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ERICA Tier 1 Dose Assessment - to support a variation to Berkeley Site environmental permit (EPR/ZP3893SG)

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ERICA TIER 1 DOSE ASSESSMENT - TO SUPPORT A VARIATION TO BERKELEY SITE ENVIRONMENTAL PERMIT (EPR/ZP3893SG)

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SUMMARY

Berkeley Site is undertaking an environmental permit variation, subject to regulatory review. The variation will increase the annual aerial discharge limit for tritium from 20 to 2000 GBq. This is resulting from activities associated with the forthcoming MILWEP[1] facility, as well as waste retrieval, sorting and packing at the active waste vault.

This report assesses the radiological dose impacts to non-human biota in the terrestrial environment from potential site gaseous discharges at the proposed permit limits. This assessment has been made using the 'Environmental Risk from Ionising Contaminants: Assessment and Management' (ERICA) assessment tool. The purpose of this assessment is to determine if there is a possibility of significant impact to non-human biota from gaseous discharge of radionuclides at the limits proposed in the permit variation.

The results of the ERICA Tier 1 assessment show negligible dose risk to non-human biota from the new proposed radioactive gaseous limit. To provide an understanding of dose impacts for all site discharges, the site's existing aqueous radioactive discharge limits were also assessed (although these will not be subject to a proposed permit change). The results demonstrate that aqueous discharges from Berkeley site pose a negligible dose risk to non-human biota.

[1] Modular Intermediate Level Waste Encapsulation Plant

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1 INTRODUCTION

1.1 Background

Berkeley Site is being decommissioned, and is currently seeking a variation to its Environmental Permitting Regulations 2016 (EPR16) [1] permit. The variation proposed covers an increase to the authorised aerial tritium limit. The proposed decommissioning activities will result in an increased aerial discharge of tritium, and the limit is proposed to change from 20 to 2000GBq. The limit increase is associated with planned activities that include the further retrieval and subsequent encapsulation of Intermediate Level Waste (ILW) present at Berkeley Site. Specifically, this is associated with the commissioning of a new waste conditioning and encapsulation plant known as the Modular Intermediate Level Waste Encapsulation Plant (MILWEP).

To provide a holistic assessment of dose impacts to non-human biota from all Berkeley site discharges this report also includes an assessment of aqueous discharges. Similarly, the assessment will be carried out against the permit limits. However, the limits for aqueous discharges are not due to change as a result of the proposed permit variation.

There is a regulatory requirement to assess the impact of radioactive discharges to non-human biota, associated with the proposed increases to annual gaseous discharge limits on the site's EPR16 Permit, EPR/ZP3893SG [2]. Assessing the effects of radiation dose upon non-human organisms is necessary to preserve biological diversity, through assessment of risk to populations as a whole, rather than protecting individual members of populations. This helps to conserve species and protect the health and status of natural habitats and communities of living organisms.

The 'Environmental Risk from Ionising Contaminants: Assessment and Management' (ERICA) assessment tool Version 1.2.1 [3] has been used in this assessment. ERICA applies a three tiered integrated approach; Tier 1: Risk screening, Tier 2: Generic quantitative and Tier 3: Detailed quantitative. This allows for application of a risk assessment relevant to the level of detail available and which is proportionate to the nature and complexity of the risk being addressed and consistent with decision-making needs.

This report documents the findings of two Tier 1 ERICA assessments for the gaseous and aqueous discharges of radioactive waste from Berkeley site. A terrestrial assessment was carried out for the gaseous discharge limits seen in Table 1, and a marine assessment for the aqueous discharge limits in Table 2;

- ***Terrestrial ecosystems*** – to identify impacts to non-human biota in localised terrestrial receptors, from exposure to gaseous radioactive waste; and
- ***Marine ecosystems*** – to identify impacts to non-human biota in localised marine receptors in the Severn estuary, from exposure to aqueous radioactive waste.

1.2 Site Description

Berkeley Site is a twin reactor Magnox power station currently undergoing decommissioning. The site covers an area of 11 hectares and is situated on the eastern bank of the River Severn, close to the town of Berkeley in Gloucestershire.

The western boundary of Berkeley Site is adjacent to the Severn Estuary Site of Special Scientific Interest (SSSI). The Upper Severn Estuary (6 km north-north-east of Berkeley Site) is also a SSSI. Both sites have also been designated as Special Protection Areas under the European Union (EU) Bird Directive and Wetlands of International Importance under the Ramsar Convention.

1.3 Purpose & Scope

The purpose of this assessment is to determine the dose risk to non-human organisms from exposure to site gaseous and aqueous discharges. The ERICA dose assessment approach is a recognised tool for non-human radioactive dose assessment.

The assessment is based upon the new proposed gaseous annual limits presented in Table 1, and the existing aqueous limits (which will remain the same) in Table 2. The ERICA dose rate screening value of 10 $\mu Gy.h^{-1}$ has been used to provide an initial indication of whether populations of non-human organisms and their habitats could be adversely affected by the proposed gaseous and aqueous waste permit limits and identify whether more detailed assessment is required.

Table 1 - *Berkeley Site new proposed limits for gaseous discharges.*

Radionuclide or group of nuclides	Annual limit (GBq)
Tritium (H-3)	2,000
Carbon-14	5
Beta-emitting radionuclides associated with particulate matter	0.02

Table 2 - *Berkeley Site existing permitted limits for aqueous discharges* [2].

Radionuclide or group of nuclides	Annual limit (GBq)
Tritium (H-3)	1,000
Caesium-137	200
"Other radionuclides"	200

2 METHODOLOGY - DOSE ASSESSMENT TO NON-HUMAN BIOTA

ERICA uses a tiered approach to assess the dose impacts of radionuclides to non-human biota. Tier 1 is designed to be simple and conservative, whereby the user inputs media activity concentrations (in soil, water, sediment) which are compared to pre-calculated concentrations estimated to give rise to the screening dose rate for the most exposed organism (Limiting Reference Organism - LRO) for each radionuclide.

Tier 1 assessments aim to identify sites of negligible concern, such that these are removed from further assessment with a high degree of confidence. The sites that are not screened out at this stage can be assessed in more detail using Tier 2 and Tier 3 assessments.

A conservative ERICA dose rate screening value of 10 $\mu Gy.h^{-1}$is provided in the ERICA assessment tool to give a threshold for assessment. This has been derived from exposure-response information. It is this screening dose rate which has been used in this assessment for the Berkeley discharges.

It is considered that for initial assessments this screening value is sufficiently cautious, that if not exceeded populations of non-human organisms and their habitats are unlikely to be adversely affected. If the screening value is exceeded it is expected that more site specific data will be required to generate a more realistic assessment.

At Tier 1 the radionuclide activity concentrations (Mn) in environmental media are compared with Environmental Media Concentration Limits (EMCLs). EMCLs define the radionuclide concentrations in environmental media at which an organism would be expected to receive a dose rate equal to the screening level. This produces a risk quotient for each specific radionuclide selected for inclusion in the assessment. The risk quotient (RQ) (unit-less) is defined by:

$$RQ_n = \frac{M_n}{EMCL_n}$$

RQn = Risk quotient for radionuclide "n";

M_n = measured activity concentration for radionuclide "n" in medium M in $Bq.l^{-1}$ for water, Bq kg^{-1} for soil or seabed sediment or $Bq.m^{-3}$ for air;

$EMCL_n$ = Environmental Media Concentration Limit for radionuclide "n" (same units as Mn).

A single EMCL value is provided for each combination of radionuclide and environmental media (water, seabed sediment and soil). These correspond to the lowest (limiting media concentration) values taken from across the whole suite of ERICA reference organisms (i.e. which will return the highest radionuclide specific RQ value) for each individual radionuclide. The RQs are then summed for all radionuclides included in the assessment.

When the RQs are summed across the radionuclides present in a given situation, the most exposed organism or LRO is identified, however this may not be the same for each radionuclide.

If the sum of the risk quotients is <1, then it can be assured that there is a very low probability that the assessment dose rate to any organism exceeds the screening level (10 $\mu Gy.h^{-1}$) and therefore the risk to non-human biota can be considered negligible. The site may then be 'screened out' from further assessment. If the RQ value exceeds 1, then further evaluation may be required.

2.1 Determining input data for the ERICA Tier 1 assessment

The input data required for running a Tier 1 ERICA assessment are the relevant environmental media activity concentrations values ($Bq.m^{-3}$ air, Bq/m^{-3} soil/sediment and Bq/l water) for each specific radionuclide being discharged.

Therefore it was necessary to determine the relevant media concentration values for each specific radionuclide listed on the Berkeley permit [2]. Before this could be done a representative(s) for the non-specific radionuclide groups for both gaseous and aqueous needed to be identified. Section 2.1.1 and 2.1.2 below summarise how the input data for the ERICA Tier 1 assessments were obtained, which is provided in full detail in Appendix A. Determining the input data involved the use of both PCCREAM08 [4] and the ERICA assessment tool.

2.1.1 Determining representatives for Non- Specific Radionuclide groups

The Berkeley site permit [2] identifies limits for "Beta-emitting radionuclides" (gaseous) and "other radionuclides" (aqueous) which are non-specific radionuclide groups.

To run an ERICA assessment, a specific radionuclide must be selected, and so representative radionuclide(s) for each group had to first be determined.

To define the representative radionuclide(s) for the non-specific gaseous and aqueous groups, two methods were available:

- **Worst-case analogue (most conservative)** – Using a known fingerprint of radionuclides (which were assessed in the Article 37 submission [5]) that may contribute towards the group, it is assumed that the maximum permitted limit for that group is entirely comprised of the radionuclide with the highest dose consequence to non-human biota. This is not a realistic worst-case, it is highly pessimistic representation of the discharge to be assessed. This method is consistent with the approach used to calculate dose impacts to humans in the Article 37 submission [5] and is the 'first screen' approach for this non-human biota assessment.

- **Fingerprint scale-up** – If the 'worst case' representative discharge exceeds the ERICA 10 µGy.h-1 screening level, then a more realistic representation of the discharge is used to input to the Tier 1 assessment. Still highly conservative, as it assumes the maximum permitted (or proposed) limit is discharged, this method proportionately scales all of the radionuclides which could be in the discharge using fingerprint data [6].

Full details of how representative radionuclides for the non-specific groups listed on the Berkeley permit is detailed in Appendix A, but are summarised in Table 3 below.

Table 3 - *Radionuclides to represent the non-specific groups in the Tier 1 ERICA assessment.*

Radioactive waste type	Radionuclide group name	Appropriate Representative Method	Representative radionuclide (s) for input to the Tier 1 assessment
Gaseous	'Beta-emitting radionuclides associated with particulate matter'	Worst-Case analogue	Cs-134
Aqueous	"Other radionuclides"	Fingerprint scale-up	Am-241, Cm-243, Cm-244, Pu-238, Pu-239, Pu-240, Pu-241, Sr-90

2.1.2 Determining media concentration values to input to the ERICA Tier 1 assessment

For both the aqueous and gaseous releases, the relevant media concentration values (Bq/m^3 for soil / sediment and Bq/l for water) had to be obtained for each radionuclide which could be input to the ERICA Tier 1 assessment. The media concentration values were calculated using PC-CREAM08 using the maximum permitted (or proposed) discharge release rates. Media concentration values from gaseous discharges

The PC-CREAM08 PLUME model calculates the atmospheric dispersion of gaseous radionuclides using an input of activity release rates ($Bq.yr^{-1}$). The proposed annual permit limit values shown in Table 1 were given for the H-3, C-14 and Cs-134 (to represent Beta-emitting radionuclides associated with particulate matter)[2]. PC-CREAM08 provides results based upon two variables; distance from stack and meteorological stability category. The highest (most conservative) media activity concentrations (Bq/m^{-3}) were taken from the PCCREAM08 outputs from each radionuclide (Table 4 below). The media concentration values which are to be used in the ERICA Tier 1 assessment are summarised in Table 4 below.

Table 4 - *Media concentration values used for gaseous discharges.*

Radionuclide	*Discharge Rate (Bq/y)*	*Media conc. Value Bq m^{-3}*
H-3	2.00E+12	8.74E-01
C-14	5.00E+9	2.19E-03
Beta-emitting radionuclides associated with particulate matter' (*Represented by C-134)*	2.00E+7	8.74E-06

[2] As described in 2.1.1 and Appendix A

2.1.2.1 Media concentration values from aqueous discharges

The PC-CREAM08 DORIS model calculates the marine dispersion of radionuclides. The software requires an input of activity release rates ($Bq.yr^{-1}$). The annual permit limit values in Table 2 were given for the H-3 and Cs-137. PC-CREAM08 provided results with temporal variability, up to 10 years ahead (specified in the DORIS model output parameters).

Appendix A details how the fingerprint scale up method was used to determine the radionuclides representing the group 'Other radionuclides'. This also details how the maximum media concentration values to be used for each of the representative radionuclides which have been proportionately scaled to the annual permit limit of 200GBq.

The media concentration values which are to be used in the ERICA Tier 1 assessment are summarised in Table 5 below.

Table 5 - *Media concentration values used for aqueous discharges Tier 1 assessment*

Radionuclide or Group		***Discharge Rate (Bq/y)***		***Media conc. Value Bq m^{-3}***	
				seabed sediment ($Bq.kg^{-1}$)	seawater (unfiltered) ($Bq.l^{-1}$)
H-3		1.00E+12		**3.95E-01**	**2.50E-01**
Cs-137		2.00E+11		**3.40E+01**	**4.90E-02**
Other Radionuclides	*Am-241*	1.08E+09	Combined discharge rate 2.00E+11	**5.04E-01**	**2.57E-04**
	Cm-243	8.12E+06		**3.42E-03**	**1.92E-06**
	Cm-244	8.12E+06		**3.22E-03**	**1.92E-06**
	Pu-238	1.31E+08		**5.70E-02**	**3.12E-05**
	Pu-239	4.47E+08		**2.02E-01**	**1.06E-04**
	Pu-240	4.47E+08		**2.01E-01**	**1.06E-04**
	Pu-241	4.06E+09		**1.48E+00**	**9.62E-04**
	Sr-90	9.71E+10		**7.74E+00**	**2.41E-02**

3 ASSUMPTIONS

This report makes the following assumptions;

- To provide a conservative assessment it is assumed that discharges are at the maximum proposed limits (for gaseous) or the existing limits as detailed on the permit [2] (for aqueous)
- In all cases where activity concentrations were modelled within PC-CREAM08, the most pessimistic output value has been selected for processing in the ERICA Tier 1 assessment. The values from the PLUME assessment are derived from a matrix of two variables; meteorological stability and distance from stack. This gave a much more conservative approach to risk. For the DORIS assessments, all were undertaken with a 1-10 year temporal range. The highest values from the PCCREAM08 outputs were selected for further assessment in ERICA.
- Stack release height for modelling of activity concentration in PC-CREAM08 PLUME model has been assumed as a singular discharge point, 30m above the ground.

- Roughness length in the PC-CREAM08 PLUME model has been assumed as 0.3m (agricultural) in all instances.
- Default categories of meteorological stability were selected from the Hosker-Smith scheme for the PC-CREAM08 PLUME model in all instances.
- This report assumes the release of gaseous radionuclides exclusively impacts via the terrestrial pathway (ERICA terrestrial assessment). Similarly, aqueous releases of radionuclides exclusively impacts via the marine pathway (ERICA marine assessment).
- ERICA assessment assumes that the Severn estuary is a marine environment.

4 RESULTS

If the sum of the risk quotients (RQ) is <1, then it is considered that there is a very low probability that the assessment dose rate to any organism would exceed the incremental screening dose rate and therefore the risk to non-human biota can be considered negligible.

4.1 Tier 1 Terrestrial results for gaseous release

The terrestrial assessment for gaseous discharges of H-3, C-14 and Beta-emitting radionuclides associated with particulate matter (represented by Cs-134 as the worst case) conservatively assumed the maximum proposed discharge limits.

The results of the Tier 1 terrestrial assessment are presented in Table 6 below. The RQ for tritium was 3.31E-04 and the limiting reference organism (LRO) was 'Bird'. The RQ for carbon-14 was 2.61E-05 and the LRO was 'Mammal – small burrowing'. The RQ for caesium-134 was 7.17E-09 and the LRO was 'Mammal – large'.

The results show that at the ERICA dose screening level of 10 $\mu Gy.hr^{-1}$, no single radionuclide has a risk quotient greater than 1, and the sum of risk quotients is below 1 (3.57E-04). Therefore, it is considered, with a high degree of confidence, that the risk to non-human biota from the proposed new gaseous limits is of negligible concern, and that no further assessment is required.

Table 6 – *Tier 1 Terrestrial assessment for Berkeley gaseous discharges.*

Radionuclide	Permit Discharge limit ($Bq.yr^{-1}$)	Maximum activity concentration in air ($Bq.m^{-3}$)	Risk Quotient (RQ) at ERICA dose rate Screening value ($10\mu Gy.h^{-1}$)	Limiting Reference Organism
H-3	2.00E+12	8.74E-01	3.31E-04	Bird
C-14	5.00E+09	2.19E-03	2.61E-05	Mammal – small-burrowing
Cs-134	2.00E+07	8.74E-06	7.17E-09	Mammal - large
Sum of Risk Quotients			**3.57E-04**	

4.2 Tier 1 Marine assessment results for aqueous release

The Tier 1 marine assessment for aqueous discharges of H-3, Cs-137 and 'Other radionuclides' (represented by the scaled fingerprint of a bulk effluent sample [6]), conservatively assumed the maximum current permit limits are discharged.

The results are presented in Table 7. The RQ for tritium was 3.60E-06 and the limiting reference organism (LRO) was 'Phytoplankton'. The RQ for Cs-137 was 6.42E-02 and the LRO was 'Polychaete worm'.

For 'Other radionuclides' the radionuclides identified as above the limit of detection in the bulk effluent sample were proportionately scaled to the maximum permit limit for discharge. The highest RQ for the group was Am-241 at 4.83E-01 and the LRO was Phytoplankton.

The sum of all risk quotients is less than 1 (9.42E-01), and so it is considered with a high degree of confidence that the risk of significant impact from dose to non-human biota from the current aqueous limits is of negligible concern, and no further assessment is required.

Table 7 - Tier 1 Marine assessment results for Berkeley aqueous discharges

Radionuclide		Discharge rate (Permit limit) ($Bq.yr^{-1}$)		Maximum activity concentration in seabed sediment ($Bq.m^{-3}$) [3]	Maximum activity concentration in seawater (unfiltered) ($Bq.l^{-2}$) [3]	Risk Quotient (RQ) at ERICA dose rate Screening value ($10\mu Gy.h^{-1}$)	Limiting Reference Organism (LRO)
H-3		1.00E+12		3.95E-01	2.50E-01	3.60E-06	Phytoplankton
Cs-137		2.00E+11		3.40E+01	4.90E-02	6.42E-02	Polychaete worm
Other radionuclides[4]	*Am-241*	1.08E+09	Combined 2.00E+11	5.04E-01	2.57E-04	4.83E-01	Phytoplankton
	Cm-243	8.12E+06		3.42E-03	1.92E-06	4.34E-03	Phytoplankton
	Cm-244	8.12E+06		3.22E-03	1.92E-06	4.32E-03	Phytoplankton
	Pu-238	1.31E+08		5.70E-02	3.12E-05	3.81E-02	Phytoplankton
	Pu-239	4.47E+08		2.02E-01	1.06E-04	1.22E-01	Phytoplankton
	Pu-240	4.47E+08		2.01E-01	1.06E-04	1.22E-01	Phytoplankton
	Pu-241	4.06E+09		1.48E+00	9.62E-04	3.01E-04	Phytoplankton
	Sr-90	9.71E+10		7.74E+00	2.41E-02	1.04E-1	Mammal
					Sum of Risk Quotients	**9.42E-1**	

[3] Derived from PCCREAM08 DORIS assessment using the permit discharge limit for each radionuclide. Media concentration values were selected from the ten year accumulation to add conservatism to the assessment.
[4] Represented by radionuclides identified as above the limit of detection from bulk effluent sample, proportionately scaled to the maximum discharge limit.

5 CONCLUSIONS

Tier 1 ERICA assessments are designed to be conservative and aimed at identifying areas or receptors of negligible concern, such that these are removed from further assessment with a high degree of confidence. This compounded with the added pessimistic measures described in the methodology was gives further confidence to the results.

For the Tier 1 assessment, the conservative ERICA dose rate screening value of 10 µGy.h-1 was selected. It is considered that for initial assessments this screening value is sufficiently cautious, and if not exceeded populations of non-human organisms and their habitats are unlikely to be adversely affected.

If the sum of the risk quotients is <1, then it can be assured that there is a very low probability that dose rates to any organism would exceed the screening level (10 µGy.h-1) and therefore the risk to non-human biota can be considered negligible. The site may then be 'screened out' from further assessment.

5.1 Gaseous releases

The results demonstrate that based on the existing discharge limits even if the maximum proposed limits were discharged, the sum of all risk quotients is less than 1 (3.57E-04). It is therefore considered with a high degree of confidence that the risk to non-human biota from the Berkeley gaseous discharges at the proposed limits is of negligible concern, and no further assessment is required

5.2 Aqueous releases

The results demonstrate that based on the existing discharge limits even if the maximum proposed limits were discharged, the sum of all risk quotients is less than 1 (9.42E-01). It is therefore considered with a high degree of confidence that the risk to non-human biota from the current Berkeley aqueous discharges is of negligible concern, and no further assessment is required.

6 REFERENCES

[1] The Environmental Permitting (England and Wales) Regulations," 2016.

[2] Environment Agency, "Environmental Permit (EPR/ZP3893SG)," August 2019.

[3] ERICA Assessment Tool Version 1.2.1.," July 2018.

[4] PC-CREAM08 Radiological Impact Assessment Software," Public Health England

[5] C. Cartwright, "Berkeley Site - Annex V (Article 37): General data applicable to modifications of a plan on which an opinion has already been given," Magnox Ltd, March 2019.

[6] N. Summers, "Analytical Report for Magnox Ltd - Radiometric and Radiochemical Analysis of Effluent," Amec Foster Wheeler, June 2018.

[7] Magnox Ltd, Berkeley site, Aqueous liquid effluent discharge returns 2019, Permit ref. EPR/ZP3893SG/V003.

APPENDIX A – METHODOLOGY FOR DETERMINING THE REPRESENTATION OF RADIONUCLIDE GROUPS

For the purpose of being able to determine relevant media concentration values which could be used in the ERICA Tier 1 assessment, a conservative representation for the non-specific radionuclide groups for both gaseous and aqueous needed to be determined.

Two methods were available to determine this;

- **the Worst case analogue** – highly conservative 'first screen'; and
- **Fingerprint scale-up** – still very conservative but proportionately scaled to all radionuclides potentially in the discharge.

B.1 Determining representative for Gaseous group - Beta-emitting radionuclides associated with particulate matter

Table 8 presents the predicted radionuclide composition of beta particulate in aerial discharges (for activity totalling 20MBq) at Berkeley site which was assessed in the associated Article 37 submission [5].

This composition is an estimate and a 'worst-case' approach has been taken to account for any differences in the quantities of individual beta particulate radionuclides present in real discharges.

Table 8 - *Estimated radionuclide composition of beta particulate in aerial discharges from Berkeley Power Station [5]*

Radionuclide	Quantity (MBq)
Calcium-45	8.67×10^{-7}
Cobalt-60	1.24×10^{1}
Nickel-63	6.80
Strontium-90	4.43×10^{-3}
Technetium-99	2.71×10^{-6}
Ruthenium-106	3.40×10^{-5}
Antimony-125	1.44×10^{-9}
Caesium-134	4.49×10^{-5}
Caesium-137	2.36×10^{-2}
Promethium-147	1.95×10^{-4}
Europium-154	3.81×10^{-1}
Europium-155	3.57×10^{-1}
Plutonium-241	2.13×10^{-2}
Total	**2.00×10^{1}**

To determine a representative for 'Beta emitting radionuclides' in the gaseous discharges, the worst case method was first applied. (For consistency this follows the same approach that was taken for the calculation of human dose in the Article 37 submission). This method looks to identify the radionuclide presented in Table 8 that has the highest dose consequence to non-human biota. As a worst case it would then be assumed that the radionuclide with the highest dose consequence accounts for the entire discharge at the proposed permit limit for Beta-emitting radionuclides associated with particulate matter' (0.02 GBq,).

To determine the most conservative radionuclide, the following steps were taken:

1. Run a PLUME assessment in PC-CREAM08 with a common discharge rate of 2.00E+07Bq.yr^{-1} (maximum proposed discharge limit) for all radionuclide from the fingerprint (Table 6). All radionuclides were assessed against default meteorological categories, a stack height of 30m, and distances from the discharge point were set to output in the range 100m-10km.

2. The highest (most conservative) media concentration values (Bq.m-3) for each radionuclide were taken from the PLUME output tables. (*Presented in Table 9 below).*

3. Using the ERICA tool (using a terrestrial Tier 1), the highest media concentration values were run for each radionuclide[5] to determine which has the highest RQ value, and therefore has the highest dose consequence. (See Table 9.)

4. The determination of the worst-case analogue for 'beta emitting radionuclides associated with particulate matter' showed that Cs-134 had the highest RQ value, and was therefore the most conservative analogue.

5. In ERICA, if the risk quotient is <1, then it can be assured that there is a very low probability that the assessment dose rate to any organism exceeds the screening level (10 µGy.h-1). As the risk quotient for Cs-134 was <1 even assuming very conservatively that this made up the entire discharge at the maximum permitted level it was considered unnecessary to apply the fingerprint method to represent gaseous discharges.

[5] With the exception of Pm-147 and Eu-155 as these were not available in the ERICA tool.

Table 9 - Determination of worst-case analogue Cs-134 to represent 'beta emitting radionuclides associated with particulate matter'.

Radionuclide	Discharge input to PC-CREAM08 ($Bq.yr^{-1}$)	Activity concentration in air ($Bq.m^{-3}$) [6]	Risk Quotient (unitless)
Ca-45	2.00E+7	8.74E-06	1.15E-09
Co-60	2.00E+7	8.74E-06	1.20E-09
Ni-63	2.00E+7	8.74E-06	9.96E-12
Sr-90	2.00E+7	8.74E-06	4.30E-09
Tc-99	2.00E+7	8.74E-06	1.90E-09
Ru-106	2.00E+7	8.74E-06	3.91E-09
Sb-125	2.00E+7	8.74E-06	1.98E-10
Cs-134	**2.00E+7**	**8.74E-06**	**7.17E-09**
Cs-137	2.00E+7	8.74E-06	3.84E-09
Eu-154	2.00E+7	8.74E-06	5.56E-10
Pu-241	2.00E+7	8.74E-06	2.97E-12

B.2 Determining representative for Aqueous – 'Other radionuclides'

Estimated radionuclide composition for the aqueous group 'Other radionuclides' has been determined by first applying the Worst case analogue 'first screen' as well as the fingerprint scale up approach. Both approaches were based on a fingerprint (see Table 10 below) taken from an effluent bulk sample [6].

Table 10 – *Composition of the Berkeley bulk effluent sample*

Radionuclides	Discharge Activity (GBq)	(Bq)	% contribution
Am-241	2.63E-04	2.63E+05	0.539%
Cm-243/244	1.98E-06	1.98E+03	0.004%
Pu-238	3.20E-05	3.20E+04	0.066%
Pu-239/240	1.09E-04	1.09E+05	0.223%
Pu-241	9.90E-04	9.90E+05	2.029%
Sr-90	2.37E-02	2.37E+07	48.570%
Y-90	2.37E-02	2.37E+07	48.570%
TOTAL	**4.88E-02**	**4.88E+07**	

Worst-case analogue determination for "Other radionuclides"

To remain consistent with the gaseous approach and the method used in the Article 37 submission, the worst-case analogue radionuclide was first determined. This very conservatively assumed the full 200GBq discharge limit used following methodology:

[6] This is the highest concentration given for each nuclide when modelled at distances between 100m and 10,000m and across the 8 default meteorological categories in PC-CREAM08.

1. The radionuclides which were found above the analytical limit of detection in the 2017 bulk effluent sample (Table 8) were entered into the PC-CREAM08 DORIS module[7] to model the dispersion at the maximum permit limit of 200 GBq.yr^{-1} release rate for each radionuclide. A temporal variation between 1 and 10 years was specified in the DORIS parameters.

2. The DORIS module gave an output for two media concentration types – seabed sediment (Bq.kg-1) and unfiltered seawater (Bq.l-1), For added conservatism, the highest media concentration values for each radionuclide were selected (presented in Table 11 below) for seabed sediment and unfiltered seawater. In all cases the 10 year value was the highest due to accumulation.

Table 11 – *Worst case analogue determination for aqueous discharges*

	Discharge rate (GBq.yr^{-1})	PC-CREAM08 DORIS maximum media concentration outputs (10 years)		RQ value (ERICA)
		seabed sediment (Bq.kg^{-1})	seawater (unfiltered) (Bq.l^{-1})	
Am-241	200	9.34E+01	4.76E-02	8.95E+01
Cm-243	**200**	**8.42E+01**	**4.74E-02**	**1.07E+2**
Cm-244	200	7.92E+01	4.72E-02	1.06E+2
Pu-238	200	8.70E+01	4.76E-02	5.81E+1
Pu-239	200	9.02E+01	4.76E-02	5.47E+1
Pu-240	200	9.00E+01	4.76E-02	5.47E+1
Pu-241	200	7.28E+01	4.74E-02	1.48E-02
Sr-90	200	1.59E+01	4.96E-02	2.13E-01

3. The maximum seabed sediment and seawater concentrations were entered into ERICA (using a marine Tier 1 assessment) to generate the RQ values and allow determination of the worst-case analogue for "other radionuclides".

4. The ERICA assessment showed that the worst case analogue is Cm-243 as this has the highest RQ value. However, in taking this highly conservative approach and assuming that the entire maximum limit discharged was comprised of Cm-243, for a period of 10 years the RQ value would exceed 1 and so would challenge the ERICA screening level (10 µGy.h-1).

   This approach is not considered realistic or representative of the actual discharges particularly as Cm-243 makes up only 0.004% of the bulk sample. Furthermore, based on the most recent discharge returns, the total 12 month discharges [7] of 'Other radionuclides' represented only <0.01% of the 200 GBq annual permit limit.

[7] With the exception of Y-90 as this radionuclide is not available in the ERICA tool.

This finding indicated the need to move to the next method of screening to use the fingerprint scale up method. Although still highly conservative it applies a more proportionate representation of the discharges.

The worst case analogue for aqueous discharges was therefore not used in representing the group 'Other radionuclides' in the ERICA Tier 1 assessment.

Fingerprint scale-up determination for "Other radionuclides"

To apply a representation to the 'Other radionuclide group, the fingerprint data presented in Table 10 was used to proportionately scale the contribution of each radionuclide to the maximum limit 200GBq.

1. The radionuclides identified in the analysis, above limits of detection, totaled a discharge of 4.88E+07 Bq. To scale the discharges to 200GBq, a factor was determined:

   2E+11GBq / 4.88E+07= **4098**

2. The factor of 4098 was then used to provide scaled discharge rates for each radionuclide to total 2E+11Bq (200GBq).

3. The scaled discharge rates were input to PCCREAM08 DORIS module. This provided an output for two media concentration types – seabed sediment (Bq.kg-1) and unfiltered seawater (Bq.l-1). For added conservatism, the highest media concentration values for each radionuclide were selected for seabed sediment and unfiltered seawater. In all cases the 10 year value was the highest due to accumulation.

4. Using the ERICA tool (Tier 1 marine assessment) the maximum concentrations for both seabed sediment and seawater unfiltered were input for each radionuclide to provide an RQ value (See Table 12). This determined that the sum of all radionuclides was below the ERICA screening dose rate of 10 µGy.h-1.

This approach applies a much more proportionate representation of the discharges for the group 'Other radionuclides' and so has been used in the wider Tier 1 ERICA assessment for aqueous discharges. Therefore the maximum media concentration values as presented in Table 12 will be input to ERICA for the Tier 1 assessment for aqueous discharges.

This approach is still highly conservative because it assumes that the maximum permit limit is being discharged and it uses media concentration values which assume 10 year accumulation of discharges at this level.

Table 12 - Scaled discharge rates to 200GBq and resulting media concentration values to be used to represent Other radionuclides in the aqueous Tier 1 ERICA assessment.

Radionuclide	Discharge activity from bulk sample [6] (Bq)	Scaled Discharge rate ($Bq.yr^{-1}$)	PC-CREAM08 DORIS maximum media concentration outputs		RQ value (ERICA)
			seabed sediment ($Bq.kg^{-1}$)	seawater (unfiltered) ($Bq.l^{-1}$)	
Am-241	2.63.E+05	1.08E+09	**5.04E-01**	**2.57E-04**	4.83E-01
Cm-243[8]	1.98.E+03	8.12E+06	**3.42E-03**	**1.92E-06**	4.34E-03
Cm-244	1.98.E+03	8.12E+06	**3.22E-03**	**1.92E-06**	4.32E-03
Pu-238	3.20.E+04	1.31E+08	**5.70E-02**	**3.12E-05**	3.81E-02
Pu-239	1.09.E+05	4.47E+08	**2.02E-01**	**1.06E-04**	1.22E-01
Pu-240	1.09.E+05	4.47E+08	**2.01E-01**	**1.06E-04**	1.22E-01
Pu-241	9.90.E+05	4.06E+09	**1.48E+00**	**9.62E-04**	3.01E-04
Sr-90	2.37.E+07	9.71E+10	**7.74E+00**	**2.41E-02**	1.04E-01
Total		**2.00E+11**			**8.78E-01**

[8] Cm243 / Cm-244 and Pu-239/240 are presented as a combined radionuclide group in the analysis of effluent are separated here to obtain the highest, and therefore most conservative, RQ value.