosion radiological assessment report (Towler *et al*., 2011) and the updated activity concentrations for the EDA are given in the EDA radiological assessment report for coastal erosion (Parton and Towler, 2011).

4.4 Release of Gaseous C-14

The degradation of wastes present in both the trenches and vaults can lead to the production of both carbon dioxide and methane labelled with C-14. These gases can migrate through the overlying fill and cap materials to enter the soil zone. In soil, methane can be partially or fully converted to carbon dioxide. For the 2011 LLWR ESC, the LLWR has developed a model for the uptake of C-14 by vegetation following its entry into the soil zone (Limer *et al*., 2011).

Further details of the assessment method can be found in the C-14 radiological assessment report (Limer *et al*., 2011) and the updated C-14 fluxes and activity concentrations for the EDA are given in the corresponding radiological assessment report for the C-14 release pathway (Limer, 2011).

5 Radiological Impacts of Potential Releases of Radionuclides in the Post-closure Period on Non-human Biota

5.1 Migration in Groundwater and Discharge at the Surface

Detailed results of the dose rates to biota for the EDA are presented in Appendix A (Tables A.1. to A. 6). A comparison of maximum dose rates between the RDA and EDA cases is given in Table 5.1.

Table 5.1: Ratio of the Maximum Dose Rates in the EDA Case to the Maximum Concentration in the RDA Case for the Groundwater Migration with Surface Discharge Pathway

Location	Biota type	EDA max dose rate (μGy h^{-1})	RDA max dose rate (μGy h^{-1})	Ratio
Foreshore	Terrestrial biota	1.70E-03	1.47E-04	1.16E+01
	Marine biota	4.22E-04	7.07E-06	5.97E+01
Lower Irt	Terrestrial biota	5.72E-07	4.55E-08	1.26E+01
	Freshwater biota	2.93E-04	5.05E-06	5.80E+01
Drigg Stream	Terrestrial biota	1.81E-03	1.68E-04	1.08E+01
	Freshwater biota	5.57E-02	8.57E-03	6.50E+00

Maximum dose rates for the EDA case are higher than for the RDA case for all discharge scenarios and biota types. However, all dose rates are over two orders of magnitude below the threshold of 10 μGy h^{-1}. Thus, compliance with that threshold is assured, even when an uncertainty factor of 3 to 5 in the ERICA Tool calculations is taken into account.

5.2 Migration in Groundwater and Discharge at the Surface

Detailed results of the dose rates to biota for the EDA are presented in Appendix A (Table A.7). A comparison of maximum dose rates between the RDA and EDA cases is given in Table 5.2.

Table 5.2: Ratio of the Maximum Dose Rates in the EDA Case to the Maximum Concentration in the RDA Case for the Groundwater Migration with Well Abstraction Pathway

Location	Biota type	EDA max dose rate (μGy h^{-1})	RDA max dose rate (μGy h^{-1})	Ratio
Irrigation of terrestrial environment	Terrestrial biota	3.62E-02	4.78E-03	7.57E+00

The maximum dose rate for the EDA case is higher than that for the RDA case. For both cases dose rates are over 2 orders of magnitude below the threshold of 10 μGy h^{-1}.

5.3 Coastal Erosion

For the coastal erosion discharge scenario dose rates in biota for the EDA case have been derived by comparison of predicted activity in the terrestrial environmental media between the EDA and RDA cases. For the marine environment changes in activity concentrations are minimal. Full details are provided in Appendix B. A comparison of derived terrestrial dose rates between RDA and EDA is given in Table 5.3. This comparison applies to the eroding cliff where the wastes are exposed and the storm beach at the toes of that cliff. Dose rates on the foreshore are lower.

Table 5.3: Ratio of the Derived Dose Rates in the EDA Case to the Maximum Concentration in the RDA Case for the Coastal Erosion Pathway

Location	Biota	EDA max dose rate ($\mu Gy\ h^{-1}$)	RDA max dose rate ($\mu Gy\ h^{-1}$)	Ratio
Cliff	Bird	8.79E+00	5.48E+00	1.60E+00
	Bird egg	1.19E+01	9.73E+00	1.22E+00
	Detritivorous invertebrate	1.56E+01	1.46E+01	1.07E+00
	Flying insects	1.31E+01	1.21E+01	1.08E+00
	Mammal (Rat)	9.21E+00	5.89E+00	1.56E+00
	Reptile	8.68E+00	5.37E+00	1.62E+00
	Grasses & Herbs	2.60E+01	2.39E+01	1.09E+00
Beach	Bird	9.60E+00	8.46E+00	1.13E+00
	Bird egg	1.66E+01	1.59E+01	1.05E+00
	Detritivorous invertebrate	1.75E+01	1.71E+01	1.02E+00
	Flying insects	1.45E+01	1.41E+01	1.02E+00
	Mammal (Rat)	9.44E+00	8.30E+00	1.14E+00
	Reptile	9.45E+00	8.31E+00	1.14E+00
	Grasses & Herbs	2.23E+01	2.16E+01	1.03E+00

The maximum dose rates for the EDA case are slightly higher than that for the RDA case. In view of these very small changes, all of the main conclusions in the ESC Non-human Biota Assessment report (Thorne and Schneider, 2011) relating to the coastal erosion pathway are applicable also to the Extended Disposal Area assessment.

5.4 Release of Gaseous C-14

For the gas release pathway dose rates in biota for the RDA case have been derived based on a bounding C-14 flux of 1 10^6 Bq m^{-2} y^{-1} (Thorne and Schneider, 2011). For the EDA case it could be established that gas generation rates will not exceed this bounding value (Limer, 2011). As a result the dose rates reported in the ESC Non-human Biota Assessment (Thorne and Schneider, 2011) and reproduced here in Table 5.4 remain valid for the EDA case.

Table 5.4: Dose Rates to Biota for Gaseous Releases of C-14

Organism	Total Dose Rate per organism ($\mu Gy\ h^{-1}$)
Amphibian	9.05
Bird	9.38
Bird egg	9.05
Detritivorous invertebrate	9.05
Flying insects	9.05
Gastropod	9.05
Grasses & Herbs	3.14
Lichen & bryophytes	3.14
Mammal (Deer)	9.38
Mammal (Rat)	9.38
Reptile	9.38
Shrub	3.14
Soil Invertebrate (worm)	9.05
Tree	3.25

6 Conclusions

The LLWR is situated in west Cumbria adjacent to the Irish Sea coast, about 0.5 km inland, about 0.5 km from the Drigg village and 6 km to the south-east of the Sellafield Site. To the west and south the site is contiguous with or lies close to the Drigg Coast SSSI, which is designated both as an SSSI and a Special Area of Conservation (SAC).

With development and closure of the facility, radionuclide contamination of the local environment would be expected initially to decrease. However, in the longer term (out to a few thousand years) radionuclides will be transported from the repository in groundwater and surface waters, and will be released as radioactive gases (notably C-14 labelled methane and carbon dioxide). In addition, the wastes will eventually become exposed at the cliff line due to coastal erosion and will be transported to the local marine environment across the beach and foreshore. All of these pathways of release have been studied in detail in other components of the ESC assessment related to the evaluation of radiological impacts on humans and its supplements for the EDA design of the repository. These assessments necessarily provide radionuclide concentrations in environmental media (soils, sediments and waters) as intermediate results. These concentrations have been used as inputs to the ERICA Tool to evaluate the impacts on non-human biota.

The assessment reported here comprehensively updates the radiological impacts on non-human biota for the groundwater discharge, well abstraction release, coastal erosion and gas release pathways for the EDA repository design.

For the natural groundwater discharge pathways maximum dose rates for the EDA case are higher than for the RDA case for all discharge scenarios and biota types. However, all dose rates are over two orders of magnitude below the threshold of 10 µGy h^{-1}. Thus, overall, radionuclide transport in groundwater is not identified as being of importance in determining radiological impacts on non-human biota.

For the coastal erosion pathway the maximum dose rates for the EDA case are only slightly higher than that for the RDA case. In view of these very small changes, all of the main conclusions in the ESC Non-human Biota Assessment report for the RDA case relating to the coastal erosion pathway are applicable also to the Extended Disposal Area assessment.

For the release of gaseous C-14 pathway the biota dose rates and conclusions which have been derived for the RDA case remain unchanged for the EDA case.

7 References

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Appendix A Dose Rates to Reference Organisms for the Groundwater Migration Pathways

A.1 Assessment Results for the Groundwater Migration Pathways for the EDA

The reference organism types were identified based on the characteristics of the site described in the ESC Non-human Biota Assessment (Thorne and Schneider, 2011). The various tables in this section all follow a common format. The values shown are total dose rates in $\mu Gy\ h^{-1}$ and should be compared with the ERICA Tool screening value of 10 $\mu Gy\ h^{-1}$. The calculations were undertaken for the time post-closure for which the environmental concentration of each radionuclide was highest. Therefore, the total shown at the bottom of each column is a cautious, over-estimate of the maximum dose rate that could be incurred by that type of reference organism, because the maximum concentrations of all radionuclides do not occur at the same time.

The rightmost column shows the maximum dose rate for each radionuclide for any reference organism. The total dose rate for that column is doubly a cautious over-estimate because it is the sum of maximum dose rates that may occur at different times and may be applicable to difference organism types. Thus, if this dose rate is less than 10 $\mu Gy\ h^{-1}$, it is assured that the true maximum dose rate is less than 10 $\mu Gy\ h^{-1}$.

A.2 Migration in Groundwater and Discharge at the Surface

In the case of discharges to the foreshore and into local coastal waters, the dose rates to terrestrial biota are shown in Table A.1. The cautious estimate of total dose rate is 1.70 10^{-3} $\mu Gy\ h^{-1}$, which is over three orders of magnitude lower than the threshold dose rate at which consideration has to be given to potentially deleterious effects. It should be noted that these dose rates are based on 100% occupancy of the beach and foreshore.

Results for the marine biota from discharges to the foreshore and into local coastal waters are shown in Table A.2. In this case, the maximum dose rate is rather lower than in the terrestrial case, reflecting an additional degree of dilution in the marine environment. Total dose rates are similar for all the types of reference organism considered and the cautious total value of 4.22 10^{-4} $\mu Gy\ h^{-1}$ is more than four orders of magnitude lower than the threshold dose rate.

Table A.1: Dose Rates to Terrestrial Non-human Biota for Discharges to the Foreshore ($\mu Gy\ h^{-1}$)

Radio-nuclide	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Mammal (Rat)	Reptile	Grasses & Herbs	Maximum
Am-241	1.73E-08	1.73E-08	4.27E-08	5.39E-08	1.74E-08	1.73E-08	2.15E-09	5.39E-08
C-14	1.60E-03	1.03E-03	4.96E-04	4.96E-04	1.60E-03	1.60E-03	1.03E-03	1.60E-03
Cl-36	2.01E-05	2.01E-05	7.66E-07	7.65E-07	2.01E-05	2.01E-05	4.60E-05	4.60E-05
Cm-242	1.26E-12	1.26E-12	4.25E-12	4.25E-12	1.26E-12	1.26E-12	8.63E-15	4.25E-12
Cm-243	5.23E-21	5.23E-21	1.77E-20	1.76E-20	5.32E-21	5.23E-21	1.23E-22	1.77E-20
Cm-244	1.07E-24	1.07E-24	3.61E-24	3.61E-24	1.07E-24	1.07E-24	7.32E-27	3.61E-24
Co-60	3.82E-23	3.58E-23	8.85E-23	3.41E-23	8.51E-23	3.50E-23	3.27E-23	8.85E-23
Cs-135	1.13E-11	4.51E-13	1.97E-12	8.08E-13	4.32E-11	5.40E-11	1.04E-11	5.40E-11
Cs-137	3.51E-16	1.60E-16	4.53E-16	1.78E-16	1.07E-15	1.00E-15	2.88E-16	1.07E-15
H-3	1.32E-07	1.32E-07	1.32E-07	1.24E-07	1.32E-07	1.32E-07	1.32E-07	1.32E-07
I-129	9.82E-08	3.45E-05	7.68E-08	6.59E-08	1.04E-07	9.33E-08	3.74E-08	3.45E-05
Nb-94	1.93E-10	2.14E-10	4.54E-10	1.71E-10	4.41E-10	1.78E-10	1.68E-10	4.54E-10
Ni-63	1.03E-09	1.03E-09	1.23E-10	1.19E-10	1.03E-09	1.03E-09	2.69E-09	2.69E-09
Np-237	1.67E-06	1.67E-06	4.15E-06	5.17E-06	1.67E-06	1.67E-06	7.08E-07	5.17E-06
Pb-210	5.77E-08	5.54E-08	5.29E-07	4.82E-08	3.62E-08	8.00E-08	5.53E-08	5.29E-07
Pu-238	7.69E-12	7.69E-12	1.28E-11	5.56E-12	7.69E-12	7.69E-12	4.75E-12	1.28E-11
Pu-239	2.86E-07	2.86E-07	4.74E-07	2.07E-07	2.86E-07	2.86E-07	1.76E-07	4.74E-07
Pu-240	1.06E-07	1.06E-07	1.76E-07	7.69E-08	1.06E-07	1.06E-07	6.57E-08	1.76E-07
Pu-241	3.70E-17	3.70E-17	6.14E-17	2.53E-17	3.71E-17	3.70E-17	2.29E-17	6.14E-17
Ra-226	3.14E-06	2.97E-06	7.50E-06	7.18E-06	2.52E-06	2.97E-06	3.25E-06	7.50E-06
Ra-228	2.46E-26	2.43E-26	6.29E-26	2.57E-26	5.78E-26	2.32E-26	2.42E-26	6.29E-26
Sr-90	1.62E-11	3.86E-11	6.66E-12	1.24E-12	5.05E-11	3.30E-10	4.94E-12	3.30E-10
Tc-99	4.58E-08	4.58E-06	6.06E-08	6.16E-08	6.27E-08	6.27E-08	3.39E-06	4.58E-06
Th-228	1.64E-26	1.64E-26	1.11E-25	8.74E-26	3.46E-26	1.59E-26	3.80E-25	3.80E-25
Th-230	1.98E-12	1.98E-12	4.48E-11	4.48E-11	6.50E-13	1.98E-12	2.21E-10	2.21E-10
Th-232	3.45E-14	3.45E-14	7.81E-13	7.80E-13	1.12E-14	3.45E-14	3.86E-12	3.86E-12
U-234	1.52E-08	1.52E-08	2.48E-07	2.48E-07	3.13E-09	1.40E-08	4.08E-07	4.08E-07
U-235	2.11E-09	2.11E-09	1.45E-08	1.27E-08	3.23E-09	2.01E-09	1.99E-08	1.99E-08
U-238	1.58E-08	1.58E-08	2.58E-07	2.57E-07	3.22E-09	1.46E-08	4.24E-07	4.24E-07
Total	**1.63E-03**	**1.09E-03**	**5.10E-04**	**5.10E-04**	**1.63E-03**	**1.63E-03**	**1.08E-03**	**1.70E-03**

Table A.2: Dose Rates to Marine Non-human Biota for Discharges to the Foreshore and Local Coastal Environment (μGy h^{-1})

Radio-nuclide	Benthic mollusc	Crustacean	Macroalgae	Sea anemones or true corals - colony	Sea anemones or true corals - polyp	Maximum
Am-241	1.31E-08	2.11E-09	1.36E-09	1.48E-10	1.56E-10	1.31E-08
C-14	3.83E-04	3.96E-04	3.06E-04	4.21E-04	4.21E-04	4.21E-04
Cl-36	8.51E-10	3.49E-10	4.88E-09	2.47E-09	3.03E-09	4.88E-09
Cm-242	1.89E-14	7.69E-16	7.10E-15	1.60E-15	1.60E-15	1.89E-14
Cm-243	1.72E-22	8.16E-24	6.54E-23	1.54E-23	1.59E-23	1.72E-22
Cm-244	3.67E-26	1.49E-27	1.38E-26	3.10E-27	3.10E-27	3.67E-26
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-135	6.13E-15	3.65E-15	1.12E-14	3.30E-14	3.35E-14	3.35E-14
Cs-137	1.56E-16	1.41E-16	1.68E-16	1.60E-16	1.78E-16	1.78E-16
H-3	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11
I-129	8.04E-10	4.78E-10	3.88E-08	8.57E-10	1.22E-09	3.88E-08
Nb-94	2.59E-10	2.28E-10	2.60E-10	2.26E-10	2.56E-10	2.60E-10
Ni-63	7.64E-10	6.58E-11	9.48E-11	4.54E-10	4.55E-10	7.64E-10
Np-237	6.53E-09	1.64E-09	9.75E-10	1.53E-08	1.54E-08	1.54E-08
Pb-210	3.07E-10	1.51E-09	3.17E-10	1.55E-09	1.48E-09	1.55E-09
Pu-238	3.31E-13	4.82E-14	1.24E-12	8.13E-13	8.14E-13	1.24E-12
Pu-239	2.48E-09	3.61E-10	9.26E-09	6.10E-09	6.10E-09	9.26E-09
Pu-240	1.39E-09	2.02E-10	5.17E-09	3.41E-09	3.41E-09	5.17E-09
Pu-241	3.13E-20	4.74E-21	1.16E-19	7.77E-20	7.64E-20	1.16E-19
Ra-226	2.13E-09	3.65E-09	2.66E-09	1.78E-08	1.81E-08	1.81E-08
Ra-228	2.58E-31	7.11E-31	2.97E-31	4.59E-30	3.51E-30	4.59E-30
Sr-90	4.18E-14	9.15E-15	6.57E-14	1.74E-13	1.78E-13	1.78E-13
Tc-99	4.72E-08	1.17E-07	1.57E-07	1.15E-07	1.15E-07	1.57E-07
Th-228	1.57E-28	3.04E-28	6.14E-28	8.21E-28	8.29E-28	8.29E-28
Th-230	4.19E-12	8.21E-12	1.64E-11	2.22E-11	2.22E-11	2.22E-11
Th-232	1.95E-13	3.83E-13	7.66E-13	1.03E-12	1.03E-12	1.03E-12
U-234	3.66E-09	1.14E-09	1.37E-08	1.14E-07	1.14E-07	1.14E-07
U-235	1.92E-10	7.54E-11	6.48E-10	5.14E-09	5.19E-09	5.19E-09
U-238	3.79E-09	1.19E-09	1.42E-08	1.18E-07	1.18E-07	1.18E-07
Total	**3.83E-04**	**3.96E-04**	**3.06E-04**	**4.21E-04**	**4.21E-04**	**4.22E-04**

Discharges were also considered for the Lower Irt. In this case, terrestrial and freshwater environments were considered separately. Results for these two cases are presented in Table A.3 and Table A.4, respectively. Note that some types of reference organism, e.g. amphibians, can be associated with either terrestrial or freshwater environments. The assessment was undertaken for bounding cases of 100 percent occupancy of either environment.

In this case, dose rates to freshwater biota are higher than those to terrestrial biota by over two orders of magnitude, but are, nevertheless more than four orders of magnitude below the threshold dose rate.

Table A.3: Dose Rates to Terrestrial Non-human Biota for Discharges to the Lower Irt (μGy h^{-1})

Radio-nuclide	Reptile	Amphibian	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Gastropod	Grasses & Herbs	Lichen & bryophytes	Mammal (Deer)	Mammal (Rat)	Shrub	Soil Invertebrate (worm)	Maximum
Am-241	6.87E-10	6.86E-10	6.86E-10	6.87E-10	1.69E-09	2.13E-09	3.34E-09	8.50E-11	1.74E-09	6.86E-10	6.88E-10	8.47E-11	1.68E-09	3.34E-09
C-14	4.50E-07	4.35E-07	4.50E-07	2.89E-07	1.40E-07	1.40E-07	1.40E-07	2.89E-07	2.89E-07	4.50E-07	4.50E-07	2.89E-07	1.40E-07	4.50E-07
Cl-36	1.63E-08	1.63E-08	1.63E-08	1.63E-08	6.23E-10	6.22E-10	3.63E-10	3.74E-08	1.83E-09	1.63E-08	1.63E-08	2.27E-09	3.91E-10	3.74E-08
Cm-242	7.01E-17	7.01E-17	7.01E-17	7.01E-17	2.36E-16	2.36E-16	2.36E-16	4.79E-19	1.78E-16	7.01E-17	7.01E-17	1.61E-17	2.36E-16	2.36E-16
Cm-243	2.40E-25	2.41E-25	2.39E-25	2.40E-25	8.14E-25	8.09E-25	8.07E-25	5.65E-27	6.06E-25	2.43E-25	2.45E-25	5.85E-26	8.14E-25	8.14E-25
Cm-244	5.27E-28	5.27E-28	5.27E-28	5.27E-28	1.78E-27	1.78E-27	1.78E-27	3.60E-30	1.34E-27	5.27E-28	5.27E-28	1.21E-28	1.78E-27	1.78E-27
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-135	3.51E-12	5.26E-13	7.34E-13	2.94E-14	1.28E-13	5.25E-14	4.18E-14	6.79E-13	5.35E-12	2.81E-12	2.81E-12	3.89E-12	8.75E-14	5.35E-12
Cs-137	3.34E-15	6.28E-16	9.16E-16	5.32E-16	1.51E-15	5.92E-16	3.06E-16	9.60E-16	2.86E-15	4.79E-15	3.56E-15	3.09E-15	1.45E-15	4.79E-15
H-3	3.66E-11	3.66E-11	3.66E-11	3.66E-11	3.66E-11	3.43E-11	3.66E-11	3.66E-11	3.66E-11	3.66E-11	3.66E-11	3.66E-11	3.66E-11	3.66E-11
I-129	6.94E-11	6.54E-11	7.13E-11	2.57E-08	5.71E-11	4.90E-11	2.96E-11	2.78E-11	5.43E-11	7.90E-11	7.71E-11	2.69E-11	3.55E-11	2.57E-08
Nb-94	4.51E-10	2.51E-10	2.74E-10	5.43E-10	1.15E-09	4.35E-10	2.17E-10	4.27E-10	1.96E-12	3.83E-10	1.12E-09	3.99E-10	1.14E-09	1.15E-09
Ni-63	4.93E-12	4.93E-12	4.93E-12	4.93E-12	5.90E-13	5.71E-13	1.23E-12	1.29E-11	5.96E-12	4.93E-12	4.93E-12	2.34E-12	4.49E-12	1.29E-11
Np-237	2.76E-11	2.76E-11	2.76E-11	2.76E-11	6.88E-11	8.58E-11	1.34E-10	1.18E-11	7.06E-11	2.76E-11	2.77E-11	2.10E-10	6.76E-11	2.10E-10
Pb-210	7.48E-11	9.97E-11	5.35E-11	5.19E-11	4.95E-10	4.51E-11	6.00E-12	5.18E-11	3.52E-09	3.38E-11	3.39E-11	2.34E-10	2.46E-11	3.52E-09
Pu-238	7.24E-14	7.24E-14	7.24E-14	7.24E-14	1.20E-13	5.23E-14	3.46E-13	4.46E-14	3.20E-13	7.24E-14	7.24E-14	9.75E-14	8.96E-14	3.46E-13
Pu-239	4.95E-10	4.95E-10	4.95E-10	4.95E-10	8.21E-10	3.58E-10	2.37E-09	3.06E-10	2.19E-09	4.95E-10	4.95E-10	6.67E-10	6.13E-10	2.37E-09
Pu-240	2.87E-10	2.87E-10	2.87E-10	2.87E-10	4.76E-10	2.08E-10	1.37E-09	1.77E-10	1.27E-09	2.87E-10	2.87E-10	3.87E-10	3.56E-10	1.37E-09
Pu-241	2.98E-21	2.98E-21	2.98E-21	2.98E-21	4.95E-21	2.04E-21	1.42E-20	1.84E-21	1.32E-20	2.98E-21	2.99E-21	4.02E-21	3.70E-21	1.42E-20
Ra-226	7.63E-09	7.40E-09	7.84E-09	7.65E-09	1.93E-08	1.85E-08	9.76E-09	8.36E-09	4.27E-08	5.67E-09	6.49E-09	5.26E-09	1.93E-08	4.27E-08
Ra-228	7.33E-30	4.06E-30	4.15E-30	7.68E-30	1.99E-29	8.13E-30	4.13E-30	7.66E-30	1.78E-30	4.33E-30	1.83E-29	7.11E-30	2.00E-29	2.00E-29
Sr-90	9.77E-14	6.74E-15	4.79E-15	1.14E-14	1.97E-15	3.68E-16	6.27E-16	1.46E-15	3.49E-14	1.57E-14	1.49E-14	3.50E-16	6.46E-17	9.77E-14
Tc-99	2.32E-12	3.60E-12	1.69E-12	1.69E-10	2.24E-12	2.28E-12	2.28E-12	1.25E-10	1.17E-10	2.32E-12	2.32E-12	1.25E-10	2.32E-12	1.69E-10
Th-228	1.27E-30	7.83E-31	7.81E-31	1.31E-30	8.81E-30	6.95E-30	6.43E-30	3.02E-29	6.98E-29	6.61E-31	2.75E-30	1.17E-29	8.76E-30	6.98E-29
Th-230	5.14E-14	5.12E-14	5.12E-14	5.14E-14	1.16E-12	1.16E-12	1.16E-12	5.74E-12	1.36E-11	1.61E-14	1.69E-14	2.11E-12	1.16E-12	1.36E-11
Th-232	2.75E-15	2.74E-15	2.74E-15	2.75E-15	6.22E-14	6.22E-14	6.22E-14	3.08E-13	7.28E-13	8.60E-16	8.93E-16	1.13E-13	6.22E-14	7.28E-13
U-234	1.18E-11	1.18E-11	1.28E-11	1.28E-11	2.09E-10	2.09E-10	2.09E-10	3.43E-10	1.67E-09	2.52E-12	2.63E-12	1.67E-10	2.09E-10	1.67E-09
U-235	1.73E-12	1.16E-12	1.20E-12	1.82E-12	1.25E-11	1.09E-11	1.03E-11	1.72E-11	7.73E-11	6.63E-13	2.78E-12	8.88E-12	1.25E-11	7.73E-11
U-238	1.21E-11	1.21E-11	1.31E-11	1.31E-11	2.14E-10	2.14E-10	2.14E-10	3.52E-10	1.72E-09	2.58E-12	2.67E-12	1.71E-10	2.14E-10	1.72E-09
Total	**4.76E-07**	**4.61E-07**	**4.76E-07**	**3.41E-07**	**1.65E-07**	**1.62E-07**	**1.58E-07**	**3.36E-07**	**3.46E-07**	**4.74E-07**	**4.76E-07**	**2.99E-07**	**1.64E-07**	**5.72E-07**

Table A.4: Dose Rates to Freshwater Non-human Biota for Discharges to the Lower Irt (μGy h^{-1})

Radio-nuclide	Amphibian	Bird	Gastropod	Benthic fish	Bivalve mollusc	Crustacean	Insect larvae	Mammal	Pelagic fish	Phytoplankton	Vascular plant	Zooplankton	Maximum
Am-241	3.36E-11	3.36E-11	3.05E-09	5.91E-09	7.94E-09	1.69E-09	3.36E-07	3.36E-11	3.02E-11	6.71E-07	7.06E-08	6.72E-09	6.71E-07
C-14	2.79E-04	2.89E-04	2.79E-04	1.82E-04	2.79E-04	2.79E-04	2.79E-04	2.89E-04	1.82E-04	3.90E-08	1.70E-04	1.48E-04	2.89E-04
Cl-36	2.83E-07	2.83E-07	1.62E-07	2.83E-07	1.72E-07	1.19E-07	1.19E-07	2.83E-07	2.83E-07	3.45E-09	8.53E-07	6.22E-07	8.53E-07
Cm-242	1.72E-17	2.58E-16	5.67E-16	2.58E-16	5.67E-16	1.67E-16	1.89E-15	2.58E-16	2.58E-16	3.32E-14	5.16E-16	3.32E-14	3.32E-14
Cm-243	5.86E-26	8.71E-25	1.93E-24	8.71E-25	1.91E-24	5.68E-25	6.44E-24	8.71E-25	8.71E-25	1.13E-22	1.76E-24	1.13E-22	1.13E-22
Cm-244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-135	7.58E-12	2.45E-12	2.28E-12	5.14E-12	3.76E-13	8.07E-12	8.09E-12	7.58E-12	5.79E-12	8.06E-16	9.00E-13	1.17E-12	8.09E-12
Cs-137	5.39E-15	2.20E-15	1.82E-15	5.15E-15	8.62E-16	4.55E-15	5.31E-15	7.54E-15	4.94E-15	1.82E-18	1.13E-15	4.59E-16	7.54E-15
H-3	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11	1.83E-11	7.62E-12	1.83E-11	1.83E-11	1.83E-11
I-129	2.80E-09	3.06E-09	5.31E-10	4.24E-09	5.54E-10	8.10E-09	8.11E-09	3.20E-09	4.14E-09	2.25E-11	6.08E-09	2.63E-08	2.63E-08
Nb-94	2.74E-11	4.61E-11	4.97E-10	8.66E-10	9.37E-10	9.90E-10	1.93E-09	6.10E-11	4.44E-11	9.05E-13	1.02E-09	6.24E-11	1.93E-09
Ni-63	1.18E-10	1.18E-10	7.56E-09	1.18E-10	7.56E-09	6.57E-10	6.70E-10	1.18E-10	1.18E-10	9.65E-13	7.39E-11	5.85E-09	7.56E-09
Np-237	2.51E-09	2.51E-09	1.37E-08	2.51E-09	1.37E-08	1.86E-08	3.38E-07	2.51E-09	2.51E-09	6.75E-07	7.10E-08	7.60E-09	6.75E-07
Pb-210	1.18E-10	1.23E-10	1.89E-08	1.24E-10	6.73E-10	2.35E-09	2.41E-09	1.23E-10	1.23E-10	5.33E-13	2.79E-10	4.43E-09	1.89E-08
Pu-238	7.11E-13	6.19E-15	2.54E-12	1.86E-13	2.54E-12	3.40E-12	3.40E-12	7.11E-13	1.86E-13	1.82E-11	8.04E-12	1.39E-12	1.82E-11
Pu-239	4.87E-09	4.23E-11	1.74E-08	1.27E-09	1.74E-08	2.33E-08	2.33E-08	4.87E-09	1.27E-09	1.25E-07	5.51E-08	9.53E-09	1.25E-07
Pu-240	2.82E-09	2.46E-11	1.01E-08	7.37E-10	1.01E-08	1.35E-08	1.35E-08	2.82E-09	7.37E-10	7.24E-08	3.19E-08	5.53E-09	7.24E-08
Pu-241	2.93E-20	2.55E-22	1.04E-19	7.71E-21	1.04E-19	1.40E-19	1.40E-19	2.93E-20	7.64E-21	5.78E-20	3.31E-19	5.73E-20	3.31E-19
Ra-226	6.32E-09	6.71E-09	7.44E-08	6.86E-09	1.19E-07	1.21E-07	1.21E-07	6.71E-09	6.71E-09	8.93E-08	1.45E-07	8.85E-08	1.45E-07
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	2.66E-15	2.83E-15	3.79E-14	2.86E-15	4.29E-14	1.13E-14	1.23E-14	2.88E-15	2.84E-15	1.72E-16	1.91E-14	2.36E-15	4.29E-14
Tc-99	4.34E-10	4.34E-10	2.61E-10	4.34E-10	2.61E-10	1.32E-10	1.33E-10	4.34E-10	4.34E-10	1.08E-11	1.24E-08	1.89E-10	1.24E-08
Th-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th-230	7.60E-12	7.60E-12	6.91E-12	7.60E-12	6.91E-12	6.91E-12	6.92E-12	7.60E-12	7.60E-12	2.76E-10	8.71E-11	1.38E-10	2.76E-10
Th-232	4.07E-13	4.07E-13	3.70E-13	4.07E-13	3.70E-13	3.70E-13	3.70E-13	4.07E-13	4.07E-13	1.48E-11	4.66E-12	7.40E-12	1.48E-11
U-234	3.53E-09	3.53E-09	2.12E-08	3.53E-09	2.12E-08	5.89E-08	5.89E-08	3.53E-09	3.53E-09	1.41E-08	3.41E-07	5.65E-09	3.41E-07
U-235	1.63E-10	1.63E-10	9.78E-10	1.63E-10	9.79E-10	2.75E-09	2.75E-09	1.62E-10	1.63E-10	6.33E-10	1.59E-08	2.64E-10	1.59E-08
U-238	3.62E-09	3.62E-09	2.17E-08	3.62E-09	2.17E-08	6.03E-08	6.03E-08	3.62E-09	3.62E-09	1.45E-08	3.50E-07	5.79E-09	3.50E-07
Total	**2.80E-04**	**2.90E-04**	**2.80E-04**	**1.83E-04**	**2.80E-04**	**2.80E-04**	**2.80E-04**	**2.90E-04**	**1.83E-04**	**1.70E-06**	**1.72E-04**	**1.48E-04**	**2.93E-04**

Finally, discharges were considered for the Drigg Stream. Again, terrestrial and freshwater environments were considered separately. Results for these two cases are presented in Table A.5 and Table A.6, respectively. Note that some types of reference organism, e.g. amphibians, can be associated with either terrestrial or freshwater environments. The assessment was undertaken for bounding cases of 100 percent occupancy of either environment.

Dose rates are higher for organisms associated with the Drigg Stream, primarily because the degree of dilution is substantially less than in the Lower Irt. In this case, the maximum dose rates are to freshwater biota and the overall, cautiously estimated maximum is $5.57\ 10^{-2}$ $\mu Gy\ h^{-1}$ (a value that is more than two orders of magnitude lower than the threshold dose rate).

Table A.5: Dose Rates to Terrestrial Non-human Biota for Discharges to the Drigg Stream (μGy h^{-1})

Radio-nuclide	Reptile	Amphibian	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Gastropod	Grasses & Herbs	Lichen & bryophytes	Mammal (Deer)	Mammal (Rat)	Shrub	Soil Invertebrate (worm)	Tree	Maximum
Am-241	1.98E-05	1.98E-05	1.98E-05	1.98E-05	4.87E-05	6.14E-05	9.60E-05	2.45E-06	5.00E-05	1.97E-05	1.98E-05	2.44E-06	4.84E-05	8.08E-08	9.60E-05
C-14	5.71E-07	5.52E-07	5.71E-07	3.66E-07	1.77E-07	1.77E-07	1.77E-07	3.98E-07	3.98E-07	5.71E-07	5.71E-07	3.98E-07	1.77E-07	4.12E-07	5.71E-07
Cl-36	2.19E-04	2.19E-04	2.19E-04	2.19E-04	8.36E-06	8.35E-06	4.87E-06	5.01E-04	2.45E-05	2.19E-04	2.19E-04	3.04E-05	5.24E-06	4.44E-05	5.01E-04
Cm-242	1.41E-12	1.41E-12	1.41E-12	1.41E-12	4.75E-12	4.75E-12	4.75E-12	9.64E-15	3.58E-12	1.41E-12	1.41E-12	3.23E-13	4.75E-12	3.23E-13	4.75E-12
Cm-243	2.77E-21	2.80E-21	2.78E-21	2.77E-21	9.39E-21	9.33E-21	9.33E-21	6.51E-23	6.99E-21	2.81E-21	2.82E-21	6.74E-22	9.39E-21	6.75E-22	9.39E-21
Cm-244	1.50E-23	1.50E-23	1.50E-23	1.50E-23	5.04E-23	5.04E-23	5.04E-23	1.02E-25	3.79E-23	1.50E-23	1.50E-23	3.43E-24	5.04E-23	3.43E-24	5.04E-23
Co-60	8.64E-22	8.78E-22	9.42E-22	8.83E-22	2.18E-21	8.40E-22	8.41E-22	8.08E-22	2.00E-23	8.59E-22	2.10E-21	8.49E-22	2.18E-21	6.77E-22	2.18E-21
Cs-135	7.04E-08	1.05E-08	1.47E-08	5.89E-10	2.56E-09	1.05E-09	8.38E-10	1.36E-08	1.07E-07	5.64E-08	5.64E-08	7.79E-08	1.75E-09	3.20E-09	1.07E-07
Cs-137	6.51E-11	1.72E-11	2.28E-11	1.04E-11	2.95E-11	1.15E-11	1.14E-11	1.87E-11	5.57E-11	9.33E-11	6.94E-11	6.02E-11	2.82E-11	1.28E-11	9.33E-11
H-3	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.01E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18	6.42E-18
I-129	8.21E-07	7.95E-07	8.65E-07	3.04E-04	6.76E-07	5.80E-07	3.72E-07	3.30E-07	6.43E-07	9.35E-07	9.13E-07	3.18E-07	4.21E-07	3.56E-07	3.04E-04
Nb-94	9.34E-06	9.69E-06	1.02E-05	1.12E-05	2.39E-05	8.99E-06	8.99E-06	8.84E-06	4.06E-08	7.92E-06	2.32E-05	8.25E-06	2.36E-05	7.58E-06	2.39E-05
Ni-63	1.12E-07	1.12E-07	1.12E-07	1.12E-07	1.34E-08	1.30E-08	2.80E-08	2.95E-07	1.36E-07	1.12E-07	1.12E-07	5.34E-08	1.02E-07	2.86E-08	2.95E-07
Np-237	5.41E-08	5.41E-08	5.41E-08	5.41E-08	1.35E-07	1.68E-07	2.62E-07	2.30E-08	1.38E-07	5.40E-08	5.42E-08	4.11E-07	1.32E-07	4.11E-07	4.11E-07
Pb-210	1.00E-06	1.34E-06	7.23E-07	6.95E-07	6.63E-06	6.04E-07	8.68E-08	6.93E-07	4.71E-05	4.52E-07	4.54E-07	3.14E-06	3.29E-07	8.83E-07	4.71E-05
Pu-238	2.07E-09	2.07E-09	2.07E-09	2.07E-09	3.43E-09	1.50E-09	9.89E-09	1.28E-09	9.16E-09	2.07E-09	2.07E-09	2.79E-09	2.56E-09	2.79E-09	9.89E-09
Pu-239	1.41E-05	1.41E-05	1.41E-05	1.41E-05	2.34E-05	1.02E-05	6.73E-05	8.69E-06	6.24E-05	1.41E-05	1.41E-05	1.90E-05	1.75E-05	1.90E-05	6.73E-05
Pu-240	8.21E-06	8.21E-06	8.21E-06	8.21E-06	1.36E-05	5.93E-06	3.92E-05	5.07E-06	3.63E-05	8.21E-06	8.21E-06	1.11E-05	1.02E-05	1.11E-05	3.92E-05
Pu-241	7.32E-17	7.32E-17	7.32E-17	7.32E-17	1.21E-16	5.01E-17	3.49E-16	4.52E-17	3.23E-16	7.31E-17	7.33E-17	9.86E-17	9.07E-17	9.85E-17	3.49E-16
Ra-226	1.30E-04	1.30E-04	1.37E-04	1.30E-04	3.28E-04	3.14E-04	1.70E-04	1.42E-04	7.27E-04	9.63E-05	1.10E-04	8.94E-05	3.28E-04	9.08E-06	7.27E-04
Ra-228	2.64E-26	2.76E-26	2.80E-26	2.76E-26	7.15E-26	2.93E-26	2.79E-26	2.75E-26	6.40E-27	1.56E-26	6.57E-26	2.56E-26	7.21E-26	2.06E-26	7.21E-26
Sr-90	3.42E-12	2.36E-13	1.67E-13	3.99E-13	6.89E-14	1.28E-14	2.19E-14	5.11E-14	1.22E-12	5.47E-13	5.22E-13	1.22E-14	2.26E-15	1.54E-13	3.42E-12
Tc-99	2.50E-08	3.88E-08	1.82E-08	1.82E-06	2.41E-08	2.46E-08	2.46E-08	1.35E-06	1.26E-06	2.50E-08	2.50E-08	1.35E-06	2.50E-08	1.82E-08	1.82E-06
Th-228	3.61E-27	3.72E-27	3.71E-27	3.72E-27	2.51E-26	1.98E-26	1.98E-26	8.60E-26	1.99E-25	1.88E-27	7.84E-27	3.33E-26	2.49E-26	4.49E-27	1.99E-25
Th-230	1.05E-09	1.05E-09	1.05E-09	1.05E-09	2.36E-08	2.36E-08	2.36E-08	1.17E-07	2.77E-07	3.28E-10	3.43E-10	4.29E-08	2.36E-08	2.90E-09	2.77E-07
Th-232	5.70E-11	5.70E-11	5.70E-11	5.70E-11	1.29E-09	1.29E-09	1.29E-09	6.38E-09	1.51E-08	1.78E-11	1.85E-11	2.34E-09	1.29E-09	1.58E-10	1.51E-08
U-234	7.60E-09	7.60E-09	8.25E-09	8.25E-09	1.34E-07	1.34E-07	1.34E-07	2.21E-07	1.08E-06	1.62E-09	1.70E-09	1.07E-07	1.34E-07	1.03E-07	1.08E-06
U-235	1.80E-09	1.84E-09	1.89E-09	1.89E-09	1.30E-08	1.14E-08	1.14E-08	1.79E-08	8.05E-08	6.91E-10	2.90E-09	9.25E-09	1.30E-08	8.63E-09	8.05E-08
U-238	4.70E-09	4.70E-09	5.10E-09	5.10E-09	8.31E-08	8.30E-08	8.30E-08	1.37E-07	6.66E-07	1.00E-09	1.04E-09	6.64E-08	8.31E-08	6.38E-08	6.66E-07
Total	**4.03E-04**	**4.04E-04**	**4.11E-04**	**7.10E-04**	**4.54E-04**	**4.10E-04**	**3.88E-04**	**6.72E-04**	**9.52E-04**	**3.68E-04**	**3.97E-04**	**1.67E-04**	**4.34E-04**	**9.35E-05**	**1.81E-03**

Table A.6: Dose Rates to Freshwater Non-human Biota for Discharges to the Drigg Stream (μGy h^{-1})

Radio-nuclide	Amphibian	Bird	Gastropod	Benthic fish	Bivalve mollusc	Crustacean	Insect larvae	Mammal	Pelagic fish	Phytoplankton	Vascular plant	Zooplankton	Maximum
Am-241	9.67E-07	9.67E-07	1.52E-04	2.14E-04	2.84E-04	1.20E-04	9.81E-03	9.67E-07	8.70E-07	1.93E-02	2.10E-03	1.93E-04	1.93E-02
C-14	3.85E-04	3.98E-04	3.85E-04	2.51E-04	3.85E-04	3.85E-04	3.85E-04	3.98E-04	2.51E-04	5.37E-08	2.34E-04	2.03E-04	3.98E-04
Cl-36	3.79E-03	3.79E-03	2.17E-03	3.79E-03	2.31E-03	1.60E-03	1.60E-03	3.79E-03	3.79E-03	4.62E-05	1.15E-02	8.34E-03	1.15E-02
Cm-242	3.45E-13	5.18E-12	1.14E-11	5.18E-12	1.14E-11	3.35E-12	3.80E-11	5.18E-12	5.18E-12	6.66E-10	1.04E-11	6.66E-10	6.66E-10
Cm-243	6.76E-22	1.00E-20	2.27E-20	1.04E-20	2.24E-20	6.97E-21	7.51E-20	1.00E-20	1.00E-20	1.30E-18	2.07E-20	1.30E-18	1.30E-18
Cm-244	3.66E-24	5.50E-23	1.21E-22	5.50E-23	1.21E-22	3.56E-23	4.03E-22	5.50E-23	5.50E-23	7.07E-21	1.10E-22	7.07E-21	7.07E-21
Co-60	4.83E-22	3.05E-21	2.14E-18	1.99E-18	2.14E-18	2.14E-18	4.28E-18	4.18E-21	2.68E-21	4.32E-23	2.14E-18	1.01E-21	4.28E-18
Cs-135	1.52E-07	4.90E-08	5.33E-08	1.04E-07	1.03E-08	2.23E-07	2.74E-07	1.52E-07	1.16E-07	1.62E-11	9.35E-08	2.35E-08	2.74E-07
Cs-137	1.05E-10	4.29E-11	1.73E-09	1.53E-09	1.60E-09	1.98E-09	3.89E-09	1.47E-10	9.62E-11	3.54E-14	1.92E-09	8.95E-12	3.89E-09
H-3	3.21E-18	3.21E-18	3.21E-18	3.21E-18	3.21E-18	3.21E-18	3.21E-18	3.21E-18	3.21E-18	1.34E-18	3.21E-18	3.21E-18	3.21E-18
I-129	3.32E-05	3.63E-05	1.64E-05	5.59E-05	1.50E-05	1.07E-04	1.19E-04	3.79E-05	4.91E-05	2.66E-07	8.35E-05	3.11E-04	3.11E-04
Nb-94	5.76E-07	9.62E-07	6.67E-03	5.92E-03	6.44E-03	6.97E-03	1.38E-02	1.26E-06	9.19E-07	1.87E-08	6.97E-03	1.29E-06	1.38E-02
Ni-63	2.69E-06	2.69E-06	1.73E-04	2.72E-06	1.72E-04	1.59E-05	1.70E-05	2.69E-06	2.69E-06	2.20E-08	2.70E-06	1.33E-04	1.73E-04
Np-237	4.91E-06	4.91E-06	2.68E-05	4.91E-06	2.68E-05	3.64E-05	6.61E-04	4.91E-06	4.91E-06	1.32E-03	1.39E-04	1.49E-05	1.32E-03
Pb-210	1.58E-06	1.65E-06	2.75E-04	5.67E-06	1.82E-05	6.95E-05	2.64E-04	1.65E-06	1.65E-06	7.14E-09	1.05E-04	5.94E-05	2.75E-04
Pu-238	2.04E-08	1.77E-10	7.37E-08	5.58E-09	7.32E-08	9.93E-08	1.01E-07	2.04E-08	5.31E-09	5.22E-07	2.32E-07	3.98E-08	5.22E-07
Pu-239	1.39E-04	1.20E-06	4.97E-04	3.72E-05	4.96E-04	6.68E-04	6.74E-04	1.39E-04	3.61E-05	3.55E-03	1.57E-03	2.71E-04	3.55E-03
Pu-240	8.07E-05	7.02E-07	2.92E-04	2.21E-05	2.90E-04	3.94E-04	4.01E-04	8.07E-05	2.11E-05	2.07E-03	9.20E-04	1.58E-04	2.07E-03
Pu-241	7.19E-16	6.25E-18	2.89E-15	4.08E-16	2.83E-15	3.84E-15	4.24E-15	7.19E-16	1.87E-16	1.42E-15	9.40E-15	1.41E-15	9.40E-15
Ra-226	1.07E-04	1.14E-04	1.35E-03	1.83E-04	2.09E-03	2.15E-03	2.25E-03	1.14E-04	1.14E-04	1.52E-03	2.56E-03	1.50E-03	2.56E-03
Ra-228	1.43E-27	1.70E-27	2.52E-25	2.06E-25	2.52E-25	3.02E-25	5.82E-25	1.85E-27	1.66E-27	4.61E-29	2.95E-25	8.29E-27	5.82E-25
Sr-90	9.33E-14	9.92E-14	2.43E-12	2.93E-13	1.95E-12	4.53E-12	8.52E-12	1.01E-13	9.92E-14	6.01E-15	4.07E-12	8.23E-14	8.52E-12
Tc-99	4.68E-06	4.68E-06	2.81E-06	4.68E-06	2.81E-06	1.42E-06	1.44E-06	4.68E-06	4.68E-06	1.17E-07	1.34E-04	2.03E-06	1.34E-04
Th-228	1.10E-25	1.09E-25	4.94E-23	4.09E-23	4.49E-23	6.48E-23	1.30E-22	1.09E-25	1.09E-25	4.07E-24	6.10E-23	2.04E-24	1.30E-22
Th-230	1.55E-07	1.55E-07	3.95E-07	2.70E-07	3.13E-07	5.82E-07	1.00E-06	1.55E-07	1.55E-07	5.63E-06	2.22E-06	2.81E-06	5.63E-06
Th-232	8.44E-09	8.44E-09	2.00E-08	1.27E-08	1.54E-08	3.07E-08	5.31E-08	8.44E-09	8.44E-09	3.07E-07	1.20E-07	1.54E-07	3.07E-07
U-234	2.27E-06	2.27E-06	1.36E-05	2.27E-06	1.36E-05	3.79E-05	3.79E-05	2.27E-06	2.27E-06	9.10E-06	2.20E-04	3.64E-06	2.20E-04
U-235	1.70E-07	1.70E-07	1.02E-06	1.71E-07	1.02E-06	2.86E-06	2.86E-06	1.68E-07	1.70E-07	6.59E-07	1.66E-05	2.75E-07	1.66E-05
U-238	1.41E-06	1.41E-06	8.44E-06	1.41E-06	8.44E-06	2.34E-05	2.34E-05	1.41E-06	1.41E-06	5.63E-06	1.36E-04	2.25E-06	1.36E-04
Total	**4.56E-03**	**4.36E-03**	**1.20E-02**	**1.05E-02**	**1.26E-02**	**1.26E-02**	**3.00E-02**	**4.58E-03**	**4.28E-03**	**2.78E-02**	**2.67E-02**	**1.12E-02**	**5.57E-02**

A.3 Migration in Groundwater and Well Abstraction

Comparable results to those given in Section A.1 for natural groundwater discharge have also been obtained for well abstraction, with subsequent use of the water for irrigation. Relevant results are shown in Table A.7.

These results show a maximum dose rate of 3.62 10^{-2} µGy h^{-1} and with less than one order of magnitude variation between the least and most highly exposed reference organisms.

It is also of interest to examine the key contributing radionuclides for the natural discharge and irrigation pathways. This is done in Table A.8.

In general, the poorly sorbed radionuclides, C-14, Cl-36 and I-129 dominate the assessed impacts. However, for terrestrial soils by the Drigg Stream and the Lower Irt, more highly sorbed Ra-226 can also be of significance. For the Drigg Stream, actinide contributions are also of some significance. It is thought that this is due to shorter transport times in the geosphere for this pathway. The dominant radionuclides in each case are similar to those identified in the radiological impact assessment relating to humans.

Table A.7: Dose Rates to Terrestrial Non-human Biota for Irrigation of the Terrestrial Environment (μGy h^{-1})

Radio-nuclide	Amphibian	Bird	Gastropod	Bird egg	Detritivorous invertebrate	Flying insects	Grasses & Herbs	Lichen & bryophytes	Mammal (Deer)	Mammal (Rat)	Reptile	Shrub	Soil Invertebrate (worm)	Tree	Maximum
Am-241	1.08E-06	1.08E-06	5.27E-06	1.08E-06	2.67E-06	3.37E-06	1.34E-07	2.74E-06	1.08E-06	1.09E-06	1.08E-06	1.34E-07	2.65E-06	4.43E-09	5.27E-06
C-14	3.00E-02	3.11E-02	9.64E-03	2.00E-02	9.64E-03	9.64E-03	2.17E-02	2.17E-02	3.11E-02	3.11E-02	3.11E-02	2.17E-02	9.64E-03	2.24E-02	3.11E-02
Cl-36	1.06E-03	1.06E-03	2.36E-05	1.06E-03	4.05E-05	4.04E-05	2.43E-03	1.19E-04	1.06E-03	1.06E-03	1.06E-03	1.47E-04	2.54E-05	2.15E-04	2.43E-03
Cm-242	1.14E-10	1.14E-10	3.83E-10	1.14E-10	3.83E-10	3.83E-10	7.79E-13	2.89E-10	1.14E-10	1.14E-10	1.14E-10	2.61E-11	3.83E-10	2.61E-11	3.83E-10
Cm-243	1.05E-15	1.04E-15	3.49E-15	1.04E-15	3.52E-15	3.49E-15	2.44E-17	2.62E-15	1.05E-15	1.06E-15	1.04E-15	2.53E-16	3.52E-15	2.53E-16	3.52E-15
Cm-244	1.76E-16	1.76E-16	5.93E-16	1.76E-16	5.93E-16	5.93E-16	1.20E-18	4.47E-16	1.76E-16	1.76E-16	1.76E-16	4.04E-17	5.93E-16	4.04E-17	5.93E-16
Co-60	1.05E-16	1.13E-16	1.01E-16	1.06E-16	2.62E-16	1.01E-16	9.68E-17	2.40E-18	1.03E-16	2.52E-16	1.03E-16	1.02E-16	2.62E-16	8.12E-17	2.62E-16
Cs-135	4.29E-10	6.00E-10	3.42E-11	2.40E-11	1.04E-10	4.29E-11	5.55E-10	4.37E-09	2.30E-09	2.30E-09	2.87E-09	3.18E-09	7.15E-11	1.31E-10	4.37E-09
Cs-137	1.81E-10	2.40E-10	1.19E-10	1.09E-10	3.09E-10	1.21E-10	1.96E-10	5.85E-10	9.80E-10	7.29E-10	6.83E-10	6.32E-10	2.96E-10	1.35E-10	9.80E-10
H-3	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.36E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06	2.52E-06
I-129	4.71E-06	5.12E-06	2.20E-06	1.80E-03	4.00E-06	3.43E-06	1.95E-06	3.81E-06	5.53E-06	5.41E-06	4.86E-06	1.88E-06	2.49E-06	2.10E-06	1.80E-03
Nb-94	2.63E-11	2.76E-11	2.44E-11	3.06E-11	6.49E-11	2.44E-11	2.40E-11	1.10E-13	2.15E-11	6.30E-11	2.54E-11	2.24E-11	6.42E-11	2.06E-11	6.49E-11
Ni-63	1.33E-09	1.33E-09	3.30E-10	1.33E-09	1.59E-10	1.54E-10	3.48E-09	1.60E-09	1.33E-09	1.33E-09	1.33E-09	6.30E-10	1.21E-09	3.37E-10	3.48E-09
Np-237	2.37E-06	2.37E-06	1.15E-05	2.37E-06	5.90E-06	7.37E-06	1.01E-06	6.06E-06	2.37E-06	2.38E-06	2.37E-06	1.80E-05	5.80E-06	1.80E-05	1.80E-05
Pb-210	7.81E-07	4.21E-07	5.06E-08	4.05E-07	3.86E-06	3.52E-07	4.04E-07	2.74E-05	2.63E-07	2.64E-07	5.84E-07	1.83E-06	1.92E-07	5.14E-07	2.74E-05
Pu-238	4.56E-10	4.56E-10	2.18E-09	4.56E-10	7.56E-10	3.29E-10	2.81E-10	2.02E-09	4.56E-10	4.56E-10	4.56E-10	6.14E-10	5.65E-10	6.14E-10	2.18E-09
Pu-239	1.20E-05	1.20E-05	5.71E-05	1.20E-05	1.98E-05	8.64E-06	7.38E-06	5.29E-05	1.20E-05	1.20E-05	1.20E-05	1.61E-05	1.48E-05	1.61E-05	5.71E-05
Pu-240	4.67E-06	4.67E-06	2.23E-05	4.67E-06	7.73E-06	3.37E-06	2.88E-06	2.06E-05	4.67E-06	4.67E-06	4.67E-06	6.28E-06	5.78E-06	6.28E-06	2.23E-05
Pu-241	9.80E-16	9.80E-16	4.67E-15	9.80E-16	1.62E-15	6.70E-16	6.05E-16	4.33E-15	9.79E-16	9.81E-16	9.80E-16	1.32E-15	1.21E-15	1.32E-15	4.67E-15
Ra-226	1.07E-04	1.13E-04	1.41E-04	1.07E-04	2.70E-04	2.59E-04	1.17E-04	6.00E-04	7.95E-05	9.10E-05	1.07E-04	7.38E-05	2.70E-04	7.49E-06	6.00E-04
Ra-228	5.37E-21	5.43E-21	5.42E-21	5.37E-21	1.39E-20	5.68E-21	5.35E-21	1.24E-21	3.02E-21	1.28E-20	5.12E-21	4.97E-21	1.40E-20	4.01E-21	1.40E-20
Sr-90	3.73E-09	2.65E-09	3.47E-10	6.31E-09	1.09E-09	2.03E-10	8.08E-10	1.93E-08	8.66E-09	8.26E-09	5.40E-08	1.94E-10	3.57E-11	2.43E-09	5.40E-08
Tc-99	3.35E-07	1.57E-07	2.12E-07	1.57E-05	2.08E-07	2.12E-07	1.17E-05	1.09E-05	2.16E-07	2.16E-07	2.16E-07	1.17E-05	2.16E-07	1.57E-07	1.57E-05
Th-228	9.77E-21	9.75E-21	5.19E-20	9.77E-21	6.59E-20	5.19E-20	2.26E-19	5.21E-19	4.94E-21	2.06E-20	9.48E-21	8.73E-20	6.54E-20	1.18E-20	5.21E-19
Th-230	2.61E-10	2.61E-10	5.89E-09	2.61E-10	5.90E-09	5.89E-09	2.92E-08	6.90E-08	8.18E-11	8.56E-11	2.61E-10	1.07E-08	5.90E-09	7.22E-10	6.90E-08
Th-232	5.85E-11	5.85E-11	1.32E-09	5.85E-11	1.32E-09	1.32E-09	6.55E-09	1.55E-08	1.83E-11	1.90E-11	5.85E-11	2.40E-09	1.32E-09	1.62E-10	1.55E-08
U-234	3.57E-07	3.88E-07	6.31E-06	3.88E-07	6.31E-06	6.31E-06	1.04E-05	5.06E-05	7.63E-08	7.97E-08	3.57E-07	5.04E-06	6.31E-06	4.85E-06	5.06E-05
U-235	5.22E-08	5.36E-08	3.22E-07	5.36E-08	3.68E-07	3.22E-07	5.06E-07	2.28E-06	1.96E-08	8.20E-08	5.10E-08	2.62E-07	3.68E-07	2.44E-07	2.28E-06
U-238	3.72E-07	4.04E-07	6.57E-06	4.04E-07	6.58E-06	6.57E-06	1.08E-05	5.27E-05	7.94E-08	8.21E-08	3.72E-07	5.25E-06	6.58E-06	5.05E-06	5.27E-05
Total	**3.12E-02**	**3.23E-02**	**9.92E-03**	**2.30E-02**	**1.00E-02**	**9.98E-03**	**2.43E-02**	**2.26E-02**	**3.23E-02**	**3.23E-02**	**3.23E-02**	**2.20E-02**	**9.98E-03**	**2.27E-02**	**3.62E-02**

Table A.8: Dominant Radionuclides for Different Groundwater-mediated Pathways

Environment and Biota	Dominant Radionuclides							Total Dose Rate (µGy h^{-1})
Beach Terrestrial Biota	C-14							1.70E-03
Foreshore and Local Coastal Waters: Marine Biota	C-14							4.22E-04
Lower Irt: Terrestrial Biota	C-14	Ra-226	Cl-36	I-129				5.72E-07
Lower Irt: Freshwater Biota	C-14							2.93E-04
Drigg Stream: Terrestrial Biota	Ra-226	Cl-36	I-129	Am-241	Pu-239	Pb-210	Pu-240	1.81E-03
Drigg Stream: Freshwater Biota	Am-241	Nb-94	Cl-36	Pu-239	Ra-226	Pu-240	Np-237	5.57E-02
Irrigated Soil: Terrestrial Biota	C-14	Cl-36						3.62E-02

A.4 References for Appendix A

Thorne MC and Schneider S, *Assessment of the Impacts on Non-human Biota for the LLWR 2011 ESC*, Serco Report SERCO/TCS/00435/01 Issue 2, April 2011.

Appendix B Assessment Results for the Coastal Erosion Pathway for the EDA

B.1 Comparison of Activity Concentrations

In order to establish the potential impact on biota of the EDA in contrast to the RDA for the coastal erosion pathway a comparison the activity concentrations in the environmental media of interest has been carried out. This approach is appropriate as doses to biota previously established and reported in the ESC Non-human Biota Assessment report (Thorne and Schneider, 2011) can be scaled directly by the activity concentrations recalculated for the EDA case.

The activity concentrations in the cliff, beach, foreshore, sediments and seawater for the EDA case, reported in the EDA radiological assessment report for coastal erosion (Parton and Towler, 2011) have been compared with those for the RDA case reported in the coastal erosion radiological assessment report (Towler *et al.*, 2011).

This comparison is shown in Table B.1. Table B.2 shows a comparison of the time of maximum impact.

Table B.1: Ratio of the Maximum Concentration in the EDA Case to the Maximum Concentration in the RDA Case for the Coastal Erosion Pathway

Radio-nuclide	Cliff	Beach	Foreshore	Local Offshore Sediments	St Bees to Ravenglass Sediments	Marine Water (Dissolved)	Marine Water (Dissolved plus Susp. Sediment)
Ac-227	8.17E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.89E-01	9.89E-01
Ag-108m	9.16E-01	9.04E-01	8.99E-01	8.99E-01	1.04E+00	1.03E+00	1.03E+00
Am-241	8.75E-01	8.86E-01	8.78E-01	8.78E-01	1.01E+00	9.98E-01	9.98E-01
Am-242m	8.65E-01	8.81E-01	8.73E-01	8.73E-01	1.00E+00	9.92E-01	9.92E-01
Am-243	8.15E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.89E-01	9.89E-01
C-14	**5.17E+00**	**1.81E+00**	**1.81E+00**	**1.81E+00**	**2.77E+00**	**1.89E+00**	**1.89E+00**
Cl-36	**1.31E+00**	9.63E-01	9.72E-01	9.72E-01	**1.32E+00**	**1.25E+00**	**1.25E+00**
Cm-242	8.65E-01	8.81E-01	8.73E-01	8.73E-01	1.00E+00	9.92E-01	9.92E-01
Cm-243	8.65E-01	8.81E-01	8.73E-01	8.73E-01	1.00E+00	9.98E-01	9.98E-01
Cm-244	8.89E-01	8.92E-01	8.85E-01	8.85E-01	1.01E+00	1.01E+00	1.01E+00
Cm-245	8.05E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.89E-01	9.89E-01
Cm-246	7.92E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.89E-01	9.89E-01
Cm-248	8.09E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.89E-01	9.89E-01
Cs-135	8.06E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.90E-01	9.91E-01
Cs-137	9.76E-01	9.29E-01	9.23E-01	9.23E-01	1.06E+00	1.06E+00	1.06E+00
I-129	8.09E-01	7.94E-01	7.82E-01	7.82E-01	1.01E+00	1.00E+00	1.00E+00
Mo-93	**3.24E+01**	**6.92E+00**	**7.34E+00**	**7.37E+00**	**1.01E+01**	**7.52E+00**	**7.52E+00**
Nb-93m	**4.84E+00**	**1.45E+00**	**1.47E+00**	**1.41E+00**	**1.20E+00**	**1.49E+00**	**1.49E+00**
Nb-94	**3.57E+00**	**1.16E+00**	**1.16E+00**	**1.16E+00**	**1.88E+00**	**1.46E+00**	**1.46E+00**
Ni-63	**1.26E+00**	1.04E+00	1.04E+00	1.04E+00	**1.21E+00**	**1.18E+00**	**1.18E+00**
Np-237	8.03E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.99E-01	9.99E-01
Pa-231	8.17E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.99E-01	9.99E-01
Pb-210	8.28E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.98E-01	9.98E-01
Pu-238	8.67E-01	8.82E-01	8.74E-01	8.74E-01	1.00E+00	9.94E-01	9.94E-01
Pu-239	8.14E-01	7.93E-01	7.81E-01	7.81E-01	1.00E+00	9.90E-01	9.90E-01
Pu-240	6.89E-01	7.95E-01	7.83E-01	7.83E-01	1.01E+00	1.01E+00	1.01E+00
Pu-241	8.05E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.89E-01	9.89E-01
Pu-242	7.78E-01	7.93E-01	7.80E-01	7.81E-01	1.00E+00	9.90E-01	9.90E-01
Pu-244	7.71E-01	7.92E-01	7.80E-01	7.74E-01	1.00E+00	9.89E-01	9.89E-01
Ra-226	8.28E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.97E-01	9.97E-01
Ra-228	7.55E-01	1.03E+00	1.01E+00	1.02E+00	1.00E+00	1.10E+00	1.10E+00
Se-79	8.02E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.90E-01	9.90E-01
Sr-90	1.01E+00	9.45E-01	9.40E-01	9.40E-01	1.08E+00	1.08E+00	1.08E+00
Tc-99	7.91E-01	7.93E-01	7.81E-01	7.81E-01	1.00E+00	1.00E+00	1.00E+00
Th-228	7.55E-01	1.03E+00	1.02E+00	1.02E+00	1.00E+00	1.06E+00	1.06E+00
Th-229	7.71E-01	7.92E-01	7.80E-01	7.75E-01	1.00E+00	9.84E-01	9.84E-01
Th-230	7.26E-01	9.24E-01	9.27E-01	9.47E-01	1.00E+00	1.05E+00	1.05E+00
Th-232	7.55E-01	1.03E+00	1.02E+00	1.02E+00	1.00E+00	1.06E+00	1.06E+00
U-233	7.75E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	1.00E+00	1.00E+00
U-234	7.36E-01	9.19E-01	9.05E-01	9.27E-01	1.00E+00	1.00E+00	1.00E+00
U-235	7.36E-01	9.20E-01	9.06E-01	9.29E-01	1.00E+00	1.00E+00	1.00E+00
U-236	7.50E-01	7.97E-01	7.86E-01	7.86E-01	1.02E+00	1.01E+00	1.01E+00
U-238	7.35E-01	9.19E-01	9.05E-01	9.27E-01	1.00E+00	1.00E+00	1.00E+00
Zr-93	7.76E-01	7.92E-01	7.80E-01	7.80E-01	1.00E+00	9.85E-01	9.85E-01

Table B.2: Difference in the Time of Maximum Concentration between the EDA Case and the RDA Case (negative values indicate that the maximum in the EDA case occurs earlier)

Radio-nuclide	Cliff	Beach	Foreshore	Local Offshore Sediments	St Bees to Ravenglass Sediments	Marine Water (Dissolved)	Marine Water (Dissolved plus Susp. Sediment)
Ac-227	**-190**	0	0	-10	0	0	0
Ag-108m	0	0	0	0	0	0	0
Am-241	0	0	0	0	0	0	0
Am-242m	0	0	0	0	0	0	0
Am-243	**-190**	0	0	0	0	0	0
C-14	**570**	**540**	**540**	**540**	**530**	-10	-10
Cl-36	**-190**	0	0	**-20**	**50**	0	0
Cm-242	0	0	0	0	0	0	0
Cm-243	0	0	0	0	0	0	0
Cm-244	0	0	0	0	0	0	0
Cm-245	**-190**	0	0	0	0	0	0
Cm-246	**-190**	0	0	0	0	0	0
Cm-248	**-190**	-10	0	0	0	0	0
Cs-135	**-190**	10	0	0	0	-10	-10
Cs-137	0	0	0	0	0	0	0
I-129	**-190**	-10	0	0	10	0	0
Mo-93	**650**	**630**	**630**	**630**	**840**	**250**	**250**
Nb-93m	**650**	**-30**	**-30**	**-30**	10	-10	-10
Nb-94	**650**	0	-10	-10	**510**	0	0
Ni-63	0	0	0	0	10	0	0
Np-237	**-190**	0	**40**	0	0	0	0
Pa-231	**-190**	0	0	0	0	0	0
Pb-210	**-190**	0	0	0	0	0	0
Pu-238	0	0	0	0	0	0	0
Pu-239	**-190**	0	0	0	**20**	0	0
Pu-240	**240**	0	0	0	10	0	0
Pu-241	**-190**	0	0	0	0	0	0
Pu-242	**-190**	0	0	**30**	0	0	0
Pu-244	0	0	0	-10	**-20**	0	0
Ra-226	**-190**	0	0	0	0	-10	-10
Ra-228	**70**	**80**	**70**	**70**	0	10	10
Se-79	**-190**	0	0	0	0	0	0
Sr-90	0	0	0	0	0	0	0
Tc-99	**-190**	0	10	0	0	**20**	-10
Th-228	**70**	**80**	**70**	**70**	0	0	0
Th-229	0	0	0	-10	0	0	0
Th-230	-10	10	10	10	0	**70**	**70**
Th-232	**70**	**80**	**70**	**70**	0	0	0
U-233	**-30**	0	0	0	0	0	0
U-234	0	10	10	10	0	0	0
U-235	0	10	10	10	0	0	0
U-236	0	-10	**20**	-10	0	0	0
U-238	0	10	10	10	0	0	0
Zr-93	0	-10	0	-10	0	0	0

In Table B.1 ratios of more than 1.1 are highlighted in bold. It can be seen that concentrations in the EDA case are only increased over those for the RDA case for C-14, Cl-36, Mo-93, Nb-93m, Nb-94 and Ni-63. However, as illustrated in Table B.2, times of maximum impact have changed for rather more radionuclides. In Table B.2, shifts of more than 10 years (i.e. more than one model output time step) are highlighted in bold. The larger shifts, e.g. for Mo-93, are explicable because more than one period of significant release is projected and the change in time represents a change in which period gives the maximum concentration.

B.2 Implications for Dose Rates in Biota

In Appendix F of the ESC Non-human Biota Assessment report (Thorne and Schneider, 2011) it is stated that the ERICA Tool analysis indicates that particular attention should be given to types of organism associated with the cliff and storm beach, because these incur the highest dose rates. As dose rates to organisms associated with the storm beach are generally rather higher than those associated with the cliff, the relative importance of different radionuclides was examined by consideration of results for the storm beach.

For terrestrial organisms, the fractional contributions to the total dose rate by radionuclide are shown in Table B.3. Radionuclides contributing more than 0.01 of the total are shown in bold.

Table B.3: Fractional Contributions to the Total Dose Rate by Radionuclide for Exposure on the Storm Beach for Terrestrial Organisms

Radionuclide	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Mammal (Rat)	Reptile	Grasses & Herbs
Am-241	**3.51E-02**	**1.87E-02**	**4.28E-02**	**6.54E-02**	**3.58E-02**	**3.57E-02**	1.70E-03
C-14	**1.66E-01**	**5.66E-02**	**2.54E-02**	**3.08E-02**	**1.69E-01**	**1.69E-01**	**4.17E-02**
Cl-36	**4.33E-02**	**2.30E-02**	8.17E-04	9.89E-04	**4.41E-02**	**4.41E-02**	**3.88E-02**
Cm-242	1.58E-05	8.42E-06	2.64E-05	3.19E-05	1.61E-05	1.61E-05	4.24E-08
Cm-243	1.65E-14	8.79E-15	2.77E-14	3.33E-14	1.71E-14	1.68E-14	1.52E-16
Cm-244	1.25E-19	6.65E-20	2.08E-19	2.52E-19	1.27E-19	1.27E-19	3.35E-22
Cs-135	2.93E-06	6.24E-08	2.53E-07	1.26E-07	1.14E-05	1.43E-05	1.06E-06
Cs-137	8.21E-11	1.99E-11	5.24E-11	2.49E-11	2.55E-10	2.38E-10	2.64E-11
I-129	1.60E-05	2.99E-03	6.18E-06	6.42E-06	1.72E-05	1.54E-05	2.39E-06
Nb-94	1.55E-04	9.11E-05	1.80E-04	8.21E-05	3.59E-04	1.45E-04	5.28E-05
Ni-63	2.20E-06	1.17E-06	1.30E-07	1.53E-07	2.24E-06	2.24E-06	2.26E-06
Np-237	**4.28E-02**	**2.28E-02**	**5.27E-02**	**7.97E-02**	**4.37E-02**	**4.35E-02**	7.14E-03
Pb-210	9.78E-04	5.00E-04	4.44E-03	4.90E-04	6.25E-04	1.38E-03	3.68E-04
Pu-238	3.42E-05	1.82E-05	2.81E-05	1.48E-05	3.49E-05	3.48E-05	8.28E-06
Pu-239	**2.82E-01**	**1.50E-01**	**2.31E-01**	**1.22E-01**	**2.87E-01**	**2.87E-01**	**6.82E-02**
Pu-240	**3.58E-02**	**1.91E-02**	**2.94E-02**	**1.55E-02**	**3.65E-02**	**3.65E-02**	8.67E-03
Pu-241	2.25E-10	1.20E-10	1.85E-10	9.24E-11	2.30E-10	2.29E-10	5.46E-11
Ra-226	**3.27E-01**	**1.65E-01**	**3.86E-01**	**4.48E-01**	**2.67E-01**	**3.14E-01**	**1.33E-01**
Ra-228	**1.57E-02**	8.25E-03	**1.98E-02**	9.84E-03	**3.76E-02**	**1.51E-02**	6.06E-03
Se-79	3.93E-10	2.09E-10	4.54E-09	5.51E-09	4.00E-10	4.00E-10	1.37E-09
Sr-90	1.34E-11	1.70E-11	2.73E-12	6.17E-13	4.26E-11	2.78E-10	1.60E-12
Tc-99	9.61E-03	**5.11E-01**	6.29E-03	7.76E-03	**1.34E-02**	**1.34E-02**	**2.79E-01**
Th-228	**2.78E-02**	**1.48E-02**	**9.28E-02**	**8.88E-02**	**5.98E-02**	**2.75E-02**	**2.52E-01**
Th-230	6.91E-05	3.68E-05	7.72E-04	9.36E-04	2.31E-05	7.03E-05	3.03E-03
Th-232	6.91E-04	3.68E-04	7.74E-03	9.38E-03	2.29E-04	7.03E-04	**3.04E-02**
U-234	6.33E-03	3.37E-03	5.10E-02	6.18E-02	1.33E-03	5.94E-03	**6.65E-02**
U-235	8.58E-04	4.57E-04	2.91E-03	3.09E-03	1.34E-03	8.30E-04	3.18E-03
U-238	5.70E-03	3.03E-03	**4.59E-02**	**5.56E-02**	1.18E-03	5.34E-03	**5.99E-02**
Total	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00

There is a general consistency as to the important radionuclides. These are: Am-241, C-14, Cl-36, Np-237, Pu-239, Pu-240, Ra-226, Ra-228, Tc-99, Th-228, Th-232, U-234 and U-238.

Corresponding results for marine organisms are shown in Table B.4.

Table B.4: Fractional Contributions to the Total Dose Rate by Radionuclide for Exposure on the Storm Beach for Marine Organisms

Radio-nuclide	Benthic mollusc	Crustacean	Macroalgae	Sea anemones or true corals - colony	Sea anemones or true corals - polyp
Am-241	7.50E-04	7.88E-05	4.04E-05	4.06E-06	7.02E-06
C-14	**1.09E-02**	6.16E-03	2.94E-03	1.63E-03	1.63E-03
Cl-36	2.65E-03	1.40E-03	**1.15E-02**	4.56E-03	4.63E-03
Cm-242	1.27E-06	2.82E-08	1.61E-07	1.45E-08	1.46E-08
Cm-243	1.40E-15	7.18E-17	1.98E-16	2.41E-17	2.76E-17
Cm-244	1.00E-20	2.23E-22	1.27E-21	1.15E-22	1.15E-22
Cs-135	1.49E-08	4.74E-09	9.33E-09	1.07E-08	1.07E-08
Cs-137	1.08E-11	5.32E-12	3.90E-12	1.42E-12	1.61E-12
I-129	2.30E-06	5.29E-07	1.37E-04	8.84E-07	8.40E-07
Nb-94	3.84E-05	1.91E-05	1.33E-05	4.69E-06	5.33E-06
Ni-63	2.01E-06	9.45E-08	8.44E-08	1.63E-07	1.62E-07
Np-237	**8.96E-02**	**1.17E-02**	3.84E-03	**2.90E-02**	**2.90E-02**
Pb-210	1.32E-04	1.82E-04	1.06E-04	5.24E-05	5.97E-05
Pu-238	3.29E-06	2.61E-07	4.14E-06	1.10E-06	1.09E-06
Pu-239	**2.71E-02**	2.15E-03	**3.41E-02**	9.03E-03	9.02E-03
Pu-240	3.44E-03	2.74E-04	4.33E-03	1.15E-03	1.15E-03
Pu-241	2.17E-11	1.77E-12	2.72E-11	7.30E-12	7.21E-12
Ra-226	**5.90E-02**	**7.39E-02**	**2.70E-02**	**1.11E-01**	**1.12E-01**
Ra-228	4.55E-03	2.38E-03	1.65E-03	9.18E-04	9.12E-04
Se-79	2.11E-09	1.64E-09	3.28E-11	4.09E-10	4.08E-10
Sr-90	6.91E-11	4.48E-12	6.61E-12	7.80E-11	6.72E-11
Tc-99	**6.46E-01**	**8.72E-01**	**7.23E-01**	**2.13E-01**	**2.13E-01**
Th-228	7.87E-03	4.08E-03	3.57E-03	1.27E-03	1.42E-03
Th-230	6.41E-06	6.65E-06	8.25E-06	4.43E-06	4.45E-06
Th-232	6.39E-05	6.64E-05	8.27E-05	4.44E-05	4.46E-05
U-234	**7.60E-02**	**1.30E-02**	**9.64E-02**	**3.23E-01**	**3.23E-01**
U-235	3.55E-03	6.68E-04	4.33E-03	1.42E-02	**1.43E-02**
U-238	**6.85E-02**	**1.17E-02**	**8.68E-02**	**2.91E-01**	**2.91E-01**
Total	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00

In this case, a rather smaller set of radionuclides is of importance. These are: C-14, Cl-36, Np-237, Pu-239, Ra-226, Tc-99, U-234, U-235 and U-238. Of these, C-14, Cl-36, Np-237, Pu-239, Ra-226 and U-235 are of limited significance. For molluscs, crustaceans and macroalgae, Tc-99 dominates.

Thus, the change in maximum concentrations of Mo-93, Nb-93m, Nb-94 and Ni-63 in the EDA relative to the RDA are of little significance. Mo-93 and Nb-93m were judged to be radionuclides of minor significance and were not carried through into the ERICA Tool analyses, and the fractional contributions of Nb-94 and Ni-63 to total dose rates were never more than 4 10^{-4}. Thus, attention can be concentrated on the effects of changes in the peak concentrations of C-14 and Cl-36.

Cl-36 never makes a fractional contribution to the total dose rate of more than 0.05. Furthermore, the maximum increase in concentration is no more than 1.32 (it is 1.31 at the cliff, but there is a slight decrease in concentration for the beach). In the worst case, the increase in dose rates due to the change in inventory and distribution of Cl-36 in the wastes could be no more than 0.05×0.32 = 0.016. For the beach no increase is projected to arise. On this basis, any change in dose rates due to the change in inventory of Cl-36 can be neglected.

In the case of C-14, there is an increase in maximum concentration in the cliff by a factor of 5.17 and on the beach by a factor of 1.81. Fractional contributions of C-14 to the total dose rate for different types of organism in the context of the beach are given in Table B.5.

Table B.5: Fractional Contributions of C-14 to Dose Rates for Organism Types present on the Beach

Organism Type	Fractional Contribution	Organism Type	Fractional Contribution
Bird	1.66E-01	Grasses & Herbs	4.17E-02
Bird egg	5.66E-02	Benthic mollusc	1.09E-02
Detritivorous invertebrate	2.54E-02	Crustacean	6.16E-03
Flying insects	3.08E-02	Macroalgae	2.94E-03
Mammal (Rat)	1.69E-01	Sea anemones or true corals - colony	1.63E-03
Reptile	1.69E-01	Sea anemones or true corals - polyp	1.63E-03

The primary focus of interest is terrestrial organisms, since the fractional contributions to dose rates to marine organisms are never more than 0.0109. For, terrestrial organisms, fractional contributions at the beach are found to range up to a value of 0.169. Taken together with an increase in maximum concentration on the beach by a factor of 1.81, the overall dose rate to organisms that are resident on the beach could be increased by $0.81 \times 0.169 = 0.14$.

However, the situation is rather different for the cliff. The ESC Non-human Biota Assessment report (Thorne and Schneider, 2011) does not give fractional contributions by radionuclide at the cliff. However, the underlying results from the assessment have been inspected and the corresponding fractional contributions are given in Table B.6.

Table B.6: Fractional Contributions of C-14 to Dose Rates for Organism Types present on the Cliff

Bird	Bird egg	Detritivorous invertebrate	Flying insects	Mammal (Rat)	Reptile	Grasses & Herbs
1.45E-01	5.24E-02	1.68E-02	2.03E-02	1.35E-01	1.48E-01	2.13E-02

In this case, there is an increase in maximum concentration by a factor of 5.17 and the fractional contributions range up to 0.148. Thus, overall dose rates could be increased by $4.17 \times 0.148 = 0.62$.

These increases can be set in the context of the results presented in Appendix F of the ESC Non-human Biota Assessment report (Thorne and Schneider, 2011). Dose rates to terrestrial organisms on the cliff and beach are given in Table F.3 of that report and are reproduced here in Table B.7.

Table B.7: Dose Rates (μGy h^{-1}) for the Terrestrial Assessments

Location and Pathway	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Mammal (Rat)	Reptile	Grasses & Herbs
Cliff - External	6.86E-01	6.86E-01	1.84E+00	6.89E-01	1.72E+00	6.61E-01	6.73E-01
Cliff - Internal	4.79E+00	9.04E+00	1.28E+01	1.15E+01	4.16E+00	4.71E+00	2.32E+01
Cliff - Total	5.48E+00	9.73E+00	1.46E+01	1.21E+01	5.89E+00	5.37E+00	2.39E+01
Beach - External	4.91E-01	4.91E-01	1.32E+00	4.97E-01	1.23E+00	4.76E-01	4.81E-01
Beach - Internal	7.97E+00	1.54E+01	1.58E+01	1.36E+01	7.07E+00	7.84E+00	2.11E+01
Beach - Total	8.46E+00	1.59E+01	1.71E+01	1.41E+01	8.30E+00	8.31E+00	2.16E+01

The total dose rates can be recalculated with appropriate increases due to the enhanced contribution from C-14 as shown in Table B.8.

Table B.8 Revised Dose Rates for the Cliff and Beach

	Bird	Bird egg	Detritivorous invertebrate	Flying insects	Mammal (Rat)	Reptile	Grasses & Herbs
Cliff - Original Dose Rate (μGy h^{-1})	5.48E+00	9.73E+00	1.46E+01	1.21E+01	5.89E+00	5.37E+00	2.39E+01
Ratio of Inventories	5.17	5.17	5.17	5.17	5.17	5.17	5.17
Fractional contribution of C-14	1.45E-01	5.24E-02	1.68E-02	2.03E-02	1.35E-01	1.48E-01	2.13E-02
Cliff - Final Dose Rate (μGy h^{-1})	8.79E+00	1.19E+01	1.56E+01	1.31E+01	9.21E+00	8.68E+00	2.60E+01
Beach - Original Dose Rate (μGy h^{-1})	8.46E+00	1.59E+01	1.71E+01	1.41E+01	8.30E+00	8.31E+00	2.16E+01
Ratio of Inventories	1.81	1.81	1.81	1.81	1.81	1.81	1.81
Fractional contribution of C-14	1.66E-01	5.66E-02	2.54E-02	3.08E-02	1.69E-01	1.69E-01	4.17E-02
Beach - Final Dose Rate (μGy h^{-1})	9.60E+00	1.66E+01	1.75E+01	1.45E+01	9.44E+00	9.45E+00	2.23E+01

B.3 References for Appendix B

Thorne MC and Schneider S, *Assessment of the Impacts on Non-human Biota for the LLWR 2011 ESC*, Serco Report SERCO/TCS/00435/01 Issue 2, April 2011.

Parton N and Towler G, *Assessment Calculations for Coastal Erosion for the LLWR 2011 ESC (Extended Disposal Area)*, Quintessa Report QRS-1443ZF-R1 Version 2, April 2011.

Towler GH, Penfold JSS, Limer LMC and Paulley A, *Assessment Calculations for Coastal Erosion for the LLWR 2011 ESC*, Quintessa Report QRS-1443ZC-R1 Version 3, April 2011.