Addendum to Environmental Safety Case: Disposal of Low Activity Low Level Radioactive Waste at East Northants Resource Management Facility

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List of Terms and Acronyms

ALARA As low As Reasonably Achievable

AOD Above Ordnance Datum

bgl Below ground level

BGS British Geological Survey

Biosphere The part of the environment where living organisms exist, or which is capable of supporting life

BPM Best Practicable Means

Cefas Centre for Environment, Fisheries and Aquaculture Science

CLEA Contaminated Land Exposure Assessment Model

CoRWM Committee on Radioactive Waste Management

DfT Department for Transport

EA Environment Agency

EFEPs External features, Events and Processes

EH&S Environment, Health and Safety

EHS&QM Environment, Health, Safety and Quality Manager

EIA Environmental Impact Assessment

EMP Environmental Management Plan

EMS Environmental Management System

ESC Environmental Safety Case

ESS Environmental Safety Strategy

Far Field The geosphere external to the engineered features of the disposal system.

FEPs Features, Events and Processes

GDF Geological Disposal Facility

Geosphere The solid component of the earth (rock and soil etc.)

NS-GRA Guidance on the requirements for authorisation for near-surface disposal facilities on land for solid radioactive wastes

PHE Public Health England

IAEA International Atomic Energy Agency

ICRP International Commission on Radiological Protection

IPPC Integrated Pollution Prevention and Control

LA-LLW Lower Activity Low Level Waste

LLW Low Level Waste

LOAEL Lowest Observable Adverse Effects Level

MDI Mean Daily Intake

NDA Nuclear Decommissioning Authority

NE Normal Evolution (a description of the reference case for the evolution of the disposal system)

Near Field The wastes, waste packages and engineered barriers within the disposal system.

NHB Non-Human Biota

NOAEL No Observable Adverse Effects Level

PA Performance Assessment

PEG Potentially Exposed Group

QMS Quality Management System

RWMD Radioactive Waste Management Directorate (part of the NDA)

SEPA Scottish Environment Protection Agency

SQEP Suitably Qualified and Experienced Personnel

UKCP UK Climate Projections

VLLW Very Low Level Waste

WAC Waste Acceptance Criteria

WASSC Waste Safety Standards Committee (part of the IAEA Safety Standards Commission and Committees)

Units and Prefixes

SI units of radiation and radioactivity

Quantity	SI unit and abbreviation
Absorbed dose	Gray (Gy)
Effective Dose	Sievert (Sv)
Radioactivity	Becquerel (Bq)

Multiples and sub-multiples of SI units

Factor	Prefix and abbreviation	Factor	Prefix and abbreviation
10^{18}	exa (E)	10^{-3}	milli (m)
10^{15}	peta (P)	10^{-6}	micro (µ)
10^{12}	tera (T)	10^{-9}	nano (n)
10^{9}	giga (G)	10^{-12}	pico (p)
10^{6}	mega (M)	10^{-15}	femto (f)
10^{3}	kilo (k)	10^{-18}	atto (a)

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1 Introduction

1. This document is an Addendum to the Environmental Safety Case (ESC) (Eden Nuclear and Environment Ltd, 2015) presented to the Environment Agency (EA) in July 2015 to support a request for a variation to Environment Agency Permit number CD8503, for receipt and disposal of low level radioactive waste at the East Northants Resource Management Facility (ENRMF), Stamford Road, King's Cliffe, Northamptonshire, PE8 6XX, United Kingdom (the centre of the site lies approximately at OS Grid Reference TF 0084 0002, 52.5887^{o} N 0.5130^{o} W). The application reference for the permit variation is EPR/FB3598DD/V001.

2. Augean South Limited (Augean) is the operator of the ENRMF which comprises a hazardous waste treatment facility at which materials are recycled, recovered and hazardous properties reduced and a landfill at which a range of hazardous wastes and low activity radioactive waste is disposed. The Environment Agency Permit number CD8503 covers disposal in cells 4B, 5A and 5B of the landfill. On 11th July 2013, the Secretary of State (The East Northamptonshire Resource Management Facility Order, 2013) approved the extension of the ENRMF to include an additional void of 1.2 10^6 m^3 (1.2 million cubic metres) over an area of approximately 11 ha (hectares) and an increase in the annual capacity of the treatment facility to 150,000 t y^{-1} (tonnes per year). The order permits disposal of 150,000 t y^{-1} of hazardous and low level radioactive waste (LLW) direct to landfill. It states that radioactive waste, to a maximum specific activity of 200 Bq g^{-1} (Becquerel per gramme) may be disposed in cells 4B, 5A and 5B and Phases 6 to 11. LLW input to the site is capped at 448,000 t (tonnes). The permit variation would extend the Environmental Permit for the LLW disposal area to include Phases 6 to 11 as well as cells 4B, 5A and 5B. A revised permit for the disposal of hazardous wastes including phases 6 to 11 was issued on 5th October 2015 (EPR/TP3430GW).

3. The EA requested further information to support the application in correspondence dated 8th October 2015 and 20th November 2015. These requests are reproduced in Annex A. The purpose of this document is to provide the requested information. In order to avoid confusion between the ESC (Eden Nuclear and Environment Ltd, 2015) and the Addendum, the former used Appendices and this document uses Annexes.

Document structure

4. Further information was requested concerning the half-life of radionuclides included in the “Other radionuclides” group, in an email dated 8th October 2015 (Annex A). A response was sent to the EA on 20th November 2015 and this is reproduced here in Annex B. This justifies why the permit should considering only those “Other radionuclides” that have a half-life greater than 1 year.

5. In the EA letter dated 20th November 2015 (Annex A) 11 further requests were provided and these are considered in Section 2 and Annex C. Transcription errors were identified in two ESC tables during this work and corrected versions are provided in Section 3. The ESC included a proposed schedule of limits for the revised permit and an amended version of this table, taking account of EA comments and our responses, is presented and discussed in Section 4.

2 Responses to letter of 20th November 2015

2.1 Large scale intrusion scenario

1) A number of smaller intrusion scenarios have been considered within the Environmental Safety Case provided with the above application.

However, we note that a scenario for a larger intrusion involving substantial amounts of waste being displaced, for example: to make way for a major road, has been excluded from the assessment. This query originates from the fact that a large intrusion was considered in the 2009 ESC and that it was limiting for some radionuclides.

We ask Augean to provide justification as to why a large intrusion scenario has not been considered in the Environmental Safety Case;

6. The 2009 ESC does not consider a large intrusion scenario. It was based on the SNIFFER methodology and considered doses to workers during a small scale intrusion, and redevelopment for housing. The radiological capacity was limited by doses to workers for a small scale intrusion after 60 years for 23 radionuclides, and the dose to residents following intrusion at 60 years limited the radiological capacity of 2 radionuclides. The 2009 ESC results for intrusion have been reproduced using the SNIFFER default parameters combined with any alternative values specified in the 2009 ESC (Section A.3 of Annex A, and Appendix B).

7. A site re-engineering/remediation scenario is included in the SNIFFER methodology to cover the situation where a site operator has no records of radioactive waste disposals or their location, and excavates waste during final site restoration works. In the case of the ENRMF, which is a hazardous waste landfill with a Permit to receive LLW, records would be maintained as a condition of the Permit. Any remediation work would be done with the knowledge that there was radioactive material on the site and it can be assumed that appropriate precautions against exposure would be adopted. Site rules also prevent any disposal of radioactive waste within 2 m of basal liners and within 1 m of the top of the cell. No results for this scenario are presented in 2009 ESC. Hence this scenario was not considered in the 2015 ESC (Section E5, paragraph 767).

8. The ESC considers the period of authorisation (see Figure 15 of the 2015 ESC) and this is assumed to include a period of active management lasting for 60 years after capping. There will be a period following this active management period during which records and knowledge will exist about the site, and during which any development of the site will be undertaken with the knowledge that the site was a hazardous and radioactive waste disposal facility. This is a passive form of control that will apply for a period of time, until records become lost or are not referred to, after which intrusion into the site without knowledge of what is there would be possible.

9. The site will be restored to a mix of woodland, scrub and species rich neutral grassland, in accordance with the planning permission/Development Order. Future development of the site would need planning permission and this would result in associated searches of the records (for example those held by the EA, DECC and the local authority, planning records, the development consent order and local maps). These records will inform the future

development of the site. Any work would therefore be carried out with the knowledge that there is radioactive material on the site and it can be assumed that appropriate precautions against exposure would be adopted and that contaminated material would be disposed of safely. Intrusion with knowledge of the site and its contents is not relevant to the ESC, and would be regulated by the HSE under the Ionising Radiations Regulations. Small exploratory intrusions might occur but large projects are unlikely to get planning permission during this passive management phase.

10. The ESC intrusion scenarios assume that the workers and residents have no knowledge of any contamination and very cautiously considered that controls limiting development or intrusions will be ineffective after 60 years for small scale intrusions such as a Borehole, but would remain effective for up to 150 years for the Resident scenario and up to 200 years for the Smallholder scenario. Whilst it is not possible to predict when passive controls will fail to identify the historic use of the site, 60 years is clearly too early.

11. The resident and smallholder intrusion scenarios considered in the 2015 ESC involve substantial excavation of material, including wastes. However, a large intrusion relating to developments such as motorways, a major road or railways was not explicitly considered as it was not considered to be credible for a site containing hazardous and radioactive wastes such as the ENRMF. This type of development would require planning permission. If planning permission was granted while records were available then the excavation would be performed in full knowledge of the nature of the site and this is not relevant to the ESC. At later times when records may not be available it is possible that development of a road or railway through the site could be considered. However, thorough geotechnical investigations would precede a major development of this type and they would reveal artificial made ground; based on current practice, this finding would not be ignored and further investigations would follow. The presence of wastes and potentially hazardous materials would also be discovered through trial pits and other small intrusions. It needs to be emphasised that this is a hazardous waste landfill, containing identifiable wastes such as asbestos which do not degrade in soil. Developers of brownfield sites, e.g. sites containing artificial made ground, are aware that contamination is possibly an issue and take this into account when planning construction activities e.g. see site investigation (AGS, 2013) and construction industry (CIRIA, 2014) guidance on asbestos in soil and made ground. The GRA considers current technologies (paragraph 6.3.48) and hence it is unreasonable to assume that future groundworks would pay less attention to potential contamination of brownfield sites and made ground than currently. With these arguments in mind a large intrusion such as that associated with a road cutting carried out with no knowledge of site contamination was not considered to be credible and it has not been considered in the ESC.

12. The EA has not yet revoked a disposal permit for a near surface radioactive waste disposal site. There is guidance from SEPA on principles and expectations on the revocation of authorisations for radioactive substances (SEPA, 2014) and we are aware that the EA is looking at development controls that can be put in place through the planning regime: these could be used to prevent development of landfills containing radioactive waste for a specified time or until the EA/SEPA advise that the restriction can be lifted. Such restrictions would give further legal protection against intrusion at early times (60 to 150 years) and are a reliable and legally binding form of passive control.

2.2 Time-dependent trends in groundwater concentrations

2) We note that Appendix F in the Environmental Safety Case includes information relating to interim concentrations for radionuclides in groundwater below the landfill. However, this information is partial and it is unclear to us whether these concentrations have been used in the assessment or are purely indicative.

Interim concentrations of radionuclides in groundwater that have been assumed for the "well constructed at the site boundary" scenario do not appear to have been explicitly provided in the Environmental Safety Case.

In order to provide further clarification and confidence in the assessment we ask Augean to provide us with time trend graphs showing concentrations per unit disposal at close to the well abstraction point for the following radionuclides: H-3, C-14, Cl-36, Tc-99, Sn-126, I-129, Ra-226**, Ra-226, U-234, U-235, U-238, Np-237, Pu-240 and Pu-242.***

13. Interim concentrations of radionuclides in groundwater for the "well constructed at the site boundary" scenario were not explicitly provided in the 2015 ESC. The concentrations in groundwater extracted from a well constructed at the site boundary that correspond to the doses presented in the ESC are presented in Annex C of this addendum report for the radionuclides listed above. The concentrations of Cl-36, Ra-226 and Pb-210 in groundwater that were provided in Appendix F of the 2015 ESC were used for model checking and incorporated a higher waste porosity value, see Section 2.7.

2.3 Infant doses from Cl-36 in groundwater

3) The Environmental Safety Case does not consider infant and child doses but rather provides an analysis that additional calculations are not necessary as previous assessments from the 2009 Environmental Safety Case show that doses to children and infants (plus the foetus/embryo) will be lower than adult doses for the majority of radionuclides (paras 430-431). We note, however, from the 2009 Environmental Safety Case that, in the case of consumption of foodstuffs contaminated with Cl-36, the child/infant doses in the were higher than adult doses by a factor of 2.5 (2009 application document Annex B table C5 – note that child/infant doses for all other radionuclides are lower than corresponding adult doses).

We have considered the results for Cl-36 for the smallholder scenario in the (2015) Environmental Safety Case submitted in support of the variation application in light of the above:

The dose from the maximum inventory of Cl-36 to a smallholder at 200 y is 0.08 mSv/y (Table 18). A factor of 2.5 increase in this dose would be well below the dose guidance level. Similarly, for the leachate treatment scenario, peak impacts to the farming family from Cl-36 are 0.005 uSv/y. However, the limiting capacity for Cl-36 is associated with the well scenario – in these calculations the irrigation pathway (which includes consumption of foodstuffs contaminated with contaminated groundwater) contributes about 80% of dose compared with 20% for the water drinking pathway for Cl-36 (Tables 78, 79).

We take view that the Cl-36 radiological capacity may not be conservative for infants and children. We therefore ask Augean to formally assess impacts to child/infant receptors for Cl-36 in a well[1] scenario and revise the Cl-36 radiological capacity accordingly. The outcome of this assessment should be provided to us.

Note 1. Confirmed 30/11/2015 that the well scenario limited capacity and should be assessed.

14. The dose to infants from groundwater was assessed for a well located at the boundary of the site by scaling Goldsim outputs to account for age related dose coefficients and infant consumption rates. The main contributions to dose for infants and children are from the consumption of root vegetables and milk. Hence, these are at 97.5th percentile intake values and all others are at average intakes.

15. The age-related Cl-36 ingestion dose coefficients for different age groups (Table 1) and consumption rates for infants (Table 2) are presented below. The contribution from inhalation or ingestion of Cl-36 contaminated dusts/soil are both less than 1.0 x 10^{-10} µSv y^{-1} MBq^{-1} and are not therefore considered here.

Table 1 Age related dose coefficients for Cl-36 (ICRP, 1996)

Radionuclide	Ingestion dose coefficient ($Sv\ Bq^{-1}$)					
	Infant	1 y	5 y	10 y	15 y	Adult
Cl-36	8.8 x 10^{-9}	6.3 x 10^{-9}	3.2 x 10^{-9}	1.9 x 10^{-9}	1.2 x 10^{-9}	9.3 x 10^{-10}

Table 2 Mean and 97.5 percentile consumption rates for infants

Pathway	Infant average	Infant 97.5th	Comment
Milk consumption (l y^{-1})	148	320	From (Smith & Jones, 2003).
Cow meat consumption (kg y^{-1})	3	10	
Sheep meat consumption (kg y^{-1})	0.8	3	
Offal consumption (kg y^{-1})	1	5.5	
Green & other domestic veg consumption (kg y^{-1})	5	15	
Root veg & potatoes consumption (kg y^{-1})	15	45	
Drinking water (m^3 y^{-1})[1]	0.26		

Note 1. A single value based on reference man is provided by (Smith & Jones, 2003).

16. This assessment produces a total dose to an infant that is a factor of 4.0 greater than the adult dose (Table 3). The dose to a 10 year old child was a factor of 1.4 greater than the adult dose and is not therefore discussed further. The relative contribution of the drinking water pathway to the total dose is 17.9% for an adult and 18.3% for an infant.

Table 3 Maximum annual doses for adults, 10 year olds and infants based on a unit inventory of 1 MBq of Cl-36 for a well at the site boundary

Radionuclide	Total dose ($\mu Sv\ y^{-1}\ MBq^{-1}$)			
	Adult	10 y	Infant	Infant/Adult
Cl-36	1.35×10^{-5}	1.89×10^{-5}	5.41×10^{-5}	4.0

17. The radiological capacity based on the dose to an adult is 1.48 TBq, it is 0.370 TBq based on the dose to an infant.

2.4 Monthly leachate treatment

4) Doses for leachate treatment scenarios are significantly lower (factor ~6) in the final 2015 Environmental Safety Case compared with the draft. The original model assumed 2400 m^3/y based on GoldSim groundwater model output. The revised model assumes 403 m^3/y based on 28 m^3 monthly loads with an allowance of 20% for peak rainfall (para 609). We understand that the revised calculations in the Environmental Safety Case submitted with the application use a 'realistic volume of leachate' but the data used to support these calculations is unclear to us.

We ask Augean to provide justification for the reduction in values for the annual quantities of leachate that have been used in the revised model. We ask also that Augean explains the source of the 28m^3 figure that has been used for monthly loads of leachate removed from site.

18. Records indicate that the amount of leachate dispatched to the offsite leachate treatment facility in the last 33 months is irregular and can vary substantially from quarter to quarter.

19. While the Soil Treatment Facility is in operation pumped leachate will be used in the stabilisation process. The amount used on site varies depending on waste throughput at the stabilisation plant with a maximum of about 5200 m^3 per quarter in the last 18 months (email from S. Moyle; 17-12-2015).

20. The 28 m^3 per month used in the ESC was based on the volume of a tanker load, and a view that one tanker per month was a reasonable estimate of the experience at the site at the time the 2015 ESC was finalised, taking into account the fact that no leachate was sent off-site in one quarter in 2013, in one quarter in 2014, and anticipated hazardous waste permit requirements (granted October 2015). Following receipt of the EA comment we have re-evaluated the data and now take the view that the estimate of one tanker per month was based on a period of low leachate production which has not continued, but it may still be a good estimate of the future usage of the off-site treatment facility under the new hazardous waste Permit. We have now revised the estimate used in the calculations as described below.

Table 4 Leachate disposal to Avonmouth

Period	Tonnage	Comment
2013 minimum per quarter (Q2)	0	
2013 maximum per quarter (Q3)	1,021	
2013 total in 2013	2,236	
2014 minimum per quarter (Q1)	0	
2014 maximum per quarter (Q2)	302	
2014 total in 2014	566	
Annual average Q1 2013 to Q4 2014	1,401	Used for leachate treatment calculations
Annual average Q2 2014 to Q1 2015	1,344	
2015 minimum per quarter (Q1)	778	
2015 maximum per quarter (Q2)	4,132	additional leachate to Avonmouth during this period due to one off pumping campaign

21. A review of data available from Q1 2013 to Q3 2015 (email from S. Moyle; 17-12-2015) shows a recent increase in the use of the off-site facility at Avonmouth for leachate processing: a high volume was sent off-site in Q2 2015 due to a campaign aimed at adjusting leachate sump levels within the waste cells. This high level of leachate transfer will not occur again because the new hazardous waste permit (granted in October 2015) allows a greater depth of leachate to accumulate and this will provide a buffer against fluctuations in the use of leachate at the on-site Soil Treatment Facility. Hence, it is expected that future use of the off-site treatment facility will be lower than in the past.

22. The majority of leachate comes from uncapped waste cells and sequential capping will therefore reduce the inventory available to leachate. In general, only 2 cells at any one time would be uncapped (the cell being filled and the cell that has just been completed), though operational considerations may mean that full capping of a cell may be delayed. Under these circumstances only a proportion of the inventory, e.g. 2 out of a total of 15 cells at the ENRMF, produce most of the leachate. Assuming a constant disposal rate for radioactive waste and disposal into cells 4a to 11b (15 cells), it is therefore appropriate to scale the leached inventory during the operational period by a factor corresponding to the uncapped cell fraction. The current configuration at the ENRMF means that an uncapped cell factor of 4/15 is most appropriate.

23. During the operational period past records show that the amount of leachate will vary and the annual average up to the end of Q4 2104 is about 1,401 m^3. We have used this value in the revised calculations for Co-60 presented in Section 2.5 of this addendum. We have not used the Q2 2015 values since they represent an unusual situation that will not be repeated now the new hazardous waste permit has been granted. Once the site is fully capped the 2014 HRA calculates that about 70 m^3 of leachate will be produced per annum and this will need to be disposed off-site.

2.5 Co-60 in leachate

5) The reduced leachate volume suggested in point 4 is also of relevance for Co-60, as the dose for Co-60 at the leachate treatment facility (operational period) is reduced from 584 uSv/y in the draft Environmental Safety Case to 86 uSv/y in the final Environmental Safety Case. Despite this potentially high dose, Augean does not propose to use this scenario to limit the Co-60 capacity because (a) Co-60 accounts for only about 6% of the LLW activity in the UK national inventory, (b) the estimate assumes that all leachate is sent for treatment, which will not be the case and (c) the model is conservative because it does not take into account sorption within waste materials.

While we acknowledge these reasons, we would like Augean to provide additional justification as to why the leachate treatment facility (operational period) scenario has not been used to limit Co-60, in the context of the historic and planned use of the Avonmouth facility for treatment and disposal of leachate from the ENRMF.

24. Leachate is routinely monitored for Co-60. Ad-hoc monitoring of Co-60 by the EA recorded <1 Bq l^{-1} in leachate during 2014 (LGC Ltd, 2014). Routine monitoring of Co-60 by Augean has not found an increase in leachate concentrations as a result of Co-60 disposals.

25. The leachate treatment facility (operational period) scenario was not used to limit Co-60 disposals in the 2015 ESC because at the ENRMF the scenario is not certain since the leachate is predominantly used for the waste stabilisation plant on-site, and because the dose would be very low. Past disposals to the leachate treatment facility at Avonmouth are described in Section 2.4. Sometimes there is not sufficient leachate generated for the waste stabilisation plant and no leachate is transported off-site. However, sometimes there is an excess of leachate and this is the situation that leads to transport of the leachate off-site to the leachate treatment facility at Avonmouth. However, past disposals do not necessarily indicate the future pattern since this will be influenced by the maximum level of leachate that can be maintained in the landfill site and the fluctuations in the requirements of the waste stabilisation plant. There is no intention to increase the use of the leachate treatment facility: in fact the opposite is planned.

26. As described in the ESC, the national inventory of Co-60 (3.7 TBq) is such that the dose from the leachate treatment pathway will not exceed a few µSv y^{-1}. Note that the value of dose to the worker at the leachate treatment facility presented in the ESC (86 µSv y^{-1}) is a gross overestimate, based on disposal of the maximum inventory that can be disposed of at the ENRMF, as specified in the Development Order conditions (89.6 TBq), and ignoring radioactive decay during the operational period of the site, sorption on the waste and the fraction of the site that is uncapped.

27. At the end of the operational period, the dose to a treatment facility worker at Avonmouth from the disposal of 70 m^3 of leachate once the whole site is capped is estimated to be about 15 µSv y^{-1} from 89.6 TBq of Co-60, ignoring any radioactive decay and assuming that all Co-60 in the waste is soluble. This is a gross overestimate.

28. Following the review of leachate disposal to the off-site treatment facility, we have re-evaluated the assumption made in the ESC regarding this scenario. We have now decided to use the scenario to limit the radiological capacity of Co-60. We have evaluated doses to the leachate treatment facility worker for an annual average off-site leachate treatment rate

of 1,401 m^3, applying the uncapped cell factor described in Section 2.4. The results are shown in Table 5 and are overestimates since they ignore sorption on the waste. Results are also given for the leachate off-site treatment rate of 403.2 m^3 per annum given in the 2015 ESC, and the maximum off-site treatment rate of 2,236 m^3 per annum recorded prior to the 2015 Q2 campaign.

29. The radiological capacity of Co-60 in the 2015 ESC is 3.83 10^5 TBq based on the other scenarios. Using the leachate treatment scenario (at 1,400 m^3) to limit the Co-60 radiological capacity results in a radiological capacity of 22.5 TBq, less than the maximum inventory based on the Development Order (89.6 TBq), but still greater than the national inventory of Co-60 (3.7 TBq). Hence, it will now limit the Co-60 that can be received at the site. The results are given in Table 5. For all other radionuclides, doses from this scenario are limited by the maximum inventory (89.6 TBq) to below 20 µSv y^{-1} and are not considered further.

Table 5 Radiological capacity for Co-60 adjusted for various leachate treatment rates and the uncapped cell factor

Radionuclide	Radiological capacity (other scenarios) (TBq)	Radiological capacity based on off-site treatment leachate rates (TBq)		
		Low (403.2 m^3)	Reference (1,400 m^3)	High (2,236 m^3)
Co-60	3.83 10^5	7.81 10^1	2.25 10^1	1.41 10^1

Note: 403.2 m^3 was used in the 2015 ESC

2.6 Timing of bathtubbing event

6) Bathtubbing impacts are calculated in the final Environmental Safety Case at 450 y after closure ('the point in time the groundwater model suggests overtopping will occur', para 198). We note that in the draft Environmental Safety Case these impacts were calculated at 350 y after closure. We note also that modelling in the final Environmental Safety Case suggests that overtopping will occur, whereas the assumption in the draft Environmental Safety Case was that overtopping is uncertain to occur.

We ask Augean to explain these changes to the bathtubbing scenario impacts.

30. The hydrological risk assessment (HRA) asserts that overtopping would not occur at the site since it is a hazardous waste landfill site, leachate monitoring would continue while the Permit was in force, and the Permit would not be revoked if there was a risk of overtopping. However, the scenario was included in the 2015 ESC following discussions with the EA.

31. The draft ESC simply used a notional time of 350 years based on discussions with the authors of the HRA. The final ESC used a time of 450 years based on scoping calculations using the GoldSim groundwater model. This is described in Appendix E (section E4.5) of the 2015 ESC. We do not consider that this scenario is certain to occur and we recognise that the text could be clearer. The text in paragraphs 740 to 743 describes the basis for adopting a 450 year period, and clearly states in the last sentence that this scenario is unlikely to occur. The main report considers bathtubbing in paragraphs 198 to 202 and the

last sentence of paragraph 198 identifies a time at which the Goldsim groundwater model suggests overtopping will occur. This statement was a comment in relation to the scoping calculations performed using the Goldsim model and not an expectation that the event is expected to occur. The language used in the last sentence of paragraph 198 was not meant to suggest that this scenario was considered certain to occur or to contradict the earlier parts of that paragraph that concluded it is unlikely to occur.

32. The scoping calculations using the Goldsim groundwater model are based on the assumption that leachate management ceases 60 years after closure of the site, and the cap and liner gradually degrade beyond that time. The assumed end date for the period of authorisation is 60 years to be consistent with the other assumptions in the ESC. It is, by definition, inconsistent with the HRA since it does not consider that the period of authorisation will last for a longer period, until it is established that overtopping cannot occur (paragraph 740). Bathtubbing would not be expected to occur while an authorisation is in place since leachate monitoring and management would continue. The time at which bathtubbing can occur is based on a balance of the water input into the site (percolation through the cap) and the water output (leachate extraction and percolation through the sides and liner). The GoldSim calculations were cautious since they assumed that the sides remained impervious, maximising the risk of overtopping. Once the basal liner or facility side walls have fully degraded, overtopping cannot occur.

2.7 Basis for parameter changes

7) We have noted a number of changes to the calculation parameters used in the final Environmental Safety Case, in comparison to the values used in the draft:

- Infiltration rate to grassland is reduced by factor of ~5 in the final Environmental Safety Case (Table 43).

- The waste porosity is reduced from 0.5 to 0.1 in the final Environmental Safety Case (Table 46).

- The inhalation and irradiation dose coefficients for Ra-226, when Pb-210 is modelled explicitly, are different. The former has increased by factor of 3 (Table 54). We note that data from the 2011 Low Level Waste Repository Environmental Safety Case data were used in the draft Environmental Safety Case but ICRP data have been used in the final version.

We ask that Augean provides an explanation for these changes.

33. The values used have changed following a review of the database; some have changed to be consistent with the values given in the most recent version of the HRA, which was not available when the draft ESC was prepared.

Infiltration rate

34. The values of both the cap design infiltration rate and infiltration rate to grassland have increased between the draft and final ESC, not reduced as stated by EA. We are using 4.97 mm y^{-1} in the model for the Cap design infiltration rate and 74.3 mm y^{-1} for the infiltration rate to grassland, both the text (paragraph 409) and Table 43 were amended in

the final ESC. The cap design infiltration rate was 0.27 mm y^{-1} in the draft ESC (paragraph 411). The infiltration rate to grassland used in the draft ESC was 18.7 mm y^{-1}, a best estimate based on a log-normal distribution (paragraph 572).

35. The infiltration rate of 4.97 mm y^{-1} is based on the calculated maximum flux through the cap determined in the 2004 HRA based on the use of a composite cap comprising a geosynthetic clay liner (GCL) and a 1 mm thick linear low density polyethylene (LLDPE) geomembrane liner. Use of the calculated maximum flux is conservative and in the 2004 HRA the base case model assuming good cap performance has a flux through the cap of 0.27 mm y^{-1}. Supplementary calculations presented to the EA in support of the 2014 HRA investigated assumptions regarding the head of water above the cap, the density and size of defects in the cap and the range of potential hydraulic conductivity of the sub-grade which will underlie the geomembrane in the cap. The cap infiltration value of 4.97 mm y^{-1} is close to the middle of the range of the supplementary calculated cap infiltration rates. This is the value used in the 2014 HRA and in the final version of the 2015 ESC.

Waste porosity

36. The waste porosity was updated to be consistent with the assumptions used in the 2014 HRA. The 2011 HRA used a range of waste porosity from 0.455 to 0.556 (Table HRA 3) and the draft ESC adopted a mid-point value of 0.5. The final updated 2014 HRA used a range of waste porosity from 0.01 to 0.2 (Table HRA 2) and a mid-range value (0.1) was applied in the final ESC.

37. In the 2014 HRA the range of values assumed with regard to waste porosity is derived from information presented in the literature (McWhorter & Sunada, 1977) and is based on assumptions regarding the nature of the materials that will be deposited. The values used are based on literature values for effective porosity rather than total porosity. The use of effective porosity values in the 2014 HRA and 2015 ESC is more conservative than the use of total porosity values.

Dose coefficients

38. The Ra-226 inhalation value in Table 54 in the 2015 ESC is not correct and is not the value that was used in the calculations: this table was changed in error in the final version of the ESC. The Ra-226 parameters used in the model were the values reported in the draft ESC. Table 54 should read as follows:

Table 54 revised: Radium 226 and Th-232 dose coefficients used when Pb-210 and Ra-228 are modelled explicitly

Radionuclide	Ingestion (Sv Bq^{-1})	Inhalation (Sv Bq^{-1})	External Irradiation from slab (Sv y^{-1} Bq^{-1} kg)
Ra-226	$2.8\ 10^{-7}$	$3.49\ 10^{-6}$	$3.03\ 10^{-6}$
Th-232	$2.3\ 10^{-7}$	$1.1\ 10^{-4}$	$1.41\ 10^{-10}$

39. The LLWR data set provided a convenient source of data for dose coefficients that included doses from short-lived daughter radionuclides. This data set was used in the draft ESC. The final ESC calculated the dose coefficients from first principles using ICRP data and other original papers.

2.8 Groundwater monitoring programme

8) The Environmental Safety Case identifies the main contributors to dose from leachate migration via groundwater are likely to be H-3, Cl-36, Sr-90, I-129 and Pb-210 (para 171). The updated ESC goes on to say that 'groundwater monitoring for these radionuclides and comparison against background levels in groundwater ... would provide an indication of releases into the environment through this pathway'.

We note that Only H-3 and Pb-210 appear to be in the current groundwater analytical suite.

We ask Augean to review their current monitoring programme for groundwater, in light of the above and taking into account the predicted groundwater concentrations in point 2 above, and to provide us with the outcome of this review.

40. We have reviewed the monitoring programme taking into account the predicted groundwater concentrations, the detection limits and the expected doses from the predicted concentrations.

41. The peak groundwater concentrations at the boundary of the site are shown in Table 6 for the radionuclides listed above, assuming disposal of the maximum inventory (the minimum of the inventory permitted by the Development Order and the radiological capacity) for each radionuclide. The peak concentration during the period of authorisation (PoA) and that observed over the whole period modelled are presented. The tritium peak occurs during the PoA and the same concentration therefore appears in both columns.

Table 6 Peak groundwater concentrations at the site boundary, analytical detection limits and water concentrations producing a dose of 20 µSv

Radionuclide	Typical detection limit	Projected groundwater concentration after disposal of the maximum inventory[2]			Drinking water concentration giving a dose of 20 µSv (Bq l^{-1})
		Peak (Bq l^{-1})	Year of peak	Max during PoA (Bq l^{-1})	
H-3	4 Bq l^{-1}	2.39 10^{-1}	44	2.39 10^{-1}	2000
Cl-36[1]	0.29 Bq l^{-1}	6.95	759	3.73 10^{-2}	20.8
Sr-90[1]	0.11 Bq l^{-1}	7.01 10^{-5}	138	3.97 10^{-5}	0.8
I-129[1]	0.02 Bq l^{-1}	6.90 10^{-2}	2100	1.15 10^{-4}	0.20
Pb-210	0.002 Bq g^{-1}	4.33 10^{-8}	95	3.95 10^{-8}	0.012

1. Detection limit reported for Sellafield groundwater assessments.
2. Minimum of the Development Order limit (89.6 TBq) and the radiological capacity

42. Typical detection limits are also listed. This shows that even if the maximum inventory (see Section 6 of the 2015 ESC) is disposed of at the site, the only radionuclide that could be detected in groundwater during the PoA is Cl-36. The detection limit corresponds to disposal of 11 TBq of Cl-36 at the site. However, the inventory of Cl-36 in the LLW waste that has been sent to ENRMF is a very small fraction of the total radionuclide inventory, amounting to a total of 3.1 10^{-5} TBq in June 2015.

43. The last column of the table provides an estimate of activity concentrations in water that result in a dose of 20 µSv y^{-1}, based on HPA assessments (Ewers & Mobbs, 2010). Their value is always greater than the projected groundwater concentration, indicating that doses from groundwater will be lower than 20 µSv y^{-1} even if the listed radionuclide is disposed of at the maximum inventory.

44. This review shows that, based on the maximum inventory that can be disposed of at the site and the radionuclide mix of the wastes, these radionuclides are very unlikely to be detected in groundwater using current techniques. Routine analysis of radionuclides that are expected to be at levels below the detection limits, and are found to be below the detections limits, does not provide any useful information. The two radionuclides that give the earliest peak groundwater concentrations are H-3, which peaks after 44 years, and Pb-210, which peaks after 95 years; both of these are included in routine groundwater analyses. The other radionuclides peak at much later times.

45. There is uncertainty associated with the groundwater model predictions and for this reason the ESC recommended reviewing the list of radionuclides routinely analysed in groundwater as the inventory accumulates (paragraphs 165 and 171). Thus, additional radionuclides would be analysed as the inventory of the radionuclides in the ENRMF increased and passed certain trigger levels. The trigger levels were not specified in the ESC. As part of this review, we have developed trigger levels for the radionuclides identified by EA above.

46. A factor of 30 is the largest ratio of maximum to minimum results in the groundwater model output observed in the sensitivity analyses. The radionuclide inventory corresponding to groundwater concentrations above the analytical detection limit is given in Table 9, together with the inventory assuming a factor of 30 uncertainty. We propose to use the inventory reduced by a factor of 30 (column 4 in Table 9) to trigger inclusion of a radionuclide in the analytical suite.

Table 7 Cumulative inventory to trigger inclusion of additional radionuclides in routine monitoring of groundwater

Radionuclide	Maximum inventory[1] (TBq)	Inventory required to exceed detection limit (TBq)	Inventory to exceed detection limit reduced by a factor 30 (TBq)	Inventory June 2015 (TBq)
H-3	$8.96\ 10^{1}$	$1.50\ 10^{3}$	$5.00\ 10^{1}$	$2.38\ 10^{-2}$
Cl-36	1.48	$1.15\ 10^{1}$	$3.82\ 10^{-1}$	$3.10\ 10^{-5}$
Sr-90	$8.96\ 10^{1}$	$2.48\ 10^{5}$	$8.28\ 10^{3}$	$2.73\ 10^{-3}$
I-129	$4.16\ 10^{-2}$	7.26	$2.42\ 10^{-1}$	$1.80\ 10^{-6}$
Pb-210	$8.96\ 10^{1}$	$4.99\ 10^{6}$	$1.66\ 10^{5}$	$1.47\ 10^{-2}$

Note 1. The maximum inventory is the minimum of the inventory permitted by the Development Order and the radiological capacity for each radionuclide

47. The Sr-90 trigger inventory remains greater than the maximum inventory and hence it will not be included in the routine analysis using this approach.

48. Routine groundwater monitoring will therefore continue with H-3 and Pb-210 as the radionuclides that are analysed for. If the levels are found to be above those expected, then following confirmation of the unexpected results, the analytical approach will be changed to look for all of the radionuclides identified above.

2.9 Timing of smallholder scenario

9) The sensitivity analysis for the smallholder potentially exposed group considers doses at earlier and later times than 200 y (which is the default time used for capacity determination). At times less than 90 y this scenario becomes limiting for Sr-90 (para 1101). At these times the radiological capacity for Sr-90 becomes less than the proposed 89.6 TBq capacity limit for the ENRMF. The current limiting scenario for Sr-90 is the smallholder at 200 y scenario but the proposed capacity of this radionuclide is limited by tonnage and not by dose (tables 24 and 25)

We note that 60 y is the assumed period of authorisation for the ENRMF site and so it seems reasonable that the Sr-90 capacity is brought in line with the smallholder intrusion scenario impacts (at 60 y).

We ask Augean to reassess the Sr-90 capacity based on peak smallholder impacts at 60 y and to provide us with the outcome of this assessment.

49. The timing of human intrusion scenarios is a matter of judgement. The philosophy behind the ESC is to use realistic but conservative assumptions, not bounding assumptions. Section 2.1 has discussed factors that will influence the timing of human intrusion scenarios affecting a site resident. We do not believe it is reasonable to assume that residential or smallholder developments will occur at the site 60 years after site closure i.e. at the time that it is assumed that the authorisation is revoked. The future development of the site will need planning permission and there are multiple public records (for example held by the EA, DECC and the local authority, planning records, the development consent order and local maps) showing the existence of the hazardous landfill site that will inform any future development at the site. Furthermore, the environment agencies are developing revocation guidance that will clarify the interaction between the environment agencies and the planning authorities at the time of the revocation of the Permit or Authorisation. This will specifically identify any planning controls that are required. The revocation of the Permit or Authorisation will involve assessment of the risks presented by the ENRMF, both from the point of view of the LLW wastes and of the hazardous wastes within the site. It is assumed for the purposes of the calculations that the Permit will be revoked 60 years after closure: if the EA consider that there is a need to retain controls for longer, e.g. to continue monitoring or to prevent intrusions into the site, then either the Permit will remain for longer or suitable planning controls will be put in place. Hence the timescales for intrusion considered in the ESC take into account the characteristics of the site and are appropriate. Intrusion with knowledge and understanding of the nature of the site is not relevant to the intrusion calculations in the ESC as the appropriate precautions will be taken.

50. Other assessments of near surface disposal facilities, e.g. the IAEA ISAM study (IAEA, 2004) discuss the active management and subsequent passive control periods for a near surface disposal site, suggesting periods of 100 years for the Permit followed by a period of 200 years during which passive (planning) controls are effective. This gives a total of 300 years post closure before intrusion is considered, considerably longer than the 200 years

assumed for the Smallholder scenario in the ESC which appears very cautious. LLWR assumed a minimum of 100 years post closure when knowledge of the site is maintained (Thorne, 2009) and we do not think it is reasonable to apply a shorter time span. It should be remembered that these timescales for unintentional or uninformed intrusion are values for the purposes of the calculation. There is no intention to destroy records of the presence of the site at that time, and in fact the control provided by the presence of the records could last for much longer.

51. The analysis of uncertainty in the ESC was undertaken to highlight the sensitivity of assessment calculations to selected parameters, and to illustrate the robustness of the calculations. There was no suggestion that the capacity values could be based on worst case assumptions: indeed to do so would be counter to accepted international guidance on assessment methodologies. It is not surprising that the doses from Sr-90 increase if the intrusion is assumed to occur earlier since Sr-90 has a half-life of about 30 years.

52. As requested by EA, we have calculated the radiological capacity of Sr-90 based on intrusion into the site corresponding to occupancy of the site by a smallholder occurring 60 years after site closure. We have also calculated the radiological capacity based on this intrusion occurring 100 years after site closure. These results, together with the results presented in the ESC for intrusion occurring at 200 years are given in Table 8.

Table 8 Maximum annual doses for adults: Smallholder scenario at 60, 100 and 200 years

Year	Total dose	
	Dose ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Radiological capacity (TBq)
60	$7.15\ 10^{-5}$	$4.19\ 10^{1}$
100	$2.72\ 10^{-5}$	$1.10\ 10^{2}$
200	$2.42\ 10^{-6}$	$1.24\ 10^{3}$

2.10 Use of peak doses to determine radiological capacity from intrusion scenarios

10) We note that radiological capacities for a number of other radionuclides are also based on the smallholder scenario at 200 y and this scenario provides the limiting capacity for Th-230, Th-232 and Pa-231. Since we cannot necessarily rely on any controls on land use after the assumed 60 y period of authorisation we consider it reasonable for the capacities for Th-230, Th-232 and Pa-231 to be brought in line with their respective peak doses calculated throughout the assessment period (periods between 60 and 20,000 y, as opposed to the dose at 200 y.

We ask Augean to reassess the capacities for Th-230, Th-232 and Pa-231 based on their respective peak doses calculated over the assessment period and to provide us with the outcome of this assessment.

53. As explained above, we think that it is inappropriate to assume that no controls will be present on the redevelopment of the site at the end of the authorisation period. As part of the planning permission for development of the site, it will be restored to grassland and

mixed scrub/woodland. Any development for residential or smallholding will require planning permission and it is not reasonable to assume that this would be granted immediately after the Permit was revoked unless a risk assessment showed that the resulting doses would be acceptable. This would also take into account the hazardous waste at the site. Nevertheless, we understand that radiological assessment methodologies consider that passive control through records cannot be assumed to last forever and this is the basis of the intrusion assessments. Small scale intrusions would be expected to occur earlier than large scale intrusions that would require planning permission. This is why we have assessed a small scale intrusion at 60 years post closure and larger scale intrusions at later dates.

54. For most radionuclides the peak dose from intrusion scenarios occurs at the earliest time that the intrusion is expected to occur. However, for long lived radionuclides where gradual ingrowth of daughter radionuclides is important, this may not be the case. As requested by EA we have calculated the peak doses from the smallholder scenario for the three radionuclides listed. The results are summarised in Table 9, along with the results assuming intrusion occurs at 200 years.

55. For Th-230 the peak dose arises for intrusion occurring 9,000 years after closure. For Pa-231 and Th-232 the intrusion dose is practically constant for the first 200 years post closure, slowly reducing over time. Hence, the peak intrusion dose over the assessment period for Pa-231 and Th-232 is practically identical to the dose for intrusion at 200 years. However, for Th-230, the peak dose is about an order of magnitude greater than the dose from intrusion at 200 years. Although this peak dose occurs 9,000 years after closure, a very long time after closure, it can be argued that the radiological capacity for Th-230 for the smallholder intrusion scenario should be based on the dose at 9,000 years rather than at 200 years.

Table 9 Maximum annual doses for adults: Smallholder scenario

Radionuclide	Maximum over 60-20,000 years		Results for intrusion at 200 years		Comment
	Dose ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Radiological capacity (TBq)	Dose ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Radiological capacity (TBq)	
Pa-231	$1.63\ 10^{-4}$	$1.84\ 10^{1}$	$1.61\ 10^{-4}$	$1.86\ 10^{1}$	practically constant for 200 years
Th-230	$5.17\ 10^{-4}$	5.8	$4.33\ 10^{-5}$	$6.93\ 10^{1}$	Maximum dose occurs at 9,000 y
Th-232	$4.24\ 10^{-5}$	$7.08\ 10^{1}$	$4.19\ 10^{-5}$	$7.16\ 10^{1}$	Practically constant for 200 years

2.11 Exposure of protected species

11) The final Environmental Safety Case includes an assessment of dose to rabbits burrowing into the waste materials. This assessment of this scenario indicates potential doses of > 40 uGy/h to the rabbits at 60 y (max 210 uGy/h). This is a limiting scenario for Pa-231, Cm-243 and Cm-244. The Environmental Safety Case proposes that radiological capacities for these radionuclides could be set for this scenario using the 40 uGy/h action

level - resulting in radiological capacity reduction factors of 4, 6 and 3 for Pa-231, Cm-243 and Cm-244 respectively (table 141).

We note that rabbits are not a protected species and our assessment does not indicate any significant adverse impact on a European site, Site of Special Scientific Interest, Area of Outstanding Natural Beauty or other conservation site.

However, limiting the capacity of the radionuclides that lead to doses in excess of 40 uGy/h for other burrowing species that are protected, such as badgers, should be precautionary, given that these radionuclides are very unlikely to form a significant part of the ENRMF inventory, and that ecological protection is considered at the population level as opposed to the individual level.

We ask Augean to consider reducing the capacity of Pa-231, Cm-243 and Cm-244, based on the outcome of the assessment of the potential doses to non-human species that may burrow into the waste in future.

56. The assessment undertaken for burrowing animals using the ERICA model is generic and applies to other burrowing species that could burrow deep enough to reach the waste. Badger tunnels can be four metres deep, though most are less than one metre deep. Hence it is appropriate to consider them in the assessment and the results given for rabbits are also applicable to badgers.

57. The waste management principal of 'concentrate and contain' will inevitably mean that some sites will contain wastes while the rest of the environment does not. Hence, it could be argued that protection of the environment is already achieved by placing the wastes in a specific facility. However, we note the EA comment that it would be precautionary to apply the radiological capacity reduction factors given above to limit the dose rate to badgers intruding into the waste to 40 µGy/h. Given that the radionuclides that these reduction factors apply to are very unlikely to form a significant part of the ENRMF inventory, we have applied these reduction factors to the radiological capacity. The revised values are given in Table 10.

Table 10 Reduction factors for radiological capacity due to burrowing animals

Radionuclide	Radiological capacity (TBq) 2015 ESC	Reduction factor[1]	Adjusted Radiological capacity (TBq)
Pa-231	$1.86\ 10^{1}$	3.9	4.76
Cm-243	$4.28\ 10^{3}$	5.2	$8.18\ 10^{2}$
Cm-244	$1.59\ 10^{4}$	2.2	$7.24\ 10^{3}$

Note 1. ESC rounded up all values.

3 Corrigenda

58. In responding to the EA comments two tables in the ESC were found to contain transcription errors. These errors were in the lower part of each table and were specific to these tables only. No other tables in the ESC were affected by these errors and the conclusions of the assessment were unchanged. The corrected tables are included here and given their original table numbers. Corrected cells are shaded grey.

Table 21 revised: Scenario radiological capacity calculated for exposures after the period of authorisation

Radionuclide	Bathtubbing		Groundwater (Well at boundary)		Recreational user	
	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)
H-3	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	5.95 10^{-3}	3.01 10^{11}
C-14	1.10 10^{-11}	1.82 10^{12}	3.49 10^{-9}	5.73 10^{9}	2.97	6.04 10^{8}
Cl-36	1.25 10^{-7}	1.60 10^{8}	1.35 10^{-5}	1.48 10^{6}	3.93 10^{-25}	7.51 10^{31}
Fe-55	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	0	nd*
Co-60	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	1.75 10^{-13}	1.02 10^{22}
Ni-63	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	0	nd*
Sr-90	1.58 10^{-12}	1.27 10^{13}	<1.0 10^{-10}	>2.0 10^{11}	8.48 10^{-21}	2.11 10^{29}
Nb-94	3.45 10^{-9}	5.80 10^{9}	2.23 10^{-9}	8.96 10^{9}	2.50 10^{-12}	7.18 10^{20}
Tc-99	2.02 10^{-7}	9.92 10^{7}	1.26 10^{-7}	1.58 10^{8}	4.52 10^{-45}	3.97 10^{53}
Ru-106	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	7.49 10^{-32}	2.39 10^{40}
Ag-108m	2.93 10^{-9}	6.83 10^{9}	9.03 10^{-10}	2.21 10^{10}	1.33 10^{-13}	1.34 10^{22}
Sb-125	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	3.08 10^{-21}	5.83 10^{29}
Sn-126	1.21 10^{-9}	1.66 10^{10}	9.10 10^{-8}	2.20 10^{8}	9.80 10^{-14}	1.83 10^{22}
I-129	1.59 10^{-7}	1.26 10^{8}	4.80 10^{-4}	4.17 10^{4}	1.25 10^{-150}	6.65 10^{155}
Ba-133	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	2.35 10^{-19}	7.63 10^{27}
Cs-134	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	1.59 10^{-21}	1.13 10^{30}
Cs-137	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	4.19 10^{-14}	4.28 10^{22}
Pm-147	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	5.77 10^{-51}	3.11 10^{59}
Eu-152	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	6.57 10^{-13}	2.73 10^{21}
Eu-154	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	1.62 10^{-13}	1.11 10^{22}
Eu-155	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	2.98 10^{-40}	6.02 10^{48}
Pb-210	<1.0 10^{-10}	>2.0 10^{11}	<1.0 10^{-10}	>2.0 10^{11}	9.45 10^{-19}	1.90 10^{27}

Radionuclide	Bathtubbing		Groundwater (Well at boundary)		Recreational user	
	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)
Ra-226	$2.74\ 10^{-9}$	$7.29\ 10^{9}$	$5.15\ 10^{-9}$	$3.88\ 10^{9}$	$1.30\ 10^{-8}$	$1.38\ 10^{17}$
Ra-228	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$2.90\ 10^{-11}$	$6.18\ 10^{19}$
Ac-227	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$1.96\ 10^{-17}$	$9.15\ 10^{25}$
Th-229	$5.26\ 10^{-11}$	$3.81\ 10^{11}$	$3.68\ 10^{-8}$	$5.44\ 10^{8}$	$6.13\ 10^{-14}$	$2.92\ 10^{22}$
Th-230	$5.74\ 10^{-10}$	$3.48\ 10^{10}$	$6.94\ 10^{-8}$	$2.88\ 10^{8}$	$2.29\ 10^{-29}$	$6.05\ 10^{37}$
Th-232	$3.08\ 10^{-9}$	$6.50\ 10^{9}$	$1.23\ 10^{-7}$	$1.63\ 10^{8}$	$6.01\ 10^{-11}$	$2.38\ 10^{19}$
Pa-231	$1.55\ 10^{-9}$	$1.29\ 10^{10}$	$9.02\ 10^{-8}$	$2.22\ 10^{8}$	$2.33\ 10^{-17}$	$1.60\ 10^{25}$
U-232	$5.16\ 10^{-12}$	$3.87\ 10^{12}$	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$4.96\ 10^{-34}$	$3.61\ 10^{42}$
U-233	$1.18\ 10^{-10}$	$1.69\ 10^{11}$	$6.38\ 10^{-7}$	$3.13\ 10^{7}$	$1.22\ 10^{-16}$	$5.14\ 10^{24}$
U-234	$8.76\ 10^{-11}$	$2.28\ 10^{11}$	$3.12\ 10^{-6}$	$6.41\ 10^{6}$	$4.33\ 10^{-38}$	$2.96\ 10^{45}$
U-235	$1.42\ 10^{-9}$	$1.41\ 10^{10}$	$4.07\ 10^{-6}$	$4.92\ 10^{6}$	$4.06\ 10^{-24}$	$2.42\ 10^{31}$
U-236	$7.95\ 10^{-11}$	$2.52\ 10^{11}$	$1.39\ 10^{-7}$	$1.44\ 10^{8}$	$2.23\ 10^{-19}$	$8.03\ 10^{27}$
U-238	$3.09\ 10^{-10}$	$6.48\ 10^{10}$	$7.89\ 10^{-7}$	$2.53\ 10^{7}$	$3.07\ 10^{-17}$	$1.65\ 10^{25}$
Np-237	$1.88\ 10^{-8}$	$1.06\ 10^{9}$	$4.43\ 10^{-5}$	$4.52\ 10^{5}$	$2.60\ 10^{-32}$	$3.48\ 10^{38}$
Pu-238	$7.99\ 10^{-13}$	$2.50\ 10^{13}$	$8.28\ 10^{-10}$	$2.42\ 10^{10}$	$7.57\ 10^{-44}$	$2.37\ 10^{52}$
Pu-239	$3.47\ 10^{-11}$	$5.76\ 10^{11}$	$6.62\ 10^{-9}$	$3.02\ 10^{9}$	$7.65\ 10^{-26}$	$2.34\ 10^{34}$
Pu-240	$3.35\ 10^{-11}$	$5.96\ 10^{11}$	$1.51\ 10^{-9}$	$1.32\ 10^{10}$	$7.90\ 10^{-43}$	$2.27\ 10^{51}$
Pu-241	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$1.92\ 10^{-10}$	$1.04\ 10^{11}$	$1.40\ 10^{-37}$	$1.28\ 10^{46}$
Pu-242	$3.28\ 10^{-11}$	$6.10\ 10^{11}$	$4.06\ 10^{-8}$	$4.93\ 10^{8}$	$1.01\ 10^{-24}$	$1.77\ 10^{33}$
Am-241	$6.89\ 10^{-12}$	$2.90\ 10^{12}$	$8.91\ 10^{-9}$	$2.24\ 10^{9}$	$4.92\ 10^{-38}$	$3.64\ 10^{46}$
Cm-243	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$1.92\ 10^{-24}$	$9.33\ 10^{32}$
Cm-244	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$<1.0\ 10^{-10}$	$>2.0\ 10^{11}$	$2.62\ 10^{-54}$	$6.84\ 10^{62}$

* Where dose is effectively zero the radiological capacity is infinite, marked here as nd (not determined).

Table 23 revised: Scenario radiological capacity calculated for exposures from human intrusion – residents and smallholders

Radionuclide	Residential occupant (150 y)		Smallholder (200 y)		Resident – cap intact (150 y)	
	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)
H-3	$3.53\ 10^{-10}$	$8.51\ 10^{12}$	$2.81\ 10^{-11}$	$1.07\ 10^{14}$	$2.95\ 10^{-2}$	$6.06\ 10^{10}$
C-14	$4.35\ 10^{-6}$	$6.90\ 10^{8}$	$3.71\ 10^{-6}$	$8.08\ 10^{8}$	$3.84\ 10^{2}$	$4.67\ 10^{6}$
Cl-36	$5.47\ 10^{-6}$	$5.49\ 10^{8}$	$5.55\ 10^{-5}$	$5.40\ 10^{7}$	$1.29\ 10^{-24}$	$2.30\ 10^{31}$
Fe-55	$1.11\ 10^{-26}$	$2.69\ 10^{29}$	$7.76\ 10^{-31}$	$3.87\ 10^{33}$	0	nd*
Co-60	$8.26\ 10^{-14}$	$3.63\ 10^{16}$	$1.35\ 10^{-16}$	$2.23\ 10^{19}$	$4.16\ 10^{-18}$	$4.31\ 10^{26}$
Ni-63	$1.91\ 10^{-9}$	$1.57\ 10^{12}$	$1.08\ 10^{-8}$	$2.78\ 10^{11}$	0	nd*
Sr-90	$1.13\ 10^{-6}$	$2.64\ 10^{9}$	$2.42\ 10^{-6}$	$1.24\ 10^{9}$	$3.18\ 10^{-21}$	$5.64\ 10^{29}$
Nb-94	$1.81\ 10^{-5}$	$1.66\ 10^{8}$	$2.09\ 10^{-5}$	$1.44\ 10^{8}$	$8.14\ 10^{-12}$	$2.20\ 10^{20}$
Tc-99	$7.52\ 10^{-6}$	$3.99\ 10^{8}$	$3.31\ 10^{-5}$	$9.07\ 10^{7}$	$1.48\ 10^{-44}$	$1.21\ 10^{53}$
Ru-106	$1.80\ 10^{-50}$	$1.66\ 10^{53}$	$6.64\ 10^{-65}$	$4.52\ 10^{67}$	$8.05\ 10^{-58}$	$2.23\ 10^{66}$
Ag-108m	$1.41\ 10^{-5}$	$2.13\ 10^{8}$	$1.50\ 10^{-5}$	$2.00\ 10^{8}$	$3.76\ 10^{-13}$	$4.77\ 10^{21}$
Sb-125	$1.98\ 10^{-22}$	$1.51\ 10^{25}$	$8.08\ 10^{-28}$	$3.71\ 10^{30}$	$1.52\ 10^{-30}$	$1.18\ 10^{39}$
Sn-126	$5.35\ 10^{-6}$	$5.60\ 10^{8}$	$8.33\ 10^{-6}$	$3.60\ 10^{8}$	$3.20\ 10^{-13}$	$5.59\ 10^{21}$
I-129	$1.30\ 10^{-5}$	$2.30\ 10^{8}$	$1.12\ 10^{-4}$	$2.69\ 10^{7}$	$4.10\ 10^{-150}$	$2.03\ 10^{155}$
Ba-133	$1.90\ 10^{-10}$	$1.58\ 10^{13}$	$8.22\ 10^{-12}$	$3.65\ 10^{14}$	$2.04\ 10^{-21}$	$8.76\ 10^{29}$
Cs-134	$2.50\ 10^{-27}$	$1.20\ 10^{30}$	$1.92\ 10^{-34}$	$1.56\ 10^{37}$	$3.94\ 10^{-34}$	$4.55\ 10^{42}$
Cs-137	$2.18\ 10^{-7}$	$1.38\ 10^{10}$	$1.23\ 10^{-7}$	$2.44\ 10^{10}$	$1.73\ 10^{-14}$	$1.03\ 10^{23}$
Pm-147	$7.47\ 10^{-27}$	$4.02\ 10^{29}$	$5.81\ 10^{-32}$	$5.16\ 10^{34}$	$8.85\ 10^{-61}$	$2.02\ 10^{69}$
Eu-152	$6.06\ 10^{-9}$	$4.95\ 10^{11}$	$5.41\ 10^{-10}$	$5.54\ 10^{12}$	$2.15\ 10^{-14}$	$8.35\ 10^{22}$
Eu-154	$8.02\ 10^{-11}$	$3.74\ 10^{13}$	$1.64\ 10^{-12}$	$1.83\ 10^{15}$	$3.72\ 10^{-16}$	$4.82\ 10^{24}$
Eu-155	$1.12\ 10^{-16}$	$2.67\ 10^{19}$	$9.02\ 10^{-20}$	$3.33\ 10^{22}$	$1.99\ 10^{-45}$	$9.02\ 10^{53}$
Pb-210	$2.19\ 10^{-7}$	$1.37\ 10^{10}$	$1.97\ 10^{-7}$	$1.52\ 10^{10}$	$1.86\ 10^{-19}$	$9.63\ 10^{27}$
Ra-226**	$1.62\ 10^{-11}$	$1.85\ 10^{14}$	$1.49\ 10^{-11}$	$2.01\ 10^{14}$	$9.81\ 10^{-6}$	$1.83\ 10^{14}$

Radionuclide	Residential occupant (150 y)		Smallholder (200 y)		Resident – cap intact (150 y)	
	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)	Dose per MBq (µSv y^{-1} MBq^{-1})	Scenario Radiological Capacity (MBq)
Ra-226***	$1.20\ 10^{-3}$	$2.51\ 10^{6}$	$5.08\ 10^{-4}$	$5.90\ 10^{6}$	$3.26\ 10^{-2}$	$1.37\ 10^{9}$
Ra-228	$9.87\ 10^{-13}$	$3.04\ 10^{15}$	$7.39\ 10^{-15}$	$4.06\ 10^{17}$	$1.84\ 10^{-15}$	$9.72\ 10^{23}$
Ac-227	$6.63\ 10^{-8}$	$4.53\ 10^{10}$	$2.37\ 10^{-8}$	$1.26\ 10^{11}$	$3.65\ 10^{-18}$	$4.91\ 10^{26}$
Th-229	$4.85\ 10^{-6}$	$6.18\ 10^{8}$	$8.17\ 10^{-6}$	$3.67\ 10^{8}$	$1.99\ 10^{-13}$	$9.01\ 10^{21}$
Th-230	$8.55\ 10^{-6}$	$3.51\ 10^{8}$	$4.33\ 10^{-5}$	$6.93\ 10^{7}$	$2.25\ 10^{-28}$	$6.17\ 10^{36}$
Th-232	$3.24\ 10^{-5}$	$9.26\ 10^{7}$	$4.19\ 10^{-5}$	$7.16\ 10^{7}$	$1.97\ 10^{-10}$	$7.29\ 10^{18}$
Pa-231	$4.25\ 10^{-5}$	$7.06\ 10^{7}$	$1.61\ 10^{-4}$	$1.86\ 10^{7}$	$8.83\ 10^{-17}$	$4.21\ 10^{24}$
U-232	$1.76\ 10^{-7}$	$1.71\ 10^{10}$	$3.27\ 10^{-7}$	$9.17\ 10^{9}$	$6.57\ 10^{-34}$	$2.73\ 10^{42}$
U-233	$2.11\ 10^{-7}$	$1.42\ 10^{10}$	$5.57\ 10^{-7}$	$5.39\ 10^{9}$	$9.93\ 10^{-16}$	$6.31\ 10^{23}$
U-234	$1.36\ 10^{-7}$	$2.20\ 10^{10}$	$3.88\ 10^{-7}$	$7.74\ 10^{9}$	$3.54\ 10^{-37}$	$3.62\ 10^{44}$
U-235	$1.66\ 10^{-6}$	$1.81\ 10^{9}$	$2.63\ 10^{-6}$	$1.14\ 10^{9}$	$3.18\ 10^{-23}$	$3.09\ 10^{30}$
U-236	$1.28\ 10^{-7}$	$2.34\ 10^{10}$	$3.67\ 10^{-7}$	$8.17\ 10^{9}$	$1.83\ 10^{-18}$	$9.81\ 10^{26}$
U-238	$3.76\ 10^{-7}$	$7.99\ 10^{9}$	$6.59\ 10^{-7}$	$4.55\ 10^{9}$	$1.01\ 10^{-16}$	$5.04\ 10^{24}$
Np-237	$2.92\ 10^{-6}$	$1.03\ 10^{9}$	$5.32\ 10^{-6}$	$5.64\ 10^{8}$	$2.12\ 10^{-31}$	$4.26\ 10^{37}$
Pu-238	$2.53\ 10^{-7}$	$1.18\ 10^{10}$	$3.18\ 10^{-7}$	$9.43\ 10^{9}$	$1.31\ 10^{-43}$	$1.36\ 10^{52}$
Pu-239	$8.99\ 10^{-7}$	$3.34\ 10^{9}$	$1.67\ 10^{-6}$	$1.79\ 10^{9}$	$2.50\ 10^{-25}$	$7.18\ 10^{33}$
Pu-240	$8.88\ 10^{-7}$	$3.38\ 10^{9}$	$1.65\ 10^{-6}$	$1.82\ 10^{9}$	$6.44\ 10^{-42}$	$2.78\ 10^{50}$
Pu-241	$2.39\ 10^{-8}$	$1.26\ 10^{11}$	$4.50\ 10^{-8}$	$6.67\ 10^{10}$	$5.95\ 10^{-39}$	$3.01\ 10^{47}$
Pu-242	$8.44\ 10^{-7}$	$3.56\ 10^{9}$	$1.59\ 10^{-6}$	$1.89\ 10^{9}$	$8.26\ 10^{-24}$	$2.17\ 10^{32}$
Am-241	$6.93\ 10^{-7}$	$4.33\ 10^{9}$	$1.30\ 10^{-6}$	$2.30\ 10^{9}$	$3.75\ 10^{-37}$	$4.78\ 10^{45}$
Cm-243	$4.66\ 10^{-8}$	$6.44\ 10^{10}$	$2.13\ 10^{-8}$	$1.41\ 10^{11}$	$7.37\ 10^{-25}$	$2.43\ 10^{33}$
Cm-244	$3.84\ 10^{-9}$	$7.82\ 10^{11}$	$4.95\ 10^{-9}$	$6.06\ 10^{11}$	$9.42\ 10^{-54}$	$1.90\ 10^{62}$

* Where dose is effectively zero the radiological capacity is infinite, marked here as nd (not determined).

Radionuclide	Residential occupant (150 y)		Smallholder (200 y)		Resident – cap intact (150 y)	
	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)	Dose per MBq ($\mu Sv\ y^{-1}\ MBq^{-1}$)	Scenario Radiological Capacity (MBq)

** Assuming that wastes containing significant activity concentrations of Ra-226 are 5m below the restored surface

*** Wastes not containing significant activity concentrations of Ra-226 (<5 Bq g^{-1})

4 Updates resulting from responses to EA questions

59. Annex B presents information and arguments to support a category of "Other radionuclides" that only includes radionuclides with a half-life greater than 1 year. Radiological capacities are also provided in Annex B for radionuclides between 3 months and 1 year. This information could be used either to define a second "Other radionuclides" group for short half-life radionuclides or to include radiological capacities for each of the short-half-life radionuclides discussed.

4.1 Summary of changes

60. The following table summarises the changes discussed in the report (Table 11).

Table 11 Changes suggested in this addendum

Section	Subject	Change to radiological capacity
1, 4 and Annex B	Short half-lives	New radiological capacities that could be applied to short half-life radionuclides in Schedule 3
2.1	Large scale intrusion	No change
2.2	Time dependent trends in GW concentration	No change
2.3	Cl36 infant dose	Reduced radiological capacity for Cl-36
2.4	Monthly leachate treatment	No change
2.5	Co-60 leachate treatment	Reduced radiological capacity for Co-60
2.6	Timing of bathtubbing	No change
2.7	Parameter value changes	No change
2.8	Groundwater monitoring	No change
2.9	Timing of smallholder scenario	No change
2.10	Peak dose for intrusion scenarios	Reduced radiological capacity for 3 radionuclides
2.11	Exposure of protected species	Reduced radiological capacity for 3 radionuclides

61. The revised radiological capacity values are shown in Table 25 and 26. These tables (Table 25 and Table 26) are shown with the original ESC numbers for ease of reference and modified rows are shaded grey.

Table 25 revised: ENRMF Radiological capacity and constraint

Radionuclide	Radiological Capacity (TBq)	Scenario	Constraint*
H-3	$4.12\ 10^{3}$	Recreational (0 years)	
C-14	$1.20\ 10^{2}$	Recreational (0 years)	
Cl-36	$3.70\ 10^{-1}$	Well at boundary (All pathways)	Limiting capacity
Fe-55	$5.83\ 10^{13}$	Excavator (Borehole) 60 years	
Co-60	$2.25\ 10^{1}$	Leachate treatment	Limiting capacity
Ni-63	$2.78\ 10^{5}$	Small holding 200 years	
Sr-90	$1.24\ 10^{3}$	Small holding 200 years	
Nb-94	$1.44\ 10^{2}$	Small holding 200 years	
Tc-99	$9.07\ 10^{1}$	Small holding 200 years	
Ru-106	$5.29\ 10^{16}$	Recreational (0 years)	
Ag-108m	$2.00\ 10^{2}$	Small holding 200 years	
Sb-125	$3.33\ 10^{9}$	Excavator (Borehole) 60 years	
Sn-126	$2.20\ 10^{2}$	Well at boundary (All pathways)	
I-129	$4.17\ 10^{-2}$	Well at boundary (All pathways)	Limiting capacity
Ba-133	$6.11\ 10^{4}$	Excavator (Borehole) 60 years	
Cs-134	$1.37\ 10^{11}$	Excavator (Borehole) 60 years	
Cs-137	$2.70\ 10^{3}$	Excavator (Borehole) 60 years	
Pm-147	$4.74\ 10^{13}$	Excavator (Borehole) 60 years	
Eu-152	$7.16\ 10^{3}$	Excavator (Borehole) 60 years	
Eu-154	$3.81\ 10^{4}$	Excavator (Borehole) 60 years	
Eu-155	$7.91\ 10^{7}$	Excavator (Borehole) 60 years	
Pb-210	$4.44\ 10^{3}$	Well at boundary (All pathways) POA	
Ra-226**	$1.56\ 10^{2}$	Excavator (Borehole) 60 years	
Ra-226***	2.51	Residential 150 years	Limiting capacity
Ra-228	$1.80\ 10^{5}$	Excavator (Borehole) 60 years	
Ac-227	$1.02\ 10^{3}$	Excavator (Borehole) 60 years	
Th-229	$2.98\ 10^{2}$	Excavator (Borehole) 60 years	
Th-230	5.80	Small holding 200 years	Limiting capacity
Th-232	$7.08\ 10^{1}$	Small holding 200 years	Limiting capacity
Pa-231	4.76	Exposure of non-human species	Limiting capacity
U-232	$4.25\ 10^{3}$	Excavator (Borehole) 60 years	
U-233	$3.13\ 10^{1}$	Well at boundary (All pathways)	Limiting capacity
U-234	6.41	Well at boundary (All pathways)	Limiting capacity
U-235	4.92	Well at boundary (All pathways)	Limiting capacity
U-236	$1.44\ 10^{2}$	Well at boundary (All pathways)	
U-238	$2.53\ 10^{1}$	Well at boundary (All pathways)	Limiting capacity
Np-237	$4.52\ 10^{-1}$	Well at boundary (All pathways)	Limiting capacity
Pu-238	$1.40\ 10^{3}$	Excavator (Borehole) 60 years	
Pu-239	$8.01\ 10^{2}$	Excavator (Borehole) 60 years	
Pu-240	$8.05\ 10^{2}$	Excavator (Borehole) 60 years	

Radionuclide	Radiological Capacity (TBq)	Scenario	Constraint*
Pu-241	$3.20\ 10^{4}$	Excavator (Borehole) 60 years	
Pu-242	$4.93\ 10^{2}$	Well at boundary (All pathways)	
Am-241	$1.08\ 10^{3}$	Excavator (Borehole) 60 years	
Cm-243	$8.18\ 10^{2}$	Exposure of non-human species	
Cm-244	$7.24\ 10^{3}$	Exposure of non-human species	

*"Limiting capacity" identifies those radionuclides where the radiological capacity is less than inventory arising from disposing of 448,000 t of LLW at 200 Bq g^{-1}.

** Assuming that wastes containing significant activity concentrations of Ra-226 are 5m below the restored surface

*** Wastes not containing significant activity concentrations of Ra-226 (<5 Bq g^{-1})

Table 26 revised: Suggested Schedule 3 – Disposals of radioactive waste and monitoring

Table 3.1 Disposal by burial on the premises				
Waste type	Disposal route	Sum of fractions limits		
		Radionuclide or group of nuclides	Relevant value (TBq)	Maximum total volume
Solid waste with a maximum total activity concentration of 200 Bq/g	Burial on the premises in cells 4B, 5A, 5B, 6, 7, 8, 9, 10 and 11 of the East Northants Resource Management Facility.	H-3	$4.12\ 10^{3}$	Not specified
		C-14	$1.20\ 10^{2}$	
		Cl-36	$3.70\ 10^{-1}$	
		Fe-55	$5.83\ 10^{13}$	
		Co-60	$2.25\ 10^{1}$	
		Ni-63	$2.78\ 10^{5}$	
		Sr-90	$1.24\ 10^{3}$	
		Nb-94	$1.44\ 10^{2}$	
		Tc-99	$9.07\ 10^{1}$	
		Ru-106	$5.29\ 10^{16}$	
		Ag-108m	$2.00\ 10^{2}$	
		Sb-125	$3.33\ 10^{9}$	
		Sn-126	$2.20\ 10^{2}$	
		I-129	$4.17\ 10^{-2}$	
		Ba-133	$6.11\ 10^{4}$	
		Cs-134	$1.37\ 10^{11}$	
		Cs-137	$2.70\ 10^{3}$	
		Pm-147	$4.74\ 10^{13}$	
		Eu-152	$7.16\ 10^{3}$	
		Eu-154	$3.81\ 10^{4}$	
		Eu-155	$7.91\ 10^{7}$	
		Pb-210***	$4.44\ 10^{3}$	

Table 3.1 Disposal by burial on the premises				
Waste type	Disposal route	Sum of fractions limits		
		Radionuclide or group of nuclides	Relevant value (TBq)	Maximum total volume
		Ra-226*	$1.56\ 10^{2}$	
		Ra-226**	2.51	
		Ra-228***	$1.80\ 10^{5}$	
		Ac-227	$1.02\ 10^{3}$	
		Th-229	$2.98\ 10^{2}$	
		Th-230	5.80	
		Th-232	$7.08\ 10^{1}$	
		Pa-231	4.76	
		U-232	$4.25\ 10^{3}$	
		U-233	$3.13\ 10^{1}$	
		U-234	6.41	
		U-235	4.92	
		U-236	$1.44\ 10^{2}$	
		U-238	$2.53\ 10^{1}$	
		Np-237	$4.52\ 10^{-1}$	
		Pu-238	$1.40\ 10^{3}$	
		Pu-239	$8.01\ 10^{2}$	
		Pu-240	$8.05\ 10^{2}$	
		Pu-241	$3.20\ 10^{4}$	
		Pu-242	$4.93\ 10^{2}$	
		Am-241	$1.08\ 10^{3}$	
		Cm-243	$8.18\ 10^{2}$	
		Cm-244	$7.24\ 10^{3}$	
		Any other radionuclide	$4.17\ 10^{-2}$	

* Assuming that wastes containing significant activity concentrations of Ra-226 are 5 m below the restored surface

** Wastes not containing significant activity concentrations of Ra-226 (<5 Bq g^{-1})

*** Only applies to activity that is not supported by the parent

5 References

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Annex A. EA Correspondence

From: "Green, Rob"
Date: 8 October 2015 10:05:10 GMT
To: Gene Wilson
Cc: "Mantas, Roy"
Subject: Proposed Definition of 'Other Radionuclides' in ESC to support ENRMF variation application

Dear Gene,

As mentioned previously I have noted in the Environmental Safety Case, submitted as part of Augean's application to vary the permit at the ENRMF site, that there is an assumption that 'other radionuclides' to be limited in the permit should include radionuclides not otherwise listed that have half lives of greater than a year. This is a somewhat longer timescale than the half lives of greater than 3 months definition of 'other radionuclides' that is commonly used in the permits that we have previously issued elsewhere, including for other landfill sites such as Clifton Marsh and Lillyhall.

I spoke briefly to Nick Mitchell regarding this and he suggested that the proposed definition in the ESC for 'other radionuclides' was decided on due to operational reasons. However, he could not be more specific.

You'll appreciate that there is a need for us to ensure that we are consistent in our decision making. Consistency is achieved, in part, by making judgments based on sound evidence.

We don't feel that sufficient evidence or reasoning has been presented in the application as to why the definition for 'other radionuclides' should include those radionuclides that are not otherwise listed in the permit and have half lives of greater than a year, as opposed to greater than 3 months.

However, we are keen to better understand Augean's reasoning for this suggestion and so ask that you write to us with your justification for this proposal, which we will consider as part of our determination of the application.

Yours sincerely

Rob

Rob Green
Nuclear Regulator
Nuclear Regulation Group (South)

Environment Agency

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Environment Agency

The Company Secretary
Augean South Limited
4 Rudgate Court
Walton
Wetherby
West Yorkshire
LS23 7BF

Our ref: EPR/FB3598DD/V001
Your ref:

Date: 20 November 2015

Dear Sir or Madam,

Request for further information to support your application

Application reference: EPR/FB3598DD/V001
Operator: Augean South Limited
Facility: East Northants. Resource Management Facility

We have undertaken a review of the Environmental Safety Case that was submitted in support of the above application. There are a number of points that we require further clarification on, as well as some areas where we feel that further work and/or justification is needed. We need this information so that we may continue to process your application.

I enclose a notice that asks you to send us more information to support your application. The notice specifies what you need to send and when you must send it by.

If we do not receive it by the date set out in the notice then we can treat your application as having been withdrawn.

If you have any concerns about being able to provide this information on time please let me know.

If you have any questions about this notice please phone me on 01491 828463 or email robert.green1@environment-agency.gov.uk.

Yours faithfully

Rob Green
Nuclear Regulator

cc. Dr Gene Wilson, East Northants Resource Management Facility, Stamford Road, Kings Cliffe, Northamptonshire PE8 6XX

Environment Agency

Notice requiring further information

To: The Company Secretary

Augean South Limited
4 Rudgate Court
Walton
Wetherby
West Yorkshire
LS23 7BF

Application number: EPR/FB3598DD/V001

The Environment Agency, in exercise of its powers under **paragraph 4 of Part 1 of Schedule 5** of the above Regulations, requires you to provide the information detailed in the attached schedule. The information is required in order to determine your permit application dated **24 July 2015**. The information requested should be sent to the following address by **7 December 2015**.

Information should be sent to:

Environment Agency
Nuclear Regulation Group
Red Kite House
Howbery Park
Wallingford
OX10 8BD

Name	Date
Rob Green	20 November 2015

Authorised on behalf of the Environment Agency

Schedule

1. The information requested in supplementary letter 'Annexe 1' that accompanies this notice

Annexe 1 – summary of further information requested from Augean South Limited in support of permit application EPR/FB3598DD/V001

1) A number of smaller intrusion scenarios have been considered within the Environmental Safety Case provided with the above application.

   However, we note that a scenario for a larger intrusion involving substantial amounts of waste being displaced, for example: to make way for a major road, has been excluded from the assessment. This query originates from the fact that a large intrusion was considered in the 2009 ESC and that it was limiting for some radionuclides.

   We ask Augean to provide justification as to why a large intrusion scenario has not been considered in the Environmental Safety Case;

2) We note that Appendix F in the Environmental Safety Case includes information relating to interim concentrations for radionuclides in groundwater below the landfill. However, this information is partial and it is unclear to us whether these concentrations have been used in the assessment or are purely indicative.

   Interim concentrations of radionuclides in groundwater that have been assumed for the "well constructed at the site boundary" scenario do not appear to have been explicitly provided in the Environmental Safety Case.

   In order to provide further clarification and confidence in the assessment **we ask Augean to provide us with time trend graphs showing concentrations per unit disposal at close to the well abstraction point for the following radionuclides: H3, C-14, C-36, Tc-99, Sn-126, I-129, Ra-226**, Ra-226***, U-234, U-235, U-238, Np-237, Pu-240 and Pu-242.**

3) The Environmental Safety Case does not consider infant and child doses but rather provides an analysis that additional calculations are not necessary as previous assessments from the 2009 Environmental Safety Case show that doses to children and infants (plus the foetus/embryo) will be lower than adult doses for the majority of radionuclides (paras 430-431). We note, however, from the 2009 Environmental Safety Case that, in the case of consumption of foodstuffs contaminated with Cl-36, the child/infant doses in the were higher than adult doses by a factor of 2.5 (2009 application document Annex B table C5 – note that child/infant doses for all other radionuclides are lower than corresponding adult doses).

   We have considered the results for Cl-36 for the smallholder scenario in the (2015) Environmental Safety Case submitted in support of the variation application in light of the above:

   The dose from the maximum inventory of Cl-36 to a smallholder at 200 y is 0.08 mSv/y (table 18). A factor of 2.5 increase in this dose would be well below the dose guidance level. Similarly, for the leachate treatment scenario, peak impacts to the farming family from Cl-36 are 0.005 uSv/y. However, the limiting capacity for Cl-36 is associated with the well scenario – in these calculations the irrigation pathway (which includes consumption of foodstuffs contaminated with contaminated groundwater) contributes

about 80% of dose compared with 20% for the water drinking pathway for Cl-36 (Tables 78, 79).

We take view that the Cl-36 radiological capacity may not be conservative for infants and children. We therefore ask Augean to formally assess impacts to child/infant receptors for Cl-36 smallholder scenario and revise the Cl-36 radiological capacity accordingly. The outcome of this assessment should be provided to us.

4) Doses for leachate treatment scenarios are significantly lower (factor ~6) in the final 2015 Environmental Safety Case compared with the draft. The original model assumed 2400 m3/y based on GoldSim groundwater model output. The revised model assumes 403 m3/y based on 28 m3 monthly loads with an allowance of 20% for peak rainfall (para 609). We understand that the revised calculations in the Environmental Safety Case submitted with the application use a *'realistic volume of leachate'* but the data used to support these calculations is unclear to us.

   We ask Augean to provide justification for the reduction in values for the annual quantities of leachate that have been used in the revised model. We ask also that Augean explains the source of the 28m3 figure that has been used for monthly loads of leachate removed from site.

5) The reduced leachate volume suggested in point 4 is also of relevance for Co-60, as the dose for Co-60 at the leachate treatment facility (operational period) is reduced from 584 uSv/y in the draft Environmental Safety Case to 86 uSv/y in the final Environmental Safety Case. Despite this potentially high dose, Augean does not propose to use this scenario to limit the Co-60 capacity because (a) Co-60 accounts for only about 6% of the LLW activity in the UK national inventory, (b) the estimate assumes that all leachate is sent for treatment, which will not be the case and (c) the model is conservative because it does not take into account sorption within waste materials.

   While we acknowledge these reasons, we would like Augean to provide additional justification as to why the leachate treatment facility (operational period) scenario has not been used to limit Co-60, in the context of the historic and planned use of the Avonmouth facility for treatment and disposal of leachate from the ENRMF.

6) Bathtubbing impacts are calculated in the final Environmental Safety Case at 450 y after closure (*'the point in time the groundwater model suggests overtopping will occur'*, para 198). We note that in the draft Environmental Safety Case these impacts were calculated at 350 y after closure. We note also that modelling in the final Environmental Safety Case suggests that overtopping **will** occur, whereas the assumption in the draft Environmental Safety Case was that overtopping is uncertain to occur.

   We ask Augean to explain these changes to the bathtubbing scenario impacts.

7) We have noted a number of changes to the calculation parameters used in the final Environmental Safety Case, in comparison to the values used in the draft:

   - Infiltration rate to grassland is reduced by factor of ~5 in the final Environmental Safety Case (Table 43).

- The waste porosity is reduced from 0.5 to 0.1 in the final Environmental Safety Case (Table 46).
- The inhalation and irradiation dose coefficients for Ra-226, when Pb-210 is modelled explicitly, are different. The former has increased by factor of 3 (Table 54). We note that data from the 2011 Low Level Waste Repository Environmental Safety Case data were used in the draft Environmental Safety Case but ICRP data have been used in the final version.

We ask that Augean provides an explanation for these changes.

8) The Environmental Safety Case identifies the main contributors to dose from leachate migration via groundwater are likely to be H-3, Cl-36, Sr-90, I-129 and Pb-210 (para 171). The updated ESC goes on to say that '*groundwater monitoring for these radionuclides and comparison against background levels in groundwater ... would provide an indication of releases into the environment through this pathway*'.

   We note that Only H-3 and Pb-210 appear to be in the current groundwater analytical suite. **We ask Augean to review their current monitoring programme for groundwater, in light of the above and taking into account the predicted groundwater concentrations in point 2 above, and to provide us with the outcome of this review.**

9) The sensitivity analysis for the smallholder potentially exposed group considers doses at earlier and later times than 200 y (which is the default time used for capacity determination). At times less than 90 y this scenario becomes limiting for Sr-90 (para 1101). At these times the radiological capacity for Sr-90 becomes less than the proposed 89.6 TBq capacity limit for the ENRMF. The current limiting scenario for Sr-90 is the smallholder at 200 y scenario but the proposed capacity of this radionuclide is limited by tonnage and not by dose (tables 24 and 25)

   We note that 60y is the assumed period of authorisation for the ENRMF site and so it seems reasonable that the Sr-90 capacity is brought in line with the smallholder intrusion scenario impacts (at 60y).

   We ask Augean to reassess the Sr-90 capacity based on peak smallholder impacts at 60y and to provide us with the outcome of this assessment.

10) We note that radiological capacities for a number of other radionuclides are also based on the smallholder scenario at 200 y and this scenario provides the limiting capacity for Th-230, Th-232 and Pa-231. Since we cannot necessarily rely on any controls on land use after the assued 60 y period of authorisation we consider it reasonable for the capacities for Th-230, Th-232 and Pa-231 to be brought in line with their respective peak doses calculated throughout the assessment period (periods between 60 and 20,000 y, as opposed to the dose at 200 y.

    We ask Augean to reassess the capacities for Th-230, th-232 and Pa-231 based on their respective peak doses calculated over the assessment period and to provide us with the outcome of this assessment.

    The final Environmental Safety Case includes an assessment of dose to rabbits burrowing into the waste materials. This assessment of this scenario indicates potential

doses of > 40 uGy/h to the rabbits at 60 y (max 210 uGy/h). This is a limiting scenario for Pa-231, Cm-243 and Cm-244. The Environmental Safety Case proposes that radiological capacities for these radionuclides could be set for this scenario using the 40 uGy/h action level - resulting in radiological capacity reduction factors of 4, 6 ad 3 for Pa-231, Cm-243 and Cm-244 respectively (table 141).

We note that rabbits are not a protected species and our assessment does not indicate any significant adverse impact on a European site, Site of Special Scientific Interest, Area of Outstanding Natural Beauty or other conservation site.

However, limiting the capacity of the radionuclides that lead to doses in excess of 40 uGy/h for other burrowing species that are protected, such as badgers, should be precautionary, given that these radionuclides are very unlikely to form a significant part of the ENRMF inventory, and that ecological protection is considered at the population level as opposed to the individual level.

We ask Augean to consider reducing the capacity of Pa-231, Cm-243 and Cm-244, based on the outcome of the assessment of the potential doses to non-human species that may burrow into the waste in future.

We would prefer to receive Augean's response to the above requests as a short addendum to the Environmental Safety Case. This should include an updated summary table clarifying the limiting capacities and scenarios for each radionuclide.

Annex B. Consideration of radionuclides with half-lives less than a year

Aim

The EA (Rob Green, 8/10/2015) requested clarification of the definition of 'other radionuclides' proposed in the sum of fractions approach in the ESC presented in July 2015 (Eden Nuclear and Environment Ltd, 2015). The ESC was submitted in support of an application for a variation to the existing (2011) Permit for the ENRMF landfill site. The EA comment that they do not feel that sufficient evidence or reasoning has been presented in the ESC as to why the definition for 'other radionuclides' should include those radionuclides that are not otherwise listed in the permit and have half-lives of greater than a year, as opposed to greater than 3 months.

The radiological assessments supporting the 2015 ESC considered radionuclides with a half-life of greater than 1 year. This note presents assessments for short-lived radionuclides that support the use of a half-life cut-off of 1 year. It provides arguments why a half-life cut-off of 1 year in the sum of fractions approach is appropriate and proportionate at the ENRMF.

Background

Radionuclides with a short half-life are unlikely to lead to exposure of the public before radioactive decay reduces the inventory to insignificant levels. The EA have suggested a 3 month half-life as the cut-off that should apply. For example in the Lillyhall permit:

> *Additionally, we limited the need to consider other radionuclides to those with half-lives greater than three months, on the basis that radionuclides with half-lives less than three months will have substantially decayed before they could cause any dose impact to the public.*

The Lillyhall ESC assessments included radionuclides with half-lives between 3 months and 1 year.

ENRMF approach to accepting waste

The maximum specific activity of a consignment of low level radioactive waste (LLW) that can be accepted at the ENRMF is 200 Bq g^{-1} under the site development consent order (DCO) and the disposal restriction of 448,000 t of LLW therefore limits the maximum site inventory (to 89.6 TBq). These limits are included in the 2015 ESC.

The current Permit lists the radionuclides that can be accepted for disposal and gives disposal limit totals for each radionuclide. It also includes a limit for "Any other radionuclide" and this limit is based on the most limiting radionuclide listed, which is Pu-239 in the current permit. No half-life cut-off is specified.

The 2015 ESC proposes a 'sum of fractions' approach to limiting the radionuclides that can be accepted for disposal. As part of this approach it includes a radiological capacity for 'Any other radionuclide' and this is based on the most limiting radionuclide which is I-129 in the 2015 ESC. Paragraph 307 of the 2015 ESC defines "Any other radionuclide" as those with a half-life greater than 1 year.

The "Conditions for Acceptance" (CFA) used at the ENRMF state:

In the "others" category, radionuclides of less than one year half-life are not normally included. If such nuclides are present in significant quantities (>5 MBq/tonne or a high percentage relative to the overall activity content) this shall be notified to ERNMF for acceptance.

Thus, the CFA provides ENRMF with knowledge of any short half-life activity between 5 Bq g^{-1} and the site limit of 200 Bq g^{-1}, this notification requirement is also included in the 2015 ESC (Paragraph 323).

Radiological capacity for any other radionuclide

It would not be appropriate or proportionate to use the radiological capacity of the "Any other radionuclide" category set using I-129 (long-lived and mobile) for less mobile short half-life radionuclides in the 'sum of fractions' approach since they will have a significantly larger radiological capacity. This significantly larger radiological capacity, and the correspondingly small contribution that short-lived radionuclides would make to the 'sum of fractions', is discussed below drawing on other related assessments and on specific calculations.

Related assessments

Radionuclides with half-lives of 1 year to 6 years

The ESC assessed 8 radionuclides with half-lives of between 1 and about 6 years (Ru-106, Cs-134, Pm-147, Fe-55, Sb-125, Eu-155, Co-60 and Ra-228). The radionuclide with the shortest half-life was Ru-106 with a half-life of 1.02 years.

The radiological capacity of each of these is shown in Table 12 with the associated limiting scenario. These radiological capacities are all significantly higher than the I-129 radiological capacity of 4.17 10^{-2} TBq which is used for "Any other radionuclide". Thus, using the 'Any other radionuclide' radiological capacity would not be appropriate for these radionuclides.

Table 12 Radionuclides with half-lives 1 to 6 years considered in the ESC

Radionuclide	Radiological Capacity (TBq)	Scenario	Kd (m^3 kg^{-1})
Fe-55	5.83 10^{13}	Excavator (Borehole) 60 years	0.22
Co-60	3.83 10^{5}	Excavator (Borehole) 60 years	0.06
Ru-106	5.29 10^{16}	Recreational (0 years)	0.055
Sb-125	3.33 10^{9}	Excavator (Borehole) 60 years	0.045
Cs-134	1.37 10^{11}	Excavator (Borehole) 60 years	0.27
Pm-147	4.74 10^{13}	Excavator (Borehole) 60 years	0.24
Eu-155	7.91 10^{7}	Excavator (Borehole) 60 years	0.24
Ra-228	1.80 10^{5}	Excavator (Borehole) 60 years	0.49

The radiological capacities calculated for these radionuclides can be used to give an indication of the contribution of short lived radionuclides to the 'sum of fractions'. The ESC assessed radionuclides

with half-lives between 1 and about 6 years are not limited by the groundwater pathways. In each case the radiological capacity is very large, well above the maximum inventory (89.6 TBq – see Section 6 of the 2015 ESC) that can be disposed of at the site under the DCO. The most restrictive radiological capacity for these 8 radionuclides applies to Ra-228, and is a factor of 2000 greater than the maximum inventory (1.8×10^5 TBq/89.6 TBq). Thus the maximum contribution of Ra-228 disposals to a sum of fractions would come from disposal of 89.6 TBq Ra-228, and the fraction would be 0.0005 (89.6 TBq/1.8×10^5 TBq). The corresponding dose from each exposure scenario would be a factor of 2000 or more below the dose criterion. The contribution of the other radionuclides to the sum of fractions, even from disposal of the maximum inventory, would be smaller than 0.0005 since their radiological capacities are even larger.

These very low doses and very low contributions to the sum of fractions could in fact support a case for not accounting for radionuclides with half-lives between 1 and about 6 years in the sum of fractions; however, this is not proposed here. We will consider them in the sum of fractions and in assessments against the 200 Bq g^{-1} activity limit, as described in the ESC.

Half-lives less than 1 year

It is expected that radionuclides with shorter half-lives will have larger radiological capacities than the values given in Table 12. This is confirmed by looking at the ratio of radiological capacities obtained in the Lillyhall ESC for radionuclides with half-lives between 3 months and 1 year. The ratio to the capacity for Co-60 is presented in Table 13.

Table 13 Relative radiological capacities for Lillyhall

Radionuclide	Ratio of Lillyhall relevant value for the radionuclide to Lillyhall relevant value of Co-60
Ag-110m	4.19
Ce-144	1.97×10^3
Cm-242	1.29×10^4
Mn-54	1.16×10^1
Po-210	9.35
Zn-65	1.58×10^1

Hence, all these radionuclides would be expected to have radiological capacities greater than that for Co-60; and since the ratio for Ra-228 in the ESC is 2.13, they would also be expected to have radiological capacities greater than that for Ra-228. Hence they would contribute even less to the sum of fractions calculations and use of the radiological capacity for 'other radionuclides' would not be appropriate.

Explicit consideration of half-lives 3 months to 1 year

Radionuclides considered

ICRP (ICRP, 2012) list 40 radionuclides with a half-life of between 3 months and 1 year, 10 of which appear in the UK national waste inventory (Nuclear Decommissioning Authority, 2014) and might

therefore appear in waste streams accepted for disposal (see Table 14). This group of 10 radionuclides was therefore selected for further consideration.

Table 14 Radionuclides with half-lives between 3 months and 1 year

Radionuclide	Half-life (y)	UK Waste Inventory (MBq)	Kd (m^3 kg^{-1})	Ingestion dose coefficient (Sv Bq^{-1})
Ag-110m	0.684	2.9×10^3	0.09	2.80×10^{-9}
Ce-144	0.778	1.3×10^5	0.49	5.20×10^{-9}
Cm-242	0.446	1.6×10^3	4	1.20×10^{-8}
Gd-153	0.663	2.1×10^{-10}	0.24[1]	2.70×10^{-10}
Mn-54	0.856	5.6×10^4	0.049	7.10×10^{-10}
Po-210	0.379	1.6×10^4	0.15	1.20×10^{-6}
Sn-119m	0.802	1.4×10^{-7}	0.13	3.40×10^{-10}
Sn-123	0.354	3.5×10^{-8}	0.13	2.10×10^{-9}
Te-127m	0.298	2.2×10^1	0.13	2.30×10^{-9}
Zn-65	0.668	5.9×10^3	0.2	3.90×10^{-9}

1. The Kd for Gd-153 is based on the assumption that it has properties similar to Europium.

The national inventory of any of these radionuclides is well below (by at least a factor of 689) the maximum site inventory of 89.6 TBq. Thus the contribution to the sum of fractions would be less than 0.0015 (1/689) on the basis of the inventory alone. Furthermore, the results for the 1 to 6 year half-life radionuclides given above, and the fact that at Lillyhall shorter lived radionuclides would have larger radiological capacities than these radionuclides, suggest that the actual contribution to the sum of fractions would be much lower when radioactive decay in the different exposure scenarios was taken into account (e.g. leading to a sum of fractions contribution of 1/689*0.0005 or less). This is explored further below.

Note that the CFA requirement to notify the presence of short-lived radionuclides at >5 Bq g^{-1} could mean that in 448,000 tonnes of waste a maximum of 2.24×10^6 MBq could be un-notified, a value that is at least a factor of 10 greater than the national inventory of any of these radionuclides, and substantially greater for many of these radionuclides. This is also addressed below.

Dose results for short-lived radionuclides

The ESC explicitly considers 8 radiological assessment scenarios for the period of authorisation (see Section E3 of the ESC) and 4 scenarios relating to the period after authorisation (see Sections E4 and E5). These scenarios are listed in Table 14. The bathtubbing scenario is assumed to occur 450 years after closure and therefore the short-half radionuclides will have decayed to insignificant levels by this time: hence this scenario was not considered further. A similar argument was made for the two human intrusion scenarios which are assumed to occur 150 or 200 years after closure, respectively. Although a similar argument could also be made for the recreational scenario and borehole scenario since they occur 60 years after closure of the site, they were explicitly considered just to illustrate the level of dose. Furthermore, the recreational scenario was conservatively assumed to occur immediately at site closure rather than 60 years after closure.

The recreational use scenario, borehole scenario and the scenarios relating to the period of authorisation were explicitly considered for the 10 short half-life radionuclides listed in Table 14 and a summary of the dose results is given in Table 15. The values are based on disposal of the entire UK inventory of each of these short lived radionuclides in the ENRMF. Further details of the calculations and arguments supporting these results are given in Appendix A.

It can be seen from Table 15 that the dose results for these radionuclides are extremely low, even assuming that the entire inventory of these radionuclides is disposed of at the ENRMF. Since, this is extremely unlikely, these radionuclides with half-lives of 3 months to a year will make an insignificant contribution to the overall dose from the LLW disposed of at the site.

Table 15 Dose results for radionuclides with half-lives between 3 months and 1 year

Scenario	Exposed group	Results for radionuclides with a half-life <1 year
Period of Authorisation – expected to occur		
Direct exposure (external exposure)	Worker	Limited by dose rate criterion not radiological capacity
	Member of public	
Leachate processing off-site	Treatment worker	Dose from UK inventory <0.015 µSv y^{-1}
	Farming family/Angler	
Release to atmosphere	Member of public	Not considered as will not be released in a gaseous form
Release to groundwater	Member of public	Dose from UK inventory <1 x 10^{-10} µSv y^{-1}
Period of Authorisation – not certain to occur		
Leachate spillage	Farming family	Dose from UK inventory <0.006 µSv
Dropped load	Worker	Highly conservative assumptions give dose 1.2 x 10^{-3} µSv or less
Aircraft impact	Member of public	Doses from impact disturbing UK inventory <10^{-2} mSv
Wound exposure	Worker	Unlikely to exceed criterion based on the arguments used for all other radionuclides (i.e. low inventory)
After the period of Authorisation		
Recreational use	Member of public	Dose at time of closure from UK inventory <1.7 x 10^{-15} µSv y^{-1}
Groundwater abstraction	Member of public	Dose at 60 y from UK inventory <1.7 x 10^{-28} µSv y^{-1}
Bathtubbing	Member of public	Modelled to occur 450 years post closure by which time short half-life radionuclides will have decayed to insignificant levels.
Human intrusion		Earliest time of intrusion is 60, 150 or 200 years post closure by which time short half-life radionuclides will have decayed to insignificant levels. Dose from UK inventory of Cm-242 (inc ingrowth) <3.4 x 10^{-3} µSv y^{-1}

Radiological capacity

The direct exposure, leachate processing, leachate spillage, dropped load, aircraft impact, bathtubbing and wound exposure scenarios are not relevant to the calculation of radionuclide capacity since they consider individual loads and/or fractions of the inventory in the site. The

scenarios that determine the radiological capacity are release to groundwater, recreational use, groundwater abstraction and human intrusion.

The calculations indicate that the radiological capacity determined from the recreational scenario occurring immediately after closure would be 7 x 10^{19} MBq or greater, and that for the groundwater scenarios would be 2 x 10^{16} MBq or greater. The dose from disposal of the maximum inventory for each of the short lived radionuclides would be less than 1 x 10^{-10} µSv y^{-1} and the maximum contribution to the sum of fractions is 6 x 10^{-12}. For the borehole scenario, the radiological capacities for all radionuclides except Cm-242 are greater than 1 x 10^{29} MBq, and are greater than those for the groundwater scenario. The radiological capacity for Cm-242 (including ingrowth of Pu-238) is 5 x 10^{8} MBq but since the national inventory is 2 MBq, the contribution to the sum of fractions would be negligible.

Hence it is appropriate and proportionate to not consider these short lived radionuclides in the sum of fractions calculations.

Conclusion

Radioactive decay reduces the inventory of short half-life radionuclides to insignificant levels by the end of the period of authorisation. The doses estimated for the short half-life radionuclides during the period of authorisation are all significantly below the relevant dose criteria, even assuming that the entire UK inventory of that radionuclide is disposed of at the ENRMF. The very low doses from the entire UK inventory mean that the radiological capacity for these radionuclides is very large and hence these radionuclides would make a negligible contribution to the sum of fractions i.e. including them would have an insignificant impact as the sum of fractions would not change. Hence, the main regulatory mechanism is not sensitive to the consideration of short half-life radionuclides. In reality the sum of fractions is also not sensitive to the inclusion or omission of radionuclides with a half-life of between 1 and 6 years in the sum of fractions calculations, though these radionuclides will continue to be accounted for and explicitly included in the sum of fractions.

The assessments discussed here show that the proposed 1 year cut-off for “Any other radionuclides” in the sum of fractions calculations does not have any impact on the dose to members of the public. In addition, the dose rate criterion protects workers and members of the public when the LLW is received and disposed of, and applies irrespective of the half-life of the radionuclides in the waste.

These results provide a strong case for not including radionuclides with half-lives less than 1 year in the sum of fractions calculations. The low national waste inventory of the short half-life radionuclides suggests that they will not be presented for disposal at the ENRMF in any great amount and the precaution of reporting them if they are present in the LLW at greater than 5 Bq g^{-1} allows their occurrence to be monitored in a proportionate manner.

Appendix A to Annex B

Introduction

Calculations were performed for each radionuclide and then scaled for the UK inventory of that radionuclide, or the hypothetical maximum 'unreported inventory' of 2.24 x 10^6 MBq. The Cm-242 dose conversion factors used in the calculations assumed complete ingrowth of Pu-238.

Direct exposure

The dose to workers from waste handling operations was assessed by HPA (now PHE) and reported in the 2015 ESC (Appendix H). The doses to workers or to a member of the public at the site fence are constrained by the limit that is applied to the external dose rate from the LLW package (10 µSv h^{-1}) which applies to a waste package irrespective of the half-life. Hence, the radiological capacity is not relevant to this scenario.

Leachate processing off-site

The EA initial assessment methodology considers Ag-110m, Ce-144, Cm-242, Mn-54, Po-210 and Zn-65. The results for the short-lived radionuclides follow the same pattern observed for those with a half-life greater than 1 year, giving very low doses to a Farming family (adult) or Fisherman (adult) and slightly larger doses to the sewage treatment facility worker.

The highest doses arise from processing leachate containing Ag-110m or Mn-54, and disposal of the complete UK inventory would produce a dose of about 0.003 µSv y^{-1} and 0.015 µSv y^{-1}, respectively.

Disposal of a hypothetical maximum unreported inventory of 2.24 x 10^6 MBq would result in a dose to the sewage treatment worker of about 1.8 µSv y^{-1} for Ag-110m and 0.6 µSv y^{-1} for Mn-54, and doses to the farming family or fisherman would be <0.005 µSv y^{-1}. Note that this hypothetical inventory is a factor of 700 and 40 higher than the national inventory of these radionuclides, respectively.

The short half-life radionuclides will therefore have no impact on doses from the leachate treatment scenario.

Release to groundwater

The activity concentration at the groundwater extraction point depends on the inventory, the dilution in the groundwater and the time taken for the radionuclide to travel to that point. For radionuclides with very short half-lives, a significant amount of radioactive decay will have occurred during that time. For a given inventory, water flow rate and Kd value, the shorter the half-life, the earlier and smaller the peak activity concentration at a given extraction point. The peak activity concentration at the site boundary for H-3 occurs at 40 years, that for Sr-90 at 138 years and that for I-129 at 2100 years.

The transit time from a waste cell to a well at the site boundary or the existing extraction point is influenced by the radionuclide Kd, the rate at which water moves from the waste cell to the water table beneath the site and the distance to the extraction point through groundwater flow. If the

transit time from the base of the landfill to the extraction point is long compared with the half-life then any radioactivity entering groundwater will decay before it reaches a member of the public.

There is Kd information for all short half-life radionuclides except Gd-153, for which Europium was used, and these values are given in Table 14.

The Kd values in Table 14 are all greater than that for Sr-90 (0.013) and hence the 10 short lived radionuclides would therefore be expected to travel slower over the groundwater pathway than Sr-90, leading to longer transit times to the site boundary. Hence Sr-90 transport can be used as a bounding surrogate for these 10 short-lived radionuclides.

GoldSim output shows that the Sr-90 concentration in groundwater at the boundary well increases from breakthrough at about 10 years, peaking at 138 years. At 25 years, the concentration is greater than that at 10 years but remains a small fraction (0.14) of the peak concentration. With a half-life of 1 year there would be 0.1% of an initial inventory remaining after 10 years and the activity concentration would be expected to decrease at longer times, rather than increase.

A scoping calculation was performed based on the assumption that the peak activity concentration for the short lived radionuclides occurred at the breakthrough time (10 years) and that the breakthrough curve followed the same shape as Sr-90 but was modified by radioactive decay. It was also conservatively assumed that the activity concentration at 10 years for Sr-90 was 0.14 of the peak activity concentration, whereas it would be lower. The doses for the short lived radionuclides were then obtained from the Sr-90 dose by applying radioactive decay and scaling by the ratio of the dose coefficients. The dose coefficients for all the short lived radionuclides except Po-210 are lower than that for Sr-90 (3.07 10^{-8} Sv Bq^{-1}) so the dose from a 'short half-life Sr-90' can be used as a surrogate for all except Po-210.

Taking the peak groundwater dose for Sr-90 (1.53 x 10^{-10} µSv MBq^{-1}), and applying the fraction of the peak dose at 25 years (0.14), the dose from Sr-90 at 25 years is 2.1 x 10^{-11} µSv MBq^{-1}. Correcting for radioactive decay of Sr-90 at 25 years, the dose from Sr-90 at 25 years (assuming no decay) would be 3.8 x 10^{-11} µSv MBq^{-1}. As discussed above, the Sr-90 dose at 10 years would be less than this value but this is used here as a conservative estimate. The dose from all the short lived radionuclides would be <0.1% of this value based on radioactive decay alone, i.e. <3.8 x 10^{-14} µSv MBq^{-1} (the results range from 3.2 x 10^{-21} µSv MBq^{-1} for Te-127m to 1.2 x 10^{-14} µSv MBq^{-1} for Mn-54). Scaling by the ratio of the dose coefficients gives the estimated doses given in Table 16.

Table 16 Results for the groundwater calculations for a breakthrough time of 10 years

Radionuclide	UK Waste Inventory (MBq)	Estimated dose per unit disposal (µSv y^{-1} MBq^{-1})	Estimated capacity from groundwater migration (MBq)	Ratio UK national inventory/capacity
Ag-110m	2.9E+03	1.4E-16	1.4E+17	2E-14
Ce-144	1.3E+05	8.9E-16	2.2E+16	6E-12
Cm-242	1.6E+03	2.7E-18	7.5E+18	2E-16
Gd-153	2.1E-10	9.8E-18	2.0E+18	1E-28
Mn-54	5.6E+04	2.7E-16	7.4E+16	8E-13
Po-210	1.6E+04	1.7E-17	1.2E+18	1E-14
Sn-119m	1.4E-07	7.6E-17	2.6E+17	5E-25
Sn-123	3.5E-08	8.2E-21	2.4E+21	1E-29
Te-127m	2.2E+01	2.4E-22	8.4E+22	3E-22
Zn-65	5.9E+03	1.5E-16	1.3E+17	5E-14

Disposal of the complete UK national waste inventory of Po-210 at the site will result in a dose of 3 x 10^{-13} µSv y^{-1} (with a contribution to the sum of fractions of 1 x 10^{-14}). The corresponding dose from disposal of the maximum inventory for each of the short lived radionuclides would be less than 1 x 10^{-10} µSv y^{-1} and the maximum contribution to the sum of fractions is 6 x 10^{-12}. Assuming a breakthrough time of 5 years and the same Sr-90 dose as at 25 years, the maximum contribution to the sum of fractions is 5 x 10^{-10}.

The contribution of short half-life radionuclides to dose will therefore be negligible and they will have no impact on the sum of fractions for the groundwater pathway capacity.

Leachate spillage

Spilt leachate that enters water resources would become diluted and effective mitigation measures would be difficult to achieve. The assessment of leachate spillage therefore focusses on pathways related to the use of water resources (drinking, irrigation, livestock and angling). The leachate activity concentration used in the calculations is the maximum that could occur based on the same approach used in the GoldSim model and assuming no radioactive decay.

The highest dose arises from spillage of leachate containing Po-210, the dose arising from disposal of the complete UK inventory would be about 0.006 µSv. Disposal of 2.24 x 10^{6} MBq would result in a dose of about 0.9 µSv, though this is a factor of 140 greater than the national inventory.

The short half-life radionuclides will have no impact through the leachate spillage scenario.

Dropped load and Aircraft impact

Assessments have been undertaken for dropped waste containers and an aircraft crash at the site. The maximum doses arising from a dropped container and an aircraft impact depend on the specific activity of waste (assumed to be 5 Bq g^{-1}). The dropped load assessment calculations assume that the bag is filled with a loose dry material that disperses readily, that the package fails and that the

worker does not respond correctly. These are highly conservative assumptions. In the case of an aircraft impact 300 m^3 of waste are assumed to be displaced and the dose to a member of the public and a worker is assumed to be the same in the early stages of the response to the accident. 300 m^3 at 5 Bq g^{-1} implies a released inventory that is greater than the national inventory for 5 of the short half-life radionuclides.

The dropped load dose assessment for these radionuclides meets the site criterion for workers for all radionuclides: max is for Cm-242 (+Pu-238) with 1 x 10^{-2} mSv) (Cm-242 without Pu-238 ingrowth gives 5 x 10^{-4} mSv). All doses to the public are significantly below 20 µSv: max for Cm-242 (+Pu-238) is 3.2 x 10^{-2} µSv (value for Po-210 is 1.2 x 10^{-3} µSv). Even at 200 Bq/g (which would never be the case) the doses from the short lived radionuclides would meet the dose criteria.

For these short half-life radionuclides, the largest calculated dose following an aircraft impact on the site (approximately 1.3 x 10^{-2} mSv) arises from inhalation of dust containing Cm-242 (+Pu-238); inhalation of Po-210 gives about 5 x 10^{-4} mSv and the remaining radionuclides give much lower doses. Even at 200 Bq/g (which would never be the case) the doses from the short lived radionuclides would meet the dose criteria. As shown above the national inventory of LLW (Nuclear Decommissioning Authority, 2013) includes relatively small amounts of these radionuclides, and hence the doses from this scenario would be much lower than these values. Assuming that the impacted area contains the complete national inventory, the doses for Cm-242(+Pu-238) would be 1.7 x 10^{-2} mSv and 3.5 x 10^{-3} mSv for Po-210.

The assessment has not taken into account the depth of daily cover, has used a high resuspension factor and assumed that a large proportion of a waste package is very powdery. This calculation is therefore conservative and the complexity of an aircraft crash means that this calculation can only be considered as a scoping calculation. Nevertheless, the scoping calculations indicate that the 3 to 20 mSv dose guidance level for human intrusion events would not be exceeded by this very low probability event.

The short half-life radionuclides will have no impact through the dropped load or aircraft impact scenarios.

Wound exposure

An assessment of exposure resulting from a wound in the ESC (Section E.3.2.3) concluded that internal doses from a contaminated wound would be very unlikely to exceed 1 mSv in practice. The highest dose from incorporation of 0.1g of material at 200 Bq/g was calculated in the ESC to be 3 mSv from Ac-227. As this radionuclide is most unlikely to predominate, it was concluded that internal doses from a contaminated wound would be very unlikely to exceed 1 mSv in practice. The short-lived radionuclide with the highest dose per unit intake by ingestion (which is relevant to incorporation in a wound) is Po-210, with a dose coefficient very similar to Ac-227 (1.2E-6 Sv/Bq instead of 1.21E-6 Sv/Bq). Po-210 is also unlikely to predominate in the waste and therefore internal doses from a contaminated wound from short lived radionuclides would be very unlikely to exceed 1 mSv in practice. The short half-life radionuclides in the LLW will be handled in the same way as other radionuclides in the LLW.

Recreational user

The intended end use of the site includes woodland and grassland with paths and a view point. An assessment is therefore made of the doses to a member of the public who spends time walking over the restored site for about 2 h d^{-1} and receives external exposure from buried waste packages. The results are calculated at the time of closure (assuming no radioactive decay). The results are shown in Table 17.

Table 17 Results for the recreational scenario

Radionuclide	UK Waste Inventory (MBq)	Estimated dose per unit disposal (µSv y^{-1} MBq^{-1})	Estimated capacity from recreational scenario (MBq)	Ratio UK national inventory/capacity
Ag-110m	2.9E+03	2.3E-19	8.7E+19	3E-17
Ce-144	1.3E+05	4.3E-38	4.7E+38	3E-34
Cm-242	1.6E+03	4.4E-45	4.6E+45	3E-43
Gd-153	2.1E-10	1.5E-46	1.3E+47	2E-57
Mn-54	5.6E+04	2.9E-20	6.9E+20	8E-17
Po-210	1.6E+04	1.4E-25	1.4E+26	1E-22
Sn-119m	1.4E-07	0.0E+00	unlimited	0E+00
Sn-123	3.5E-08	6.3E-22	3.2E+22	1E-30
Te-127m	2.2E+01	2.3E-42	8.8E+42	3E-42
Zn-65	5.9E+03	2.8E-19	7.2E+19	8E-17

The doses at the time of closure are all very low, and those after 60 years would be even lower. The highest dose per unit inventory is from Zn-65. Disposal of 2.24 x 10^{6} MBq of Zn-65 would result in a dose of about 6 x 10^{-13} µSv y^{-1}. The radiological capacities of the radionuclides are 7 10^{19} MBq or greater. Disposal of the complete UK inventory would produce a dose of about 1.7 x 10^{-15} µSv y^{-1} or less from each radionuclide (highest dose is from Zn-65).

The short half-life radionuclides will have no impact on the dose through the recreational user scenario, nor on the sum of fractions.

Groundwater extraction

The doses from groundwater extraction after the period of authorisation (i.e. after 60 years) will be much lower than those from groundwater during the period of authorisation since radioactive decay will have reduced the activity concentrations. The minimum radiological capacity is 7 x 10^{33} MBq and the maximum dose from the national inventory is 1.7 x 10^{-28} µSv y^{-1}. Hence the doses will be negligible and the contribution to the sum of fractions will be negligible.

Borehole

The doses from the borehole scenario at 60 years are very low. The maximum dose per unit disposal results from Cm-242, due to ingrowth of Pu-238. The dose from the complete UK inventory for

Cm-242 (including ingrowth of Pu-238) is 3.4 x 10^{-3} µSv y^{-1}, and the associated radiological capacity assuming a 1 mSv dose criterion is 5 x 10^{2} TBq (5 x 10^{8} MBq). For all other radionuclides the associated radiological capacity is greater than 1 x 10^{23} TBq (1 x 10^{29} MBq) and the dose from the national inventory is less than 3 x 10^{-22} µSv y^{-1}. Hence the doses will be negligible and the contribution to the sum of fractions will be negligible.

Annex C. Time-dependent concentrations in groundwater

Figure 1. Time-dependent concentrations of H-3 in groundwater

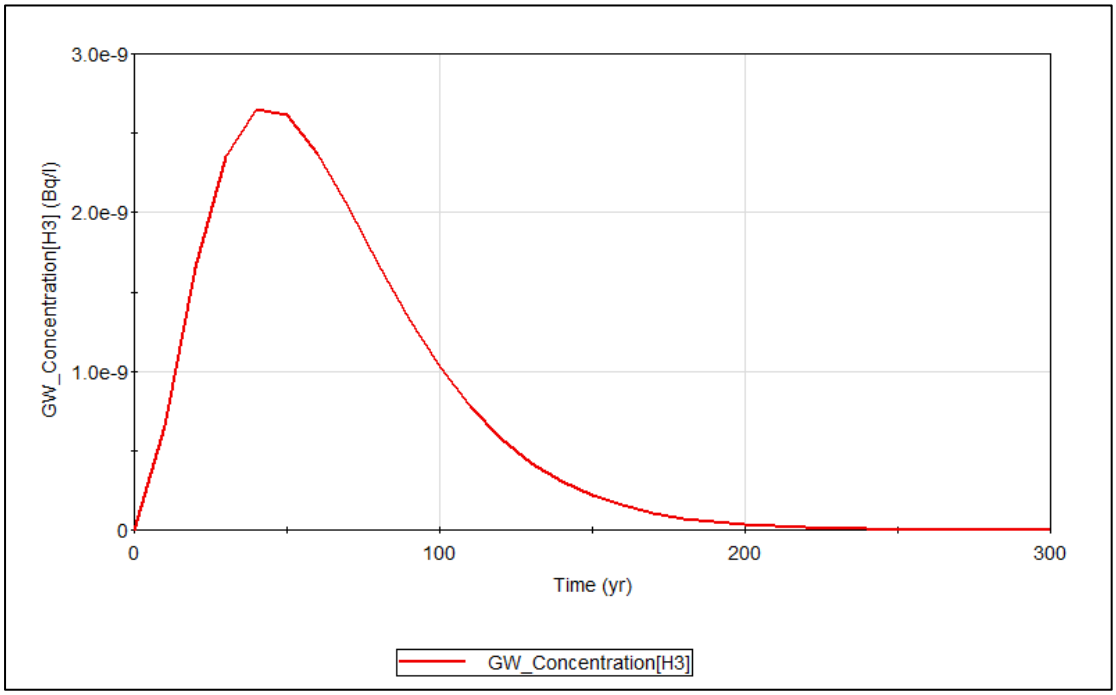


Figure 2. Time-dependent concentrations of C-14 in groundwater

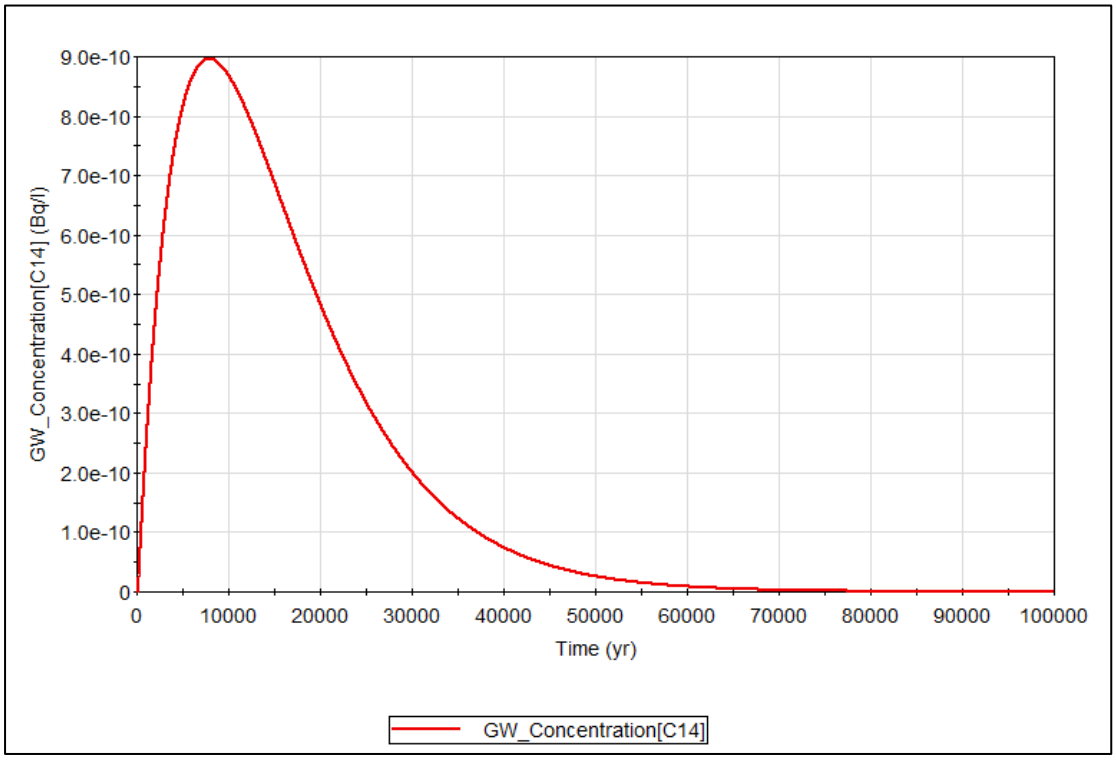


Figure 3. Time-dependent concentrations of Cl-36 in groundwater

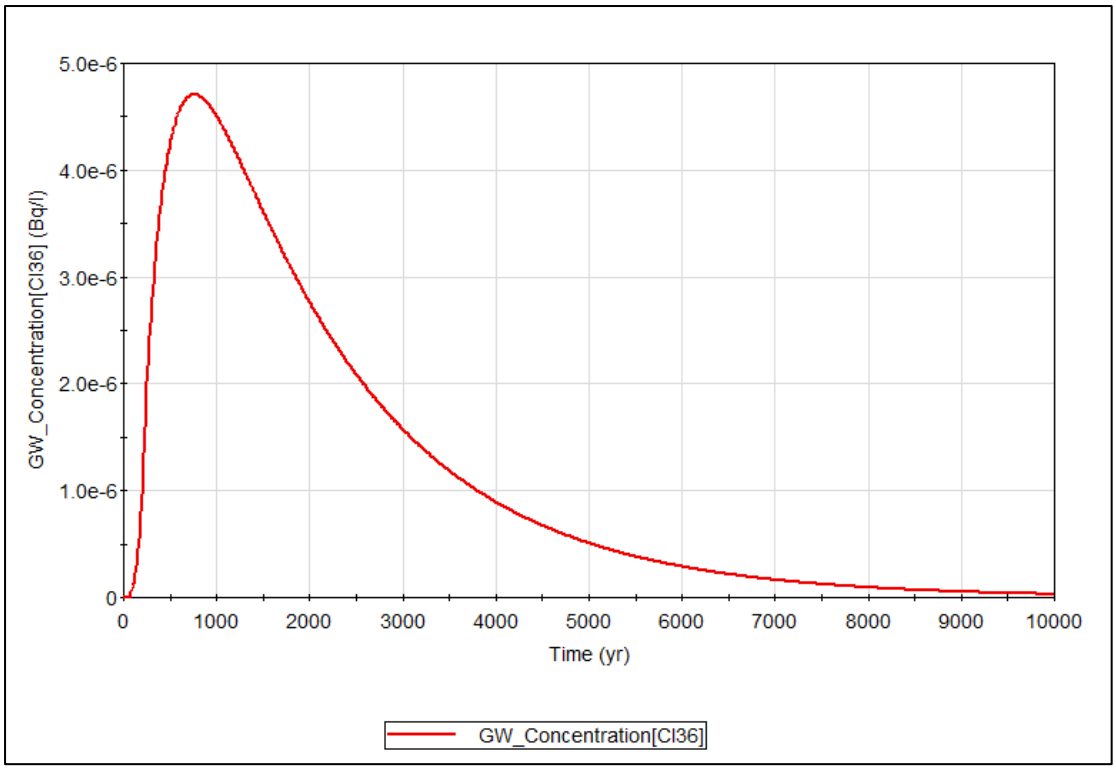


Figure 4. Time-dependent concentrations of Tc-99 in groundwater

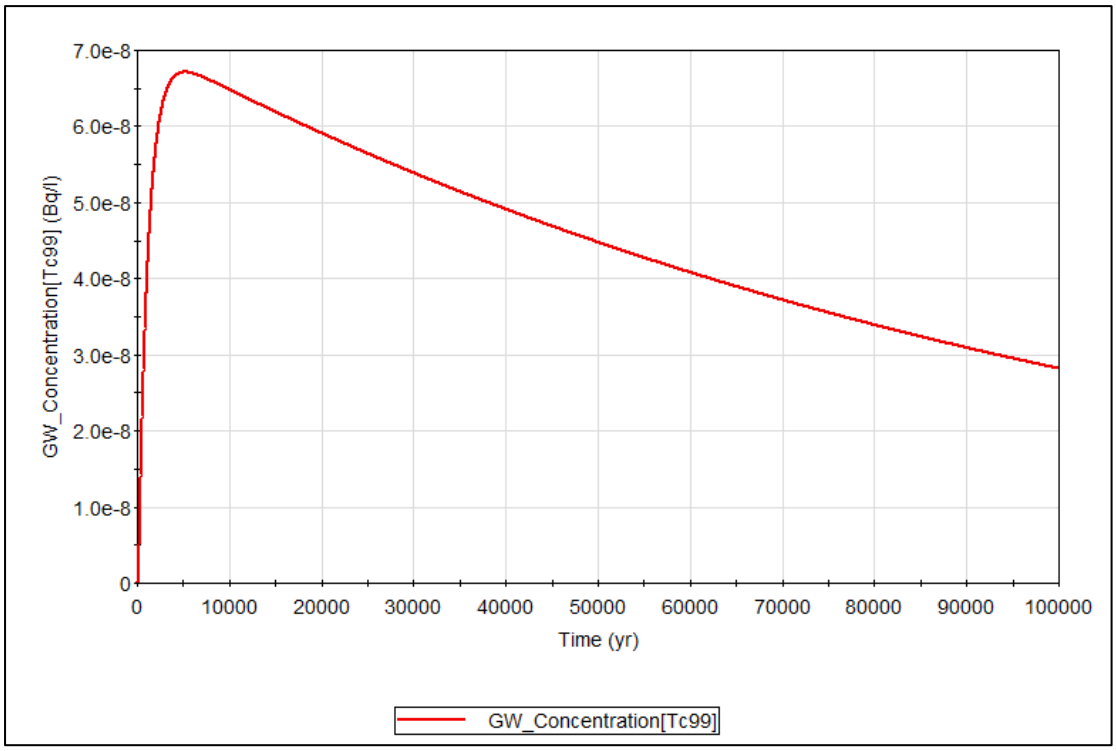


Figure 5. Time-dependent concentrations of Sn-126 in groundwater

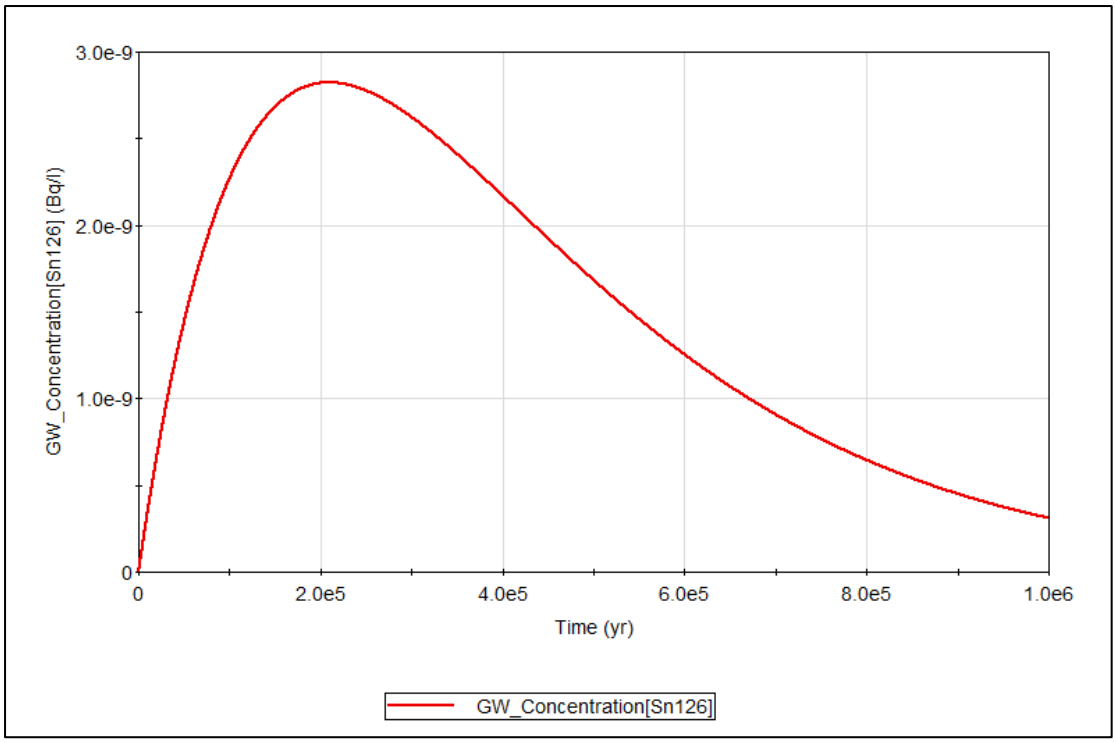


Figure 6. Time-dependent concentrations of I-129 in groundwater

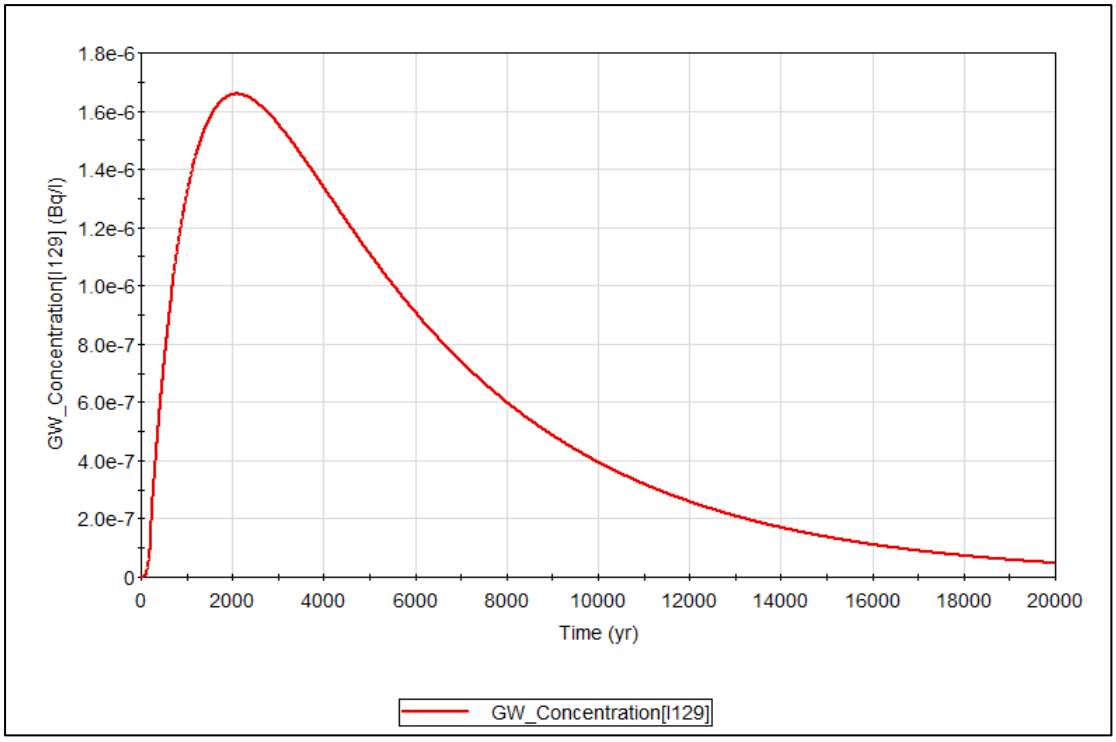


Figure 7. Time-dependent concentrations of Ra-226 in groundwater

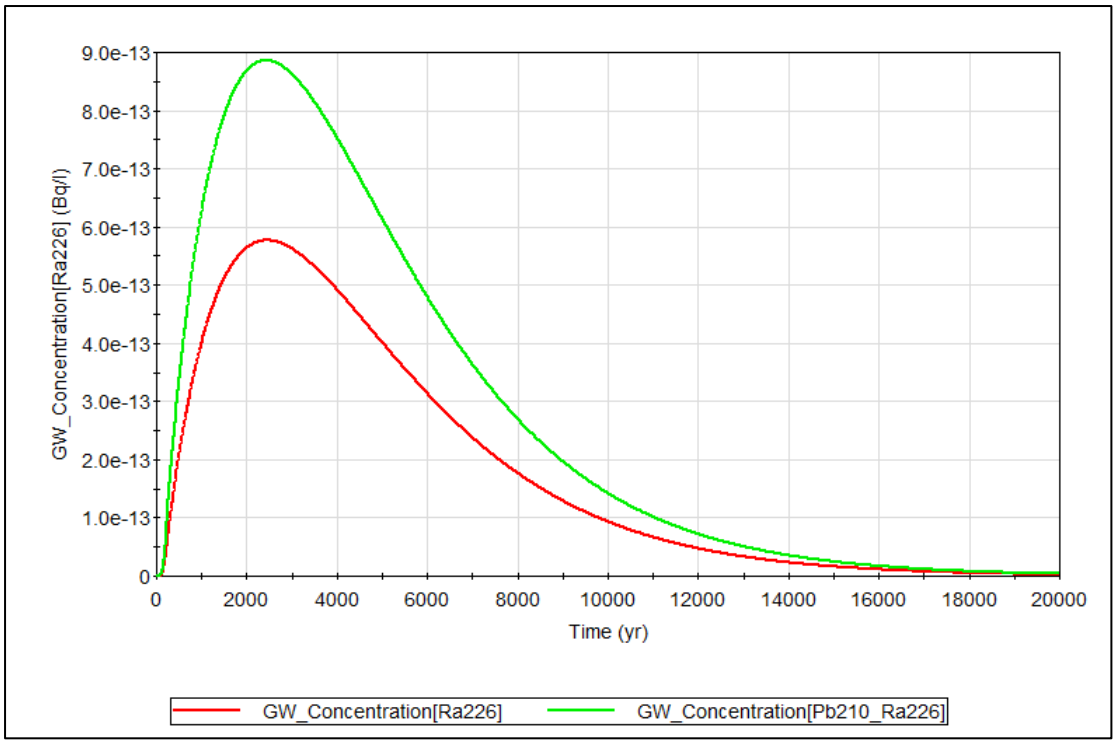


Figure 8. Time-dependent concentrations of U-234 in groundwater

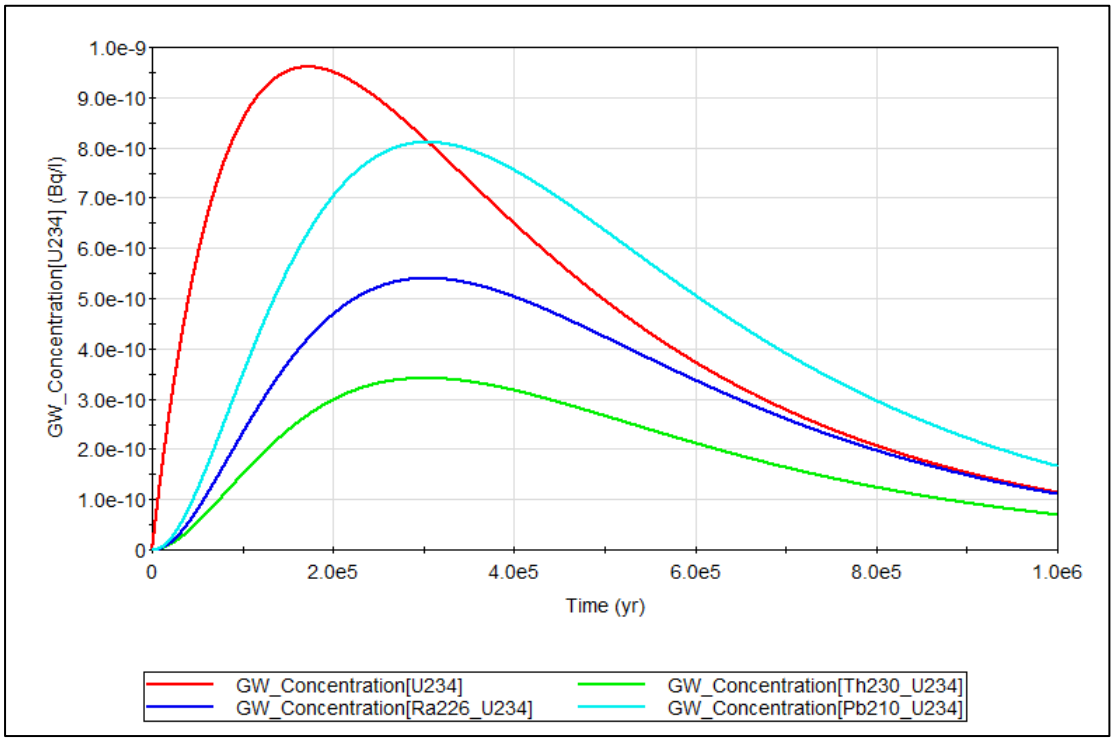


Figure 9. Time-dependent concentrations of U-235 in groundwater

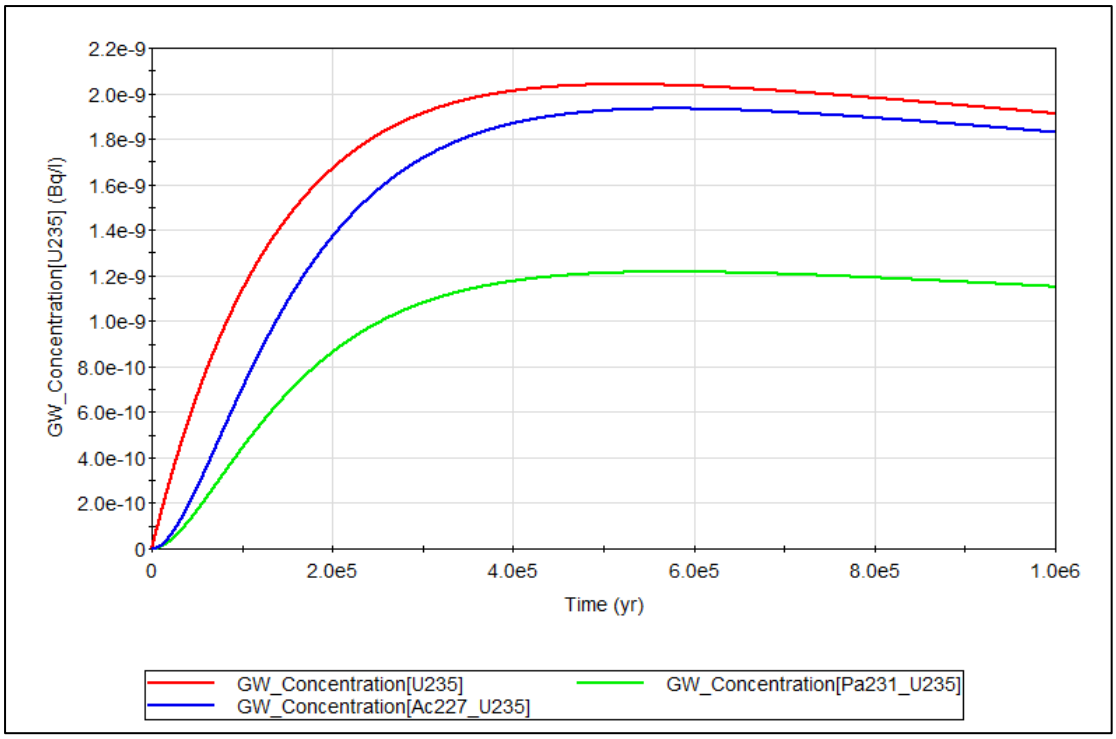


Figure 10. Time-dependent concentrations of U-238 in groundwater

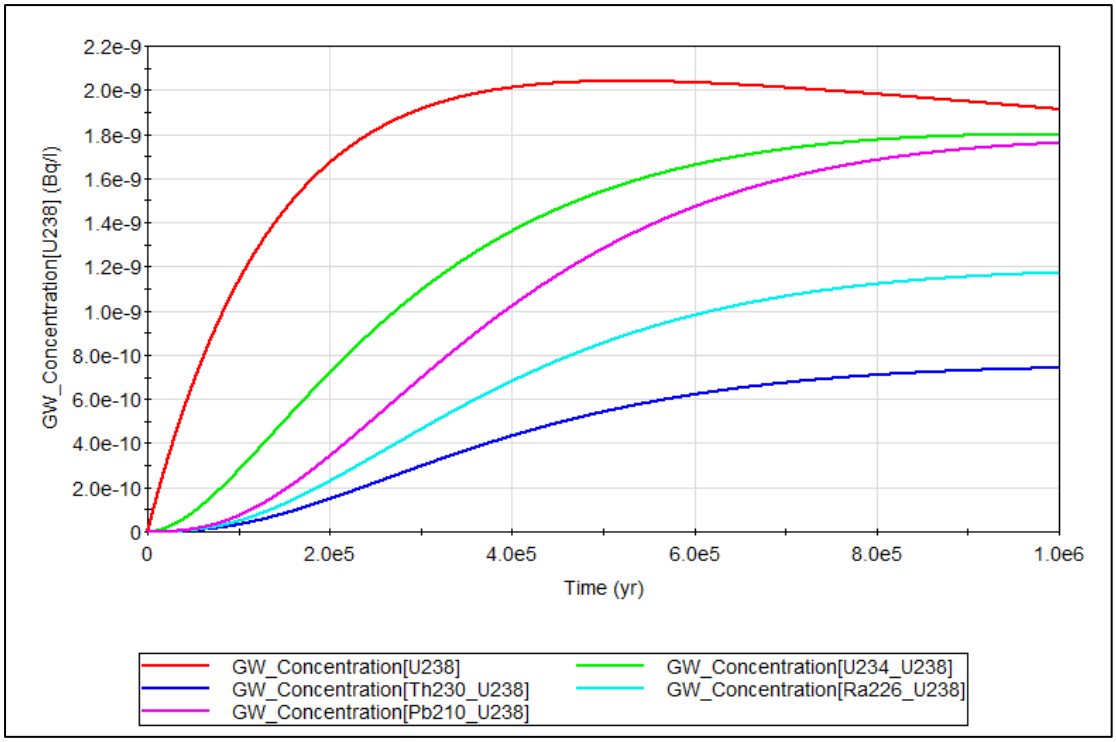


Figure 11. Time-dependent concentrations of Np-237 in groundwater

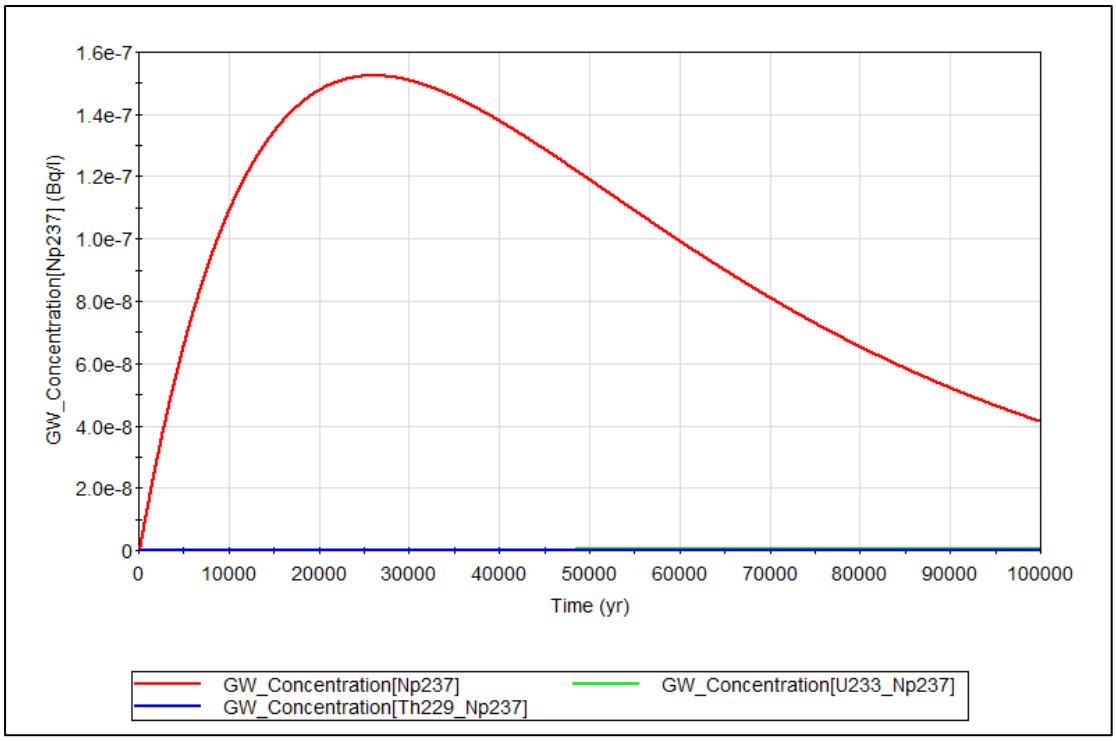


Figure 12. Time-dependent concentrations of Pu 240 in groundwater

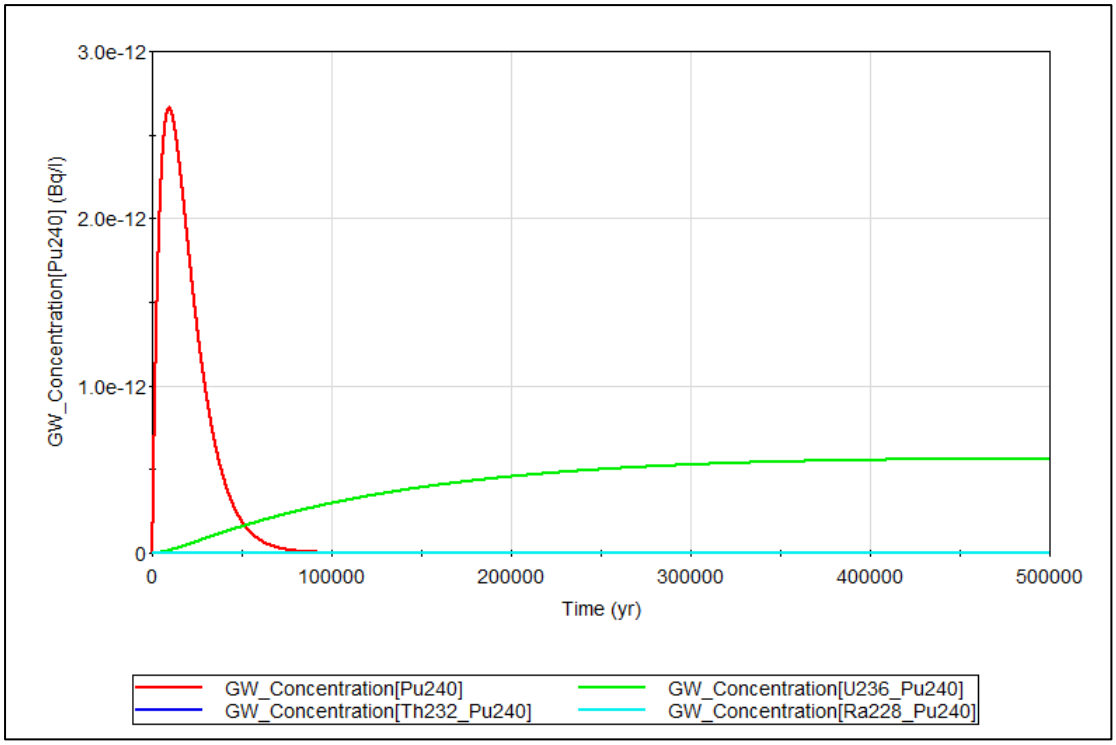
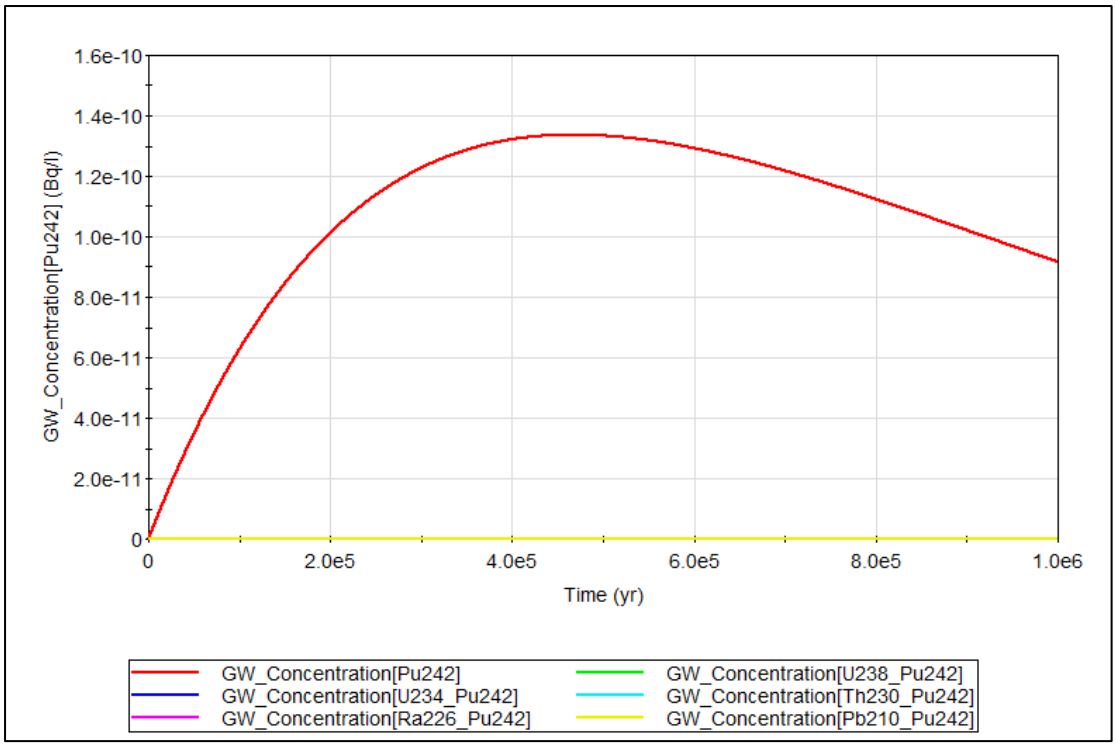


Figure 13. Time-dependent concentrations of Pu-242 in groundwater



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