Site Restoration

Winfrith Site: End State Radiological Performance Assessment 2025

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See table on page 6.

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Winfrith Site:
End State Radiological Performance Assessment 2025

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Report History

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Version	Date	Author	Amendments / Change
Version 1 Draft 1	22/12/2023	T.D. Baldwin *et al.*	First draft for NRS review.
Version 1 Draft 2	22/03/2024	T.D. Baldwin *et al.*	Revised in response to NRS review comments and to reflect the revised mire design.
Version 1 Draft 3	01/11/2024	T.D. Baldwin *et al.*	Revised in response to Quintessa Ltd peer review comments and to reflect the revised A59 and Dragon Mortuary Holes inventory data.
Version 1 Draft 4	08/12/2024	T.D. Baldwin *et al.*	Revised in response to NRS review comments, finalisation of the peer review and to reflect changes in the following revised reports: Restoration Management Plan, Site Description, and Conceptual Site Model.
Version 1 Draft 5	16/12/2024	T.D. Baldwin *et al.*	Revised in response to additional NRS review comments.
Version 1	17/12/2024	T.D. Baldwin *et al.*	Revised in response to final approval comments from NRS (formatting changes only).
Version 2	30/04/2025	T.D. Baldwin *et al.*	Minor correction made to the human intrusion dose calculation results; there are no changes to the conclusions, dominant radionuclides or dose pathways.

Executive Summary

E1 NRS is developing a proposal for the decommissioning of the Winfrith nuclear site that includes on-site disposal of radioactive waste. This involves a combination of disposal in-situ of radioactive below-ground structures, disposal of radioactive waste (mainly blocks of concrete and broken concrete from demolition of the above-ground building structures), and deposit of non-radioactive waste (blocks of concrete and broken concrete) for the purpose of infilling unwanted below-ground voids as part of land restoration.

E2 This report presents a radiological performance assessment of the risk and potential doses arising from all radioactive sources on the Winfrith site once decommissioning activities are complete and the proposed end state for each source has been implemented. The assessment supports development of the Winfrith site's Waste Management Plan (WMP) and Site Wide Environmental Safety Case (SWESC), which will be submitted to the Environment Agency as part of the application for a variation to the site's radioactive substances regulation (RSR) permit under the Environmental Permitting Regulations (EPR) to allow on-site disposal of radioactive wastes. The principal regulatory guidance of relevance to this application is the environment agencies' *Guidance on Requirements for Release from Radioactive Substances Regulation* (GRR). This assessment also supports continued optimisation of the site end state design and management arrangements.

E3 The potential radiological impacts arising from the proposed Winfrith on-site disposals are assessed against the quantitative Requirements of the GRR. The scope of this assessment includes radiological impacts arising from:

- natural evolution of the disposals through aqueous release of radionuclides to areas where a representative person might become exposed in the future (GRR Requirements R9 and R10);
- direct external irradiation of a representative person where sub-surface contamination remains in-situ and undisturbed (GRR Requirements R9 and R10);
- inadvertent human intrusion and the subsequent exposure of a representative person to radioactivity (GRR Requirement R11); and
- radiological impacts to non-human biota (GRR Requirement R14).

E4 Assessment of natural disruptive processes on the Winfrith site (GRR Requirement R12), such as erosion, flooding, earthquakes and climate change, has informed both the scenario and assessment case identification approach and development of the natural evolution assessment model. No natural processes that would disrupt the site and that would also lead to exposed radioactive materials have been identified. Where justified, the impact of natural disruptive processes on the disposals has been quantitatively assessed through the consideration of variant scenarios (e.g. the impact of a major earthquake) and the incorporation of processes into the natural evolution assessment conceptual models (e.g. groundwater level rises).

E5 Three broad radiological site feature groups[1] are considered: the Steam Generating Heavy Water Reactor (SGHWR) complex; the Dragon reactor complex; and the former A59 area of contaminated land. Each feature group includes features that comprise discrete contaminated structures or areas with an explicit inventory that are individually modelled. The two reactor buildings form the disposal structures, the below-ground voids of which will be filled with radioactive and non-radioactive wastes and then covered with engineered caps. The A59 feature group consists of historically contaminated land; NRS intends to further remediate the radiological contamination in this area sufficient to demonstrate that the remaining ground is out-of-scope (OoS) of RSR. Thus, the A59 area does not form part of the permit application for on-site disposal. However, the A59 feature group has been included in the PA, albeit with a radiological inventory that is OoS of RSR, to ensure a robust transparent assessment.

E6 The Reference Case calculations presented in this report assume a cautious, but credible, reference estimate for the radioactive inventory and activity concentrations of features and components that are expected to form the on-site disposals. The estimates are based on existing characterisation data, provenance information and/or cautious assumptions, depending on the availability of relevant information. The end state inventory is dominated by the SGHWR feature group (98% of the total radioactivity) over that of the Dragon reactor complex and OoS A59 area (around 1% each).

E7 Whilst conservative assumptions have been made to develop the Reference Case inventory, the estimates must still be credible (i.e. not overly conservative), otherwise appropriate optimisation assessments cannot be made. Nonetheless, it is also important to understand the impact of current inventory uncertainty, which cannot be reduced until access is possible to some areas of the reactors and further characterisation undertaken. Thus, the identified gaps, uncertainties and assumptions in the inventory have been used to support derivation of alternative, more conservative, inventory estimates. The alternative inventory estimates assume the maximum, rather than average, characterisation data by default, but alternative assumptions have been made where there are other sources of uncertainty. The alternative inventory accounts for variations in possible fingerprints and radionuclide content, or contamination volume / surface area, for components where this is considered appropriate.

Natural Evolution Assessment

E8 The Winfrith natural evolution assessment model, implemented in the GoldSim software package, has been developed to consider radionuclide aqueous release and transport, consistent with the site-specific Winfrith Conceptual Site Model. The model divides the radionuclide release and transport system into three discrete but interacting modules based on the source-pathway-receptor linkage: the near field (which includes the source); the geosphere; and the biosphere. Releases from the geosphere are assumed to enter three compartments in the modelled biosphere where humans may be exposed to radioactive contamination:

[1] A group of associated site features, such as reactor buildings for which it is logical to administer together due to common prior use, close locality or shared structural components. For Winfrith, the SGHWR and Dragon reactor complex, and the former A59 areas, form feature groups.

- an on-site Land/Mire (an area of land between SGHWR and Soldier's Bridge potentially receiving releases from the SGHWR and A59 feature groups);
- the River Frome (a stretch of the River close to the site boundary potentially receiving releases from all three feature groups); and
- an off-site Field (a field assumed to neighbour the River Frome potentially contaminated by river water, either through flooding or irrigation).

E9 To explore uncertainties in the application of the model to the site and uncertainties in the available information, a deterministic Reference Case assessment has first been defined based on realistic and best estimate parameter values. The effects of uncertainties have been considered through additional deterministic calculations: 18 alternative assessment cases, 18 variant scenarios and two "what-if" scenarios. The Reference Case assessment uses the reference radiological inventory for the features proposed to remain on-site, but the impact of uncertainty in the inventory is explored through the two alternative inventory estimates in the alternative assessment cases. For most assessment cases and scenarios, a set of seven representative persons (RPs) has been defined, based on local habits: an angler, a river paddler, a mire mudder (a participant in a "tough mudder" style obstacle course event), a park user, a construction worker, a farmer and a smallholder.

E10 It is important to note that the radiological impacts for all RPs presented here are conditional doses, that is, they are conditional on the assumed scenario occurring. For example, given the evidence of local habits, a receptor walking across the site in the future or fishing in the River Frome is expected. However, the probability of someone living on the site, growing crops and raising livestock, and doing so directly on the small area of land potentially contaminated by releases from the disposals (the Smallholder RP), has a much lower probability. Nonetheless, all the RPs considered in the Reference Case assessment are assumed to occur.

E11 In the Reference Case assessment, the total calculated peak dose rates for all of the RPs resulting from natural evolution of the proposed on-site disposals are more than an order of magnitude below the dose rate equivalent of the GRR Requirement R10 risk guidance level (RGL, 1.7E-02 mSv y^{-1}). The highest peak dose rate (3.0E-04 mSv y^{-1} occurring around 56,800 years in the future) is associated with the Smallholder (Land/Mire) RP, who is assumed to reside, grow and consume vegetables and fruit, and raise and consume livestock, on land contaminated by groundwater releases from the SGHWR and A59 feature groups. Peak dose rates for the other RPs are up to five orders of magnitude lower than the peak Smallholder (Land/Mire) RP dose. All peak dose rates occur more than 50,000 years in the future except for the Mire Mudder and Construction Worker (Land/Mire) RPs, which occur after 50 years and are associated with A59 releases to the Land/Mire model compartment (but which have peak dose rates orders of magnitude lower than the Smallholder RP).

E12 Dose rates are dominated by the ingestion of contaminated foodstuffs for all RPs that consider the ingestion exposure pathway. Dose rates for the Smallholder (Land/Mire) RP are primarily associated with the ingestion of foodstuffs contaminated with ^{90}Sr,

^{210}Pb, ^{226}Ra, ^{234}U and ^{238}U. Ingestion of animal foodstuffs and terrestrially-grown plants are the dominant contributors.

E13 Peaks in dose rates at early times are generally associated with ^{90}Sr, whilst later peaks tend to be associated with ^{210}Pb, ^{226}Ra and the actinides. However, some actinides contribute to peaks at early times and those are generally associated with releases from the OoS A59 feature group. Differences in the timing of the peaks are associated with the half-life and near-field sorption potential of the dominant dose-contributing radionuclides, and the presence and degradation status of the concrete structures.

E14 Of the three feature groups, the SGHWR is the dominant dose-contributing feature to the peak dose rate for all RPs except for the Mire Mudder and Construction Worker (Land/Mire) RPs, where the OoS A59 feature group dominates. In the first 1,000 years the OoS A59 feature group is the dominant contributor to dose rate for all RPs.

E15 The 18 alternative assessment cases consider the potential effects of parameter uncertainty on calculated dose rates by undertaking deterministic calculations assuming parameter values at the extremes of their ranges. The Smallholder (Land/Mire) RP continues to receive the highest dose rate of all the RPs, across every alternative assessment case considered. In all but one of the alternative assessment cases considered peak dose rates to all RPs remain below the dose rate equivalent of the RGL. The exception relates to an alternative assessment for biosphere food uptake factors, which specify what proportion of a radionuclide in water or soil will be taken up by a plant or animal foodstuff. The Reference Case considered best estimate food uptake factors for every radionuclide. In the alternative case that considers maximum values for foodstuff biosphere uptake factors, the peak dose rate for the Farmer and Smallholder RPs in the Land/Mire compartment exceeds the dose rate equivalent of the RGL by about a factor of about five after 1,000 years (peaking at 7.5E-02 mSv y^{-1} for the Smallholder RP). However, it is important to recognise that this calculation considers the extreme of the value range for every food product uptake factor for every radionuclide. In addition, these calculations assume that the RP scenarios occur; the probability of a smallholder living directly on the contaminated area in the future would be expected to be less than one. Whilst farming in the area is a probable activity, doing so on the contaminated area is less likely, as is assuming that the Farmer RP's entire meat and vegetable intake is derived from the area and is contaminated. The results suggest that uncertainty in the following parameters could most influence dose rates: inventory, biosphere pathway food product uptake factors; radioelement partition coefficients for concrete, Poole Formation material, soil and sediment; and average annual outflow rates from the proposed mire to the River Frome.

E16 The 18 variant scenarios considered in the Winfrith natural evolution assessment can be split between the 13 that consider uncertainty in the conceptual model, including uncertainty in the future evolution of the proposed on-site disposals and their setting, and the five that consider uncertainty in the configuration of the features:

- In all but one of the variant concept scenarios, peak dose rates to all RPs remain below the dose rate equivalent of the RGL. Dose rates are highest for a Well Abstractor RP in the groundwater abstraction variant scenario, where an RP is assumed to abstract and consume groundwater released from a well 1 m down-gradient of each radioactive feature. The peak conditional dose for both the SGHWR and Dragon reactor complex Well Abstractor RPs is below the dose equivalent of the RGL for the entire assessment period. The modelled A59 area inventory satisfies RSR OoS criteria and this feature does not form part of the application for on-site disposal, but it was included as part of a robust assessment. The OoS A59 feature calculated peak dose rate exceeds the dose rate equivalent of the RGL by a factor of about two in the first 60 years after the SRS. However, the calculated conditional dose does not account for likelihood – the probability of drilling such a well and its use as a sole drinking source is low. Based on the number of wells in the region and the area of potential contamination between the A59 area and the River Frome, an annual probability of 1E-03 has been estimated. When multiplied with the calculated peak dose rate, this would greatly reduce the associated peak risk, falling to two orders of magnitude below the RGL.

- Of the other variant concept scenarios, which have peak dose rates less than the RGL, those with the most significant impact are seasonally fluctuating groundwater levels on top of the Reasonable Worst Case groundwater levels, and assuming the entire flow path from SGHWR and A59 reaches the Land/Mire compartment.
- The five variant configuration scenarios considered (e.g. changing concrete block size, replacing blocks with rubble, or grouting all voids) have negligible impact on the peak dose rates for all RPs and dose rates to all RPs remain below the dose rate equivalent of the RGL.

E17 The two "what-if" scenarios consider highly speculative situations that are not deemed to be credible future outcomes. As such, they do not reflect the general uncertainty in the evolution of the disposal system but can be used to bound worst-case events. The what-if cases are instantaneous hydraulic failure of the concrete structures from the start of disposal implementation (e.g. due to an earthquake) and extreme climate change with groundwater to 1 m below surface-level. In both of these scenarios, peak dose rates to all RPs remain below the dose rate equivalent of the RGL.

E18 In summary, the Reference Case NE assessment results for all RPs are at least an order of magnitude beneath the Requirement R9 dose constraint and the dose equivalent of the Requirement R10 risk guidance level for the entire assessment period. Consideration of uncertainties in parameter values, conceptual uncertainties and disposal system configuration identifies the assumptions and processes that the system is most sensitive to. The variant scenario calculations that lead to higher dose rates are associated with low likelihood scenarios that combine conservative assumptions and values at the extreme of the identified parameter ranges.

Site Occupancy Assessment

E19 MicroShield® has been used to determine potential doses to site occupiers in situations where sub-surface contamination remains in-situ and undisturbed. This scenario may be applicable when considering the future use of the site for recreational purposes, or for considering the dose to a person in a "portacabin"-type office, in a caravan or in a vehicle parked in a car park situated above the buried contamination. Assessment cases have considered exposure of people to radioactivity as a result of walking a dog, camping and living in a caravan above buried structures (worst-case site occupancy scenarios) in the years 2036 (the assumed site Interim End Point (IEP) date) and 2066 (the assumed Site Reference State (SRS) date). NRS will retain control over the site between the IEP and the SRS such that it would not be possible to live on the site during this time; therefore, a caravan dweller receptor is only considered feasible from 2066. The calculated doses are all below the dose equivalent of the RGL (Requirement R10) for the Reference Case.

E20 The key results can be summarised as follows:

- For the Reference Case (which assumes the reference inventory and the following engineered cap/cover material thicknesses: SGHWR 4.0 m thick cap; Dragon 3.8 m thick cap; and A59 0.5 m thick cover material), the calculated annual effective doses to all receptors are at least an order of magnitude below the dose rate equivalent of the RGL for all modelled features at the IEP and SRS.
- For alternative assessment cases that assume the more conservative alternative inventory, the calculated annual effective doses to all receptors are many orders of magnitude below the dose rate equivalent of the RGL for all modelled features at the IEP and SRS.
- Variant configuration cases have been considered to inform future optimisation of the engineered caps above the reactor structures and to assess the impact of uncertainty in the thickness of cover material above the A59 area (noting that this area will be OoS and therefore will not require further optimisation). For variant cases that assume the reference inventory and a thinner layer of engineered cap or clean cover material:
    - The calculated annual effective doses to all receptors are many orders of magnitude below the dose rate equivalent of the RGL for the SGHWR and Dragon structures at the IEP and SRS for all cap thicknesses considered.
    - For OoS A59 features, calculated annual effective doses to the dog walker and camper RPs are below the dose rate equivalent of the RGL even if no cover material is assumed. Only when considering the unrealistic scenario of a caravan dweller lying horizontally for an entire year with no cover material directly above the remediated A591/HVA area at the SRS is a dose comparable to that of the RGL calculated. The ground survey that will be completed as part of the site closure process will ensure that there is appropriate clean cover material in place.

Inadvertent Human Intrusion Assessment

E21 Assessments of the potential dose impacts from inadvertent human intrusion into the proposed Winfrith on-site disposals have been made using the NRS Generic Intrusion Methodology (GIM) tool. This considers exposure of intruders and the subsequent exposure of a representative person to radioactivity as a result of various stylised intrusion scenarios.

E22 The Reference Case calculations assume that intrusion occurs in 2066 (when the SRS is reached) and consider the reference inventory and reference thickness for the engineered cap/cover material above each feature group. In cases where the GRR Requirement R11 dose guidance levels are exceeded with these assumptions, further calculations have been undertaken at dates beyond 2066 to identify when the calculated dose falls below the dose guidance level.

E23 The calculated doses are compared to the GRR Requirement R11 dose guidance level, which is specified as a range of around 3 mSv y^{-1} to around 20 mSv in total. Values towards the lower end of this range are applicable to prolonged exposures (for example, an infant living on contaminated material), while values towards the upper end of the range are applicable only to transitory exposures (such as for workers excavating material).

E24 Key points from the GIM intrusion calculations for the Reference Case are as follows:

- All doses from intrusions into all parts of the SGHWR feature group in 2066 are below the dose guidance level if the mortuary tubes are excluded. The largest doses arise from the large, deep excavations with the infant land user receiving the greatest dose.
- If the conservatively estimated residual SGHWR mortuary tube inventory is included, doses from the large, deep excavation and borehole array to infant land users are above the dose guidance level in 2066 in the Reference Case. For the large, deep intrusion, the dose falls below the dose guidance level by 2156. For the borehole array, the dose is below the dose guidance level by 2076. However, there is significant uncertainty associated with the SGHWR mortuary tubes inventory estimate due to the inability to access them at this time. These results support the planned work to empty, clean and characterise this feature during decommissioning to better constrain, and optimise as appropriate, the residual inventory.
- All Reference Case intrusions into the Dragon reactor building in 2066 are below the dose guidance level. The assessed borehole arrays are considered to have a low probability due to the limited areal extent of some of the features considered; however, these still result in doses significantly below the dose guidance level in 2066. All intrusions into the Dragon B78 building floor slab and the mortuary hole structure in 2066 are significantly below the dose guidance level.
- All intrusions in 2066 into the various parts of the A59 area, which are assumed to be OoS, are significantly below the dose guidance level.
- The receptor subject to the greatest dose is generally the infant via ingestion from land use and the dominant radionuclide dose contributor is typically ^{90}Sr.

E25 Alternative assessment cases and variant configuration case calculations have been undertaken to consider: intrusion prior to 2066 (to inform optimisation of the SRS date); thinner cap/cover material thicknesses (to inform optimisation of the engineered caps and to consider uncertainty in the thickness of cover material above the OoS A59 area);

and alternative inventory cases to consider the impact of uncertainty in the reference disposal inventory estimate. The key findings are as follows:

- None of the calculations undertaken result in a change to the overall conclusions for SGHWR, the Dragon reactor complex or the OoS A59 area. If the SGHWR mortuary tubes inventory estimate is excluded, then all doses are below the dose guidance level in all cases. If the estimated SGHWR mortuary tubes residual inventory were to be present (noting that this feature is yet to be accessed, cleaned and characterised), then doses from the large, deep excavation and borehole array to infant land users are above the dose guidance level for prolonged exposures (3 mSv y^{-1}) for each variant case.
- Doses from borehole intrusions into SGHWR and the Dragon reactor building are insensitive to cap thickness due to the depth of the intrusion exceeding the depth of the cap and in-situ disposals combined for all cap thicknesses assessed. Doses from large, deep intrusions, boreholes and piles into the B78 building floor slab are insensitive to cap thickness for the same reason.
- Doses from large, deep intrusions, piles and boreholes into the OoS A59 area are insensitive to the thickness of cover material due to the depth of these intrusions exceeding the depth of the cover material and the remediated contamination combined for all cover material thicknesses assessed.

E26 Therefore, subject to emptying, characterisation and optimisation of the SGHWR mortuary tubes, the human intrusion calculations show that there is no need for a control period beyond 2066.

Non-human Biota Assessment

E27 Assessments of potential dose to non-human biota have been made using the ERICA assessment tool. A Tier 2 assessment was run against the most conservative default ERICA dose rate screening criterion of 10 µGy h^{-1}, with the full suite of ERICA reference organisms for the appropriate ecosystem, for three separate biosphere compartments: Field, Land/Mire and River Frome. The Land/Mire was modelled both as a terrestrial ecosystem and as a freshwater ecosystem, bounding the expected impacts. Several other conservatisms were built into the assessment, including the assumption that (in the absence of detailed ecological data) sensitive ecological receptors would be exposed to the maximum environmental media concentrations. This level of conservatism is considered appropriate in light of the proximity of statutory designations and notable habitats and species on and near to the site.

E28 Tier 2 results are reported both as dose rates and as unitless Risk Quotient (RQ) values for each organism. Two RQ values are calculated: an expected value equal to the estimated total dose rate for each reference organism divided by the screening level, and a conservative RQ which multiplies the expected RQ by un uncertainty factor (UF). A UF of 3 tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential. When a UF of 3 or higher is used, Tier 2 conservative RQ values below one indicate that there is low probability that the estimated dose rate exceeds the screening dose rate and the risk to non-human biota can be considered to be trivial, based on analyses of effects data conducted to derive the ERICA screening dose rate.

E29 The results from the Winfrith non-human biota assessment show that, for all organisms in all three compartments (Field, River Frome and Land/Mire, whether modelled as a freshwater or terrestrial ecosystem) and for both the reference and alternative inventories, estimated dose rates are below the 10 $\mu Gy\ h^{-1}$ screening criterion and expected and conservative RQ values are at least an order of magnitude below one. The highest values are seen in the Land/Mire compartment when modelled as a freshwater ecosystem, and the lowest values in the Field compartment.

E30 The Tier 2 screening level is not exceeded in any case even with the assessment taking into account many conservatisms. These conservatisms include the low screening dose rate, inventory estimate, expected absence of some freshwater ecosystem organisms in a shallow, ephemeral mire during periods when it dries out entirely, and the assumption that peak media concentrations will occur at the same time for all radionuclides. Therefore, it is considered that the risk to non-human biota in all biosphere compartments is negligible for the assumed inventories and site end state configuration and no further assessment is required.

Conclusion

E31 Based on the results of the deterministic calculations reported here and comparison with the relevant quantitative GRR Requirements, this radiological performance assessment supports the conclusion that the Reference Case for the proposed on-site disposals will provide an appropriate degree of environmental safety, from the point of implementation of the end state for each radioactive feature to long after release of the site from RSR. The aqueous release results indicate that changing the infill concrete block or rubble proportions, or grouting the infill, has no notable impact and therefore puts no requirements, from a post-IEP radiological risk viewpoint, on the end state engineering and backfill optimisation. The human intrusion and site occupancy calculations favour thicker caps and additional ground cover but show that thinner caps would still comply with GRR Requirements. Calculational results also identify where future characterisation and clean-up should be prioritised.

Contents

Glossary and Acronyms

ACL	Above Cutline – the cutline is the horizontal level to which an in-situ structure is assumed to be demolished.
ALARP	As Low As Reasonably Practicable
ALES	Active Liquid Effluent System
AOD	Above Ordnance Datum
AP geometry	Anterior-posterior geometry
APC	Area of Potential Concern
Assessment Case	A calculation undertaken to consider a specific evolution of the disposals. A **scenario** can encompass one or more assessment cases.
BCL	Below Cutline – the cutline is the horizontal level to which an in-situ structure is assumed to be demolished.
BEIS	Department for Business, Energy and Industrial Strategy
BGS	British Geological Survey
CAD	Computer Aided Design
CAU geometry	Caudal geometry
CE	Common Era is the year notation for the Gregorian calendar.
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
Component	A part of a **feature** for which a separate inventory is derived, such as individual rooms, the tritium ingress component of general building contamination, etc.
cps	counts per second
CR	Concentration ratio
CRA geometry	Cranial geometry
CSM	Conceptual Site Model
DfaP	Disposal for a Purpose: Infilling unwanted voids with radioactive waste. Defined in the **GRR** as "On-site disposal of solid radioactive waste by permanent deposit where, if

	radioactive waste were not available, other materials would have to be found to fulfil the purpose”.
DGL	(GRR) Dose Guidance Level
Dose Pathway	A broad mechanism or process that could lead to RPs potentially receiving a radiation dose. For example, migration of radionuclides from a source or natural disruption of a source.
DPUR	Dose per Unit Release – factors used to convert radionuclide fluxes to the biosphere to dose to receptors.
EA	Environment Agency
EAST	External Active Sludge Tanks
EMCL	Environmental Media Concentration Limit
EPR16	Environmental Permitting Regulations 2016 (as amended)
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
ESC	Environmental Safety Case - The collection of arguments, provided by the developer or operator of a disposal facility that seeks to demonstrate that the required standard of environmental safety is achieved (also see SWESC).
Feature	Discrete contaminated structure or area, composed of one or more **components**. For the SGHWR **reactor complex**, features include Region 1 (which includes the mortuary tubes, primary containment and the ponds components), the bioshield, Region 2 (including the secondary containment and ancillary areas components). For the Dragon **reactor complex**, features include the bioshield, reactor building and primary mortuary hole structure.
Feature Group	A group of associated site **features**, such as a pond complex or reactor buildings for which it is logical to administer together due to common prior use, close locality or shared structural components. For Winfrith, the SGHWR and Dragon reactor complex, and the A59 contaminated land areas, form feature groups.
FEP	Final End Point
FML	Flexible Membrane Liner
GCL	Geosynthetic Clay Liner

GIM	Generic Intrusion Methodology
GRR	A guidance document produced by the UK's environment agencies, with the full title "Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from **RSR**".
GSL	Galson Sciences Ltd
GWDTE	Groundwater Dependent Terrestrial Ecosystem
ha	hectare
Human intrusion	Any human action that accesses the waste or that damages a barrier providing an environmental safety function after the release from RSR. In the case of inadvertent human intrusion, such actions are unintentional.
HVA	(A59) Heavy Vehicle Airlock
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ISAM	IAEA Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM) methodology
ISO geometry	Isotropic geometry
IEP	Interim End Point. The point in time at which the Winfrith IES is achieved.
IES	Interim End State. The condition of the Winfrith **site** following all physical decommissioning and clean-up activities required to make the land suitable for the next planned use of the site (but an environmental permit or other restrictions remain in force).
In-situ disposal(s)	(Of redundant below-ground radioactive structures) On-site disposal of solid radioactive waste, such as a buried structure, by leaving it permanently in position, together with any necessary preparatory works.
IWS	Integrated Waste Strategy
LLAT geometry	Left Lateral geometry
LLWR	Low Level Waste Repository
LOD	Limit of Detection

LRO	Limiting Reference Organism
LSD	Liquid Shut Down
m agl / bgl	metres above/below ground level
Mire Mudder	A receptor assumed in the natural evolution assessment based on participants in a "tough mudder" style obstacle course event.
Mortuary tubes / mortuary holes	Structures within the reactor complexes used for storing a variety of radioactive items. Within this report, the terms "mortuary tubes" and "mortuary holes" are used to refer to the structures associated with **SGHWR** and Dragon Reactor respectively. This usage reflects both the terminology most commonly found in plant documentation and their differing geometry (the SGHWR mortuary tubes have a smaller diameter than the Dragon mortuary holes and are open-ended, whereas the Dragon mortuary holes are closed at the bottom).
NDA	Nuclear Decommissioning Authority
NE	Natural Evolution (assessment)
NRPB	National Radiological Protection Board
NRS	Nuclear Restoration Services
OECD	Organisation of Economic Co-operation and Development
ONR	Office for Nuclear Regulation
Out of Scope / OoS	Material or waste with a level of radioactivity such that it is deemed to be non-radioactive and not subject to regulation under **RSR**.
PA	Performance Assessment
PEG	Potentially Exposed Group
PGPC	Purge Gas Pre-Cooler
PIE	Post Irradiation Examination
PSA	(A59) Pressurised Suit Area
QA	Quality Assurance
Radioactive waste	Radioactive material that is no longer of use.

Radioactive material	Material in which the concentrations of radionuclides are greater than the values specified in RSR. Excludes material lawfully disposed of as waste or contaminated land that remains where it was contaminated.
Reactor complex	The group of buildings and other structures associated with the Dragon reactor remaining on the Winfrith **site**.
Reference Case	The **assessment case** considering the expected evolution (as described in Section 3) of the Winfrith site as based on current understanding of the proposed on-site disposals, site characteristics, and the surrounding region.
Restricted use	Controls over a site that contribute to radiological protection of people and the environment.
RF	Review Form
RGL	(GRR) Risk Guidance Level
RLAT geometry	Right Lateral geometry
ROT geometry	Rotational geometry
RP	Representative Person. The **GRR** defines an RP as "an individual receiving a dose that is representative of the more highly exposed individuals in the population" and notes that it is "equivalent of, and replaces" the previously used terms "average member of the critical group" and "potentially exposed group".
RPV	Reactor Pressure Vessel
RQ	Risk Quotient
RSA 93	Radioactive Substances Act 1993
RSR	Radioactive Substances Regulation. A generic term used by the environment agencies. In England, radioactive substances regulation is under the **EPR16**.
RSRL	Research Sites Restoration Limited
RT	Radionuclide Transport
SAC	Special Area of Conservation
Scenarios	Descriptions of alternative possible evolutions of the disposal system, representing structured combinations of **FEPs** relevant to the performance of the disposal system.

SES	Site end state - The condition of the entire site (including the land, structures and infrastructure) once decommissioning and clean-up activities have ceased.
SGHWR	Steam Generating Heavy Water Reactor
Site Reference State	State of the site marking the boundary between the period of restricted use of a site and a subsequent period of unrestricted use.
SIMP	Staged Inventory Management Plan
SKB	Swedish Nuclear Fuel and Waste Management Company
SPA	Special Protection Area
SRS	Site Reference State
SSSI	Site of Special Scientific Interest
SWESC	Site-Wide Environmental Safety Case. A documented set of claims to demonstrate achievement by the **site** as a whole of the required standard of environmental safety.
UF	Uncertainty Factor
UKAEA	United Kingdom Atomic Energy Authority
UMD	Uncertainties Management Database
UMM	Uncertainties Management Methodology
UMP	Uncertainties Management Plan
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
Validation monitoring	Monitoring to confirm that the state and behaviour of the site is in accordance with the assumptions of the SWESC. Validation monitoring is carried out by the permit holder and may continue for a period after the end of all planned work on site involving radioactive substances.
WMP	Waste Management Plan
WSCP	Winfrith Site Closure Programme

Winfrith Site: End State Radiological Performance Assessment 2025

1 Introduction

1.1 Background

1 The Winfrith nuclear site, located in Dorset, is a former nuclear power research and development site. Nine experimental reactors, each with a unique design, and associated laboratories were developed and operated on the site between 1957 and 1995 [1]. The site, owned by the Nuclear Decommissioning Authority (NDA) and operated by Nuclear Restoration Services (NRS)[2], is currently being decommissioned.

2 NRS engagement with local stakeholders over the past few decades has identified the preferred next planned land use of the site as heathland with public access of amenity value to the local community. In accordance with stakeholder views, NRS intends to decommission the remaining facilities to provide a site end state (the condition of the entire site once decommissioning and clean-up activities have ceased) suitable for heathland with public access.

3 The Winfrith site has been extensively decommissioned over a number of decades, with seven of the nine reactors and all of the active laboratories removed. The current aim is to reach the Interim End Point (IEP) before 2040. The IEP is the point at which all physical decommissioning and waste management activities will be completed and public access to the site is planned. As part of this, all higher-activity radioactive waste is being removed from the site for storage and subsequent disposal in dedicated facilities elsewhere in the UK.

4 Key site features currently remaining include: the last two reactors (the Steam Generating Heavy Water Reactor (SGHWR) and the Dragon reactor complex, which both have substantial below-ground void spaces); the Active Liquid Effluent System (ALES) and associated Sea Discharge Pipeline; some areas of potentially radioactively-contaminated land such as the A59 area; and general site infrastructure (Figure 1.1).

[2] Established by the United Kingdom Energy Authority (UKAEA), site ownership was transferred to the NDA in 2005. The site was originally operated directly by UKAEA and then by a variety of subsidiaries, including Research Sites Restoration Ltd (RSRL). Magnox Ltd, which managed the site from 2015, transitioned to NRS on 1 April 2024.

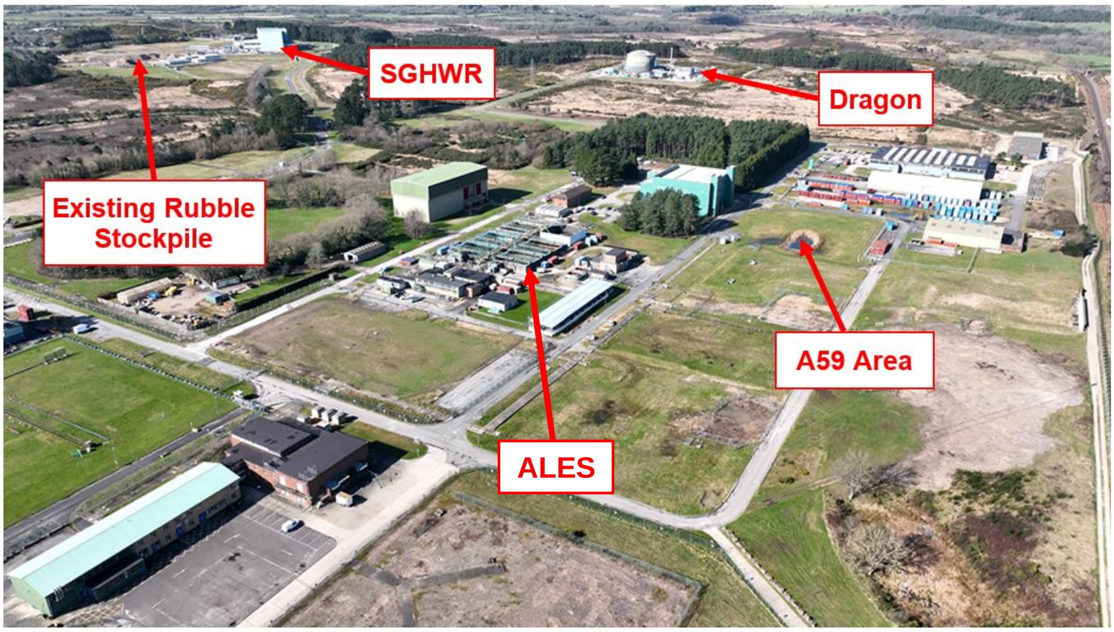

Figure 1.1: Aerial view of the Winfrith site from the east with some key features marked.

5 Activities involving radioactive substances in England are regulated by the Environment Agency (EA), under the Environmental Permitting (England and Wales) Regulations 2016 (EPR16) [2] and as amended in 2018 [3; 4], 2019 [5] and 2023 [6]. The environmental permit for the Winfrith site specifies what radioactive substances activities are allowed. Release from radioactive substances regulation (RSR)[3] cannot take place until the EA is satisfied that all activities involving radioactive substances and any disposals of radioactive waste (solid, liquid or gaseous) on or from the site have ceased, and that the site is in a state that will ensure a satisfactory standard of protection for people and the environment. The environment agencies use the term Site Reference State (SRS) for the condition of a nuclear site when it is fully compliant with the requirements for release of the site from RSR. Regulatory guidance was published in July 2018 in the *Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from Radioactive Substances Regulation* (referred to here as the GRR) [7].

6 The GRR requires operators to assess different options for the disposal of radioactive waste arising from decommissioning, including in-situ, on-site and off-site disposal options. Following options analysis and stakeholder engagement, on-site disposal has been identified as the preferred option for managing radioactive structures associated with the SGHWR and Dragon reactor complex [8]. Therefore, NRS has developed a proposal for submission to the EA that entails on-site disposal of radioactive waste and deposit of recovered non-radioactive waste whereby:

[3] Radioactive substances regulation is a generic term used by the environmental regulators that encompasses the distinct regulations in place in the four different countries of the United Kingdom.

- the below-ground portion of the SGHWR reactor building is disposed of in-situ, with the above-ground portion demolished and the resulting concrete demolition arisings used to fill the below-ground voids;
- the below-ground portion of the Dragon reactor building is disposed of in-situ, with the above-ground portion demolished and the resulting concrete demolition arisings used to fill the below-ground voids;
- the floor slab of the neighbouring Dragon fuel storage building is disposed of in-situ, with the remainder of the building structure demolished and the resulting concrete demolition arisings used to fill the Dragon reactor below-ground voids;
- the Dragon primary (spent fuel) mortuary holes, set in the Dragon fuel storage building floor, remain in place and are backfilled with cementitious material;
- demolition arisings from the existing rubble stockpile[4] of historically decommissioned site facilities are used to infill any remaining below-ground voids in the SGHWR and Dragon reactor buildings; and
- engineered caps are installed above the in-situ disposals.

7 The following materials and wastes do not form part of the proposal because they will be removed for off-site management and disposal:

- all higher-activity radioactive waste (including wastes currently stored in the SGHWR mortuary tubes);
- plant, equipment and ancillary items including bulk asbestos, accessible non-structural metalwork, and other recoverable materials and wastes removed from the SGHWR and Dragon reactor complex buildings;
- SGHWR and Dragon reactor complex material that does meet the Emplacement Acceptance Criteria [10]; and
- all other radioactive features, including radioactively contaminated structures, infrastructure and ground[5].

8 Implementation of the proposed on-site disposals will require several regulatory permissions. These comprise a variation to the site's RSR Permit under the terms of Schedule 23 of EPR16 to allow on-site disposal of radioactive wastes, a permit for a 'Deposit for Recovery' (DfR) operation to permit the use of recovered non-radioactive waste to fill unwanted voids, and planning permission to implement the proposals.

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4 The majority of the rubble stockpile was deemed to satisfy the Radioactive Substances Act 1993 Substances of Low Activity (SoLA) Exemption Order. Since this time EPR16 has been implemented (and subsequently amended) with revised assessment criteria for determining whether material is out-of-scope (OoS) of RSR. The rubble stockpiles are expected to satisfy the revised criteria, but a full programme of characterisation is planned prior to sentencing for final disposal [9].

5 Radioactively contaminated land will be remediated and demonstrated to be out-of-scope (OoS) of RSR.

9 As stipulated in the site's RSR Permit [11] and consistent with the GRR, the EA requires NRS to prepare and maintain throughout the lifecycle of the permitted site:

- a Waste Management Plan (WMP) that documents the optimised approach to managing all radioactive substances on or adjacent to the site; and
- an overarching Site-Wide Environmental Safety Case (SWESC) that demonstrates that people and the environment are now, and will continue to be, adequately protected from the radiological hazard and any non-radiological hazards associated with the radioactive substances remaining on or adjacent to the site.

10 A suite of documents, headed by the SWESC and WMP, and supported by a series of underpinning topic reports (Figure 1.2), have been produced to support the regulatory applications. A key supporting report is the radiological risk, or performance, assessment for the proposed on-site disposals, which is presented in this work.

1.2 Objectives

11 The overall objective of this radiological performance assessment (PA) is to evaluate the risk and potential doses from all radioactive sources on the Winfrith site once decommissioning activities are complete and the proposed end state for each source has been implemented. The results obtained in the PA are used to support both the environmental safety arguments presented in the SWESC and continued optimisation of the Winfrith end state.

12 Initial PA calculations for the Winfrith site [12; 13; 14; 15; 16] were undertaken to evaluate the radiological impact on humans, in support of Winfrith’s participation in the trial of the Draft GRR [17]. Initial PA calculations were also performed in support of assessment of possible end state options and aided identification of those radioactive features that are credible candidates for on-site disposal [8]. As such, the initial PA calculations considered additional features and alternative engineering assumptions that are not part of the proposal being made to the EA and are no longer considered in this version. This PA builds on the initial work and develops the proposed disposal system further, using the additional knowledge of the local environment and site that has been gained by NRS over the last few years, as well as the technical and design assessments undertaken, to address the GRR requirements sufficient to support a permit application.

13 Key objectives, which form part of meeting the overall objective, are to:

- document the approach used to undertake the radiological PA for the proposed Winfrith end state;
- identify potential exposure scenarios, pathways and receptors, accounting for uncertainties and information gaps;
- describe the modelling basis, including the conceptual models, for quantitatively assessing the scenarios and assessment cases;
- describe the implementation of the models applied;

- estimate the radiological impacts from the proposed on-site disposals and compare them to regulatory guidance levels (noting that detailed comparison of the results to regulatory requirements and associated decision-making is undertaken in other documents forming the WMP and SWESC document suite); and
- collate parameters used in the radiological PA calculations to form a single reference point.

14 This report is one of the Tier 2 topic reports that supports the disposal permit application (Figure 1.2).

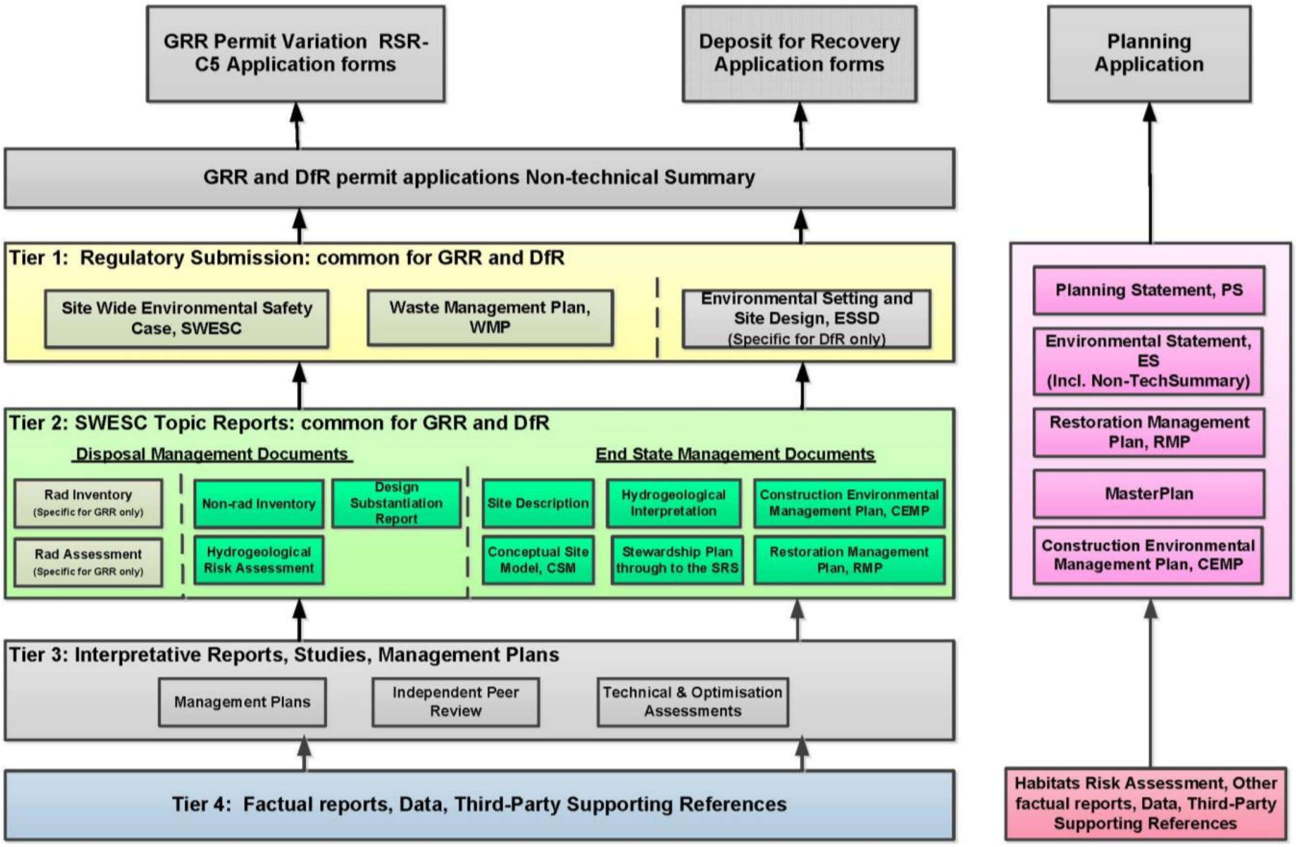

Figure 1.2: Winfrith end state GRR permit variation and deposit for recovery application documentation hierarchy (NRS, November 2024).

1.3 Scope

15 This PA evaluates the radiological impacts of radioactive features proposed to remain on the Winfrith site only. The radioactive features proposed for in-situ disposal and disposal for a purpose and that are assessed in this work are the below-ground structures of the SGHWR and the Dragon reactor complex remaining following decommissioning.

16 The A59 area refers to the former location of the A59 active handling and decontamination building. The potentially radiologically-contaminated land in the A59 area will be remediated sufficient to demonstrate that the remaining ground is out-of-scope (OoS) of RSR [18] prior to the IEP and therefore it is outside the scope of the RSR permit application. However, as discussed later, there is the potential for combination of releases from both the SGHWR and OoS A59 features. Therefore, the A59 area remains within the scope of the PA, albeit with a radiological inventory that is OoS of RSR, in order to ensure a robust transparent assessment and to inform understanding of future site monitoring results once the proposed reactor disposals have been implemented.

17 The scope excludes the Sea Discharge Pipeline and Active Liquid Effluent System (ALES) as NRS intends to decommission and remove these features. The scope also excludes any other areas of radioactively-contaminated land, as it is assumed that these will be remediated to OoS.

18 The PA addresses the GRR requirements relevant to assessment of potential radiological impacts, which are set out in Section 2.1. Thus, the scope of this PA includes:

- radiological impacts arising from natural evolution (NE) of the disposals through aqueous release of radionuclides to areas where a representative person might become exposed in the future;
- radiological impacts arising from direct external irradiation of a representative person where sub-surface contamination remains in-situ and undisturbed;
- radiological impacts arising from inadvertent human intrusion and the subsequent exposure of a representative person to radioactivity;
- radiological impacts arising from natural disruptive processes which expose radioactive waste or contamination, or impair protective barriers; and
- radiological impacts to non-human biota.

19 Non-radiological hazards to humans resulting from the proposed disposals are outside the scope of this work and are reported in a tiered (non-radiological) hydrogeological risk assessment [19], which assesses the risks to groundwater. The conceptual models in the radiological and non-radiological assessments are consistent [20], and the results of the assessments of all hazards are addressed collectively in the SWESC.

20 The PA considers potential radiological impacts from the point at which the proposed end state for each individual feature has been implemented. Potential radiological impacts in the period prior to implementation of each feature end state are assessed as part of the decommissioning plans for the Winfrith site and are considered in the SWESC. There will be a period of about five years when the Dragon reactor complex has been decommissioned and its end state implemented but other site decommissioning works and operational discharges are ongoing, including implementation of the SGHWR end state, before the site as a whole reaches the IEP (the end state dates assumed in this PA for each feature, referred to as the Disposal Start Date hereafter, are identified in Section 2.2). The combined radiological impacts of

ongoing decommissioning activities and the implemented disposals are considered in the SWESC, along with the potential for combined impacts from the neighbouring permitted Tradebe Inutec nuclear site.

21 Gaps in available information as well as uncertainties and assumptions associated with the PA are recorded in this report for future use in the NRS uncertainties management plan (UMP) [21]. These uncertainties and assumptions are noted within this report using an identifier of the form “PA-000, which is an index to Table A.1.

1.4 Report Structure

22 The remainder of this report is structured as follows:

- Section 2 summarises the assessment approach, the requirements set out in the GRR relevant to assessment of radiological impact (which are used to assess the calculation results in subsequent sections), the assessment timeframes and the treatment of uncertainties.
- Section 3 presents the disposal system that is assessed, describing the Winfrith site, the features proposed for on-site disposal, the local site characteristics, and how these are expected to evolve in the future.
- Section 4 describes the approach taken to the identification of scenarios and assessment cases, including a discussion of relevant dose pathways.
- Section 5 describes the model modules (the source term, interface, geosphere and biosphere) that together form the natural evolution (NE) assessment model; this includes their conceptual models, mathematical representation and computational model implementation.
- Section 6 describes the site occupancy assessment model and its computational model implementation.
- Section 7 describes the inadvertent human intrusion assessment and its computational model implementation.
- Section 8 presents a summary of the screened scenarios and assessment cases considered, including a summary of the Reference Case key parameters and assumptions.
- Section 9 describes the non-human biota assessment approach and methodology, and its model implementation.
- Section 10 presents the calculated radiological impacts for the considered scenarios and assessment cases, for each of the above assessment models.
- Section 11 summarises the verification and quality assurance procedures associated with the radiological assessments.
- Section 12 presents the conclusions of the performance assessment.
- Section 13 lists the references used in the main part of the report.

- Appendix A presents the uncertainties and assumptions associated with the radiological PA.
- Appendix B presents the radionuclide screening assessment that was undertaken to identify the radionuclides that are potentially important in terms of their radiological impact from natural evolution of the future disposals on the Winfrith site. The output of this assessment is the list of radionuclides that are explicitly (or implicitly) modelled in the NE assessment. The radionuclides that are assessed in the human intrusion assessment are also identified. Uncertainties associated with the radionuclide screening are noted as PA-001.
- Appendix C presents the scenario and assessment case identification methodology that was used to define the scenarios and assessment cases considered in the PA (as summarised in Sections 4 and 8).
- Appendix D presents the parameterisation for the mathematical models used in the PA, along with justifications for the selected values.
- Appendix E presents plots of total dose rates as a function of time for the alternative assessment cases, variant scenarios and "what-if" scenarios considered in the NE assessment. These supplement the discussion of NE model results in Sections 10.1 to 10.3
- Appendix F presents tables of calculated dose rates above buried in-situ features for the alternative assessment cases and variant scenarios considered in the site occupancy assessment to supplement the discussion of results in Sections 10.4.2 and 10.4.3.
- Appendix G presents tables of potential human intrusion doses for variant assessment cases to supplement the discussion of human intrusion model results in Section 10.5.
- Appendix H provides details of the individual NE model runs that have been performed to generate the results presented in Sections 10.1 to 10.3.

2 Assessment Approach

23 This performance assessment has been developed using a structured approach consistent with the International Atomic Energy Agency (IAEA) guidance for best practice (e.g. [22; 23]) and illustrated in Figure 2.1. This section sets out the assessment context in terms of the regulations that are being addressed, the purpose and scope of the PA, the outputs or performance measures that the PA models will calculate, as well as the timeframes the PA will consider.

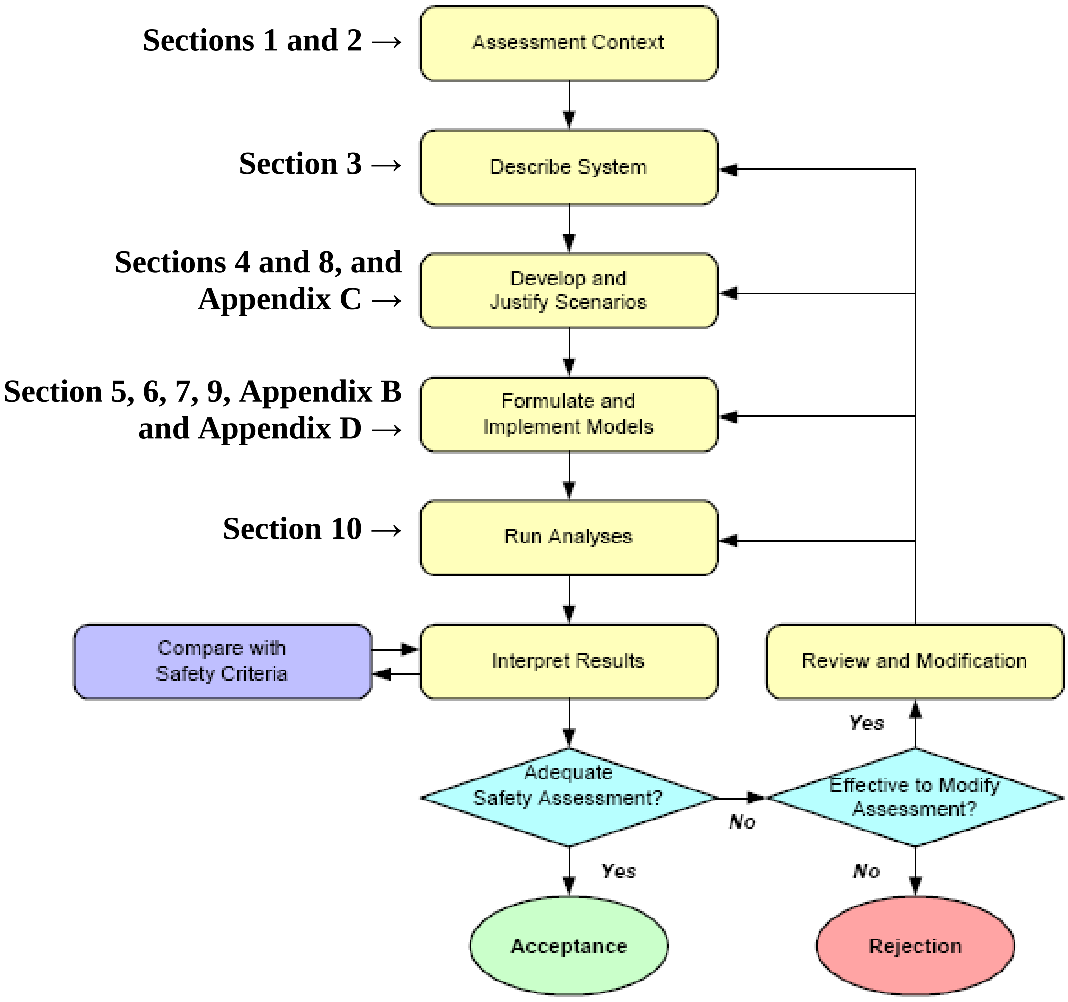

Figure 2.1: The IAEA Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM) methodology (based on [22, Fig.1]). Regarding the lower part of the figure, the comparison and interpretation of results is also undertaken in Section 10, and the decisions and revision in the context of the assessment have been undertaken in developing this assessment from previous work. Decisions, revision and acceptance or rejection in the context of the design of on-site disposals are set out in the SWESC.

2.1 Addressing the GRR Radiological Requirements

24 As explained in Section 1.1, disposals of radioactive waste (solid, liquid or gaseous) on or from a site are regulated under RSR. Release of a site from RSR cannot take place until such disposals have ceased and permission for any on-site disposal has been granted. Guidance on the release of nuclear sites from RSR was published in July 2018 by the environment agencies – the GRR [7].

25 The site will reach its IEP at the conclusion of all physical decommissioning and waste management activities and will then be subject to a period of environmental validation monitoring. Monitoring and control of the site will remain ongoing until it can be released from RSR, which is expected to be of the order of a few decades. The GRR defines *"the condition of a nuclear site when it is fully compliant with the requirements for release from RSR"* as the Site Reference State (SRS; Figure 2.2).

26 Radiological assessment criteria are defined in the GRR for the periods prior to and after release from RSR. As illustrated in Figure 2.2, it is the SRS date that marks the transition point between different GRR Requirements.

27 Radiological impacts associated with natural evolution and occupation of the site are assessed against two quantitative criteria: the dose constraints during the period of RSR (Requirement R9) and the risk guidance level (RGL) after release from RSR (Requirement R10) – these are discussed in Section 2.1.1. GRR Requirement R11 defines a dose guidance level specifically for assessment of inadvertent human intrusion after release from RSR (Section 2.1.2). The potential effects of natural disruptive processes on the application of the RGL (Requirement R12) are also considered (Section 2.1.3). Finally, the impact on non-human biota is assessed with respect to GRR Requirement 14 on protection of the environment (Section 2.1.4).

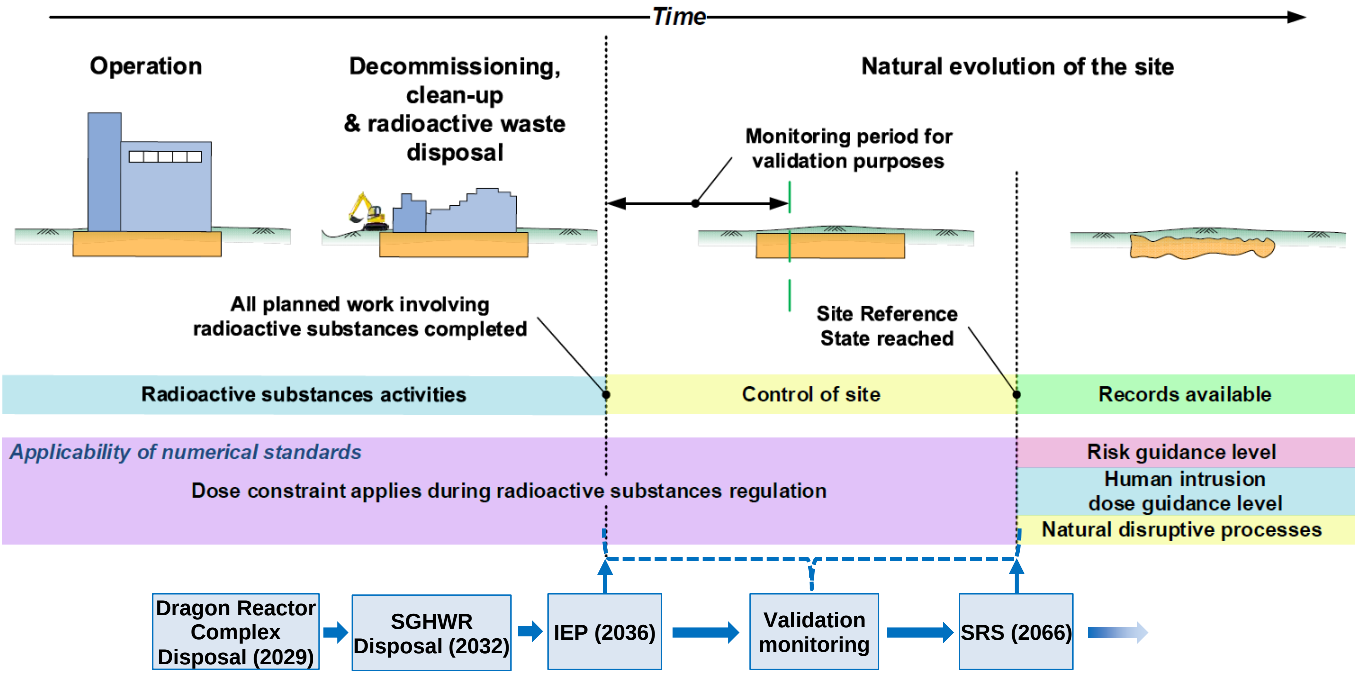

Figure 2.2: Milestones in decommissioning and evolution of the site and applicable GRR requirements. Extracted from the GRR [7, Fig.4] with labels relevant to the Winfrith site added in blue at the bottom. The dates noted are assumptions for the purposes of this PA (see Section 2.2).

2.1.1 Requirements R9 and R10

Requirement R9. Dose constraints during the period of radioactive substances regulation

During the period of radioactive substances regulation the effective dose, from the authorised site, to a representative person shall not exceed a source-related dose constraint and a site-related dose constraint [7, ¶A4.23].

28 In relation to this Requirement, the GRR further states [7, ¶A4.24]:

The environment agencies are required (Scottish Executive 2000 and EPR 2016) to have regard to the following maximum doses to individual members of the public which may result from a defined source, for use at the planning stage in radiation protection:

- *0.3 mSv per year from any source from which radioactive discharges are made; and*
- *0.5 mSv per year from the discharges from any single site.*

The dose constraints place upper bounds on optimisation that apply during the period of RSR. They cease to apply when the site is released from RSR [7, ¶A4.25].

Requirement R10. Risk guidance level after release from radioactive substances regulation

Operators should demonstrate through the SWESC that, after release from radioactive substances regulation, the assessed risk from the remaining radiological hazards to a representative person should be consistent with a risk guidance level of 10^{-6} per year (that is, a risk of death or heritable defect of 1 in a million per year due to exposure to ionising radiation) [7, ¶A4.30].

29 Several terms in these requirements can be expanded upon:

- Effective dose is a quantity defined by the International Commission on Radiological Protection (ICRP) that is used to quantify low doses and relates to protection against the occurrence of stochastic effects (cancer and heritable effects). It is not applicable to high doses where there is a possibility of tissue reactions [24, p.17]. Within the Winfrith PA, all calculated doses are effective doses.
- For Requirement R9:
  - “Source” means a facility, or group of facilities, which can be optimised as an integral whole in terms of radioactive waste disposals.
  - “Radioactive discharges” are assumed here to include both the migration of radionuclides from the site and any authorised discharge.
  - “Site” in this context encompasses any number of sources with contiguous boundaries at a single location (for example “A” and “B” power stations), irrespective of whether different sources on the site are owned or operated by the same or by different organisations.

  As such, for Winfrith, the “site” when considering Requirement R9 includes the neighbouring Tradebe Inutec nuclear site. This site has been considered here when developing the PA model and defining the pathways and receptors, but any parallel impacts from the Tradebe Inutec site have not been included in the presentation of the PA results (see Section 3). Any additive impacts from the contiguous sources are considered as appropriate in the SWESC.
- Both Requirement R9 and R10 refer to a “representative person” (RP). This term has been introduced by the ICRP [25] to replace the terminology of “critical group” and “potentially exposed groups”, which have been used previously in UK regulatory guidance (such as in guidance on Near-Surface Disposal Facilities Requirements for Authorisation (the GRA) [26]). The GRR defines an RP as *“an individual receiving a dose that is representative of the more highly exposed individuals in the population”* and notes that it is *“equivalent of, and replaces”* the *“average member of the critical group”* and *“potentially exposed group”* [7, p.C10].

30 For the purposes of the Winfrith PA, the radiological criteria are as follows (Figure 2.2):

- The dose constraint in R9 applies to each modelled feature until the SRS is reached.
- The risk guidance level (RGL) in R10 applies after the SRS is reached.

31 The 2023 NDA Business Plan [27, p.55] identifies 2036 as the year that the site will complete all physical decommissioning works (the IEP). The date for the SRS is not defined but is expected to be some decades after this point. For the purposes of the PA the SRS date is assumed to be 2066. Thus, the dose constraint in Requirement R9 will apply until this point.

32 The physical configuration of the implemented on-site disposals will be the same both prior to and after the SRS. Therefore, the same assessment model and calculational method can be used to demonstrate compliance with Requirements R9 and R10 (although the radiological impacts may be expressed differently). The radiological criterion in Requirement R10 is more stringent[6] than in Requirement R9 (when calculating conditional risks – see below), and therefore it is cautiously assumed in the Winfrith PA NE model that there will be no period of administrative control beyond completion of the IEP. Thus, the calculated radiological impacts are assessed against the Requirement R10 criterion, although the implications of any period of control in assessing radiological impacts are noted and comparison made against Requirement R9 where appropriate.

33 Calculation of radiological risk for Requirement R10 corresponds to the product of the estimated probability that detriment to the RP would occur as a consequence of unit received dose (i.e. the dose to risk conversion factor), the estimated probability that the dose will be received and the estimated effective dose rate that could be received [7, ¶A4.34]. This can be expressed as [24, p.17]:

$$R = \gamma \sum_i p_i E_i \qquad (2.1)$$

where: R = Excess risk of harm (e.g. death or severe heritable effects) in the year considered (y^{-1}).

γ = Dose to risk conversion factor (Sv^{-1}).

p_i = The probability of event i, which if it occurs gives rise to an effective dose of E_i in the year considered.

E_i = The effective dose rate resulting from an occurrence of event i ($Sv\ y^{-1}$).

34 For the dose to risk conversion factor (γ), the GRR [7, ¶A4.35] states that *"for situations in which only stochastic effects of radiation exposure need to be considered (i.e. when the estimated annual effective dose is less than 100 mSv and the estimated equivalent dose to each tissue is below the relevant threshold for tissue reactions), a*

[6] Particularly when treated as a constraint rather than guidance – this is discussed in Annex B of the GRR, but to simplify the assessment here it has been considered as a constraint.

risk coefficient of 0.06 per Sv should be used". This corresponds to recommendations set out in Health Protection Agency[7] advice on the disposal of solid radioactive waste [24]. The Winfrith natural evolution assessment cautiously assumes that the probability of the event occurring that leads to a dose (p_i) is unity (i.e. consideration of conditional risk) in all assessment cases. The probability of particular events such as the drilling of a well is discussed separately alongside the results where appropriate.

35 As p_i is assumed to be one, radiological impacts can therefore be expressed in two ways:

- As a conditional risk, calculated using Equation (2.1) and a p_i of one, with comparisons made against the RGL of 10^{-6} y^{-1}.
- As a dose rate, with comparisons made against the dose rate equivalent of the RGL assuming exposure (0.017 mSv y^{-1}), calculated by dividing the RGL by γ. If dose rates are below the dose rate equivalent of the RGL, then the associated risks would be below the RGL.

36 The latter approach is used here, as it allows for estimated radiological impacts prior to and after the SRS to be presented together as dose rates.

2.1.2 Requirement R11

Requirement R11. Inadvertent human intrusion dose guidance level after release from radioactive substances regulation

Operators should assess the potential consequences of inadvertent human intrusion into any local concentrations of radioactive substances on the site after release from radioactive substances regulation. The assessed effective dose to a representative person during and after the assumed intrusion should not exceed a dose guidance level in the range of around 3 millisieverts per year (3 mSv/y) to around 20 millisieverts in total (20 mSv). Values towards the lower end of this range are applicable to prolonged exposures, while values towards the upper end of the range are applicable only to transitory exposures [7, ¶A4.56].

37 The GRR requires assessment of inadvertent human intrusion from the SRS on the assumption that there are sufficient controls in place to prevent accidental intrusions into radioactive waste disposals prior to this, but that excavations could happen afterwards in the future when knowledge of the site is lost. Public access to the Winfrith site will be possible between the IEP and the SRS, consistent with the projected end state of the site of heathland with public access, but sufficient control of the site will be retained by NRS during this period to prevent human intrusion [28]. Therefore, the impact of exposure due to intrusion is calculated in the PA from the SRS in the Reference Case. However, the impact of exposure due to intrusion is calculated in the PA in an alternative assessment calculation prior to the SRS date to inform optimisation

[7] The functions of the Health Protection Agency are now devolved to separate country-specific agencies.

of the site and the timescales required to successfully achieve the SRS (i.e. the minimum period of site control required).

2.1.3 Requirement R12

Requirement R12. Natural disruptive processes after release from radioactive substances regulation: application of risk guidance level and dose guidance level

Operators should show in the SWESC that people will be adequately protected in the case of natural disruptive processes which expose radioactive waste or contamination, or impair protective barriers after the site is released from radioactive substances regulation [7, ¶A4.84].

38 The GRR [7, ¶A4.87] notes that in some cases, natural disruptive processes may give rise only to exposure or leaching of radioactive substances that are broadly homogeneous, without any local concentrations of radioactivity; in such cases, the operator should include suitable scenarios in the SWESC to assess the risks and should compare the results of the assessments with the RGL under Requirement R10. In other cases, local concentrations of radioactive substances or articles may be uncovered and lead to exposure of people [7, ¶A4.88]. As the future behaviours of people that might lead to them encountering local concentrations of radioactive substances uncovered by natural disruptive processes cannot be predicted, the probability of exposure cannot be quantified (as is the case for inadvertent human intrusion) [7, ¶A4.89]. In such cases, the GRR expects the operator to carry out illustrative dose assessments, comparing the results of the assessments with the dose guidance level for human intrusion under Requirement R11 [7, ¶A4.90]. In addition, when applying the dose guidance level, the agencies consider that values towards the lower end of the range are likely to be more generally applicable [7, ¶A4.91].

39 Natural disruptive processes can include processes such as coastal erosion, flooding, the actions of non-human organisms, climate change and sea level rise. The potential for natural disruptive processes to occur and their relative magnitude at the Winfrith site (as summarised in Section 3.2.7) have informed both the scenario and assessment case identification approach (Sections 4 and 8, and Appendix C) and development of the Winfrith NE assessment model (Section 5). No natural processes that would disrupt the site and that would also lead to exposed radioactive materials have been identified. Where justified, the impact of natural disruptive processes on the disposals is quantitatively assessed through the incorporation of processes into the NE assessment conceptual models (e.g. groundwater level rises) and/or by consideration of variant scenarios (e.g. the impact of a major earthquake).

2.1.4 Requirement R14

Requirement R14. Protection of the environment

Operators shall assess the radiological effects of the site on the environment with a view to showing that all aspects of the environment are adequately protected, both during the period of, and after release from, radioactive substances regulation [7, ¶A4.97].

40 There are no statutory criteria for determining radiological protection of the environment [7, ¶A4.100]. The environment agencies state in the GRR that they use the "Environmental Risk from Ionising Contaminants: Assessment and Management" (ERICA) approach [29]. The same ERICA approach has been adopted here to assess the impacts of the proposed on-site disposals for the Winfrith end state on non-human biota. The basis for this assessment is a quantitative estimate of radionuclide concentration in accessible environmental media (soil, water), which is derived from the NE assessment model and is used in the ERICA software to determine potential impacts on non-human biota. The GRR states [7, ¶A2.4] that the general intent is to protect ecosystems against radiation exposure that would have adverse consequences for a population as a whole, as distinct from protecting individual members of that population.

2.2 Assessment Timeframes

41 Assessment of the NE cases and scenarios commences in the NE model from 2027, the date of the activity estimates presented in the Winfrith End State Radiological Inventory Report [83; 84]. However, radionuclide releases from the radioactive features are assumed to start either:

- at the start of the model run, for the A59 contaminated land feature group[8] that is already interacting with groundwater and for which no additional engineering (other than remediation to OoS) is planned; or
- after completion of the decommissioning and implementation of the disposal and its engineered cap, which is referred to as the feature Disposal Start Date - the Dragon reactor complex Start Date is expected to be reached in 2029, before that of the SGHWR in 2032 [30].

42 For assessment purposes, it is assumed that the IEP will be achieved in 2036, although the exact date depends on site decommissioning progress and the regulatory permitting, licensing and planning processes, and thus is subject to change. The SRS will be reached after a further period that allows for environmental monitoring – this is currently assumed to be 2066, but is also subject to change (PA-002). Sensitivity to the nature and duration of the period between the IEP and the SRS is considered by evaluation of the calculated impacts against both the pre-RSR and the more restrictive post-SRS radiological requirements (see Section 2.1).

43 Table 2.1 summarises the key dates considered in the radiological risk assessment.

44 The overall period considered in the NE model runs is sufficient to capture the peak total dose rate for all RPs, when summed across all modelled radionuclides; the peak dose typically occurs around 60,000 years in the future for the Reference Case and the model has been run to at least 100,000 years. Over this period, the behaviour of, and

[8] A group of associated site features, such as a pond complex or reactor buildings for which it is logical to administer together due to common prior use, close locality or shared structural components. For Winfrith, the SGHWR and Dragon reactor complex, and the A59 contaminated land areas, form feature groups. Feature groups, features and components are discussed in Section 3.3.4.

contribution to the total dose of, each modelled radionuclide is recorded, accounting for radioactive decay and ingrowth as appropriate.

Table 2.1: Key Winfrith site decommissioning and management dates assumed in this PA and their relation to the radiological risk assessment.

Date	Description
2027	Date of activity estimates in the End State Radiological Inventory Report [83; 84]. NE assessment model start date (and the point from which releases from the A59 feature group are modelled). Radioactive decay of all feature inventory estimates commences.
2029	Dragon reactor complex end state implemented (facility decommissioned, waste emplaced in below-ground voids and engineered cap implemented). The below-ground structures are assumed to be dry to this point. From the date of disposal implementation, the NE model assumes that concrete degradation and water infiltration (for those features below the water table) starts and radionuclide releases are possible (see Section 5.2.1).
2032	SGHWR end state implemented (facility decommissioned, waste emplaced in below-ground voids and engineered cap implemented). As for the Dragon reactor complex, material degradation, saturation and radionuclide releases are assumed to be possible in the NE model (see Section 5.2.1).
2036	Site IEP achieved and public access planned. NRS retains sufficient control to prevent inadvertent intrusion and site residency, but exposure of public receptors accessing the site to external irradiation from sub-surface contamination is assessed.
2066	Site Reference State achieved (marks transition between GRR Requirements R9 and R10, and the start of R11). The site occupancy model now also considers the potential for site residency receptors. Human intrusion is assumed to be possible.

2.3 Quantitative Modelling

45 To provide quantitative understanding of the key processes and results relevant to long-term radiological performance, separate models have been developed to assess the following different pathways by which contaminants may lead to radiological exposure:

- NE of the site resulting in aqueous release and migration of radionuclides, which may or may not be influenced by natural disruptive processes.
- Direct external irradiation of receptors (RPs) in situations where sub-surface contamination remains in-situ and undisturbed (site occupancy).
- Consequences arising from inadvertent human intrusion into the waste and its subsequent use.
- Consequences of NE of the site and migration of radionuclides for non-human biota.

46 Each of the pathways is analysed and modelled independently, taking account of the range of uncertainties for each pathway (discussed below). Models are developed to consider relevant processes in a cautiously realistic manner where data and knowledge allow, but cautious data and model representations are applied where uncertainties are not quantifiable or knowledge is limited. The models are generally simplified and some data are cautiously selected so that radiological impacts are not underestimated.

47 Software packages for use in the PA have been selected on the basis of their ability to most appropriately model each of the above pathways. The key packages used are GoldSim Radionuclide Transport for assessment of natural evolution, MicroShield® for site occupancy, the NRS Generic Intrusion Methodology (GIM) tool for human intrusion, and the ERICA tool for non-human biota. The pedigree of each of these programs and the reasons for their selection are discussed in the dedicated conceptual model and mathematical implementation chapters for each pathway: Section 5 (natural evolution), Section 6 (site occupancy), Section 7 (human intrusion) and Section 9 (non-human biota). Where possible and appropriate, consistent datasets and assumptions have been applied across the separate models (e.g. ensuring consistent dimensional and inventory parameters, and consistent material properties where relevant). In some cases this is not possible; the impact of this is generally small but is discussed in the relevant model sections (e.g. the limited list of radionuclides that may be modelled in GIM compared to GoldSim (Section 7.3)).

48 Quality assurance procedures have been followed to ensure that the relevant models correctly implement the conceptual model and its mathematical interpretation, and that the models have used appropriately. The quality assurance and verification processes, and the run management applied, are discussed in Section 11.

2.4 Estimation of Radiological Impacts

49 The PA estimates radiological impacts separately for many of the features reported in the Winfrith End State Radiological Inventory [83; 84] (and described in Section 3.2.9). For example, in the NE model, the SGHWR bioshield, Region 1 (including the ponds and primary containment), Region 2 (covering the turbine hall and much of the secondary containment), and North and South Annexe features, are modelled as individual sources in the near-field. As discussed in Section 5.2, radionuclides released from each source contribute to the same groundwater pathway (one pathway for each of the three SGHWR, Dragon reactor complex and A59 feature groups), at times commensurate with their relevant release mechanisms, and then travel through the geosphere and enter the biosphere. This means that if releases from individual sources are coincident, then the concentration in the individual groundwater pathway will be the sum of the contributing sources and this is reflected in the doses calculated for the relevant receptors. Similarly, any combination in the geo/biosphere of releases from the three feature groups is also accounted for in the calculated receptor doses. This approach of considering features as separate sources in the NE model, rather than as a single amalgamated source for the whole of the site, is adopted specifically to understand the impacts from the heterogenous distribution of radioactivity across disparate parts of the site. The understanding gained from this approach is expected to help inform prioritisation of future radiological characterisation and design

optimisation. This approach assumes that there are no interactions between the features that could give rise to situations (radionuclide fluxes or concentrations) for RPs higher than the appropriate sum of those from the individual features; this uncertainty is captured in Appendix A as PA-024.

50 The human intrusion assessment considers smaller-scale waste volumes than the NE model, where groundwater flows through a broad structure/region. Therefore, intrusions into more discrete features and components are considered, such as boreholes intersecting the SGHWR mortuary tubes, the pond walls or the bioshield (see Section 7). Localised features that represent elevated levels of activity are explicitly considered, with intrusion cases designed to be worst cases (i.e. intersect the most active features).

51 This PA is limited to on-site facilities managed by NRS. The SWESC considers potential doses arising from radioactive waste management operations at the neighbouring Tradebe Inutec nuclear site.

2.5 Treatment of Uncertainties

52 Uncertainties identified both during the methodological development of this PA, and in relevant strands of previous work across the GRR-related document suite, have been systematically captured and evaluated as part of the scenario identification process described in Section 4 and Appendix C.

2.5.1 Within this Assessment

53 The Winfrith PA adopts a standard approach to considering associated uncertainty, by partitioning the uncertainty into three categories (e.g. [23, §5.56]):

- Uncertainty in the future evolution of the disposal system, referred to as **scenario uncertainty**.
- Uncertainty in the models used to represent this evolution, introduced through the inevitable assumptions and, in most cases, simplifications made in developing the conceptual and mathematical representation of natural processes, referred to as **model uncertainty**. This can be sub-divided into conceptual model uncertainty and mathematical and numerical model uncertainty.
- Uncertainty in the parameter values used in the modelling to evaluate the potential consequences of scenarios, referred to as **parameter uncertainty.**

54 All three of these types of uncertainty are carried through into the calculation of radiological impacts:

- For a single or deterministic calculation, interpretation of the calculation result must be combined with consideration of the uncertainty associated with, or probability of, the scenario and model assumptions and single parameter values used to calculate the result. The probability of a deterministic calculation is often expressed qualitatively (e.g. realistic, cautious, bounding/worst-case).

This Winfrith PA includes best estimate, conservative and bounding deterministic assessment cases.

- An alternative approach is to undertake a probabilistic simulation, whereby many single calculations are performed, sampling the possible range of parameter values and/or assumptions and/or scenarios. The results of all of the calculations are then combined probabilistically into a mean result for the simulation and the confidence limits associated with the result; that is, the confidence limits bound an area in which, accounting for the uncertainty in the system, it is highly probable that the true result lies. Probabilistic calculations have not been undertaken in this Winfrith PA for various reasons:
  - The inherent lack of resolution in probabilistic model outputs. The Winfrith PA models involve many different source terms, which would make it difficult to understand the individual contributions of features to the overall probabilistic output for the proposed on-site disposals.
  - The potential difficulty in communicating probabilistic outputs to non-technical stakeholders.
  - The difficulty in substantiating the probability distributions for many parameters (e.g. hydraulic conductivity of degraded concrete).
  - The difficulty in placing uncertainty ranges on certain aspects of the assessment, such as the probability of a scenario or the preference of one model over another.
  - The preparation time and longer run times associated with probabilistic simulations would make the Winfrith PA a considerably more labour-intensive undertaking that is not warranted given the low levels of contamination and attendant risk associated.
  - The estimated doses for the proposed Winfrith disposals are sufficiently low that bounding calculations using conservative simplifications are considered appropriate to the hazard presented and do not drive non-optimal behaviours or design decisions.

55 The Winfrith PA considers scenario and parameter uncertainties by undertaking multiple scenarios and assessment cases, respectively. There are numerous variations on the exact meaning of the term “scenario” and other associated terms. IAEA terminology and definitions [23, ¶5.37 & ¶5.38], as set out in Section 4.1, are used in this report.

56 Deterministic calculations illustrate the potential consequences of each scenario or assessment case, were it to occur. This approach aligns with guidance on managing uncertainties in the GRR, where it is noted that the uncertainty in future events can be explored through the use of separate “risk assessments” for each set of possible events [7, ¶A4.47].

57 The GRR acknowledges that some scenarios *“involve future events so uncertain that it may not be appropriate to undertake numerical risk assessments for comparison with the risk guidance level, as this could distort the overall picture of risks”* [7, ¶A4.48].

A sub-set of scenario and parameter uncertainties considered in this Winfrith PA are classed as “what-if” scenarios. These scenarios consider highly speculative and unlikely future outcomes for the proposed on-site disposals and do not reflect the general uncertainty in the characteristics of the disposal system.

58 The Winfrith PA considers conceptual model uncertainties through deterministic assessment of alternative models. Mathematical and numerical model uncertainties are, in general, considered to be small compared to conceptual model uncertainties and have been largely considered in the development of the conceptual models and their mathematical representation, rather than in additional scenarios and assessment cases.

59 Information on how uncertainties have been considered as part of the scenario and assessment case identification approach is presented in Section 4 and Appendix C.

2.5.2 Across the GRR-related Document Suite

60 The methodology for management of technical uncertainties for GRR-related matters has been standardised across all NRS sites [21], and an Uncertainties Assessment in accordance with that methodology has been undertaken for this PA. This is presented in Table A.1 and comprises a list of directly related uncertainties (including knowledge gaps) and associated assumptions, each with an assessment of significance/impact and a recommended course of action to address it. NRS evaluates these recommendations in accordance with its GRR Uncertainties Management Methodology [21] and makes judgements (informed by relevant information outside the scope of this report) as to whether to accept or modify the recommended courses of action in light of its own assessments of significance.

61 Identified uncertainties are collated in an appendix in each GRR-related report, with the aim of populating a central database also tracking the actions planned, and subsequently taken, by NRS to address the uncertainties (and, where possible, the ultimate close-out justifications for the uncertainties). As part of the Winfrith PA scenario development process (Appendix C), the current entries in relevant reports have been reviewed to identify those of relevance to doses potentially arising from the proposed on-site disposals. These are subsequently discussed in terms of their treatment within the Winfrith PA (Appendix C.4), with a sub-set of the identified uncertainties being addressed in this Winfrith PA through the definition of alternative assessment cases or additional scenarios.

3 Disposal System Description

62 This section provides information on the proposed on-site disposals and surrounding environment:

- Section 3.1 gives a general overview of the Winfrith site and the envisaged site end state.
- Section 3.2 summarises the characteristics of the Winfrith site and local surrounding region as at the present day.
- Section 3.3 provides details on the characteristics of the modelled on-site disposal features themselves and the radiological inventory forming the source term in the PA.
- Section 3.4 provides an overview of the expected evolution of the various aspects of the disposal system, including both changes assumed to occur as a result of implementing the IEP and longer-term events and processes that are expected over the assessment timeframe.

63 It is important to recognise that there are two significant sources of uncertainty in the description of the disposal system:

- uncertainty associated with characterising the system as it is at present; and
- uncertainty associated with its future evolution, after completion of the IEP.

64 Sections 3.1, 3.2 and 3.3 are generally restricted to presenting what is currently known (or estimated) for the initial state of the disposal system. This is consistent with the scope of the guidance on system description set out in the ISAM methodology (summarised in Figure 2.1). However, to underpin the selection of the scenarios and assessment cases (Sections 4 and 8) and to provide a basis upon which the natural evolution model can be conceptually designed and implemented (Section 5), it is important to consider how the disposal system is likely to evolve with time. This is addressed in Section 3.4.

3.1 The Winfrith Site and Envisaged End State

3.1.1 Site Overview

65 The Winfrith site is located approximately four miles from the south Dorset coast (Figure 3.1). The Dorset Innovation Park and Tradebe Inutec nuclear licensed site lie along the eastern boundary of the site and to the north there is a railway line and the valley of the River Frome. The River Win, a tributary of the Frome, runs close to the southern boundary of the site.

66 Much of the site is located within the Winfrith Heath Site of Special Scientific Interest (SSSI), and is adjacent to the Winfrith and Tadnoll Heath nature reserve, an internationally significant conservation area which also encompasses the wetland Ramsar site [31]. The Winfrith Heath SSSI encompasses a range of heath and mire ecological communities. The area supports a diverse population of nationally rare

plant, insects, animal and bird life, including nightjar, Dartford warbler, silver studded blue butterfly and all six species of native reptiles.

Figure 3.1: Map of the region surrounding the Winfrith site (developed using OS OpenData January 2024 release © Crown copyright). The red star denotes the approximate location of the site.

67 There are a number of residential and commercial properties less than 1 km from the site [60, §6.1]. Five residential properties are located to the north of the site, the Dorset Innovation Park to the east, and to the south of the site in the village of East Knighton there are several farms, residences and businesses. The Tadnoll and Winfrith Heath Nature Reserve covers most of the area to the west of the site, where free-roaming cattle graze all year round.

68 Constructed from 1957 and officially opened in 1961, the Winfrith nuclear site was a centre for reactor research, design and development, housing nine unique experimental reactors over its lifetime [1]. The Winfrith site also had facilities for nuclear fuel manufacture and examination and other experimental laboratories, as well as waste treatment and storage facilities. Decommissioning of the site started in the 1990s, and the last operational reactors, NESTOR and DIMPLE, were shut down in 1995 [1, p.10]. The remaining reactor fuel was removed from the site in 1995.

69 The site is licensed for specific activities involving nuclear materials by the Office of Nuclear Regulation (ONR) under the Nuclear Installations Act 1965, as amended [32]. Initially the site encompassed 129.4 ha, however the eastern section of the site was delicensed and transferred to English Partnerships in 2004. This area has now been developed, along with additional adjacent land, as the Dorset Innovation Park, and land has been sold to Tradebe Inutec. The remaining 83 ha is enclosed by a perimeter fence (Figure 3.2) and is referred to as the "Winfrith site" in this report. However, only 70 ha of this falls under the nuclear site licence, while the land covered by the environmental permit extends beyond the perimeter fence as shown in Figure 3.2.

70 The two most well-known reactors on the Winfrith site, Dragon and the SGHWR, became operational in the 1960s and 1970s [1, p.8]. The Dragon reactor was a prototype 20 MW high-temperature helium-gas-cooled experimental reactor, built and managed as part of an Organisation of Economic Co-operation and Development (OECD) project to develop high temperature reactors and to develop graphite-coated uranium-thorium fuel cycle technology. The SGHWR was a 100 MW light-water cooled and heavy-water moderated reactor that supplied electricity to the national grid from 1968 to 1990 and was the only Winfrith reactor to do so. The other seven research reactors, which have all now been decommissioned and removed from the site, were zero or very low power systems.

71 An electricity sub-station that previously received electricity produced by SGHWR is located in the south-west corner of the site, and high voltage overhead power lines from this head north across the site. Scottish & Southern Electricity own the power lines and the sub-station equipment and will continue to operate these after the IEP.

72 Key features of the site and surrounds are shown in Figure 3.3.

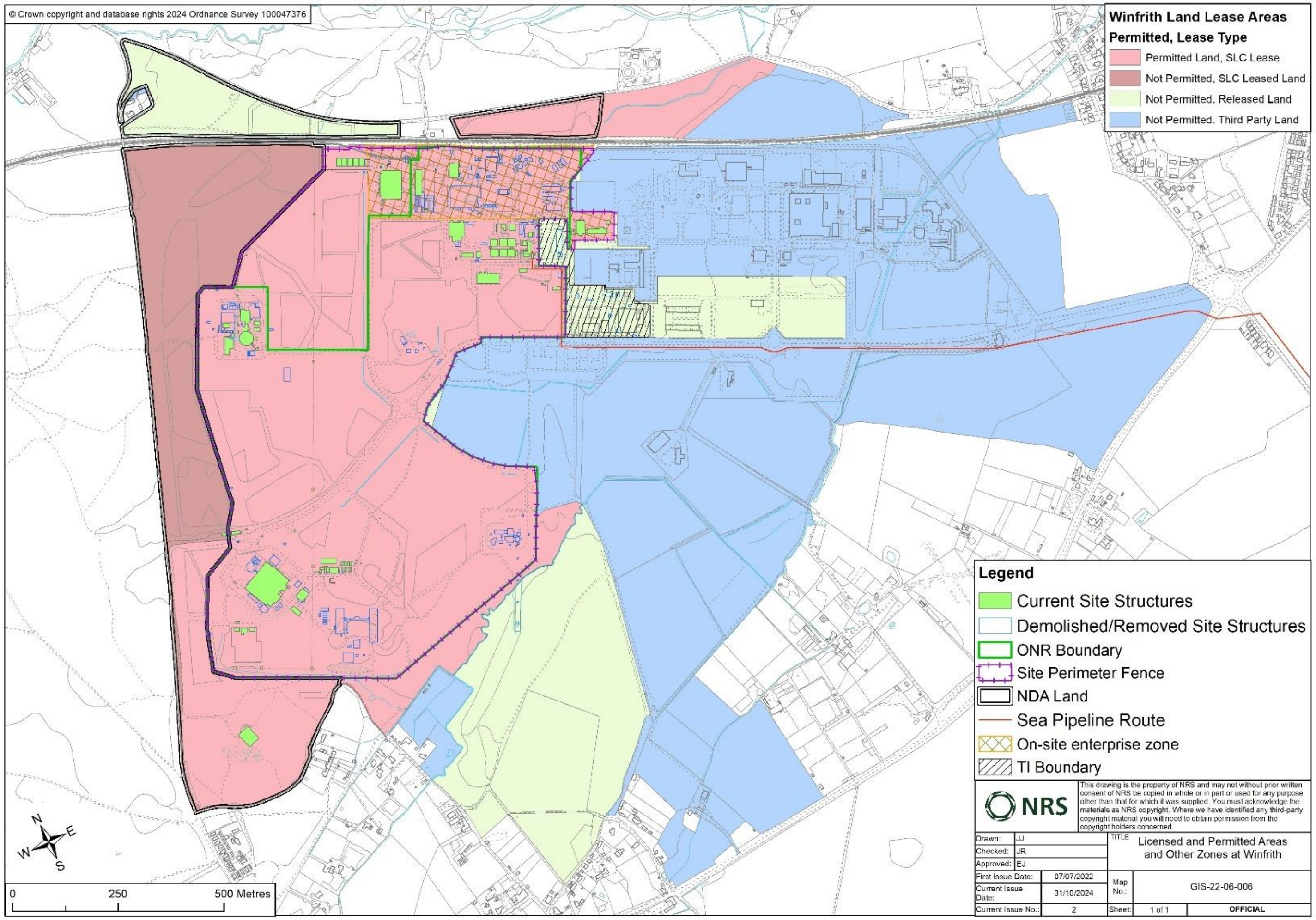

Figure 3.2: Licensed and permitted areas on the Winfrith site – the perimeter fence is denoted by the purple hashed line, the nuclear site licence by the green line, and pink shading denotes land covered by the environmental permit.

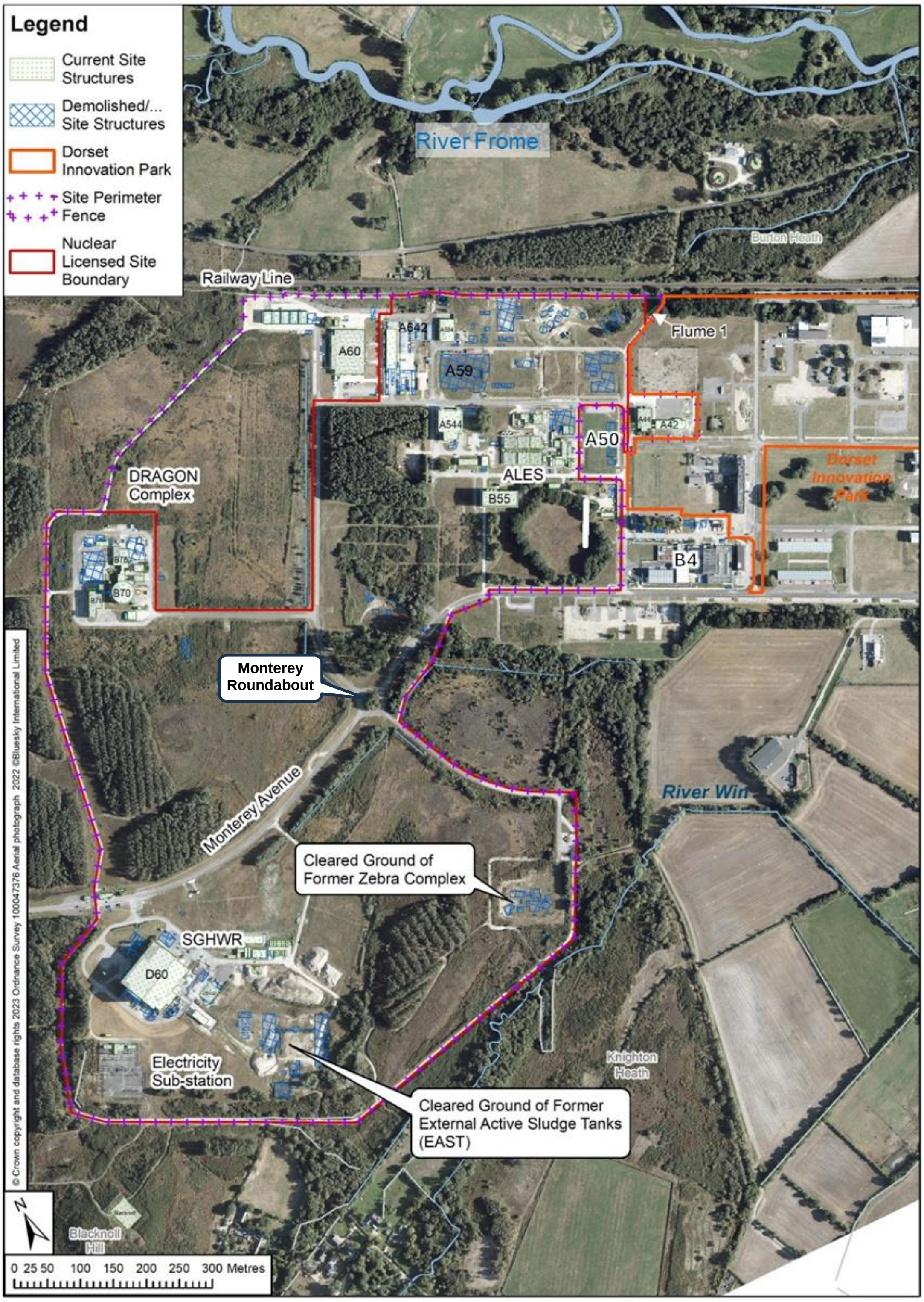

Figure 3.3: Aerial photograph (2022) with the principal features of the Winfrith site and its surroundings indicated, including current and demolished site structures [20, Fig.606/2]. The land and facilities labelled A50 and B4 correspond to the Tradebe Inutec nuclear licensed site. Flume 1 is the route of surface water discharge from the site to the Frome Ditch and then to the River Frome.

3.1.2 Site End State Vision and Specification

73 The site end state is the condition of the entire site once decommissioning and waste management activities have been completed. At Winfrith, an Interim End State (IES) is also defined, which is also the condition of the site following all physical decommissioning and activities required to make the land suitable for the next planned use of the site, but the 'interim' descriptor indicates that a RSR permit remains in force. There will be on-going management of the site after reaching the IEP and the liability will continue to be managed until the EA is satisfied that the SRS has been reached and that the RSR permit can be surrendered.

74 The NDA states that the site's end state is defined by *"the high-level remediation objectives of the site, considering the land's next planned use or probable futures"* [33]. The next planned use of a decommissioned nuclear site is influenced by the local environment and community views. The Winfrith site sits within an important and sensitive local environment, with nationally and internationally recognised heathland and wetland conservation areas. Engagement with local stakeholders identified the preferred next planned land use for the site as a heathland with public access, of amenity value to the community [34]. A consultation in 2006/2007 identified a 'Heathland Landscape' as the preferred option with the possibility of retaining some areas for commercial use in the north of the site. A further consultation in 2013 aimed at defining the end state in more detail [35] explored views around landscape and management options, finding a preference for restoration of the natural environment and protection of the site's flora and fauna. Subsequent engagement (2018 - 2023) with the local community, local parish councils, the general public, regulatory bodies and other site stakeholders further shaped the decommissioning strategy and the vision for the end state.

75 The plan for the physical appearance and hydrological function of the site at the end state is set out in the Restoration Management Plan (RMP) [36]. The RMP sets out the approach to creation and regeneration of a mosaic of acid grassland and heathland habitats on the Winfrith site. Following engagement with Natural England, Dorset Wildlife Trust, Dorset Council and the EA, the RMP sets an objective to restore the natural hydrological function of the site [36, §1.2]. The RMP describes the activities required to ensure that the site functions as required, once all active management systems have been removed. For example, the RMP provides information on the mitigations required to manage flood risk once the site drainage network has been decommissioned (see Section 3.4.2). The RMP supports the planning application and has been developed with awareness of the risk assessments.

76 Natural regeneration of habitats within the site is the primary means of habitat restoration set out within the RMP, although low-intervention management methods are planned (e.g. grazing at low stocking density, vegetation management, culvert management and measures necessary to maintain safety) [36, §6]. The natural regeneration of acid grassland, heathland and open mosaic habitats on the site of the previous Zebra reactor at Winfrith over the last ten years is used as a reference site for this approach [36, §8.3]. Supplementary planting/sowing of seed/plant material may be used to establish habitats at risk of erosion. Features like bare ground, open mosaic

habitat and acid grassland/heathland transition are important components of the intended future landscape, and timescales for habitat creation may be several decades [36, §1.3].

77 The planned status of structures, contamination and infrastructure at the IEP is set out in the End Point Specification [37]. The decommissioning plan and End Point Specification [37] support regeneration of appropriate heath, grass and mire habitats to meet stakeholder expectations, and provide an end state suitable for heathland with public access. The End Point Specification describes, at a high level, the end state for each aspect of the site to ensure the next planned land use is delivered. Table 3.1 summarises the currently intended interim end state for all site aspects, subject to detailed design development and future optimisation.

78 NRS intends to achieve the IEP before 2040, with the fence-line being removed after the IEP to allow public access. Following the IEP, the site will continue to be owned by the NDA and operated by NRS (or an alternative suitably permitted entity) through a site stewardship phase to ensure effective management of the site, the habitats and the disposals.

79 Following a period of approximately three decades to allow for environmental monitoring in the site stewardship phase (see Section 2.2), and subject to regulatory approval, the permit will be surrendered and the site will meet the SRS. Once the SRS has been reached the site will fall under normal planning and development controls managed in line with the Town and Country Planning Act [38].

80 The main future use of the Winfrith site by members of the public is expected to be walking; there will be no public vehicle access. Footpath design is intended to provide access to the site without causing disturbance to sensitive ecological features [36, §3].

81 The neighbouring Dorset Innovation Park, Scottish and Southern Electricity sub-station, and the Tradebe Inutec site [39; 40; 41] are expected to remain in operation.

Table 3.1: Specification for the intended site end state. Adapted from [37, App.A].

Aspect	Description
Drains	Drains will be assessed for contamination in-situ and, where demonstrated as OoS, will be decommissioned and isolated to prevent flow paths developing and will remain in place. Drains that do not meet end state threshold values (radiological/non-radiological) will be removed and managed as waste.
Surface water	Isolate or remove artificial drainage to restore natural hydrograph. Backfill land drains to encourage natural flood management, including decommissioning of the 48” main drain and re-profiling of Flume 1. Creation of a valley mire in the north-east of the site to mitigate surface water flood risk and prevent an increase in flood risk to neighbours (see Section 3.4 for more information on the proposed mire).
Structures	Remove all structures to at least 1 m below ground level, with the exception of the Dragon reactor complex which will be demolished in accordance with the optimised strategy to ground level.

Aspect	Description
	Demonstrate absence of contamination in any remaining below-ground structures (with the exception of the proposed disposals). Provide suitable cover over sub-surface structures to encourage heathland development.
Voids	Sufficiently backfill or re-profile voids to prevent subsidence hazards. Backfill material to be determined by suitable risk assessment and further optimisation. Demolition wastes are only to be used for backfilling the proposed disposals at SGHWR and the Dragon reactor complex. All other voids, should they need backfilling, will use soil.
Adopted services	The majority of the utilities and services on site are adopted and all removal activities will need to be completed by the services owner. A programme of removal is required, although this may not align with site decommissioning plans.
Un-adopted services	Above-ground services to be removed. Below-ground services to be isolated and mapped.
Surface features	Remove surface features including car parks, roads, most fences and certain footpaths. The top surface for roads will be removed and sub-base will be broken up. Fences in proximity to the rail head are the responsibility of Network Rail who will determine the on-going requirements.
Landscaping	Undertake landscaping as required, including emplacing caps above in-situ disposals. Re-profiling to mitigate flood risk is also required.
Ecology and habitats	Provision of conditions suitable for heathland regeneration and management to maximise habitat values. Removal of non-native plantation trees.

3.2 Site Characteristics

82 This section provides a summary description of the site characteristics as at the present day relevant to the development of the Winfrith PA models (full details are reported in the separate Site Description [42] and Hydrogeological Interpretation [43] reports). The expected evolution of the disposals, site and surrounding area due to implementation of the IEP and in the long term is discussed in Section 3.4.

3.2.1 Topography and Physiography

83 The Winfrith site is located approximately four miles from the south Dorset coast, two miles west of the town of Wool and ten miles east of Dorchester. The site is bordered by two distinct river systems (Figure 3.3): to the north, the River Frome and, skirting the south-east of the site, the smaller River Win (itself a tributary of the Frome). To the north, the site is bordered by the London-Weymouth railway line and beyond that the River Frome SSSI.

84 The site is located within the low-lying valley of the River Frome, with the Purbeck ridge system of elevated chalk downs to the south, between the site and the coast. The

highest points of the ridge are Ridgeway Hill (199 m) and Bindon Hill (168 m). The site itself is relatively low-lying, with ground elevations ranging from 20 m AOD in the north-east to 50 m AOD in the south-west; the ground slopes downwards towards the Rivers Win and Frome from the summit of Blacknoll Hill at 62 m AOD, just south of the south-west corner of the site [42, §2.2; 43, §3.1] (Figure 3.4).

85 Around 85% of the Winfrith site is classed as permeable ground. This consists of heathland, tree plantations and grassland, and includes an ancient protected woodland (Coltsclose Corner). Made ground includes buildings, associated hard-standing areas, a network of roads and car-parking areas [43, §8.1.1].

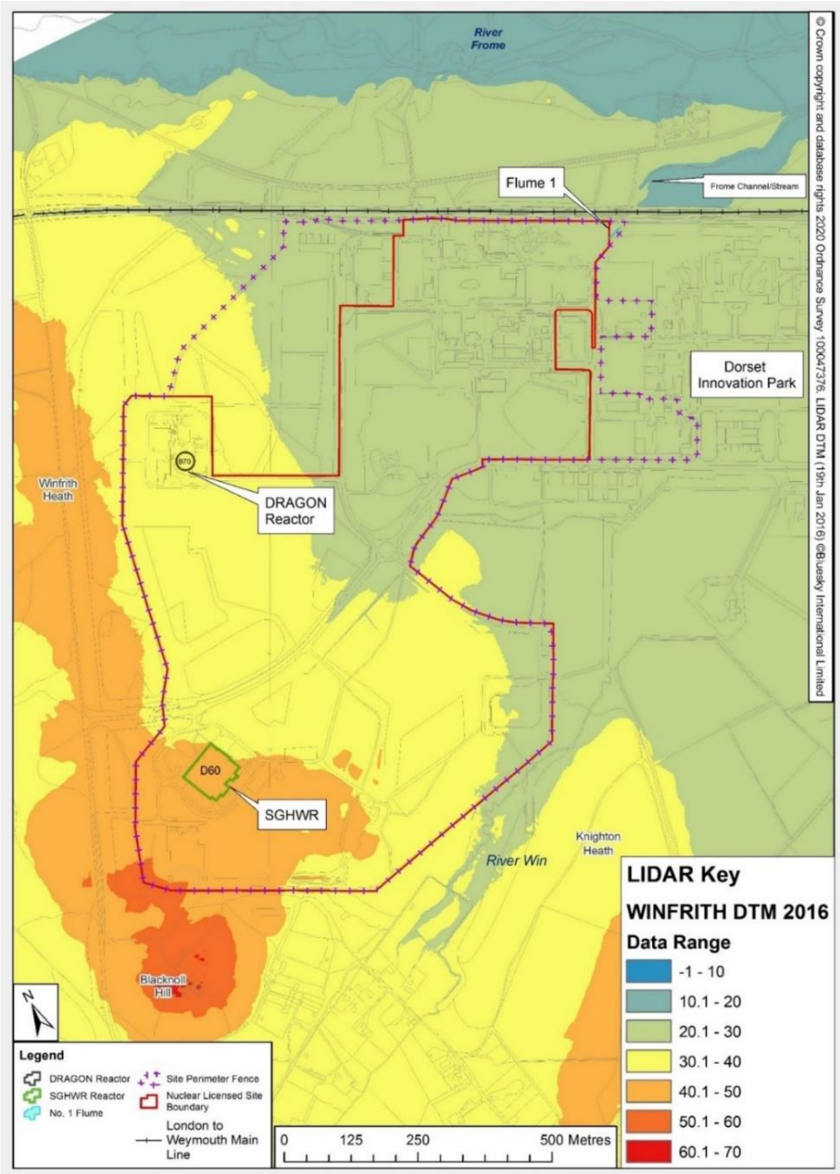

Figure 3.4: Winfrith site topography; the colour scale corresponds to m AOD [43, Fig.604/5].

3.2.2 Soils and Geology

86 The soils underlying the site are defined as the “Shirrell Heath 1 Formation”, comprising well-drained, acid, sandy soils, with a bleached sub-surface horizon [44]. In general terms, this formation is a podzol (Figure 3.5), which are typified by a leached sandy layer and are often associated with heathlands.

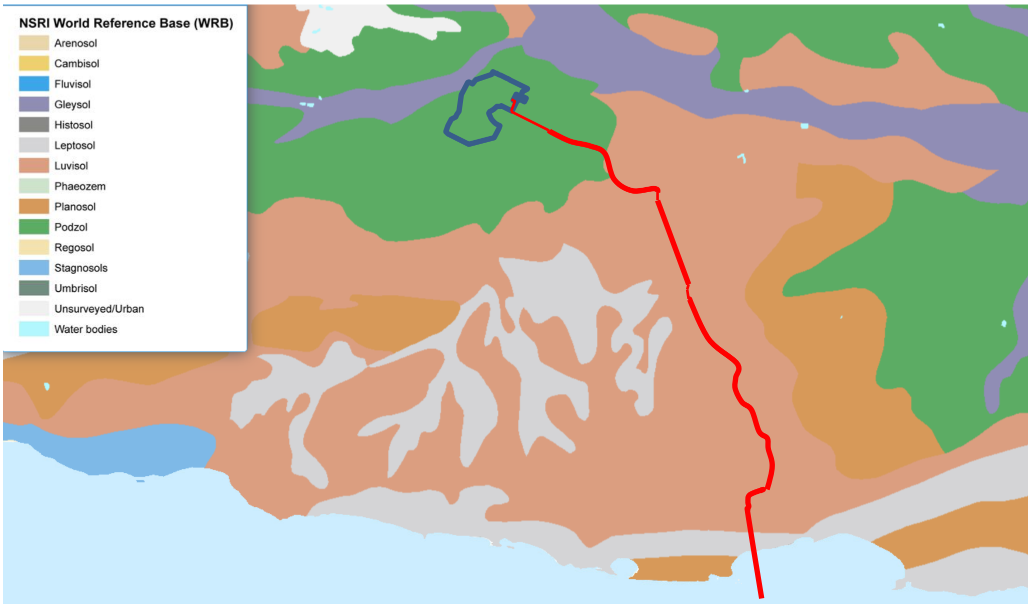

Figure 3.5: Map showing the soil types in the Dorset region [44], with an indicative outline of the site location and route of the Sea Discharge Pipeline.

87 The bedrock geology of Dorset is dominated by Cenozoic and Mesozoic formations that are folded in a broad synclinal basin, termed the Wareham Basin. The main Cenozoic Groups underlying the Winfrith site are the Bracklesham and Thames Groups, of which the Poole and London Clay Formations are the main units, and these are underlain by the Mesozoic age White Chalk, of which the local formation is termed the Portsdown Chalk Formation. The superficial and bedrock geology in the region of the Winfrith site, in order of increasing depth, is listed in Table 3.2 and shown in Figure 3.6. The units are described as follows [42, §4.2; 43, §5]:

- Made Ground - This includes asphalt, paving, the remains of demolished buildings and reworked natural material. The site was heavily modified during the 1950s/1960s construction phase, so very little of the pre-construction surface levels remain. In areas that have been further developed there is typically around 1 m of Made Ground. Greater thicknesses of made ground also exist locally where excavations have been backfilled.
- Quaternary Deposits - Head and River Terrace Deposits are present across much of the site and are up to 4 m thick, although much of the west of the site (including the sites of SGHWR and Dragon reactor complex) lacks superficial deposits and the Poole Formation is exposed [43, §5.2]. Head deposits comprise clay, silt, sand and gravel, and on the site tend to be associated with the slopes

of higher ground and run northwards through the central part of the site. The River Terrace Deposits comprise sand and gravel and are associated with the trace of the Rivers Frome and Win, being particularly dominant on the east of the site. The boundary between the Quaternary deposits and underlying Poole Formation cannot be defined with confidence across parts of the site.

- Poole Formation - This is the bedrock formation beneath the site and much of the immediate surrounding area to the north and west. The Poole Formation consists of a sequence of alternating clays and fine to coarse sands, but is highly variable. The sand units within the Formation are 10–15 m thick on average [45, p.18], whilst clay units are 6–16 m thick on average [45, p.18]. The Poole Formation is highly laterally variable, making cross-correlation between boreholes challenging. The thickness of the Formation to the north-east of the site is reported to be around 25–30 m. The thickness to the south of the site (in the vicinity of the SGHWR) is not clear due to uncertainty in the depth of its boundary with the London Clay (see Paragraph 88).
- London Clay Formation - The London Clay Formation includes sand and clay rich zones. The West Park Farm member of the London Clay Formation lies beneath the site. The West Park Farm member is glauconitic sand or sandy clay, locally with shells and flint pebbles overlain by mottled red, orange and grey silty clay. The Formation outcrops immediately to the south of the site perimeter fence. The variable nature of the London Clay means that there are alternative interpretations of its thickness beneath the Winfrith site (see Paragraph 88).
- Portsdown Chalk Formation - The Chalk underlies the London Clay Formation and is present some 60 m below ground surface. Regionally up to 130 m thick, the thickness of the Chalk beneath site is uncertain. The Formation outcrops at the surface about 2 km to the south of the site and is up to 130 m thick. Borehole investigations suggest surface elevations between -30 and -40 m AOD at the site.

88 Determining the precise boundary between the Poole Formation and London Clay is challenging as they can appear very similar in samples. The clay below some parts of the site, including SGHWR (the base of which is known to be founded on a “very hard grey clay” layer [46]), can therefore be interpreted as part of the London Clay or could be a significant clay lens in the Poole Formation [43, §5.2.5]. The former interpretation would suggest that the overlying Poole Formation is 8-10 m thick in the vicinity of the SGHWR while the latter would suggest a thickness in excess of 30 m. The differing interpretations of the London Clay surface are illustrated in Figure 3.7. However, regardless of which interpretation is correct, the presence of a thick clay layer beneath the SGHWR and immediate surrounds would act locally as an aquitard, preventing migration down from the SGHWR and acting as an effective barrier to possible contaminant migration.

89 The Dragon reactor is known to be founded in the Poole Formation.

Table 3.2: The superficial and bedrock geology in the region of the Winfrith site in order of increasing depth [43, Tab.604/5].

Geological Group	Formation	Description	Approx. Thickness
Quaternary Deposits	Head	Poorly stratified clay, silt, sand, gravel and chalk	Up to 4 m. Locally absent from the west of the site (including from SGHWR and Dragon reactor complex).
	River Terrace Deposits	Mainly angular flint gravel in a sandy, locally clayey, matrix	
	Alluvium	Soft, organic mud	
Bracklesham Group‡ (Palaeogene)	Poole Formation	Sand and clay	8 m or thicker to the south of the Winfrith site, and 30 m thick to the north-east.
Thames Group (Palaeogene)	London Clay Formation comprising the West Park Member	Sandy clay and sand, locally pebbly	10 m or thicker to the south of the Winfrith site, thickness not proven to the north-east.
White Chalk (Cretaceous)	Portsdown Chalk Formation	Chalk, soft, marly near base, flintier in upper part	Up to 130 m thick regionally.

‡ Also referred to as the Bagshot Formation/Bagshot Beds.

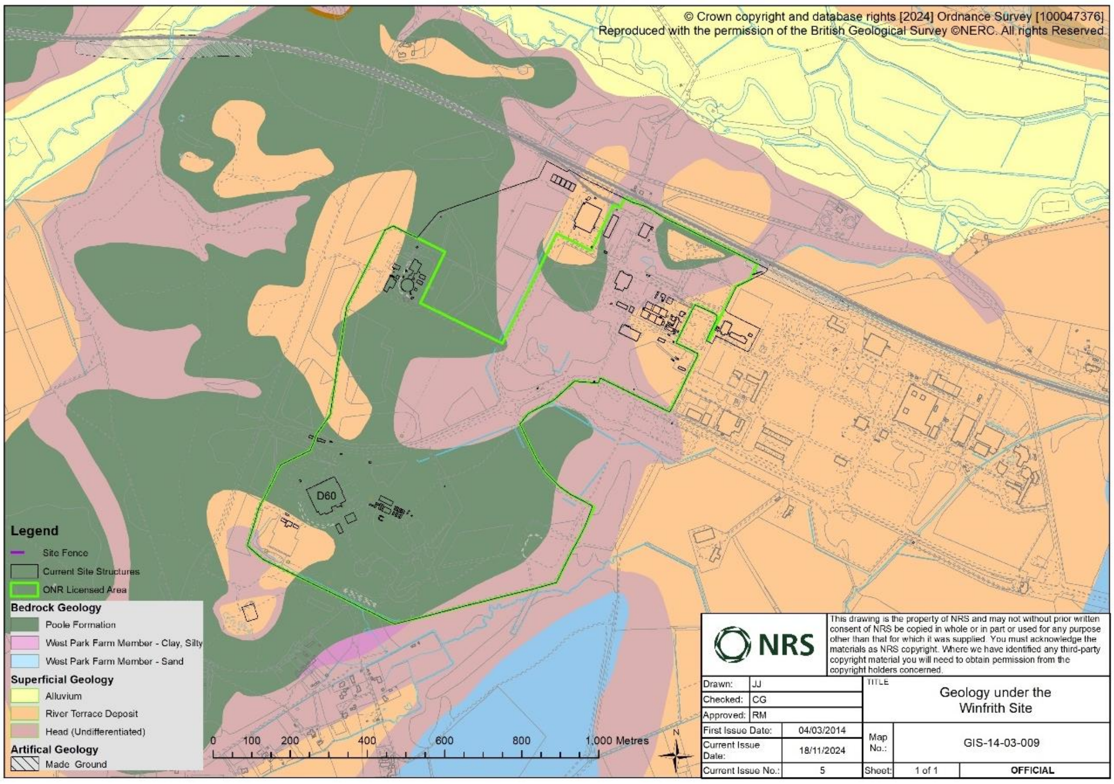

Figure 3.6: Bedrock and superficial geology of the Winfrith site.

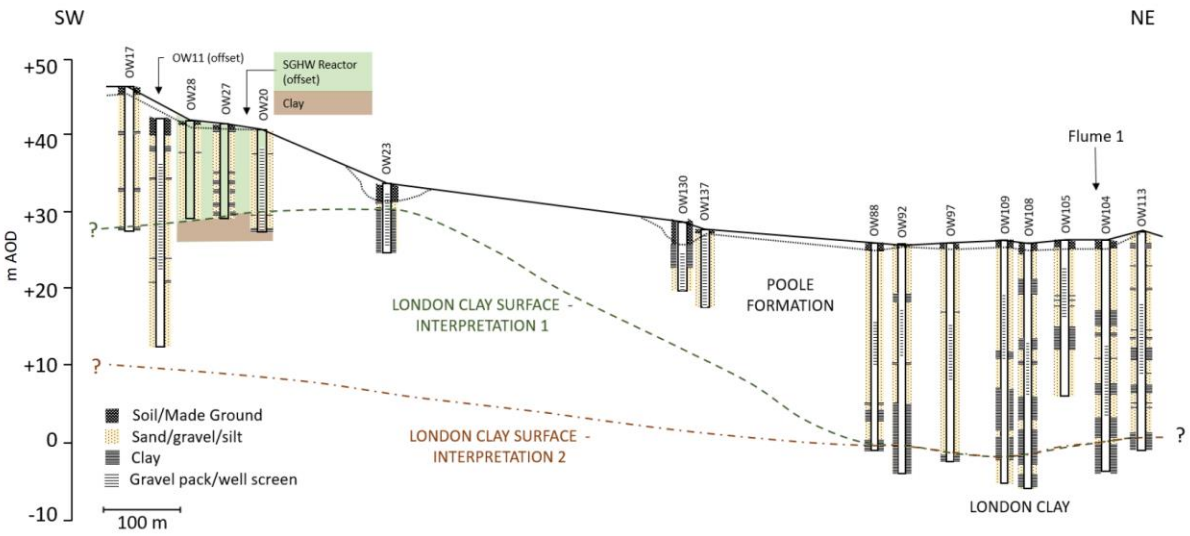

Figure 3.7: Geological cross-section south-west to north-east across the Winfrith site illustrating both conceptual interpretations for the southern part of the site (the London Clay elevation) [43, Fig.604/21].

3.2.3 Climate

90 The present-day climate of the Winfrith site is mild, characterised by temperate conditions and warm summers.

91 Historical rainfall data (1961 to 2004) are available from the site rain gauge. The average annual rainfall over that period was 915 mm [43, §3.2]. This is consistent with publicly available rainfall data for the area; the Hurn weather station recorded an average annual rainfall of 840.5 mm over the period 1957 to October 2020 [43, §3.2]. The site rainfall trend is consistent with local trends - it is typically wetter in winter and drier in summer, with average site winter (November–February) monthly rainfall roughly double that of the average summer (June–September) monthly rainfall.

3.2.4 Hydrology and Drainage

92 There are two rivers close to the site, the River Frome and its tributary, the River Win (Figure 3.3). The Frome is the larger river, located approximately 300 m to the north of the site and flowing to the east, discharging into Poole Harbour around 12 km from the site [42, §5.2]. The River Win is located to the south and east of the site, and flows north-east, meeting the River Frome approximately 1.5 km east-north-east of the site at East Burton.

93 Flow data for the River Frome for the period 1965 to 2021 indicates the mean flow rate is 6.72 $m^3 s^{-1}$ [42, §5.2]. The River Win has been gauged for flow by the EA and the estimated mean flow rate near the site for the period 1975 to 2022 is 0.038 $m^3 s^{-1}$ [42, §5.2].

94 Ignoring the effect of drainage, the site can be split into two natural catchments [43, §3.4] (Figure 3.8). The northern catchment is approximately 69.75 ha and drains the

majority of the site to the north-east and east towards Flume 1 and the Frome Ditch[9] surface water features (Figure 3.9). The southern catchment is smaller, approximately 14.2 ha, and drains south and south-east towards the River Win.

95 Rainfall runoff at the site is primarily drained through an extensive network of surface water and land drains that were built during the late 1950s. The drainage network broadly comprises [43, §3.5.1]:

- Surface water drains consisting of a series of salt-glazed clay pipes, which collect rainfall runoff from impermeable areas, such as the roofs of buildings, and discharge it into either the local watercourses (in some cases via flumes) or soakaways.
- Soakaways and French drains, that encourage direct infiltration of rainfall runoff into the soil.
- Rubble drains/open-channel ditches that collect, store and convey drained surface water into local watercourses (in some cases via flumes). These drains are open-channel ditches that are subject to maintenance which involves periodic dredging and clearance of vegetation.

96 Surface water and rubble drains reduce the areas of waterlogging and the risk of flooding on the site. Groundwater flowing north-eastwards across the site is intercepted by the network of rubble drains [43, §3.5.2]. The discharge of groundwater to surface water also occurs to the Frome Ditch and the River Frome. Surface water flow is mostly routed along roads, especially Monterey Avenue (the main north-east to south-west road near SGHWR). Across the site, depressions in the land surface produce surface water ponds, which are mostly fed by rainfall and some by shallow groundwater.

97 Flume 1 (Figure 3.9a) receives most of the water from the on-site surface water drainage network. Flume 1 is fed by a 48” (1.2 m) diameter main surface drain that crosses the site; a flow rate of 350 $m^3\ day^{-1}$ was recorded in May 2003 [43, Tab.604/2]. From Flume 1, water flows through an 80-m long, 1.2 m wide pipe beneath the railway into the Frome Ditch before reaching the River Frome (Figure 3.8) [36, §4.1 and Fig.1-4]. The Frome Ditch is culverted for approximately 40 m downstream of the railway, after which it is unlined [43]. The average flow in the Frome Ditch is 23,328 $m^3\ day^{-1}$ [43, Tab.604/2][10].

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[9] The Frome Ditch is referred to inconsistently as the Frome Ditch, Stream, Channel and Canal; Ditch is the term used here.

[10] The flow rate reported in Flume 1 is lower than the lowest and average flow measured in the Frome Ditch. It is not clear whether the measurement in May 2003 was during particularly dry weather or whether additional water is being added to the Frome Ditch beyond that supplied by Flume 1 [43, p.37].

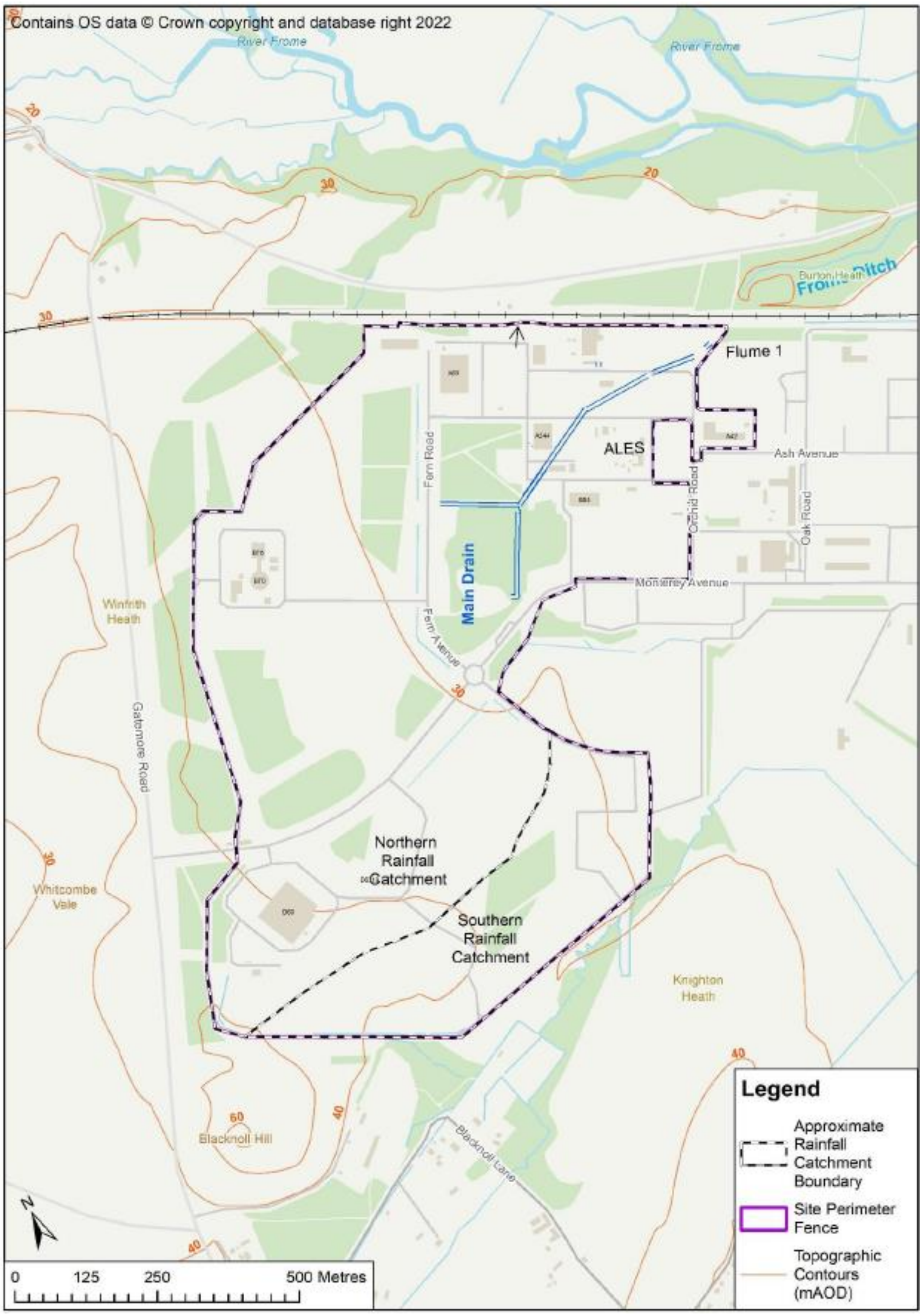

Figure 3.8: Overview of site hydrology [43, Fig.604/10].

Figure 3.9: (a) Flume 1 (February 2024), which carries surface and ground water from the drainage network to a 1.2 m wide pipe under the railway line and into the Frome Ditch [36, Fig.1-4]. (b) The Frome Ditch in 2004, which carries water from Flume 1 and the culvert beneath the railway line to the River Frome (from the NRS IMAGES database).

3.2.5 Hydrogeology

98 The Hydrogeological Interpretation Report [43, §6.1] indicates that the geology of the site can be divided into three hydrogeological units: the Poole Formation and superficial geology, the London Clay and the Portsdown Chalk (see Section 3.2.2). The superficial geology, comprising Made Ground, River Terrace deposits and Head deposits, may be combined with the Poole Formation and treated as a single hydrogeological unit due to the similar overall lithography [43, §6.1].

99 The hydraulic conductivity within this combined formation is highly variable across the site due to its heterogeneity [43, §6.4]. The clay lenses within the Poole Formation are highlighted as likely to cause localised effects on the groundwater level and flow. Elsewhere, clay lenses may result in “perched” (sub-surface) water tables. The results of large-scale tests for hydraulic conductivity in geological strata beneath the site range from 7×10^{-5} m s^{-1} to 4.7×10^{-4} m s^{-1} [20; 43, §6.4], with the mid-point at 2.7×10^{-4} m s^{-1}.

100 The Poole Formation is classified as a Secondary A aquifer of medium to high vulnerability [43, §6.2]. Secondary A aquifers typically comprise permeable layers capable of supporting water supplies at a local rather than strategic scale and which, in some cases, form an important source of base flow to rivers. Areas with high groundwater vulnerability easily transmit pollution to groundwater and are characterised by high-leaching soils and the absence of low-permeability superficial

deposits. Areas with medium vulnerability have overlying soils and superficial deposits that offer some groundwater protection.

101 In the London area, the London Clay is traditionally considered to permit little groundwater flow due to its high clay content and it is typically conceptualised as forming the base (or surface) of more transmissive near-surface aquifer units. However, further west and beneath the site, the stratum is generally more sandy. The West Park Farm member of the London Clay Formation comprises both sand-rich and clay layers and it is not known which function dominates beneath the site [43, §6.1]. Where frequent and persistent clay layers dominate, this layer forms a barrier to vertical flow, whereas the sand-rich zones may facilitate the local vertical movement of groundwater. The London Clay Formation is classed as an Unproductive Aquifer and has little or no resource potential [43, §6.2].

102 Where clay-rich London Clay layers are laterally persistent, groundwater in the Portsdown Chalk may be locally confined. Although not hydraulically tested beneath the site, the Portsdown Chalk is understood to be transmissive and is classified as a Principal Aquifer by the EA. The aquifer in the Portsdown Chalk Formation is the most likely to be targeted by any future abstraction borehole on, or downstream from, the site [43, §6.3.2].

103 The groundwater head, and therefore flow around the site, largely mirrors the surface topography [43, §8.1.2]. Hydraulic gradients in the west of the site in the region between the SGHWR and Dragon reactor complex are, on average, around 0.01 and are highest in the vicinity of Dragon, around 0.025 [43, §7.1.2]. The hydraulic gradient reduces to around 0.005 in the north-east part of the site [43, §7.1.2].

104 The hydrogeology of the site is dominated by the near-surface sands of the Poole Formation and the Quaternary deposits that affect shallow groundwater flow. Contaminated groundwater flow on site is expected to occur predominantly in the Poole Formation. Flow is primarily horizontal through the sandy horizons, although there is evidence of localised vertical flows and perturbations due to local clay lenses [43, §6.1]. The majority of the groundwater beneath the site flows in a north and north-easterly direction towards the River Frome while a portion flows more easterly towards the River Win. The divide between these flows is positioned south of the SGHWR (Figure 3.8). Modelling [43, §7.1.2] predicts that in drought conditions all groundwater flow on site is towards the River Frome.

105 Groundwater discharge locations include both natural and man-made features, including [43, §8.1.4]:

- Groundwater passing north-east beneath the site is captured by “rubble” drains which then transport groundwater eastwards into the 48” surface water drain and then on to Flume 1, the Frome Ditch and River Frome.
- Groundwater which passes both the SGHWR and the Dragon reactor complex discharges to the River Frome.

106 The conceptual model for groundwater flow on site, accounting for the impacts of implementing the end state and climate change (discussed in Section 3.4), is summarised graphically in Figure 3.29.

107 Groundwater elevations range from between 34 and 37 m AOD in the south-west and west of the site to around 20 m AOD in the north-east corner of the site and in the Dorset Innovation Park. Groundwater elevations in proximity to SGHWR are above the base slabs of regions 1 and 2, but below the tops of the base slabs of the Annexes (Section 3.3.1). Groundwater elevations in proximity to the Dragon reactor building are below the top of the base slab for all historical measurements (Section 3.3.2).

108 The depth to groundwater ranges between 1 m and 6 m across much of the site, lowest along the eastern boundary of the site and beyond to the Dorset Innovation Park, and increasing to around 9 m in the vicinity of the SGHWR and Dragon reactor. There is a thin unsaturated zone (less than 1 m) around borehole OW44 immediately west of the Monterey roundabout, which is an area of mire/wet heath. High frequency groundwater level monitoring in this area from late 2020 to early 2022 showed the presence of near-surface water that, following rainfall, rose to ground level [43, §7.1.2].

109 On- and off-site borehole measurements for the period 2003 to 2020 do not show a long-term changing trend in the groundwater levels across the site [43, §7.1.1]. Seasonality in groundwater level is observed, with levels peaking around January after the typically higher rainfall during the winter months, and with levels at their lowest around August. The seasonal range is typically around 1 m, reducing to between 0.4 m and 0.6 m in the north of the site [43, §7.1.1].

3.2.6 Hydrogeochemistry

110 The chemistry of the site groundwater controls the speciation, solubility and hence the retardation of many contaminants. The chemistry of groundwater also controls its potability and, in turn, its value and likely exploitation as a resource for potential abstraction.

111 Groundwater beneath the site is fresh (has a total dissolved solids content of less than 1,000 mg l^{-1}) and is within potable limits. Electrical conductivity, which is a proxy for salinity as electrical conductivity of water increases with increased salinity, is lowest at the western edge of the site (often less than 100 µS cm^{-1}) and is higher under the developed parts of the site at around 250 µS cm^{-1} [43, §9.2]. There is a tendency for the electrical conductivity to be lower than typical in winter months when groundwater recharge can be expected to have been higher.

112 Samples of groundwater collected from boreholes in heathland areas are typically sodium-chloride type to sodium/calcium-chloride/sulphate type [43, §9.3]. Samples of groundwater collected from boreholes in the east of the site are calcium-bicarbonate type. Groundwater flowing from beneath the heathland onto the developed parts of the site transitions between the two water types and this occurs beneath the SGHWR.

113 Of potential importance to the integrity of concrete structures is the sulphate concentration in groundwater. The sulphate concentrations measured in groundwater

around the SGHWR and Dragon reactors (~20 mg l^{-1}) fall comfortably into the lowest concrete design class for the least aggressive chemical environments [43, §9.3].

114 Under heathland the median pH is typically less than 5.5 (and as low as 4). Under ground cover that is not heathland, including the developed parts of the site, the pH rises to neutral (pH 7). The SGHWR is in an area of transition and groundwater pH changes from around 5 on its upgradient side to above 6 on its down gradient side, but a similar change in groundwater pH does not occur at the Dragon reactor. The transition in groundwater pH at the SGHWR appears to be associated with change in ground cover rather than the SGHWR structure *per se* [43, §9.4.2]. The pH in borehole OW44 approximately 350 m downgradient of the SGHWR in the direction of the location of groundwater emergence close to the roundabout varies between 5.7 and 7.0 with a mean value of 6.2 [43, §9.4.1]. The pH of groundwater in two shallow (<2 m bgl) hand auger holes west of Monterey roundabout is around 4; the shallow groundwater may have been locally recharged by rainfall and the pH lowered by Sphagnum.

115 The effect of changes in the pH associated with sorption behaviour varies for different radionuclides. For those elements which sorb by surface complexation, sorption generally decreases with decreasing pH. This is true for cobalt and nickel, trivalent actinides and the lanthanides [47, §3.1].

3.2.7 Natural Disruptive Processes

116 The potential for natural disruptive processes to occur and their relative magnitude at the Winfrith site are discussed in the Site Description Report [42] and are summarised here. Over longer timescales, the potential for natural disruptive events increases as a consequence of climate change and this is discussed in Section 3.4.

117 The potential for natural disruptive events to compromise the integrity of structures disposed of in-situ is noted as an uncertainty (PA-009) in Appendix A.

Erosion

118 As the main site is over 5 km from the coast, coastal erosion and sea-level rise are not expected to impact the site.

119 The principal types of surface erosion are soil erosion, through wind or rainfall, and fluvial erosion, through incision or migration. Soil erosion is of concern across the UK and particularly in the Winfrith region due to the agricultural land use, although mapping by the European Soil Data Centre [48] indicates rates of less than 5 te ha^{-1} y^{-1} for soil erosion by water in the Dorset region. Erosion is also of concern for heathlands, with special consideration being given to understanding heaths near urban areas in Dorset [49; 50]. One of the main causes of erosion is public access and associated trampling of soils [51, Tab.1]. The clay-to-silt content of soils will affect erosion, with more silty soils more susceptible to erosion, while more clay-rich soils are less susceptible [52, §4.4].

120 The Winfrith Heaths are susceptible to burning as heathland flora is flammable [53]. Hot, dry summers and arson are the most common causes of burning, with four heath

fires recorded in the local region between 2011 and 2020 [42, §4.4.1]. Fires not only damage the local environment, but they may also be a hazard to people and fauna in the area, may damage infrastructure on site, and can lead to significant erosion, as bare soils will be more readily eroded by wind and rain. Heathland fires affecting the site cannot be ruled out but are not expected to significantly increase surface erosion as burned heather should continue to protect the soil until regrowth is established. A surface vegetation fire is unlikely to allow heat to penetrate to the envisaged depth of the low permeability membrane in the proposed engineered cap (Section 3.2.9). Planned public access routes and maintenance tracks across the site (a 2-3 m wide non-vegetated strip between heathland) will also function as a firebreak and reduce the potential for spread of wildfire across the site [36, Tab.A-6]. The possibility of a fire contributing to increased doses is captured in Appendix A as uncertainty PA-017.

121 Erosion along the River Frome can be significant. However, due to the local topography, the relative size of the river and the distance from the site, river erosion is assumed not to have any effects over the timescales of concern.

122 Overall, the low rates of surface erosion and lack of mechanism for rapid erosion events mean that there is low likelihood of the on-site disposals being exposed by surface erosion over the assessment timescale and other effects on the site will be negligible.

Flood

123 The majority of the Winfrith site is not at risk of surface water flooding. However, some small areas of the site range from low to high risk in localised areas, particularly between the Dorset Innovation Park and the River Win (Figure 3.10) [54]. Site operators have not recorded any historical flood events of note as having occurred on the site [42, §5.6].

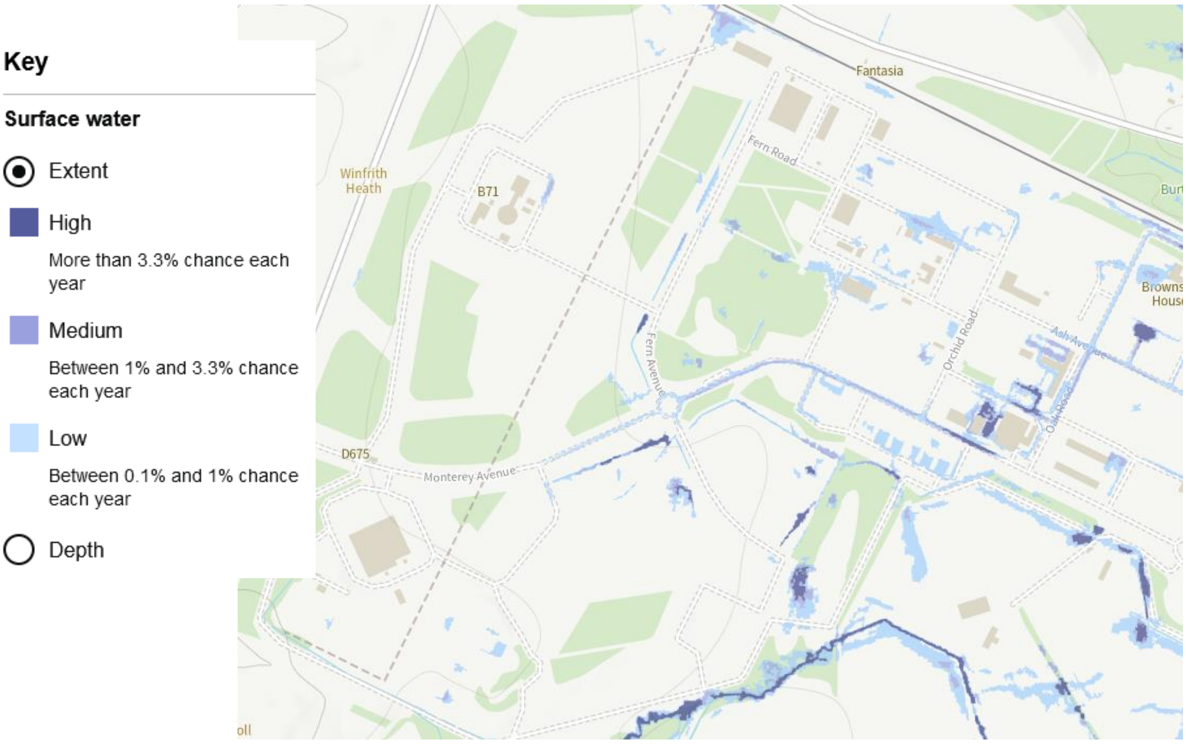

Figure 3.10: Surface water flood risk map for the site [54]. © Crown copyright.

124 There is a flood risk to the north of the site from the functional floodplain of the River Frome, and to the east and south of the site from the River Win, but the site itself is in Zone 1 and has a low probability of flooding from rivers and sea (Figure 3.11). The current (and future) risk of tidal flooding on-site is low due to the average elevation (>25 m AOD) and the long distance from the discharge point of the River Frome in Poole harbour [55, §4.3].

125 Groundwater modelling of the site has assessed the current risk of groundwater flooding [56].[11] and shows that during periods of average recharge this is limited to regions near the Frome Ditch, the site of the old Zebra reactor and several other regions off-site. Further modelling of the site at the planned end state has assessed the effect of changes to drainage and land use and is described in Section 3.4.

126 A number of perched aquifers exist across the site in the Poole Formation due to clay lenses within the sand formations. Following heavy rainfall this may lead to some ponding of surface water and potential flood risk. Some soils associated with the 'Shirrell Heath 1 Formation' are slow draining and hence susceptible to some seasonal waterlogging.

[11] This groundwater modelling has largely been superseded by work reported in the Hydrogeological Interpretation Report [43], which uses a revised approach to defining recharge and is more appropriate for assessing groundwater responses to climate change. The conclusions in the flood risk modelling [56] relating to current flood risks are considered to remain valid.

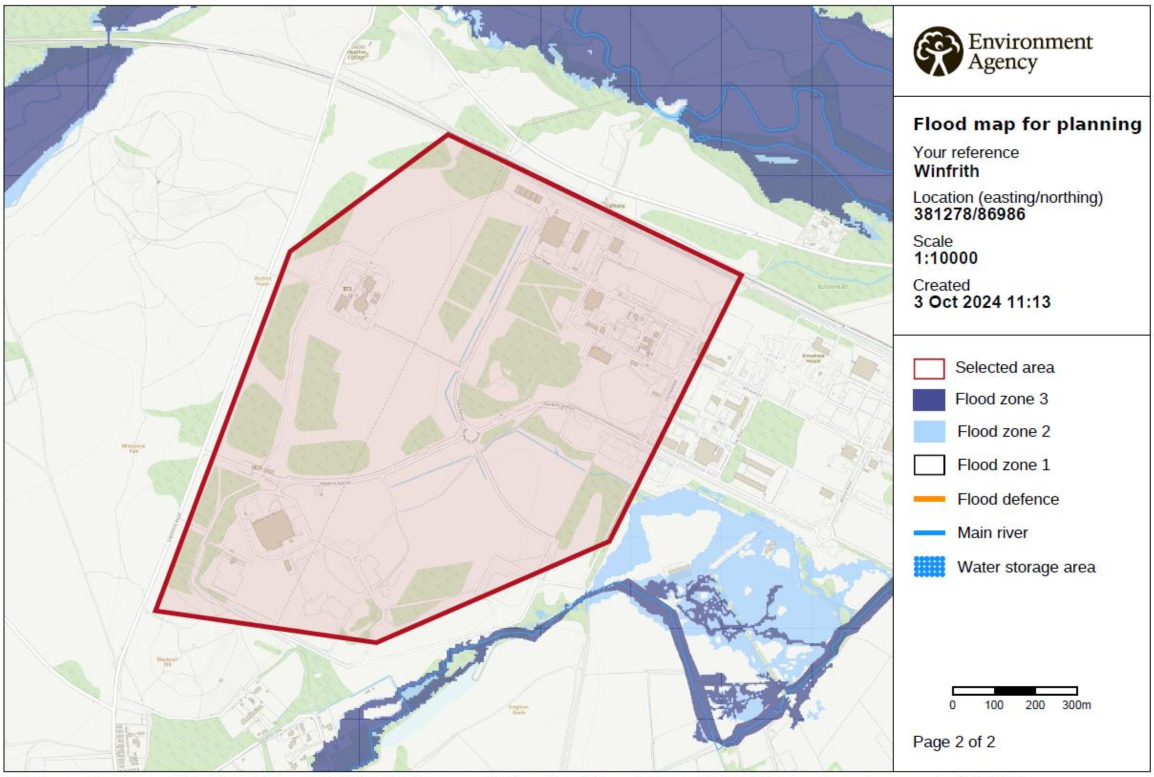

Figure 3.11: Flood risk map from rivers and sea for the site [57]. © EA and Crown copyright. The selected area is illustrative of the site boundaries only.

Seismicity

127 The UK is in a geologically inactive setting, situated far from any plate boundaries, and levels of seismicity are characteristically low. However, the UK does experience a number of earthquakes of local magnitude $M_L > 4$ per decade. The largest instrumentally-recorded earthquake close to the Winfrith site was a $M_L = 2.9$ event that occurred on 23 March 1998 near Weymouth.

128 Assessment by the British Geological Survey (BGS) [58] predicts that the zone in which the site is located will experience 0.06 events of moment magnitude $M_W \geq 4.5$ in the next 300 years, while the region has experienced no events of such magnitude in the last 300 years. This assessment zone was the joint least active of the UK seismic zones considered by the BGS.

129 The low likelihood of large earthquakes occurring in the area coupled with only minor ground motions means that the seismic hazard is likely to be insignificant at Winfrith [42, §4.2.2].

3.2.8 Local Human Habits

130 Two habits and land use surveys of the Winfrith area have been conducted by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) on behalf of the Environment Agency in 2003 [59] and 2019 [60]. Broadly similar activities were observed across the two surveys.

131 The survey area consists of a terrestrial survey, covering all land and freshwater watercourses within 5 km of the site centre, and an aquatic survey, covering tidal waters and intertidal areas and the adjacent offshore area from Portland Bill to St Alban's Head. The aquatic survey is primarily applicable to the impact of the Sea Discharge Pipeline, as it covers the immediate area of the pipeline outlet, and therefore is not considered here (it is currently assumed that the pipeline will be decommissioned and removed). Natural water flow on site discharges into sea via the River Frome at Poole Harbour, which is outside the survey area.

132 Figure 3.12 displays the 2019 survey area for both the direct radiation survey and terrestrial survey. The direct radiation survey covers land within 1 km of the licensed site boundary. The occupancy data collected from this survey are applicable to inhalation and external exposure pathways. Since the previous survey in 2003, de-licensing of a portion of the eastern side of the nuclear licensed site has reduced the area of the site by approximately 10%. This has resulted in a small reduction of the 2019 direct radiation survey area, resulting in the village of East Burton not being included [60, §6.1]. The terrestrial survey area covers land within 5 km of the centre point of the site (National Grid Reference: SY 813 869).

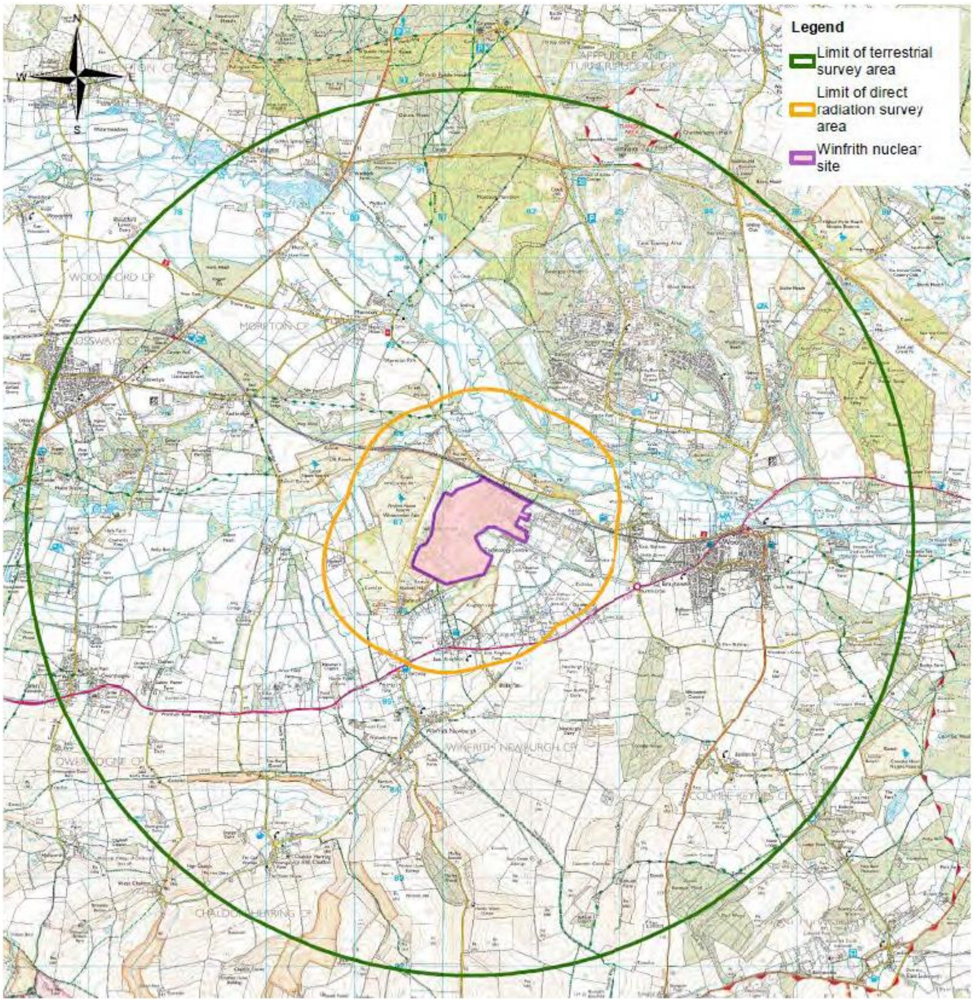

Figure 3.12: The Winfrith terrestrial and direct radiation survey areas [59, §2.3].

133 The main use of land in the terrestrial survey region is for farming, and both CEFAS surveys identified 35 working farms and up to three smallholdings in the survey area. In addition to growing arable crops, the farms produced the following:

- Around eleven farms produced milk (from dairy cattle), and raised dairy followers (young dairy cattle, intended to replace older dairy cattle) or dry dairy cows (waiting to calf) in both the 2019 and 2003 surveys.
- Six farms reared beef cattle in 2019 (one of which also reared geese and turkeys), an increase from two in 2003.
- Six farms reared beef cattle and lambs in the 2019 survey; five such farms were noted in 2003.
- One farm reared lambs in 2019, while a farm producing lamb meat and sheep’s milk was observed in 2003.
- The rearing of chickens for the sale of eggs was not noted in 2019, while nine such farms were noted in 2003.
- Six farms produced arable crops for animal feed in 2009 while “many” such farms were noted in the 2003 survey.
- One nursery growing fruit-producing plants on sale to the public was noted in 2003.
- Four farms produced salad crops and one produced watercress in 2019, a slight increase from two producing salad leaves and one producing watercress in 2003.
- There were two pig and chicken-egg farms identified in 2003.
- Two smallholdings producing pigs, lambs and chicken eggs were noted in 2019. A third smallholding reared lamb in 2019.

134 The CEFAS surveys record the consumption rates for foods from the terrestrial and aquatic survey area. Farmers, smallholders and their families were consuming milk, beef, lamb, watercress, pork, chicken and chicken eggs, goose and turkey produced commercially on their own farms or smallholdings. In addition, non-commercial production of fruits and vegetables was identified in private gardens and allotments within the survey area, as well as the rearing of chickens for the small-scale sale of eggs and the production of honey. Wild foods were collected and consumed, including blackberries, chestnuts, damsons, elderberries, elderflowers, rosehips, hawthorn fruit, hazelnuts, sloes and mushrooms. Game shooting was identified, and pheasant, pigeon, partridge, rabbit and venison were consumed.

135 It was also identified that beef cattle and ponies graze the Tadnoll and Winfrith Heath nature reserve to the west of the site.

136 In the 2003 survey [59, p.35], livestock on two farms had access to water from the River Frome and on another farm they were supplied by water from a borehole. However, in all cases the animals were also supplied with mains water. The same was identified in 2019 [60, §5.1], with livestock drinking mains water and having access to spring, stream water and water from a borehole.

137 One household was identified in 2003 whose sole water supply was from a borehole, and two properties near the Winfrith site had capped or disused wells in their gardens [59, p.35]. In 2019 human consumption of groundwater via boreholes was identified at “several” farmhouses [60, §5.1] (the exact number of farmhouses was not stated).

138 Surveys of the occupancy rates in the direct radiation survey area (within 1 km of the site boundary) identified the following activities occurring in the area:

- commercial activities at Dorset Innovation Park (formerly the Winfrith Technology Centre), where approximately 1,700 individuals worked in 2003 and 650 individuals worked in 2019;
- farming, with several farms having fields within the survey area;
- operation of the Wool Sewage Treatment Works to the north of the site;
- commercial activities by a number of small businesses in East Knighton;
- residence in properties in the village of East Knighton to the south of the site and at a handful of properties to the north and south-west of the site;
- leisure activities in the nature reserve, primarily walking and dog walking, with horse riding also reported; and
- growing of fruits and vegetables and the collection of wild food.

3.2.9 Resource Potential

Geology

139 The east Dorset area surrounding the site has historically been exploited for a range of natural resources which mostly comprise three main groups of materials [42, §4.3]:

- sand and gravel from the Cenozoic Poole, London Clay formations and Quaternary River Terrace deposits;
- Ball Clay, a mixture of kaolinite, mica and quartz; and
- hydrocarbons.

140 A number of quarries in the region currently extract sand and gravel, mostly for use in concrete aggregates. Ball Clay has been extensively mined in Dorset, although the site itself and surrounds are located on the sand-rich Poole Formation. Hydrocarbon extraction boreholes have historically been in operation within several kilometres of the site, although these are now plugged and abandoned. There are no known plans for extraction of these materials on or near the site but exploration or exploitation in the future cannot be excluded.

Groundwater and Surface Water

141 Both groundwater and surface water in the surrounding area are exploited as a drinking water resource or for agricultural use. There are a number of groundwater abstraction stations within 5 km of the site (Figure 3.13), which are mostly small to medium-sized [42, §5.5]. Based on the aquifer classification (Section 3.2.5), it is possible that

groundwater within the shallow aquifers around the site could be used as a future resource [43, §6.3.2]. However, it is most likely that any abstraction borehole would be into the Portsdown Chalk aquifer, rather than the shallower Poole Formation.

142 Some of the land between the north boundary of the site and the River Frome is designated as a SSSI due to the presence of groundwater-supported aquatic and bankside vegetation (Section 3.2.10) and therefore water abstraction would be less likely to be granted permission. There is also a sewage treatment works located between the site and the River Frome SSSI that would make this area a less favourable location for a water supply source. These factors combined make it unlikely that a future groundwater abstraction would be located on the site or between the site and the River Frome within the Poole Formation or Quaternary deposits, at least in the near term.

143 Figure 3.13 shows a number of medium to large-sized surface water abstraction sites. Although the River Frome is a SSSI, this does not prevent other parties from requesting abstraction licences from the EA, who would determine if there is sufficient water availability. Therefore, surface water within the River Frome represents a potential future resource.

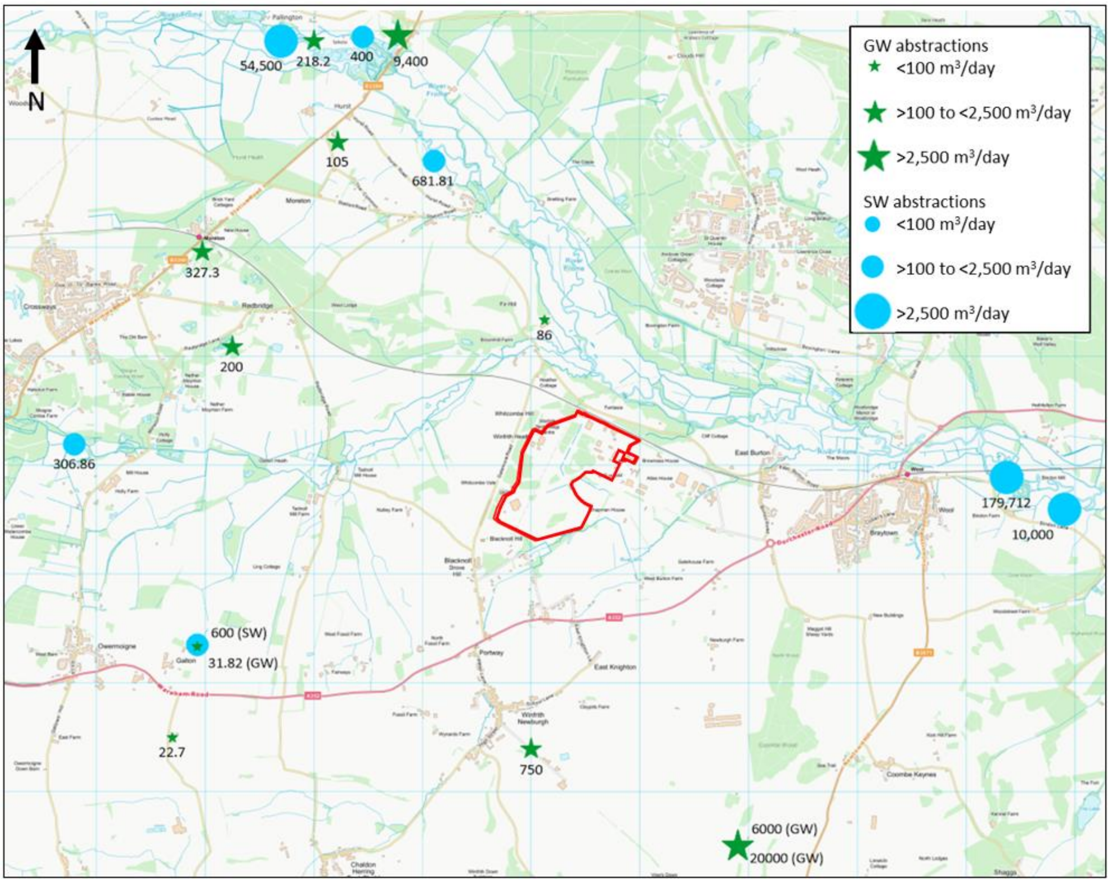

Figure 3.13: Location of licensed groundwater and surface abstractions (December 2020). Edited based on [43, Fig.604/23].

3.2.10 Habitats, Designations and Protected Species

144 Much of the heathland on-site sits within the Winfrith Heath SSSI (Figure 3.14), although the SGHWR and Dragon reactor complex areas are specifically excluded [61]. The Winfrith Heath SSSI is a substantial and varied tract of heathland near the western limit of the Dorset Heaths encompassing a range of heath and mire ecological communities. This SSSI includes the Winfrith and Tadnoll Heath Nature Reserve, an internationally significant conservation area which also encompasses the wetland Ramsar site [31], and parts of the site are designated as the Dorset Heath Special Area of Conservation (SAC) and the Dorset Heathlands Special Protection Area (SPA). To the south of the site is Dorset's National Landscape.

145 Due to the presence of groundwater dependent vegetation, the extent of Winfrith Heath SSSI has also been identified as a Groundwater Dependent Terrestrial Ecosystem (GWDTE) by the EA, which indicates wetlands critically dependant on groundwater. However, M16 (*Erica tetralix* - *Sphagnum compactum* wet heath) is the only plant community associated with the Winfrith Heath SSSI which is dependent on groundwater and this plant community is only found in certain parts of the SSSI [62].

146 Protected species surveys were undertaken in 2022 and 2023 [63] to determine the potential of the site to support these species, and to establish a baseline value for the site. Habitats and species identified included: a maternity roost for common pipistrelle and soprano pipistrelle bats; evidence for the presence of great crested newt; and 58 species of birds using the site (including all three ground-nesting species of the Dorset Heathlands SPA - the woodlark, Dartford warbler and nightjar). All six of the UK's native species of reptiles were recorded during the reptile survey including two rare species, the smooth snake and the sand lizard. Potential badger foraging activity was identified. Evidence of other mammals was also noted, including fox, deer, hedgehog and rabbit.

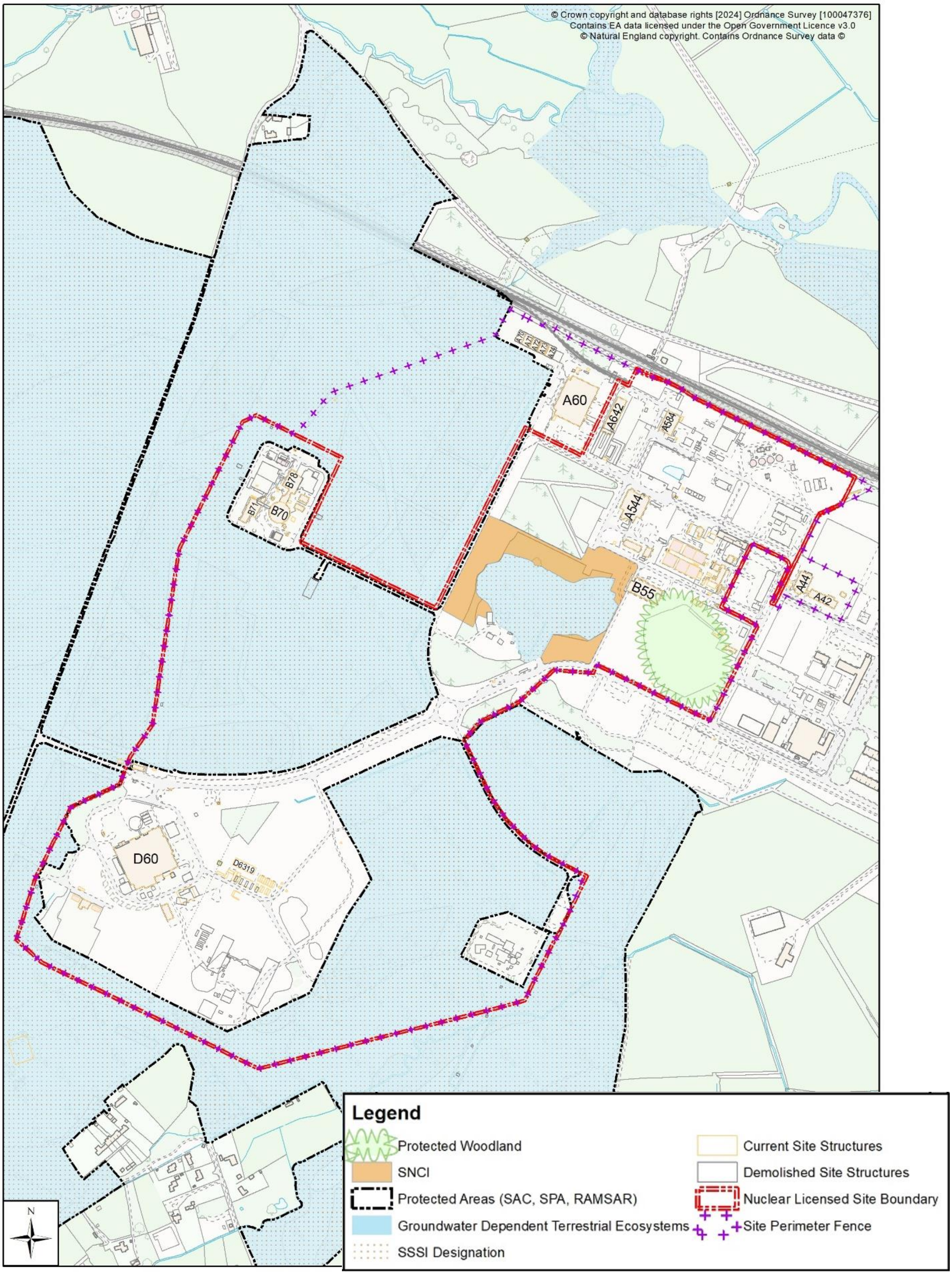

Figure 3.14: Habitat designations on the Winfrith site (NRS, March 2024).

3.3 Modelled Radiological Features

147 The current strategy for the Winfrith site reflects the NDA's overall strategy to decommission the reactor sites as soon as reasonably practicable, taking account of life-cycle risks to people and the environment and other relevant factors [64]. Thus, the plan for the Winfrith site is to complete the decommissioning and demolition of all remaining facilities as soon as possible, followed by remediation and landscaping.

148 The Winfrith Starting Case [65] defined the features (structures and areas of contamination) that could potentially form part of the end state. Subsequent optimisation assessments and NDA/NRS strategic decision-making[12] means that, subject to further optimisation and characterisation, the two radiological features proposed for in-situ disposal as part of the Winfrith end state permit application are:

- the Steam Generating Heavy Water Reactor (SGHWR); and
- the Dragon reactor complex, including the B78 Dragon fuel storage building and the primary mortuary hole structure within it.

149 The A59 area of radiologically-contaminated land will be remediated to OoS and does not form part of the permit application, but is considered in this PA (as discussed in Paragraph 16).

150 Other non-radiological (i.e. OoS of RSR) features on the site, such as demolition materials from buildings and excavations (e.g. soil, concrete, brick) and existing material stockpiles and soil mounds, will be used for void filling, capping and landscaping on the site [65]. Any excess material will be removed from the site for re-use or disposal [66, §3.4].

151 The subsequent sub-sections describe each modelled feature group and its proposed configuration at the IEP. Section 3.3.4 summarises the radioactive inventory that is estimated to be present in each feature group at the IEP, including an overview of inventory derivation and a summary of the activities assumed in this PA.

152 During preparation of this PA, various uncertainties have been identified in the geometry of structures in both the SGHWR and Dragon reactor complex; both those that will form in-situ disposals and those that will be demolished and used to fill voids (DfaP). These are listed in full in Appendix A as PA-021.

3.3.1 Steam Generating Heavy Water Reactor (SGHWR)

153 The largest reactor on the site, the SGHWR was built as a prototype power-generating water-cooled reactor to demonstrate the viability of such systems. The SGHWR was the only light-water cooled and heavy-water moderated reactor ever to be built in the UK [67]. A 100 MW reactor, the SGHWR used slightly enriched uranium fuel. The

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[12] All radioactive features and wastes on the Winfrith site are listed in the site Waste Management Plan (WMP). The WMP identifies the anticipated management route for each feature/waste stream and the optimisation assessments undertaken to support decision-making.

reactor core consisted of 104 zirconium alloy pressure tubes, which passed through vertical aluminium tubes into a tank (calandria) of heavy water. The reactor was formally switched on in 1968 and, after 23 years of research and electricity supply to the national grid, was switched off in 1990.

154 The reactor building, D60, consists of ten levels, three of which are below ground (Figure 3.15). Above ground, the structure is a steel-clad metal frame with masonry (brick) and concrete internal structures. Below ground, the structure is mainly reinforced concrete. The reactor has been defueled and ancillary equipment and facilities decommissioned. The concept design for the end state is for the SGHWR reactor and plant building (D60) to be demolished to 1 m below ground level[13] (m bgl). Most internal walls in the below-ground structure will remain in-situ unless they need to be removed. Plant and accessible non-structural metal will be removed where optimal to do so. The above-ground structure will be demolished and the radiologically-contaminated concrete blocks and rubble produced will be used to backfill the below-ground void spaces (constituting disposal for a purpose (DfaP)). Spoil from existing rubble mounds located elsewhere on site, which is expected to be OoS of RSR, will also be used to infill the below-ground voids.

155 As explained in the Winfrith Conceptual Site Model Report (CSM) [20], although the SGHWR comprises many rooms, the below ground level elements of the SGHWR can be simplified into four regions based on the elevation of the floor slab in each region (Table 3.3). These are shown in section in Figure 3.15 and in plan in Figure 3.16 and form the basis of the SGHWR near-field conceptual model described in Section 5.2.1.

[13] The ground elevation around SGHWR is 40.53 m AOD on the north side and 41.61 m AOD on the south side [20, §2.3]. The bioshield extends to 132’ 10” AOD (40.5 m AOD) [68]. The “1 m bgl cutline” for SGHWR is taken with reference to the 41.61 m AOD ground elevation on the south side.

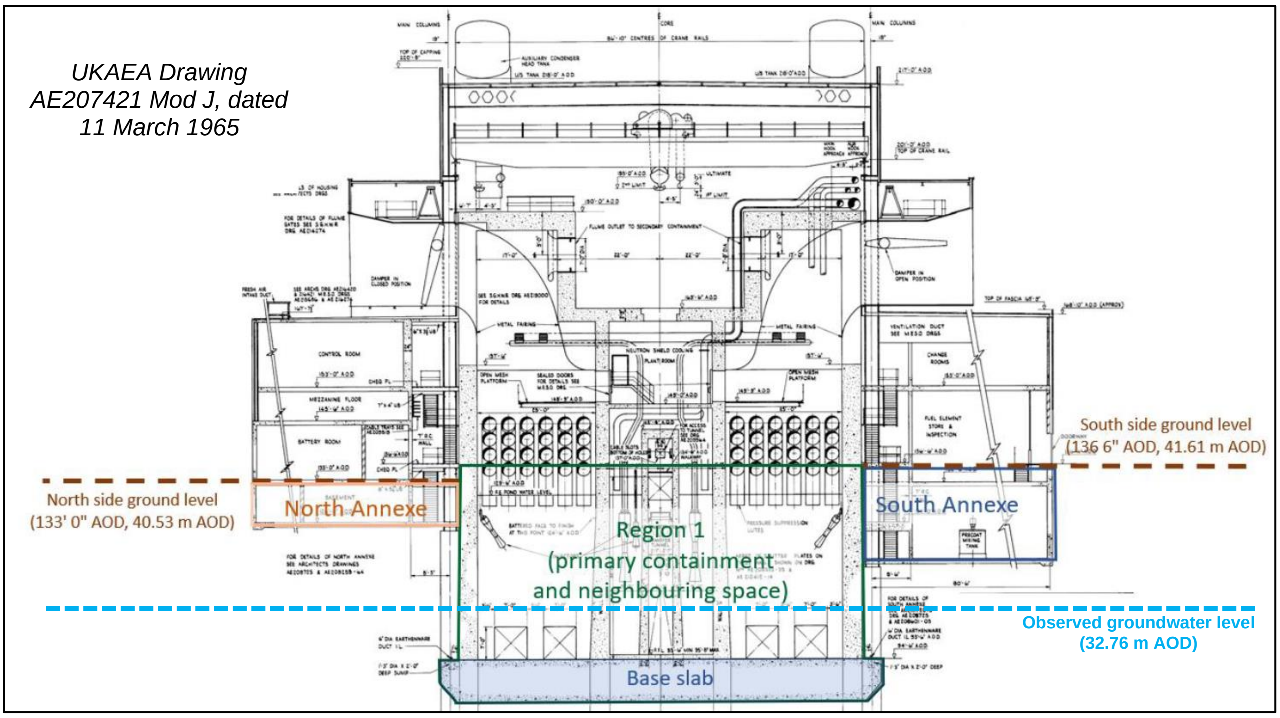

Figure 3.15: Cross-section through the SGHWR building with ground level and current groundwater level indicated. Edited based on [20, Fig.606/5]. Note the diagram shows plant and equipment that has been decommissioned and removed.

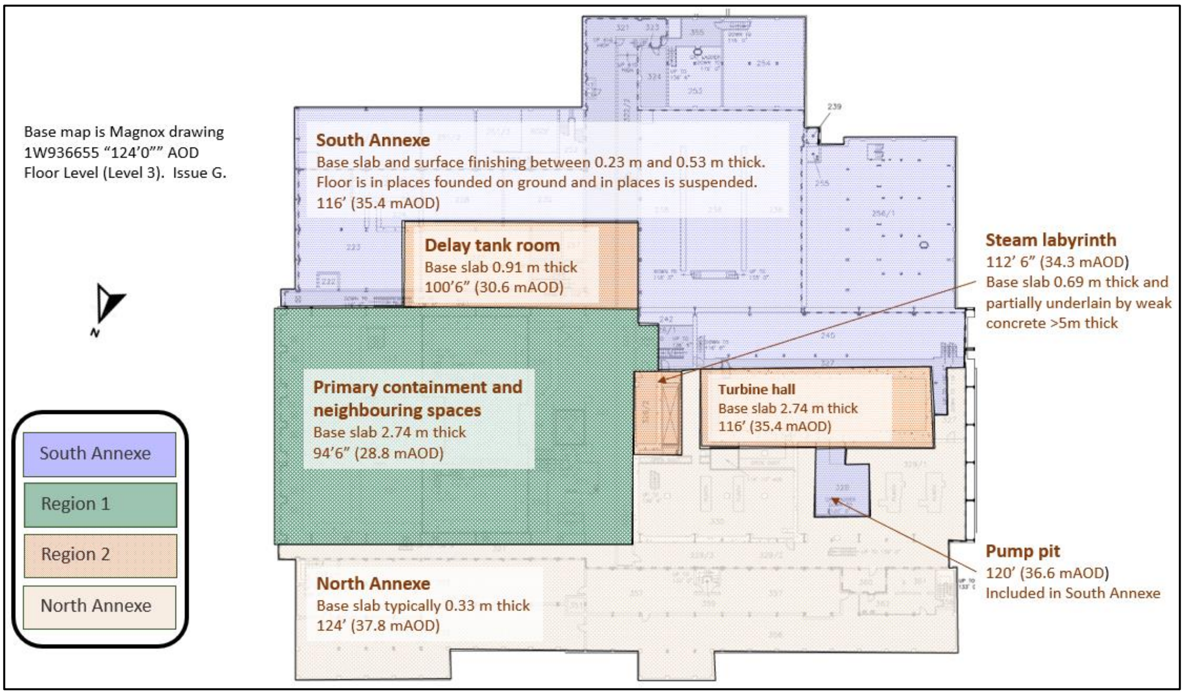

Figure 3.16: Plan showing the four below-ground regions of the SGHWR considered in the PA [20, Fig.604/4].

Table 3.3: Summary of SGHWR regions (based on [20, §2.2.1]). The current observed average groundwater elevation around SGHWR is 32.76 m AOD [97, Tab.616/1].

Model Region	Features	Top of floor slab elevation (m AOD)	Depth from ground surface (m)†	Floor slab thickness and description
Region 1	Reactor bioshield, mortuary tubes, ponds, primary containment and immediate surrounds, part of the secondary containment	28.8	12.81	2.74 m reinforced concrete
Region 2	Steam labyrinth to the west of the primary containment, the delay tank room, part of the secondary containment, and turbine hall	30.6 to 35.4	11.01 to 6.21	Reinforced concrete: Turbine hall: 2.74 m Delay tank room: 0.91 m Steam labyrinth: 0.69 m
South Annexe	Includes the pump pit to the north of the turbine hall and part of the secondary containment	35.4 to 36.6	6.21 to 5.01	Variable, between 0.23 m and 0.53 m reinforced concrete
North Annexe	Stores, workshops and part of the secondary containment	37.8	3.81	Typically, 0.33 m reinforced concrete

† Calculated with reference to the 41.61 m AOD ground elevation on the south side of SGHWR.

156 Optimisation of the end state SGHWR configuration is ongoing, including the nature of the infill and the engineered cap [8; 69; 70] (PA-011). Studies have also been undertaken to assess the integrity of the structures now and during the demolition and waste emplacement process to understand if below-ground walls need propping and if any cracks exist or may be created in the walls and floors (see [71; 72] and Section 3.4.1). The Reference Case configuration for this PA assumes:

- The below-ground walls and floors of Regions 1 and 2 are thick robust reinforced concrete that will retain their integrity. Any minor penetrations and cracks will be sealed where optimal to do so.
- The North and South Annexes are of a more standard building construction, with comparatively thinner walls and floors, and so are more likely to crack during demolition and waste emplacement.
- Region 1 will be infilled with contaminated concrete blocks at the bottom of the void and then concrete demolition rubble above. The other three regions will be filled with concrete demolition rubble.

157 The impacts of grouting the infilled below-ground structures or replacing the concrete blocks with rubble are considered as variant cases in the PA (see Table C.8).

158 A conceptual design for the engineered cap that will be placed over the below-ground structures (in the top 1 m and mounded over the ground) to slow infiltration and

leaching above the water table has been developed [20, §5.3] (Figure 3.17). Detailed design of the cap will take place following the Permit application. Therefore, specific cap details are not assumed in the PA models in order not to unnecessarily constrain future optimisation. The cap is considered purely in terms of its infiltration rate in the natural evolution assessment and in terms of its potential thickness in the site occupancy and human intrusion assessments. The cap is assumed to reduce infiltration from the average recharge for the area of 279 mm y^{-1} [43, §3.3] to 5 mm y^{-1} [20, p.93] upon installation (see Section 5.2.1 and Table D.33 for the assumed degradation behaviour).

159 The current conceptual cap design for SGHWR is a multi-layer system that is 4.0 m thick in total, so this is assumed in the Reference Case. Optimisation may result in a thinner cap (e.g. to minimise import of fresh materials); alternative cases consider 2.25 m and 3.0 m thick caps based on the current understanding of the minimum layer thickness necessary for the cap to perform the required functions.

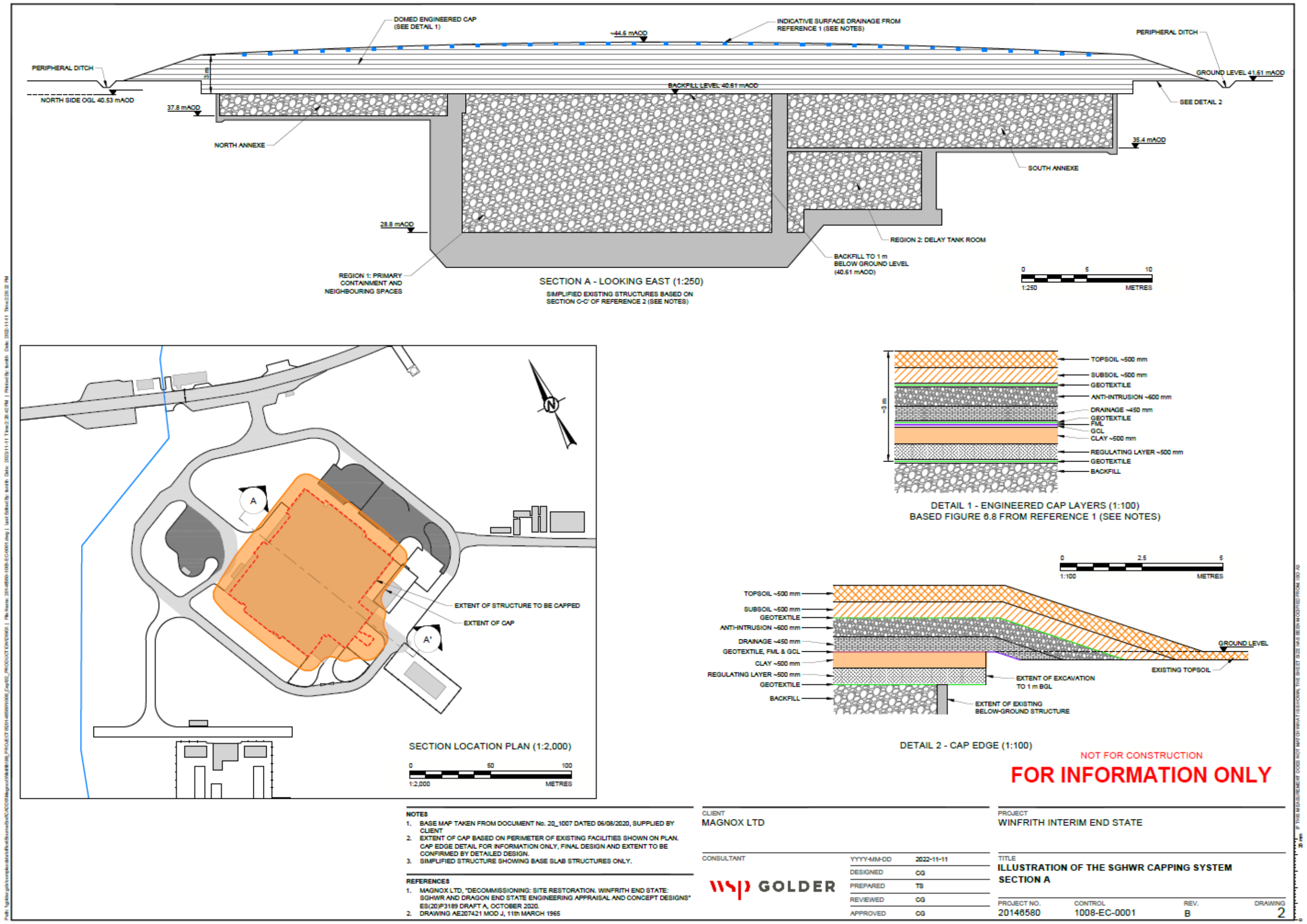

Figure 3.17: Schematic representation of the conceptual SGHWR engineered cap [20, Fig.606/16].

3.3.2 Dragon Reactor Complex

160 The Dragon reactor (Figure 3.18), operational between June 1965 and September 1975 [73], was a 20 MW high-temperature experimental reactor. The reactor core was graphite moderated and cooled with helium gas [74]. It was built and managed as part of an OECD project to develop high temperature reactors and to develop graphite-coated uranium-thorium fuel cycle technology. The Dragon reactor building, B70, was attached by a corridor to the fuel storage building, B78 (Figure 3.19). The floor slab of the B78 building is contiguous with that of the B70 building vehicle airlock and there are steel rail tracks embedded in the floor slab running from B78 to the reactor core.

161 As shown in Figure 3.18, the Dragon reactor structure is founded on a 3.7-m-thick steel-reinforced concrete base slab and has an outer concrete wall (Wall A) that is 2’ (0.61 m) thick. The top of the base slab is at 27.34 m AOD [20, §2.2.2]. The ground elevation around the reactor is 35.05 m AOD [20, §2.3]. The Dragon reactor is circular in plan-view and has three concentric concrete walls referred to as Wall A, Wall B and Wall C from the outside in (Figure 3.18). There is a steel inner containment shell between Walls B and C, and Wall D forms the concrete bioshield around the reactor.

162 The current observed average groundwater elevation around the Dragon reactor complex is 24.73 m AOD [97, Tab.616/1], so sits just above the bottom of the concrete base slab.

163 Built into the floor of building B78 is the mortuary hole structure, comprising 90 mortuary holes that were used to store Dragon fuel elements during its operational life, although they were also used for the storage of other materials following defueling of the Dragon reactor. The mortuary hole structure includes a 50-hole used fuel (“primary”) store and a 40-hole fresh fuel store [74, §1]. Constructed in a concrete lined and filled pit roughly 5 m below ground level in building B78, the mortuary hole system comprises vertical galvanised mild steel tubes.

164 As for the SGHWR and as per the CSM [20], the below-ground-level elements of the Dragon reactor complex can be grouped into six assessment features based on their location and inventory. These are summarised in Table 3.4 and form the basis of the Dragon reactor complex near-field conceptual model described in Section 5.2.1.

Table 3.4: Summary of Dragon reactor complex assessment features.

Assessment feature	Inventory features and components included
Dragon bioshield	• Bioshield, including Portland concrete, barytes concrete and rebar.
Dragon reactor building – inside Wall C	• Reactor building contamination inside of Wall C, comprising surface contamination and tritium ingress. • All backfill derived from above-ground bioshield.
Dragon reactor building – Walls A-C (up-gradient)	• Half of general reactor building contamination covering Walls A-C, comprising surface contamination and tritium ingress.

Assessment feature	Inventory features and components included
	• Betalite store area[14], comprising surface contamination and tritium ingress. • Residual contamination from the Purge Gas Pre-Cooler (PGPC) spill[15]. • Half of the total backfill derived from above-ground B70 and B78 buildings plus stockpile rubble.
Dragon reactor building – Walls A-C (down-gradient)	• Half of general reactor building contamination covering Walls A-C, comprising surface contamination and tritium ingress. • Half of the total backfill derived from above-ground B70 and B78 buildings plus stockpile rubble.
Dragon mortuary holes	• Primary mortuary hole structure.
Dragon B78 floor slab	• Fuel storage building (B78) floor slab, excluding primary mortuary hole structure.

165 As for the SGHWR, optimisation of the Dragon reactor complex structures end state configuration is ongoing [8; 69; 71] (PA-011). The end state concept assumes demolition of the reactor and fuel storage buildings to ground level [75], with the B78 fuel storage building floor slab remaining in place and re-profiling of the ground. Most internal walls in the sub-surface structure will remain in-situ unless they need to be removed to gain access for deposition of the infill material, and accessible non-structural metal will be removed. Demolition and site-derived material will be placed into the reactor building voids. The 50-hole used fuel primary mortuary hole structure is planned to be filled with clean grout; the 40-hole fresh fuel mortuary hole structure can be relatively easily removed from its concrete pit and will be disposed of off-site [76]. The Reference Case configuration for this PA assumes (see Section 3.4.1):

- The thick reinforced concrete floor slab of the Dragon reactor building retains its integrity during demolition and waste emplacement. The external Wall A may crack during demolition and waste emplacement.
- Contaminated concrete blocks are placed at the bottom of the void within Wall C and then concrete demolition rubble is placed above the blocks. Concrete demolition rubble is used to fill the below-ground void between Walls A and C.

166 The impacts of grouting the infilled below-ground structures or replacing the concrete blocks with rubble are considered as variant cases in the PA (see Table C.8).

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14 Historically, ^{3}H dials, known as Betalites, were stored at the -25’ level in the outer annulus of the Dragon reactor building, the leaking of which led to some contamination.

15 During a lifting operation in the cathedral area on the 22 March 2021 to transfer the PGPC into a bespoke shielded container, contaminated water spilled onto the concrete floor. Although it is intended to remove the entire volume of contaminated concrete, it is not clear whether this will be possible, so the Radiological Inventory Report includes an estimate for residual contamination that could remain as part of the disposal after optimisation.

167 An engineered cap will be emplaced over the below-ground B70 Dragon structure and the B78 floor slab, including the mortuary hole structure [20, §5.3] (Figure 3.20). As discussed in Section 3.3.1, the design of the cap will be developed at the detailed design stage so it is only considered in this PA simply in terms of its infiltration rate (5 mm y^{-1} [20, p.93] upon installation; see Table D.33) and potential thickness.

168 The current conceptual cap design for the Dragon reactor complex is a multi-layer system that is 3.8 m thick in total, so this is assumed for the Reference Case. Future optimisation may result in a thinner cap (e.g. to minimise import of fresh materials), so alternative cases consider 1.5 m and 2.5 m thick caps based on the current understanding of the minimum layer thickness necessary for the cap to perform the required functions. The Dragon reactor complex cap can be thinner than the SGHWR cap due to lower radiological and non-radiological risks associated with the Dragon reactor complex features.

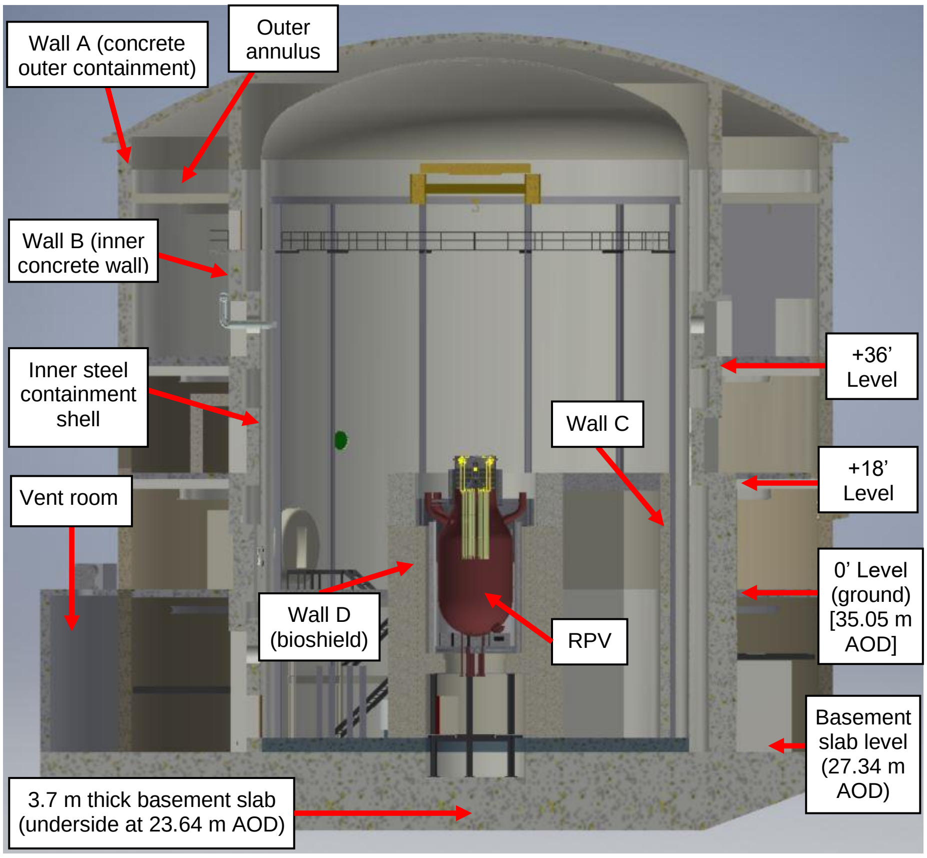
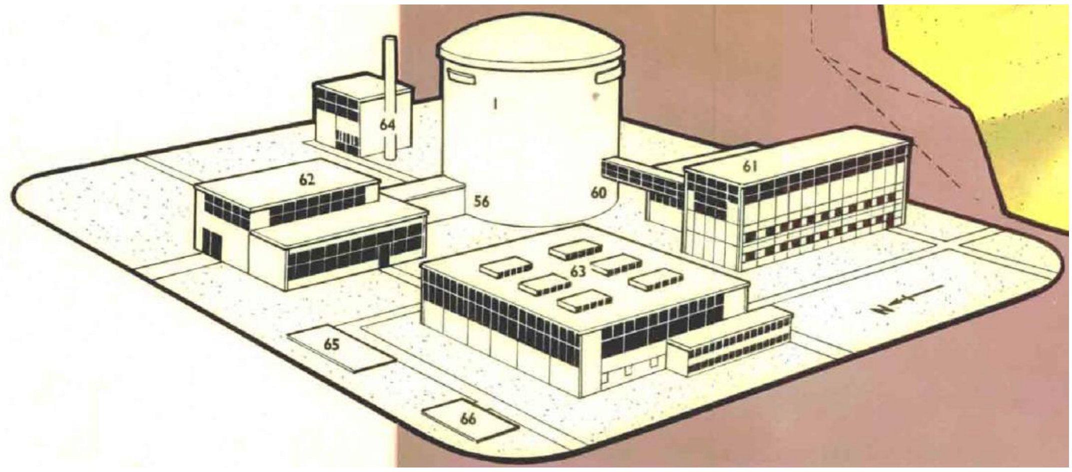


Figure 3.18: Split-view graphical model of the status in 2018 of the Dragon reactor building (edited from [77, Fig.1]).



Key:

1 = Outer concrete containment/B70 reactor building
56 = Vehicle airlock entrance
60 = Personnel walkway
61 = Control building (B71)/Western Offices
62 = Active fuel storage building (B78)
63 = Services building (removed to basement) B72
64 = Cooler building (B75) and stack
65 = Delay tanks (B76)
66 = Fuel oil storage tanks (now removed)

Figure 3.19: Dragon reactor complex (edited from [78]).

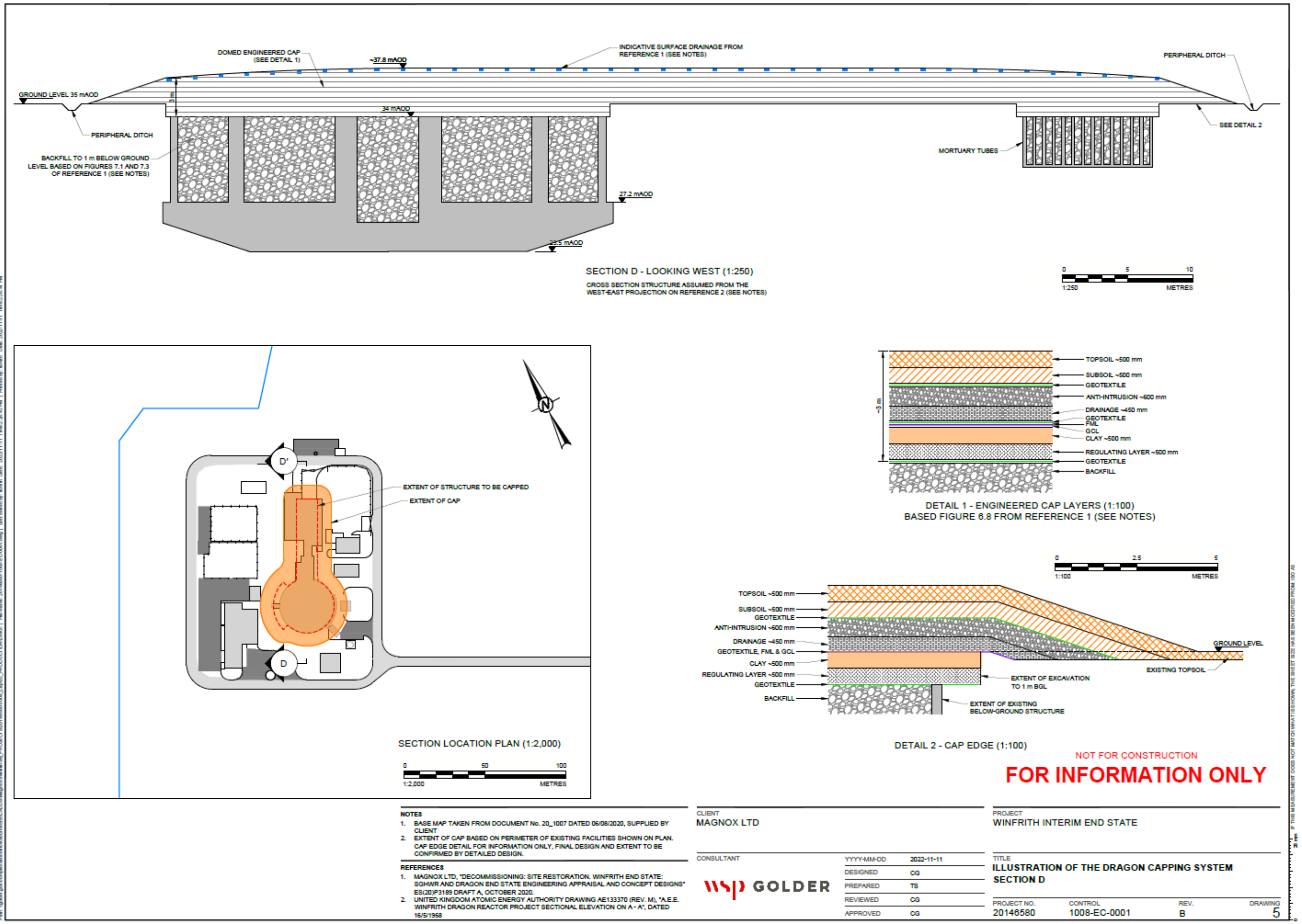


Figure 3.20: Schematic representation of the conceptual Dragon reactor complex engineered cap [20, Fig.606/17]. Note that this diagram pre-dates the decision to demolish to ground level, rather than 1 m bgl, and before the B78 floor slab was included in the scope.

3.3.3 A59 Area

169 The A59 area of contaminated land was formerly the location of the A59 active handling and decontamination building (Figure 3.21). Building A59 was the site of a Post-Irradiation Examination (PIE) facility and was used to examine reactor fuel assemblies and structural components from various reactors on site, and from national and international facilities, until operations ceased in 1992 [79, §3.2.2]. The building was subsequently used for other active handling tasks until 1999 [80, p.1].

170 The A591 facility was located on the south-eastern side of the A59 building and comprised a below-ground sump fitted with tanks and discharge pumps/pipes [79, §3.2.2]. The facility formed part of the connection between the operations within the A59 building and the discharge of active liquid wastes to the Active Liquid Effluent System (ALES). Figure 3.22 highlights key features of the A59 complex.

171 Incidents were recorded in A59 and A591 records that were considered at the time of reporting to have had the potential to impact the environment beyond the operational area [81; 82]. Many of the reported incidents relate to leakage from the active drainage pipework running beneath and away from the building, with contamination often associated with 'drawpits'. Both the A591/Heavy Vehicle Airlock (HVA) and the Pit 3/Pressurised Suit Area (PSA) (Figure 3.23) are identified by NRS as Areas of Potential Concern (APC).

172 Decommissioning of the facility began in 2001 with an initial clear out of the building before demolition [80, p.2]. Radiologically-contaminated soil was excavated and the area remediated. There were challenges during the remediation process and residual contamination remains below-ground and some potentially contaminated soil was used to backfill the excavation [82, App. 6; 83]. As shown in Table 3.6, the key radionuclides are ^{63}Ni (making up nearly half of the estimated contamination across the A59 area) and ^{90}Sr, ^{238}U, ^{234}U and ^{137}Cs (making up another ~40% between them), although plutonium and americium isotopes are also significant in the Pit 3/PSA area. Average activity concentrations are estimated to be around 0.1-0.2 Bq/g, with the exception of the A591/HVA area which has an estimated average activity concentration of around 2 Bq/g [83].

173 The majority of the remaining contamination is expected to lie at the base of the excavations. However, there is some uncertainty regarding the thickness of clean material above the contamination (PA-026). The Reference Case calculations assume that there is 0.5 m of clean cover, but alternative calculations explore this uncertainty by considering less cover (0.1 m and 0.3 m) and even conservatively consider that the contamination extends to the ground surface with no clean cover at all.

174 Options for managing this contamination have been considered by NRS [18]. The preferred optimised approach is that the contaminated land (above OoS levels) of the A59 area will be remediated prior to the end state (Figure 3.23). As the A59 area will be OoS of RSR, it does not form part of the RSR permit application. An estimate for the residual OoS radiological A59 contamination has been included in this assessment to ensure a thorough approach to assessment of all radiological impacts and

demonstration of safety margins at the site, and to inform understanding of the site validation monitoring.

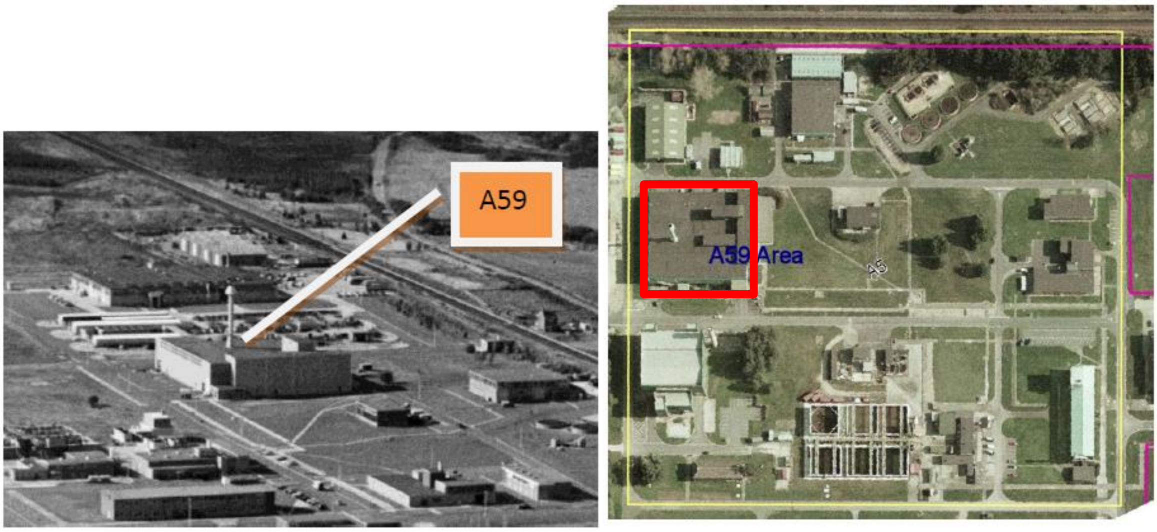


Figure 3.21: (Left) Photograph of the A59 facility circa 1966 and (right) an aerial photograph of the A59 facility in 2005 [82, App. B, Fig.2 & 3] with a red line delineating the facility.

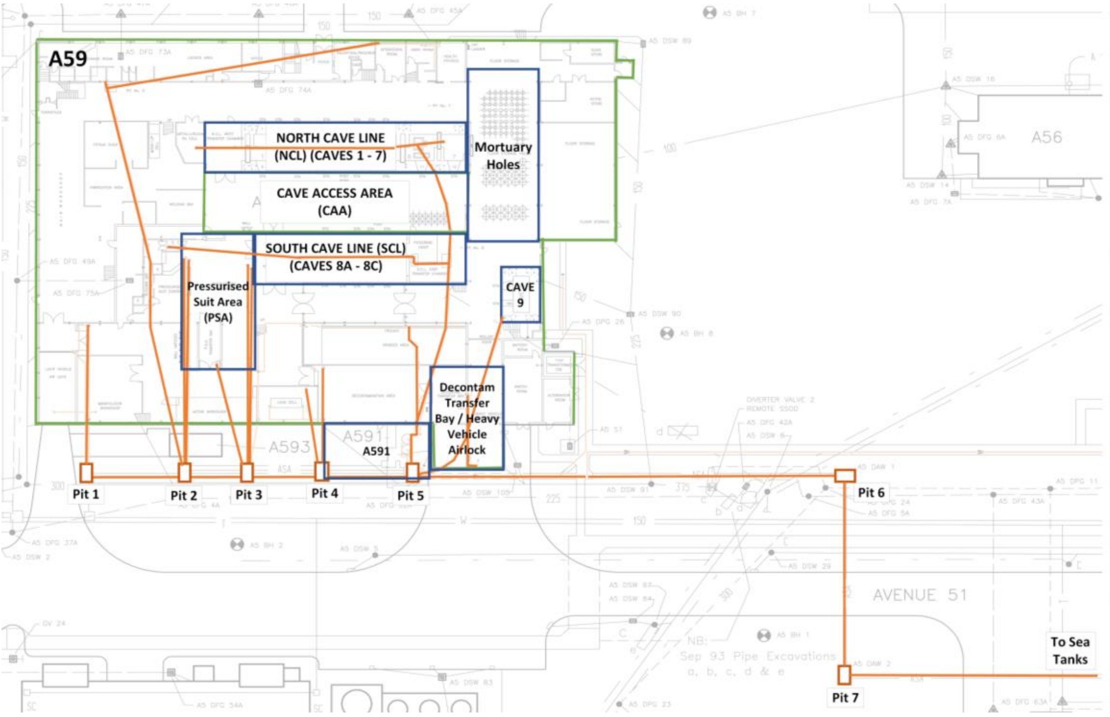


Figure 3.22: Key features of the A59 complex and active drain system.

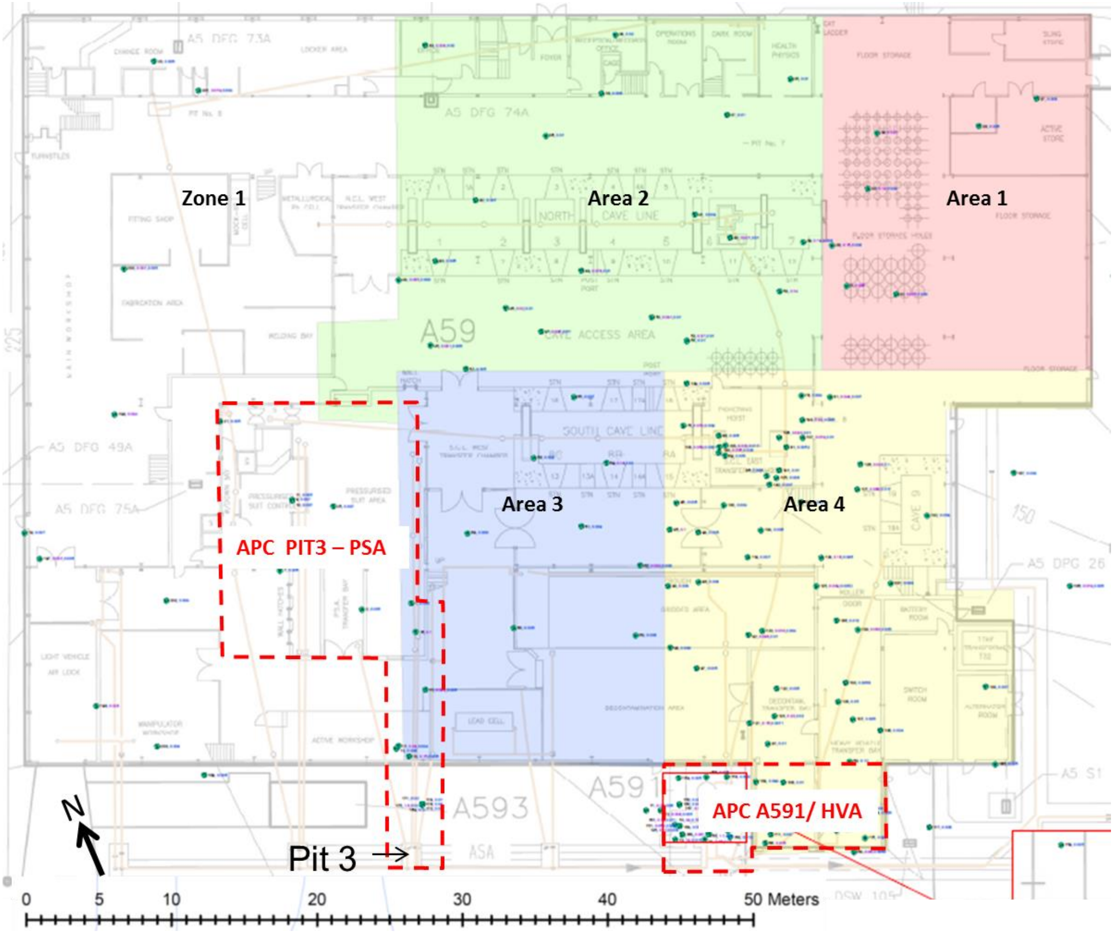


Figure 3.23: Plan of the A59 area, showing APCs within the former A59 building footprint (indicated by red dashed lines) to be remediated prior to IEP.

3.3.4 Source Inventory

175 Detailed radiological inventories for the features expected to remain on site at the end state are discussed and presented in dedicated reports [83; 84]. These reports present cautious, but credible, Reference Case estimates of the radioactive inventory and activity concentrations of features and components that are expected to form the on-site disposals, for an activity date of 1 January 2027. The estimates are based on existing characterisation data, provenance information and/or cautious assumptions, depending on the availability of relevant information. The inventory reports also derive alternative, more conservative, inventory estimates to understand the impact of inventory uncertainty.

176 Separate inventory estimates have been developed for in-situ features that are distinctly different in radiological fingerprint, or amount, or spatial extent of contamination or activation. The following terminology is used:

- Feature Group – A group of associated site **features**, such as reactor buildings, for which it is logical to administer together due to common prior use, close locality or shared structural components. For Winfrith, the SGHWR and Dragon reactor complex, and the OoS A59 land area, form feature groups.

- Feature – Discrete contaminated structure or area, composed of one or more **components**. For the SGHWR, features include Region 1 (which includes the mortuary tubes, primary containment and the ponds components), the bioshield, and Region 2 (including the secondary containment and ancillary areas components). For the Dragon reactor complex, features include the bioshield, reactor building and primary mortuary hole structure.
- Component – A part of a **feature** for which a separate inventory is derived, such as individual rooms, the tritium ingress component of general building contamination, etc.

177 The radiological inventory reports construct the estimates from individual components and rooms. These estimates have been aggregated into features of a scale appropriate for consideration in the PA. In addition, the inventory of some components has been assigned based on depth rather than plan location; for example, the SGHWR Delay Tank Room geographically could be assigned to the SGHWR South Annexe feature, but the depth of its floor slab and contamination makes it more appropriate to consider as part of the Region 2 feature (see Figure 3.16).

Inventory Derivation Overview

178 As noted above, detailed inventory derivation is presented in separate reports [83; 84]. An overview is given here to aid understanding of the basis of the Reference Case inventories.

179 The general approach followed was to:

- Interview facility staff to understand key components and processes, the range of data available, and ongoing decommissioning plans.
- Compile the available characterisation data and calculate inventory estimates for each component. The estimates developed consider, so far as is practicable, the appropriate mechanisms by which structures may have become contaminated (i.e. neutron activation and/or radiological contamination).
- Compare the estimates to facility plans to identify any missing components, and check use histories to assess appropriateness of fingerprints and inventory estimates; discuss with NRS staff to identify any inappropriate assumptions, gaps and inconsistencies, and any additional data.
- Qualitatively assess confidence in the inventory estimates for each component and use this, along with known uncertainty data, to undertake sensitivity analysis and develop alternative inventory estimates. These are summarised in Table 3.7 and associated text.

180 The derivation approach for the Reference Case estimate for each inventory feature is summarised in Table 3.5.

Table 3.5: Available characterisation data and approaches applied for derivation of Reference Case inventory estimates for radiological features (and components where the approach is component-specific) proposed for the end state. More detail can be found in [84 and 83]. Note that the Radiological Inventory Report derives estimates for each of the features and components listed in this table, but these inventories have been grouped into the 13 features identified in Table 3.9 for modelling in the PA (see discussion in Paragraph 155 for SGHWR and Paragraph 164 for the Dragon reactor complex).

Feature / component	Feature/contamination description and key characterisation data	Reference Case inventory derivation approach
SGHWR Bioshield	Reinforced concrete structure located entirely below ground (level 1 to level 3), at the centre of the primary containment that enclosed the reactor core during operation. The bioshield is 7 m high and its walls vary in thickness from 1.2 m to 2.8 m (shared with the primary containment). Two cores from 2005 (including limited rebar samples), supported by neutron activation modelling.	Uniform 1.55 m thick, full-height cylindrical layer of activated concrete assumed to be present close to reactor core, contained within a simplified outer cuboid of contaminated concrete. Paint assumed to cover all surfaces of simplified geometry except where joined to primary containment. Inventory is the sum of the following four components: • Concrete activation component derived from core data, with missing radionuclides derived from activation modelling fingerprint scaled to core data. • Rebar activation component derived from activation modelling due to limited measurement. • Paint contamination derived from single sample from inner edge of bioshield. • Concrete contamination (assumed depth 20 mm) derived by scaling SGHWR Primary External Contamination fingerprint to core data.
SGHWR Mortuary Tubes	Ten storage locations for irradiated items, each comprising a 0.2 m diameter ‘cast-in’ liner and running from the top of the bioshield to 2.7 m below the bioshield, then via a 90° bend into the primary containment. Residual radioactivity is expected to remain following removal of stored items and cleaning. No characterisation data as the tubes are currently inaccessible.	Conservative preliminary estimate based on the sum of five potential sources of residual activity, each derived by scaling a suitable fingerprint to an activity expected to be limiting: • contamination from reactor core items; • contamination from items that may have been in contact with the moderator circuit; • contamination from items that came from the ponds; • contamination arising from degradation of activated stored items; and • activation of the metal tubes themselves due to the reactor neutron flux in the bioshield.

Feature / component	Feature/contamination description and key characterisation data	Reference Case inventory derivation approach
SGHWR Primary Containment	Massive concrete structure with walls 1.2 to 1.5 m thick extending above and below ground (level 1 to level 6), it housed the reactor core, bioshield, mortuary tubes, and support operations including steam drums, clean-up plant and electrical control. Exposed to contamination due to operational leaks from liquid circuits. Two characterisation coring campaigns in 2005 and 2019.	Inventories derived for rooms/areas with similar process history from average of decay-corrected core samples, then summed. Missing radionuclides scaled from appropriate fingerprint using core data. Paint layer treated separately where appropriate. Contamination generally assumed to penetrate 150 mm into the concrete and 1 mm into paint layers. Separate component derived for bulk concrete tritium penetration over full wall thickness. Using the calculated volumes of the differing height sections of the primary containment, the proportion of the contaminated structure remaining in-situ below ground is estimated to be 67%, with the remaining 33% contributing to the demolition material to be emplaced in the below ground void.
SGHWR Secondary Containment	Concrete structure extending from level 1 to level 9 that housed the turbine/alternator, emergency water supplies, additional circuit supplies, plantrooms, ponds complex, effluent facilities, waste processing areas, and workshop areas. Circuits/systems in the primary containment fed into the secondary containment, allowing the transfer of contamination. Characterisation highly variable with some rooms/areas extensively cored and others (generally of low contamination significance) not at all.	Inventories derived for rooms/areas with similar process history, then summed. Estimates based on the materials and dimensions for each room, the (averaged, decay-corrected) available characterisation data and appropriate radionuclide fingerprints, and assumed penetration depths (generally 150 mm into the concrete and 1 mm into paint layers). Paint layer treated separately where appropriate. Secondary containment activity on levels 1 to 3 of the existing structure was assigned to the inventory of the contaminated structure remaining in-situ below ground, with the remainder assigned to the above ground demolition material to be emplaced in the below ground void.
SGHWR Ponds	Fuel element storage ponds, dump ponds and suppression ponds. Emptied after fuel transfer ceased and drained with limited cleaning. Significant characterisation programme completed in 2016 comprising 17 cores from pond floor areas and 126 wall cores with associated health physics monitoring	Core data show that the majority of the contamination is held within the fibreglass pond liners. Separate fibreglass liner and concrete inventories were derived from the average measured sample activities for each pond, assuming a liner thickness of 3 mm and a contamination depth of 200 mm in the concrete, and surface areas determined from engineering plans. Additional inventory was included from contaminated cracks and construction joints that were targeted by a subset of the wall cores, assuming that contamination spread 2.2 mm each side of the joint/crack.
SGHWR Ancillary Areas	Rooms outside the secondary containment structure. Some (such as the active workshops) supported active process operations and have been characterised via coring. Many areas did not support active process operations and are uncharacterised.	Inventories derived for rooms/areas with similar process history, then summed. Estimates based on the materials and dimensions for each room, the available characterisation data and fingerprints, and assumed penetration depths (generally 150 mm into the concrete and 1 mm into paint layers). Paint layer treated separately where appropriate. The approach to inclusion (using data from similar rooms) or exclusion of uncharacterised rooms was considered on a case-by-case basis.

Feature / component	Feature/contamination description and key characterisation data	Reference Case inventory derivation approach
SGHWR Bulk Structure	Core depths for many features do not bound highly mobile tritium; tritium is also present in areas with no active process history. Therefore, an inventory was derived for the bulk volume of SGHWR structure concrete, including both uncharacterised rooms (mainly ancillary areas) and deeper intervals of structural materials not captured by core data in characterised rooms across the SGHWR.	Reference inventory calculated assuming that the tritium contamination of the bulk structure is equal to the median tritium activity for characterised rooms. This approach avoids the strong bias that would be introduced to a mean by the small number of very active rooms, but also includes all the source data in the derived value. The volume of bulk concrete to which this applies was determined by subtracting the total volume of all other inventory entries from the estimated total volume of all SGHWR structural materials.
SGHWR Backfill	Backfill assumed to consist of both concrete blocks and brick/concrete arisings from demolition of the above ground (levels 4 to 10) SGHWR structure (comprising some of the primary containment, secondary containment, ancillary areas and bulk structure), and demolition arisings from stockpiles already on site. The existing stockpiles have been characterised via surveying and surface/near-surface sampling in 2018.	Above-ground portions of the SGHWR structure features derived as described above. Available characterisation data for the existing stockpiles suggests that the majority of the material is at OoS levels with respect to EPR 2016, although this will not be confirmed until the time of disposal. For the purposes of the SGHWR disposal inventory it is assumed that the entirety of the stockpiled material is at OoS levels as determined from the A59 fingerprint (building A59 was a significant source of the potentially active material in the main rubble mounds), but also including a contribution for some radionuclides based on average sampling activities. It is assumed that the entirety of the stockpiled material will be emplaced in the SGHWR voids.
Dragon Bioshield	Reinforced concrete cylinder (including some barytes concrete) surrounding the reactor pressure vessel. The structure is 1.75 m thick, with an inner diameter of 4.7 m and a current height of 12.6 m. Mildly activated (the majority of the bioshield was shielded from significant activation by thermal shields). Six cores were taken through the bioshield in 2005, 2013 and 2017, including limited rebar samples.	Activated concrete inventory derived from core data (using ratios in relevant fingerprints and SGHWR activation modelling to infer activities for small number of radionuclides not directly measured), applied to the first 750 mm of bioshield thickness assuming a uniform activity profile. Separate inventory derived for barytes concrete component (volume estimated from drawings) by scaling the bioshield concrete activation fingerprint to an average proportion reduction in Ca content and an increase in Ba content between ordinary and (generic) barytes concretes. Rebar inventory derived using averaged sample data, with missing radionuclides derived from an appropriate mild steel fingerprint scaled to sample data.

Feature / component	Feature/contamination description and key characterisation data	Reference Case inventory derivation approach
Dragon B70 Building General Contamination	Two sources of contamination: • surface contamination of walls, floors and ceilings exposed to reactor area atmosphere; and • tritium ingress to the concrete structures from the storage of Betalites. Characterisation data exist from ten sampling datasets taken at various locations throughout Dragon between 1999 and 2016. An in-situ survey undertaken by ViridiScope in 2018.	Surface contamination fingerprint derived from averaged, decay-corrected sample data from appropriate areas/materials (data show limited variation in fingerprint throughout reactor complex). Maximum hotspot activity of 100 cps identified from the ViridiScope survey and used to scale the fingerprint, using an assumption that only 5% of surface activity is present to avoid extreme pessimism, applied to total surface area including internal walls. Tritium ingress component based on average activities from two core sample datasets, calculated separately for paint layer and several depth intervals up to 30 cm. Separate estimates derived for surface contamination and tritium ingress in the Betalite store area, using just the data relevant to this area.
Dragon B70 Building PGPC Spill	Although clean-up of the PGPC spill is ongoing, it is assumed that there will be residual contamination. Only dose rate measurements and a smear sample from the PGPC currently exist, although further characterisation is expected in future.	Preliminary inventory derived based on total activity estimated using dose rate measurements combined with MicroShield modelling. Dragon primary coolant fingerprint (aligned with PGPC smear contamination) applied to estimated total activity to give radionuclide breakdown. As NRS does not intend to dispose of ILW on site, the spill will be sufficiently decontaminated to reduce the activity concentration to at least the upper limit of LLW, corresponding to the removal of 95.5% of the activity currently estimated to be present[16].
Dragon B78 Building General Contamination	Sampling datasets used for the Dragon reactor building included samples from the B78 fuel storage building, to which it is connected via the vehicle airlock.	Same approach taken as for Dragon reactor building, applied to surface area (including internal walls) of B78 as estimated from drawings. Tritium ingress component only applied to 15 cm depth as B78 walls are generally only 30 cm thick.
Dragon Primary Mortuary Holes	Primary mortuary hole structure set into the floor of B78 for the storage of spent fuel from the Dragon reactor. Systematic sampling campaign undertaken in 2023: all holes surveyed and smear samples taken at top, cross vent and full height; radioisotope analysis on samples with highest cps readings at the three locations.	Sum of the following three components: • Inventory for all mortuary holes derived from fingerprint and probe response value from the top smear and full-height samples, applied to relevant cps reading for each individual hole. The average value (of top smear and full-height values) was adopted for each radionuclide. • Inventory for cross vents derived from fingerprint and probe response value from cross vent sample, applied to average cross vent cps reading for each group of five holes connected by each of the ten cross vents. • Main ventilation ducts and sump inventory based on 2016 inventory estimate which used a smear from the ventilation stack outlet.

[16] Subsequent to derivation of the inventory estimate, NRS identified that the optimised approach is to remediate the spill to below 200 Bq g^{-1}.

Feature / component	Feature/contamination description and key characterisation data	Reference Case inventory derivation approach
Dragon Backfill	Backfill assumed to consist of both concrete blocks and brick/concrete arisings from demolition of the above ground Dragon structure (from both the reactor building and B78), and demolition arisings from stockpiles already on site (as for SGHWR).	Above-ground portions of the Dragon structure features derived as described above. The stockpile fingerprint was derived as explained for the SGHWR backfill, applied to the void volume that is assumed to be left after emplacement of above-ground Dragon reactor complex demolition material. Since it is also assumed that the entirety of the stockpiled material will be emplaced into the SGHWR voids, this represents deliberate double counting for the purpose of inventory derivation; however, only a small volume is estimated to be needed to fill the Dragon reactor shortfall.
A59 PSA / Pit 3	Contaminated land at the site of the former A59 building (PIE facility) to be remediated to OoS levels. Characterisation data includes: • surface sampling and monitoring of the A59 excavation surface prior to backfilling and capping (2007-2008, primary information source for in-situ contamination); • restored ground surface sampling and monitoring (2009-2010); and • various more recent site investigations and monitoring.	OoS inventory derived for each feature based on the samples within the area and assumed volumes, taking into account the "spottiness" of the contamination (see [83] for detailed explanation).
A59 A591 / HVA		
A59 other areas		

PA Inventory Summary

181 The Radiological Inventory Report [84] indicates the radionuclides expected to be present in the radioactive end state features on the Winfrith site on 1 January 2027. Many of these radionuclides are present with low activities and/or have short half-lives, such that they cannot contribute significantly to future radiological impacts. Therefore, as reported in Appendix B, the inventory has been screened to target effort on obtaining data for a sub-set of potentially significant radionuclides. Following augmentation to include decay chain progeny and screening, 51 radionuclides have been considered in the PA. The inventory presented in this report is that screened for use in the PA and so there are small differences from that presented in the inventory reports [83; 84].

182 Table 3.6 summarises the total activity and top five contributing radionuclides for the Reference Case inventory estimate. This presents a cautious but credible estimate of the inventory that could be left on the Winfrith site at the end state and clearly indicates the dominance of the SGHWR inventory (98% of the total radioactivity) over that of the Dragon reactor complex and OoS A59 area (around 1% each). The most significant individual features are the SGHWR bioshield (57% of the site total), and then SGHWR Region 1 (32%) and the SGHWR South Annexe (5%).

Table 3.6: The PA Reference Case inventory estimate summarised by feature group for an activity date of 1 January 2027. Coloured shading indicates the greatest (red) and smallest (green) activities.

		SGHWR		Dragon Reactor Complex		A59	
Total (MBq)	**In-situ**	5.27E+05		3.35E+03		5.49E+03	
	Infill	8.15E+04		3.88E+03		0.00E+00	
	Total	6.09E+05		7.23E+03		5.49E+03	
Top 5 nuclides	**1**	4.88E+05	H3	4.26E+03	H3	2.66E+03	Ni63
	2	4.13E+04	Cs137	1.89E+03	Cs137	9.39E+02	Sr90
	3	1.89E+04	Eu152	3.65E+02	Sr90	5.33E+02	U238
	4	1.62E+04	Ni63	2.04E+02	Eu152	5.19E+02	U234
	5	1.33E+04	Sr90	1.42E+02	Ni63	3.50E+02	Cs137
Remaining nuclides		3.15E+04	-	3.66E+02	-	4.97E+02	-
Approx Displacement Volume (m^3)[17]		46,123		10,460		9,519	

183 Whilst cautious assumptions have been made to develop the Reference Case inventory, the estimates must still be credible (i.e. not overly conservative), otherwise appropriate optimisation assessments cannot be made. Nonetheless, it is also important to understand the impact of inventory uncertainty. Thus, the identified gaps, uncertainties and assumptions were used in the inventory reports [83; 84] to support derivation of alternative, more conservative, inventory estimates. The alternative inventory estimates assume the maximum, rather than average, characterisation data by default, but alternative assumptions have been made where there are other sources of uncertainty. Note that the maximum concentration has been derived from the maximum activity concentration measured for each radionuclide across all samples obtained for a given feature, not from the sample with the maximum total concentration; therefore, it is unlikely that such a conservative maximum represents reality. The alternative inventory estimates also account for variations in possible fingerprints and radionuclide content, or contamination volume/surface area, for components where this is considered appropriate. The approaches used to derive alternative inventories for each feature (or component where the approach is component-specific), together with the key uncertainties that these aim to address, are summarised in Table 3.7. A variant case (see Section 4.4) considers the impact of the alternative inventory estimates in the PA, which are summarised for the feature groups in Table 3.8. The SGHWR PA reference inventory is estimated to have a total activity of 6.09E+05 MBq, which is increased by a factor of 9.7 to 5.88E+06 MBq when conservatively accounting for uncertainties in the alternative inventory components. The increase in the Dragon reactor complex inventory is not so significant, increasing by a factor of 3.5 from 7.23E+03 MBq to 2.55E+04 MBq. The A59 inventory increases by a factor of 2.4 from 5.49E+03 MBq to 1.30E+04 MBq. A second alternative inventory, which considers a Pu-containing

[17] The displacement volume is the volume of material that would be required to infill the below cutline void if the feature group were to be entirely removed (including the in-situ structure itself).

fingerprint for the Dragon B70 and B78 building general contamination is also assessed in a further variant case (see Section 4.4 and Appendix D.2.2).

Table 3.7: Approaches applied for derivation of alternative inventory estimates for radiological features (and components where the approach is component-specific) proposed for on-site disposal and the key uncertainties that they aim to address. More detail can be found in [84]. The Alternative Inventory and the Pu Alternative Inventory (only relevant for Dragon general building contamination) are assessed in two separate variant cases in the PA. Note that the Radiological Inventory Report derives estimates for each of the features and components listed in this table, but these inventories have been grouped into the 13 features identified in Table 3.9 for modelling the PA (see discussion in Paragraph 155 for SGHWR and Paragraph 164 for Dragon reactor complex).

Feature / component	Key Inventory Uncertainties	Alternative Inventory Approach	Pu Alt Inventory Approach
SGHWR Bioshield	Adequateness and statistical robustness of characterisation data; extent of bioshield activation; poor fit of activation modelling to measured data	Activation inventory (based on measurements) scaled by a factor of 14.9 to bring into line with activation modelling (more conservative than applying maximum measured activity concentrations)	Not relevant - as for Alternative Inventory
SGHWR Mortuary Tubes	Lack of samples and characterisation data – contamination level and fingerprint uncertain	Alternative fingerprint derived based on average modelled activation of Zircaloy fuel channel tubes and with longer-lived radionuclides than the reference inventory	
SGHWR Primary Containment	Adequateness and statistical robustness of characterisation data	Inventory calculated based on maximum activity concentration values, rather than average as in the reference inventory	
SGHWR Secondary Containment	Adequateness and statistical robustness of characterisation data	Inventory calculated based on maximum activity concentration values, rather than average as in the reference inventory	
SGHWR Ponds	Volume of material assumed to be contaminated	More pessimistic dimensional assumptions assumed, leading to a greater contaminated volume (average activity concentrations still used, as contamination is believed to be well characterised)	
SGHWR Ancillary Areas	Adequateness and statistical robustness of characterisation data	Inventory calculated based on maximum activity concentration values, rather than average as in the reference inventory	
SGHWR Bulk Structure	Lack of characterisation; uncharacterised rooms	Average measured activity concentrations for ancillary areas assumed to apply to all uncharacterised structure	
SGHWR Backfill	Those affecting contributing features (as noted above); overall volume	As above for contributing features; inventory for rubble mounds calculated using the highest of the maximum activity concentrations of the RSR exclusion criteria; each feature assumed to contribute extra 10% contaminated material volume	

Feature / component	Key Inventory Uncertainties	Alternative Inventory Approach	Pu Alt Inventory Approach
Dragon Bioshield	Adequateness and statistical robustness of characterisation data	Inventory calculated based on maximum activity concentration values, rather than average as in the reference inventory	Not relevant - as for Alternative Inventory
Dragon B70 Building General Contamination	Adequateness and statistical robustness of characterisation data; extent of contamination; potential for very high ^{3}H contamination within Betalite store; potential presence of Pu isotopes	100% of surface contamination assumed to be present rather than 5% as in reference inventory; anomalously high ^{3}H result included in Betalite area fingerprint; maximum activity concentrations used for ^{3}H ingress component rather than average as in reference inventory	As for Alternative Inventory AND Pu-containing fingerprint applied (based on items to be consigned off-site)
Dragon B70 Building PGPC Spill	Level of contamination; level of clean-up (it is intended to remove all of the residual contamination, but it is uncertain whether this will be possible)	None; contamination is assumed to be at the upper LLW limit for both the reference and alternative inventories	Not relevant - as for Alternative Inventory
Dragon B78 Building General Contamination	Adequateness and statistical robustness of characterisation data; extent of contamination; potential presence of Pu isotopes	100% of surface contamination assumed to be present rather than 5% as in reference inventory; maximum activity concentrations used for ^{3}H ingress component rather than average as in reference inventory	As for Alternative Inventory AND Pu-containing fingerprint applied (based on items to be consigned off-site)
Dragon Primary Mortuary Holes	Fixed contamination fingerprint and ratio of loose to fixed contamination uncertain; no direct characterisation of some parts of system including bottom vents	Mortuary hole inventory derived using the maximum value of full-height and top smear count rates for each radionuclide; cross-vent inventory derived using maximum rather than average cross vent smear count rate for group of five holes connected by each of ten cross vents	Not relevant - as for Alternative Inventory
Dragon Backfill	Those affecting contributing features (as noted above)	As above for contributing features; inventory for rubble mounds calculated using maximum activity concentrations	
A59 PSA/ Pit 3	Adequateness and statistical robustness of characterisation data; geometry and distribution of contamination	Inventory calculated based on maximum activity concentration values then scaled so that they just meet OoS criteria, rather than average as in the reference inventory	Not relevant - as for Alternative Inventory
A59 A591/ HVA			
A59 Other Areas			

Table 3.8: The PA alternative case inventory summarised by feature group for an activity date of 1 January 2027. Coloured shading indicates the greatest (red) and smallest (green) activities.

		SGHWR	Dragon Reactor Complex	A59
	In-situ	5.68E+06	1.39E+04	1.30E+04

		SGHWR		Dragon Reactor Complex		A59	
Total (MBq)	**Infill**	2.00E+05		1.16E+04		0.00E+00	
	Total	5.88E+06		2.55E+04		1.30E+04	
Top 5 nuclides	**1**	5.00E+06	H3	2.05E+04	H3	7.59E+03	Ni63
	2	2.77E+05	Eu152	2.19E+03	Cs137	1.95E+03	Sr90
	3	1.48E+05	Cs137	7.73E+02	Sr90	8.10E+02	Cs137
	4	1.34E+05	Ni63	6.28E+02	Eu152	5.64E+02	Pu241
	5	6.11E+04	Ca41	3.05E+02	Ba133	5.35E+02	U238
Remaining nuclides		2.58E+05	-	1.11E+03	-	1.52E+03	-

184 The SGHWR and Dragon reactor complex features primarily comprise concrete and masonry structures that have become contaminated and some parts that are activated (thin paint layers on the concrete have been neglected in the PA). The main sources of contamination are associated with general operational activities, relevant reactor primary and moderator circuits and direct contact with fuel (particularly in SGHWR), contact with pond water, leaks (including atmospheric ^{3}H in Dragon), and historic decommissioning activities. Coring data summarised in the Radiological Inventory Report [84] shows contamination in the concrete up to ~0.15 m in different parts of the SGHWR complex and to ~0.05 m in parts of Dragon reactor complex. The majority of the contamination is typically nearer the surface and assumption of a thinner contamination layer leads to shorter diffusion paths and earlier release times than if a thicker contamination layer were assumed. Therefore, the following contamination depths have been assumed in the PA for near-surface contaminated layers present on the exposed surfaces of features: 0.1 m for SGHWR Regions 1 and 2; 0.05 m for the SGHWR annexes (due to their different use profile and level of contamination); and 0.03 m in the Dragon reactor building. Bulk contamination due to ^{3}H has been observed at greater depths, but this is also assumed to be limited to the same general contamination depth. The bioshields in both reactors are contaminated and activated; coring data shows signs of activation in SGHWR to 1.55 m although the clearest trend suggests the majority is in the first 1 m, and activation in the Dragon bioshield is observed to 0.75 m. The depth of bioshield activation in the PA has been conservatively assumed to be shallower, at 0.75 m for SGHWR and 0.5 m for the Dragon reactor.

185 The 13 features considered in this report are identified in Table 3.9, along with a summary of the PA Reference Case and alternative case in-situ and infill inventories associated with each. The full inventory breakdown used in the PA is presented in Appendix D.2.2.

Table 3.9: The end state features considered in the PA and their reference and alternative case inventory estimates. Coloured shading indicates the greatest (red) and smallest (green) activities.

Feature	Displacement Volume (m^3)	Reference Inventory (MBq)			Alternative Inventory (MBq)		
		In-situ	Infill	Total	In-situ	Infill	Total
SGHWR Region 1 (exc. bioshield)*	20,767	1.46E+05	5.42E+04	2.00E+05	4.02E+05	1.58E+05	5.60E+05
SGHWR Bioshield	221	3.57E+05	0.00E+00	3.57E+05	5.20E+06	0.00E+00	5.20E+06
SGHWR Region 2	7,610	7.02E+03	5.98E+03	1.30E+04	2.41E+04	1.40E+04	3.80E+04
SGHWR South Annexe	12,333	1.46E+04	1.45E+04	2.92E+04	5.03E+04	1.78E+04	6.81E+04
SGHWR North Annexe	5,192	2.92E+03	6.79E+03	9.71E+03	6.04E+03	1.10E+04	1.71E+04
Dragon Inside Wall C*	2,741	1.74E+02	1.14E+03	1.31E+03	6.84E+02	4.83E+03	5.51E+03
Dragon Bioshield	256	1.51E+03	0.00E+00	1.51E+03	6.41E+03	0.00E+00	6.41E+03
Dragon Walls A-C Up-gradient	3,252	1.37E+03	1.37E+03	2.75E+03	5.72E+03	3.37E+03	9.09E+03
Dragon Walls A-C Down-gradient	3,252	2.14E+02	1.37E+03	1.59E+03	8.42E+02	3.37E+03	4.21E+03
Dragon Primary Mortuary Holes	454	3.37E+01	0.00E+00	3.37E+01	4.76E+01	0.00E+00	4.76E+01
Dragon B78 floor slab	505	4.01E+01	0.00E+00	4.01E+01	2.20E+02	0.00E+00	2.20E+02
A59 PSA/ Pit 3	1,100	3.41E+02	0.00E+00	3.41E+02	9.05E+02	0.00E+00	9.05E+02
A59 A591/ HVA	347	1.29E+03	0.00E+00	1.29E+03	1.60E+03	0.00E+00	1.60E+03
A59 other areas	8,072	3.86E+03	0.00E+00	3.86E+03	1.05E+04	0.00E+00	1.05E+04

* For the human intrusion assessment, the inventories associated with the SGHWR ponds and mortuary tube components in Region 1, in addition to the bioshield, are considered individually (see Appendix D.2.2). Similarly, intrusions into the PGPC spill and Betalite store contamination in the Dragon reactor building are also considered in specific intrusion cases.

3.4 Expected Evolution

186 This section outlines the expected evolution of the proposed on-site disposals, the Winfrith site and local surrounding region, from implementation of the disposals until after the time of peak dose, thousands of years in the future (Section 2.2).

187 Note that whilst the evolution outlined below is considered the most likely, and thus underpins the Winfrith PA Reference Case, other evolutions are also considered in alternative assessment cases and scenarios (see Section 4). The approaches used to model the events and processes discussed in this section and in Appendix C are discussed in Section 5.

3.4.1 Evolution of the Proposed On-site Disposals

Concrete Structures and Demolition Rubble

188 The proposed reactor disposals encompass several below-ground concrete structures, most of which are robust, steel reinforced and are currently in good condition. Those below-ground structures sitting below the water table (termed boundary structures in the Design Substantiation Report [72]) are expected to retain their integrity and constitute a barrier to groundwater flow at the IEP and beyond. Exceptions to an assumption of concrete integrity after the IEP have been identified (although there are mitigations that can be employed [71]):

- The SGHWR Annexes will be susceptible to cracking, deterioration and joint failure due to their construction and the demolition and disposal process (the conventional demolition techniques expected to be used and the subsequent loading by demolition arisings are expected to damage the base slabs [85]).
- Wall A of the Dragon reactor building is a conventional concrete structure, expected to crack during end state implementation [86].

189 In addition, dues to the large access ways in Wall C of the Dragon reactor building it does not present a barrier to groundwater flow [87].

190 As discussed in Section 3.1, the disposals encompass below-ground redundant structures left in-situ and above-ground concrete and masonry demolition arisings used to infill below-ground voids. These disposals have hydraulic characteristics that limit the transport of radionuclides out of the disposals and chemical characteristics that provide containment (retardation) of some key radionuclides, and thus limit their mobility.

191 Active maintenance of the below-ground boundary wall structures is assumed to cease once the on-site disposals have been implemented. Thus, over time, the concrete structures will degrade through a combination of processes. NRS [85; 86] has considered a range of physical and chemical factors which could affect the integrity of the reactor structures, including abrasion/erosion, cavitation, frost, exfoliation, fire, sulphate attack and acid attack. These processes are considered by NRS [85; 86] to have a low risk of compromising the integrity of the below-ground boundary structures. Carbonation, decalcification and corrosion of steel reinforcement are also considered, and it is concluded by NRS [85; 86] that these effects may have some potential to reduce the integrity of the structures, although the timescales of these long-term degradation effects (over hundreds to thousands of years) are uncertain.

192 Degradation of the structures will increase the likelihood of a defect (e.g. crack or joint failure) developing that could allow water into and radionuclides out of the in-situ disposals. The processes driving flow will differ depending on the relative elevation of the structure:

- for structures located above the water table, rainfall could infiltrate through cracks or joints in the SGHWR or Dragon reactor complex cap; and

- for structures located below the water table, groundwater could seep in and out through cracks or joints in the walls or floors of the structure.

193 Depending on the water retention properties of the structures, water entering the disposals could either flow out relatively unimpeded along cracks or joints, or potentially build up within the pore space of infilled voids. This balance of water flows is explicitly considered in the natural evolution model (Section 5.2.1). This includes consideration of the potential for "bath-tubbing" (water inflow to the below-ground void exceeding the available capacity and overtopping the concrete structure (Paragraph 278)).

194 The transport of radionuclides within the in-situ disposals is expected to vary based on the characteristics of the contaminated components:

- It is expected that diffusion along concentration gradients (from areas of high to low concentration) will be the main driver of radionuclide transport out of near-surface contaminated layers. As most contamination is located close to the surface of the concrete structures (Section 3.3.4) the diffusion distance is relatively short. However, the relatively low hydraulic conductivity of intact concrete will restrict the flow of water to localised paths of higher permeability, such as cracks or failed joints in the concrete, rather than through the entire near-surface contaminated layer.
- It is expected that advection will be the main driver of radionuclide transport in cracks, joints and void infills. For void infills, this is because the infill material will (in the reference configuration at least) have a higher hydraulic conductivity (more favourable to the flow of water) than structural concrete and/or have a geometry that is less favourable to rapid diffusive transport (due to the potential diffusive length within infilled voids being much greater).

195 Over time, it is expected that more flow pathways (e.g. cracks and failed joints) into and out of the in-situ disposals will develop as the structures degrade, increasing flow rates and thus radionuclide advection rates. Degradation could also influence the rate of diffusion, such as through reducing the diffusive length to an advective flow path.

196 Transport of some of the radionuclides within the disposals is expected to be retarded by sorption. Sorption describes the partitioning of dissolved contaminants between a fluid (porewater) and a solid material (e.g. concrete), and is generally considered to be reversible. Dissolved species are able to sorb to the medium through which they are travelling, leading to increased travel times of contaminants along the pathway, and can precipitate out of solution if the solubility limit is exceeded. However, for the estimated inventories in Section 3.3.4, dissolved radionuclide concentrations are unlikely to be limited by solubility constraints.

197 Chemical degradation processes will lead to changes in the near-field chemical environment, with the key parameter of interest being pH, due to its importance in determining the sorption behaviour of radionuclides. The main chemical degradation process associated with changes in pH is concrete leaching, with four stages expected [88; 89]:

- Stage 1: Leaching of alkali metal hydroxides (pH > 12.5).
- Stage 2: Dissolution of portlandite (pH = 12.5).
- Stage 3: Dissolution of calcium-silicate-hydrate phases (pH between 12.5 and 10).
- Stage 4: The porewater has pH ≤ 10, and is controlled by the dissolution of calcite, formed by carbonation of cementitious phases, and potentially from any calcite in the aggregate, if calcareous.

198 The effect of changes in the pH associated with the leaching stages on sorption behaviour varies for different radionuclides, though typically sorption is greatest for most radionuclides at high pH (Stages 1 and 2) [90, Tab.7-7 to 7-10]. Thus, leaching of concrete will tend to reduce radionuclide sorption within the in-situ disposals over time, as well as increasing matrix permeability and hence the potential for advective flow.

199 The rate at which concrete transitions through these stages is primarily controlled by the ratio of the cumulative volume of water that has flowed through it relative to its volume[18]. There is significant uncertainty in these ratios, but they are expected to range from tens, for the early stages, to thousands, for the later stages, of volumes of water per unit volume of concrete [91, App.D.1.3; 92].

200 After thousands of years the concrete of the in-situ disposals will completely degrade. At such a time, the radioactivity within the disposals will be greatly lower than at the IEP, either due to decay of radionuclides or through their aqueous release to the local geosphere and groundwater.

Formerly Contaminated Land

201 The OoS A59 area does not include any concrete structures or demolished concrete infill, so the discussion of concrete degradation above does not apply. Radionuclides present in the OoS A59 area are already considered to be in the local geosphere (see Sections 5.2.1 and 5.3.1) and the processes discussed in Section 3.4.2 are relevant.

3.4.2 Evolution of the Winfrith Site and Surrounding Region

202 Radionuclides released from the on-site disposals will enter the local geosphere. The hydrogeological conditions of the geosphere are expected to lead to dilution and dispersion of radionuclides. In addition, as with the materials in the disposals, radionuclides are expected to sorb to geosphere materials, leading to their retardation (and in some cases attenuation due to radioactive decay in transit).

[18] Strictly speaking it is the volume of cement paste that is important, but the cited literature discuss this process in terms of the volume of concrete, so this approach is also used here.

Evolution due to End State Implementation

203 At present, the Winfrith site is undergoing decommissioning and encompasses a series of buildings and associated infrastructure, such as roadways and drainage systems. As decommissioning continues and the IEP is reached, changes associated with the buildings and infrastructure (including ground cover) could potentially influence radionuclide transport within groundwater across the site.

204 As described in Section 3.1, the proposed end state of the Winfrith site is an acidic heathland landscape. NRS intends to implement a passive water management approach in the end state that minimises flood risk to neighbours and maximises the potential to generate a sustainable wet-heathland habitat [43, §3.5.3]. When the existing drains are decommissioned, the wettest points on the site will be the centre (currently Monterey roundabout) and the north-east corner, where the site connects with the existing pipe under the railway and which is 5 m lower than the Monterey roundabout.

205 To minimise the risk of site flooding, mitigation measures will be put in place, key to which is the creation of a valley mire in the north-east of the site, downstream of SGHWR and close to A59 (Figure 3.24). The mire will be periodically inundated with surface water following rainfall and is likely to be wet/waterlogged in winter and dry in summer [36, §4.1 and §5]. The mire bed and bank slopes will have a shallow gradient to reduce flow velocities and replicate local mire geometries, and to encourage a range of habitats [93, §3.2]. Rainfall will either infiltrate the soils or run-off overland towards the mire. During flood events, water will attenuate (i.e. be held up) in the mire and will discharge over a number of hours to constrain the impact on the downstream flow rate [36, Tab.6-1]. The mire is also designed to intercept cross-catchment flows to the adjacent Dorset Innovation Park and the Win Catchment [36, App.A].

206 The mire will replace the existing drainage system including Flume 1, which carries surface and ground water from the drainage network to a pipe under the railway line and into the Frome Ditch [36, §4.1]. However, the site will remain hydraulically connected to the Frome Ditch via the existing pipe under the railway line (Section 3.2.4). For this system to function a grate will need to be placed on the culvert mouth to prevent blockage and to prevent flows passed to the River Frome from increasing – the cross-sectional area of the outlet pipe is assumed to be reduced by 25%, thus reducing the current pipe diameter from 1.20 m to 1.04 m [93, §3.1]. The area of excavation to create the proposed mire (the blue shaded area in Figure 3.24) is approximately 63,290 m^2 [36, §5].

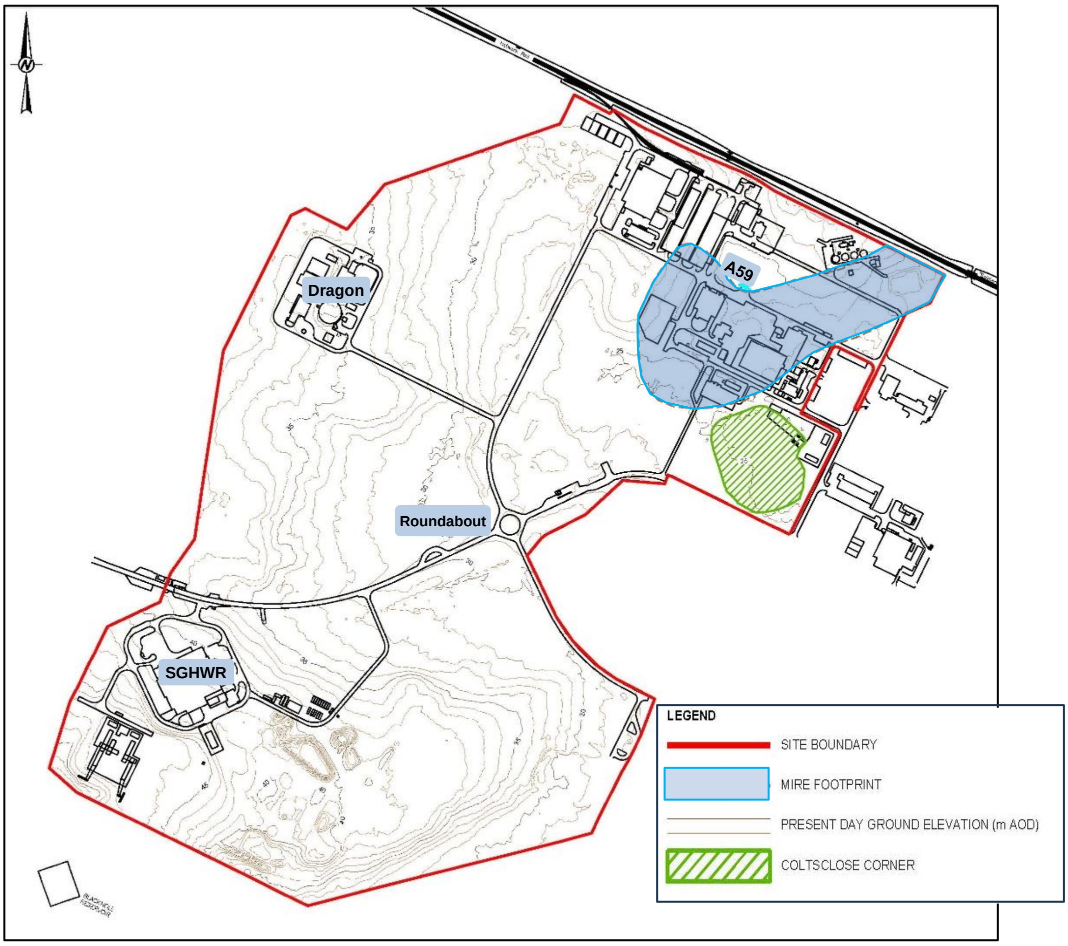


Figure 3.24: Current site topography with the location of the proposed mire indicated, along with the locations of the modelled feature groups and the Monterey roundabout. Edited from WSP [94].

207 The actions required to achieve the passive water management approach at the IEP include decommissioning the existing surface water drainage network, removing the drainage capacity, removing hardstanding (roads and pavements) and structures on the site, and creating a depression where the mire can form. Following this work, there will be increased infiltration of rainfall and most surface water will drain via the mire to the Frome Ditch as a consequence of the blocking of the rubble drains south of Monterey Avenue, which currently divert water into the River Win. Changes in average groundwater level as a result of implementing the end state are predicted to be small (0.4 m increase at SGHWR and 0.3 m at the Dragon reactor complex [43, §7.2.3]) because groundwater levels and flows are a response to recharge across the Win catchment, such that the scale of change on site is very small in comparison to the catchment as a whole [42, §6.1].

Evolution due to Climate Change

208 The climate of the Winfrith site will continue to change after the IEP, whether due to natural variations or human-induced climate change, and this will impact the site hydrogeological conditions and hence the release of radionuclides to the accessible

environment. The expected changes are discussed in detail in the Site Description [42] and Hydrogeological Interpretation [43] reports, with a summary provided below.

Future Groundwater Elevations to 2100

209 Climate projections performed by the Meteorological Office indicate that summer and winter temperatures in south-west England will increase over the next century, whilst winters will get wetter and summers are expected to be drier [42, §6]. The changes in ground conditions caused by these climate variations will produce changes in flood risk. Increased winter rainfall may produce larger surface flooding events, whilst hotter, drier summers can lead to compaction of the soil, preventing infiltration and further increasing surface run-off. There may also be an increased risk of heathland fires.

210 The UK Climate Projections (UKCP) is a climate analysis tool that is used to assess potential future climate scenarios. Using the UKCP09 scenarios[19], the Centre of Ecology and Hydrology (CEH) produced 11 simulations of future UK climate, based on the International Panel on Climate Change (IPCC) SRES scenario A1B (this scenario assumes future human global behaviour leads to medium levels of greenhouse gas emissions). The 11 simulations consist of an unperturbed simulation and ten perturbed simulations to capture the main climate variability and modelling uncertainties. The impacts of these climate change projections on groundwater recharge have been assessed by the BGS in the EA-commissioned *National Groundwater Recharge Assessment under Climate Change* project [96]. The BGS study was recommended to NRS by the EA in their letter of 23 June 2020 as "*a reasonable estimate based on good data and therefore should not be considered extreme, nor conservative. It is a reasonable assessment of what may happen in the future*". The BGS modelled the potential impacts of each of the 11 simulations on groundwater recharge values for Great Britain. Daily recharge data extracted from the BGS model for the Lower Frome and Piddle catchment over the period 1950 to 2099 have been used in the Winfrith groundwater flow model and reported in [97] for two of the 11 simulations: simulation afixq represents a cautious central estimate (CCE) of what might happen in the periods 2045-2069 (2050s) and 2075-2099 (2080s); and simulation afixh, with the highest average annual recharge in the 2080s, represents the reasonable worst case (RWC) of what might happen.

211 The assessments completed assume groundwater levels will rise to allow a pessimistic assessment of risks, but a reduction in groundwater recharge due to climate change is also possible. Due to the availability of data, the groundwater flow model considers the 11 simulations generated by the CEH based on the IPCC SRES scenario A1B, which assumes rapid economic growth with a balanced emphasis on energy sources. Many other scenarios are possible, which could result in drier or wetter conditions, and climate projections are frequently updated. The IAEA [98] emphasises that *"projections should not be considered as predictions, since alternative scenarios for*

[19] UKCP18 data have now been published, but daily recharge data for the Winfrith area using the latest simulations are not yet available. Comparison between UKCP09 and UKCP18 scenarios [95] for a nearby site concluded that the future modelled groundwater elevation at the Winfrith site would be little different if recharge were calculated using the RCP8.5 high emissions scenario of UKCP18.

greenhouse gas and aerosol emissions have very different climatic consequences and there is also the potential for geoengineering approaches to limiting the impact of greenhouse gas emissions".

212 Table 3.10 summarises the calculated average groundwater levels for the SGHWR and Dragon reactors for the CCE and RWC climate simulations in the 2050s and 2080s, and identifies the percentage of time over the defined periods that groundwater is estimated to be higher than the top of the base slabs of the SGHWR and Dragon reactor structures. Figure 3.25 shows the variation in groundwater levels with time over the 2080s model period. For the CCE groundwater simulation, the highest groundwater level in the modelled results at the SGHWR is 1.1 m above the base of the South Annexe for 4% of the time and 0.8 m above the base of the Dragon reactor up to 5% of the time, but for most of the modelled period the groundwater remains beneath these features [20, §7.1.3].

213 When considering the RWC simulation of future climate change under a medium emissions scenario, the groundwater levels are modelled to be on average a little higher and the frequency with which groundwater rises above the top of the base of the South Annexe and Dragon reactor increases slightly (Table 3.10). The highest groundwater level in the modelled results at SGHWR is 1.6 m above the base of the South Annexe for 12% of the time and 1.4 m above the base of Dragon reactor for 9% of the time.

Table 3.10: Average groundwater elevations assuming the CCE and RWC climate simulations in the Winfrith groundwater flow model for the 2050s and 2080s, as well as the percentage of the assessed period that the groundwater is higher than the relevant reactor base slab (extracted from [43, Tab.604/7]). The top of the South Annexe base slab is at 35.40 m AOD and the top of the Dragon reactor base slab is at 27.34 m AOD.

	SGHWR		**Dragon Reactor and Primary Mortuary Holes**	
	Average Groundwater Elevation (m AOD)	**Percentage of Time Groundwater Elevation is Higher than the Base**	**Average Groundwater Elevation (m AOD)**	**Percentage of Time Groundwater Elevation is Higher than the Base**
Modelled 2050s with the CCE recharge	33.6	100% (Region 1&2) 4% (South Annexe) 0% (North Annexe)	24.9	5% (Dragon reactor) 0% (Mortuary holes)
Modelled 2080s with the CCE recharge	34.0	100% (Region 1&2) 4% (South Annexe) 0% (North Annexe)	25.1	2% (Dragon reactor) 0% (Mortuary holes)
Modelled 2080s with the RWC recharge	34.1	100% (Region 1&2) 12% (South Annexe) 0% (North Annexe)	25.3	9% (Dragon reactor) 0% (Mortuary holes)

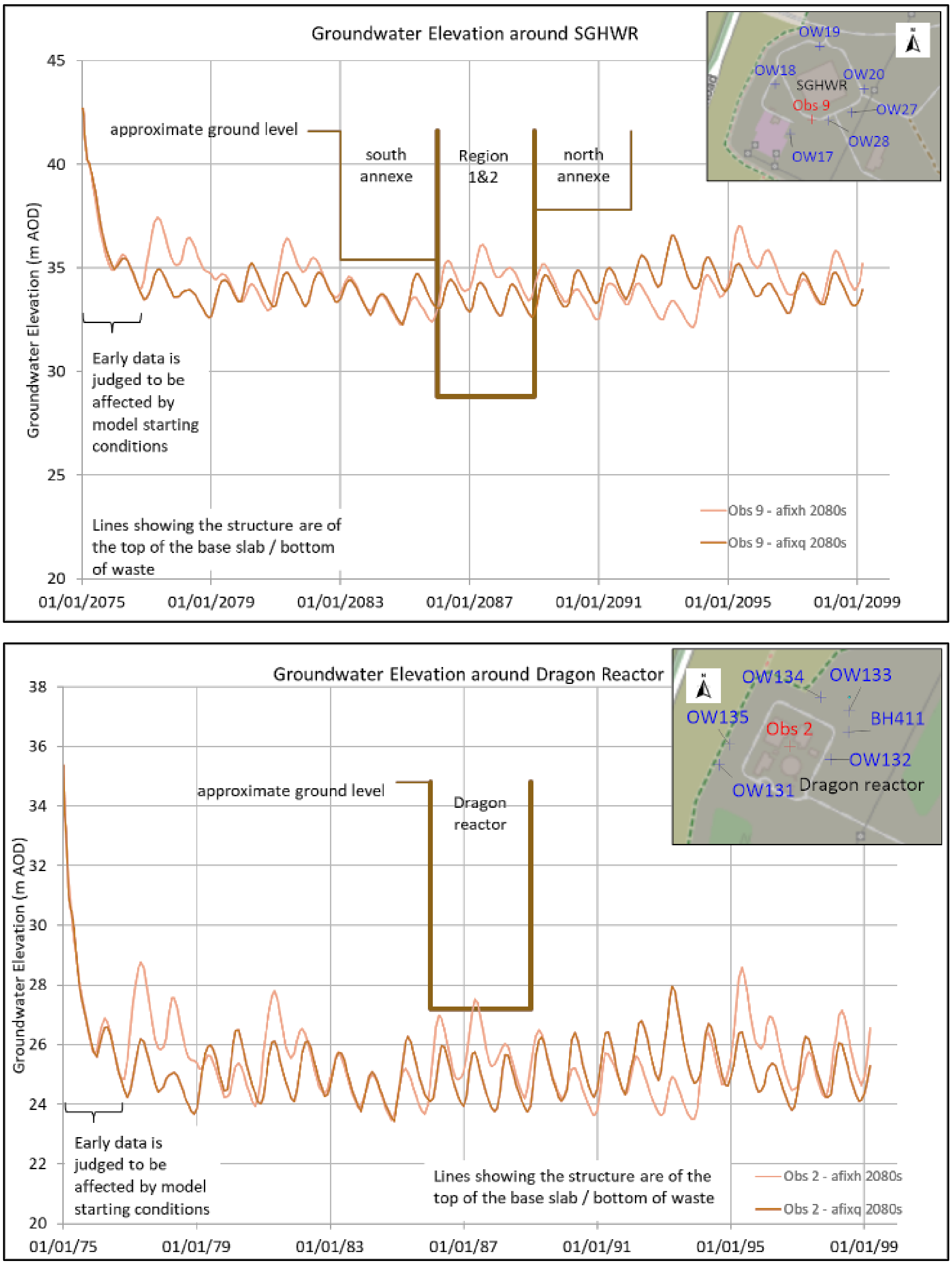


Figure 3.25: Modelled hydrographs for the 2080s at the SGHWR (top) and Dragon reactor (bottom) for the CCE (dark orange) and RWC (pale orange) groundwater recharge simulations [43, Fig.604/41].

214 The site groundwater model was adapted to account for the planned end state by importing the topography of the proposed site and using the CCE recharge sequence for a time period commencing immediately after the assumed IEP (2030 to 2099) [36, App.B, §4]. Calculated discharge rates of groundwater into the proposed mire varied,

with a minimum of 0 $m^3 d^{-1}$, a mean value of 86 $m^3 d^{-1}$ and a maximum of 1,191 $m^3 d^{-1}$ [36, App.B, §4.3]. For approximately 40% of the time period simulated there was no groundwater discharge to the mire.

215 Figure 3.26 shows areas of groundwater emergence for the month with the modelled maximum groundwater discharge to the mire. As the location of groundwater emergence changes for each time step depending on the season, climatic conditions and associated groundwater levels, Figure 3.27 shows areas of groundwater emergence for other months selected to illustrate changes in the location of emergence and discharge to the mire.

216 The removal of surface water drainage combined with climate change is modelled to result in increasing incidences of ground water emergence over the next century during wetter months. The main area of emergence in the proposed mire is towards the southwest with further areas of emergence developing to the northeast of the mire (downslope towards the railway line) during months of relatively high discharge. During months of highest discharge, emergence is observed around the area currently occupied by the Monterey roundabout, down-gradient of SGHWR. Down-gradient of the Dragon reactor complex, groundwater is modelled to emerge in low-lying land close to, and in, the River Frome. However, Figure 3.27 also shows the more limited nature of groundwater emergence on site during drier periods.

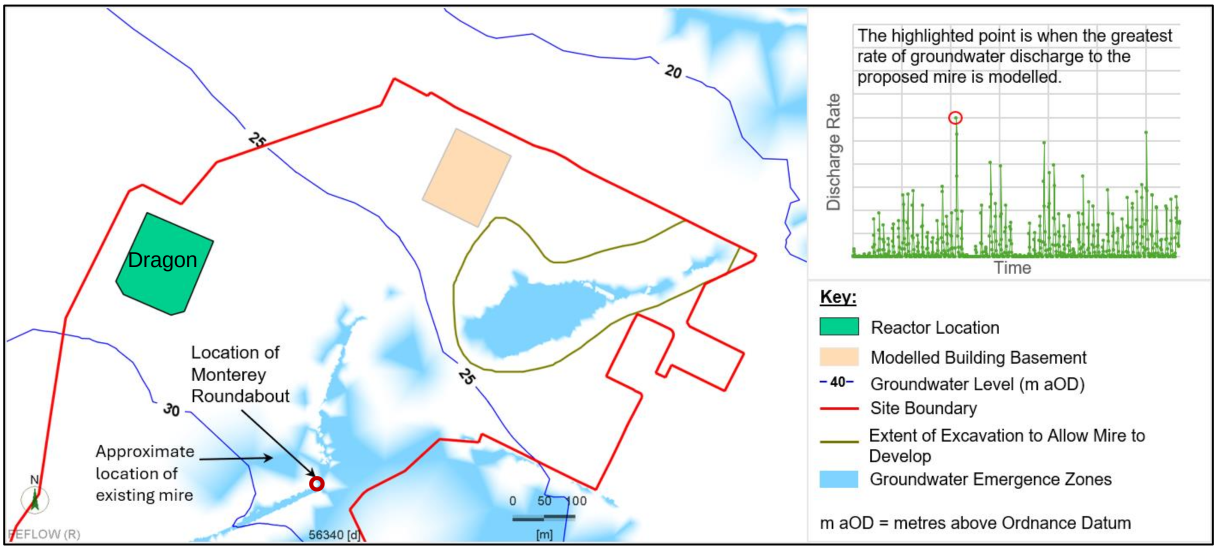


Figure 3.26: Modelled groundwater emergence with assumed end state conditions and the CCE climate simulation for the month with the maximum groundwater discharge to the mire (~1,200 $m^3 d^{-1}$). Edited from [36, App.B, Fig.4-6]. ⭘ indicates the approximate location of the Monterey roundabout.

Figure 3.27: Modelled groundwater emergence with assumed end state conditions and the CCE climate simulation for a range of groundwater discharge rates to the mire: (a) 600 m^3 d^{-1}; (b) 400 m^3 d^{-1}; (c) 250 m^3 d^{-1} and (d) the projected mean rate (86 m^3 d^{-1}). Key as per Figure 3.26; ⭘ indicates the approximate location of the Monterey roundabout. Edited from [36, App.B, Fig.4-7 to Fig.4-10].

217 As described in Section 3.2.5, contaminated groundwater flow on site is expected to occur predominantly in the Poole Formation, largely mirroring surface topography. Groundwater modelling [36, App.B] undertaken in support of the RMP predicts that, for end state conditions and the CCE simulation, groundwater will continue to flow in a north-easterly direction from the Dragon reactor complex and north and north-east from the SGHWR from the IEP. Forward pathline tracking (Figure 3.28) shows that modelled groundwater beneath the SGHWR in January 2033 (modelled at this time in order to avoid early time modelling artefacts) either emerges on the site, in the area near the Monterey roundabout and in the mire, or into the River Frome and the low-lying marshy ground surface in the Frome Valley. Figure 3.28 also shows that, in addition to flowing to the land/mire and the River Frome, groundwater from SGHWR may under some conditions also flow from SGHWR towards the Dragon reactor complex, where it would join with releases from Dragon, eventually entering the River Frome.

218 All the forward pathlines from the Dragon reactor complex extend towards the River Frome, with none to the proposed mire location (Figure 3.28). This is consistent with the findings of reverse pathline modelling for groundwater at the mire, which showed that none of the emergent groundwater within the mire had a flowline that tracked back to the Dragon reactor during the timestep of maximum discharge [36, App.B, §4.4.1].

219 Pathlines were not modelled from the OoS A59 area feature group in the RMP groundwater modelling [36, App.B], but given the proximity of A59 to the mire and the relatively shallow water table in the area, it is possible that releases from A59 could emerge in the mire as well as flow to the River Frome.

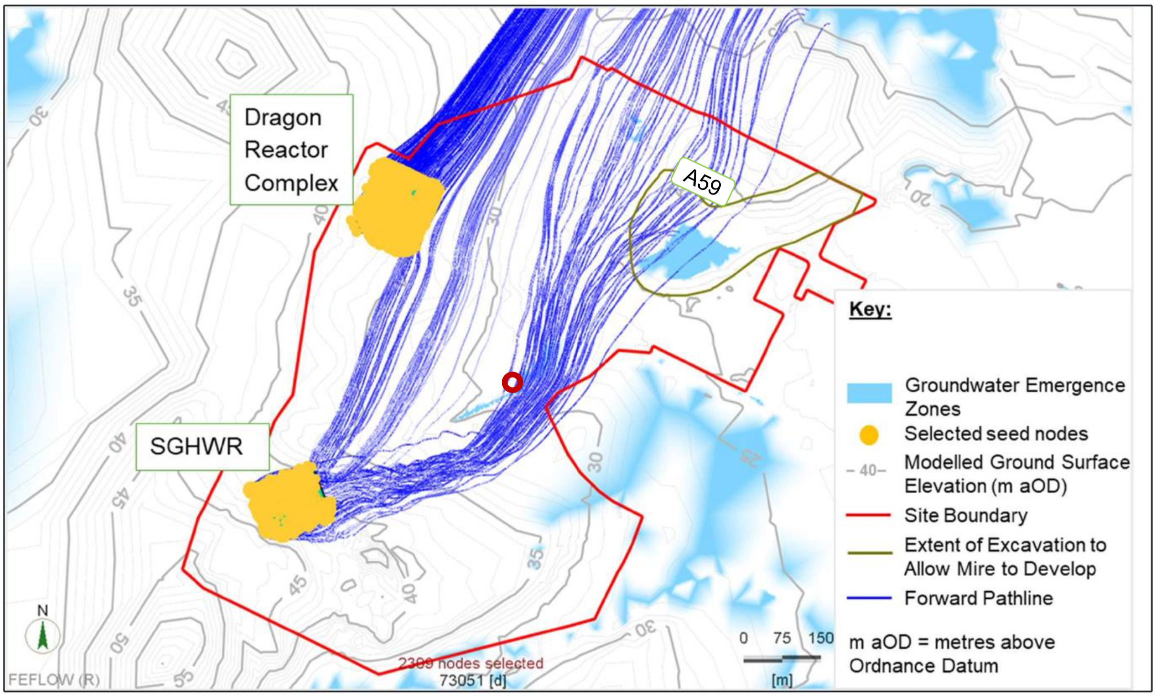


Figure 3.28: Modelled forward pathlines from the SGHWR and Dragon reactor complex with assumed end state conditions and the CCE climate simulation in January 2033 [36, App.B, Fig.4-12]. The location of the A59 area has been added and ⭘ indicates the approximate Monterey roundabout location.

220 Modelling of a potentially wetter future climate using the RWC recharge sequence was also undertaken for a time period commencing immediately after the assumed IEP (2030 to 2099). Calculated discharge rates of groundwater into the proposed mire varied, with a minimum of 0 $m^3 d^{-1}$, a mean value of 109 $m^3 d^{-1}$ and a maximum of 1,101 $m^3 d^{-1}$ [36, App.B, §6.2]. For approximately 30% of the time period simulated there was no groundwater discharge to the mire. As would be expected for a wetter future climate, higher rates and greater areal extent of groundwater emergence and more frequent discharge from the mire, along with less frequent periods of zero discharge, were calculated than for the CCE recharge sequence. However, the locations of groundwater emergence and the pattern of pathlines from the SGHWR and Dragon reactor complex were unchanged from those of the CCE simulation [36, App.B, §6].

221 The hydrogeological interpretation of the site, including the expected evolution of groundwater level and flow in the period to 2100, is summarised graphically in Figure 3.29.

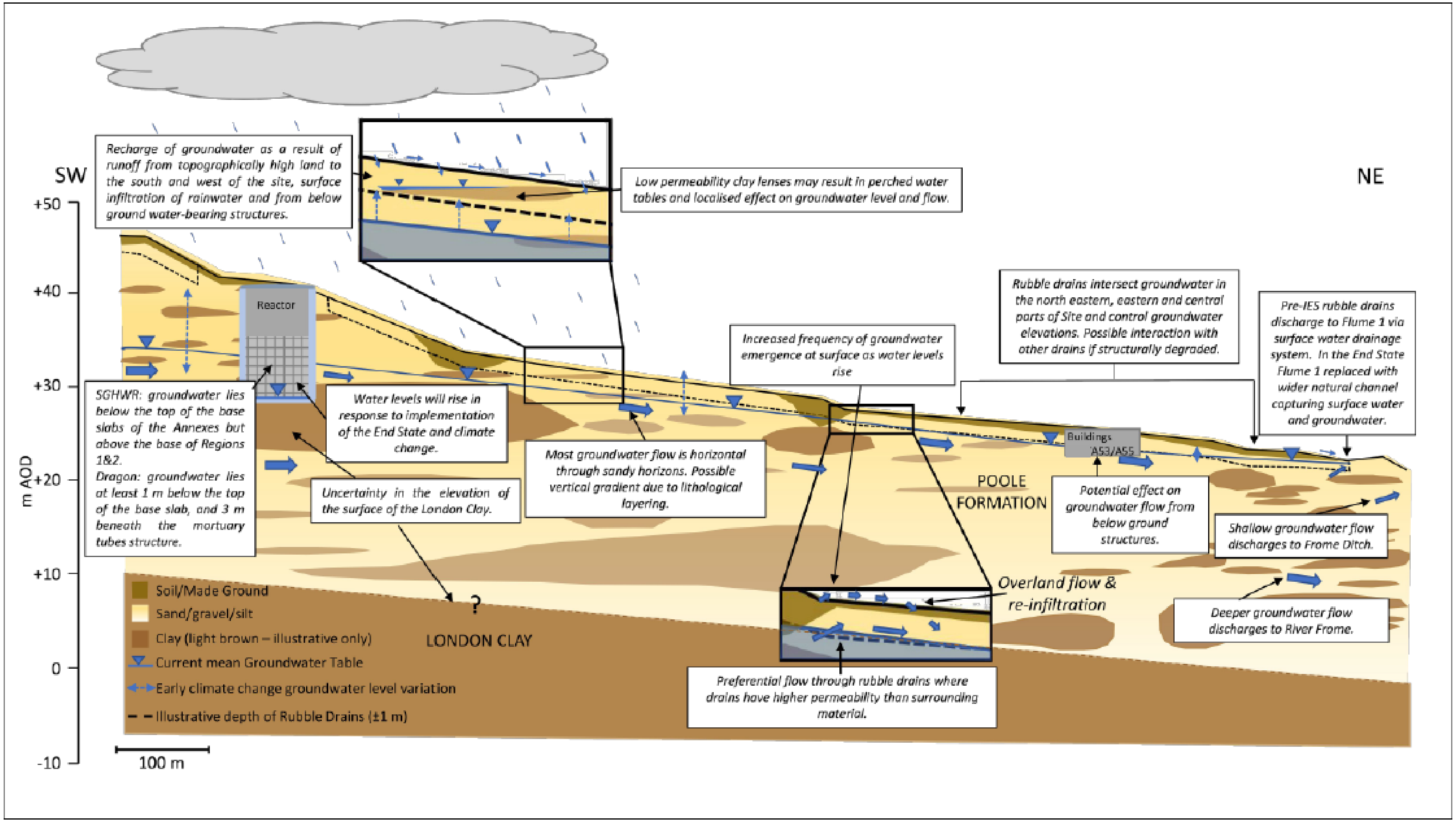


Figure 3.29: Summary hydrogeological interpretation of the Winfrith site [43, Fig.604/51].

Climate Change and Groundwater Levels Beyond 2100

222 The IAEA [98] provides a summary of modelling conducted for climate change over four time periods. On the shortest timescales (up to 1,000 years), the IAEA [98] observes that the processes with the most impact are those associated with recovery from the disturbance associated with disposal facility construction (e.g. resaturation of concrete) and degradation of engineered components. Although the disposals at Winfrith are not purpose-built disposal facilities, a similar emphasis is placed in the risk assessment modelling on the resaturation of the low permeability structures and their content, and on the degradation of the concrete and dissolution of contaminants.

223 On timescales of up to about 10,000 years, the IAEA [98] notes that the overall landscape is likely to remain similar in form to that observed at the present day, whereas the climate is likely to be as warm, or somewhat warmer, than at the present day. Thus, the climate-influenced processes of relevance to assessment models are likely to be similar to those of relevance at the present day, though their relative importance may change.

224 Projections of future climate evolution are obtained using models of varying complexity. The projections considered by the IPCC and UKCP out to around 2100 are generally based on detailed modelling such as that discussed above. However, studies of the climate evolution over longer timescales are usually performed with models of less complexity and/or coarser resolution. There is considerable uncertainty in the timescale over which the global surface air temperature will remain elevated compared to present and how far into the future it might be until the next glacial period. The IAEA [98] suggests two potential future timings of the next glacial inception: around 50,000 years after present and around 100,000 years after present. However, icesheets did not reach as far south as Winfrith at the last global maximum and any future glaciation event is expected to have a similar pattern. Therefore, glaciation is not expected to impact the proposed disposals.

225 Changes in global temperature are expected to persist and will, potentially, have a significant impact on eustatic (global) sea level through melting of land-based ice and thermal expansion of the oceans. However, for sites such as Winfrith that are inland and at elevation, changes in sea level will not be important. Therefore, the main impact of climate and temperature change at Winfrith will continue to be the changes in the amount and seasonality of precipitation and the knock-on effects on the water balance, on surface water and groundwater levels, and on flora and fauna.

Climate Change and Cap Resilience

226 The mechanisms by which components of the proposed engineered cap may degrade over the long-term have been reviewed [100]. Under climate change conditions involving acute effects of extreme hot and dry weather events desiccation cracking of the cap mineral layer (Figure 3.30) is possible, but only if the layer is exposed at, or becomes very close to, the surface. The protecting cover soils in the conceptual cap design will prevent the mineral layer from being affected by desiccation cracking.

227 An increase in cap infiltration is expected as a consequence of oxidation of the polyethylene layer and the infiltration rate will become progressively controlled by the geosynthetic clay layer (GCL), for which no mechanisms for long-term degradation have been identified [100]. There is uncertainty as to the extent of the degradation of the polyethylene geomembrane in the proposed cap as a result of increased average annual temperature caused by climate change (this is recorded in Appendix A as uncertainty PA-006).

228 The joint regulators' position statement on the use of UKCP18 data [99] requires that any proposals for a nuclear development/installation have a high level of climate resilience built-in from the start and that the proposals can be adapted over their predicted lifetimes to remain resilient to a credible maximum climate change scenario. In support of this, the cap performance review [100] recommends sandy cover soils are selected to reduce the potential for desiccation cracking to occur and, prudently, that the cap management plan includes periodic inspection to check that surface fissures have not developed during periods of higher temperature or drought.

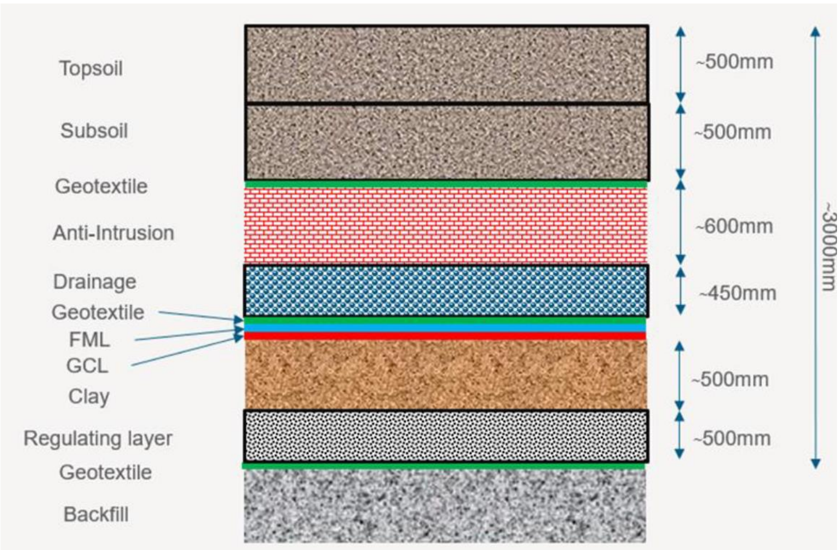


Figure 3.30: Illustration of the ten capping layers in the conceptual design for the engineered cap over the on-site disposals [100, Fig.615/1]. Acronyms: FML = Flexible Membrane Liner; GCL = Geosynthetic Clay Liner. The geomembrane, geosynthetic clay and mineral layers act together to vertical movement of infiltrating water. The overlying drainage layer is intended to shed infiltrating water to the edge of the cap.

4 Scenarios and Assessment Cases

This section summarises the systematic and detailed identification of scenarios and assessment cases undertaken as part of this PA, which is fully described in Appendix C.

4.1 Terminology

229 When assessing the safety of waste disposals, it is important to consider how the performance of the disposal system may evolve over time. This requires the different factors that could influence its performance and evolution to be taken into account. This is typically achieved through the formulation and analysis of a set of scenarios and assessment cases. In this report, the following terms are used as defined by the IAEA [23, ¶5.37 and ¶5.38]:

- **Scenarios** are "descriptions of alternative possible evolutions of the disposal system" and "represent structured combinations of features, events and processes (FEPs) relevant to the performance of the disposal system".
- Each scenario is underlain by one or more "**assessment cases**" (also known as "calculation cases", e.g. [101]) that are consistent with the assessment context. Each assessment case addresses an aspect of parameter uncertainty and may represent or bound a range of similar possible evolutions of the disposal system.

230 In this PA for the Winfrith site, four types of scenarios are defined. These and their relationship to underlying assessment cases are as follows:

- A single ***"expected evolution" scenario***, encompassing:
  - The *"reference" assessment case (henceforth called the Reference Case)*, considering the expected evolution (as described in Section 3) of the Winfrith site as based on current understanding of the proposed on-site disposals, site characteristics and the surrounding region, and its robust model implementation. The Reference Case includes both natural evolution of the site and a range of appropriate inadvertent human intrusion and site occupancy activities.
  - *"Alternative" assessment cases*, investigating the impact of parameter uncertainty in the reference assessment case. Each alternative assessment case investigates the effect of varying a single parameter or a set of related parameters.
- Several ***"variant configuration" scenarios***, which investigate potential options for the configuration of the proposed on-site disposals, including in-situ, backfill and engineered components. *Each variant configuration scenario typically consists of a single assessment case.*
- Several ***"variant concept" scenarios***, which investigate uncertainty in the conceptual model, including different interpretations of climate change. *Each variant concept scenario typically consists of a single assessment case.* While

all variant concept scenarios are considered credible, each has a different probability of occurrence.

- Several ***"what-if" scenarios***, which are not considered to represent likely evolutions and do not reflect general system uncertainty but can be used to explore the system response to hypothetical events and situations, including extreme climate change. *Each "what-if" scenario typically consists of a single assessment case.*

4.2 Scenario Identification Approach

231 Radiological safety assessments use scenarios to formulate the calculation of radiological exposures. For present day and planned situations, the pathways and behaviour habits (conditions and events) can be readily identified, such as the external exposure to radiation at a certain distance from a routinely operating nuclear power plant. However, formulation of scenarios becomes more difficult when considering the future and hypothetical or non-routine situations. Although relevant to decommissioning in general, most work in this area has been undertaken in the field of radioactive waste disposal. IAEA guidance on safety assessment for the disposal of radioactive waste identifies development of scenarios as the fundamental basis for a quantitative assessment [23].

232 There is no single approved methodology for conducting scenario development for radioactive waste disposal assessment. However, two main approaches to the problem can be defined (bottom-up and top-down approaches [23]), although there can be considerable overlap between them. Independently of the approach employed, it should be shown that all potentially significant migration pathways from the facility have been considered and that possible evolutions of the system have been taken into account.

233 For this Winfrith PA, a "top-down" approach has been used. This is summarised in Figure 4.1 and described fully in Appendix C. This approach aligns with international best practice guidance [23; 101] and is analogous to that used in the natural evolution assessment for the Trawsfynydd Ponds Complex in 2023 [102]. It draws on Galson Sciences Ltd (GSL) experience gained through previous GRR work for NRS and ESC development for UK near-surface disposal facilities.

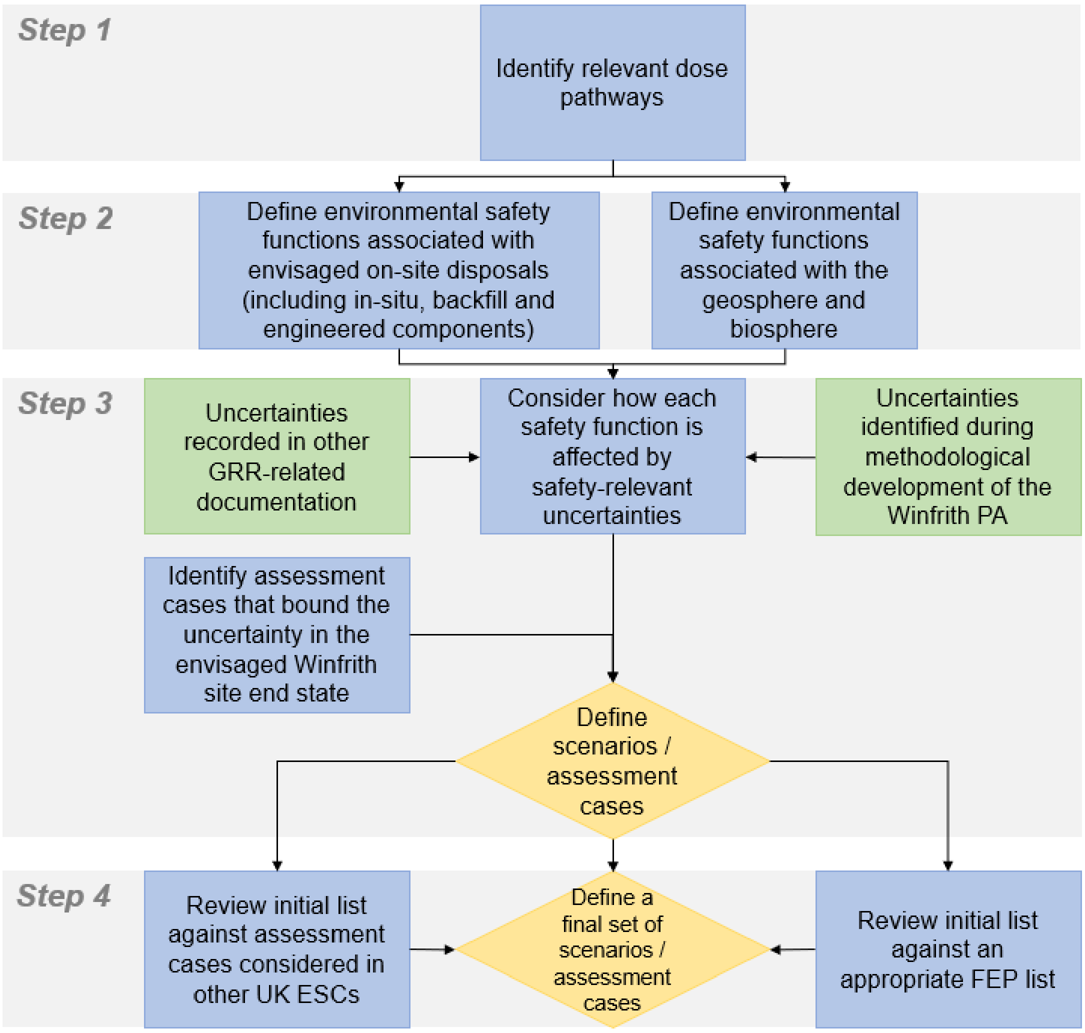


Figure 4.1: Flowchart outlining the scenario and assessment case identification approach used in this assessment. FEP = features, events and processes.

4.3 Relevant Dose Pathways

234 Step 1 in this approach to scenario development is the identification of the relevant dose pathways for assessment in the PA. A "dose pathway" is considered to be a broad mechanism or process that could lead to representative persons (RPs) potentially receiving a radiation dose. Consideration of the GRR in the context of the proposed on-site disposals, Winfrith site and the local surrounding region (Section 3) leads to the identification of three overarching dose pathways of relevance:

- **Natural evolution** of the site resulting in aqueous and gaseous release of radionuclides, which may or may not be influenced by natural disruptive processes. This overarching pathway includes the potential abstraction of surface water and/or groundwater for drinking.
- Direct external irradiation of site occupier RPs in situations where sub-surface contamination remains in-situ and undisturbed (**site occupancy**).

- Consequences arising from inadvertent **human intrusion** into the waste and its subsequent use (for example as a building material) after release of the site from RSR.

235 The models used to calculate the potential doses arising from these three overarching pathways are discussed in detail in Section 5 (natural evolution), Section 6 (site occupancy) and Section 7 (human intrusion).

236 A detailed discussion of relevant dose pathways, activities and associated RPs, including those screened both in and out of this assessment, and the justification for those decisions, is presented in Appendix C.2.

4.4 Identification of Scenarios and Assessment Cases

237 Steps 2 to 4 of the methodology (Figure 4.1) are presented in detail in Appendices C.3 to C.5. Key to the methodology is the consideration of safety-relevant uncertainties (i.e. those with the potential to affect safety functions), which have been systematically captured from both relevant strands of previous work and during methodological development of this PA (as listed in Appendix A). This is followed by the identification and justification of an appropriate treatment for each such uncertainty in this PA. Possible treatment approaches can be summarised as “tolerate”, “cautious parameterisation or modelling in the Reference Case”, or “address via an alternative assessment case, variant concept scenario, variant configuration scenario or “what-if” scenario”.

238 The output of Steps 2 to 4 of the methodology is a set of appropriate assessment cases and scenarios of the types outlined in Section 4.1. These are summarised in Section 8.2, following the sections describing the models used for the three identified dose pathways: natural evolution, site occupancy and human intrusion (Sections 5, 6 and 7, respectively).

5 Natural Evolution Model

239 This section presents the natural evolution (NE) PA model developed to assess the impact of on-site disposals. As discussed in Appendix C, scenario and assessment case identification for natural evolution has identified aqueous release as the primary dose pathway, with gaseous release screened out on the basis that no significant exposure pathways were identified (Paragraph C23). As such, the Winfrith NE model has been developed to consider radionuclide aqueous release and transport, consistent with the generic conceptual model proposed for Magnox reactor sites ([103] and summarised in Figure 5.1) and the site-specific Winfrith Conceptual Site Model (CSM) [20]. The Winfrith NE assessment model is divided into three discrete but interacting modules, based on the source-pathway-receptor linkage:

- The near field, which comprises the source (contaminated material within the disposals from which radionuclides may be released, for example through diffusion) and the interface (volumes within the disposals where radionuclides from the source can be transported, in flowing water, to the geosphere).
- The geosphere, the pathway through which releases from the interface are transported, in flowing groundwater, from the disposals to the surrounding biosphere.
- The biosphere, the area normally inhabited by living organisms into which radionuclides transported through the geosphere may be released (e.g. to the ground surface and surface waters). The assessment model calculates the doses that might be received by humans and non-human biota present within the biosphere.

240 This section documents the overall model implementation approach and software platform (Section 5.1), and the basis that underpins its implementation (Sections 5.2 to 5.4). For the latter, descriptions are structured around the three model modules outlined above and include discussion of their conceptual models and the mathematics that underly their representation in the NE assessment. Note that parameter values used in the implementation of the conceptual models are primarily documented in Appendix D.

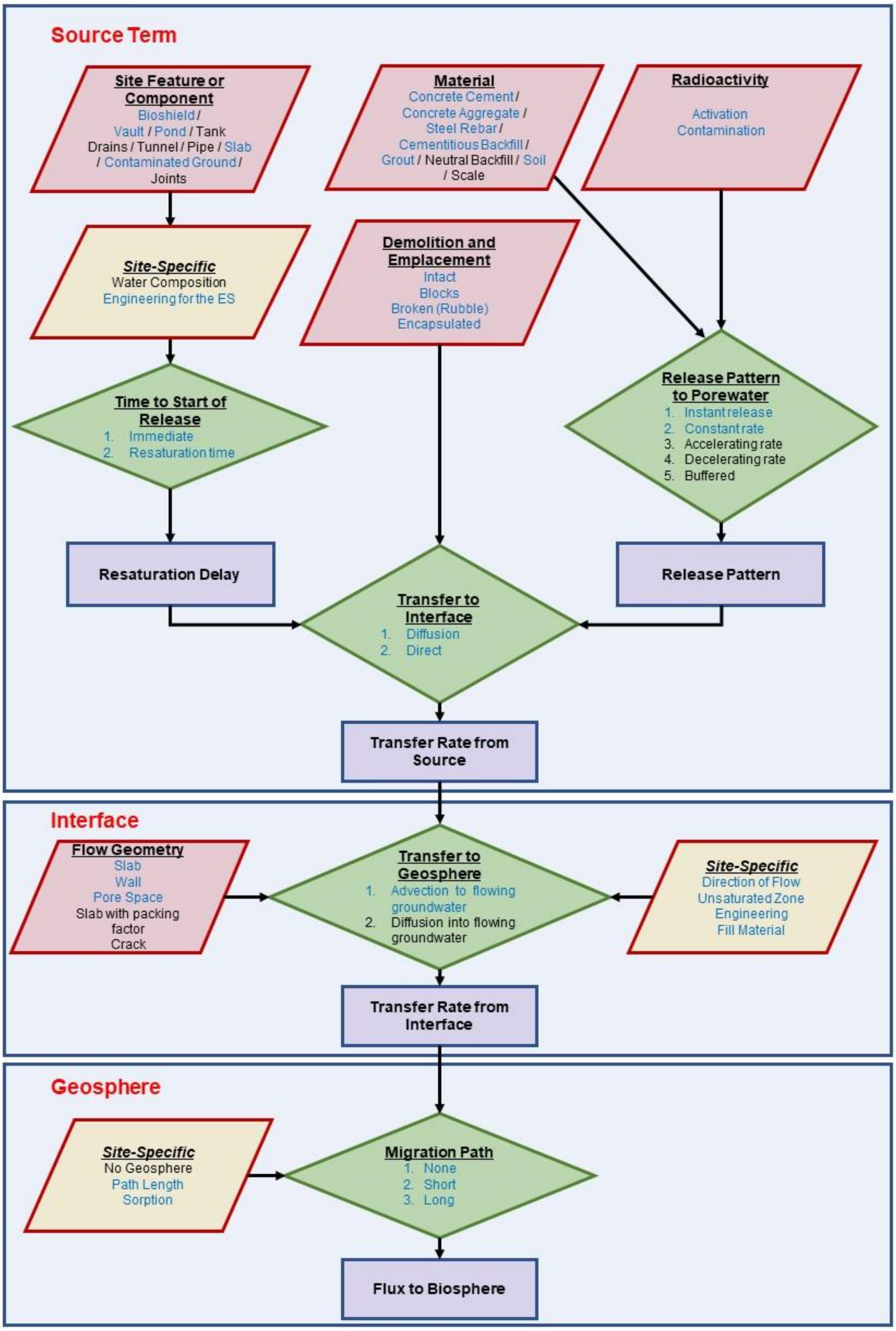


Figure 5.1: Generic flowchart showing a methodology for development of the conceptual model for aqueous release of radionuclides at NRS sites (adapted from [103]). Parallelograms show inputs (red = generic, orange = site-specific); green diamonds show decisions; and rectangles show model outputs. Blue text highlights elements and methods that are used for the Winfrith NE assessment.

5.1 Model Implementation

241 The Winfrith NE assessment is implemented in the GoldSim Radionuclide Transport (RT) modelling tool [104; 105], a leading software platform used internationally for more than 20 years to conduct radioactive waste disposal assessments. A number of different software packages could have been used for the NE assessment but GoldSim-RT was selected for the following reasons:

- GoldSim-RT has been used to conduct assessments of radioactive waste disposal facilities in the UK (Low Level Waste Repository (LLWR); Dounreay LLW Disposal Facilities (D3100)), the US (Yucca Mountain), Spain (ENRESA), France (ANDRA) and Japan (NUMO).
- GoldSim-RT was also used for the 2023 NRS Trawsfynydd site risk assessment for on-site disposal of radioactive waste [102] and so is familiar to NRS staff.
- GSL staff are expert users of this software platform.
- GoldSim was also used by WSP Ltd for the sister model for the Winfrith non-radiological risk assessment, which simplified implementation and cross-checking of the same conceptual model.

242 Therefore, GoldSim-RT can be used with a high degree of assurance that it is fit for purpose and an appropriate software choice. For the Winfrith NE assessment GoldSim-RT Version 14.0 R2 Build #412 has been used (released February 2023). The quality assurance and model verification processes applied are discussed in Section 11.

243 GoldSim provides a highly graphical programming interface for carrying out dynamic, deterministic and probabilistic simulations [104]. The Contaminant Transport (CT) module is an extension that allows dynamic modelling of mass transport and the RT module provides the further capability of modelling radioactive decay and ingrowth during transport [105]. The CT and RT modules contain specialised elements for representing contaminant species, transport media, transport pathways, contaminant sources and receptors, and the coupled sets of differential equations underlying these systems. By linking the specialised elements together and integrating them with GoldSim's basic elements, contaminant transport simulations can be undertaken.

244 Several functions provided by GoldSim-RT, and key to the Winfrith NE assessment model, are described in this section. The user guides for GoldSim [104] and GoldSim-RT [105] provide the mathematical equations for these functions. The key specialised elements provided by GoldSim-CT and GoldSim-RT are the transport pathway elements, as these essentially define the mathematical representation of the system to be simulated. The Winfrith NE assessment model uses two different transport pathway elements: cell elements and aquifer elements. The model also uses a specialised source element to represent the features where the radioactive contamination is held at the start of the assessment.

Cell Element

245 Cell elements are intended to represent discrete, well-mixed environmental compartments. Cell elements are commonly applied to simulate discrete entities in an environmental system (such as ponds, lakes, shallow soil compartments, or the atmosphere). GoldSim-RT does not solve directly for the movement of media and thus the media flow rates associated with advective flux links between elements must be specified. Diffusive flux links between cell elements are defined by specifying the dimensions of the diffusive interface. When multiple cell elements are linked together via advective and diffusive flux links, a cell element network is created. The behaviour of the cell element network is mathematically described using a coupled system of differential equations (i.e. fluxes within a cell element network are computed simultaneously). In effect, it is mathematically equivalent to a finite difference network. Fluxes between different cell element networks or non-cell elements are uncoupled. At each timestep, the upstream system is solved first, the outputs determined, and then the downstream system is solved.

246 Within cell elements, multiple fluids or solid media can be specified and contaminants distributed between them, according to partition coefficients. Solubility limits can be specified and advective and diffusive transport mechanisms can be explicitly represented (using advective and diffusive mass flux links). Other transport mechanisms can also be represented by using direct transfers and direct flux links. Material present in a cell element can be specified to be suspended in the cell element's fluid, such that the transport of contaminants on suspended material can be explicitly modelled. The mathematical equations solved for cell elements are introduced in Section 5.2.2 and are presented fully in Appendix B of the GoldSim-RT user guide [105].

Aquifer Element

247 Aquifer elements can be used to represent features that essentially behave as a fluid conduit, for example, aquifers, rivers, channels and pipelines. An aquifer element performs its computations by creating a temporary set of linked cell elements (forming a cell element network) during the simulation. As aquifer elements internally use cells to carry out their calculations, they can represent most of the same processes that can be represented by a cell, such as one-dimensional advection, longitudinal dispersion, diffusion, retardation, decay and ingrowth. As multiple cell elements are defined during computations, aquifer elements can be used to generate a cell element network using a single element.

Source Element

248 Source elements are a specialised type of element that allow an initial inventory for each modelled contaminant/radionuclide to be specified at a particular location and the nature and timing of release of the inventory to be defined. Source elements are described in Section 5 of the GoldSim-RT user guide [105]. The distribution of the inventory with respect to any barriers (e.g. concrete, grout), the failure pattern of the

barriers, and the rate of degradation of the waste matrix to release contaminants to porewater can all be specified.

249 Each source element contains one or more cell elements. If diffusive mass flux links are used to connect these cells together, and at least one of the cells is connected to an external element (outside the source element), then diffusive transport out of a source can be modelled. To ensure accurate modelling of diffusion within the source, at least five cell elements are utilised in the Winfrith NE assessment, where relevant (see Section 5.2.1).

Time Stepping

250 Timesteps for a simulation in GoldSim-RT are set by the user. In general, timesteps are selected *a priori* for each run by the user to reflect the rate of change in the system (e.g. timesteps are selected to be less than the travel time of a radionuclide through a model element). However, in addition to the user-selected timesteps, GoldSim-RT also applies an algorithm that automatically sub-divides timesteps if discrete changes or events occur within a timestep.

251 For the Winfrith NE assessment, each assessment case is run for a period of at least 100,000 years, using a timestep of half a year for the first 200 years, one year between 200 years and 1,100 years, five years up to 5,000 years, ten years up to 10,000 years, 25 years up to 20,000 years, and then 50-year timesteps after that. The use of shorter timesteps at the start of the simulation was implemented following examination of the results during model development and is intended to adequately capture the impacts resulting from the relatively rapid changes in material properties (concrete) that occur over the first few hundred years of a model run, whilst maintaining manageable computational run times. Additional (unreported) timesteps are also added dynamically to the model at key times to reduce model instability, such as when model features switch on (i.e. at the feature Disposal Start Date) and when concrete chemical degradation is assumed to reach its final state.

5.2 Near Field

252 As outlined in Section 3.1, after the IEP the Winfrith site is expected to consist of a mixture of below-ground in-situ radioactively contaminated structures, possibly infilled with radioactively-contaminated and/or radiologically-clean material, and some (potentially out-of-scope) radioactively-contaminated land. These features form the near field of the Winfrith NE assessment model. Within this section, the conceptual model for the near field (Section 5.2.1) and its mathematical representation in GoldSim (Section 5.2.2) are described.

5.2.1 Conceptual Model

253 The Reference Case inventory is heterogeneous and its distribution spatially complex (uncertainty PA-003). Some of the features lie below and some above the present water table (BWT/AWT), and this will evolve over time as climate change proceeds. Therefore, the near-field module of the NE assessment model is granular, separately modelling each radioactively-contaminated feature within the SGHWR, Dragon reactor

complex and OoS A59 area feature groups, and modelling the portions above and below the local groundwater water level. Radioactively-contaminated demolition arisings, associated with in-situ features located above the demolition cutline (ACL) and from the existing rubble piles, are considered by assuming emplacement in specific modelled voids of below-cutline (BCL) features.

254 Within the sub-sections below, information on specific aspects of the near-field conceptual model is presented. A summary is provided in the penultimate sub-section, graphically summarised in Figure 5.10 and tabulated in Table 5.3.

Source and Interface Compartments

255 Consistent with the approach suggested in the generic NRS conceptual model [103] (Figure 5.1), a "source" and an "interface", each consisting of one or more components, are used to model each in-situ feature.

256 The source represents parts of features initially (i.e. at the start of the model/IEP; see Section 2.2) contaminated with radionuclides. The dimensions of modelled radioactive source compartments are restricted to the radioactively-contaminated parts of a feature and thus exclude associated uncontaminated materials[20]. Once released to the interface compartment radionuclides may interact with other (uncontaminated) parts of the feature (depending on the water balance and flow).

257 For the NE assessment, two types of source compartment are considered (Figure 5.2):

- A near-surface contaminated layer, associated with the in-situ structure of a BCL feature, emplaced concrete blocks that are used to infill a void in a BCL feature, or with a reactor bioshield.
- A contaminated infill, such as broken concrete rubble, where radionuclides are assumed to have a uniform activity concentration across the material that fills the void of the BCL feature.

258 Radionuclide release and transport processes differ between these two types of source compartment, as described in the Radionuclide Release and Radionuclide Transport sections below.

259 Inventories are assigned to source compartments based on the Radiological Inventory Report [84]. As summarised in Section 3.3.4, the inventory apportions activity between:

- the individual features considered; and
- the position of contamination relative to the demolition cutline.

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[20] For example, contamination associated with intact walls and floors of the reactor buildings is generally expected to be limited to a near-surface contaminated layer (Section 3.3.4); only this layer would be modelled in the source compartment and not the clean concrete beneath (Figure 5.2). However, the full volume of concrete is considered when determining the system hydraulics (sub-section Water Balance).

260 Thus, for source compartments representing the in-situ structures of BCL features, a radioactive inventory can be directly assigned. For source compartments representing the voids of BCL features infilled with contaminated demolition arisings, the infill activity is defined in the Radiological Inventory Report [84] through the summation of the associated inventory of each contributing ACL feature (or part thereof) and any additional material from other on-site sources (e.g. from the rubble mounds). Allocation of the infill activity to the source compartment in the NE model then depends on the assumed emplacement configuration. That is, if the infill material includes concrete blocks, then the activity is allocated to a near-surface layer associated with each block. Radioactivity associated with rubble or grout infill, potentially in a layer above emplaced concrete blocks, is assumed to have a uniform activity concentration across the rubble/grout infill volume. Further details of the near-field configurations modelled across the set of scenarios and assessment cases considered in the NE assessment are described in the Configuration of Features section below.

261 Radionuclides are assumed to be homogeneously distributed throughout the material in both types of source compartment. This approach aligns with the assumptions used to derive the Radiological Inventory Report [84] and is cautious in regards to near-surface contaminated layers as thinner contamination layers have typically been assumed in the NE model (leading to earlier release) than observed (see Section 3.3.4).

262 The interface relates to a specific volume, either directly adjacent to or within the source, where advection of radionuclides out of the near field can occur. An interface can be present along the surface of a wall or be the pore space within an infilled void of a feature. In the NE assessment, the characteristics of the modelled interface compartments differ based on the characteristics of the modelled feature (see Feature Types section below).

263 The source and interface compartments are implemented in GoldSim as follows:

- Each source compartment is modelled using a source element, which contains one or more cell elements that are used to model radionuclide transfer to the interface.
- Each interface compartment is modelled using a cell element.

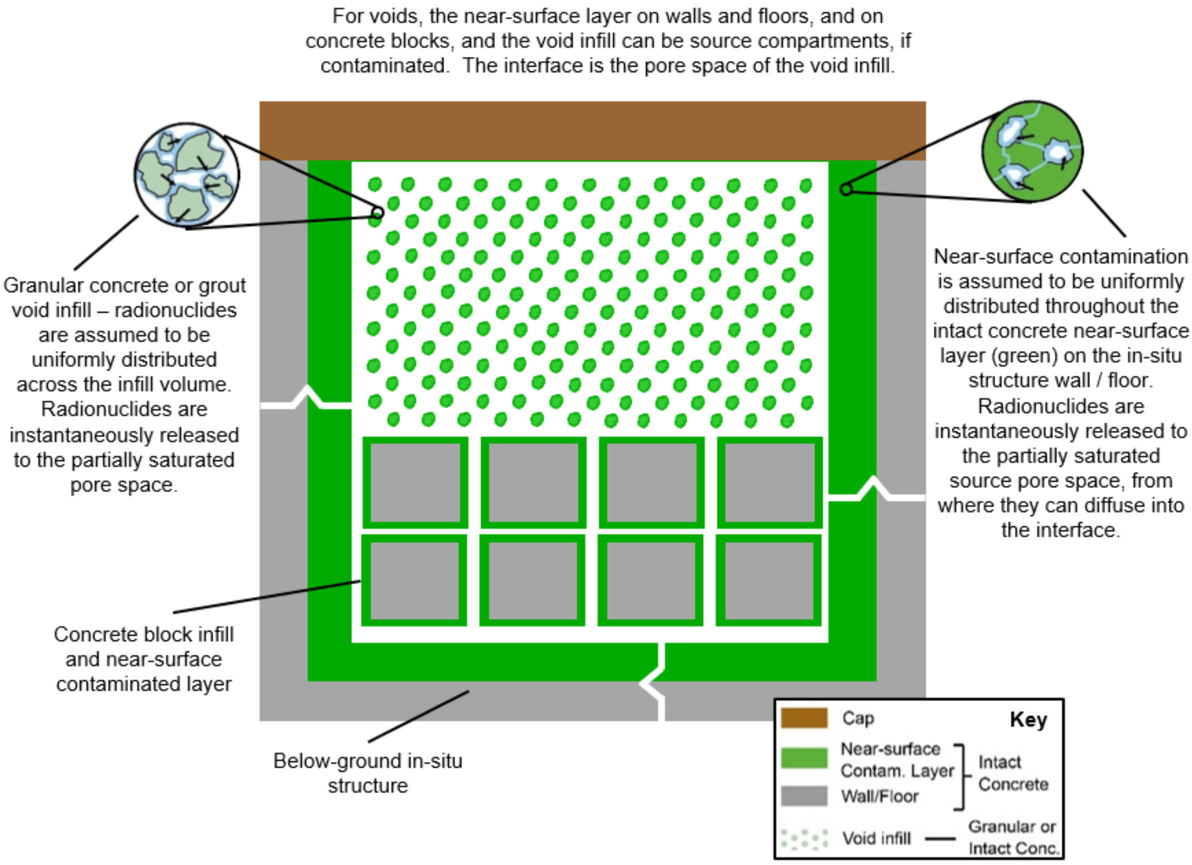

Figure 5.2: Schematic of near-field source and interface compartments for a below-ground structure infilled with concrete blocks and granular concrete/rubble.

Near-field Media

264 There are three modelled material types associated with the near-field module:

- "Intact concrete" – This is concrete that is mechanically competent and of low permeability at the start of a model run (it is assumed to degrade with time as described in the Concrete Degradation sub-section below). In the NE assessment, intact concrete is used to represent a range of structures and emplacements and is varied depending on the scenario being considered:
  - Intact in-situ concrete – Such as found in the near-surface contaminated layers present on the exposed surfaces of BCL features.
  - Grouted infill – Such as could be used to infill voids (conditioned to form a monolith).
    - A grouted infill could be produced from demolition arisings (i.e. grouted demolition arisings considered in a variant scenario) and thus be radioactively contaminated, or be formed from clean material (e.g. as planned to fill the Dragon mortuary holes).

   - Concrete blocks – Generated by demolishing ACL features using wireline cutting to produce large blocks.

  Uncertainties in the properties of intact concrete, such as density, porosity and hydraulic conductivity, are noted in Appendix A as PA-008 and are discussed and identified in the following sections. Intact concrete is assumed to have the same properties for all three uses described above; the concrete blocks will be formed of the same building as the in-situ concrete and so are expected not to have significantly different properties (variant configuration scenarios in Table 8.2 do separately consider the impact of additional spacing between the blocks). The grouted infill could have different density and porosity, but this uncertainty is tolerated because grout infill of the reactor void spaces to create a monolith forms a single variant configuration calculation and is not part of the current engineering design.

- "Granular concrete" – This is a relatively porous granular material formed of broken concrete/masonry demolition arisings (i.e. concrete rubble). In the NE assessment, granular concrete is used to represent emplacements of ungrouted demolition arisings. Uncertainties in the properties of granular concrete, such as porosity and compaction during emplacement, are noted in Appendix A as PA-008.
- "Poole Formation" – This material represents the clays and fine to coarse sands of the Poole Formation, which is typically exposed towards the west of the site (including around SGHWR and the Dragon reactor complex). This is relevant to specific features where a geosphere compartment forms the interface (see Feature Types section below). As discussed in Section 3.2.2, the Poole Formation consists of a sequence of alternating clays and sands, and is highly variable. The exact properties of the Formation across the site (e.g. sorption, conductivity, etc.) will vary, partly depending on the proportions of clay and sand. Treating the Formation as a single material is a reasonable model simplification necessary to produce a tractable model. Uncertainties in the sorption properties of the Poole Formation are considered in Paragraph 344 and noted in Appendix A as PA-016.

265 Note that water is the only fluid considered in the near-field model (as well as the geosphere and biosphere).

Feature Types

266 To adequately consider the range of in-situ features that form part of the Reference Case inventory and determine their radiological impact, two different feature types are modelled:

- Void – A cuboid structure with a height, width and length of the order of metres. A void feature consists of a concrete floor and walls that enclose a void space (or spaces). Such voids are assumed to be overlain by an engineered cap. For example, void features are used to represent SGHWR Regions 1 and 2, both Annexes and the Dragon reactor building. Contamination can be present:
   - In near-surface layers, located:

- on the floor and walls of the void structure;
- on concrete blocks emplaced in the void(s); or
- on a bioshield situated in the void (noting that the thickness of the near-surface layer is substantially thicker to account for the greater depth of contamination resulting from neutron activation in this case – see Table D.28).

– Distributed throughout the void infill. Homogeneously contaminated infills can be formed of either ungrouted or grouted demolition arisings. This is represented in the model using granular or intact concrete, respectively.

Note that the Winfrith in-situ disposal features modelled as voids contain internal dividing walls that create multiple void spaces within the feature. In such cases:

– near-surface contaminated layers, be they on the external or internal walls, are modelled collectively, as a single source; and

– the multiple void spaces are modelled collectively, as a single interface.

- Slab – A cuboid structure with a height, width and length of the order of metres, but with no void space to be infilled. A slab feature consists of either:

  – a concrete slab (such as the Dragon B78 building floor slab or Dragon primary mortuary holes[21]) overlain by an engineered cap; or

  – a cuboidal region of contaminated land (such as those associated with the A59 area), modelled as Poole Formation media without an overlying engineered cap.

  Contamination is assumed to be homogeneously distributed throughout the slab volume.

267 While both feature types have a source and interface, the assumptions and characteristics of the associated modelled compartments differ significantly between them; this is detailed in Table 5.1.

[21] The Dragon primary mortuary holes consist of contaminated metal tubes set in a block of concrete, which will be infilled with clean grout. As a model simplification for the NE assessment, the feature is modelled as a single block of concrete containing homogeneously distributed contamination.

Table 5.1: Summary of potential source and interface compartments and the associated material for the feature types modelled in the NE assessment.

<table>
<tr><th rowspan="2">Feature Type</th><th colspan="2">Source Compartment(s)</th><th colspan="3">Interface Compartment(s)</th></tr>
<tr><th>Description</th><th>Material</th><th>Location</th><th>Description</th><th>Material</th></tr>
<tr><td rowspan="4">Void</td><td>Near-surface contaminated layers on the floor and/or walls</td><td rowspan="3">Intact concrete</td><td rowspan="3">Adjoining the source compartment</td><td rowspan="4">Pore space within the infilled void</td><td rowspan="4">Intact or granular concrete</td></tr>
<tr><td>Near-surface contaminated layers on emplaced concrete blocks</td></tr>
<tr><td>Near-surface contaminated layers on a bioshield</td></tr>
<tr><td>Contaminated infill, where radioactivity is distributed over the entire infilled void volume</td><td>Intact or granular concrete</td><td>Within the source compartment</td></tr>
<tr><td>Slab</td><td>Contamination distributed over the entire slab volume</td><td>Intact concrete or Poole Formation</td><td>Within the source compartment</td><td>Pore space within the slab</td><td>Intact concrete or Poole Formation</td></tr>
</table>

Radionuclide Release

268 There are several ways to model the release of radionuclides from the materials of source compartments to porewater, for example, instantaneous, constant rate or accelerating rate release (Figure 5.1); in the generic conceptual model, this is termed the release pattern[22]. For the Winfrith NE assessment, instantaneous release is cautiously assumed for all sources. This aligns with the fact that the majority of the features in the disposals are radioactively contaminated, rather than activated, and thus source concrete is unlikely to require degradation/dissolution to occur before radionuclides become accessible to porewater. Bioshield feature sources comprise both contamination and activation, but the activation proportion is conservatively included with the contamination inventory, such that the radioactivity is assumed to be released earlier than would be the reality (although a much thicker near-surface “contamination” layer is modelled (Table D.28)).

269 The timing of the instantaneous release is set to either:

- The start of the model, for features already in contact with groundwater. This applies to all contaminated land slab features (see Configuration of Features section below).
- Upon completion of the feature end state, for features that are currently believed to be dry. For such features, it is cautious to assume that porewater is present as soon as the end state is implemented (i.e. no resaturation delay; see Water Balance section below).

[22] Note that the release pattern is independent of the sorption processes discussed below. Sorption is modelled only *after* radionuclides are released to the porewater.

270 For near-surface contaminated layers, radionuclides are assumed to be released to source porewater, allowing diffusive transport to the interface porewater to be modelled (see Radionuclide Transport section below). For homogeneously contaminated infills, as the interface is the pore space of the source (Table 5.1), radionuclides are instantaneously released to the interface porewater (identified as "direct transfer" to the interface in Figure 5.1) and no diffusion is modelled. Uncertainties in radionuclide release mechanisms are noted in Appendix A as PA-007.

271 For the activity estimates of the Reference Case inventory, dissolved radionuclide concentrations are unlikely to be greatly limited by solubility constraints (uncertainty PA-005). As such, for the NE assessment, unlimited solubility is cautiously assumed.

Water Balance

272 A key modelling assumption employed in some aqueous release assessments is that the near field and geosphere are fully saturated (i.e. the water table is at the ground surface). Such an assumption is a simplification of the actual system, but it is generally a cautious approach for an aqueous release assessment as it exposes the entire inventory to flowing water. For the Winfrith NE assessment, an enhanced hydrogeological modelling approach is used to better represent the impact of the groundwater system and rainfall infiltration on radionuclide transport in the near field, taking into account aspects such as infiltration through the engineered caps and the impact of climate change, and to be consistent with various other arguments made regarding the lack of a direct discharge of pollutants to groundwater. Uncertainties associated with water balance are captured in Appendix A as PA-010.

273 At present, the average water table across the on-site disposals is typically located between approximately 2 m (in the A59 area) and 11 m (around the Dragon reactor complex) below the ground surface. As discussed in Sections 3.2.5 and 3.4.2, the restoration of the site, including removal of surface water drainage, combined with climate change, is predicted to result in increasing average groundwater levels and greater fluctuation between wetter winters and drier summers (uncertainty PA-015). Thus, dependent on the depth and geometry of a BCL feature, a feature can be located fully above or straddling the water table, and the saturated and unsaturated portions may change over time.

274 As a model simplification, most radiological NE assessments models assume that the elevation of the water table, and thus the position of a BCL feature relative to it, remains static over the model timeframe, and consider the impact of changing water levels through variant calculations. However, given the importance of the groundwater protection arguments to the in-situ disposal case being made, NRS requested that the same approach to modelling the changing hydraulics of the near-field system as applied in the shorter timeframe non-radiological assessment was applied in the radiological performance assessment. Therefore, as outlined in the Winfrith CSM [20, §5.4], the balance of water flows in and out of each void feature type and the water level within each below-ground void is calculated in the natural evolution assessment as a function of the assumed hydraulic integrity of the feature walls and floors, the concrete degradation status, infiltration though the cap and the local water table.

275 As noted above, the in-situ structures and their contents are assumed to be dry at the point that the feature end state is implemented (referred to as the feature Disposal Start Date); the thick concrete walls/floors and their structural integrity inhibit water ingress into the parts of the features that are currently below the water table (e.g. SGHWR Regions 1 and 2). However, over hundreds to thousands of years, the concrete will degrade (see the Concrete Degradation section below) and groundwater ingress will gradually increase. As groundwater levels rise (see Section 3.4.2), there is also the potential for groundwater ingress into features that are currently above the water table [20, §5.2] and for which the walls and/or floors may not retain their structural integrity following implementation of the end state (i.e. may have higher hydraulic conductivity). In addition, rainwater will infiltrate the soil or through the engineered cap (if present) into the in-situ features, and this inflow rate may increase with climate change and as the engineered cap degrades (see [20, §5.3] and Appendix D.2.5). Thus, the water level within each BCL void feature is determined in the model using Darcy's law as a time-varying function of the vertical rain infiltration, the external groundwater level, and the geometry, degradation status and assumed structural integrity of the void feature concrete walls and floor.

276 The evolution of the near-field water balance for the SGHWR feature group is illustrated at four timepoints in Figure 5.3 to Figure 5.6. At the feature Disposal Start Date, for the Reference Case the South and North Annexes will be infilled with rubble, while Regions 1 and 2 will contain concrete blocks at the bottom of the void and rubble above the blocks. An engineered cap will be emplaced over the SGHWR building. The Annexes, which are assumed to have cracked walls and floors such that they conservatively present no resistance to water flow and have the same hydraulic conductivity as the surrounding geosphere, will be above the local groundwater level. The base of SGHWR is founded on a hard clay layer (see Section 3.2.2) so no water flow across the floor slab is assumed. The intact thick concrete walls of Regions 1 and 2 are expected to retain their structural integrity during the demolition process such that their initial hydraulic conductivity is low and a direct discharge to groundwater from the disposals does not occur [72]. The water level will gradually rise within Regions 1 and 2 because of infiltration of water through the cap. From 250 years the rate of infiltration will increase as the cap progressively degrades (see Appendix D.2.5). The leakage rate through the Annexes will be equal to the inflow rate through the cap over their surface.

277 The illustrations in Figure 5.4 and Figure 5.5 show a situation where the Regions 1 and 2 internal water level may be above the base of the Annexes. In this situation, it is possible that there could be outflow from Regions 1 and 2 to the Annexes. As a model simplification, each of the Regions and Annexes are modelled separately and any flow through the walls is conservatively passed directly to the geosphere rather than a neighbouring feature (see Paragraph 281 and uncertainty PA-024). From the results of the water balance calculations reported in Section 10.1.1 for the Expected Evolution Scenario and Reference Case parameters, the maximum internal water elevation inside Region 1 is 35.68 m AOD, which is 28 cm above the floor of the South Annexe – the water elevation remains above the floor of the annexe for the period 121 to 175 years after model start. Thus, there could only be flow from Region 1 to the South Annexe for a 54-year period, during which the wall would have to saturate to allow flow and

then flow could only occur over a small wall sub-section. Therefore, this model simplification is considered reasonable.

278 The water level within SGHWR Regions 1 and 2 could potentially reach the tops of the walls and thereafter any over-topping water could migrate into the Annexes (Figure 5.4). Whether the water level over-tops the walls ("bath-tubbing") is dependent on the relative magnitude of the rate of water inflow through the progressively degrading cap and the rate of water outflow through the progressively degrading structure. For the Expected Evolution Scenario and Reference Case parameters, it has been calculated that the long-term stable water level inside the Region 1 void is only a few centimetres above the external water level (see Section 10.1.1). Even when considering the maximum temporary water elevation during system resaturation, the water height remains almost 5 m below the top of Region 1 and so there is no potential for over-topping.

279 The local groundwater level is assumed to rise in accordance with climate change predictions for the area (see Section 3.4), with increases predicted for the 2050s and 2080s in the Cautious Central Estimate (CCE) and Reasonable Worst Case (RWC) climate predictions, which are both based on a medium emissions scenario. Given the additional uncertainty in climate change and future human actions, the water level at 2100 is assumed to persist into the far future [20, §7.1.4] (Section 3.4.2). The impact of this uncertainty is captured through additional sensitivity calculations and bounded by the "1 m bgl groundwater" "what-if" scenario (Section 8). The modelled groundwater levels in some of the variant scenario calculations mean that the impact of groundwater entry into the Annexes is considered.

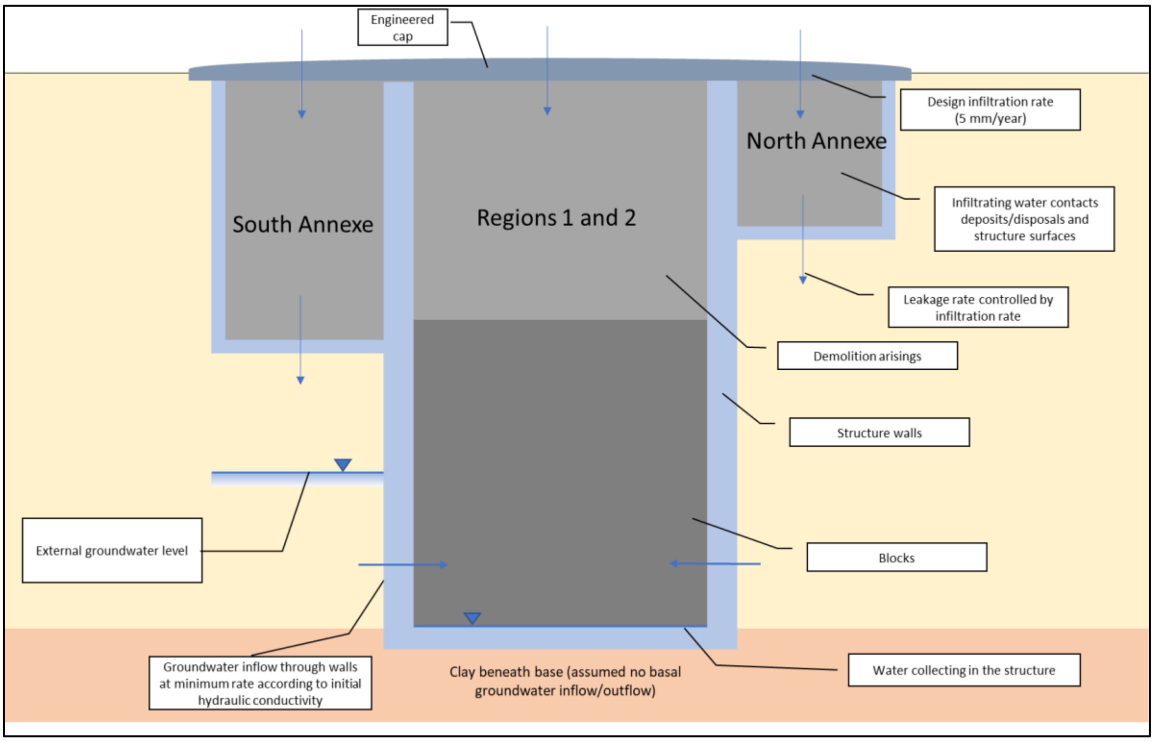

Figure 5.3: SGHWR feature group near-field water balance immediately following implementation of the end state [20, Fig.606/22].

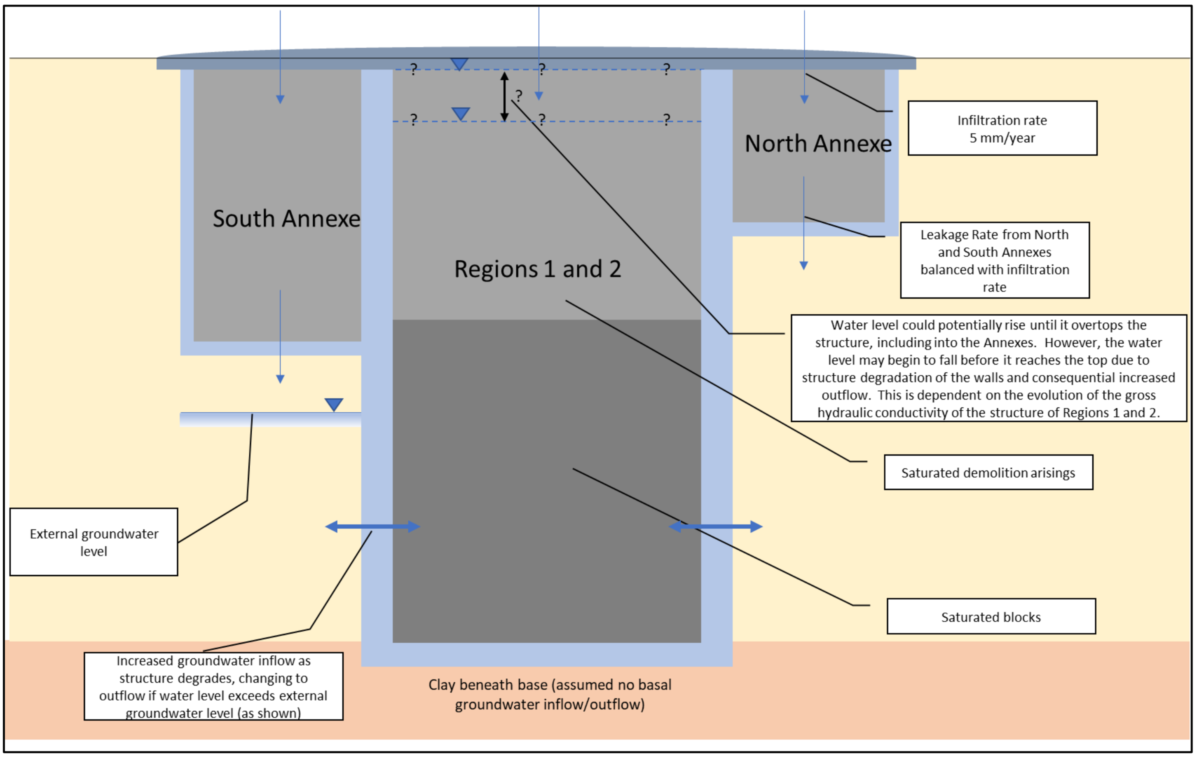

Figure 5.4: SGHWR feature group water balance after approximately 100 years [20, Fig.606/23].

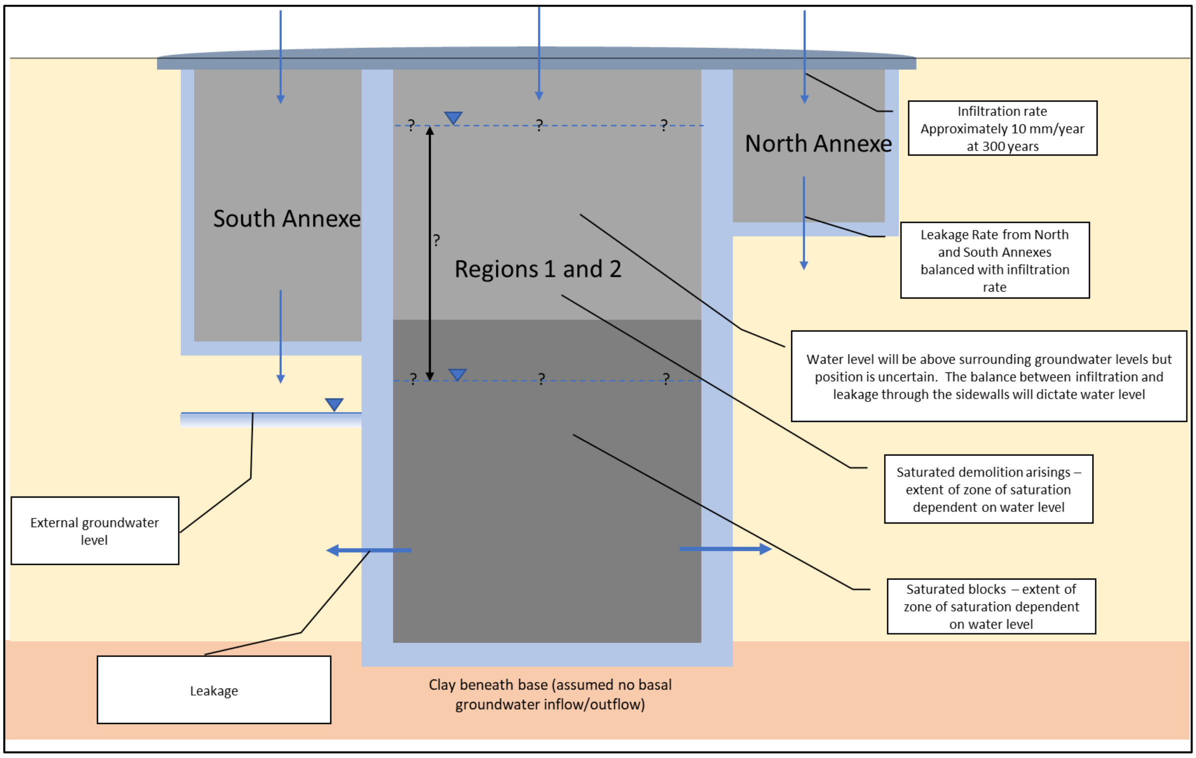

Figure 5.5: SGHWR feature group water balance after approximately 300 years [20, Fig.606/24].

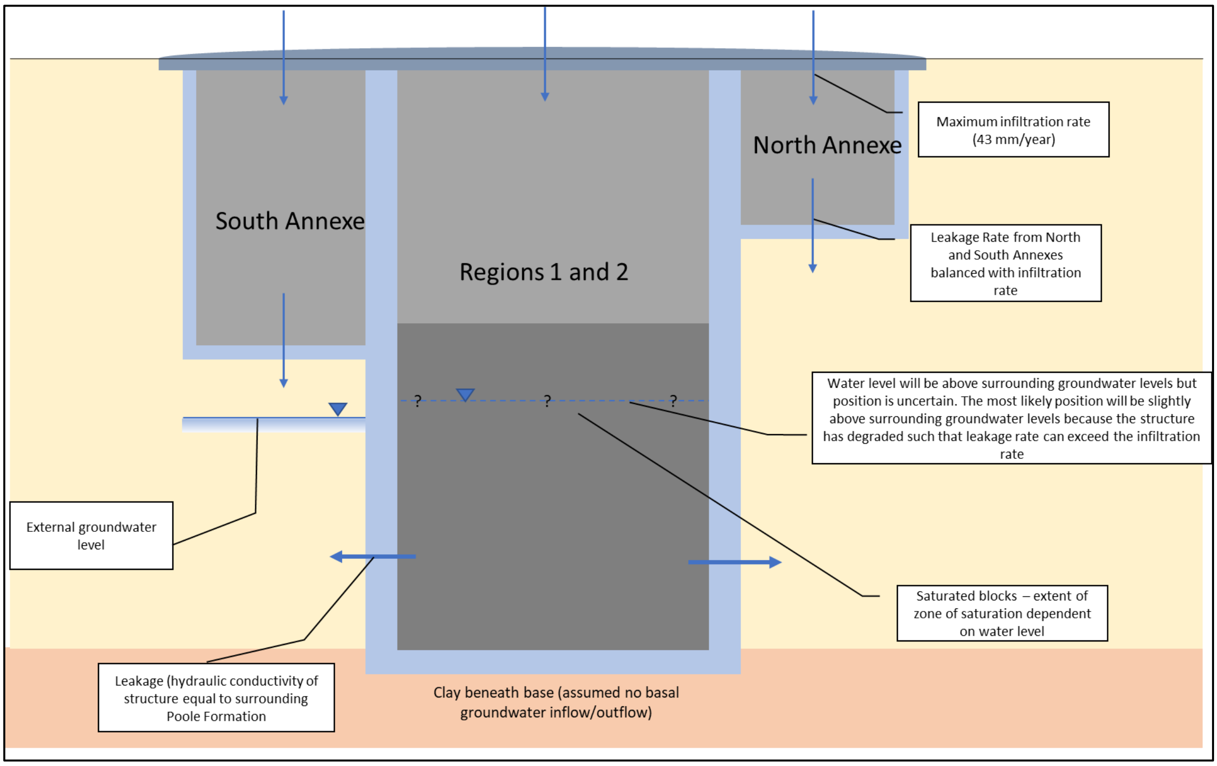

Figure 5.6: SGHWR feature group water balance after approximately 1,000 years [20, Fig.606/25].

280 As each modelled feature can straddle the water table, the source and interface compartments are separately modelled above and below the internal water table, and the volume of these compartments changes according to the water balance. Flow through the above-water-table (AWT) interface compartment is driven by the downward infiltration of rainwater, while flow through the below-water-table (BWT) part of the interface is driven by both infiltration from above and groundwater flow entering/leaving the interface.

281 To simplify the water balance calculations, each disposal feature is considered in isolation[23]. For example, the SGHWR South Annexe feature void is up-stream of Regions 1 and 2, so any contamination released through the assumed-to-be-cracked Annexe floor would be transported through the Poole Formation medium beneath the Annexe and potentially through Regions 1 and 2, thereby increasing their inventory. However, as a model simplification, contamination released from the South Annexe is assumed to leave the near-field module immediately, without accounting for the delay that would be incurred by transport through the surrounding medium or through Regions 1 and 2. Similarly, if Regions 1 or 2 were to over-top the void, the over-flow

[23] Within the near-field compartment, the conceptual model (and its implementation) considers each source of contamination individually. However, the potential for combined impacts from the on-site disposals is assessed, as all near-field releases are made to the same geosphere compartment where combined releases are considered (see Section 5.3).

would migrate into the Annexes and the surrounding medium, and would need to travel through these to leave the near-field, but any such over-flow is also conservatively modelled as immediately leaving the near-field module.

282 As noted in Section 3.4.1, Dragon reactor building Walls A and C are conservatively assumed to be cracked during end state implementation and/or have accessway gaps such that they present no resistance to flow and have the same hydraulic conductivity as the surrounding geosphere (uncertainty PA-025). Wall B and the inaccessible parts of the steel shell will provide some additional containment, but these are conservatively not accounted for. Therefore, whilst the Dragon reactor building contains multiple voids with potentially different infill options and features with distinct radiological inventories, the water balance calculations are undertaken for the B70 Dragon reactor building as a whole, with Darcy's law used to calculate the balance of flow across Wall A and the floor, and with rainfall infiltration through the cap (Figure 5.7).

283 The Dragon B78 floor slab, Dragon primary mortuary holes and three A59 area contaminated features are all modelled using the slab feature type as a single homogeneous medium without separate additional walls and floor. Due to the smaller scale of these features, the lack of modelled walls, and the fact that the A59 features are composed of the Poole Formation solid (the same as the geosphere), a complex water balance across these features has not been modelled. The slab features are conservatively assumed to present no barrier to water flow, so the external groundwater level is applied across the feature and water flows into and out of the feature always balance (assuming that they are below the water table, which is not the case for the two Dragon reactor complex features in all but the most extreme water level sensitivity cases). This means that there is no resaturation delay associated with these features.

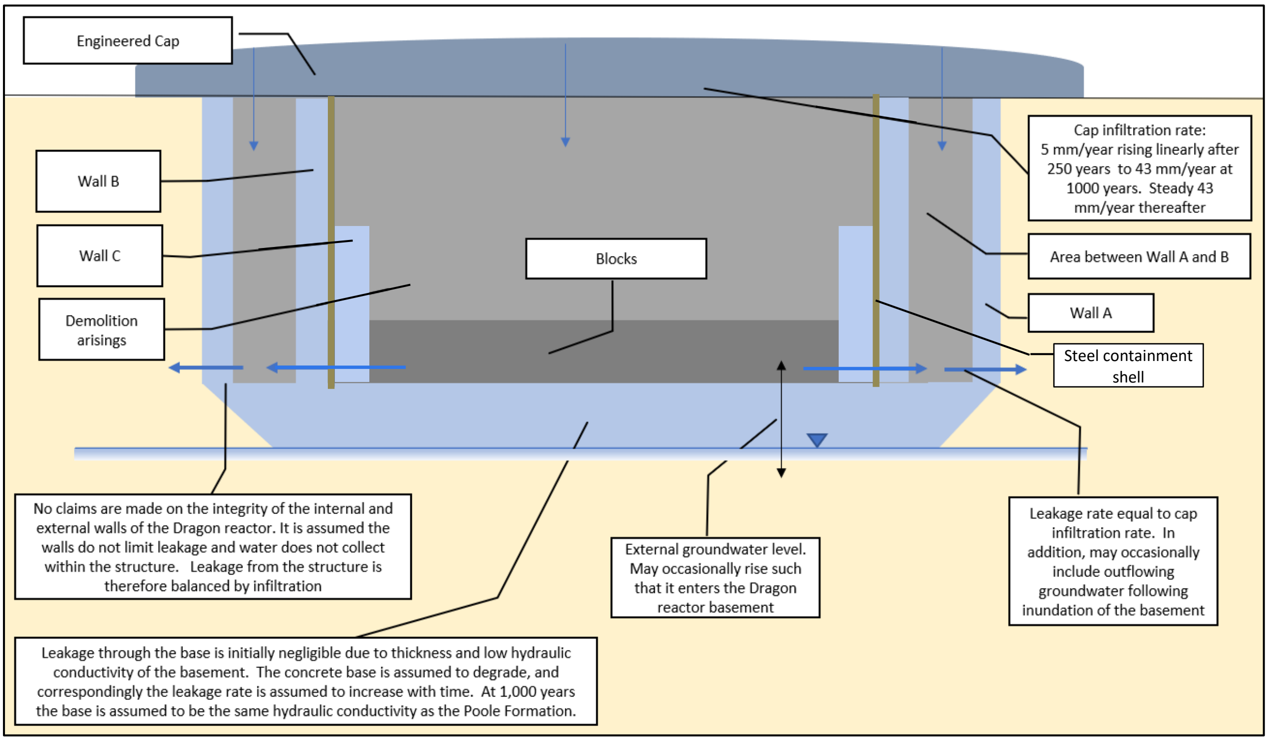

Figure 5.7: Dragon reactor building water balance following implementation of the end state. Edited from [20, Fig.606/26].

Radionuclide Transport

284 As introduced in Section 3.3.4, it is expected that diffusion will be the main driver of radionuclide transport out of near-surface contaminated layers, whilst radionuclides within the interface will be transported by advection in flowing water (Figure 5.8).

285 Diffusive transport out of near-surface contaminated layers is modelled only between the porewater in the source compartment and the associated adjacent interface compartment; diffusion further into uncontaminated parts of intact concrete is cautiously excluded (PA-007). Near-surface contaminated layers are represented in the GoldSim model by nesting multiple cell elements within a source element. Such source elements contain five cell elements[24] that are used to model diffusive radionuclide transport through the near-surface contaminated layer to the interface. The inventory associated with each source is assumed to be uniformly distributed over the porewater within the five cell elements upon radionuclide release (see Radionuclide Release section above).

286 Key parameters that influence modelled diffusion are:

- The diffusion length – This is assumed to be the thickness of the near-surface contaminated layer, which is generally 0.03 m to 0.1 m for most inventory features[25]. As diffusion time is generally proportional to the square of distance[26], diffusion of (non-sorbing) radionuclides into the interface over such distances is expected to occur relatively rapidly (over a period of less than a decade, assuming a typical effective diffusion coefficient for saturated structural concrete of around 10^{-11} m^2 s^{-1}).
- Properties of the fluid, such as its diffusion coefficient and the saturation level – Above the water table, materials may only be partially saturated (see Water Balance section above). This will tend to reduce the effective diffusion coefficient between the source and interface.
- The properties of the material, such as the surface area (over which diffusion can occur), porosity and tortuosity factor – The last of these, as defined in GoldSim (which differs to other definitions), is the ratio of the straight distance between the ends of the flow path to the actual flow path length. Thus, values are always less than or equal to one, with one representing a straight flow path. In the Winfrith NE assessment, the tortuosity value is assumed to increase

24 Prior experience has shown that at least five cell elements are necessary to appropriately model diffusion. Five elements have been modelled for the thin near-surface contamination layers. Ten cell elements are used to model diffusive radionuclide transport through the thicker contamination layer associated with a reactor bioshield.

25 Thicker contamination layers are assumed for the bioshield features, namely 0.75 m for the SGHWR bioshield and 0.5 m for the Dragon bioshield. Table D.28 presents the contamination depth assumed for each modelled feature.

26 Based on the characteristic diffusion length (L) equation: $L^2 = 4\,D\,t$, where D is the effective diffusion coefficient in saturated concrete and t is the time taken to diffuse through a length L.

(i.e. the flow path becomes less convoluted) as intact concrete degrades (see the Concrete Degradation section below).

287 As outlined in the Water Balance section above, depending on the position of the interface relative to the water table, advection will be driven by rainwater infiltration, groundwater flow or a combination of both processes (Figure 5.8). Independently of the driver, flow rates through the interface, and thus advection rates, will be controlled by:

- The hydraulic gradient:
  - A hydraulic gradient of one is assumed for rainfall infiltrating the near field, as the flow direction is vertically downward and thus aligned with gravity. This value aligns with observations (e.g. [106]) and common assumptions (e.g. [107]) associated with water infiltration of soil.
  - The hydraulic gradient for groundwater entering the near field (i.e. the gradient associated with groundwater upstream and downstream of the in-situ feature) is assumed to be the same as the hydraulic gradient of the local groundwater table in the region of each feature (Table D.37).
- The geometry of a feature relative to the flow direction(s) – The geometry can greatly influence the volume of water intersecting a feature. For example, if the length of a feature is greatly different to its width, groundwater-driven fluxes are relatively low when flow is parallel to the feature long-axis (i.e. flow through a small cross-sectional area), whereas fluxes are relatively high when flow is orthogonal to the feature long axis (i.e. flow through a large cross-sectional area)[27].
- The hydraulic conductivity of near-field materials – Flow rates through the interface can be limited by the hydraulic conductivity of associated materials; this is estimated in the NE assessment using Darcy's law.

  Early in a model run, the hydraulic conductivity of intact concrete limits the overall flow through the interface of most BCL features, and thus limits advection rates. This is due to the interface being either formed of intact concrete (e.g. such as a grouted infill) or bounded by intact concrete (e.g. void walls) that is assumed to initially have a low hydraulic conductivity representative of good quality concrete. Flow into the features is also limited by the low conductivity of the clay mineral/bentonite layer in the engineered cap [20, §5.3]. Thus, whilst undegraded, intact concrete and the engineered cap:
  - Minimise rainfall infiltration entering the interface to rates significantly below that of the hydrologically effective rainfall rate, per unit area[28].

---

[27] Flow focussing and diversion, caused by permeability contrasts, are not considered. As most BCL features are expected to be low permeability, the uniform gradient assumption is expected to be cautious with respect to the calculation of flow rates through them.

[28] The engineered cap surface run-off is not considered further as part of the near-field model. This water is likely to infiltrate into surrounding ground and enter the geosphere, leading to increased dilution of any near-field contaminants.

- Limit groundwater flow entering the interface to rates significantly below that of the background groundwater flow rate, per unit area (orthogonal to the flow).

As intact concrete hydraulically degrades (see Concrete Degradation section below), and the number of cracks in the concrete increases, its hydraulic conductivity is assumed to transition towards higher values, ultimately reaching values found locally in the Poole Formation. Thus, over time, flow rates through the interface of a BCL feature will tend towards either the hydrologically effective rainfall rate or the background groundwater flow rate in the Poole Formation, dependent on the primary driver of flow.

288 There are two exceptions where flow through an interface is not constrained by the properties of the near-field materials, and is thus only dictated by the two other controls listed above:

- Cases where intact concrete does not form or bound the interface of a BCL feature. This applies to A59 contaminated land slab features.
- Cases where intact concrete does form or bound the interface of a BCL feature, but due to defects in the concrete structure or assumed early hydraulic degradation in some variant scenarios, the interface transmits flow.

289 As noted above, each feature source and interface comprise a pair of cells, representing the proportion above and below the internal feature water table (AWT/BWT; i.e. saturated and unsaturated parts). As the water table varies over time, the volumes of water and masses of near-field media in each part of the AWT and BWT pairs is recalculated. Similarly, the proportion of radioactive contamination in each part of the pair that has not yet left the source or interface is adjusted using a direct transfer in GoldSim, based on the change in cell volume between timesteps.

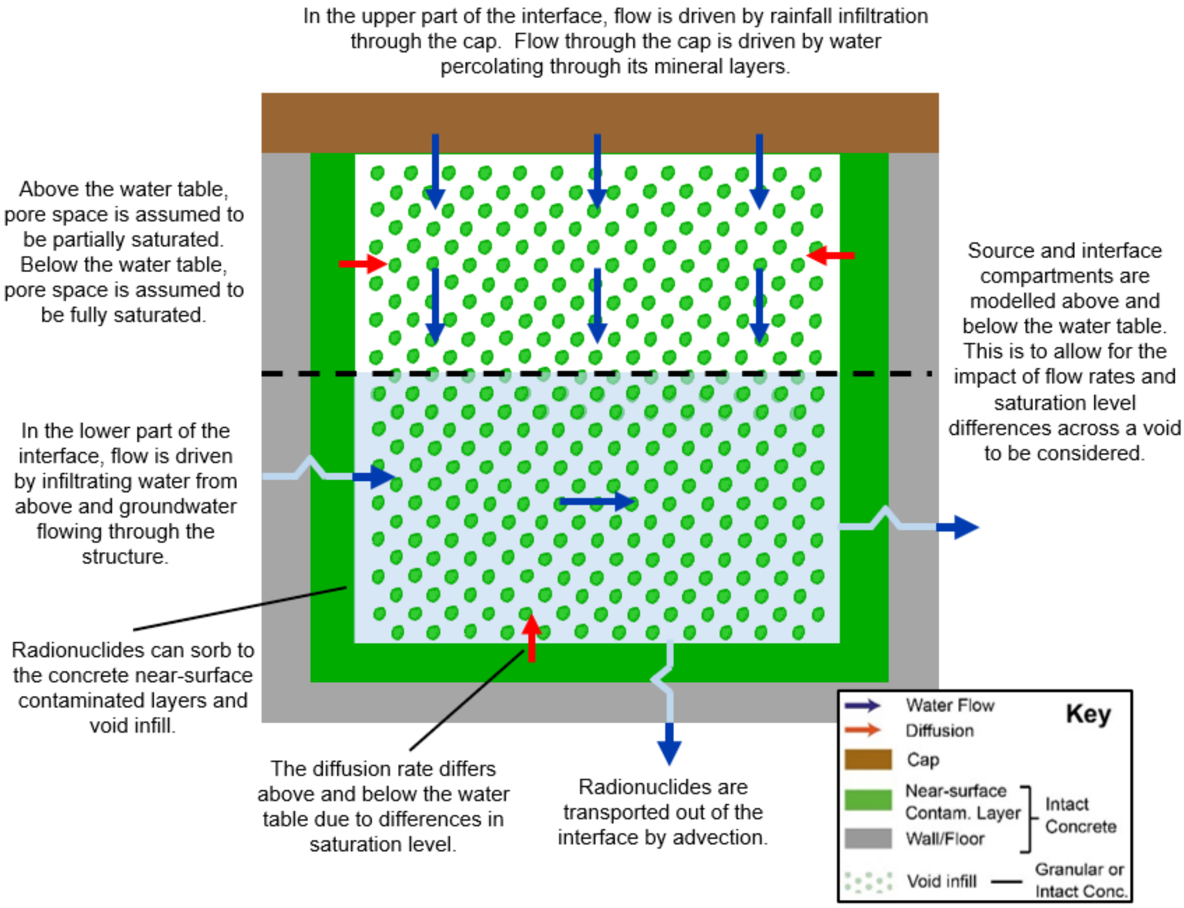

Figure 5.8: Schematic of flow and radionuclide transport into and from the near-field source and interface compartments for a below-ground structure infilled with granular concrete/rubble. The diagram illustrates the case where the water table is above the base of the void and the system has saturated.

Sorption

290 As introduced in Section 3.4.1, it is expected that the transport of some radionuclides will be retarded through sorption to near-field materials. There are several different types of sorption processes associated with concrete, including:

- Chemisorption (or chemical adsorption), in which the forces involved are strong ionic valence forces of the same kind as those operating in the formation of chemical compounds. Chemisorption can involve ion exchange type reactions.
- Physisorption (or physical adsorption), in which the forces involved are weaker intermolecular forces (van der Waals forces).
- Oxide surfaces in aqueous systems adsorbing water molecules via strong electrostatic interactions called hydrogen bonds, where a proton on a water molecule associates with the surface oxygen at the oxide surface.

291 Different radionuclides are affected by different sorption processes, and some radionuclides sorb strongly while others are weakly retarded. For example, the main sorption mechanism for the cations caesium and strontium is ion exchange, which can result in significant retardation, while soluble anions such as chlorine and iodine show little sorption by any process and hence are weakly retarded. For radioelements that sorb strongly to concrete (such as uranium and plutonium), sorption is expected to reduce and/or delay their transport out of the disposals. Uncertainties in sorption properties of the near-field are noted in Appendix A (PA-004).

292 For the Winfrith NE assessment, the impact of radionuclide sorption to the near-field media of concrete and Poole Formation is modelled through the use of element-specific partition coefficients that implicitly encompass all of the sorption processes outlined above. For feature types and compartments where the interface is within the source (see Table 5.3), care is taken to avoid double counting of the material mass, which could lead to an over-estimate of radionuclide sorption.

293 Sorption to concrete is dependent on the chemical degradation state of the concrete (see Section 3.4.1 and the Concrete Degradation section below). Therefore, sorption is modelled through the use of two sets of partition coefficients: partition coefficients for sorption to the cement paste are applied while the concrete is undegraded, and a second set of partition coefficients for sorption to the aggregate in concrete are applied to fully degraded concrete (as the cement paste is assumed to have degraded and been removed). The partition coefficients applied gradually transition from the initial set to the final set over the defined degradation period, as discussed in the Concrete Degradation section below. Sorption to cement paste is heavily dependent on the composition of the porewater, with the most important parameters being pH, redox potential and concentrations of complexing agents [90; 91, ¶214; 108]:

- The pH of the near field will change as concrete degrades, reflecting changes to the cement chemistry and form. The impact of these changes on radionuclide sorption is accounted for in the NE assessment (see Concrete Degradation section below).
- The groundwater in and around the site generally has a positive redox potential and high levels of dissolved oxygen. As such, oxidising conditions are assumed to persist over the model timeframe. This assumption is also cautious as oxidising conditions generally tend to reduce radionuclide sorption (e.g. [90, Tab.7-7 to 7-10]).
- The impact of complexing agents, such as might be derived from cellulose breakdown, is not explicitly considered in the Winfrith NE assessment as their presence is expected to be minimal due to the vast majority of the proposed on-site disposals and near-field structures being concrete and masonry. Based on sorption reduction factors reported by the Swedish Nuclear Fuel and Waste Management Company (SKB) [90, Tab.7-11a to 7-11c], the potential for complexing agents to reduce sorption should be implicitly captured, for most radionuclides, through the minimum near-field sorption assessment case (Section 4.4).

294 Uncertainties in sorption properties of the near field are noted in Appendix A (PA-004).

Concrete Degradation

295 The conceptual model for concrete degradation is set out in the Winfrith CSM [20] and a summary is presented here.

296 Concrete within the disposals is expected to degrade through a combination of physical, chemical and mechanical processes, as discussed in Section 3.4.1. The concept for concrete degradation used in the Winfrith PA comprises two key processes [20, §5.1]:

- cracking caused by rebar corrosion that increases the bulk hydraulic conductivity of the concrete over a few centuries until it provides no hydraulic resistance to the flow of water; and
- dissolution of the cement until all that remains is the concrete aggregate. This changes the density, porosity and tortuosity of the concrete over millennia.

297 In the Winfrith NE assessment, concrete degradation is considered through separate modelling of hydraulic degradation and concrete leaching. The exact timescales over which these processes take place is uncertain (PA-006). Separate modelling is favoured as hydraulic degradation could result from multiple physical, chemical and mechanical processes (i.e. not just leaching).

Hydraulic degradation of intact concrete

298 No claims have been made on the hydraulic integrity of the concrete structure of the SGHWR Annexes and Dragon reactor building exterior Wall A and interior Wall C, which are generally conventional concrete structures and may be adversely affected by the demolition process. Therefore, as noted above, these structures are assumed in the Winfrith NE assessment to present no barrier to groundwater flow from the model start (noting that they are currently above the water table) and are specified to have the same hydraulic conductivity as the surrounding Poole Formation. This is a conservative modelling assumption as these structures will provide some level of containment. Thus, consideration of concrete cracking and hydraulic degradation is only relevant to SGHWR Regions 1 and 2, the reactor floor slabs and bioshields.

299 Magnox Ltd [85] calculated the current effective hydraulic conductivity of the SGHWR Regions 1 and 2 structure to be 4.4×10^{-11} m s^{-1} based on the reported rate of water ingress to it (of the order of 5 m^3 y^{-1}). There is uncertainty about the provenance of water entering SGHWR Regions 1 and 2 (sources include a leak in the roof that has now been repaired and cutting operations) but, if the reported inflow is not all from groundwater, then the calculated current effective hydraulic conductivity would be an over-estimate[29]. The robust SGHWR and Dragon structures are not expected to be

[29] In winter/spring 2024 an increased rate of water ingress into SGHWR was observed, which coincided with very high rainfall and external groundwater levels [72, §4.2.4]. The reasons for this increase and the ingress routes are under investigation. The bulk of the water ingress is known to have occurred through an open duct; structural repairs to seal this are planned, which will reduce water ingress back to nominal levels. Water ingress will continue to be monitored as decommissioning work is carried out and reasonable endeavours will be made to identify and optimally remediate any identified or potential direct discharge pathways.

adversely affected by demolition and backfilling [71], and minor defects and penetrations will be assessed and sealed where optimal before backfilling commences. On this basis the current effective hydraulic conductivity is assumed to remain appropriate at the point that the feature end state is implemented (the Disposal Start Date).

300 A hydraulic degradation rate has been defined for intact concrete based on the assumed degradation rates of concrete barriers in near-surface disposal facility safety assessments (Table 5.2). When not accelerated by external events or processes, hydraulic degradation of intact concrete, which leads to the development of a greater number of higher permeability flow paths (cracks) within the concrete, is expected to occur relatively slowly, over hundreds to thousands of years. There are many differences between the designs and environments for the near-surface disposal facilities considered in Table 5.2 (hence leading to the differences in degradation periods assumed), and between these purpose-built facilities and the extant SGHWR and Dragon structures. However, the safety assessments are generally associated with pessimistic modelling assumptions rather than attempted realism and provide a benchmark to support development of the Winfrith assessments. The time for complete hydraulic degradation of the concrete structures in the assessments in Table 5.2 varies between a few hundred years and a few thousand years. The middle of the range in Table 5.2 is around 1,000 years, which is judged to be a reasonable modelling assumption for complete hydraulic degradation of the structure for the Reference Case assessment. Degradation is assumed to begin upon commencement of radionuclide release (the Disposal Start Date).

301 It also necessary to describe how the effective hydraulic conductivity will evolve from its current value to that representative of complete degradation. In assessments for near-surface disposal facilities (Table 5.2), changes in hydraulic degradation of concrete barriers are sometimes assumed to occur instantaneously, whilst others assume gradual linear change. An intermediate approach is taken here, whereby it is assumed that the degradation of the structure will accelerate with time and so the hydraulic degradation is modelled using an exponential function. This results in small changes in the concrete hydraulic conductivity early-on (e.g. associated with minor cracking), with much larger changes when it is significantly degraded (e.g. associated with failure of steel reinforcement). Thus, the effective hydraulic conductivity at time t (k_t) between 0 years and the complete degradation time (t_d; 1,000 years from the feature Disposal Start Date for the Reference Case) is described as:

$$k_t = 10^{[log k_0 - ((log k_0 - log k_{t_d})\frac{t}{t_d})]} \quad (5.1)$$

where:

K_0:	effective hydraulic conductivity at the feature Disposal Start Date (m s^{-1});
Kt_d:	effective hydraulic conductivity at the time of complete degradation when it is assumed no further increases in effective hydraulic conductivity will occur (m s^{-1}); and
t:	time from the feature Disposal Start Date (years).

302 Over the period of hydraulic degradation, the hydraulic conductivity of intact concrete is modelled to increase exponentially from a value assumed for ingress into SGHWR Regions 1 and 2, to a value representative of the surrounding Poole Formation. A Poole Formation value is cautiously assumed for the degraded state as it removes the ability of intact concrete to act as a barrier to rainfall infiltration and groundwater flow (see Radionuclide Transport section above).

303 There is uncertainty about the current effective hydraulic conductivity of the intact concrete and the period over which degradation takes place.

- The current effective hydraulic conductivity could be lower than assumed. The LLWR performance assessment used an initial concrete hydraulic conductivity for its concrete vault walls above the water table of 1×10^{-12} m s^{-1} [112], which was also assumed for the Belgian disposal facility reference case [116]. This initial concrete hydraulic conductivity value is for newly constructed facilities and is therefore judged to be the minimum possible effective hydraulic conductivity for the aged Winfrith concrete. It is possible that the initial effective hydraulic conductivity could be higher than that calculated based on SGHWR Regions 1 and 2 ingress. It is assumed here that the initial effective hydraulic conductivity could be as high as 1×10^{-9} m s^{-1}. The impact of this range in initial hydraulic conductivity is considered in variant scenario calculations (see Figure 5.9 and Section 8).
- The period for complete hydraulic degradation of the concrete could be shorter than 1,000 years. Reference to Table 5.2 indicates that complete degradation in 300 years has been assumed in other assessments and so the impact of this shorter degradation period is considered through a variant scenario calculation. An additional what-if calculation has also been undertaken where all concrete structures are assumed to present no barrier to flow right from the start of the relevant feature Disposal Start Date (see Section 8). Degradation over a longer period is not considered as the radiological impact would not be worse than the Reference Case period assumed and the low hydraulic conductivity variant calculation.

Table 5.2: Assumed hydraulic degradation rates for concrete barriers in safety assessments for near-surface disposal facilities.

Assessment	Material	Hydraulic Degradation rate	Reference
Centre de l'Aube (France)	Concrete	Instantaneous change – Assumed failure and not modelled after 300 years.	[109]
LLWR (UK)	Concrete base	Linear change – Initial reduction in hydraulic performance after 1,000 years followed by gradual degradation to geosphere values over 10,000 years.	[110]
	Concrete walls		
	Grouted LLW		
	Concrete base (future vaults)	Linear change – Initial reduction in hydraulic performance after 100 years followed by a further reduction after 5,000 years.	[111; 112, §2.5.1]
	Concrete walls (future vaults)		

Assessment	Material	Hydraulic Degradation rate	Reference
D3100 LLW Disposal (UK)	Concrete barriers	Linear change – Reductions in hydraulic performance over 200 and 500 years, complete degradation after 1,000 years.	[91, App. D.1.4]
	Grouted LLW	Linear change – Reductions in hydraulic performance over 300 years, complete degradation after 1,000 years.	
	Cementitious backfill		
	Unencapsulated (demolition) LLW	Linear change – High initial conductivity decreases by an order of magnitude over 600 years due to clogging and settlement. At 1,600 years conductivity increases as the concrete completely degrades.	
El Cabril (Spain)	Concrete	Instantaneous change – Degradation to a porous sand after 300 years.	[109]
Savannah River (US)	Concrete floor	Degradation after 1,050 years.	[109]
SFR (Sweden)	Concrete	Intact for 10,000 years or degraded after 1,000 years.	[113; 114]
	Waste		
SFR (Sweden)	Concrete barriers	Intact concrete hydraulic conductivity is $\leq 1 \times 10^{-9}$ m s^{-1}. Depending on its use, concrete degrades to a hydraulic conductivity of: • 1×10^{-7} m s^{-1} in 2,000-3,000 years; • 1×10^{-5} m s^{-1} in 2,000-22,000 years; and • 1×10^{-3} m s^{-1} in 12,000-52,000 years.	[115]
Dessel (Belgium)	Walls	Degradation implemented using an “S-shaped” function – Fully degraded after 816 years.	[116]
	Base		
	Roof		
	Grouted waste monolith		

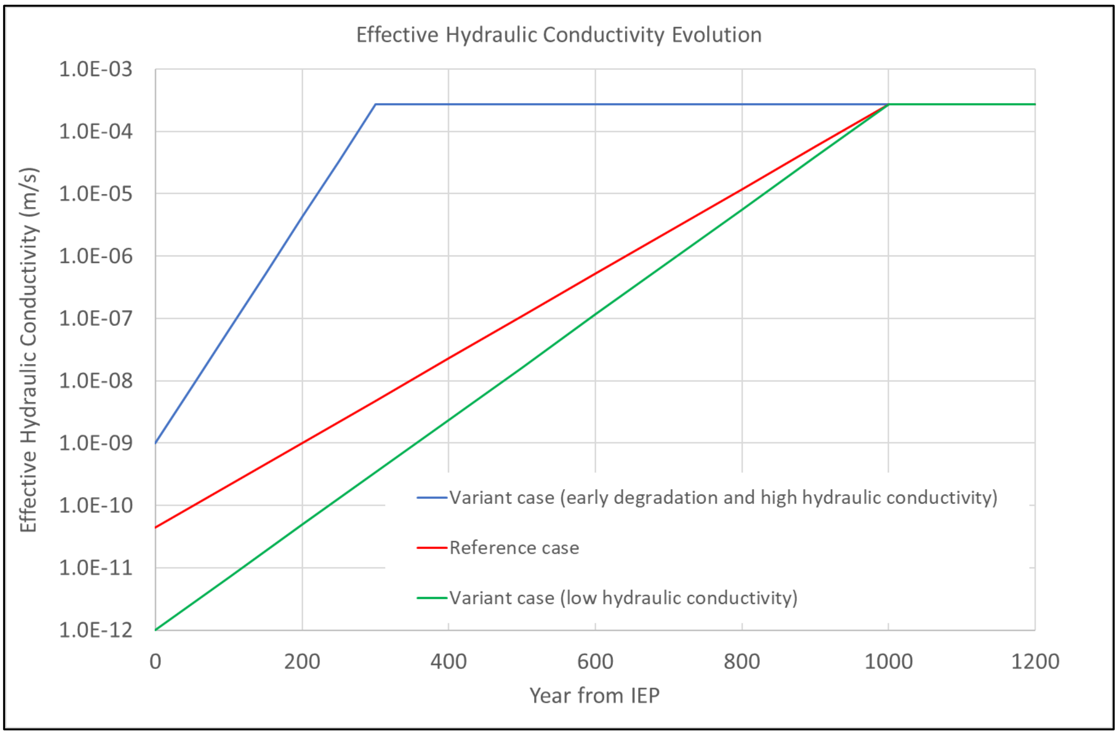

Figure 5.9: Reference and Variant Cases developed to represent the evolution of effective hydraulic conductivity of intact concrete.

Leaching of concrete

304 As water saturates and flows through concrete, the calcium-silicate-hydrate (CSH) phases in the concrete are gradually dissolved and removed, eventually leaving behind the concrete aggregate. Leaching of concrete is modelled to result in:

- Changes in the physical properties of intact concrete. This includes:
  - The porosity and bulk density increasing and decreasing, respectively, to represent the leaching away of constituents of the cement paste.
  - The saturation level of intact concrete located above the water table transitioning to the granular concrete value. This is to represent changes in the hydraulic retention properties of intact concrete with changes in its porosity and bulk density.
  - The tortuosity factor increasing to the granular concrete value. The tortuosity factor forms a key parameter for calculating the effective diffusion coefficient (see Radionuclide Transport section above). This factor increases, reflecting a reduction in tortuosity, as intact concrete degrades to represent the generation of shorter diffusive pathways to the interface (e.g. through dissolution).
- Partition coefficients for intact and granular concrete, transitioning from Stage 2 to Stage 4 values (Section 3.4.1). Due to only a small amount of water being needed to leach out the relatively small quantity of alkali metal hydroxides associated with Stage 1 and the fact that some of the Winfrith in-situ disposal

concrete is over 60 years old, modelled intact concrete is assumed to start at Stage 2. Stage 2 and Stage 4 sorption are modelled using cement paste and granite aggregate (assuming a pH < 10) partition coefficients, respectively (see Appendix D.2.3).

305 There is uncertainty regarding how long it will take for complete cement dissolution (PA-006). A review of concrete leaching suggests between 750 and 2000 kg of water per dm^3 of concrete [92, p.147] is needed to leach all the CSH phases. An estimate for the time required for complete cement dissolution based on the mass of concrete present in SGHWR Regions 1 and 2 (7,900 tonnes [117]), the maximum engineered cap infiltration rate (43 mm y^{-1}) and the volume of water passing through the cement, is calculated to be over 50,000 years [20, §5.1.5]. This estimate cautiously assumes all infiltrating water contacts all the cement of the concrete as it flows into the ground surrounding the structure, rather than passing only through cracks in the concrete (which is what would be expected, at least initially). This period is consistent with the 45,000 years assumed for chemical degradation of the Dounreay D3100 disposal facility cement [91]. Given the uncertainties over evolution of the cap and disposals over such long timescales (PA-006), as well as the climate, for the purposes of simplicity the Reference Case assumes a chemical degradation duration of 50,000 years after the end state[30].

306 The changes in concrete properties with leaching (see above) are modelled to occur linearly with time. This is a simplifying assumption, as used in some near-surface disposal facility assessments (e.g. [91]). In reality, these property changes are likely to occur at different rates, dependent on the leaching stage and the property that is varying, and location and flow through the concrete structure (i.e. above or below the water table).

307 To bound uncertainty associated with degradation (PA-006), an alternative cautious approach is considered in the "linked hydraulic-chemical degradation" variant scenario (see Section 8). In this scenario, chemical degradation is conservatively assumed to take place on the same timescale as the reference hydraulic degradation case (1,000 years).

Summary of Near-field Properties and Processes

308 To assist understanding of the Winfrith NE assessment near-field conceptual model, key aspects are summarised schematically and are tabulated in Figure 5.10 and Table 5.3, respectively.

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30 To simplify the model implementation, chemical degradation starts in the NE assessment model after the system hydraulics and water balance have stabilised. This adds a small delay of a few decades to hundreds of years, depending on the feature, but is also realistic as, until there is flow through the concrete, the cement cannot dissolve.

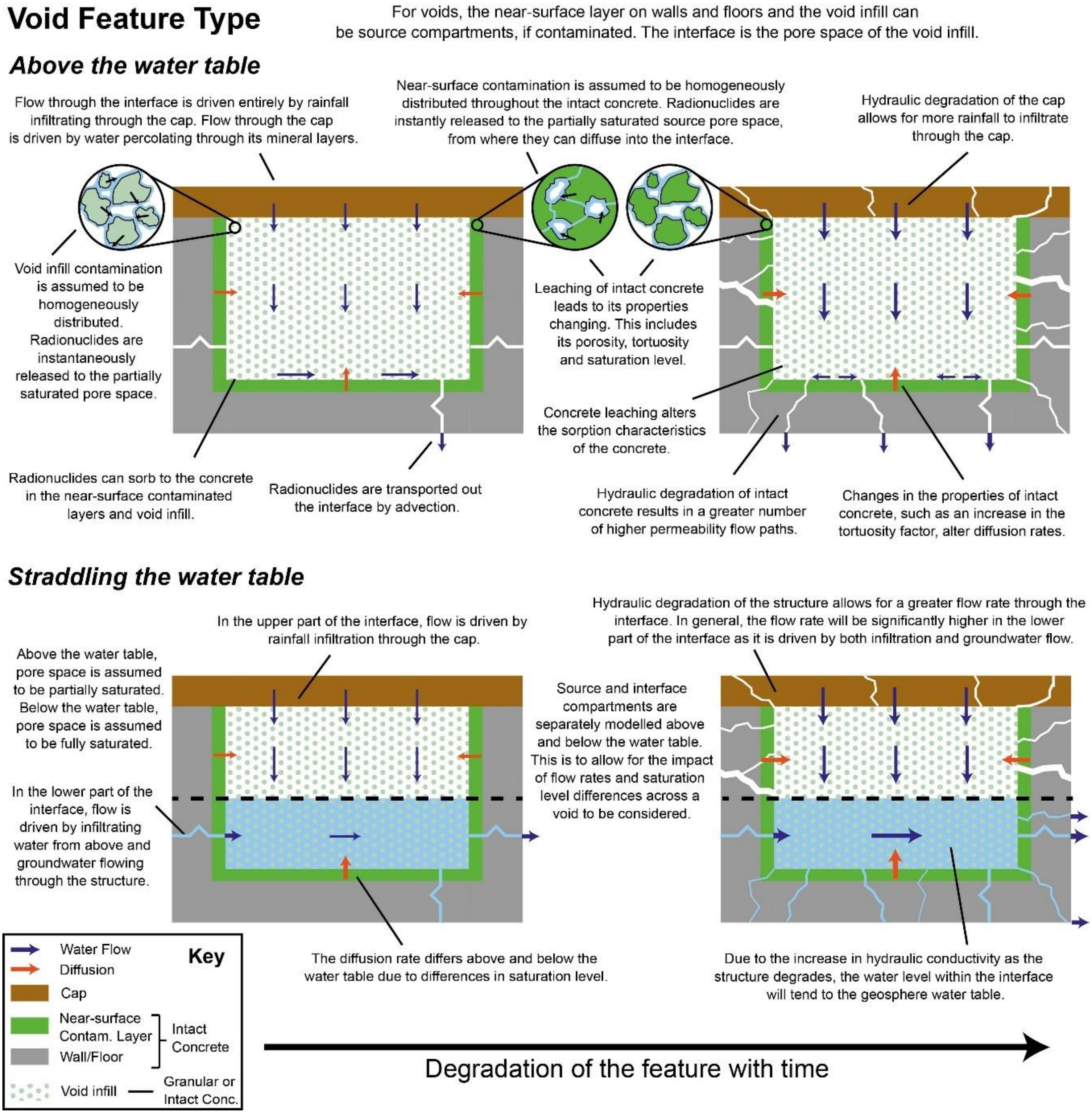

Figure 5.10: Schematic of near-field vault/pond radionuclide transport. Note that comments for straddling the water table highlight key differences only.

Table 5.3: Summary of the properties and processes considered for the feature types of the Winfrith NE assessment near-field conceptual model.

Feature Type	Source Compartment(s)		Interface Compartment(s)			Radionuclide Release from Source	Feature Relative to Groundwater	Radionuclide Transport		Sorption	Concrete Degradation
	Description	**Material**	**Location**	**Description**	**Material**			**Source to Interface**	**Interface to Geosphere**		
Void	Near-surface contaminated layers on the floor and/or walls	Intact concrete	Adjoining the source compartment	Pore space within the infilled void space	Intact or granular concrete	Instantaneous release to source porewater	Above or straddling the water table	Diffusion modelled between source and interface porewater	Advection driven by rainfall infiltration and/or groundwater flow	Radionuclides can sorb to the concrete in the source and interface. Where the interface is within the source compartment, care is taken to avoid double counting of the mass of concrete.	Hydraulic degradation of intact concrete and leaching of concrete modelled separately. Hydraulic conductivity of all intact concrete increases exponentially over a fixed period. Density, porosity and tortuosity of intact concrete, and partition coefficients of intact concrete and rubble, vary linearly over a fixed period to represent the impact of concrete leaching.
	Near-surface contaminated layers on emplaced concrete blocks										
	Near-surface contaminated layers on reactor bioshield (if present)										
	Contaminated infill, where radioactivity is assumed to have a uniform concentration across the concrete that infills a void space	Intact or granular concrete	Within the source compartment			Instantaneous release to interface porewater		Direct transfer to interface porewater			
Slab	Contamination distributed over the entire slab volume	Intact concrete or Poole Formation	Within the source compartment	Pore space within the slab	Intact concrete or Poole Formation	Instantaneous release to interface porewater	Above or straddling the water table	Direct transfer to interface porewater			

Configuration of Features

309 Table 5.4 and Table 5.5 show the assignments of features (Section 3.2.9) to the feature types considered in the near-field model; these remain the same over all the scenario and assessment cases considered.

Table 5.4: Assignment of features (Section 3.2.9) to the void feature type. The assumed configuration of void features in the Reference Case assessment is also shown.

<table>
<tr><th>Void feature</th><th>Void infill material</th><th>Bioshield status</th><th>Infill activity distribution</th><th>Radionuclide release time</th><th>Intact concrete hydraulic status</th></tr>
<tr><td>SGHWR South Annexe</td><td>Granular concrete</td><td>n/a</td><td>Distributed over the entire void</td><td rowspan="4">SGHWR Disposal Start Date</td><td>Degraded at model start</td></tr>
<tr><td>SGHWR Region 1</td><td>Intact concrete blocks at base and granular concrete on top</td><td>Present</td><td>Near-surface contaminated layer in blocks and bioshield; Distributed over the granular concrete volume</td><td rowspan="2">Undegraded at model start. No flow through floor due to base in clay layer.</td></tr>
<tr><td>SGHWR Region 2</td><td>Granular concrete</td><td>n/a</td><td rowspan="2">Distributed over the entire void</td></tr>
<tr><td>SGHWR North Annexe</td><td>Granular concrete</td><td>n/a</td><td>Degraded at model start</td></tr>
<tr><td>Dragon Reactor Building</td><td>Granular concrete between Walls A and C; Intact concrete blocks at base and granular concrete on top inside Wall C</td><td>Present (inside Wall C)</td><td>Near-surface contaminated layer in blocks and bioshield; Distributed over the granular concrete volume</td><td>Dragon Disposal Start Date</td><td>Walls A and C degraded at model start; floor undegraded at model start</td></tr>
</table>

Table 5.5: Assignment of features (Section 3.2.9) to the slab feature type. The assumed configuration of void features in the Reference Case assessment is also shown.

Slab feature	Slab material	Activity distribution	Radionuclide release time	Intact concrete hydraulic status	Cap status
Dragon B78 Floor Slab	Intact concrete	Distributed over the slab volume	Dragon Disposal Start Date	Degraded at model start	Cap present (Dragon)
Dragon B78 Primary Mortuary Holes					
A59 PSA/Pit 3 Area	Poole Formation		Model start date	n/a	No cap (contaminated land)
A59 HVA/A591 Area					
A59 Remaining Area					

310 As indicated in the sections above, different configurations for each feature can be modelled depending on the feature type. Table 5.4 and Table 5.5 present the configuration of features in the Reference Case assessment, which aligns to the reference configuration outlined in Section 3.2.9. Alternative physical configurations, considered in the variant and "what-if" scenarios (see Section 8), are detailed in Table 5.6.

Table 5.6: The scenarios that consider an alternative configuration for the BCL features, and the changes that are made, relative to the reference configuration and Reference Case assessment.

Variant Scenario	Change(s)
Void infill rubble	For all void features, the void infill material is modelled as granular concrete.
Void infill grouted	For all void features, the void infill material is modelled as intact concrete.
Degraded concrete structures	All voids with intact undegraded concrete structures are modelled as degraded from model start.

5.2.2 Mathematical Representation

311 The basic mass balance equation for a GoldSim cell element containing species *s* (and any parent species *p*) is as follows [105, Eqn.B-1]:

$$m_s' = -m_s\,\lambda_s + \sum_{p=1}^{NP_s} m_p\,\lambda_p\,f_{ps}\,R_{sp}\left(\frac{A_s}{A_p}\right) + \sum_{c=1}^{NF} F_{cs} + S_s \tag{5.2}$$

where:
- m_s' Rate of increase of mass of species *s* in the cell (kg y^{-1}).
- m_s Mass of species *s* in the cell (kg).
- λ_s Rate of decay of species *s* (y^{-1}).
- NP_s Number of parents for species *s* (-).
- m_p Mass of parent species *p* in the cell (kg).
- λ_p Rate of decay of parent species *p* (y^{-1}).

f_{ps} Fraction of the time that parent species p decays to species s (i.e. the branching fraction in radioactive decay) (-).

R_{sp} Stoichiometric ratio of moles of species s produced per mole of parent species p according to a specific chemical reaction (-). In this assessment the species remain unchanged along the transport pathway such that $R_{sp} = 1$.

A_s Molecular (or atomic) mass of species s (kg mol^{-1}).

A_p Molecular (or atomic) mass of parent species p (kg mol^{-1}).

NF Number of mass flux links from/to the cell (-).

F_{cs} Influx rate of species s (into the cell) through mass flux link c (kg y^{-1}) – see Equation (5.6).

S_s Rate of direct input of species s to the cell from “external” sources (kg y^{-1}), for example an initial condition and/or a mass flux rate into the cell specified by the user.

312 The first term on the right-hand side of Equation (5.2) represents decay (or chemical degradation), the second term represents ingrowth (and chemical reaction if considered), the third term represents mass transfer in or out of the cell via mass flux links and the fourth term represents the rate of direct input to the cell from other sources.

313 For a diffusive mass flux link from cell i to cell j, the flux of species s, $f_{s,i\to j}$ (kg y^{-1}), is computed as follows [105, Eqn.B-4]:

$$f_{s,i\to j} = D_s\left(c_{ims} - \frac{c_{jns}}{K_{nms}}\right) + \sum_{t=1}^{NPT_{im}} PF_t\, D_t\left(c_{its}\, cp_{imt} - c_{jts}\, cp_{jnt}\right) \quad (5.3)$$

where: D_s Diffusive conductance for species s (m^3 y^{-1}).

c_{ims} Concentration of species s in medium m within cell i (kg m^{-3}).

c_{jns} Concentration of species s in medium n within cell j (kg m^{-3}).

K_{nms} Partition coefficient between medium m and medium n for species s (m^3 m^{-3}) (=1 if both fluids are water).

NPT_{im} Number of suspended materials in cell i (-).

PF_t Boolean flag to allow diffusion of suspended materials (-).

D_t Diffusive conductance for suspended material t (m^3 y^{-1}).

c_{its} Sorbed concentration of species s on suspended material t within cell i (kg kg^{-1}).

cp_{imt} Concentration of suspended material t in cell i (kg m^{-3}).

c_{jts} Sorbed concentration of species s on suspended material t within cell j (kg kg^{-1}).

cp_{jnt} Concentration of suspended material t in cell j (kg m^{-3}).

314 The first term on the right-hand side of Equation (5.3) accounts for diffusion of dissolved species, whilst the second term accounts for diffusion of any suspended material in the fluid. D_s is given by [105, Eqn.B-6]:

$$D_s = \left(\frac{A_d}{\frac{L_i}{f_{ms}\, d_{ms}\, r_m(\theta_m)\, t_{Pi}\, n_{Pi}} + \frac{L_j}{f_{ns}\, d_{ns}\, t_{Pj}\, r_n(\theta_n)\, n_{Pj}\, K_{nms}}} \right) \tag{5.4}$$

where: A_d Cross-sectional area of diffusive flux (m^2).
- L_i Length of diffusive link in cell *i* (m).
- L_j Length of diffusive link in cell *j* (m).
- f_{ms} Available porosity for species *s* in medium *m* within cell *i* (-).
- f_{ns} Available porosity for species *s* in medium *n* within cell *j* (-).
- d_{ms} Diffusivity for species *s* in medium *m* within cell *i* ($m^2\ y^{-1}$).
- d_{ns} Diffusivity for species *s* in medium *n* within cell *j* ($m^2\ y^{-1}$).
- $r_m(\theta_m)$ Diffusive reduction formula for medium *m* in cell *i* to account for saturation level (-).
- $r_n(\theta_n)$ Diffusive reduction formula for medium *n* in cell *j* to account for saturation level (-).
- t_{Pi}, Tortuosity for the porous medium within cell *i* (-).
- t_{Pj} Tortuosity for the porous medium within cell *j* (-).
- n_{Pi} Porosity for the porous medium within cell *i* (-).
- n_{Pj} Porosity for the porous medium within cell *j* (-).

315 The diffusive reduction formula defines how the effective diffusivity through the medium is impacted by the medium's saturation level within any cell. It is defined as [105, p.143]:

$$Diffusivity\ Reduction\ Formula\ =\ Saturation^E \tag{5.5}$$

316 This formula is used in the NE assessment to model the impact of partial saturation of near-field materials on diffusion. A value of 3.33 is used for *E* in the NE assessment; this value, derived from academic literature [118], is suggested in the GoldSim-RT user guide as appropriate for modelling aqueous diffusion [105, p.143; 119, p.135]. GoldSim internally computes the "Saturation" property of the fluid in a cell pathway by estimating the ratio of the fluid volume to the total available pore volume.

317 For an advective mass flux link from cell *i* to cell *j*, the flux of species *s*, $F_{s,i\rightarrow j}$ (kg y^{-1}), is computed as follows (based on[31] [105, Eqn.B-2]):

$$F_{s,i\rightarrow j} = c_{is}\, q + \sum_{t=1}^{NPT_i} PF_t\, c_{its}\, vm_t\, cp_{it}\, q_c \tag{5.6}$$

where: q Rate of fluid flow ($m^3\ y^{-1}$).
- c_{is} Total dissolved concentration of species *s* in the fluid within cell *i* (kg m^{-3}).
- NPT_i Number of materials suspended in water within cell (-).

[31] Equation has been revised to remove aspects associated with material advection (e.g. through erosion).

PF_t	Boolean flag (0 or 1) that indicates whether advection of material *t* suspended in the flowing water is allowed for in the mass flux link (-).
c_{its}	Sorbed concentration of species *s* in the material *t* within cell *i* (kg kg^{-3}).
vm_t	Advective velocity multiplier for suspended material *t* (-).
cp_{it}	Concentration of suspended material *t* within the groundwater in cell *i* (kg m^{-3}).
q_c	Rate of fluid flow containing suspended material (m^3 y^{-1}).

318 The first term on the right-hand side of Equation (5.6) accounts for advection of dissolved species, whilst the second accounts for the advection of suspended materials in the fluid. The NE near-field model does not consider advection of suspended materials, but this is used for suspension of river sediment in the biosphere model (Section 5.4.1).

319 The rate of fluid flow, *q*, into a cell is derived from the lower value of either the maximum flow rate that can flow through the intact concrete, calculated using Darcy's law, or the maximum flow rate that can be supplied to the cell, associated with the hydrologically effective rainfall rate (through the engineered cap or soil), the geosphere flow rate or both:

$$\textit{For geosphere-driven flow:}\ \ q = \min(q_{ic\ geo}, q_{geo}) \tag{5.7}$$

$$q_{ic\ geo} = K_{ic}\ A_{cs}\ i_{geo} \tag{5.8}$$

$$q_{geo} = K_{geo}\ A_{cs}\ i_{geo} \tag{5.9}$$

$$\textit{For rainfall-driven flow:}\ \ q = \min(q_{ic\ rain}, q_{rain}) \tag{5.10}$$

$$q_{ic\ rain} = K_{ic}\ A_p\ i_{rain} \tag{5.11}$$

$$q_{rain} = HER\ A_p \tag{5.12}$$

where:

$q_{ic\ geo}$	Maximum geosphere flow rate through intact concrete (m^3 y^{-1}).
$q_{ic\ rain}$	Maximum rainfall infiltration rate through intact concrete (m^3 y^{-1}).
q_{geo}	Maximum geosphere flow rate that could enter a cell (m^3 y^{-1}).
q_{rain}	Maximum rainfall infiltration rate that could enter a cell (m^3 y^{-1}).
K_{ic}	Hydraulic conductivity of intact concrete (m y^{-1}).
K_{geo}	Hydraulic conductivity of the geosphere (m y^{-1}).
A_{cs}	Cross-sectional area associated with a geosphere-flow-driven advective flux (m^2).
A_p	Plan area associated with a rainfall-infiltration-driven advective flux (m^2).
i_{geo}	Hydraulic gradient of the geosphere (-).
i_{rain}	Hydraulic gradient of infiltrating rainfall (-).
HER	Hydrologically effective rainfall rate (m y^{-1}).

320 When species mass enters a cell, be it either through diffusion or advection, it is instantly partitioned among the media present in the cell. The partitioning is controlled by the partition coefficients defined for each species in each medium and the quantity of each medium present. In the absence of solubility limits (as assumed in this

assessment), the total dissolved concentration, c_{is}, is computed as follows (based on[32] [105, Eqn.B-8]):

$$c_{is} = \left(\frac{K_s}{\sum_{g=1}^{NM} K_{gs}\, VM_g}\right) m_s \tag{5.13}$$

where: m_s Mass of species s in cell (kg).
K_s Partition coefficient between fluid and the Reference Fluid (water) for species s ($m^3\ m^{-3}$) (=1 if the fluid is the Reference Fluid).
K_{gs} Partition coefficient between material g and the Reference Fluid (water) for species s ($m^3\ kg^{-1}$).
VM_g Mass of material g in the cell (kg).
NM Number of media in the cell (-).

321 For undegraded concrete in the Winfrith NE assessment, for which sorption is modelled to cement paste, the partition coefficients between the material and the fluid, K_{gs}, are reduced through multiplication with a cement paste volume factor. This is to account for the relative proportion of cement paste in the concrete solids.

322 With respect to the cell radionuclide transport equations above, a network of interconnected (coupled) cell elements is solved simultaneously as a system of coupled differential equations. This mathematical solution process is described in equations B-16 to B-24 in [105].

323 The other mathematical equations associated with the near-field model are those used to represent the impact of concrete degradation. For this, the hydraulic conductivity, saturation level, porosity, density, tortuosity and partition coefficients associated with the near-field concrete are modelled to transition from undegraded to degraded values, as outlined in the Concrete Degradation section above.

5.3 Geosphere

324 The geosphere module of the Winfrith NE assessment model represents the pathway through which releases from the modelled features of the near field (Section 5.2) are transported, in flowing groundwater, to the surrounding biosphere (see Section 5.4). Within this section, the conceptual model for the geosphere (Section 5.3.1) and its mathematical representation in the GoldSim model (Section 5.3.2) are detailed.

5.3.1 Conceptual Model

325 The geosphere conceptual model has been developed based on the current understanding of the geological and hydrogeological characteristics of the in-situ disposal features and the wider site, as outlined in the Site Description [42] and Hydrogeological Interpretation [43] reports, and summarised in Section 3.

[32] Equation has been revised to specifically provide the concentration within the fluid.

Saturated Pathway

326 As discussed in Section 3.2.5, groundwater flow in the Poole Formation is expected to dominate in comparison to downwards vertical flow from the Poole Formation through the lower transmissivity basal London Clay and into the underlying Portsdown Chalk Formation [20, §6.2.1]. On this basis, the geosphere pathway in the NE assessment for the in-situ disposals is modelled to be through the saturated unconsolidated clay, sand and gravel of the Poole Formation from the point where radionuclides released from the feature enter the groundwater to the point of groundwater emergence (Figure 3.29). Any perturbation in flow lines due to the presence of clay lenses in the Poole Formation has been ignored. The London Clay and Portsdown Chalk Formation are disregarded as saturated pathways; the London Clay is considered to form a hydraulic base to the Poole Formation aquifer.

327 The saturated pathways for the disposal features in the geosphere module are defined as follows:

- the top of the pathway is the mean annual elevation of the groundwater table (which varies with time[33] in the model to reflect the potential impacts of climate change on groundwater; see Section 3.4.2 and Table D.31);
- the base of the pathway for the SGHWR is the elevation of the bottom of the floor slab of the SGHWR Regions 1 and 2 structure (26.1 m AOD);
- the base of the pathway for the Dragon reactor feature group is 5 m below the water level at the IEP (elevation 19.5 m AOD);
- the base of the pathway for the A59 feature group is the base of the deepest part of the feature, defining an elevation of 20.8 m AOD; and
- the widths of the saturated pathways are equivalent to the widths of the relevant feature in the direction orthogonal to groundwater flow[34].

328 Since GoldSim Aquifers represent one-dimensional conduits, these elements calculate the average concentration discharging from the pathway and any spatial variation in the concentration (orthogonal to the flow direction) is not represented [105; p.230]. Thus, as a cautious approach and consistent with other radiological transport assessments (e.g. [91; 102]), the model does not include transverse dispersion (i.e. lateral spreading of

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[33] The impact of mean annual groundwater levels changing due to the potential impact of climate change is considered in the NE assessment model, with reference, alternative and what-if groundwater levels assessed (see the assessment cases listed in Section 8). On shorter timescales, the groundwater levels also change on a seasonal basis, with higher levels in the winter and lower levels in the summer. However, computationally it is not a tractable problem to directly model a water level that fluctuates every few months over a 200,000-year period. Therefore, only the average annual behaviour is considered. A simplified variant calculation (VA.10) is undertaken to gain an indicative understanding of the potential combined impact of reasonable worst case groundwater levels and seasonal fluctuation (see Section 10.2.1).

[34] As discussed later, releases from A59 are modelled to flow to both the River Frome and the mire in varying proportions. These directions are orthogonal to each other. For the purposes of model simplification, the same saturated pathway width is modelled for flow in both directions, with the value corresponding to that orthogonal to flow to the River Frome.

solutes along the flow path and mixing of water leaving the feature with water in the full thickness of the Poole Formation and consequent spreading of solutes). The model includes consideration of longitudinal dispersion (dispersivity of 10% in the geosphere is assumed as a standard approximation of this effect [105]).

Groundwater Flow Paths and Emergence Locations

329 Releases to the saturated pathway from each feature in the near-field module are first directed to an "abstraction well" in the geosphere module for each feature group, before considering the flow paths beyond. This split is a modelling artefact to allow concentrations of radionuclides in the groundwater adjacent to each feature group to be interrogated. The abstraction well in the model need not actually be there and no adjustment is made to model flows; that is, if this element was removed from the model, there would be no impact on the radionuclide flows or concentrations further downstream. The leg to the well is, in fact, very short (1 m) because each borehole is modelled as being drilled where the concentrations are highest immediately downstream from each feature group (irrespective of how unlikely this assumption is). The concentrations are used to determine the maximum radiological risk of drilling a well for drinking water on the Winfrith site in the future. The subsequent pathways in the geosphere module are specific to each feature group, as discussed below.

330 Most groundwater beneath the site flows in a north and north-easterly direction toward the River Frome. Thus, the groundwater pathway in the geosphere module is concerned with sub-horizontal flow in the Poole Formation down hydraulic gradient and flow of this groundwater either to rivers and ditches (surface water features that will exist at the site end state) or to land.

331 As discussed in Sections 3.1.2 and 3.4, plans for development of the site include decommissioning of site drains and removal of non-native trees, in addition to removal of buildings and areas of hardstanding. This is expected to result in a rise to the average groundwater elevation of approximately 0.4 m at SGHWR and approximately 0.3 m at the Dragon reactor [43, §7.2.2] and an increase in average groundwater recharge, leading to an increase in groundwater flow.

332 As part of the plans discussed in Section 3.4.2 to reinstate a more natural hydrogeological regime and promote desirable habitats, a mire will be created by enhancing a natural valley on the site. Figure 3.24 shows the proposed mire location in the north-east part of the site between the OoS A59 area feature group and Coltsclose Corner. Figure 3.28 shows modelled forward groundwater pathlines for releases to the saturated pathway from the SGHWR and Dragon reactors for the assumed site IEP conditions. The model results support the dominance of flows in a north/north-easterly direction toward the River Frome, but the forward tracking also shows that groundwater from the SGHWR may emerge to land west of Monterey roundabout and in the proposed mire location, and could also travel towards the Dragon reactor (PA-012). Down-gradient of the Dragon reactor complex, groundwater is modelled to join the River Frome or emerge in the low-lying marshy ground close to the river (PA-014); the modelling results show no evidence for flow from the Dragon reactor towards the mire (see Paragraph 218). While not explicitly considered in the groundwater modelling

undertaken, given the proximity of the OoS A59 area to the proposed mire and the relatively shallow water table in the area, it is possible that releases from A59 could emerge in the mire as well as flow to the River Frome (PA-013).

333 Based on the above, the following flow paths and bounding transport distances to points of groundwater emergence are assumed for each feature group[35]:

- SGHWR: Flow paths to the land area west of Monterey roundabout (300 m; emergence on land and in the mire is considered as a single compartment, as discussed in Section 5.4.1), the River Frome (1,350 m) and to the Dragon reactor complex (550 m). The Reference Case assumes an equal split in groundwater releases to the Land/Mire and to the River Frome. However, variant scenarios consider the impact of the entire SGHWR release to each of the three possible locations.
- Dragon reactor complex: Flow to the River Frome (500 m).
- A59: Flow paths to the proposed mire (25 m) and the River Frome (350 m). The Reference Case assumes an equal split in releases to the mire and to the River Frome; variant scenarios consider the impact of the entire A59 release to either the mire or the river.

334 In the Winfrith NE assessment it is assumed that all of the groundwater emerges at a single place to a surface water feature or piece of land. In reality, the contaminated groundwater might emerge at several points across the same feature, particularly after artificial drainage ceases to operate, thereby diluting the impact calculated for a single location. It is also cautiously assumed that the distinct groundwater flow pathways from all feature groups join the River Frome at the same point (PA-027).

335 The flux of water along the saturated pathway is calculated using an average hydraulic gradient along the pathway for each feature group and a spatially averaged hydraulic conductivity for the Poole Formation.

Impact of Climate Change

336 As discussed in Section 3.4.2, groundwater modelling at the SGHWR and Dragon reactors for the late 2050s and for the late 2080s using recharge from a cautious central estimate (CCE) for future climate change under a medium-emissions scenario indicates that groundwater may temporarily rise above the base of the SGHWR South Annexe by 1.1 m and above the base of the Dragon reactor by 0.8 m for a proportion of the modelled period [20, §7.1.3].

337 When the recharge of a reasonable worst case (RWC) variant of future climate change under a medium-emissions scenario is modelled, the groundwater levels are expected to be on average a little higher and the frequency with which groundwater rises above the top of the base of the South Annexe and Dragon reactor increases. The highest

[35] Discussion of the transport distance values selected is provided in Table D.35.

groundwater level in the modelled results at SGHWR is 1.6 m above the base of the South Annexe and 1.4 m above the base of Dragon reactor [20, §7.1.3].

338 Groundwater modelling based on the CCE and RWC variant recharge estimates for the 2050s and 2080s indicates that the locations of groundwater emergence and pattern of pathlines from the SGHWR and Dragon reactors remain essentially the same (see Section 3.4.2). Therefore, the flow path directions specified above are assumed for all climate scenarios.

339 In the longer term beyond 2100 there is substantial uncertainty associated with climate change. As there is no information to suggest alternative pathways may develop, and the current pathways consider the impact of releases to land and to surface water using bounding transport distances, the flow paths specified above are assumed to persist.

340 It would be expected that the hydraulic gradient changes in accordance with groundwater levels rising as a result of increased recharge caused by climate change. However, the groundwater head contours calculated by WSP [43, Fig.604/40] suggest that the hydraulic gradient may increase only slightly in the region of A59 assuming the CCE data, and there is limited difference in the region of the SGHWR and Dragon reactors. Therefore, the hydraulic gradients are assumed to remain constant for all climate scenarios.

GoldSim Implementation

341 As outlined above, groundwater at the site predominantly flows through the Poole Formation and only the saturated parts of the geosphere pathways are modelled, with the underlying London Clay treated as an impermeable layer. The geosphere module in the GoldSim model is implemented using aquifer elements (see Section 5.1) and the term “segment” (i.e. one or more linked compartments) is used here to refer to the discretisation of the modelled geosphere. The discretised modelled flow paths are illustrated in Figure 5.11, which shows the three Well compartments, each receiving radionuclide releases from the associated features in each feature group. Additional aquifer segments then transport radionuclides through the Poole Formation in varying proportions to the Land/Mire and/or the River Frome, and also, for SGHWR releases, potentially to the Dragon reactor complex Well.

342 Each aquifer element comprises a minimum of five compartments to ensure dispersion is accurately modelled [105, p.179] and each compartment has a length of 50 m or less. The height and widths of each segment are parametrised based on the water table and feature group elevations, and the feature group widths (see the Saturated Pathway section above).

343 Radionuclide transport through the geosphere is assumed to occur through advection, accounting for longitudinal dispersion. Lateral dispersion is cautiously not modelled. Radionuclide concentrations in the geosphere porewater are assumed to remain sufficiently low that solubility limitation does not apply.

344 Radionuclide sorption to the Poole Formation sands and clays within the segments is modelled through the use of partition coefficients that are implicitly assumed to

encompass all sorption processes (Section 5.2.1). Partition coefficients are estimated primarily through analogy to the clay-rich tills, sands and gravels located around the LLWR [112, Tab.E6] (see Table D.36). Uncertainties in the sorption properties of the Poole Formation are noted in Appendix A as PA-016 and alternative cases assess the impact of this uncertainty (Table 8.2).

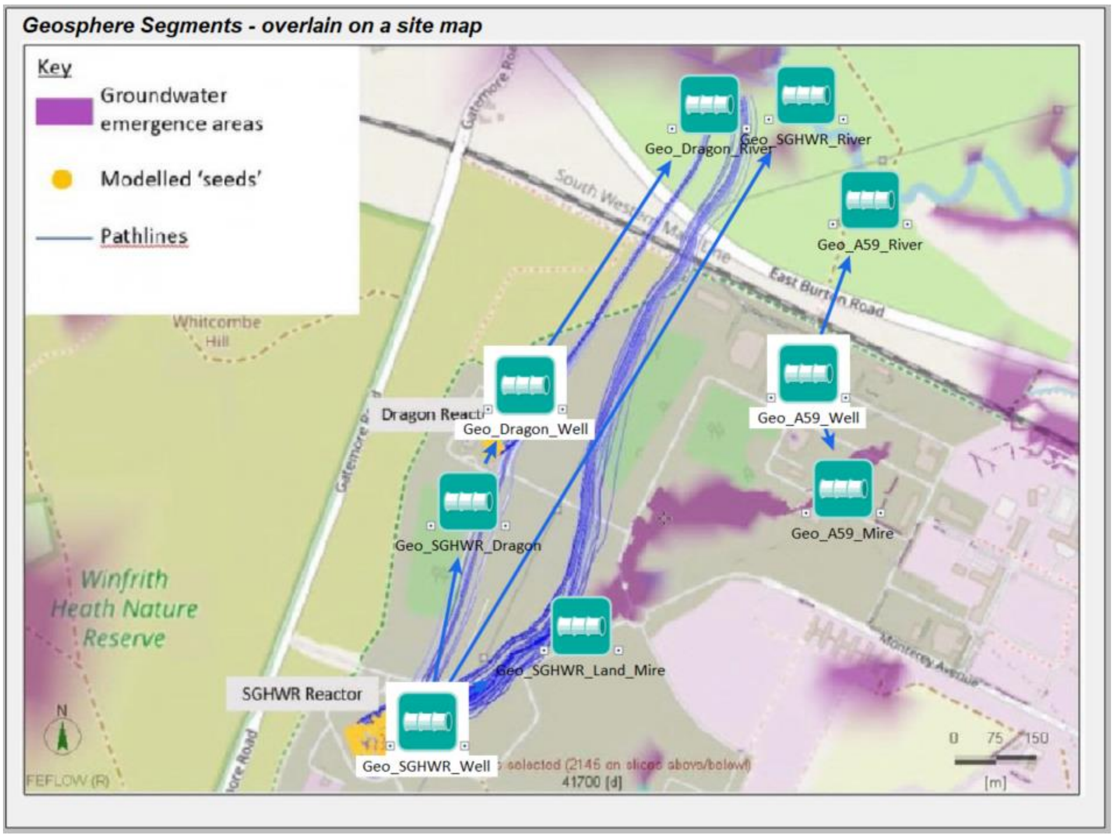

Figure 5.11: Screenshot from the NE GoldSim model geosphere module showing the geosphere compartments (aquifer elements) superimposed on a site plan, illustrating possible groundwater pathlines and emergence locations at the IEP.

5.3.2 Mathematical Representation

345 The mathematical basis for the GoldSim cell elements, and thus aquifer elements, is outlined in Section 5.2.2.

5.4 Biosphere

346 The biosphere module represents the area into which radionuclides are transferred via aqueous transport and in which RPs may then become exposed. The source-pathway-receptor schematics in Section C.2 illustrate the receptor (RP) endpoints for the assessment of each scenario identified in Section 4.4. These endpoints are described in this section in terms of the biosphere conceptual model.

347 Previous biosphere compartment models at the Winfrith site were developed in 2017 [12; 14; 15], 2018 [13] and 2019 [15]. These models report a dose per unit release (DPUR) factor which is used to convert radionuclide fluxes to the biosphere to dose to RPs [120]. Although this is aligned with an approach suggested by the Environment Agency, a revised biosphere model has been developed and implemented in GoldSim by reviewing and updating previous PA models. This approach has been undertaken for the following reasons:

- GoldSim confers greater transparency regarding key exposure modes as well as the underlying dose rate parameters and equations;
- updating the model provides the opportunity to use more recent datasets; and
- the assumptions which underpin the biosphere model can be aligned with the rest of the assessment model.

5.4.1 Conceptual Model

348 This section describes the conceptual biosphere model, including the modelled compartments. The contextual human habit understanding, described in Section 3.2.8, is used to aid the definition of the RPs in the biosphere model and to identify exposure pathways by which the RPs could receive doses.

Compartments

349 The biosphere model is discretised into a number of compartments, reflecting the current or proposed features of the site and surroundings and the environments via which RPs may be exposed. As outlined in the geosphere model (Section 5.3), there are two distinct points at which the biosphere model interacts with the geosphere model (Figure 5.11):

- The area of land and mire starting west of the Monterey roundabout and extending along the restored valley towards the north-east corner of the site, and which is assumed to receive releases from the SGHWR and A59 feature groups.
- The River Frome, which receives releases from all feature groups (some of which may reach the Frome via the mire). Water from the river may then be used to irrigate (or may flood) surrounding land and could be drunk by livestock.

350 Releases from the geosphere are assumed to enter the following three compartments in the modelled biosphere (Figure 5.12).

On-site Land/Mire

351 Modelling of groundwater emergence locations now, post implementation of the IEP and for selected climate simulations in the period to 2100 (see Sections 3.2.5 and 3.4.2) suggests that releases from SGHWR may emerge in the area of land west of the Monterey roundabout. In wet periods this release could travel as surface water downgradient to the proposed mire, but SGHWR groundwater releases may also emerge further east directly in the mire. Thus, in the NE model, the on-site land west of Monterey roundabout extending to the eastern end of the proposed mire is

conceptualised as a single compartment where releases from SGHWR (and A59) may lead to contamination of the soil and surface waters. The land may be boggy and waterlogged during wetter periods, containing ephemeral shallow pools, but is likely to be dry at other times (possibly on an annual basis). As discussed below, RPs may make use of the land when it is boggy (e.g. for a tough mudder obstacle course competition) but could also use it for recreational purposes when dry (e.g. dog walking) or farming (e.g. animal grazing). It is possible that the land could be drained in the future or remain permanently dry, and so the area could be used in the future for the bounding case of a smallholder living on the site and producing their own food.

352 For the purposes of this assessment, the length of the Land/Mire compartment is assumed to be 750 m, which is slightly less than the straight distance from just west of the Monterey roundabout (where groundwater emergence in wet periods may occur) to the corner of the site at Soldier's Bridge (where surface groundwater leaves the site via the culvert under the railway line). The area of the excavation required to create the proposed mire is 63,290 m^2 [36, §5], which equates to roughly 450 m long and 140 m wide on average (see Figure 3.24). However, the width of the potentially contaminated area will depend on the climate, with the watered area being smaller in drier periods and bigger in wetter. Thus, the width of the land and mire that may be contaminated by releases from SGHWR and A59 is assumed for the purposes of this assessment to be 150 m.

353 The volume of additional standing water in the Land/Mire compartment (in the form of waterlogged ground and shallow pools) will vary as climate conditions change and the mire drains to the River Frome. To allow for this additional standing water volume in the Land/Mire model compartment, it is arbitrarily assumed that the pools and boggy areas occupy a smaller surface area of 500 m long by 50 m wide. Based on surface water modelling work for the proposed mire, EdenvaleYoung [93, §5.2] predict that, for a 1 in 2-year return period event, surface water will have a typical depth of 0.1 m to 0.2 m. Water depths for less frequent events, such as a 1 in 100-year event, could be as high as 1.5 m, although such extreme values would only be expected to occur for a period of a few hours before draining to the River Frome. Therefore, an average water depth of 0.2 m is assumed to represent the average standing water depth over the long timescales of the NE model.

354 Thus, the Land/Mire model compartment consists of a potentially contaminated intermittently boggy soil area that is assumed to be 750 m by 150 m (112,500 m^2), within which sits an area of 500 m by 50 m that is essentially shallow standing water 0.2 m deep. The soil and water are assumed to be equally mixed throughout the compartment volume, with the Land/Mire modelled using a single GoldSim cell element. The key parameters related to the Land/Mire compartment are presented in Appendix D.3 and D.4.

355 Radionuclides are transported into and out of this compartment through aqueous transfers:

- Aqueous inflows – Potentially contaminated groundwater from the geosphere from the SGHWR and separately from the A59 area is assumed to enter the compartment. Inflows of clean ground and surface water from other areas of the site will flow towards the compartment and also from rainfall in the catchment area.

- Aqueous outflows – Land/Mire compartment water exits into the River Frome via the Frome Ditch (see below).

River Frome

356 As discussed in Section 3, the River Frome is located approximately 300 m to the north of the site and flows close to the north-north-east side of the site alongside the railway line (Figure 3.3). Releases from all the on-site disposal features will eventually reach the River Frome, some via the mire. The feature releases will enter the River Frome at different points along the stretch of the River near the site; the straight-line distance of the site parallel to the river along the railway line, from Gatemore Road to the site boundary at Soldier's Bridge (a length of 1.1 km), is assumed for the length of the River compartment. This conservatively neglects the winds in the river that are present and which extend the length considerably, minimising the volume of the modelled compartment. Relevant RPs are assumed to interact with the River at this point, rather than at locations downstream of the entry point which would be subject to dilution of the contaminated groundwater with clean river water. As such, the entry point represents the location of most concentrated contamination along the River Frome and the highest possible dose to these pathways and RPs.

357 Two GoldSim cell elements are used to model the River Frome compartment, referred to as River Water and River Sediment, the latter representing the upper sediment layer present on the river bed and river banks. The River Water cell also contains suspended sediment. Consistent with recommendations in the Environment Agency Radiological Assessment Tool [120, §F.3], contamination present in the system is assumed to be distributed evenly between all bed sediment and suspended sediment, loss of sediment to other sinks is ignored, exchange of contaminants between water and suspended sediment is assumed to be relatively rapid and therefore in equilibrium, and instantaneous mixing of contamination with river water at the entry point is assumed.

358 Radionuclides are transported into and out of this compartment through aqueous and material transfers:

- Aqueous inflows – Potentially contaminated groundwater from the geosphere from the SGHWR, Dragon reactor complex and OoS A59 area feature groups is assumed to enter the River Frome. Water from the on-site Land/Mire compartment, which itself may have received contaminated releases from the SGHWR and A59 area, will also reach the river. Additionally, potentially contaminated surface flows from the off-site Field compartment may flow into the river (see sub-section below). Inflows of clean water upstream of the site will flow through the river and will be joined by rainfall in the catchment area.
- Aqueous outflows – River water may be used to irrigate the Field compartment or saturate the Field in times of flood (see sub-section below). Any additional outflow is assumed to transport radionuclides out of the modelled biosphere.

- Sediment deposition and resuspension – Sediment interchange between river waters and the upper sediment layer, associated with suspended sediment deposition and bioturbation-driven resuspension, transfers radionuclides between the river cells. The deposition and resuspension processes are assumed to balance, such that the volume of the upper sediment layer remains fixed over the model timeframe.

The key parameters related to the River compartment are presented in Appendix D.3 and D.4.

Off-site Field

359 The Field compartment is assumed to be located neighbouring the River Frome, on the opposite side of the river from the Winfrith site where there are fields currently in use for grazing and crops. The Field compartment is assumed to be contaminated by contact with contaminated river water, whether by the river flooding the field and/or the river water being abstracted and used to irrigate the field. The fields currently neighbouring the River Frome are approximately 300 m wide (perpendicular to the Frome) so the Field compartment is represented as a rectangle of land 1,100 m (the modelled length of the neighbouring River compartment) by 300 m, giving rise to an area of 330,000 m^2. The soil depth is assumed to be 0.3 m and is modelled as a single partially-saturated layer, which maximises exposure to and uptake of radionuclides to plants, animals and humans. The Field compartment is modelled using a single GoldSim cell element. Details of the key parameters and their justification are provided in Appendix D.3 and D.4.

360 Radionuclides are transported into and out of the Field compartment through aqueous transfers between the Field and the River, with an inflow rate to the Field from the River Frome based on relevant UK irrigation rates (see Appendix D.4) and surface run-off (from rainfall and flooding) flowing to the Frome.

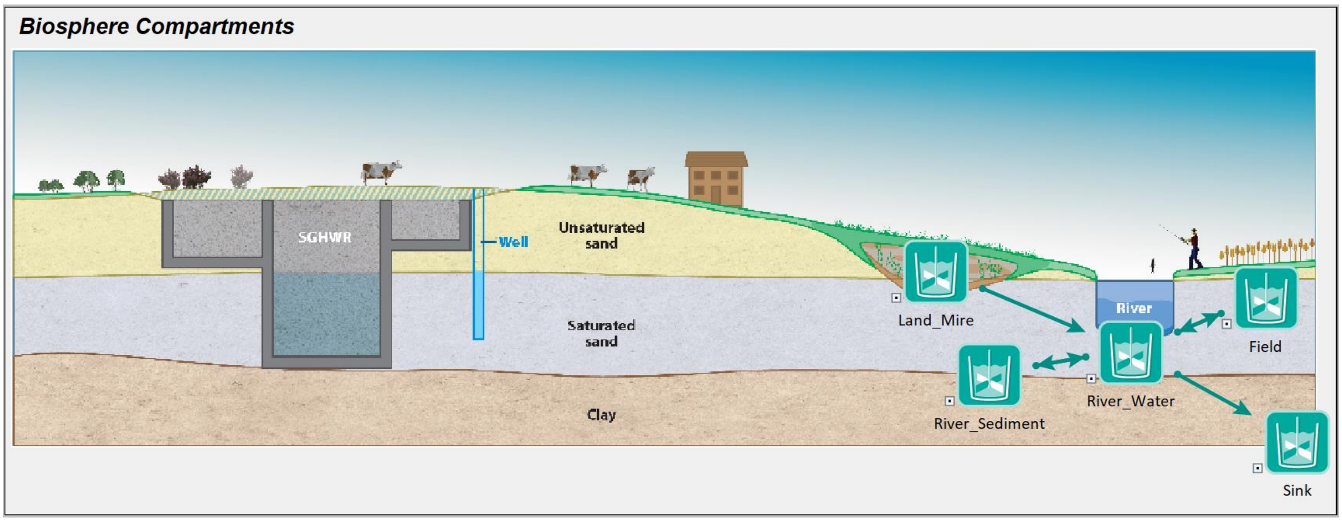

Figure 5.12: Screenshot from the NE GoldSim model biosphere module showing the biosphere compartments (cell elements) superimposed on a stylised

graphic of the SGHWR and down-gradient biosphere compartments (Land/Mire, River and Field).

Representative Persons (RPs)

Context

361 Requirement R9 of the GRR (dose constraints during the period of radioactive substances regulation) relates to "*the effective dose, from the authorised site, to a representative person*". Requirement R10 (risk guidance level after release from radioactive substances regulation) relates to "*the assessed risk from the remaining radiological hazards to a representative person*". To assess performance against Requirements R9 or R10 it is necessary to define the characteristics of a representative person exposed to the radiation as a result of the scenario occurring. As explained in Section 2.1.1, the GRR [7, §11.1] defines a representative person as *"an individual receiving a dose that is representative of the more highly exposed individuals in the population"* and that the term is *"equivalent of, and replaces"* the *"average member of the critical group"* and *"potentially exposed group"* (the latter is used in other guidance to define a group representative of the more highly exposed individuals in the population, but for whom exposure is not certain to occur).

362 The environmental permit for the Winfrith site [11] specifies disposal routes and associated radioactivity limits for gaseous, liquid and solid waste discharges. To support demonstration of compliance with the permit, NRS has undertaken monitoring of radioactivity in the environment around Winfrith. The site monitoring results [121] are used to calculate dose to a hypothetical critical group specified by Public Health England to set Generalised Derived Limits (GDLs) for radioactivity in various environmental media. The critical groups are defined using cautious assumptions about habits based on general (i.e. not site-specific) surveys and the most restrictive age group [122] and, therefore, provide a bounding representation of any site-specific critical group that might be identified. Summing of the results takes account of the possibility that the same critical group will be exposed to more than one disposal route.

363 In contrast, the PA described here considers future disposals and does not necessarily model the same releases as those considered for the current environmental permit. As a result, the PA considers different groups of people (different populations, each interacting with the site via different activities) in order to define the individuals in those groups that may receive doses that are representative of the more highly exposed individuals in each potentially exposed population. These individuals are the RPs for comparison with the dose constraint of Requirement R9 of the GRR while the site remains under RSR. The defined RPs are also compared to the RGL of Requirement R10 after the site has achieved the SRS and is released from RSR. This section is concerned with the definition of the different groups of individuals for consideration in this PA.

364 There are two steps in the process to define the RPs for the PA set out below:

- Identification of the nature (i.e. characteristics and activities) of the different groups of individuals whose exposure will be modelled for each scenario. This reflects activities that could take place in the future once public access is possible, as well as potential activities in the long-term once there are no controls on the site and knowledge of its history has been lost.

- Parameterisation of the behaviour of each group. This includes consideration of the proportion of the behaviour of the RP in each group that involves exposure to contaminated material (e.g. the proportion of the RP's fish consumption that involves contaminated fish).

365 For identification of RPs, paragraphs A4.49 and A4.50 of the GRR give the following guidance [7]:

> *"Risk assessments should consider different groups of people that have the potential to be exposed in order to define individuals that may receive doses that are representative of the more highly exposed individuals in the population (representative persons) at a given time. There is a range of possible doses that each representative person might receive and, for each dose, an assessed probability of their receiving that dose."*

> *"Operators should substantiate the choice of representative persons as being reasonable and suited to the particular circumstances. The location and characteristics of the representative persons considered should be based on the assessed releases of radioactive substances and on assumptions about changing environmental conditions. The habits and behaviour assumed for representative persons should be based on present and past habits and behaviour that have been observed and that are judged relevant. Metabolic characteristics similar to those of present-day populations should be assumed. The other parameters used to characterise a representative person should be generic enough to give confidence that the assessment of risk will apply to a range of possible future populations."*

366 There are two key parts of this guidance. The first, consistent with statements of international good practice [123, ¶60; 23, p.51], is that the PA should be based on observations of current behaviour. Two key references in this regard are the surveys of current habits around Winfrith undertaken periodically for the EA. The most recent survey was undertaken by CEFAS in 2019 [60], with a previous survey conducted in 2003 [59] (Section 3.2.8). With regard to possible exposure to discharges of radioactivity, the surveys record a wide range of agricultural practices and recreational habits. The main infrastructural changes between the 2019 and 2003 surveys relate to the ongoing development of the Dorset Innovation Park, the business park adjacent to the current eastern site boundary. Activities in this business park were covered in both surveys and have not changed in nature significantly with regard to possible exposure to radiation (although the number of workers on the site has more than halved between the two surveys). Therefore, the two CEFAS habits surveys are regarded as the best sources of information on current behaviours to inform this PA.

367 The second key aspect of the guidance is that the PA should consider changing environmental conditions and how habits might develop in the future. ICRP guidance on defining the RP [123, ¶60] suggests that current habit data (e.g. the CEFAS surveys) are valid for a period of approximately 50 years. Beyond this time, the possibility of

changes in land use may need to be considered [123, ¶63] and more emphasis may reasonably be placed on generic data. This consideration for the Winfrith assessment leads to the identification of group behaviours that capture how the land may be used beyond the time of RSR (e.g. the smallholder RP discussed below), albeit that the intent of NRS is to develop an end state of heathland with public access.

368 It is also worth noting that the GRR states that [7, ¶A4.51]:

> *"If two or more separate nuclear sites present significant risks to the same representative persons, consideration should be given to the combined risks to those representative persons."*

369 Therefore, when identifying the RPs for this PA, consideration is also given to whether the persons might be at radiological risk from the adjacent Tradebe Inutec nuclear site. Although this consideration does not affect the parameterisation of behaviour or the calculation of biosphere conversion factors for the RP, as set out below, it needs to be taken into account when presenting the calculated doses and risks in the SWESC.

Identification and Parameterisation of RPs

370 RPs are defined to provide a basis for assessment of human exposure to the radioactivity that might be released from the Winfrith site into the Land/Mire, River and Field compartments. Depending on their behaviours, RPs can be exposed to radiation via a number of different pathways, including ingestion of contaminated foods, soil or water, inhalation of contaminated dust, external exposure to radiation from contaminated media, and/or skin contamination. RPs are identified based upon existing human behavioural habits data on and around the site as well as the future envisaged use of the site (heathland with public access). Other potential future uses of the site assuming knowledge of the on-site disposals has been lost are also considered. The identification and screening of scenarios and assessment cases presented in Appendix C identifies and screens the exposure pathways and RPs (Section C.2), resulting in a justified set of appropriate RPs for the Winfrith PA (Table C.7). Seven RPs are defined for consideration in the NE Reference Case assessment (Table 5.7): an Angler, a River Paddler, a Mire Mudder (a "tough mudder" style obstacle course event), a Park User, a Construction Worker, a Farmer and a Smallholder. In addition, one further RP is defined for consideration in a specific variant concept scenario, a Well Abstractor (PA-018). Uncertainties in the ages of the different RPs are discussed below and are captured in Appendix A as PA-019.

Table 5.7: A summary of the eight representative persons (RPs) used to model dose to humans on or around the Winfrith site in the NE assessment and the biosphere compartments that they are assumed to interact with.

Exposure Pathway	RP identifier	Description
	AR1 Angler	Angling in contaminated surface water (the River compartment)

Exposure Pathway	RP identifier	Description
Natural Evolution – Aqueous Release Pathway	AR2 River Paddler	Recreation, such as paddling or swimming, in contaminated surface water (the River compartment)
	AR3 Mire Mudder	Recreation in the form of a "tough mudder" style obstacle course in contaminated mud (the Land/Mire compartment)
	AR4 Park User	Recreation such as dog walking, picnicking or playing on contaminated land (the Land/Mire or Field compartments)
	AR5 Construction Worker	Construction on contaminated land (the Land/Mire or Field compartments)
	AR6 Farmer	Agriculture involving grazing animals and growing crops on contaminated land (the Land/Mire or Field compartments, plus River water drunk by animals)
	AR7 Smallholder	Resident family smallholding producing foodstuffs and living on contaminated land (the Land/Mire or Field compartments, plus River water for aquatic plants and water drunk by animals)
Groundwater Abstraction Well (Variant Scenario)	AW1 Well Abstractor	Drinking contaminated water from a groundwater abstraction well on site (the relevant Geosphere module Well segment for each feature group)

371 The 2003 and 2019 CEFAS surveys [59; 60] enable several RPs in the PA to be readily defined based upon the overall behaviour of each exposed group. However, there are then considerations of whether the group is exposed to the same zone of contamination for all of the parameterised behaviour and whether the group is exposed by more than one mechanism or to more than one zone of contamination.

372 ICRP guidance is that the individual habits should represent the average habits of a small number of individuals that are representative of those expected to be more highly exposed to activity, not extreme habits of a single member of the population [123, ¶65]. This is achieved in the CEFAS survey by defining a high-rate behaviour on the basis of the observations (filtered as necessary by age) and using the "cut-off" method. This method takes the arithmetic mean of the maximum observed value and all values (e.g. consumption rates) observed within a factor of three of the maximum value (termed the lower threshold value) [59, p.19]. The observation-weighted mean of the high-rate behaviour is the average behaviour of the most exposed individuals (i.e. the behaviour of the RP).

373 For representative persons defined on the basis of hypothetical future changes in land use, there may be no relevant local habit survey data available. Furthermore, as noted above, future habits may differ from those observed currently and are inherently speculative. Therefore, again in accordance with ICRP guidance [123, ¶67], it may be more appropriate to use generic and average UK data, rather than local data. The 95th percentile of UK average behaviour is adopted for the representative person as a cautious assumption in the absence of site-specific data.

374 The following sub-sections summarise the behaviours and assumptions regarding habits and consumption for each RP considered in the NE assessment. Table 5.8 summarises the exposure pathways assumed for each RP and Appendix D.4.1 presents and justifies the parameter values used for each.

AR1: Angler

375 Fishing activities have been observed in the local area. Indeed, the stretch of the River Frome near the site forms one of the chalk stream fishing beats offered by the neighbouring East Burton estate[36] for trout, grayling, salmon and eel. Two individuals were noted fishing on the River Frome and consuming their catch in the 2003 CEFAS habits survey [59, p.35], although ownership of the land surrounding this section of the River Frome was privately held, which limited the number of anglers able to fish there. In the 2019 survey angling on the River Frome was identified, noting that a catch-and-release system was in place, but quantitative data were not presented.

376 For the NE assessment, the Angler RP considers an adult fishing for recreation who sits on the riverbank that contains contaminated material, fishes in a contaminated stretch of water and eats contaminated fish. The Angler RP is assumed to engage in fishing at the point of entry of radioactive contamination into the River Frome since this represents a bounding case for the highest possible dose. Building on the dose estimation scenarios presented by the National Radiological Protection Board (NRPB) in 2003 [124], the Angler RP is assumed to be exposed to contamination via the following pathways:

- ingestion of fish caught in the contaminated water;
- inadvertent ingestion of riverbank sediments and river water;
- inhalation of riverbank sediments (contaminated dust);
- external irradiation from contaminated riverbank sediments; and
- external exposure from contaminated sediments on the skin.

377 As the CEFAS habits surveys contain limited data pertaining to freshwater fishing, occupancy periods based on intertidal angling data in the aquatic survey areas were considered for the Angler RP fishing in the River Frome. The intertidal data reflect local recreational angling habits and provide an indication of angling on the River Frome. The weighted average of the high-rate group of intertidal zone anglers is 130 h y^{-1}. However, in comparison to generic UK freshwater angling data, which recommends an occupancy value of 1,000 h y^{-1} [125, §4.2.2], occupancy based on local data is low. Therefore, it was decided that the Angler RP should more conservatively consider the impact of angling on the River Frome, which will help to account for future behaviour changes. Thus, the generic UK occupancy value has been assumed (Table D.42). Similarly, the Angler RP is conservatively assumed to consume their freshwater catch at the generic UK consumption rate of 20 kg y^{-1}, rather than the high-rate weighted

[36] http://eastburtonestate.co.uk/chalkstream-fishing/

average freshwater fish consumption rate of 0.5 kg y^{-1} observed in the Winfrith CEFAS surveys (Table D.38).

AR2: River Paddler

378 Up to 50 individuals were observed paddling and playing in and around a ford on the River Frome in the 2003 CEFAS survey [172, Tab.17]. Although no such behaviour was recorded in the 2019 CEFAS survey, future such activity cannot be ruled out. Therefore, a River Paddler RP has been defined to consider a person who uses a contaminated stretch of water recreationally for paddling and swimming and who is assumed to be exposed to contamination via the following pathways:

- inadvertent ingestion of contaminated river water;
- external irradiation from contaminated riverbank sediments; and
- external exposure from immersion in the water.

379 The activity is cautiously assumed to occur at the point of groundwater entry into the river, where contamination is highest, and the RP is assumed to immerse themselves in river water for the duration of the activity. The weighted high-rate average for river paddling was recorded in the 2003 CEFAS habits survey as 81.1 h y^{-1}, as noted in Table D.42. The 2003 CEFAS survey noted that river paddling participants were mainly children [59, p.35], therefore adult, child (10 y) and infant (1 y) River Paddler RPs are considered.

AR3: Mire Mudder

380 A mire is to be created east of the Monterey roundabout (see Section 3.4.2). Once site access is unrestricted, the mire could attract recreation in the form of paddling, playing or even a "tough mudder" style obstacle course event, which is typically hosted on muddy, waterlogged land. Such obstacle course events have been popular for over 100 years, with an aquatic obstacle course race featuring in the 1900 Paris Olympics [126]. Water recreation in and around the mire would be expected to occur less frequently than a more leisure-friendly body of water such as the nearby River Frome, since it will be less accessible and muddier. However, this activity is considered separately from the River Paddler RP since the flow pathways from the SGHWR and A59 area are significantly shorter to the Land/Mire compartment than to the River Frome (see Section 5.3.1) and outflow from and dilution in the Land/Mire compartment will be lower, potentially leading to higher concentrations than in the River. Mire occupancy also introduces new dose pathways, through skin contamination from mud and inadvertent ingestion of soil, pathways that the River Paddler RP is not exposed to. Conservatively, it is assumed that an adult Mire Mudder RP engages in two such events on the site per annum and that each event lasts three hours, so the Mire Mudder RP occupancy is 6 h y^{-1}. The Mire Mudder RP is assumed to be exposed to contamination via the following pathways:

- inadvertent ingestion of contaminated mire soil and water;
- external irradiation from contaminated mire soil and water; and

- external exposure from contaminated soil on the skin.

AR4: Park User

381 The intended future use of the site is as heathland with public access, which is consistent with much of the surrounding land. This can be considered equivalent to a country park where recreational park users use the park for walking or playing. The Park User RP is assumed to use the land in each of the two terrestrial biosphere compartments (Land/Mire and Field compartments) and is exposed to contamination via the following pathways:

- ingestion of wild berries grown on contaminated soil;
- inadvertent ingestion of contaminated soil;
- external irradiation from contaminated soil;
- inhalation of contaminated soil (dust); and
- external exposure from contaminated soil on the skin.

382 A survey of dog walking habits on Dorset heathlands by English Nature recorded a high-rate group average of 470 h y^{-1} [127]. This was in reasonable agreement with, if higher than, the high-rate weighted average of local intertidal zone walking habits as recorded in CEFAS surveys (318 h y^{-1}), suggesting that 470 h y^{-1} presents a bounding occupancy for walking on Winfrith Heath and is therefore assumed for occupancy by the Park User RP. Consumption of wild berries was a behaviour noted in both CEFAS habits surveys; the Park User RP is assumed to consume foraged wild berries at the weighted mean average of the high-rate group for ‘wild/free foods’ (4.6 kg y^{-1}) [59; 60]. Since visitors to parks and open spaces quite often tend to come in family groups, child and infant Park User RPs are also considered with appropriate consumption rates based on the CEFAS surveys (see Section D.4.1).

AR5: Construction Worker

383 The intended future use of the site does not include any plan for new dwellings or commercial development. However, it is conceivable that new housing could be constructed on ground contaminated by releases from the disposals in the future. Therefore, the Construction Worker RP is defined as an adult member of a team assumed to develop contaminated land over a complete working year (eight hours per day, five days per week, 52 weeks per year, giving rise to an occupancy of 2,080 h y^{-1}) and to undertake activities such as manual and mechanical digging. Construction is assumed to take place either in the Field or the Land/Mire compartments, assuming that the mire is dry and/or has been drained in the future. The Construction Worker RP is assumed to be exposed to contamination via the following pathways:

- inadvertent ingestion of contaminated soil;
- external irradiation from contaminated soil;
- inhalation of contaminated soil (dust); and
- external exposure from contaminated soil on the skin.

384 The calculated doses are considered to be conservative estimates for most of the above pathways as no allowance is made for the protection obtained from wearing gloves or overalls, or from being enclosed in the cab of a mechanical excavator.

AR6: Farmer

385 A farmer raising a variety of livestock that graze on heath/grass or other crops grown on or around contaminated land is a credible RP based upon the agricultural nature of the local area and data in the CEFAS habits surveys [59; 60] (Table D.38). Indeed, cattle currently roam and graze the land outside the site fence and animal grazing on site with low stock density is part of the plan for natural regeneration of habitats (see Paragraph 76). However, the contaminated land area (the area of the Land/Mire or the Field compartments) is considered to form only part of the whole farm and is represented as a single field in the NE assessment. The adult Farmer RP is assumed to spend a fraction of the working year in the contaminated field, with the remaining time spent on other uncontaminated fields. The Farmer RP is assumed not to dwell on contaminated land but is assumed to receive their entire meat and vegetable (potatoes, green and root vegetables) intake from their own livestock and vegetable produce, with consumption rates based on the weighted average high-rate consumers reported in the 2003 and 2019 CEFAS surveys [59; 60]. Therefore, the Farmer RP is assumed to be exposed to contamination via the following pathways:

- ingestion of foods grown/raised on the contaminated land and fed/watered with contaminated river water;
- inadvertent ingestion of contaminated soil (e.g. whilst working the land or from residues on the crops consumed);
- external irradiation from time spent working on contaminated land;
- inhalation of contaminated soil (dust); and
- external exposure from contaminated soil on the skin.

386 The land area potentially affected by contamination represents a smaller area than is likely required to support a herd of cows, since a single cow can consume over 100 kg of pasture per day [128] – approximately 1 ha per cow per day for grazing. Therefore, it is likely that a herd of cows would graze a wider area than is potentially contaminated and thus not receive their entire nutritional needs from contaminated land. Furthermore, as a wet heathland and mire, large parts of the site will typically support around half the livestock density or less compared to typical productive grazing pastures [129]. This further decreases the likelihood that livestock will graze 100% of the time on contaminated land. Therefore, the livestock are assumed to only receive part of their annual intake from the Land/Mire or Field model compartments, although they are assumed to receive their entire annual water intake from the River compartment. It is conservatively assumed that each terrestrial compartment is sufficiently large such that both livestock and root crops can be produced (it is conservatively assumed that 100% of the Farmer's root crop intake is from the contaminated area). It is assumed that the Farmer RP spends half the year engaged in outdoor farming work, but only part of this is assumed to involve work on the contaminated land. The factor applied to cattle and farmer field occupancy is an approximate scaling factor based on the ratio of the area

of the Field or Land/Mire compartment to the average farm size of 88 ha in England [130, p.10] – this leads to scaling factors of 0.38 and 0.13, respectively.

AR7: Smallholder

387 After the SRS has been reached, some activities, while relatively unlikely, cannot be reasonably excluded. The NRPB assessment considered a broad range of future uses of contaminated land and showed that the highest calculated doses were generally found to correspond to uses for agriculture and construction [124, Tab.47 to 52]. These two uses are, therefore, considered for Winfrith as a conservative bounding case for possible future behaviour. The resident Smallholder RP is defined to make maximal use of a combination of the contaminated land exposure pathways (crop consumption, fishing, animal product consumption and agricultural work), with half of the time spent outdoors on contaminated land engaged in smallholding activities and the remaining time spent indoors in a residence built on contaminated land. It is assumed that the smallholding could be located in either the Field or Land/Mire compartments. The Smallholder RP is assumed to be exposed to contamination via the following pathways:

- ingestion of foods grown/raised on the contaminated land/river and fed/watered with contaminated river water;
- inadvertent ingestion of contaminated soil when working the land, and river water and sediment when fishing;
- external irradiation from contaminated soil (outside and when indoors) and from the river when fishing;
- inhalation of contaminated soil (dust) and river sediment; and
- external exposure from contaminated soil and river sediment on the skin.

388 Resident smallholders, gardeners and allotment keepers cultivating fruit and vegetables as well as raising a variety of livestock and poultry for consumption of meat, milk and eggs were observed in both CEFAS habits surveys. It is cautiously assumed that all vegetable and root crops, freshwater fish and plants recorded in the CEFAS surveys are consumed by the Smallholder RP. Beef, sheep and poultry reared on contaminated land (and drinking contaminated water) are consumed by the Smallholder RP, as are milk and egg products from these animals. Foraged foods such as wild mushrooms and berries are also consumed. However, the Smallholder RP does not directly consume contaminated water; this pathway is examined separately using the Well Abstractor RP. Although predicting future diet habits is difficult, it seems unlikely that a smallholder will derive their entire calorific intake solely from contaminated land on or near the Winfrith site. Therefore, consumption of uncontaminated imported foodstuffs is assumed in the estimated diet of the Smallholder RP. The consumption rates assumed for contaminated foods are those for the weighted average high-rate consumers reported in the 2003 and 2019 CEFAS surveys [59; 60] (Table D.38).

389 The Smallholder RP diet was sense-checked against generic UK adult consumption data and the calorific value of the consumed food products to confirm that the modelled diet is reasonable in terms of calorific intake; this check is summarised in Table D.39, along with the record of which food products are assumed to derive from the potentially

contaminated area or are imported from elsewhere. Smith and Jones [125, Tab.7] report the mean daily calorific intake for adults, which ranges from 1,700 kcal for women to 2,485 kcal for men (the mean for both sexes is 2,093 kcal). The constructed Smallholder RP diet represents a daily intake of 2,123 kcal. This is reasonable, with consumption at appropriately realistic rates. The foods classed as being produced on the potentially contaminated land/river represent 51.8% by calorific content. Child and infant members of the smallholder family are also considered with appropriate consumption rates based on the CEFAS surveys (see Section D.4.1).

AW1: Well Abstractor

390 The CEFAS regional habits surveys suggest construction of a residential drinking water well is relatively uncommon. The 2003 CEFAS habits survey [59, p.35] recorded only one household within a 5-km radius of the site whose sole water supply was from a borehole, and two properties near the Winfrith site had capped or disused wells in their gardens. The 2019 survey noted human consumption of groundwater via boreholes at "several" farmhouses [60, §5.1], but the exact number of farmhouses was not stated. On the basis of current water abstractions and given the proximity to nearby rivers, it is most likely that an abstraction borehole would be drilled into the confined Chalk aquifer below the London Clay, rather than potentially contaminated groundwater in the Poole Formation. In addition, given the large land area over which a well could be located, it is even less probable that the well would be positioned such that it intercepts the migrating contamination, particularly at the location of highest concentration. However, for the purposes of understanding the potential risk, a Well Abstractor RP is considered as a variant scenario where a well is conservatively assumed to be drilled immediately (1 m) downstream of each of the radioactive features (SGHWR, Dragon reactor complex and A59) to obtain a bounding dose for ingestion of contaminated water (PA-018). The rate of consumption of the well water is taken as the NRPB generalised rate for water consumption of 0.6 $m^3\ y^{-1}$ [125, Tab.10]. It is considered unrealistic to assume that the Well Abstractor RP drinks from all three wells and so the potential dose resulting from drinking from each feature well is considered separately.

Table 5.8: Summary of RP exposure pathways, denoted using green shading.

		AR1 Angler	**AR2 River Paddler**	**AR3 Mire Mudder**	**AR4 Park User**	**AR5 Construction Worker**	**AR7 Farmer**	**AR8 Smallholder**	**AW1 Well Abstractor**
Model compartment in which RP activity occurs		River	River	Mire	Field or Land / Mire	Field or Land / Mire	Field or Land / Mire	Field or Land / Mire and River	N/A
Dose Pathway	**Exposure Modes**								
Ingestion food products	Root vegetables						■	■	
	Potatoes						■	■	
	Green and other vegetables						■	■	
	Watercress							■	
	Livestock*						■	■	
	Milk						■	■	
	Poultry							■	
	Eggs							■	
	Domestic fruit							■	
	Wild berries				■			■	
	Wild mushrooms							■	
	Freshwater fish	■						■	
Ingestion non-food products	Soil†				■	■	■	■	
	River water	■	■					■	
	River sediment	■						■	
	Mire water			■					
	Mire mud			■					
	Well water								■
Inhalation	Soil†				■	■	■	■	
	River sediment	■	■					■	
	Mire mud			■					
External irradiation	Soil†				■	■	■	■	
	River	■	■					■	
	Mire			■					
Skin contamin-ation	Soil†				■	■	■	■	
	River water immersion		■						
	Riverbank sediment	■	■					■	
	Mire water immersion			■					
	Mire mud			■					

(■ = green shading)

* Includes cattle, sheep and pig meat for the Farmer RP, and additionally goat meat for the Smallholder RP.

† Where an RP activity can take place in the off-site Field or the on-site Land/Mire model compartments, the soil that may be ingested/inhaled/irradiated by is switched in the GoldSim model to use the relevant compartment soil activity concentration.

5.4.2 Mathematical Representation

Advective Transfer Equations

391 Within the biosphere model, radionuclides are transported between compartments by flows of water, soil and sediment. The equations representing these advective mass fluxes in GoldSim are outlined in Section 5.2.2.

Dose Equations

392 The methodology used to calculate dose rates from specific exposure pathways is comparable to that used in the Dounreay D3100 Run 5 performance assessment [91, §5.7.2] and the Trawsfynydd Site Disposal Area and Natural Scenarios assessment [102, §5.4.1].

Ingestion

393 The dose from livestock and associated products (e.g. eggs) grazed or reared on contaminated land and fed with contaminated water and crops, $Dose_{ing,animal}$ (Sv y^{-1}), is given by:

$$Dose_{ing,animal} = \sum_{animal}\left\{\left[Q_{animal}\left(\begin{array}{c} q_{water}\ C_{water,s}(t)\ + q_{soil}\ C_{soil,s}(t) + \\ \sum_{crop}\left(q_{crop}\ \left(C_{soil,s}(t) TF_{crop,s} + C_{soil,s}(t) Ext_{crop}\right)\right)\end{array}\right)\right] TF_{animal,s}\right\} D_{ing,s} \quad (5.14)$$

where:

Q_{animal}	Consumption rate of animal foodstuff by a human (kg y^{-1}).
q_{water}	Water consumption rate by the animal (m^3 day^{-1}).
q_{soil}	Soil consumption rate by the animal (kg day^{-1}).
q_{crop}	Crop consumption rate by the animal (kg day^{-1}).
$TF_{crop,s}$	Soil to crop uptake factor for radionuclide *s* (Bq kg^{-1} fresh weight of crop per Bq kg^{-1} of soil).
$TF_{animal,s}$	Animal product uptake factor for radionuclide *s* (days kg^{-1} for solid products, days L^{-1} for milk).
Ext_{crop}	Amount of soil present as external contamination on the crop (kg kg^{-1}).
$C_{soil,s}(t)$	Concentration of radionuclide *s* in the pasture and crop soil at time *t* (Bq kg^{-1}).
$C_{water,s}(t)$	Concentration of radionuclide *s* in the water used for drinking by livestock at time *t* (Bq m^{-3}).
$D_{ing,s}$	Dose coefficient for ingestion of radionuclide *s* (Sv Bq^{-1}).

394 The dose from crops grown on contaminated soil, $Dose_{ing,crops}$ (Sv y^{-1}), is given by:

$$Dose_{ing,crops} = \sum_{crop}\left(Q_{crop}\left[\ C_{soil,s}(t)\ TF_{crop,s}\ W_{crop}\right]\right) D_{ing,s} \quad (5.15)$$

where:

Q_{crop}	Crop consumption rate (fresh weight kg y^{-1}).
$C_{soil,s}(t)$	Concentration of radionuclide s in the crop soil at time t (Bq kg^{-1}).
$TF_{crop,s}$	Soil to crop uptake factor for radionuclide s (Bq kg^{-1} dry weight of crop per Bq kg^{-1} dry weight of soil; dimensionless).
W_{crop}	Conversion for dry weight to fresh weight for the crop (dry weight kg per fresh weight kg).
$D_{ing,s}$	Dose coefficient for ingestion of radionuclide s (Sv Bq^{-1}).

395 The term converting dry weight to fresh weight for crops, W_{crop}, relates to the fact that soil-to-crop uptake factors are generally provided in terms of dry weights (e.g. [131]) whereas consumption data are provided in terms of fresh weights. Where uptake factors are provided in terms of fresh weights, such as for fruit, the conversion term is omitted from the equation. Uncertainty in uptake factors is captured in Appendix A as PA-020. Although different (specific activity-based) approaches to calculating the concentration of ^{3}H and ^{14}C in animals and crops are available, such approaches have not been used because these radionuclides do not dominate doses, and the impact of uncertainty in radionuclide uptake is considered in alternative assessment cases.

396 A term to account for removal of contamination during processing of the crops could be introduced into Equation (5.15). However, such a term is highly uncertain (see range for loss of 0% to 90% in [131]) depending on the crop and how it is used. Also, the Winfrith PA assessment biosphere model only considers uptake from the soil through the roots, while preparation losses quoted in the literature are mainly concerned with external contamination above ground. Neglecting losses through preparation of foodstuffs is a cautious assumption in the Winfrith PA assessment.

397 The dose from eating fish from a contaminated water body, $Dose_{ing,fish}$ (Sv y^{-1}), is given by:

$$Dose_{ing,fish} = \sum_{fish} \left(Q_{fish}\, C_{water,s}(t)\, TF_{fish,s} \right) D_{ing,s} \qquad (5.16)$$

where:

Q_{fish}	Fish (aquatic foodstuff) consumption rate (kg y^{-1}).
$C_{water,s}(t)$	Concentration of radionuclide species s in the water from which the food is harvested at time t (Bq m^{-3}).
$TF_{fish,s}$	Water to fish (aquatic foodstuff) uptake factor for radionuclide species s (m^3 kg^{-1}).
$D_{ing,s}$	Dose coefficient for ingestion of radionuclide s (Sv Bq^{-1}).

398 The dose from inadvertently ingesting contaminated material (e.g. soil, sediment), $Dose_{ing,mat}$ (Sv y^{-1}), is given by:

$$Dose_{ing,mat} = Q_{mat}\, C_{mat,s}(t)\, f_{mat}\, D_{ing,s} \qquad (5.17)$$

where:

Q_{mat}	Contaminated material consumption rate (kg y^{-1}).
$C_{mat,s}(t)$	Concentration of radionuclide *s* in the material at time *t* (Bq kg^{-1}).
f_{mat}	Concentration factor for activity in the fine fraction of ingested material (-).
$D_{ing,s}$	Dose coefficient for ingestion of radionuclide *s* (Sv Bq^{-1}).

399 The dose from drinking contaminated water, $Dose_{drink}$ (Sv y^{-1}), is given by:

$$Dose_{drink} = Q_{water}\, C_{water,s}(t)\, D_{ing,s} \tag{5.18}$$

where:

Q_{water} =	Water consumption rate (m^3 y^{-1}).
$C_{water,s}(t)$	Concentration of radionuclide s in the water used for drinking at time *t* (Bq m^{-3}).
$D_{ing,s}$	Dose coefficient for ingestion of radionuclide *s* (Sv Bq^{-1}).

Inhalation

400 Dose from inhaling dust derived from contaminated land (e.g. soils), $Dose_{inh,dust}$ (Sv y^{-1}), is given by:

$$Dose_{inh,dust} = B\, O_{dust}\, C_{dust,s}(t)\, f_{dust}\, dustload\, D_{inh,s} \tag{5.19}$$

where:

O_{dust}	Time spent exposed to dust from the contaminated land (h y^{-1}).
B	Breathing rate (m^3 h^{-1}).
$C_{dust,s}(t)$	Concentration of radionuclide *s* in the dust (equivalent to the concentration in the medium from which the dust is assumed to be derived) at time *t* (Bq kg^{-1}).
f_{dust}	Concentration factor for activity in the fine fraction of dust (-).
$dustload$	Dust concentration (kg m^{-3} of air).
$D_{inh,s}$	Dose coefficient for inhalation of radionuclide *s* (Sv Bq^{-1}).

External Irradiation

401 Dose from external irradiation while occupying contaminated land (e.g. farm soil, sediment in the mire), $Dose_{irr,ground}$ (Sv y^{-1}), is given by:

$$Dose_{irr,ground} = \sum_{ground} \left(O_{ground} + \left[O_{inside}\; s_f\right]\right)\; C_{ground,s}(t) f_{geo}\, D_{irr,slab,s} \tag{5.20}$$

where:

O_{ground}	Time spent on the ground outside (h y^{-1}).
O_{inside}	Time spent on the ground inside (h y^{-1}).
s_f	Shielding factor from the ground whilst inside (-).
$C_{ground,s}(t)$	Concentration of radionuclide *s* in the ground at time *t* (Bq kg^{-1}).

f_{geo} Scaling factor to account for any difference in geometry between the source and a semi-infinite slab (-).
$D_{irr,slab,s}$ Dose conversion factor for irradiation from radionuclide *s* (Sv h^{-1} Bq^{-1} kg), based on the receptor being 1 m from the ground and assuming a semi-infinite slab of contamination.

402 Equation (5.20), excluding the indoor terms, can be used to calculate external irradiation from a contaminated water body, with concentration in the ground being replaced with concentration in the water.

Skin Contamination

403 Dose via skin contamination from contact with contaminated soil or sediment, $Dose_{skin,cont}$ (Sv y^{-1}), is given by:

$$Dose_{skin,cont} = C_{waste,s}(t)\ d_{skin}\ \rho_{dust}\ W_{skin}\ F_{UV}\ T_{skin,cont}\ D_{skin,cont} \qquad (5.21)$$

where:

$C_{waste,s}$ Concentration of radionuclide s (Bq kg^{-1}) in the sediment at time *t*.
d_{skin} Thickness of the contaminated layer on the skin (m).
ρ_{dust} Density of the contaminated material on the skin (kg m^{-3}).
W_{skin} Tissue weighting factor for ultraviolet (UV) exposed skin (-).
F_{UV} Fraction of UV exposed skin in contact with the contaminated dust (-).
$T_{skin,cont}$ Time exposed to the material (hours y^{-1}).
$D_{skin,cont}$ Dose coefficient for skin contamination of radionuclide *s* (Sv h^{-1} Bq^{-1} m^2).

404 The tissue weighting factor, W_{skin}, converts the dose to the skin into an effective dose and is defined by the ICRP as 0.01 [132, Tab.2; 133, Tab.3]. For F_{UV} the Dounreay Run 5 PA assumed that half of all of the UV exposed skin is contaminated. Exposure of shielded skin is not considered as it does not contribute significantly to the total calculated dose.

405 The dose due to complete submersion in water, $Dose_{irr,water}$ (Sv y^{-1}), is calculated as follows, which is a bounding dose from wearing contaminated wet clothing previously immersed in contaminated water:

$$Dose_{irr,water} = D_{irr,water,s}\ T_{contact}\ C_{liquid,s}(t) \qquad (5.22)$$

where:

$D_{irr,water,s}$ Dose conversion factor for irradiation from radionuclide *s* while submersed in water (Sv h^{-1} Bq^{-1} m^3).
$T_{contact}$ Time in contact with wet clothing (h y^{-1}).
$C_{liquid,s}(t)$ Concentration of radionuclide *s* (Bq m^{-3}) in the contaminated liquid wetting the clothing at time *t*.

6 Site Occupancy Model

406 This section presents the modelling approach used to determine potential doses to site occupiers in situations where sub-surface contamination remains in-situ and undisturbed. This scenario may be applicable when considering the future use of the site for recreational purposes, or for considering the dose to a person resident in a static caravan situated above the buried contamination. These scenarios consider exposure to external irradiation only since the residual contamination is not at the surface and is assumed to be undisturbed (see Appendix C.2.7).

407 Three modelling approaches were considered:

- The Generic Intrusion Methodology (GIM) [134] tool, which was developed to assist in the assessment of dose consequences for persons interacting with fully decommissioned end states of nuclear sites (see Section 7 for further details).
- MicroShield® version 11 [135; 136], which is a comprehensive photon/gamma-ray shielding and dose assessment program developed by Grove Software that is widely used for designing radiation shields, estimating source strength from radiation measurements, minimising exposure to people, and teaching shielding principles. MicroShield® uses a point kernel code. The MicroShield® software is long-established and is used across the nuclear sector by health physicists, waste managers, design engineers and radiological engineers.
- Monte Carlo N-Particle® (MCNP) [137], produced by Los Alamos National Laboratory, simulates the transport of particles through matter by using Monte Carlo algorithms. MCNP® is used to support radiation protection and dosimetry, radiation shielding, radiography, medical physics, nuclear criticality safety, critical and sub-critical experiment design and analysis, detector design and analysis, nuclear oil-well logging, accelerator target design, fission and fusion reactor design, decontamination and decommissioning, and nuclear safeguards and non-proliferation.

408 NRS [138] compared the three tools for a 50 m^3 slab of contaminated soil and a 10 m long line source covered by a layer of soil or concrete of various thicknesses. MCNP® and MicroShield® yielded very similar results, with MicroShield® generally giving slightly more conservative results. GIM was shown to have comparable results for thin layers of cover material (<0.02 m) but overestimated the dose rate by orders of magnitude for thicker caps. Comparing MicroShield® and MCNP®:

- MicroShield® calculations are fast compared to MCNP® calculations.
- The set up of the geometry and the implementation of variance reduction techniques (always necessary in shielding problems) in MCNP® can be complex and time consuming, but is relatively straightforward in MicroShield®.
- MicroShield® has simple inbuilt source geometries and simple shielding layouts but is not very convenient for complex geometries. MCNP® can model complex geometries.

- MCNP® can model the dose from multiple sources at a time whereas MicroShield® is limited to a single source term.
- MicroShield® only allows the build-up factor in one shielding material, whereas MCNP® calculates the build-up factor for all materials.

409 MicroShield® was selected for use because:

- proposed disposal features on the Winfrith site can generally be approximated by simple geometries;
- the cap design can be modelled as a single shielding material;
- model set-up is relatively straightforward;
- preliminary calculations for the proposed disposals indicated that the doses would be low and the use of more complex and computationally-intensive calculations in MCNP® would be unnecessary; and
- the NRS site assessors were familiar with MicroShield® due to its use in shielding calculations.

6.1 Mathematical and Computational Model

410 The fundamental theory of MicroShield® is based on a point-kernel model/technique with idealised geometry. MicroShield® approximates features by looking at them as a collection of hundreds or thousands of point sources. MicroShield® divides the feature into numerous sub-divisions (kernels) and replaces the total activity within each kernel with a point source located in the centre of the kernel (see Figure 6.1). The number of sub-divisions can be specified by the user. MicroShield® then solves the point source equation multiple times and sums the results.

$$D_{Ext} = \int_E \int_V \frac{SB(\mu, x)Ke^{-\mu(E)x}}{4\pi r^2} dVdE \qquad (6.1)$$

Where: S Activity of the source (Bq).
$B(\mu, x)$ Build-up factor (unitless).
K Dose conversion factor (Sv/h/photon/cm^2/s).
$\mu(E)$ Attenuation coefficient for a given photon energy (cm^{-1}).
E Photon energy (MeV).
X Thickness of the shield (cm).
R Distance to the dose point (cm).

411 Build-up is a derived factor that accounts for the scatter of gamma photons by the substances between the source and dose point. The majority of gamma photons travel in a straight line between the source and the dose point. However, some gamma photons scatter on route and lose some energy but still arrive at the dose point and contribute to the total dose. Build-up factors depend on photon energy, the mean free path travelled by a photon in the material under consideration, the geometry of the source, and the geometry of the attenuating medium. Build-up is calculated automatically by the code for a shield material specified by the user. MicroShield® only allows the user to select

a single build-up material. In the case of multiple shields (for example, engineered cap plus landscaping material), the build-up material is selected such that the most conservative results are presented.

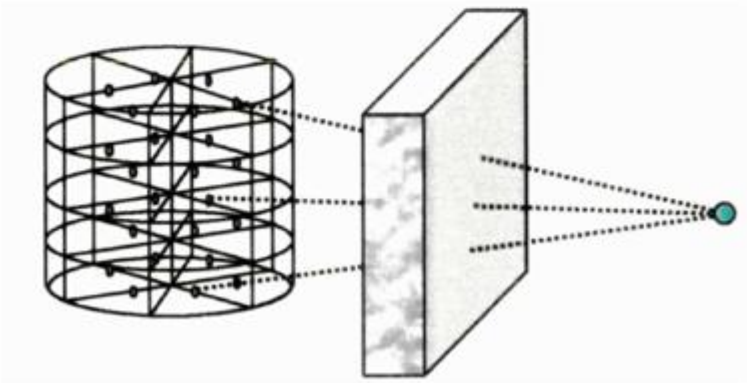

Figure 6.1: Cylinder modelled as multiple point sources.

6.2 Modelling Parameters

412 MicroShield® can only model one source at a time, that is, one block of material of a given activity and fingerprint. Features at the Winfrith site are, generally, formed of multiple "sources", each having a different specific activity; the activity of a surface-contaminated layer in the wall of a void differs from the infill material and from the floor of the void for example. Each component (source) is therefore modelled separately and the doses summed.

6.2.1 Materials

413 MicroShield® has built-in models for different materials including concrete and soil, the density of which can be specified by the user. Attenuation and build-up of radiation between a source and a dose point are affected by all intervening materials. Shield materials determine the radiation attenuation and build-up characteristics used to calculate the dose rate. MicroShield® uses published attenuation coefficient data from ANSI/ANS-6.4.3-1991, *Gamma-Ray Attenuation Coefficients and Build-up Factors for Engineering Materials*, from the American Nuclear Society.

6.2.2 Activity of the Source

414 Source activity is assumed to be uniformly distributed. Source data can be input by the user as Bq cm^{-3} per radionuclide, then MicroShield® searches its built-in library of radionuclides and retrieves the energy and probability of decay for each photon associated with each radionuclide. Annihilation photons are automatically included when a source radionuclide includes positron emitters. The standards used for attenuation coefficient and build-up factor libraries have 25 specific energy indices between 0.015 MeV and 15 MeV. Therefore, photons from a radionuclide source are sorted into 25 energy brackets (groups).

415 Parent-daughter relationships are handled automatically by MicroShield® if the user decays the source. MicroShield® calculates the correct quantities of equilibrium daughters for selected radionuclides.

6.2.3 Geometry

416 MicroShield® has the capability to model simple three-dimensional geometries (PA-022). Generally, the features at the Winfrith site are tank-like structures or floor slabs, and the components can be modelled as cuboidal or cylindrical volumes. Shields are also modelled as cuboidal or cylindrical volumes.

417 Figure 6.2 presents a schematic of how a floor slab with multiple shields is represented in MicroShield®. Shields can only be added in the X-direction for cuboidal volumes, so components are orientated such that the X-direction represents the depth of the feature/component below ground level.

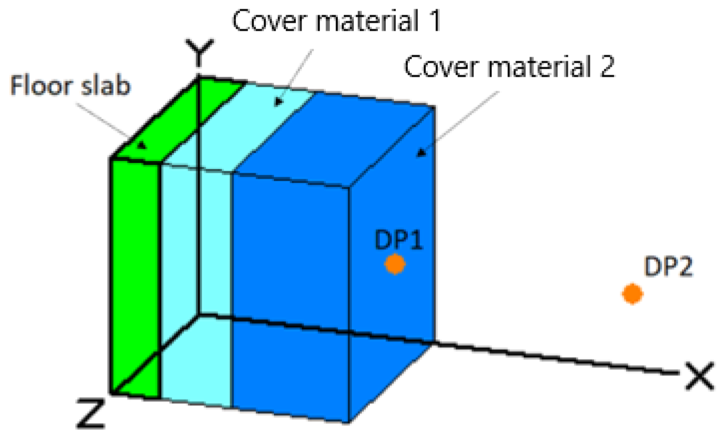

Figure 6.2: Schematic of cuboidal model in MicroShield®, representing a floor slab with cover material. DP: Dose point. X-direction represents vertical elevation for calculating dose at the surface from a buried horizontal slab.

418 Computational irradiation dosimetry typically involves several standardised irradiation geometries. These geometries refer to the direction of the ionising radiation incident on the body, which affects the dose to an individual for several reasons. The pathlengths from the source to different organs within the body change depending on the irradiation geometry, and depending on the geometry, there will be varying amounts of internal shielding of different organs. MicroShield® considers five standard irradiation geometries (see Figure 6.3) for dose assessment: anterior-posterior (AP); posterior-anterior (PA); lateral (LLAT/RLAT); rotational (ROT); and isotropic (ISO). MicroShield® does not consider cranial (CRA) and caudal (CAU) geometries. The most appropriate geometry will vary depending on what assumptions are made about the behaviour of the receptor. For simplicity, the AP geometry has been selected for this assessment because doses from this geometry give rise to the highest reported effective doses.

419 MicroShield® does not explicitly assess doses to children and infants; this is captured in Appendix A as PA-019.

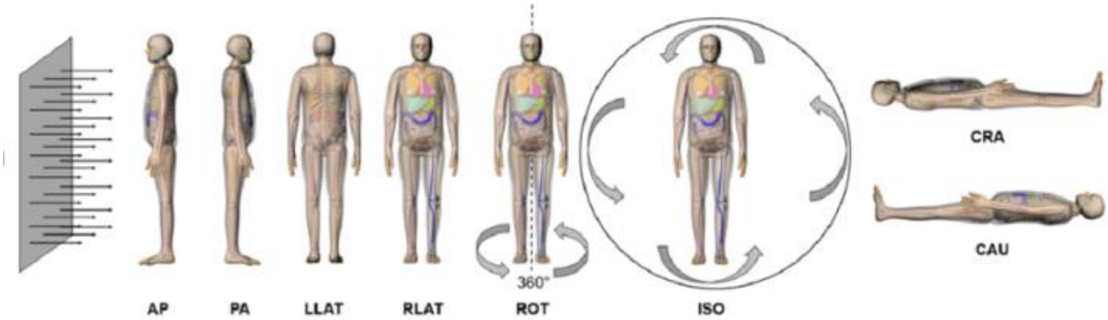

Figure 6.3: Standard irradiation geometries [139].

7 Inadvertent Human Intrusion Model

420 Assessment of inadvertent human intrusion has been undertaken using the "Generic Intrusion Methodology" (GIM) [134], which was developed for NRS by Eden Nuclear and Environment Ltd specifically to standardise assessment of inadvertent human intrusion across the NRS sites and is implemented as a Microsoft Excel spreadsheet tool [140]. GIM is focused on radionuclides and types of material relevant to fully-decommissioned NRS sites, with a stated scope that includes the ten Magnox-type reactor sites and the Harwell and Winfrith former nuclear research and prototype reactor sites. The aim of GIM is to provide stylised intrusion scenarios that enable a consistent methodology to be applied across NRS sites. Hence, GIM describes a standardised approach that uses a set of generic parameter values to define each type of intrusion scenario. The user is also able to specify some site-specific parameter values if required.

421 Version 2.1.3 of the GIM tool [134; 140] has been used here. Note that GIM Version 2 was produced based on feedback from Environment Agency reviews of trial assessments using GIM Version 1.

7.1 Intrusion Types and Exposure Pathways

422 GIM includes a generic intrusion-type identification process to support the decisions on which intrusions and activities are modelled [134]. In broad terms, these are shallow intrusions that might expose near-surface contamination, deeper intrusions that result in the removal of larger quantities of material, piles that may intersect radiological features over a wide area, and boreholes that may intersect contaminated material at depths up to 20 m (see Figure 7.1).

423 Exposure to radioactivity as a consequence of human intrusion may occur at the time of intrusion, during processing or transport of excavated material, and after the excavated material has been used or distributed. Excavation scenarios are those resulting in the more or less immediate exposure of people engaged in the removal, or partial removal, of radioactive features. Different types of excavation consider different intrusion depths and different excavated volumes.

424 Excavation activities result in the more or less immediate exposure of people engaged in the removal, or partial removal, of radioactive features. The doses relating to the subsequent processing of the excavated material are considered separately in GIM, with the quantity of material considered linked to the initial excavation event. GIM includes several routes for the processing and use of excavated material; these are shown in Figure 7.1. RPs undertaking these intrusions and activities may be exposed to radioactivity through multiple pathways modelled in GIM: external exposure; dust inhalation; dust ingestion; food ingestion; and skin contamination. Table 7.1 shows which exposure pathways apply to each of the human intrusions identified for assessment (justification of which human intrusion types are assessed in the Winfrith PA is provided in Appendix C.2.6).

425 GIM includes a set of default assumptions and parameter values for each exposure pathway based on current working practices and existing studies [134, §4]. Parameters cover the characteristics of the activities, such as the volume of material handled, dust loads and thickness of distributed material, the habits of exposed individuals, such as periods of exposure, breathing and food consumption rates, and radionuclide-specific data such as transfer factors and dose coefficients. The overall approach and parameterisation of GIM is intended to be cautiously realistic, such that key events and processes are adequately addressed, but also such that the outputs of the assessment are not unduly conservative.

426 The generic intrusion types and activities included in GIM have been used to model the dose pathways detailed in Appendix C. The default parameter values provided by GIM have largely been adopted in this assessment, other than where use of an alternative value is justified (see Appendix D.4).

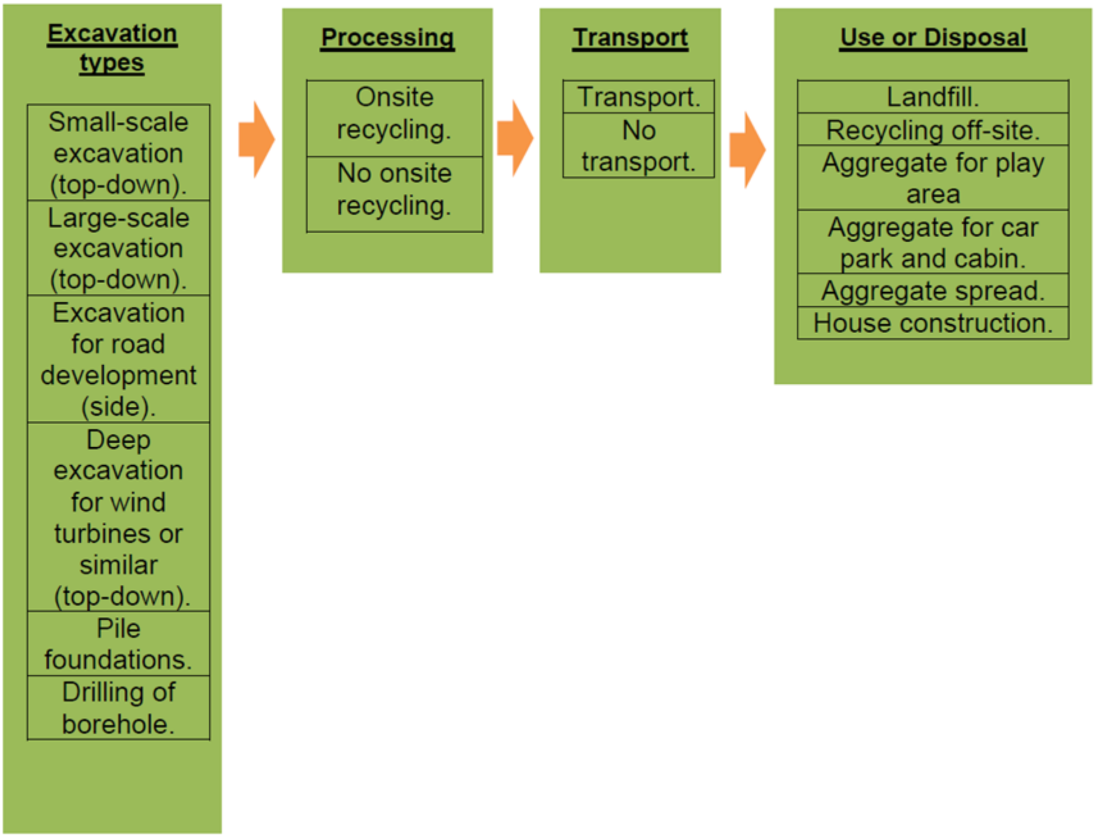

Figure 7.1: The range of generic intrusion types and associated activities available for assessment in GIM [134].

Table 7.1: Relevant exposure pathways in GIM for each human intrusion type identified in Appendix C.2.6 for the proposed Winfrith on-site disposals.

Human Intrusion Type	**GIM Excavation Type / Activity in Figure 7.1**	**Relevant Exposure Pathways**
Exploratory borehole drilling	Drilling of borehole	External irradiation Skin exposure Ingestion of dust/soil Inhalation of dust
Geotechnical investigations (multiple boreholes)	Drilling of borehole	External irradiation Skin exposure Ingestion of dust/soil Inhalation of dust
Excavation (excavation of foundations or installation of piles for site construction)	Small-scale excavation, large-scale excavation, deep excavation or pile foundations	External irradiation Skin exposure Ingestion of dust/soil Inhalation of dust
Housing development (resident in off-site building, no food)	House construction	External irradiation Skin exposure Ingestion of dust/soil Inhalation of dust
Play area (re-use of excavated material off-site)	Aggregate spread for play area	External irradiation Skin exposure Ingestion of dust/soil Inhalation of dust
Farm/smallholding (residence and food consumption)	Aggregate spread	External irradiation Skin exposure Ingestion of dust/soil Ingestion of crops Ingestion of animal produce Inhalation of dust

7.2 Conceptual Model

427 GIM includes the facility to model a number of generic concrete wall and box geometries. For each geometry GIM divides the principal components (such as the walls and the base slab) into several discrete layers for which a separate radiological specific activity can be given. This allows for differentiation of radionuclide concentrations within the feature (Figure 7.2). The area of each of these components that is intersected by an intrusion can be separately specified, within the constraint of the overall area of the intrusion. This allows more complex structures than that illustrated in Figure 7.2 to be considered. External walls, for example, can be represented by one wall and internal walls represented by the second wall. Similarly, the layers within the structure shown in Figure 7.2 can be specified to represent different materials, such as contaminated infill, intact concrete or different layers of the same component.

428 The nomenclature within GIM for the different layers is specific to a particular structure. Not all features that a user will wish to consider obviously conform to one of the available labels. For example, if there are several layers of infill material with different inventories *t(base_lining)* could be used to represent a layer of infill material or a layer could be used to represent the concrete excavated from an entire feature for a given intrusion scenario. As this Winfrith assessment treats some of these layers differently to their name/label, a generic nomenclature has been adopted to avoid confusion. The naming convention adopted in consideration of intrusions into the SGHWR and Dragon reactor complex is detailed in Table 7.2 with reference to Figure 7.2.

429 Intrusions into the A59 area have been modelled by use of a different generic geometry included in GIM, illustrated in Figure 7.3. This GIM geometry represents a body of contaminated land that may be covered by a layer of clean material.

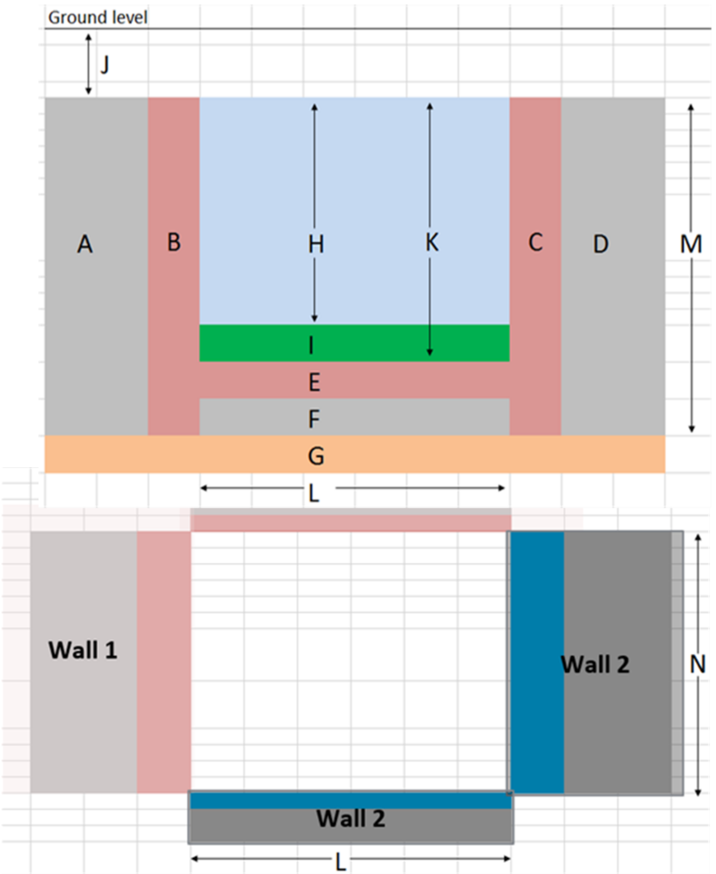

Figure 7.2: Schematic of GIM Geometry 2 [140] used to model intrusions into the SGHWR and Dragon reactor complex, with letters corresponding to the naming convention used in the Winfrith human intrusion assessment (Table 7.2). The upper figure shows a cross-section through the geometry and the lower figure a plan view.

Table 7.2: Naming convention for layers and dimensions in the GIM model used in the SGHWR and the Dragon reactor complex human intrusion assessment.

Label	GIM nomenclature	Characterisation in GIM
A	Wall_1,concrete	Thickness of the 'concrete layer' of Wall 1 - calculated in GIM by subtracting the thickness of the lining from the overall wall thickness.
B	t(wall_1,lining)	Thickness of the 'wall lining' layers. The material type of these layers can be specified.
C	t(wall_2,lining)	
D	Wall_2,concrete	Thickness of the 'concrete layer' of Wall 2 - calculated in GIM by subtracting the thickness of the lining from the overall wall thickness.
A + B	t(wall_1)	Overall thicknesses of the walls.
C + D	t(wall_2)	
E	t(base_lining)	Thickness of the 'base lining' layer. The material type of this layer can be specified.
F	Base_concrete	Thickness of the 'base concrete layer' - calculated in GIM by subtracting the thickness of lining (E) from the overall thickness of the base.
E + F	t(base)	Overall thickness of the base.
G	d(bottom)	Thickness of the 'bottom' layer. The material type of this layer can be specified.
H	d(backfill)	Depth of uncontaminated backfill.
I	d(infill)	Depth of contaminated infill.
J	d(burial)	Depth of top of feature below ground level.
K	d(cavity)	Cavity depth - depth of layer H plus the depth of layer I.
L	w(base)	Width of the base.
M	Wall depth	Wall depth – calculated in GIM from dimensions of other structures and features (H+I+E+F).
N	l(base)	Length of the base.
L and N	l(wall_1)	Lengths of the walls.
	l(wall_2)	

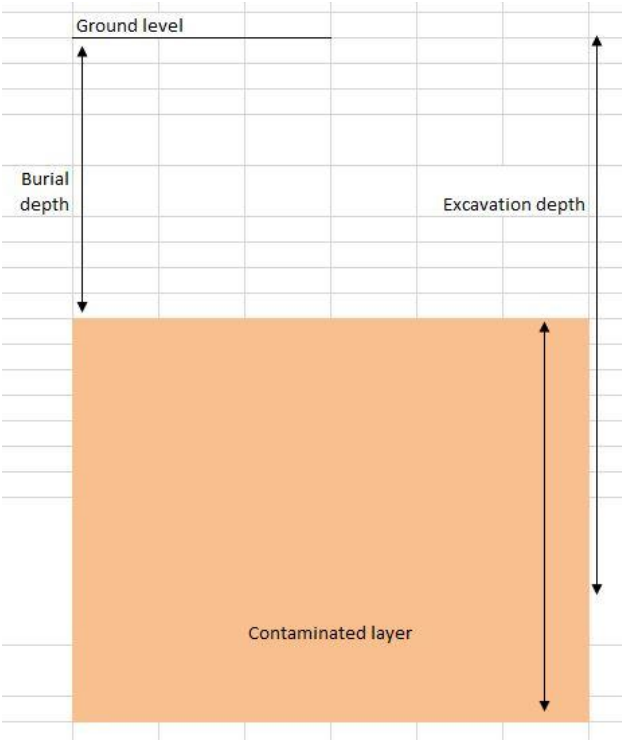

Figure 7.3: Schematic cross-section of Geometry 4 within GIM [140]. This geometry has been used to model the cases concerning intrusions into the OoS A59 area.

7.3 Assessed Radionuclides

430 GIM includes a default set of radionuclides, which are detailed in Appendix B.2 and summarised in Table 7.3. The radionuclides included in GIM represent 97.5% of the total Winfrith radiological end state reference inventory. Of this, only 79.8% of the OoS A59 area reference inventory (and only 76.1% when considering the A59 Other Areas reference inventory, that is, the A59 area excluding the remediated A591/HVA and PSA/Pit 3 APCs) is covered by GIM, primarily because the uranium isotopes that are not explicitly included in GIM form a larger fraction of the OoS A59 inventory (19.9%) compared with SGHWR and the Dragon reactor complex (less than 1% for each). However, as stated earlier, the A59 area will be remediated and demonstrated to be OoS of RSR and so does not form part of the permit variation application. The potential impact of the missing radionuclides from GIM is assessed in Paragraph 565.

Table 7.3: Radionuclides included in GIM and their half-lives.

Radionuclide	Half-life (years)	Radionuclide	Half-life (years)
H-3	1.20E+01	Y-90	7.28E-03
C-14	5.70E+03	Cs-137	3.02E+01
Cl-36	3.00E+05	Eu-152	1.30E+01
Ca-41	1.40E+05	Eu-154	8.59E+00
Fe-55	2.70E+00	Pu-238	8.78E+01
Co-60	5.30E+00	Pu-239	2.40E+04
Ni-59	7.50E+04	Pu-240	6.50E+03
Ni-63	9.60E+01	Pu-241	1.40E+01
Sr-90	2.90E+01	Am-241	4.32E+02

431 As detailed in Appendix B.2, radionuclide decay is considered in GIM over the period between the date of the inventory and the date assumed for the intrusion to take place. Radionuclide ingrowth is generally not accounted for in GIM except in the following cases (valid for intrusions occurring up to 100 years following the inventory date):

- ^{90}Y is assumed to be in secular equilibrium with its parent ^{90}Sr and so is included in the dose coefficient for ^{90}Sr.
- ^{137m}Ba is assumed to be in secular equilibrium with its parent ^{137}Cs and so is included in the dose coefficient for ^{137}Cs.
- A small contribution from ^{241}Am is included in the dose coefficient for ^{241}Pu to account for ingrowth (0.0296 of the ^{241}Am dose coefficient is included in the ^{241}Pu dose coefficient[37]).
- A small contribution from ^{234}U is included in the dose coefficient for ^{238}Pu to account for ingrowth (0.0002 of the ^{234}U dose coefficient is included in the ^{238}Pu dose coefficient[37]).

432 Note that for the Winfrith site ^{241}Pu comprises less than 1% of the SGHWR and the Dragon reactor complex inventories, and less than 4% of the A59 inventory. Therefore, there would be limited impact from ingrowth of the ^{241}Am daughter if a period greater than 100 years was considered. Similarly, ^{238}Pu comprises less than 0.2% of the SGHWR, Dragon reactor complex and A59 inventories.

433 All Reference Case calculations have been undertaken assuming intrusion in 2066 (the assumed SRS date). If doses are found to exceed the GRR dose guidance level at this date, further calculations have been undertaken at later dates to assess the benefit of radioactive decay and to identify the impact on any control period. When assessing the potential effects of a control period, it is cautiously assumed in the human intrusion assessment that the inventory is reduced by decay but not by leaching or other loss to

[37] The contribution corresponds to the maximum activity ratio that would be reached due to ingrowth over 100 years.

groundwater (this has also been assumed in the site occupancy calculations) – this is increasingly conservative as time passes.

7.4 Mathematical Representation

434 Calculations of the potential doses from human intrusion are based on the concentrations of radionuclides in the material to which RPs are exposed. These concentrations depend on the details of the intrusion geometry and any subsequent processing of excavated material but there are three broad categories of material considered in the dose calculations:

- In-situ material. The concentrations of radioactive material in-situ used in the dose calculations correspond to the concentrations reported in the inventory.
- Excavated material. Radioactive material is mixed with non-radioactive material during excavation (e.g. capping material above the radioactive waste or uncontaminated material within radioactive structures).
- Deposited material. Excavated material is mixed with additional non-radioactive material when it is deposited or used off site (e.g. soil or aggregate).

435 Calculations of effective dose are based on the concentration of individual radionuclides in material to which a person is exposed (e.g. soil, dust, water or crops). The total dose is the sum of the dose from the individual exposure pathways for all radionuclides. GIM considers four exposure pathways: external irradiation, inhalation, ingestion and skin contact. Note that there are several pathways leading to exposure through ingestion. Ingestion could occur inadvertently during excavation due to the dust generated or during occupancy scenarios from contaminated soil and dust on the ground (e.g. a child/infant in a playground built using extracted contaminated material). If the contaminated land were to be used in the future for a farm or smallholding, consumption of crops or animal produce grown or grazed on the contaminated soil by resident adults and infants is also possible. The general form of the dose equations is:

$$Dose_{Tot} = \sum_{Pathway} \sum_{s} f D_s C_s \tag{7.1}$$

where:

$Dose_{Tot}$	Total dose to an individual exposed to contaminated or activated material across all considered pathways and radionuclides s.
f	A modifying factor for each pathway, accounting for exposure geometry, attenuation, exposure time and consumption rates.
D_s	Dose coefficient for radionuclide s for each pathway.
C_s	Concentration of radionuclide s in the material.

436 Further details of the dose equations specific to each exposure pathway are provided in the GIM manual [134, §3; 140].

437 The concentration of a radionuclide used in the dose calculations is a function of the concentration in excavated contaminated material. This concentration has been

determined as an average concentration, $C_{s,contam}$, from the concentrations that are estimated to remain within different excavated contaminated features and components.

$$C_{s,contam} = \sum_{Feature} \frac{M_{Feature}\, C_{s,Feature}}{M_{Total,contam}} \tag{7.2}$$

where:

$C_{s,Feature}$	Concentration of radionuclide s in a contaminated or activated feature/component (Bq kg^{-1}).
$M_{Feature}$	Mass of the contaminated feature/component (kg).
$M_{Total,contam}$	Total mass of contaminated material excavated (kg).

438 Excavations can remove non-radioactive material in addition to contaminated or activated material and the overall concentration in excavated material, C_s, is given by:

$$C_s = C_{s,contam} \frac{M_{Total,contam}}{M_{Total}} \tag{7.3}$$

where M_{Total} is the overall mass of excavated (contaminated plus uncontaminated) material.

441 The mass of material excavated from the disposals is determined by the area of each component intersected by the intrusion and the density of the component material. Where the overall size of the assumed excavation is larger than the sum of the excavated areas, uncontaminated material from around the structure is included within the overall mass excavated (see Figure 7.4). Similarly, uncontaminated material from above or below the radioactive components may be included in the overall mass. Each intrusion calculation was cautiously assumed to excavate the maximum amount of the most contaminated features/components possible for the given intrusion scenario (i.e. the overlap of the buried feature (blue area in Figure 7.4) and the excavation case (red area) was maximised in each case). The features and components excavated in each intrusion case are described in the following sections.

442 GIM treats uncontaminated material differently depending on its origin and composition. Uncontaminated soil from around the structure and backfill with no associated radioactivity is not considered in calculations of average activity, whereas uncontaminated concrete layers are considered and hence can lower the average activity used in calculating doses through the different exposure scenarios. Further dilution of excavated material is assumed for these exposure scenarios depending, for example, on the area of land considered and the depth to which material is spread. Details of the assumptions regarding on-site and off-site dilution are provided in the GIM manual [134, §4].

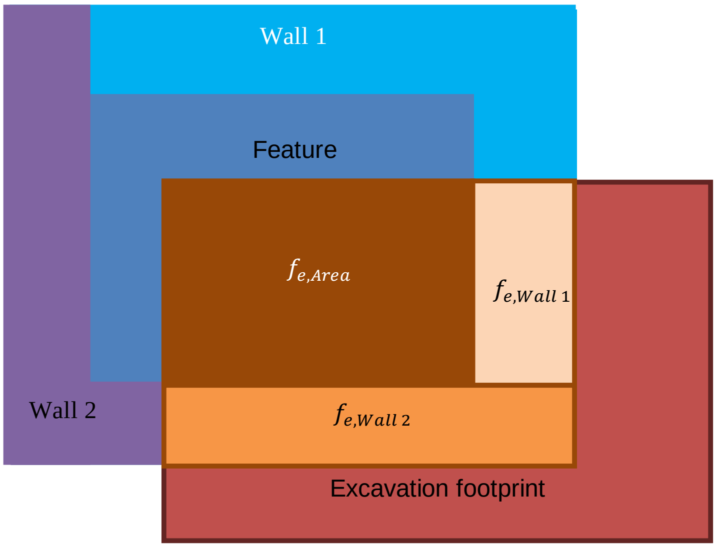

Figure 7.4: A schematic showing areas of overlap between a buried feature (shades of blue) and intrusion excavation case (shades of red). The shading shows the area-based fractions of components excavated for Wall 1 components (light orange), Wall 2 components (darker orange) and area-based infill components (darkest orange) [134].

7.5 SGHWR Feature Group Intrusion Cases

443 Assessment of inadvertent human intrusion into the SGHWR feature group has considered intrusions into the different regions shown in Figure 3.16. Due to Region 2 and the South Annexe each comprising areas that are not entirely adjacent to each other, these two regions have been considered together in the assessment of human intrusion. Shallow intrusions have not been assessed into any of the SGHWR regions because the minimum proposed cap thickness for the SGHWR (2.5 m) exceeds the depth of the shallow intrusions in GIM (2.0 m) and therefore these intrusions would not result in excavation of contaminated material and dose to RPs.

7.5.1 Region 1

444 Assessment of doses from intrusions into Region 1 (comprising the bioshield and mortuary tubes, ponds, primary containment, part of the secondary containment and backfill) has considered six cases, detailed in Table 7.4. The locations of each intrusion are illustrated in Figure 7.5 to Figure 7.7.

Table 7.4: Calculation cases considered in the assessment of inadvertent human intrusion into SGHWR Region 1 (illustrated in Figure 7.5 to Figure 7.7).

Case	GIM Intrusion Type	Dimensions	Components Intersected/Overlapping Area	Explanation
1	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Whole bioshield (31.6 m^2), part of the primary containment (119.7 m^2), part of the secondary containment (4.2 m^2), backfill (158.4 m^2)	A large-scale deep excavation into the feature of highest inventory within Region 1 (the bioshield) and surrounding features. This case excludes the residual mortuary tubes inventory estimate.
2	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Whole bioshield including mortuary tubes (31.6 m^2), part of the primary containment (119.7 m^2), part of the secondary containment (4.2 m^2), backfill (158.4 m^2)	As Case 1, but including the residual mortuary tubes inventory estimate.
3	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Secondary containment (137.8 m^2), backfill (176.2 m^2)	The secondary containment has higher activity concentration than the primary, therefore a deep intrusion solely into the secondary containment is also considered as a sensitivity.
4	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	Backfill (1.3 m^2)[38]	It is unlikely that a single pile would be installed and hence an array of piles is considered; 40 piles is the default assumed in GIM [134, §4.2.5]. It is assumed that a pile is emplaced approximately every 2 m around a 30 m by 10 m perimeter within Region 1 (based on assumptions made in GIM [134, §4.2.5]). The piles are assumed to intersect the backfill (the floor is too deep); it is not considered realistic that they would be placed into the walls.

[38] For pile array, GIM considers intrusion into the area-based components only as it is assumed that walls would be deemed an inappropriate drilling location.

Case	GIM Intrusion Type	Dimensions	Components Intersected/Overlapping Area	Explanation
5	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	5 boreholes (0.2 m^2): 1. Backfill and primary containment floor 2. Backfill and secondary containment floor 3. Bioshield wall and primary containment floor 4. Backfill, pond wall and pond floor 5. Backfill, pond wall and pond floor	An array of 5 boreholes is assumed [134, §4.2.6]. The location of each borehole has been chosen to be illustrative of the range of features within Region 1. It is assumed that two of the boreholes intersect the pond wall and pond floor as this borehole results in the highest dose and so is most conservative (when excluding the mortuary tubes).
6	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	5 boreholes (0.2 m^2): 1. Backfill and primary containment floor 2. Backfill and secondary containment floor 3. Bioshield wall and primary containment floor 4. Backfill, pond wall and pond floor 5. Mortuary tubes and primary containment floor	As Case 5, but including the residual mortuary tubes inventory estimate. Therefore, instead of two of the boreholes intersecting the bioshield, one of these is assumed to intersect the mortuary tubes.

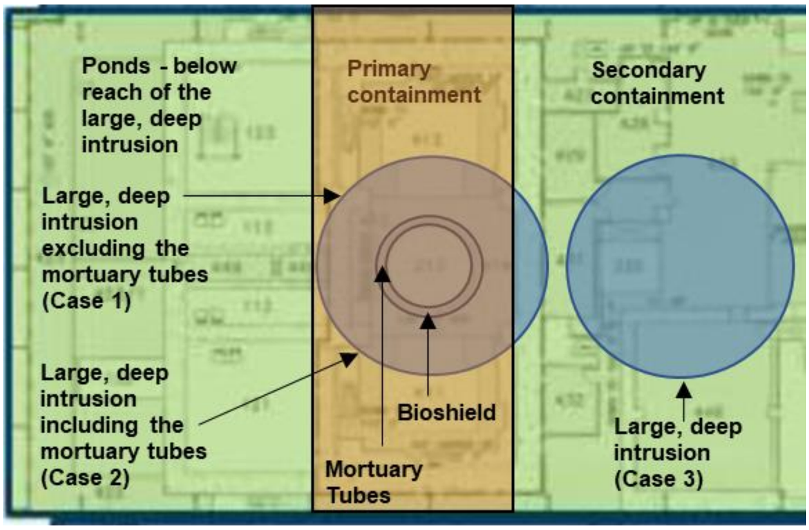

Figure 7.5: Schematic plan view of SGHWR Region 1 showing the location of the intrusions considered in Cases 1, 2 and 3.

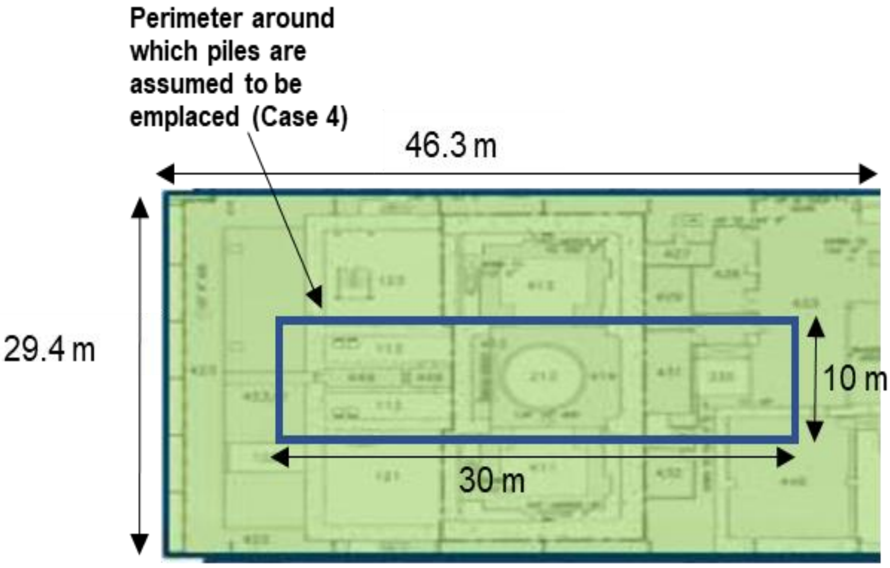

Figure 7.6: Schematic plan view of SGHWR Region 1 showing the perimeter around which piles are assumed to be emplaced in the Case 4 intrusion.

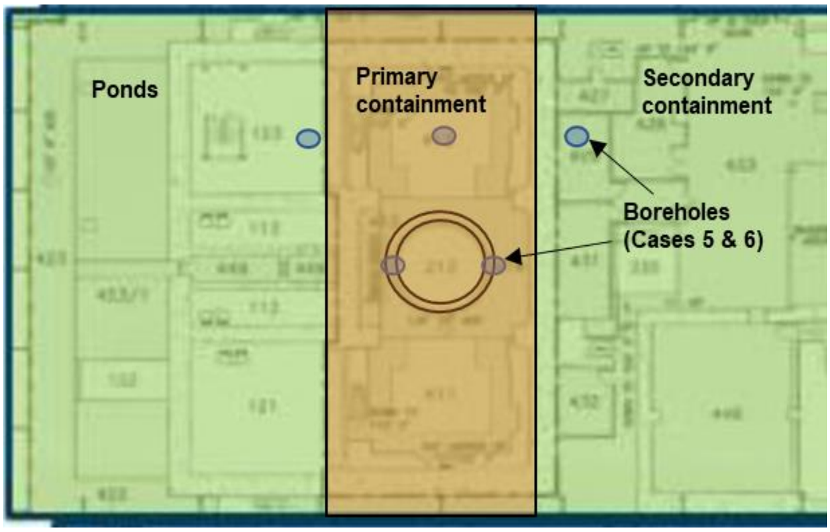

Figure 7.7: Schematic plan view of SGHWR Region 1 showing the locations at which boreholes are assumed to be emplaced in Cases 5 and 6. In Case 5, two boreholes are assumed to intersect the bioshield. In the sensitivity case (Case 6) the mortuary tubes are assumed not to have been cleaned and one of the boreholes is assumed to intersect the mortuary tubes instead.

7.5.2 North Annexe

445 Assessment of doses from intrusions into the North Annexe has considered four cases. Due to the dimensions of the North Annexe, the GIM large, deep intrusion would only fit wholly into the area if it were emplaced in the part shown directly below the Turbine Hall in the plan view (Figure 3.16). Therefore, two large, deep intrusions have been assessed: one in which the intrusion is emplaced directly below the Turbine Hall (Case 7 in Table 7.5), and a second (Case 8 in Table 7.5) in which the intrusion is emplaced below Region 1 in the plan view (Figure 3.16) and intrudes into the maximum possible area of the North Annexe with the remaining area intruding into Region 1. The locations of each intrusion are illustrated in Figure 7.8 to Figure 7.10.

Table 7.5: Calculation cases considered in the assessment of inadvertent human intrusion into the North Annexe (illustrated in Figure 7.8 to Figure 7.10).

Case	GIM Intrusion Type	Dimensions	Components Intersected / Overlapping Area	Explanation
7	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Secondary containment (walls and floor) (137.8 m^2) and backfill (176.2 m^2)	This case intrudes into the part of the North Annexe which extends to beneath the Turbine Hall in the plan view (see Figure 3.16). Due to the (limited) depth of the area, both the secondary containment walls and floor are intersected as well as the backfill.
8	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Part of the North Annexe walls (131.8 m^2) and floor (168.6 m^2), part of the primary containment walls of Region 1 (13.6 m^2), and backfill (168.6 m^2)	This case intrudes into the part of the North Annexe below Region 1 in a plan view (see Figure 3.16). Due to the dimensions of this part of the North Annexe it is not feasible for the GIM large-scale deep excavation scenario to intrude wholly into the area. Therefore, this case intrudes into the maximum possible area of the North Annexe with the remaining portion intruding into Region 1 which is adjacent.
9	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	North Annexe floor (1.3 m^2), backfill (1.3 m^2)	It is unlikely that a single pile would be installed and hence an array of piles is considered; 40 piles is the default assumed in GIM [134, §4.2.5]. It is assumed that a pile is emplaced approximately every 2 m around a 30 m by 10 m perimeter within the North Annexe (based on default assumptions made in GIM [134, §4.2.5]). The piles are assumed to intersect the North Annexe floor and backfill; it is not considered realistic that they would be placed into the walls.
10	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	North Annexe floor (0.2 m^2), backfill (0.2 m^2)	An array of 5 boreholes is the default assumed in GIM [134, §4.2.6]. The boreholes are assumed to intersect the North Annexe floor and backfill.

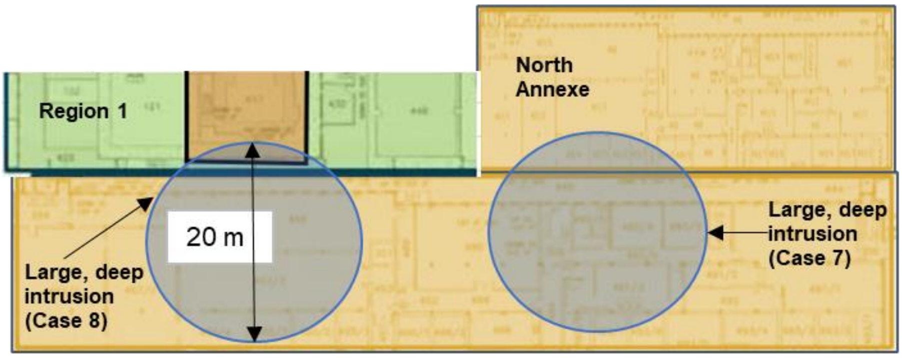

Figure 7.8: Schematic plan view of the North Annexe and part of Region 1 showing the location of the intrusions considered in Cases 7 and 8.

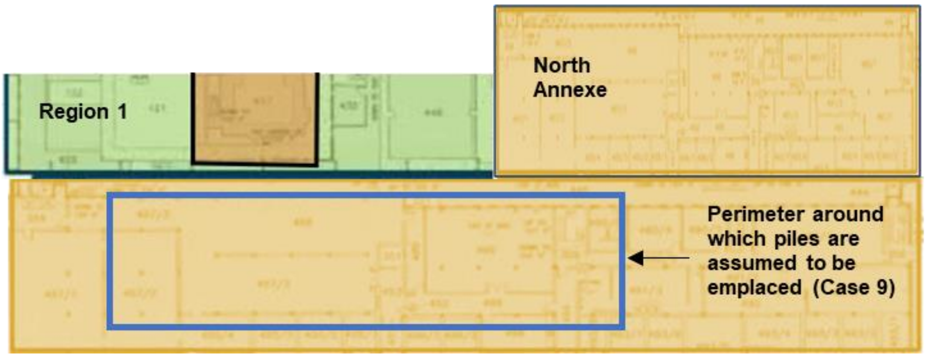

Figure 7.9: Schematic plan view of the North Annexe and part of Region 1 showing the perimeter around which piles are assumed to be placed in the Case 9 intrusion.

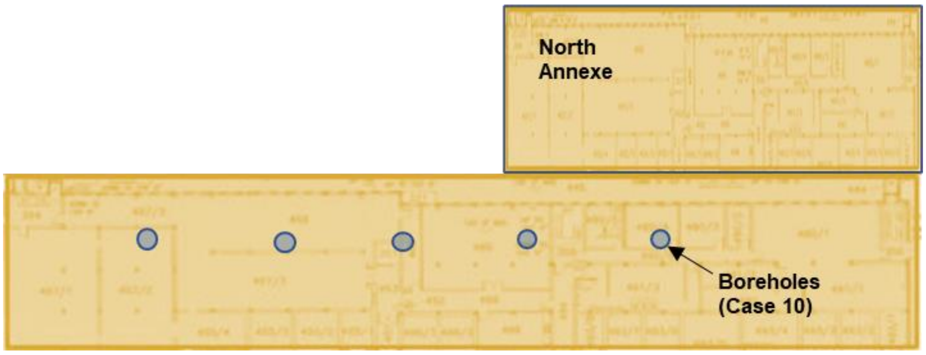

Figure 7.10: Schematic plan view of the North Annexe showing the locations at which boreholes are assumed to be drilled in Case 10.

7.5.3 Region 2 and the South Annexe

446 Due to SGHWR Region 2 comprising three separate areas (see Figure 3.16), and the proximity of these areas to the South Annexe, these two features have been considered together in the human intrusion assessment. Five cases have been assessed, as detailed in Table 7.6. The locations of each intrusion are illustrated in Figure 7.11 to Figure 7.13.

Table 7.6: Calculation cases considered in the assessment of inadvertent human intrusion into SGHWR Region 2 and the South Annexe (illustrated in Figure 7.11 to Figure 7.13).

Case	GIM Intrusion Type	Dimensions	Features Intersected / Overlapping Area	Explanation
11	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Part of the South Annexe walls (137.8 m^2), backfill (176.2 m^2)	A large-scale deep excavation into the South Annexe. The height of the South Annexe (5.25 m excluding the floor slab) means that the intrusion will not reach the floor.
12	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	South Annexe floor (1.3 m^2), South Annexe “local” backfill (1.3 m^2)	It is unlikely that a single pile would be installed and hence the GIM-default of 40 piles is considered [134, §4.2.5]. It is assumed that a pile is emplaced approximately every 2 m around a 30 m by 10 m perimeter within the South Annexe (based on assumptions made in GIM [134, §4.2.5]). The piles are assumed to intersect the South Annexe floor and backfill; it is not considered realistic that they would be placed into the walls. Conservatively, the “local” South Annexe backfill is assumed, that is, backfill coming specifically from the South Annexe.
13	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	South Annexe floor (0.2 m^2), South Annexe “local” backfill (0.2 m^2)	An array of 5 boreholes is the default assumed in GIM [134, §4.2.6]. The boreholes are assumed to intersect the South Annexe floor and backfill; it is not considered realistic that they would be drilled into the walls.
14	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	Secondary containment floor (1.3 m^2), Region 2 “local” backfill (1.3 m^2)	Intrusion into the secondary containment is assumed as adopting secondary containment activity concentrations is more conservative than adopting the overall Region 2 activity concentrations. The part of the secondary containment that is at the depth of the South Annexe is assumed so that the piles also intersect the secondary containment floor. The “local” Region 2 backfill is assumed rather than the Rubble Mounds to be conservative.
15	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep,	Secondary containment floor (0.2 m^2), Region 2 “local” backfill (0.2 m^2)	The 5 boreholes are assumed to intersect the delay tank room in Region 2. The secondary containment activity concentrations are used as these are more conservative than the overall Region 2 activity concentrations. The delay tank room has been selected as the

Case	GIM Intrusion Type	Dimensions	Features Intersected / Overlapping Area	Explanation
		5 boreholes in the array		greater depth means a larger volume of backfill is intersected. The "local" Region 2 backfill is assumed rather than the Rubble Mounds to be conservative.

Figure 7.11: Schematic plan view of parts of the South Annexe and Region 2 showing the location of the intrusion considered in Case 11 and the perimeter around which piles are assumed to be placed in the Case 12 intrusion.

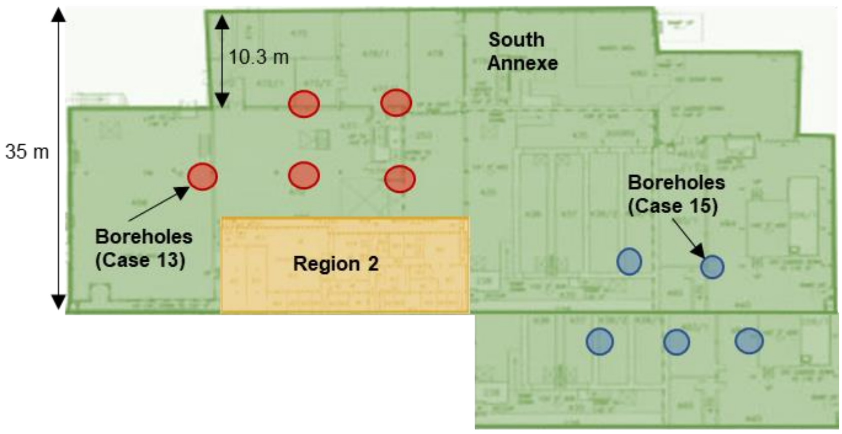

Figure 7.12: Schematic plan view of the South Annexe and part of Region 2 showing the locations at which boreholes are assumed to be drilled in Cases 13 and 15.

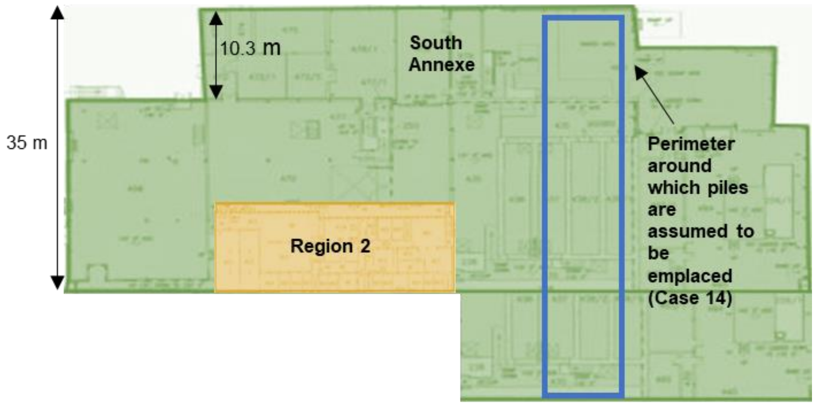

Figure 7.13: Schematic plan view of the South Annexe and part of Region 2 showing the perimeter around which piles are assumed to be placed in the Case 14 intrusion.

7.6 Dragon Reactor Complex Feature Group Intrusion Cases

447 Assessment of human intrusion into the Dragon reactor complex has considered intrusions into the reactor building structure, the B78 building floor slab, and the mortuary holes separately. Due to the distances between each of these features, it is not realistic to consider an intrusion intersecting them in combination. Shallow intrusions have been considered for the Dragon reactor complex, as the minimum proposed cap thickness is 1.5 m, which is less than the depth of the shallow intrusions in GIM (2.0 m). However, results from these are not presented in the Reference Case, which assumes a cap thickness of 3.8 m.

7.6.1 Dragon Reactor Building

448 Assessment of doses from intrusions into the Dragon reactor building has considered eight cases, detailed in Table 7.7. These cases include consideration of intrusions into the area of assumed residual contamination from the purge gas pre-cooler (PGPC) contaminated water spill (Case 21) and into the Betalite store (Case 22). A case (Case 23) considering a borehole array in which boreholes intersect both the residual PGPC spill area and the Betalite store, as well as the rest of the structure is also assessed. A borehole array in which all five boreholes intersect the bioshield is not considered on the basis that this is highly pessimistic and unrealistic. However, a borehole intersecting the bioshield is included as part of Case 23. The locations of the intrusions considered in Cases 16-20 are illustrated in Figure 7.14 and Figure 7.15. Cases 21, 22 and 23 are not shown on diagrams; these are the same as Case 20 except that the boreholes are in the location of the residual PGPC spill, the Betalite store, and a combination of these and the rest of structure, respectively.

Table 7.7: Calculation cases considered in the assessment of inadvertent human intrusion into the Dragon reactor building (illustrated in Figure 7.14 and Figure 7.15).

Case	GIM Intrusion Type	Dimensions	Components Intersected / Overlapping Area	Explanation
16	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	Bioshield (35.7 m^2), general building contamination (58.8 m^2), backfill (219.5 m^2)	A large-scale deep excavation into the feature of highest inventory within the Dragon reactor building (the bioshield) and surrounding features.
17	Large-scale, shallow	300 m^2 intrusion (assumed to be a 10 m by 30 m rectangle), 2 m deep	Bioshield (35.7 m^2), general building contamination (55.8 m^2), backfill (208.5 m^2)	A large-scale, shallow intrusion into the feature of highest inventory within the reactor building (the bioshield) and surrounding features.
18	Small-scale, shallow	5 m^2 intrusion, 2 m deep	Bioshield wall (5 m^2)	A small-scale, shallow intrusion into the feature of highest inventory within the reactor building (the bioshield).
19	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	Backfill (1.3 m^2)	It is unlikely that a single pile would be installed and hence a GIM default array of 40 piles is considered [134, §4.2.5]. It is assumed that a pile is placed approximately every 2 m around a 30 m by 10 m perimeter within the reactor building structure (based on GIM assumptions [134, §4.2.5]). The piles are assumed to intersect the backfill; the floor slab is beyond reach of the pile depth and it is not considered realistic that they would be placed into the walls.
20	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	Backfill (0.2 m^2), floor slab (0.2 m^2)	All five boreholes are assumed to intersect the backfill and the structure base only. Sensitivity cases considering borehole intrusions into different parts of the Dragon reactor building are considered in the next three cases.
21	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m	Backfill (0.2 m^2), floor slab (at the location of the PGPC contaminated water spill) (0.2 m^2)	All five boreholes are assumed to be emplaced such that they intersect the area affected by the PGPC contaminated water leak. Due to the depth of the PGPC contaminated water spill only intrusion via boreholes has been considered. This is a low probability case due to the small areal extent of the PGPC spill.

Case	GIM Intrusion Type	Dimensions	Components Intersected / Overlapping Area	Explanation
		deep, 5 boreholes in the array		
22	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	Backfill (0.2 m^2), Betalite store (0.2 m^2)	All five boreholes are assumed to be drilled such that they intersect the Betalite store. Due to the depth of the Betalite store only borehole intrusions have been considered. This is a low probability case due to the small areal extent of the Betalite store.
23	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	1 borehole into the bioshield and floor slab 1 borehole into the backfill and floor slab (where the PGPC spill is) 1 borehole into the backfill and Betalite store 2 boreholes into the backfill and floor slab	A borehole array in which it is assumed that one borehole is emplaced such that it intersects the area affected by the PGPC contaminated water spill, one such that it intersects the Betalite store, one such that it intersects the Dragon reactor bioshield and the remaining two intersect the backfill and structure base only. (An array in which all five boreholes intersect the bioshield has not considered on the basis that this is highly pessimistic and unrealistic; instead, this mixed array is considered to be more realistic).

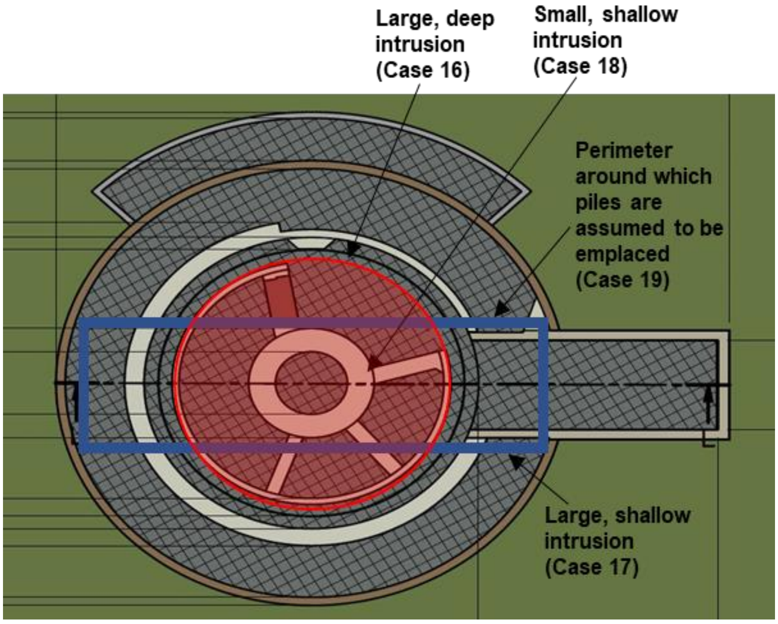

Figure 7.14: Schematic plan view of the Dragon reactor building structure showing the location of the intrusions considered in Cases 16, 17, 18 and 19.

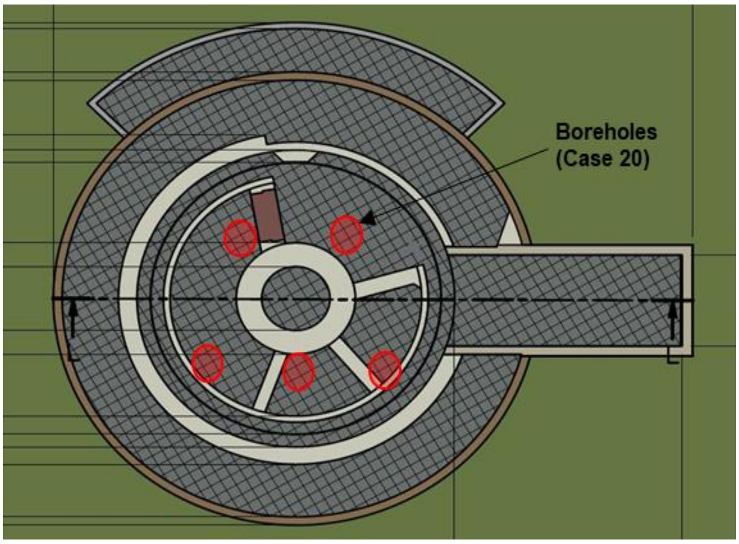

Figure 7.15: Schematic plan view of the Dragon reactor building structure showing the locations at which boreholes are assumed to be placed in Case 20.

7.6.2 B78 Building Floor Slab

449 Assessment of doses from intrusions into the Dragon B78 building floor slab considered five cases; these are detailed in Table 7.8. The locations of each of the intrusions are illustrated in Figure 7.16 to Figure 7.18.

Table 7.8: Calculation cases considered in the assessment of inadvertent human intrusion into the B78 building floor slab (illustrated in Figure 7.16 to Figure 7.18).

Case	GIM Intrusion Type	Dimensions	Components Intersected / Overlapping Area	Explanation
24	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	B78 floor slab (314 m^2)	A large-scale deep intrusion into the B78 building floor slab.
25	Large-scale, shallow	300 m^2 intrusion (assumed to be a 10 m by 30 m rectangle), 2 m deep	B78 floor slab (300 m^2)	A large-scale shallow intrusion into the B78 building floor slab.
26	Small-scale, shallow	5 m^2 intrusion, 2 m deep	B78 floor slab (5 m^2)	A small-scale shallow intrusion into the B78 building floor slab.
27	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	B78 floor slab (1.3 m^2)	The 40 piles are assumed to be placed approximately every 2 m around a 30 m by 10 m perimeter within the B78 floor slab (based on assumptions made in GIM [134, §4.2.5]).
28	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	B78 floor slab (0.2 m^2)	All five boreholes are assumed to be drilled into the B78 floor slab.

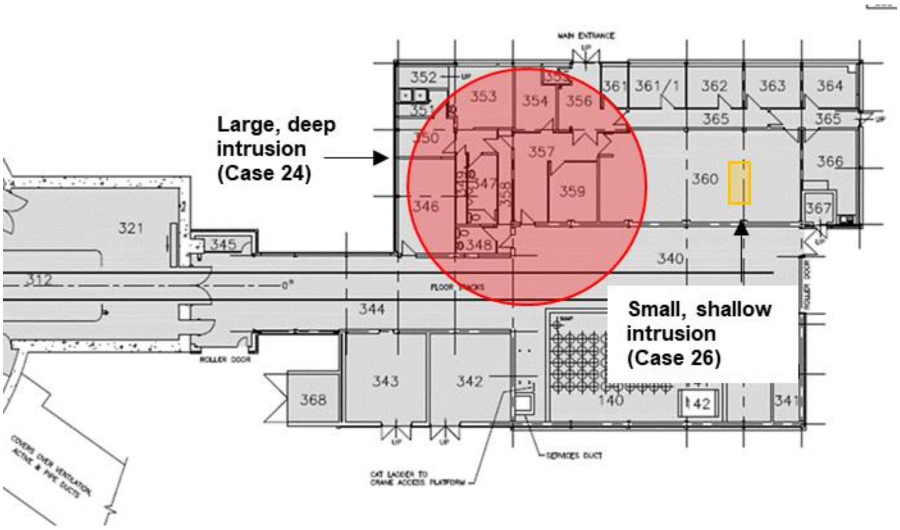

Figure 7.16: Plan view of the Dragon B78 building floor slab showing the location of the intrusions considered in Cases 24 and 26.

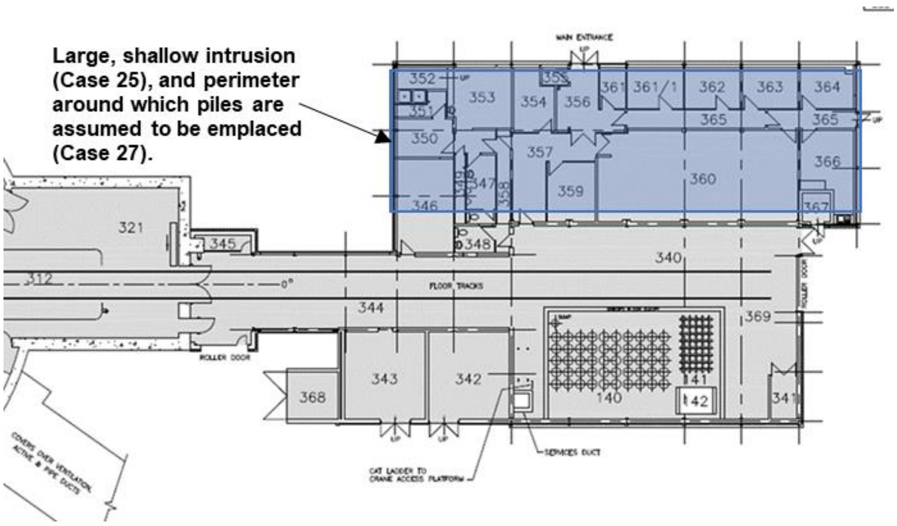

Figure 7.17: Plan view of the Dragon B78 building floor slab showing the location of the intrusions considered in Cases 25 and 27.

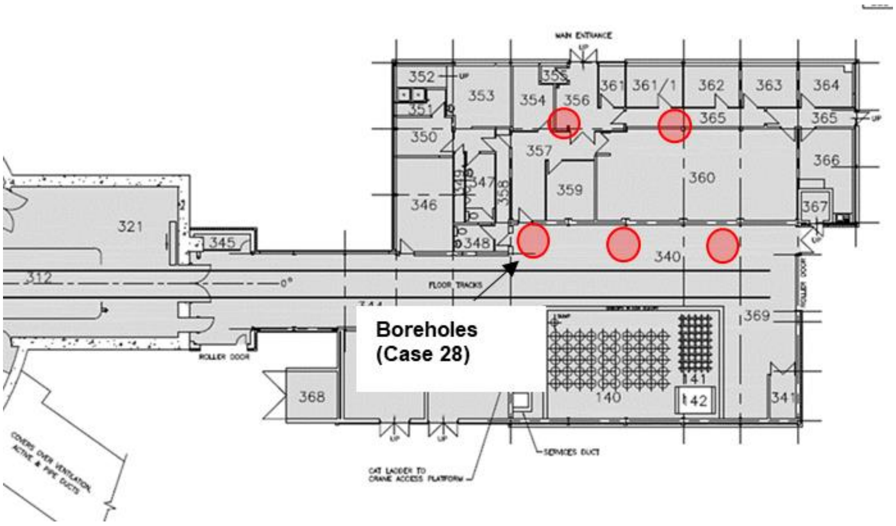

Figure 7.18: Plan view of the Dragon B78 building floor slab showing the locations at which boreholes are assumed to be emplaced in Case 28.

7.6.3 Primary Mortuary Holes

450 Assessment of doses from intrusions into the Dragon primary mortuary holes considered four cases; these are detailed in Table 7.9. A highly conservative approach has been taken for the array of boreholes (Case 32) in which each borehole has been assumed to intrude into a single mortuary hole and intersect the maximum amount of contaminated metal possible. The details of the calculations undertaken and parameters used to define this scenario are given in Appendix D.4. The locations of each of the intrusion cases used to assess human intrusion into the Dragon primary mortuary holes are illustrated in Figure 7.19 and Figure 7.20.

Table 7.9: Calculation cases considered in the assessment of inadvertent human intrusion into the Dragon primary mortuary holes (illustrated in Figure 7.19 and Figure 7.20).

Case	GIM Intrusion Type	Dimensions	Components Intersected / Overlapping Area	Explanation
29	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	All of the mortuary hole structure (87.7 m^2)	A large-scale deep intrusion intersecting all of the mortuary hole structure planned for in-situ disposal, and some of the surrounding area.
30	Small-scale, shallow	5 m^2 intrusion, 2 m deep	Part of the mortuary hole structure (5 m^2)	A small-scale shallow intrusion intersecting part of the mortuary hole structure.
31	Large-scale, shallow	300 m^2 intrusion (assumed to be a 10 m by 30 m rectangle), 2 m deep	All of the mortuary hole structure (87.7 m^2)	A large-scale shallow intrusion intersecting all of the mortuary hole structure planned for in-situ disposal, and some of the surrounding area.
32	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	Mortuary holes (0.2 m^2)	All five boreholes are assumed to intrude into a single mortuary hole each and conservatively intersect the maximum amount of contaminated metal.

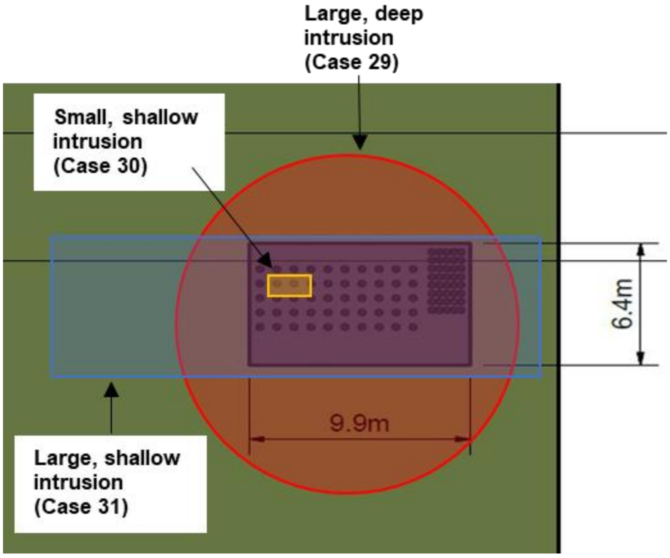

Figure 7.19: Schematic plan view of the Dragon primary mortuary holes structure showing the location of the intrusions considered in Cases 29, 30 and 31.

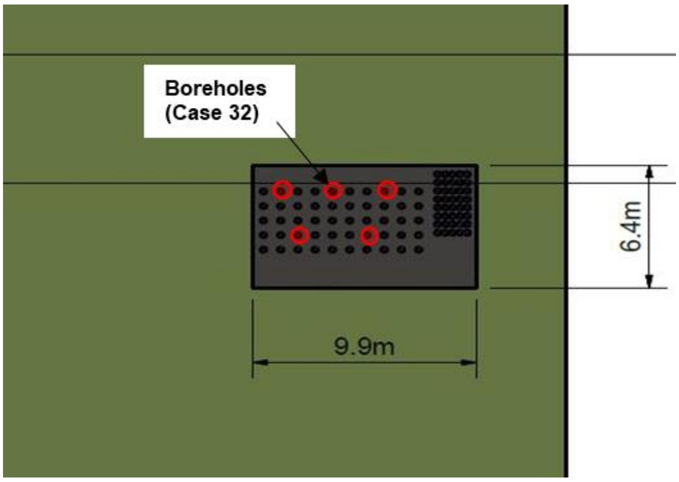

Figure 7.20: Schematic plan view of the Dragon primary mortuary holes structure showing the locations at which boreholes are assumed to be drilled in Case 32.

7.7 OoS A59 Area Feature Group Intrusion Cases

451 Assessment of human intrusion into the A59 area has considered the two areas of potential concern (the remediated A591/HVA and the PSA/Pit 3 APCs), as well as the remaining A59 area (referred to as A59 "other areas"). As all of these are in close proximity to each other, cases have been considered in which intrusions intersect material from more than one of these. A range of representative and suitably conservative intrusion cases have been assessed based on the geometry and inventory of each area, and assumption of a nominal layer of clean cover material (0.5 m in the Reference Case).

7.7.1 A59 Other Areas

452 Assessment of doses from intrusions into the A59 Other Areas has considered five cases. Further cases in which the A59 Other Areas are partially intruded into are considered as part of the A591/HVA area intrusions. As the A59 Other Areas comprise the greatest area within the A59 feature group, all relevant intrusion types assuming intrusion wholly into the A59 Other Areas have been assessed; these are detailed in Table 7.10. The locations of each intrusion case are illustrated in Figure 7.21.

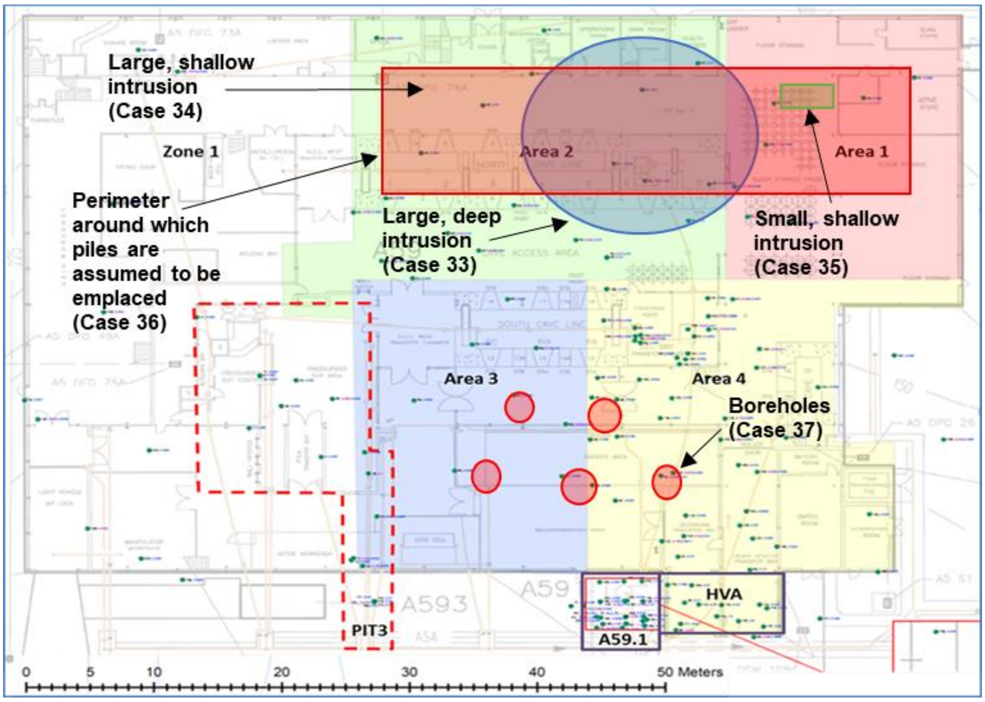

Figure 7.21: Plan view of the A59 Other Areas (labelled "Area 1", "Area 2", "Area 3" and "Area 4") showing the location of the intrusions considered in Cases 33, 34, 35, 36 and 37.

Table 7.10: Calculation cases considered in the assessment of inadvertent human intrusion into the A59 Other Areas (illustrated in Figure 7.21).

Case	GIM Intrusion Type	Dimensions	Features Intersected / Overlapping Area	Explanation
33	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	A59 Other Areas (excluding A591 /HVA and PSA/Pit3 areas) (314 m^2)	A large-scale deep intrusion into the A59 Other Areas. This case is considered due to the “Other Areas” having the largest area (larger than the A591/HVA and PSA/Pit3 areas).
34	Large-scale, shallow	300 m^2 intrusion (assumed to be a 10 m by 30 m rectangle), 2 m deep	A59 Other Areas (excluding A591 /HVA and PSA/Pit3 areas) (300 m^2)	A large-scale shallow intrusion into the A59 Other Areas.
35	Small-scale, shallow	5 m^2 intrusion, 2 m deep	A59 Other Areas (excluding A591 /HVA and PSA/Pit3 areas) (5 m^2)	A small-scale shallow intrusion into the A59 Other Areas.
36	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	A59 Other Areas (excluding A591 /HVA and PSA/Pit3 areas) (1.3 m^2)	The 40 piles are assumed to be emplaced approximately every 2 m around a 30 m by 10 m perimeter within the A59 Other Areas (based on assumptions made in GIM [134, §4.2.5]).
37	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	A59 Other Areas (excluding A591 /HVA and PSA/Pit3 areas) (0.2 m^2)	All five boreholes are assumed to be emplaced into the A59 Other Areas.

7.7.2 A591/HVA Area

453 Assessment of doses from intrusions into the remediated A591/HVA area has considered five cases. Due to the size of the area, a number of these cases also intersect the surrounding A59 Other Areas. Details of the cases assessed are given in Table 7.11 and the locations are illustrated in Figure 7.22 to Figure 7.24.

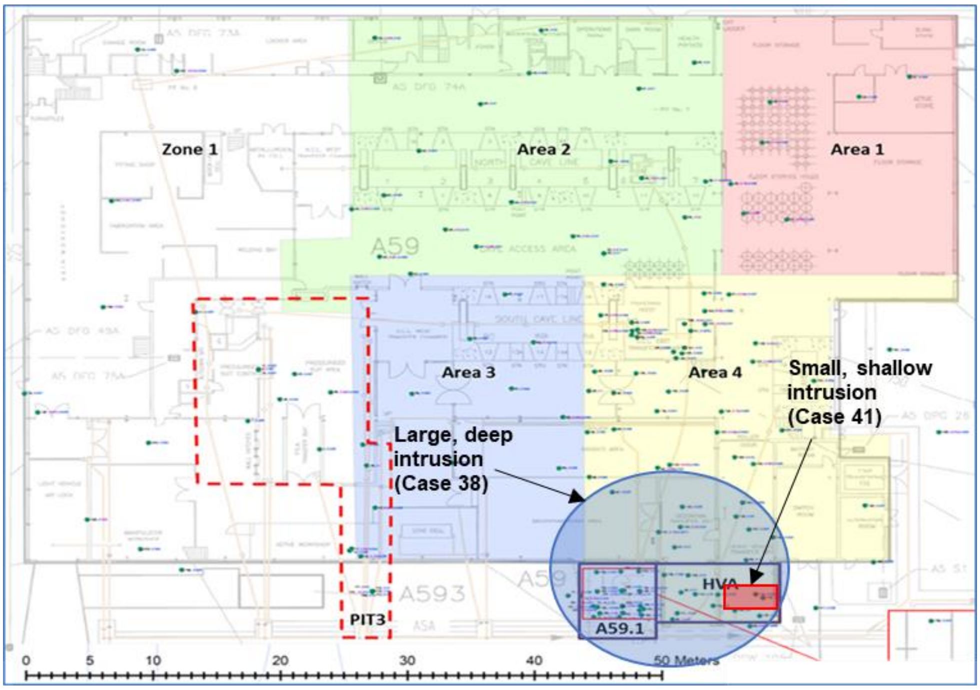

Figure 7.22: Plan view of the A59 area showing the location of the intrusions considered in Cases 38 and 41 for the A591/HVA area.

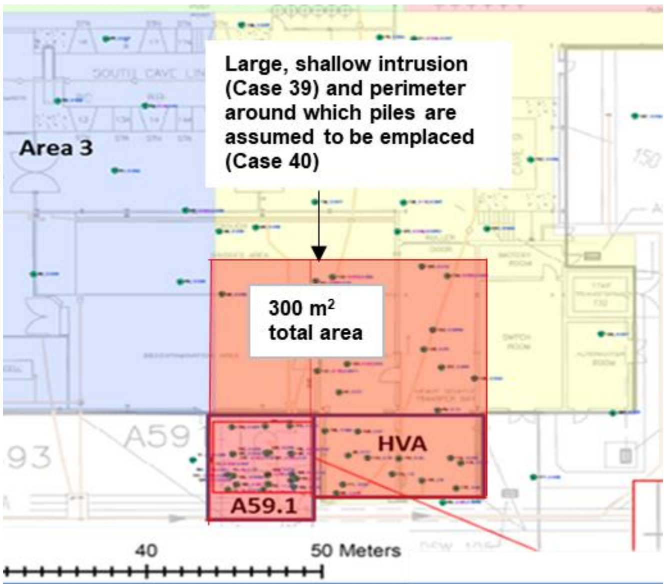

Figure 7.23: Plan view of the A59 area showing the location of the intrusions considered in Cases 39 and 40 for the A591/HVA area.

Table 7.11: Calculation cases considered in the assessment of inadvertent human intrusion into the A591/HVA area and surrounding A59 Other Areas (illustrated in Figure 7.22 to Figure 7.24).

Case	GIM Intrusion Type	Dimensions	Features Intersected / Overlapping Area	Explanation
38	Large-scale, deep	20 m diameter circular intrusion (314 m^2), 5 m deep	The whole A591/HVA area (81.7 m^2), and surrounding A59 other areas (232.3 m^2)	The remediated A591/HVA area has the highest activity concentration of the A59 features and so a large, deep intrusion excavating the whole A591/HVA area is considered. As the A591/HVA area is 81.7 m^2 and the area of the large, deep intrusion in GIM is 314 m^2, it also extracts 232.3 m^2 of the A59 Other Areas.
39	Large-scale, shallow	300 m^2 intrusion (assumed to be a 10 m by 30 m rectangle), 2 m deep	The whole A591/HVA area (81.7 m^2), and surrounding A59 Other Areas (218.3 m^2)	A large-scale shallow intrusion into the remediated A591/HVA area and surrounding A59 Other Areas.
40	Pile array	0.2 m diameter circular intrusion (0.03 m^2), 6 m deep, 40 piles in the array	11 piles into the A591/HVA area (0.3 m^2), 29 piles into the A59 Other Areas (0.9 m^2)	A pile every 2 m around a perimeter enclosing a 300 m^2 area (GIM default is a 30 m x 10 m rectangle; a different perimeter but still enclosing the same area has been assumed here (see Figure 7.23) to maximise the number of piles into the A591/HVA area). The number of piles into each area has been calculated assuming the 300 m^2 area includes the full A591/HVA area (81.7 m^2) which corresponds to approximately 27%. Assuming 40 piles in the array (based on the default GIM assumption) results in approximately 11 piles into the A591/HVA area.
41	Small-scale, shallow	5 m^2 intrusion, 2 m deep	A591/HVA Area (5 m^2)	A small-scale shallow intrusion into the remediated A591/HVA area.
42	Borehole array	0.2 m diameter circular intrusion (0.03 m^2), 20 m deep, 5 boreholes in the array	A591/HVA area (0.2 m^2)	All five boreholes are assumed to be drilled into the remediated A591/HVA area.

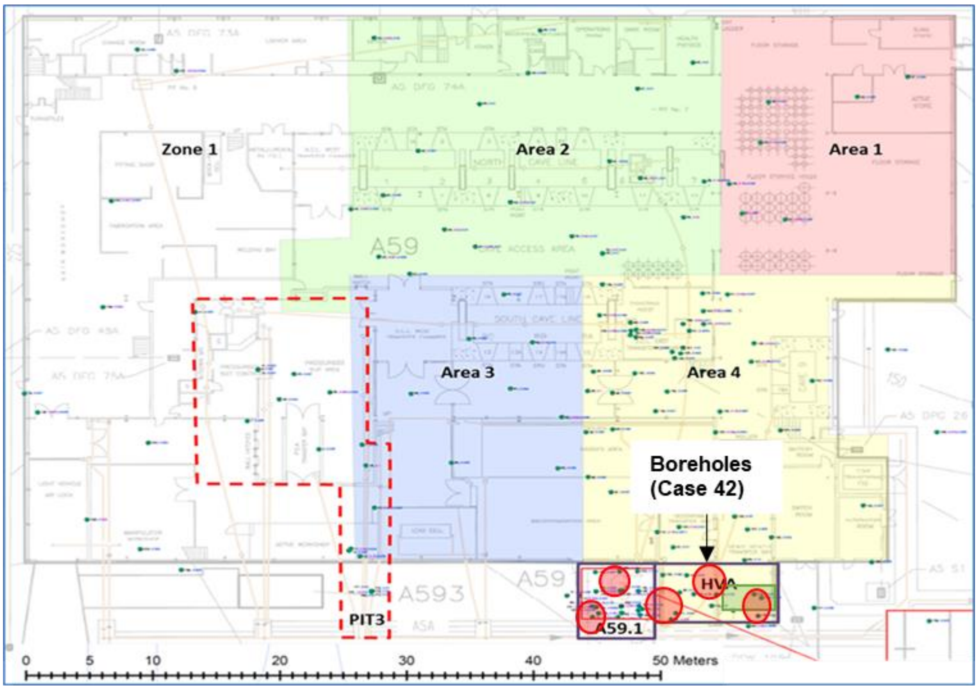

Figure 7.24: Plan view of the A59 area showing the locations at which boreholes are assumed to be emplaced within the A591/HVA area in Case 42.

7.7.3 PSA/Pit 3 Area

454 Due to the size of the PSA/Pit 3 area (16.8 m^2), assessment of doses from intrusions into it have only considered one case. The details of this case are given in Table 7.12 and the location of the intrusion is illustrated in Figure 7.25.

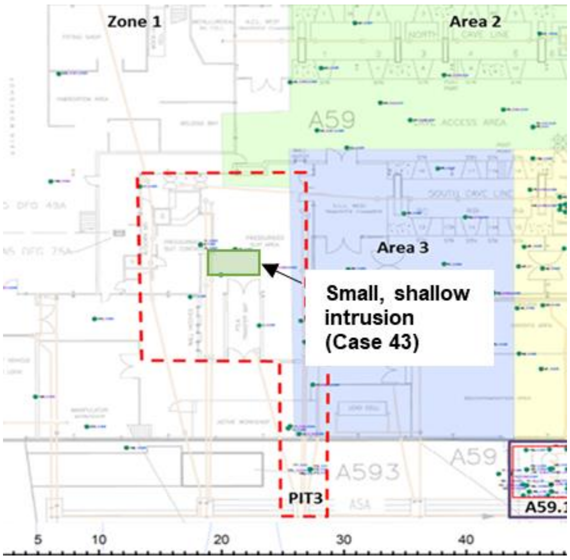

Figure 7.25: Plan view of the A59 area showing the location of the intrusion considered in Case 43.

Table 7.12: Calculation case considered in the assessment of inadvertent human intrusion into the PSA/Pit 3 area (illustrated in Figure 7.25).

Case	GIM Intrusion Type	Dimensions (GIM defaults)	Features Intersected / Overlapping Area	Explanation
43	Small-scale, shallow	5 m^2 intrusion, 2 m deep	PSA/Pit 3 Area (5 m^2)	A small-scale shallow intrusion into the remediated PSA/Pit 3 area. Note that large, deep and large, shallow intrusions into the PSA/Pit 3 area are not considered, as the area of this APC is very small (16.82 m^2) and these intrusions would be bounded by the large, deep and large, shallow intrusions already considered for A59 (due to the lower activity concentration in the PSA/Pit 3 area for the average activity). Pile and borehole intrusions are also not considered as these would be bounded by piles/boreholes into the A59 Other Areas and the A591/HVA APC area.

8 Summary of Assessed Cases and Scenarios

8.1 Reference Case

455 Table 8.1 provides a summary of the key Reference Case parameters and assumptions set out in full in Sections 5, 6 and 7.

Table 8.1: Summary description of the key parameters and assumptions made in the Reference Case for the natural evolution, human intrusion and site occupancy models. Details of the conceptual model elements mentioned here can be found in the relevant modelling sections.

Reference Case Key Parameters/Assumptions Summary	
Natural Evolution Model	
Near-field	• Consider the reference inventory, which is a cautious but credible estimate of the expected activity to remain on the site at the IEP • Conservatively assume thinner contamination layers • Radionuclides associated with structure and block contamination layers are realistically modelled to diffuse through the layer before being released to porewater • Radionuclides associated with rubble are cautiously assumed to be instantaneously available for release from the source material to porewater • Model the conceptual end state design, with concrete blocks and rubble in SGHWR Region 1 and inside Dragon Wall C, with rubble in the remaining areas (and clean grout in the Dragon primary mortuary holes) • Assume that only the thick reinforced SGHWR Region 1 and Region 2 boundary walls and floor and the Dragon reactor floor slab retain their integrity during end state implementation and present a barrier to flow • No credit taken for any other parts of the end state structures inhibiting flow • Reasonable estimates assumed for concrete hydraulic and chemical degradation periods, and for initial concrete hydraulic conductivity • Best estimate values applied for degradation of the cap and infiltration • Assumes the expected groundwater levels at the model start, the Cautious Central Estimate for climate change for groundwater levels to 2100, and then assumes that the groundwater levels remain constant for the remainder of the assessment • Enhanced hydrogeological modelling applied to realistically model saturation of the disposals rather than to assume the system is fully saturated from model start • Best-estimate partition coefficient values are applied
Geosphere	• The heights of the transport pathways are cautiously narrow (but account for predicted water table changes) and the widths are limited to the widths of the relevant feature, with transverse dispersion cautiously neglected • Transport path distances are credible, but are at the shorter end of the possible range • The expected dominant flow path directions predicted by hydrogeological modelling are modelled, with SGHWR and A59 releases split equally between the Land/Mire and the River compartments

Reference Case Key Parameters/Assumptions Summary	
Natural Evolution Model	
	• Cautiously assume all groundwater emerges at a single place to a surface water feature or area of land • Best-estimate partition coefficient values are assumed
Biosphere	• The modelled biosphere compartments are credible • The area assumed for the Land/Mire compartment is cautiously large but credible • The modelled transient wet/dry nature of the mire and low annual average water flow through it is an estimate of the anticipated mire system • The length of the River compartment conservatively does not account for the bends along its length, so maximises activity concentration • The Field is defined based on local and best estimate values, and is assumed to extend the length of the River compartment • Best-estimate partition coefficient values are applied • Best-estimate biosphere uptake factors are applied • Recommended dose coefficient values are applied • RPs are identified based upon existing human behavioural habits on and around the site as well as the future envisaged use of the site, as well as bounding habits assuming knowledge of the on-site disposals has been lost • RP habits are parameterised primarily using survey data for the local area, cautiously assuming high-rate values, and consider a range of credible exposure pathways • Dose calculations assume that the RP scenarios occur (probability of unity), but this is expected to be conservative for some RPs
Site Occupancy and Human Intrusion Models	
• Model the reference inventory, which is a cautious but credible estimate of the expected activity to remain on the site at the IEP • Model the conceptual end state design, with concrete blocks and rubble in SGHWR Region 1 and inside Dragon Wall C, with rubble in the remaining areas (and clean grout in the Dragon primary mortuary holes) • Model the conceptual design cap thickness for the SGHWR and Dragon reactor complex • Assume realistic thickness of clean cover material for the A59 remediated area • Assume that no radionuclides are leached from the disposals so the maximum (decayed) inventory always contributes to dose; this assumption is increasingly conservative over time • Site Occupancy RPs are identified based upon existing human behavioural habits on and around the site as well as possible future uses of the site • Assume that no human intrusion occurs until the SRS; assume knowledge of the on-site disposals has been lost from this point • Assume that only site occupancy activities involving transient site access (not residency) are possible between the IEP and the SRS	

8.2 Alternative Assessment Cases and Variant Scenarios

456 As set out in Section 4, the outcome of the scenario identification methodology followed in this PA and described in detail in Appendix C is a set of scenarios and assessment cases. This consists of two sub-sets: one for use in the natural evolution assessment and one for use in the human intrusion and site occupancy assessments. The human intrusion and site occupancy dose pathways are grouped together because there are strong similarities between these assessments (they both consider only in-situ radioactivity at fixed points in time and use much simpler, more constrained models than the natural evolution assessment). Many of the uncertainties considered are only relevant to the natural evolution model, and those that are relevant to all three assessments tend to be treated the same in the human intrusion and site occupancy assessments, but often differently in the natural evolution assessment (see Appendix C.4 for details).

457 Table 8.2 and Table 8.3 present the set of scenarios and assessment cases identified for the Winfrith natural evolution assessment, and human intrusion and site occupancy assessments respectively. The tables also include the modelling approach used and provide cross-references to sections of the report or appendices where further detail is presented, including explanation of the assumptions underlying the cases and scenarios. Note that these tables are intended to be digestible summaries and further detail can be found in Table C.8.

458 With regard to the modelling approach, as explained in Section 2.5, there are two main approaches that can be used to model the alternative assessment cases, variant concept and configuration scenarios, and "what-if" scenarios:

- Parameter alteration – Changing specific parameter values, relative to the Reference Case assessment. These changes can alter the properties of components, the timing of events or the rate or magnitude of specific processes considered in the assessment conceptual models, but do not fundamentally change the modelling approach. This approach is used for all of the alternative assessment cases, and some of the variant and "what-if" scenarios (including all of those in the human intrusion and site occupancy assessments).
- Conceptual model alteration – Only relevant for the natural evolution assessment, involving changes to the assessment conceptual models and their implementation in the software package GoldSim. This is only undertaken for certain scenarios considering alternative configurations, conceptual models or future evolutions that are significantly different from that considered in the Reference Case assessment.

459 Note that the Reference Case and all alternative assessment cases and variant scenarios for human intrusion include the same range of "intrusion types"; these consider different types of intrusion event into different parts of the radioactive features remaining on the Winfrith site at the end state. Because these intrusion events apply to all scenarios and assessment cases, they are not included in the following tables, but they are defined in Sections 7.5, 7.6 and 7.7 for SGHWR, the Dragon reactor complex and A59, respectively.

Table 8.2: Scenarios and assessment cases considered in the Winfrith natural evolution assessment (summarised from Table C.8 and Table C.9).

<table>
<tr><th>Scenario</th><th>Assessment case</th><th>Description</th><th>Reason for inclusion</th><th>Modelling approach</th><th>Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)</th></tr>
<tr><td rowspan="5">Expected evolution</td><td>EE.1.0 Reference Case</td><td>The expected evolution of the site, defined based on the current understanding of the proposed on-site disposals (i.e. reference configuration with the main inventory estimate), the Winfrith site and local surrounding region.</td><td>Expected evolution, based on realistic and best estimate parameter values including a cautious best estimate inventory.</td><td>-</td><td>• The expected evolution of the proposed on-site disposals, the site and the surrounding region is outlined in Section 3.4.
• The conceptual models associated with the Reference Case are presented in Sections 5.2 to 5.4, with a summary of key assumptions presented in Section 8.1.
• The parameter values for the Reference Case are presented in Appendices D.1 to D.4.</td></tr>
<tr><td>EE.1.1 Alternative inventories</td><td>Case using the alternative SGHWR, Dragon reactor complex and A59 inventory estimates (as derived in the Radiological Inventory Report) as the source terms.</td><td>Captures various uncertainties in inventory derivation, including uncertainty in fingerprint, total activity and dimensions – see Table 3.7 and Table C.8 for further detail.</td><td>Parameter alteration</td><td>• Values altered from the Reference Case are presented in Appendix D.2.2.
• The source term inventory is discussed in Section 3.3.4, with the key inventory uncertainties and approach to addressing them in the alternative inventory summarised in Table 3.7.</td></tr>
<tr><td>EE.1.2 Alternative (Pu) Dragon inventory</td><td>Case using the alternative Dragon reactor complex inventory including a general building contamination inventory derived using a Pu-containing fingerprint (as derived in the Radiological Inventory Report) as the Dragon reactor complex source term.</td><td>Although not considered likely, the presence of Pu isotopes in the Dragon reactor complex cannot be ruled out. Case allows exploration of potential impact of Pu on doses.</td><td>Parameter alteration</td><td>• Values altered from the Reference Case are presented in Appendix D.2.2.
• The source term inventory is discussed in Section 3.3.4, with the key inventory uncertainties and approach to addressing them in the alternative inventory summarised in Table 3.7.</td></tr>
<tr><td>EE.1.3 Minimum near-field sorption</td><td rowspan="2">Cases considering minimum and maximum partition coefficients (K_d values) of radionuclides to concrete in the near field.</td><td rowspan="2">Limited site-specific data. Cases allow range of possible generic values to be assessed.</td><td rowspan="2">Parameter alteration</td><td rowspan="2">• Values altered from the Reference Case are presented in Appendix D.2.3.
• Modelling of sorption to near-field concrete is discussed in Section 5.2.1.</td></tr>
<tr><td>EE.1.4 Maximum near-field sorption</td></tr>
</table>

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
	EE.1.5 Minimum concrete and rubble porosity EE.1.6 Maximum concrete and rubble porosity	Cases considering minimum and maximum porosity of undegraded concrete in blocks and in other demolition arisings in the SGHWR and the Dragon reactor complex, and in the rubble used to infill the voids.	Relevant porosities are uncertain. Cases allow range of possible values to be assessed. With EE.1.7 and EE.1.8, also covers uncertainties in density and particle size and shape of demolition arisings.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2.3. • The properties of undegraded concrete are discussed in Section 5.2.1. • The properties of rubble are discussed in Section 5.2.1.
	EE.1.7 Minimum dry bulk concrete density EE.1.8 Maximum dry bulk concrete density	Cases considering minimum and maximum density of in-situ concrete and concrete blocks.	Limited site-specific data. Cases allow range of possible generic values to be assessed. With EE.1.5 and EE.1.6, also covers uncertainties in density and particle size and shape of demolition arisings.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2.3. • The properties of undegraded concrete are discussed in Section 5.2.1.
	EE.1.9 Minimum geosphere sorption EE.1.10 Maximum geosphere sorption	Cases considering minimum and maximum partition coefficients (K_d values) of radionuclides to the geosphere (Poole Formation).	Limited site-specific data. Cases allow range of possible generic values to be assessed.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.3. • Modelling of sorption to the geosphere is discussed in Section 5.3.1.
	EE.1.11 Minimum biosphere sorption EE.1.12 Maximum biosphere sorption	Cases considering minimum and maximum partition coefficients (K_d values) of radionuclides to the biosphere (soil and sediments).	Limited site-specific data. Cases allow range of possible generic values to be assessed.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.4. • Modelling of sorption to the biosphere is discussed in Section 5.4.1.
	EE.1.13 Child RP EE.1.14 Infant RP	Cases considering child and infant RPs.	Physiology and habits of the RP affects the dose received. Cases allow calculation of doses to RPs with range of physiology and habits (for all pathways).	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.4. • The inclusion of RPs of different ages is discussed in Section 5.4.1.

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
	EE.1.15 Minimum uptake factors	Cases considering minimum and maximum uptake factors for transfer of contaminants into the food chain.	Cases bound significant uncertainty in the uptake factors that control the transfer of contaminants from model compartments into foodstuffs consumed by animals or RPs.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.4. • Uptake factors and their use in modelling are discussed in Section 5.4.2.
	EE.1.16 Maximum uptake factors				
	EE.1.17 Minimum mire outflow rate	Cases consider an order of magnitude increase and decrease in the average annual outflow rate from the Land/Mire compartment to the River compartment.	Cases bound significant uncertainty in the rate of outflow from the mire to the River Frome.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.4. • Modelling of the Land/Mire compartment flows is discussed in Section 5.4.1.
	EE.1.18 Maximum mire outflow rate				
Variant concept (VA) scenarios					
VA.1 Shorter chemical degradation duration		Scenario considering the possibility that chemical degradation takes place on the same timescale as hydraulic degradation (1,000 years), instead of 50,000 years.	Addresses uncertainty in the evolution of chemical properties associated with concrete structures by exploring the effect of significantly faster chemical degradation than judged to be likely.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Chemical degradation is discussed in Sections 3.4.1 and 5.2.1.
VA.2 Minimum initial hydraulic conductivity for SGHWR and Dragon reactor building structures		Scenario considering a lower initial hydraulic conductivity for the degraded structures.	Scenarios address uncertainty in initial hydraulic conductivity of concrete structures and its subsequent evolution, which are key parameters. Structural integrity may be affected by preparatory decommissioning works. These scenarios also cover the possibility of damage and assess the potential effects.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Hydraulic conductivity and degradation of concrete is discussed in Section 5.2.1.
VA.3 Maximum initial hydraulic conductivity and shorter degradation period		Scenario considering a higher initial hydraulic conductivity for the degraded structures, followed by linear degradation to reach the final hydraulic conductivity after 300 years instead of 1,000 years.		Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Hydraulic conductivity and degradation of concrete is discussed in Section 5.2.1.

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
VA.4 Shorter cap degradation time		Scenario considering both a shorter time to onset of cap degradation and a faster rate of cap degradation.	Addresses uncertainty in the time to onset, and rate of, degradation of the flexible membrane liner of the cap	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Cap degradation is discussed in Section 5.2.1.
VA.5 SGHWR and A59 groundwater release to River Frome		Scenarios considering alternative groundwater flow paths from the SGHWR and A59 (100% to the River Frome; 100% to the mire; and 100% from SGHWR flows via the Dragon reactor complex to the River Frome). [Reference case assumes 50% from each of SGHWR and A59 flows to the River Frome and 50% to the mire.]	There is uncertainty regarding the distribution of flow over the range of possible groundwater release pathways, which will depend on the hydrological conditions at any given time as well as on the precise mire location and dimensions, particularly for wetter future climates. These cases cover all possibilities.	Conceptual model alteration	• Expected future groundwater flow paths are discussed in Section 3.4.2 and the approach taken to modelling various groundwater pathway alternatives is described in Section 5.3.1.
VA.6 SGHWR and A59 groundwater release to mire					
VA.7 SGHWR groundwater release to the Dragon reactor complex					
VA.8 Increased rate of rainfall infiltration through soil above A59		Scenario considering a higher rate of rainfall infiltration through soil (recharge) for the A59 area.	Covers the possibility that climate change could lead to greater infiltration through soil.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Rainfall infiltration is discussed in Sections 3.4.2 and 5.3.1.
VA.9 Reasonable worst-case future groundwater levels		Scenario using reasonable worst-case estimate of future groundwater levels, instead of the cautious central estimate.	Explores uncertainty regarding the impact of climate change on regional groundwater levels, groundwater flows and future hydrogeological conditions.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Future groundwater levels are discussed in Sections 3.4.2 and 5.3.1.
VA.10 Reasonable worst-case future groundwater levels with seasonal fluctuation		Scenario using reasonable worst-case estimate of future groundwater levels and assuming that groundwater level fluctuates seasonally into the SGHWR	Explores uncertainty regarding the impact of seasonally fluctuating groundwater into the SGHWR Annexes and Dragon reactor basement.	Conceptual model and parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • Future groundwater levels and the approach to modelling seasonal fluctuation of groundwater are discussed in Sections 3.4.2 and 5.3.1.

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
		Annexes and the Dragon reactor basement.			
VA.11 Groundwater abstraction (SGHWR)		Scenario considering the drinking of radioactively-contaminated groundwater abstracted from a well 1 m downstream of each of the source terms.	As groundwater abstraction via wells is an observed present-day habit in the wider area, the possibility of such a well in the future intersecting contaminated groundwater should be considered.	Conceptual model alteration	• The modelling approach and associated Well Abstractor RP are discussed in Section 5.4.
VA.12 Groundwater abstraction (Dragon reactor complex)					
VA.13 Groundwater abstraction (A59)					
Variant configuration (VB) scenarios					
VB.1 Greater void spacing between blocks		Scenario considering wider spacing between blocks emplaced in SGHWR and Dragon disposal voids, leading to increased void space between them.	Increasing the void space between blocks could increase water flow and hence increase radionuclide leaching from the blocks.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • The configuration considered in the Reference Case is discussed in Section 3.2.9.
VB.2 Entirely rubble infill		Scenario considering that the entire void space in both the SGHWR and Dragon disposals is filled with rubble, with no emplacement of blocks.	The relative volume of blocks versus demolition arisings (rubble) to be placed in the voids, and their emplacement locations, is uncertain and could impact radionuclide leaching.	Conceptual model alteration	• The configuration considered in the Reference Case is discussed in Section 3.2.9.
VB.3 Grouting of entire volume		Scenario considering the grouting of the entire remaining void space in both the SGHWR and Dragon disposals following backfilling. [Reference case assumes no grouting.]	The extent to which grout will be used has yet to be optimised, but has potential implications for radionuclide leaching and transport.	Conceptual model alteration	• The configuration considered in the Reference Case is discussed in Section 3.2.9. • The alternative configuration considered in this variant scenario is discussed in Section 5.2.1.

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
VB.4 Minimum block size		Scenarios considering minimum and maximum volume for the blocks to be emplaced in the SGHWR and Dragon disposal voids.	Block size will vary; a smaller block size would be expected to result in greater radionuclide leaching from the blocks.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2. • The configuration considered in the Reference Case is discussed in Section 3.2.9.
VB.5 Maximum block size					
"What-if" scenarios					
WI.1 Instantaneous hydraulic degradation		What-if scenario considering instantaneous hydraulic degradation of the in-situ structural concrete and cap to limit flows. This could result from a natural disruptive event such as a large earthquake. This failure is very conservatively assumed to occur at the IEP.	Explores the worst-case impact of a very unlikely but catastrophic event. Also bounds worst-case damage to structural integrity during decommissioning preparatory works.	Parameter alteration	• Values altered from the Reference Case assessment are presented in Appendix D.2. • Modelling of hydraulic degradation of intact concrete is discussed in Section 5.2.1.
WI.2 Extreme climate change		What-if scenario considering groundwater to 1 m below surface-level.	Explores the impact of groundwater rising to extreme levels as a result of climate change or flooding. Also covers the possibility of bathtubbing, which (although not expected) cannot be ruled out.	Conceptual model alteration	• Climate change and its effects are discussed in Section 3.4.2.

Table 8.3: Scenarios and assessment cases considered in the Winfrith human intrusion and site occupancy assessments (summarised from Table C.8 and Table C.10).

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
HI.1 Expected Evolution	HI.1.0 Reference Case	Reference configuration for on-site disposals with the reference inventory estimate.	Expected evolution, based on realistic and best estimate parameter values including a cautious best estimate inventory.	-	• The reference inventory and structure of the proposed on-site disposals is outlined in Section 3.2.9. • The conceptual models associated with the Reference Case are presented in Sections 6 and 7, with a summary of key assumptions presented in Section 8.1. • The parameter values for the Reference Case are presented in Appendices D.1, D.4 and D.5.
	HI.1.1 Alternative inventories	Case using the alternative SGHWR, Dragon reactor complex and OoS A59 inventory estimates (as derived in the Radiological Inventory Report) as the source terms.	Captures various uncertainties in inventory derivation, including uncertainty in fingerprint, total activity and dimensions – see Table 3.7 and Table C.8 for further detail.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2.2. • The source term inventory is discussed in Section 3.3.4, with the key inventory uncertainties and approach to addressing them in the alternative inventory summarised in Table 3.7.
	HI.1.2 Alternative (Pu) Dragon inventory	Case using the alternative Dragon reactor complex inventory including a general building contamination inventory derived using a Pu-containing fingerprint (as derived in the Radiological Inventory Report) as the Dragon reactor complex source term.	Although not considered likely, the presence of Pu isotopes in the Dragon reactor complex cannot be ruled out. Case allows exploration of potential impact of Pu on doses.	Parameter alteration	• Values altered from the Reference Case are presented in Appendix D.2.2. • The source term inventory is discussed in Section 3.3.4, with the key inventory uncertainties and approach to addressing them in the alternative inventory summarised in Table 3.7.
	HI.1.3 Alternative human intrusion dates	In the human intrusion assessment, alternative cases examine intrusion at dates earlier than 2066 and, where the GRR Requirement R11 dose guidance	Dates earlier than 2066 are included to inform NRS decision making, and dates beyond 2066 are included (where relevant) to identify when	Parameter alteration	• Assessment timeframes are presented in Section 2.2.

Scenario	Assessment case	Description	Reason for inclusion	Modelling approach	Relevant sections and/or appendices (in all cases, further detail is also included in Table C.8)
		level is exceeded at the SRS in the Reference Case, beyond 2066.	the calculated dose falls below the dose guidance level.		
Variant configuration (VB) scenarios					
HI.VB.1 Mid-thickness cap/cover		Cases considering a range of thicknesses for the caps to be emplaced over the SGHWR and Dragon disposals, and the clean cover to be emplaced over the A59 area.	The current concept cap design, including thickness, will be subject to future optimisation, as will the thickness of clean cover to be emplaced over A59. Cover thickness can have a significant impact on doses in human intrusion and site occupancy assessments.	Parameter alteration	• The caps/cover considered in the Reference Case and possible variations in their thickness are described in Section 3.2.9. • Values altered from the Reference Case are presented in Appendices D.4 and D.5.
HI.VB.2 Low-thickness cap/cover					
HI.VB.3 No A59 cover		No clean cover material assumed for the A59 area.		Parameter alteration	• A59 cover options are discussed in Section 3.2.9.

9 Non-Human Biota Model

9.1 The ERICA Methodology

460 The 'Environmental Risk from Ionising Contaminants: Assessment and Management' ERICA methodology [29] and tool [141] has been used to determine the dose effects to non-human biota resulting from aqueous releases from the proposed on-site disposals and contaminated land at Winfrith. The ERICA methodology [29] involves the calculation of dose rates to reference organisms[39] using radionuclide concentration values in environmental media (soil, sediment, air or water).

461 Although the GRR [7, ¶A4.100] notes that there are no statutory criteria for determining radiological protection of the environment or approaches to the assessment of dose effects, it is stated that the UK environment agencies use ERICA for their own assessments of radiological impacts of discharges upon non-human organisms. ERICA has also been used to determine dose to non-human biota as part of the Trawsfynydd Ponds Complex and Disposal Project [142] and for the Dounreay LLW Disposal Facilities [143].

9.1.1 Dose Rate Screening Values

462 Dose rate screening values (measured in units of $\mu Gy\ h^{-1}$), which are derived based on exposure-response information, are provided within the ERICA tool [141] to give a threshold for assessment. Dose rates below the screening value are assumed to be safe for the biosphere, that is, there will be no adverse impacts to species at the population level based on indicators such as mortality, morbidity and reproductive effects.

463 The default dose rate screening level is set to 10 $\mu Gy\ h^{-1}$ in ERICA – this level is deemed sufficiently conservative to assume that no adverse effects are expected in non-human populations below this. The GRR [7, ¶A4.100] notes that this value is also used by the UK environment agencies for the initial assessment of doses from sites in designated conservation areas. Comparison with a level of 40 $\mu Gy\ h^{-1}$ is also possible for terrestrial birds, animals, amphibians and reptiles, with a 400 $\mu Gy\ h^{-1}$ limit for fish and other aquatic organisms. These values, derived from IAEA (1992) and UNSCEAR (1996) reports [144; 145] are designed to provide benchmarks below which non-human populations are unlikely to be harmed and are based upon underpinning scientific literature. The 40 $\mu Gy\ h^{-1}$ limit is also recognised by the UK environment agencies as an appropriate limit to assess dose rate effects to wildlife inhabiting Natura 2000 sites [146].

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[39] A reference organism is defined as '*A series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment*' [141].

9.1.2 Tiered Approach

464 A three-tiered integrated approach is taken in the tool, allowing for the relevant level of detail to be applied proportionate to the risk. The tiers are as follows: Tier 1: Risk Screening, Tier 2: Generic Quantitative and Tier 3: Detailed Quantitative Assessment. Tier 1 is a high-level screening which applies simplified but conservative assumptions. This is aimed at distinguishing areas or receptors of negligible concern (which do not require higher tier assessments) from those which may require further assessment at Tier 2 or 3. Tiers 2 and 3 allow more user-defined options (including the addition of isotopes to the default list) and the use of site-specific data, where available.

465 At Tier 1, results are generated in the form of Risk Quotients (RQs), while at Tiers 2 and 3 both RQs and dose rates are reported. The RQ is a unitless measure of risk. At Tier 1, an RQ is calculated for each radionuclide and is equal to the activity concentration in environmental media divided by the Environmental Media Concentration Limit (EMCL) for the most limiting organism for each radionuclide. EMCLs define the radionuclide concentrations in environmental media at which an organism would be expected to receive a dose equal to the screening level. If the sum of the RQs (ΣRQ) is <1, then it can be assured that there is a very low probability that the assessment dose ratio to any organism exceeds the dose rate screening level and therefore the risk to non-human biota can be considered negligible.

466 At Tier 2, two RQ values are calculated for each reference organism: an expected value, equal to the estimated total dose rate for each reference organism divided by the screening level, and a conservative value, which multiplies the expected RQ by an uncertainty factor (UF). The UF is defined as the ratio between the 95^{th}, 99^{th} or any other percentile (above the expected value) and the expected value of the probability distribution of the dose rate (and RQ), assuming that the dose rate and RQ follow exponential distributions with means equal to the estimated expected values. In this case the UFs corresponding to the 95^{th} and 99^{th} percentiles are equal to 3 and 5 respectively. The use of the UF=3 (i.e. 95th percentile) option results in conservative RQ estimates compatible with the results of Tier 1 (the EMCL value being derived from the 95th percentile value). When a UF of 3 or higher is used, Tier 2 conservative RQ values below one indicate that there is low probability that the estimated dose rate exceeds the screening dose rate and the risk to non-human biota can be considered to be trivial, based on analyses of effects data conducted to derive the ERICA screening dose rate.

9.2 Winfrith Assessment Approach

467 Assessments have been conducted for the full Winfrith site using Version 2.0 of the ERICA dose assessment tool [141], taking into account the source terms from the SGHWR, the Dragon reactor complex and the OoS A59 area (considered together). Separate assessments were conducted for the three biosphere compartments in the natural evolution assessment model (described in Section 5):

- Field;
- Land/Mire; and

- River Frome.

468 The peak environmental concentration values in these compartments are calculated in the natural evolution assessment model. Following the approach used in the recent Trawsfynydd non-human biota assessment [142], the peak environmental concentration values are based on the Reference Case as defined in Section 4. However, because the Winfrith reference inventory is not considered to be bounding, two alternative cases have also been assessed, one using the alternative (more conservative) inventories for the SGHWR, Dragon reactor complex and OoS A59 area feature groups, and the second using the Pu fingerprint alternative inventory for Dragon general building contamination. Of the other alternative cases and scenarios assessed in the natural evolution model, all of those potentially relevant to the non-human biota assessment are expected to have significantly less impact than the alternative inventory cases and so none have been included in the non-human biota assessment.

469 At Tier 1, 17 of the radionuclides included in the natural evolution assessment are not available in the ERICA tool[40]. Depending on the compartment and inventory, the missing radionuclides constitute up to 7% of the peak environmental radioactivity concentration. To ensure that the calculated dose rates sufficiently reflect the inventory, assessments have therefore been carried out at Tier 2, where additional radionuclides can be added. There are still three radionuclides for which there is insufficient default data to include at Tier 2[41], but even without these, the Tier 2 assessments cover 100% of the peak environmental radioactivity concentration in all compartments with all inventory estimates, to at least six significant figures.

470 The ERICA default screening level (10 μGy h^{-1}) has been used as a benchmark dose value, providing a conservative assessment that is appropriate for the location of the Winfrith site which sits within a SSSI as well as a Dorset Heath Special Area of Conservation (SAC), a Dorset Heathlands Special Protection Area (SPA) and a Dorset Heathland Ramsar site, as detailed in Section 3.2.1.

9.3 Model Inputs and Assumptions

471 Environmental concentration values calculated in Bq L^{-1} for the freshwater compartments and Bq kg^{-1} for terrestrial compartments as part of the natural evolution assessment model inform the ERICA model, as shown in Table 9.1. Given that site-specific concentrations are available for both water and sediment in the freshwater ecosystems, partition coefficient (K_d) values, although a required input in ERICA, are not actually used in the assessment and so results are unaffected by whether the K_d

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40 These are ^{227}Ac, ^{243}Am, ^{133}Ba, ^{41}Ca, ^{113m}Cd, ^{155}Eu, ^{55}Fe, ^{178n}Hf, ^{93m}Nb, ^{193}Pt, ^{242}Pu, ^{151}Sm, ^{121m}Sn, ^{229}Th, ^{233}U, ^{236}U and ^{93}Zr.

41 These are ^{178n}Hf, ^{193}Pt, and ^{121m}Sn. To be included, concentration ratios (CR; the ratio of the element in each reference organism compared to each reference media) are required; there are no default values in ERICA for these radionuclides and no site-specific data are available. There are also no default values in ERICA for ^{55}Fe and ^{151}Sm; however, CR values for these were taken from [147].

values input to the model are the ERICA defaults or those used for other aspects of the PA.

472 It is debatable whether the mire, which is expected to be shallow and ephemeral, should be modelled as a terrestrial or freshwater ecosystem. The former may be more appropriate during drier times when pools of standing water evaporate, while the latter may be more appropriate during wetter times when pools of standing water will be present, although it is likely that some freshwater species associated with more permanent freshwater features such as lakes would be absent. Therefore, both types of ecosystem have been modelled for the Land/Mire compartment, with the results expected to bound the actual impact on non-human biota in the mire.

Table 9.1: ERICA input values for each compartment modelled in the non-human biota assessment.

Compartment	Ecosystem type	Water Concentrations (Bq/L)	Soil/sediment concentrations (Bq/kg)
Field	Terrestrial	Not applicable	Direct output from natural evolution model
Land/Mire	Freshwater	Direct output from natural evolution model	Direct output from natural evolution model[42]
	Terrestrial	Not applicable	Direct output from natural evolution model[42]
River Frome	Freshwater	Direct output from natural evolution model	Direct output from natural evolution model

473 The actual values used in the assessments, as output from the natural evolution model, are presented in Appendix D.6: Table D.114 shows the values when the reference inventory is used as the source term, Table D.115 shows the values when the alternative inventory is used as the source term and Table D.116 shows the values when the Pu-fingerprint alternative inventory is used as the source term.

474 A number of conservatisms, both in terms of parametrisation and model implementation, in the natural evolution model are relevant to the ERICA assessment are described in Sections 5.2.1 and 5.3.1. The ERICA assessment mirrors the conservative approach taken in the natural evolution assessment model, adopting assumptions (where necessary) that are cautious and bounding. Key assumptions made in the ERICA assessment are listed below:

- All media concentrations used as input to the ERICA modelling tool assume that peak release rates into each biosphere compartment (and hence peak media

[42] The mire is modelled in the natural evolution assessment as soil and water; therefore the model outputs peak activity concentrations for mire soil. As ERICA inputs, these are used for soil concentrations when the mire is modelled as a terrestrial ecosystem and sediment concentrations when the mire is modelled as a freshwater ecosystem.

concentrations) occur at the same time for all radionuclides. It is unrealistic that each radionuclide would peak at the same time; rather radionuclides will peak at different intervals over many years (as modelled in the natural evolution assessments).

- In the absence of site-specific information, it is assumed that entire populations of sensitive ecological organisms (flora and fauna) would be present across the entirety of the modelled segments covered under the scope of this assessment. Applying the full suite of reference organisms in the ERICA modelling tool under a regime of maximum environmental media concentrations provides a bounding assessment in the effects of radioactive substances to wider sensitive receptors and designations surrounding the Winfrith site.
- It is assumed that entire populations of non-human biota species would reside in the modelled compartments. For some ecosystem-organism pairs, this assumption may be conservative as, in reality, populations of species could extend beyond just the modelled compartments.

10 Calculated Radiological Impacts

475 The calculated radiological impacts (dose and risk rates) from all the exposure pathways, scenarios and assessment cases outlined in Section 4.4 are presented in this section.

- The radiological impacts assessed using the NE assessment model described in Section 5 are presented in Sections 10.1 to 10.3. Section 10.1 presents the results for the expected evolution scenario, which consists of the Reference Case assessment and the 18 associated alternative assessment cases, Section 10.2 presents the results for the 18 variant scenarios and Section 10.3 presents the results from the two "what-if" scenarios.
- Results from the site occupancy calculations outlined in Section 6 are presented in Section 10.4.1 for the Reference Case and in Section 10.4.2 for a series of variant cases considering the alternative inventory and thinner engineered caps and cover material.
- Radiological impacts to humans from inadvertent intrusion into each of the on-site disposal features, in accordance with the model described in Section 7, are presented in Section 10.5.1 for the Reference Case and in Section 10.5.2 for a series of variant assessment cases considering alternative inventory estimates, earlier intrusion and thinner engineered cap/cover thicknesses.
- Finally, the radiological impacts to non-human biota assessed using the ERICA methodology set out in Section 9 are summarised in Section 10.6.

10.1 Natural Evolution - Expected Evolution Scenario

476 The expected natural evolution scenario is defined based on the current understanding of the proposed on-site disposals, site characteristics and the local surrounding region, and how these are expected to evolve over time (undisturbed by human intrusion), as summarised in Section 3. This understanding has been used to develop the conceptual and mathematical model described in Section 5, which considers aqueous release and transport of radionuclides from the near field, through the geosphere and to the biosphere. The resulting potential radiological impacts to humans calculated for the expected evolution scenario are presented in this section.

477 As described in Section 4, the expected evolution scenario encompasses the Reference Case assessment, which assumes best estimate and reference parameter values, and a set of alternative assessment cases that investigate the impact of parameter uncertainty in the Reference Case assessment. The calculated radiological impacts for the Reference Case are presented in Section 10.1.2 and those for the alternative cases are presented in Section 10.1.3. However, this section commences in Section 10.1.1 with discussion of the dynamic water balance implemented in the model and how this evolves over time for the Reference Case.

10.1.1 Water Balance

478 A key element of the Winfrith NE model is implementation of a dynamic water balance in the near field, that accounts for changing groundwater levels and saturation of the concrete reactor structures. This has been implemented in GoldSim via sub-containers, which are deactivated once a stable hydraulic system has been reached in each feature (inflow equals outflow) in order to reduce the computational load.

479 Figure 10.1 shows the evolution of the water balance for the SGHWR Region 1 feature under the Reference Case assumptions for the Expected Evolution Scenario. There is no flow in or out of the feature for the first five years of the model run (model start in 2027), until the SGHWR disposal is assumed to be implemented in 2032. Thereafter, inflow commences with water infiltrating the engineered cap at a rate of 5 mm y^{-1} and groundwater gradually makes its way through the intact concrete walls according to Darcy's law – no flow across the base is assumed as the SGHWR basement sits in a hard clay layer. The inflow rate from groundwater decreases as the head difference between the internal and external water levels reduces (as the water volume inside the void increases), and the overall inflow rate remains constant from 87 years. The water volume inside the void reaches its maximum at about 145 years (Figure 10.2). At this point, the outflow rate from the void to the surrounding near field exceeds the inflow rate and the water volume starts to decrease.

480 At 250 years after the SGHWR disposal is implemented, the engineered cap is assumed to start degrading and its infiltration rate linearly increases to 43 mm y^{-1} over the next 750 years. By about 320 years, the inflow and outflow rates are considered to be balanced – this is triggered in the model when a positive head is assumed not to inhibit groundwater driven inflow, which is specified to be when the positive head difference is less than the local geosphere gradient (0.01 for SGHWR) across half the length of the feature (~30 m for Region 1; the up-gradient wall to the centre of the void). This means that if the head difference is less than 15 cm over the 30 m length, the system is regarded as balanced and the hydraulic container deactivated. The impact of reducing the trigger value by a factor of ten was tested; this reduced the visibility of the step change in Figure 10.1, but led to no noticeable change in the final water volumes or elevations and significantly increased the time required by hundreds of years. Therefore, the current requirement was regarded as appropriate. Once the system is balanced, the internal water elevation is calculated to remain fractionally above the external groundwater elevation (by 23 cm, see Figure 10.2).

481 The concrete hydraulic conductivity continues to exponentially increase after the flows are balanced, and the cap infiltration rate linearly increases, until 1000 years after the SGHWR Disposal Start Date (Figure 10.1). The magnitude of the inflow and outflow rates increases, but they remain equal, and the water volume stored in the void does not change. In the longer term over the next tens of thousands of years, concrete chemical degradation takes place, where the increasing porosity and decreasing density means a slightly greater water volume can be stored, but the water elevations remain the same.

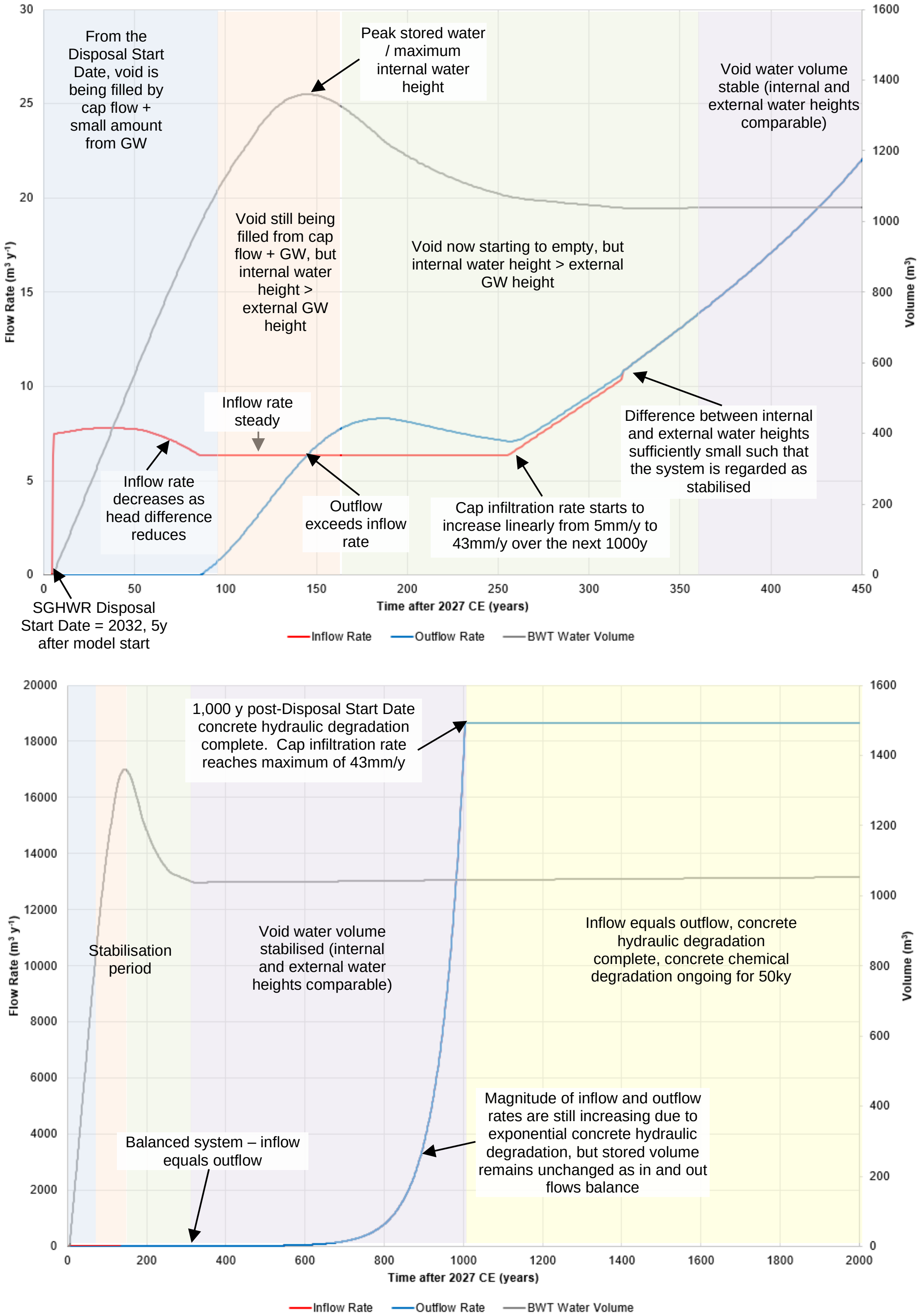

Figure 10.1: Inflow and outflow rates (left axis), and internal void water volume (right axis), for the SGHWR Region 1 void feature for the Reference Case. Top plot shows the system hydraulics at early times.

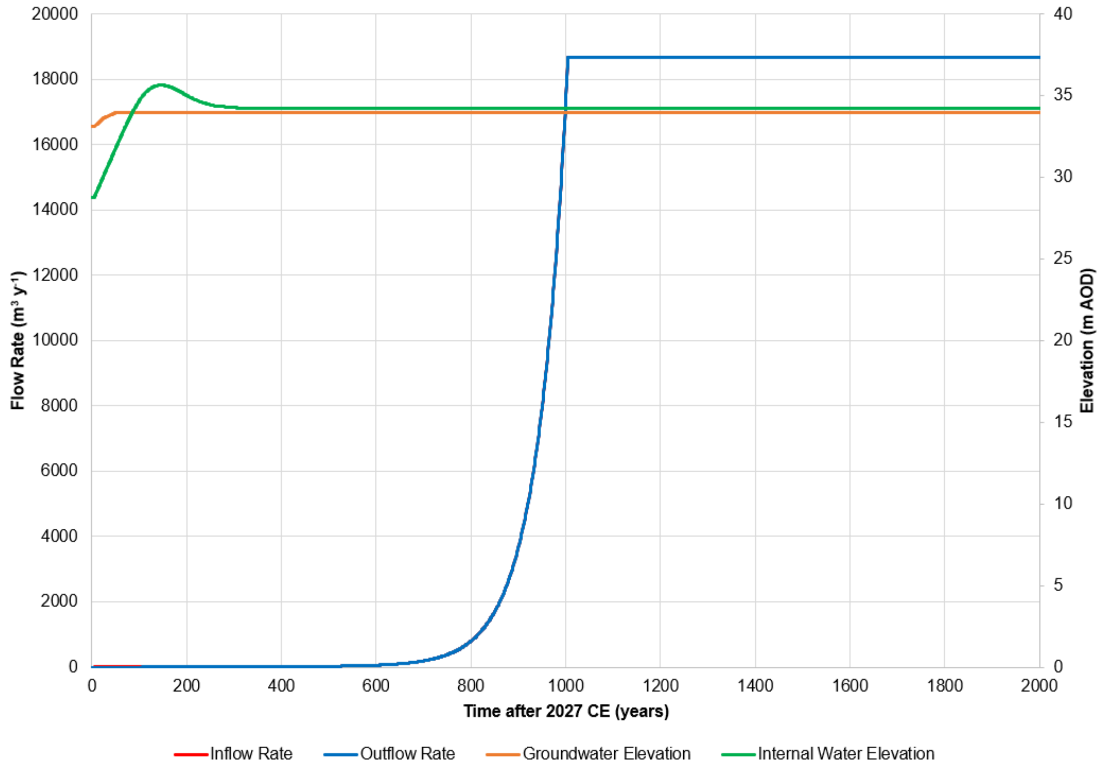

Figure 10.2: Inflow and outflow rates (left axis), and external and internal water elevations (right axis), for the SGHWR Region 1 void feature for the Reference Case.

482 The contrast in system hydraulics with a feature that is assumed to have degraded concrete walls and floor from the Disposal Start Date is illustrated for the SGHWR South Annexe in Figure 10.3, for the Reference Case of the Expected Evolution Scenario (i.e. best estimate data for future water levels). Here it can be seen that the inflow equals the outflow in less than ten years after the SGHWR Disposal Start Date. As the base elevation of the South Annexe is above the external groundwater elevation for the entire period of the Reference Case, there is no groundwater inflow component. Thus, the change in inflow rate over time is driven only by the assumptions for cap infiltration over the period to 1,000 years after the Disposal Start Date. There is no concrete hydraulic degradation effect over this period since the concrete is assumed to have the maximum hydraulic conductivity from the Disposal Start Date onwards. The small increase in internal water elevation over the period between 255 and 1,005 years corresponds to storage of a thin layer of water that develops due to the assumed cap infiltration rate fractionally exceeding the outflow rate when the cap infiltration rate is increasing.

483 The same hydraulic behaviour is observed for the SGHWR North Annexe, as this is also assumed to have degraded concrete walls and floor from the Disposal Start Date and the base lies above the external groundwater elevation.

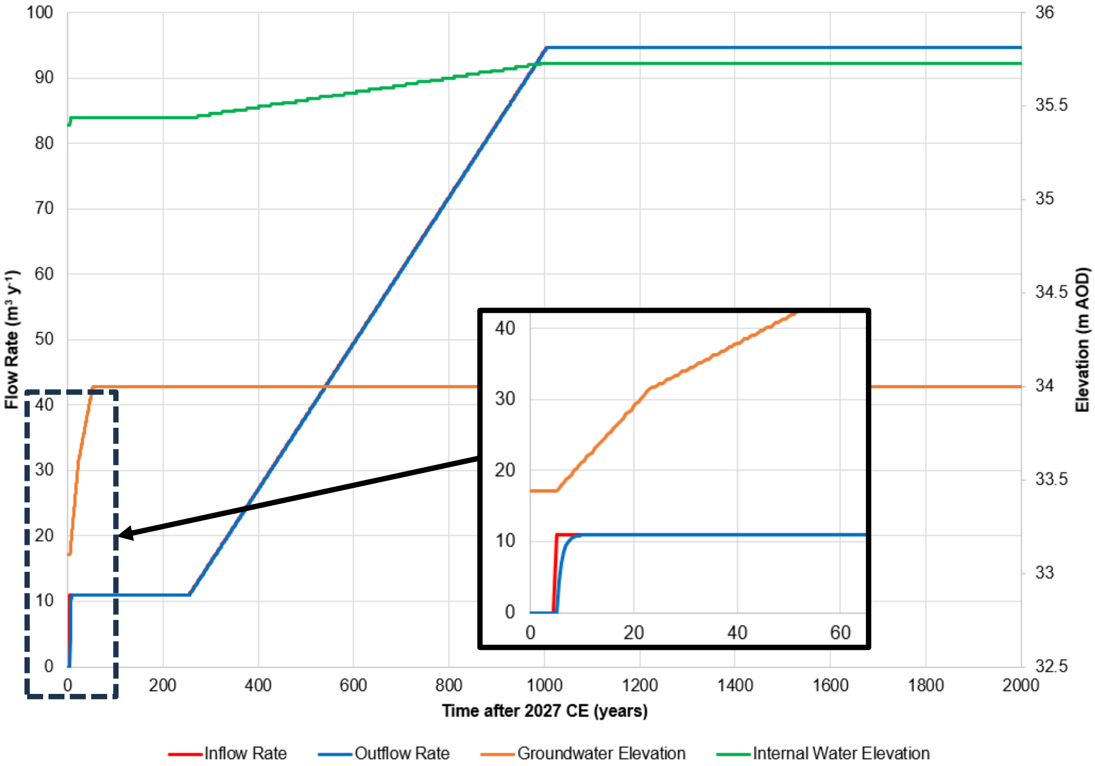

Figure 10.3: Inflow and outflow rates (left axis), and external and internal water elevations (right axis), for the SGHWR South Annexe void feature for the Reference Case.

10.1.2 Reference Case Assessment

Entire Site Combined Impacts

484 The total calculated peak annual dose rates resulting from natural evolution of the proposed Winfrith on-site disposals in the Reference Case assessment are summarised in Table 10.1 for each of the RPs, whilst dose rates as a function of time are shown in Figure 10.4. The radiological performance measure shown in Figure 10.4 is the GRR risk guidance level (RGL) of 1E-06 y^{-1} (GRR Requirement R10, the dose equivalent of which is 0.017 mSv y^{-1} or 1.7E-02 mSv y^{-1}) and the calculations make no assumptions about the length or nature of the period of control after the model start in 2027. However, while the Winfrith site remains subject to RSR and NRS retains control over the site (i.e. in the period up to the SRS), the performance measure is actually the higher source dose constraint of 0.3 mSv y^{-1} (GRR Requirement R9)[43]. As discussed

[43] As discussed in Section 2.1.1, Requirement R9 specifies a dose constraint of 0.3 mSv y^{-1} from any source and 0.5 mSv y^{-1} from any single site. A "source" means a facility, or group of facilities, which can be optimised as an integral whole in terms of radioactive waste disposals. As such, calculated doses that combine the impact of releases from both SGHWR and the Dragon reactor complex should be compared to the higher value. However, the lower source dose constraint is used here on both

previously, it is assumed for the purposes of this assessment that public access to the site is permitted from the IEP, once the disposals have been implemented and operational restoration activities are complete. For planning purposes, it is currently assumed that the IEP will occur in 2036 and that there will be a monitoring and validation period of approximately 30 years before the SRS is reached in 2066 and the site released from RSR. Thus, the period to 2066 when the dose constraint applies is also indicated on Figure 10.4, and subsequent plots. During the period to the SRS some of the considered RP activities would not be possible (i.e. NRS will retain sufficient control of the site such that accessing and walking on it [Park User RP] will be possible but living on the site would not [Smallholder RP (Land/Mire compartment)]). The discussion of radiological impacts in the remainder of this section typically makes the comparison to the RGL, but clearly where a dose is lower than the dose equivalent of the RGL it also satisfies the dose constraint requirement.

485 It is important to note that the radiological impacts for all RPs presented here are conditional doses which assume that the probability of the scenario giving rise to the exposure is unity (see Paragraph 34). For example, given the evidence of local habits (e.g. [59; 60]), a receptor walking across the site in the future or fishing in the River Frome is expected. However, the probability of someone living on the site, growing crops and raising livestock, and doing so directly on the small area of land potentially contaminated by releases from the disposals, has a much lower probability. Nonetheless, all the RPs considered in the Reference Case assessment are assumed to occur.

486 For all of the RPs, peak dose rates in the Reference Case are more than an order of magnitude below the dose rate equivalent of the GRR risk guidance level. The highest peak dose rate (3.0E-04 mSv y^{-1}) is associated with the Smallholder RP in the on-site Land/Mire compartment, occurring around 56,800 years in the future (Table 10.1). This RP is assumed to reside, grow and consume vegetables and fruit, and raise and consume livestock, on land contaminated by groundwater releases from the SGHWR and OoS A59 area feature groups. The next highest peak doses occur for the Farmer RP, also in the Land/Mire compartment, and then the Smallholder RP located on the off-site Field irrigated with water from the River compartment.

487 All peak dose rates occur more than 50,000 years in the future except for the Mire Mudder and Construction Worker (Land/Mire) RPs, which occur just after 50 years and are associated with OoS A59 area releases to the Land/Mire. Most peak doses occur after 50,000 years due to concrete associated with the near field reaching the point of full chemical degradation and the remaining inventory finally being released from the in-situ SGHWR and Dragon reactor concrete structures, thus demonstrating the degree of containment provided by the system. A second, slightly lower peak, is also observed after about 1,000 to 2,000 years, which corresponds to the point when the concrete reactor structures are assumed to have reached the point of complete hydraulic

combined and individual feature dose rate plots as this PA does not account for the currently permitted site discharges and those from the adjacent Tradebe Inutec nuclear site, which should also be included in a comparison against the site dose constraint (this is considered in the SWESC).

degradation. However, it is noted that the dose only varies by approximately an order of magnitude over thousands of years for many RPs (Figure 10.4).

Table 10.1: Peak dose rates to each RP arising from natural evolution of the proposed Winfrith on-site disposals in the Reference Case assessment. The time of peak dose rate and the dominant dose-contributing radionuclide are also shown. Note that the time of the peak is for the total dose across all radionuclides; the peak for the dominant radionuclide does not necessarily occur at the same time.

RP	Peak Dose Rate ($mSv\ y^{-1}$)	Time of peak after 2027 CE (y)	Dominant radionuclide
Angler	1.52E-06	58,272	Pb210
River Paddler	7.06E-10	51,176	Pb210
Mire Mudder	9.36E-08	52	U238
Park User (Field)	3.05E-09	59,669	Pb210
Construction Worker (Field)	3.31E-10	51,246	U238
Farmer (Field)	2.49E-07	58,872	Pb210
Smallholder (Field)	5.58E-05	55,768	Ac227
Park User (Land/Mire)	1.67E-06	57,047	Pb210
Construction Worker (Land/Mire)	2.29E-07	51	U238
Farmer (Land/Mire)	1.21E-04	56,743	Pb210
Smallholder (Land/Mire)	2.99E-04	56,777	Pb210

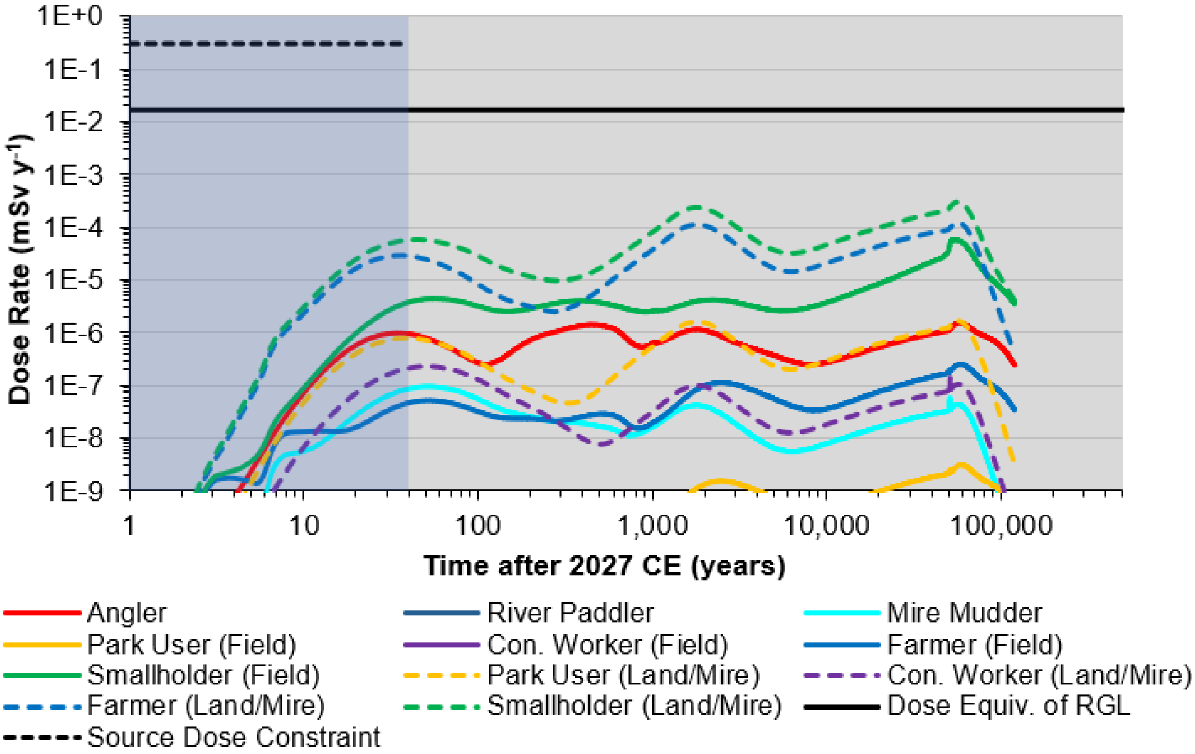

Figure 10.4: Dose rates over time for each RP, arising from natural evolution of the modelled feature groups in the Reference Case assessment. The solid black line shows the dose rate equivalent of the regulatory RGL and the dashed black line shows the dose constraint to the assumed SRS date. Note that this figure only shows calculated dose rates down to 1E-9 mSv y^{-1}; the River Paddler and Construction Worker (Field) RP dose rates are below this level.

488 Figure 10.5 and Figure 10.6 present the dose rate per exposure pathway for the Reference Case RPs, which are, as noted above, all more than an order of magnitude below the dose rate equivalent of the RGL. No dose rate plots are presented for the River Paddler and Construction Worker (Field) RPs as all their exposure pathways have dose rates less than 1E-9 mSv y^{-1}. The plots identify that ingestion of contaminated foodstuffs is dominant, with it being the largest contributor to peak dose rates for all RPs that consider ingestion. For the Smallholder (Field) RP, where multiple ingestion exposure modes are considered, the largest contributor to the peak dose rate comes from the ingestion of aquatic plant foodstuffs (Figure 10.5(d)). This pathway considers ingestion of watercress grown in contaminated river water; the modelled watercress consumption rate is high (10.4 kg y^{-1}), derived from the two high-rate consumers observed in the Winfrith CEFAS habits survey area [60, Tab.33], as are the uptake factors (see Appendix D.4.3). Therefore, this ingestion pathway is considered to be cautious; nonetheless, it is still more than two orders of magnitude beneath the RGL. For the on-site Smallholder (Land/Mire) RP, ingestion of animal foodstuffs and terrestrially-grown plants dominates over ingestion of aquatic plants due to the higher radionuclide concentration calculated to be present in the Land/Mire soil.

489 Table 10.2, and Figure 10.7 and Figure 10.8, present dose rates per radionuclide for the RPs (only dose rates above 1E-9 mSv y^{-1} are plotted, again noting that the peak dose rate for all of the RPs is at least an order of magnitude below the dose rate equivalent of the RGL). Key dose contributors are ^{90}Sr (all RPs except the Smallholder (Field)), ^{129}I (Angler, Mire Mudder and Farmer (Field) RPs), ^{210}Pb (all RPs), ^{226}Ra (all RPs except Angler, Mire Mudder and Smallholder (Field) RPs), and certain actinides – ^{227}Ac, ^{229}Th, ^{230}Th, ^{231}Pa, ^{234}U, ^{235}U, ^{238}U, ^{240}Pu and/or ^{241}Am (all RPs).

490 As would be expected due to the size of its inventory (see Appendix D.2.2), relatively short half-life (see Appendix B.1) and weak sorption potential to undegraded concrete (see Appendix D.2.3), the ^{90}Sr peak dose rate for all RPs occurs within the first hundred years. Whilst very long-lived, ^{129}I is mobile and peaks between 100 and 1,000 years. The peak dose rates for ^{210}Pb, ^{226}Ra and the actinides generally occur later, between around 1,000 and 60,000 years, due to their greater sorption potential to undegraded concrete and their longer half-lives. Proportionately greater releases of these radionuclides from the SGHWR and Dragon reactor complex feature groups occur after the concrete associated with the near field is assumed to be fully chemically degraded via leaching (see Paragraph 305). This leads to the observed peak in Figure 10.4 (and other dose plots) over 50,000 years in the future, as well as the “spikes” in ^{234}U and ^{238}U releases in Figure 10.7 and Figure 10.8 when any remaining uranium is released from the concrete structures (the observed “spikes” are a result of the change in Kd sorption coefficient to a low value when the concrete is leached). However, some actinides show peak dose rates at around 100 years – for example, ^{234}U for the River Paddler and Mire Mudder RPs and ^{238}U for the Construction Worker and Smallholder RPs (both Field and Land/Mire); these peaks at early times are associated with releases from the OoS A59 area feature group (see Feature-specific Impacts sub-section below), which has a total uranium inventory approximately one third that of the SGHWR feature group but which is not contained within a concrete structure.

491 These behaviours are illustrated in Figure 10.8(d) for the Smallholder (Land/Mire) RP. Up to the first 100 years the dose is dominated by ^{90}Sr and ^{238}U associated with the OoS A59 area feature group. As the concrete reactor structures hydraulically degrade and radionuclide decay and ingrowth occur, the peak around 2,000 years is dominated by ^{210}Pb and ^{226}Ra from the ^{238}U/^{234}U/^{230}Th decay chain (Figure B.4) and ^{227}Ac from the ^{235}U/^{231}Pa decay chain (Figure B.3). The highest peak dose rate occurs over 50,000 years after model start – the peak dose is still dominated by ^{210}Pb, with slightly more ingrown ^{227}Ac than ^{226}Ra, and a significant contribution from ^{238}U as the remaining inventory is released from the concrete structures when they are fully chemically degraded.

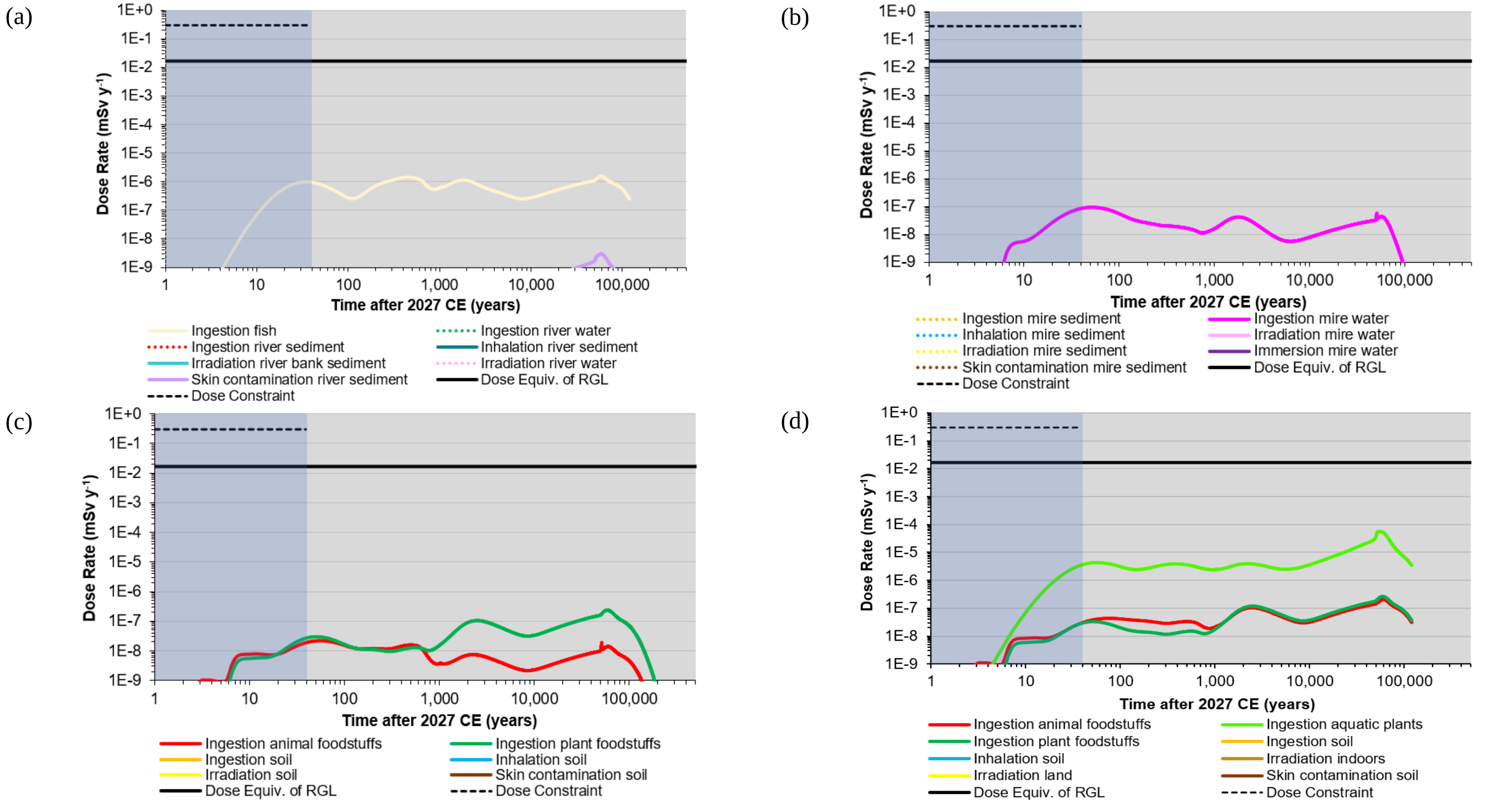

Figure 10.5: Dose rates per exposure pathway for the Reference Case assessment: (a) Angler RP; (b) Mire Mudder RP; (c) Farmer (Field) RP; and (d) Smallholder (Field) RP. Note that this figures only show calculated dose rates down to 1E-9 mSv y^{-1}; many of the exposure pathways are below this level.

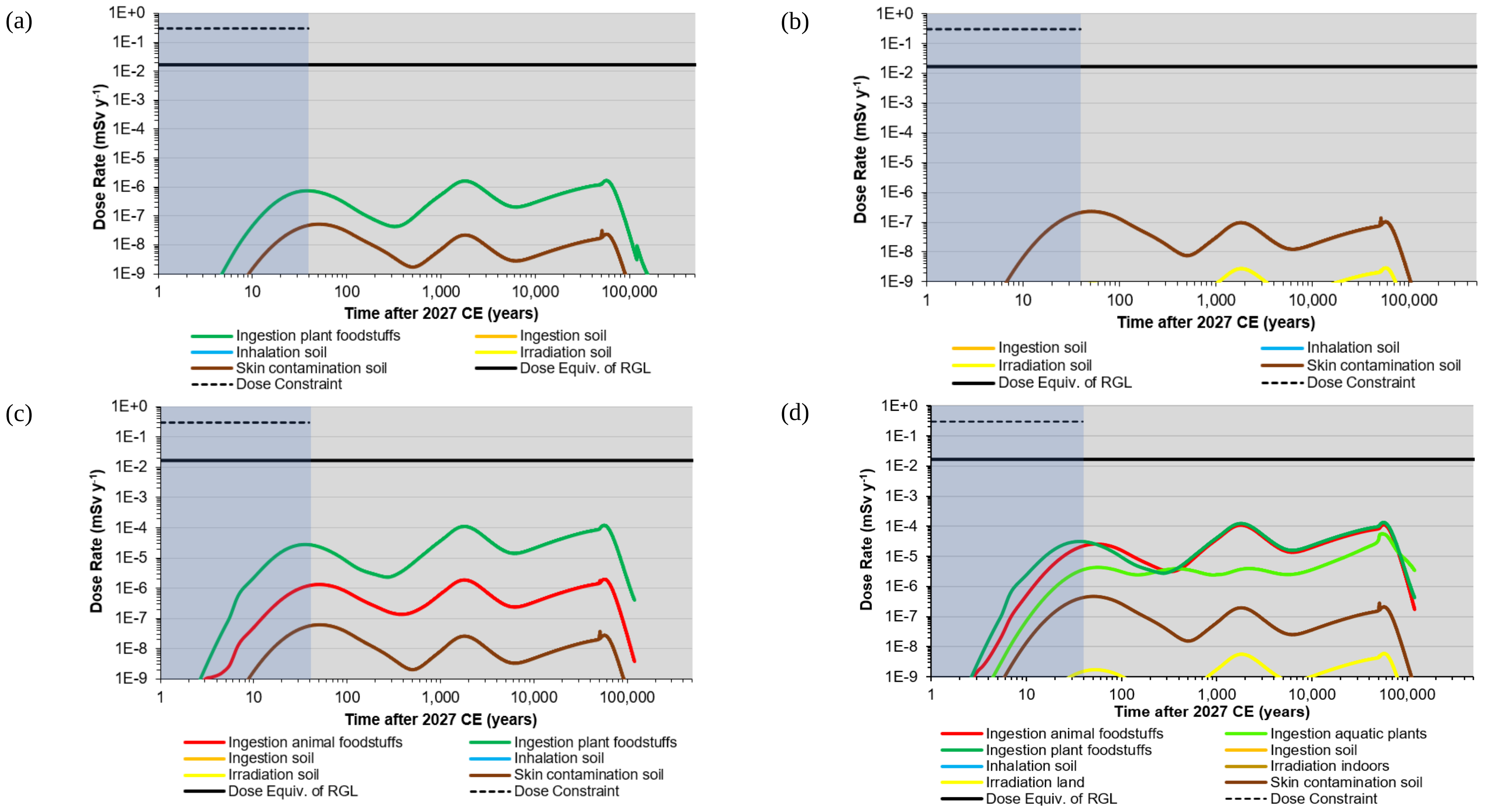

Figure 10.6: Dose rates per exposure pathway for the Reference Case assessment: (a) Park User (Land/Mire) RP; (b) Construction Worker (Land/Mire) RP; (c) Farmer (Land/Mire) RP; and (d) Smallholder (Land/Mire) RP. Note that this figure only shows calculated dose rates down to 1E-9 mSv y^{-1}.

Table 10.2: Peak dose rate, per radionuclide, to each RP, arising from natural evolution of the proposed Winfrith on-site disposals in the Reference Case assessment. The time of peak dose rate after 2027 CE is also shown. Green (low) to red (high) shading is used to identify radionuclides with the greatest dose contribution (considered separately for each RP). Radionuclides reporting zero dose for all RPs for the Reference Case are only present in the alternative inventory cases (^{59}Ni, ^{93}Zr, ^{93m}Nb, ^{121m}Sn, ^{178n}Hf, ^{193}Pt, ^{204}Tl). *Page set to A3 size.*

Rad.	Angler		River Paddler		Mire Mudder		Park User (Field)		Con. Worker (Field)		Farmer (Field)		Smallholder (Field)		Park User (Land/Mire)		Con. Worker (Land/Mire)		Farmer (Land/Mire)		Smallholder (Land/Mire)	
	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)
H3	1.02E-09	9	2.83E-11	9	4.01E-09	8	6.15E-12	9	6.98E-18	9	1.26E-08	9	1.42E-08	9	4.62E-10	8	5.24E-16	8	4.07E-07	8	4.56E-07	8
C14	9.24E-08	1,012	9.92E-12	1,195	7.31E-11	1,008	7.13E-12	1,024	1.41E-12	1,024	1.10E-09	1,018	1.71E-07	1,012	1.44E-09	1,008	2.85E-10	1,008	6.46E-08	1,008	4.62E-07	1,009
Cl36	2.81E-08	476	6.38E-13	479	4.38E-11	474	6.93E-12	476	1.30E-13	476	7.54E-10	476	4.94E-09	476	6.00E-10	474	1.13E-11	474	2.95E-08	474	8.95E-08	474
Ca41	1.68E-08	843	4.74E-13	843	6.66E-11	830	7.32E-13	847	5.24E-22	847	3.95E-10	845	3.37E-09	843	2.47E-10	830	1.77E-19	830	6.40E-08	830	1.02E-07	831
Fe55	0.00E+00	0	0.00E+00	0	6.58E-35	103	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	7.46E-35	103	2.02E-41	103	9.71E-33	103	1.48E-31	103
Co60	1.39E-15	45	2.43E-17	46	2.88E-16	45	4.54E-19	52	3.65E-19	52	1.17E-17	51	8.80E-15	45	6.70E-15	45	5.38E-15	45	1.39E-13	45	1.97E-13	45
Ni59	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Ni63	4.04E-09	97	1.03E-12	97	1.53E-10	97	3.10E-12	149	1.47E-15	149	3.41E-10	140	1.15E-08	98	3.94E-09	97	1.88E-12	97	3.54E-07	97	5.63E-07	97
Sr90	8.38E-07	33	1.46E-10	33	2.21E-08	33	6.29E-10	48	7.56E-11	48	3.09E-08	46	5.69E-07	33	5.43E-07	33	6.53E-08	33	2.35E-05	33	2.92E-05	33
Zr93	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Nb93m	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Nb94	6.40E-13	13,725	2.93E-14	13,725	5.09E-13	13,700	3.03E-14	14,525	1.22E-13	14,525	2.28E-13	14,525	3.87E-11	13,725	1.25E-11	13,700	4.99E-11	13,700	6.73E-11	13,700	2.06E-10	13,700
Tc99	4.40E-10	474	1.74E-13	484	1.23E-11	469	6.27E-12	474	2.42E-14	474	1.25E-10	474	3.34E-10	474	4.68E-10	469	1.80E-12	469	8.42E-09	469	1.42E-08	469
Cd113m	1.50E-22	165	1.13E-26	165	2.05E-24	164	8.48E-28	250	3.36E-27	250	4.71E-24	250	4.45E-21	165	2.37E-24	164	9.40E-24	164	1.27E-20	164	1.88E-20	165
Sn121m	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Sb125	1.04E-19	23	3.25E-21	23	6.08E-20	22	3.40E-23	26	1.50E-22	26	9.95E-22	23	1.33E-19	22	1.34E-19	22	5.90E-19	22	2.65E-19	22	2.17E-18	22
I129	5.94E-07	514	8.26E-11	522	5.97E-09	485	1.25E-11	518	1.77E-13	518	1.49E-08	516	1.16E-07	514	2.40E-09	485	3.38E-11	485	1.18E-06	485	1.47E-06	487
Cs134	8.89E-27	31	7.29E-31	31	2.87E-29	31	9.24E-33	34	9.04E-33	34	2.19E-29	31	1.21E-27	31	8.24E-28	31	8.06E-28	31	7.00E-26	31	3.17E-25	31
Cs137	4.35E-11	213	4.33E-15	232	1.18E-13	202	7.02E-16	253	1.04E-15	253	1.67E-13	229	6.12E-12	214	4.15E-12	202	6.17E-12	202	3.02E-10	202	1.37E-09	202
Ba133	1.85E-11	7	7.00E-14	7	1.40E-16	118	1.94E-16	8	8.18E-16	8	8.52E-14	7	4.73E-11	7	3.79E-18	118	1.59E-17	118	8.41E-14	7	4.73E-11	7
Sm151	5.17E-21	137	4.89E-25	137	1.88E-26	1,675	6.04E-26	1,055	1.89E-26	1,055	2.93E-24	1,048	9.08E-21	137	1.44E-25	1,675	4.53E-26	1,675	6.35E-24	1,670	9.08E-21	137
Eu152	4.83E-20	90	1.30E-21	90	2.07E-26	152	9.08E-28	198	3.62E-27	198	4.28E-23	90	1.31E-19	90	6.66E-25	152	2.66E-24	152	4.65E-23	90	1.31E-19	90
Eu154	1.86E-22	90	3.80E-24	90	5.28E-28	90	6.15E-31	119	2.53E-30	119	1.65E-25	90	5.02E-22	90	2.31E-26	90	9.51E-26	90	3.02E-25	90	5.02E-22	90
Eu155	2.23E-31	91	1.02E-33	91	1.11E-31	90	2.66E-35	97	1.09E-34	97	3.17E-34	95	5.96E-31	91	6.67E-30	90	2.74E-29	90	4.13E-29	90	9.31E-29	90
Hf178n	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Pt193	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Tl204	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
Pb210	1.38E-06	58,384	3.76E-10	58,618	3.75E-08	57,063	2.51E-09	59,878	6.18E-11	59,878	1.72E-07	59,861	2.54E-06	58,608	1.45E-06	57,063	3.57E-08	57,063	9.56E-05	57,063	2.15E-04	57,073
Ra226	7.11E-08	58,404	1.10E-10	60,279	3.68E-09	57,398	4.38E-10	59,931	1.39E-10	59,931	4.38E-08	59,906	7.13E-07	58,482	2.01E-07	57,398	6.40E-08	57,398	1.85E-05	57,398	2.57E-05	57,418
Ra228	2.75E-11	56,432	2.31E-14	56,577	3.56E-16	61,249	1.88E-14	57,697	1.22E-15	57,697	2.23E-12	57,574	2.59E-10	56,444	1.95E-14	61,249	1.26E-15	61,249	2.12E-12	60,886	2.58E-10	56,451
Ac227	1.44E-08	52,443	9.86E-11	52,595	1.12E-09	51,976	7.32E-11	53,842	1.64E-11	53,842	1.77E-09	53,839	4.55E-05	52,429	1.53E-08	51,976	3.42E-09	51,976	3.64E-07	51,976	4.59E-05	52,423
Th228	1.90E-12	56,482	2.28E-14	56,714	1.04E-16	61,251	7.27E-16	57,697	2.44E-15	57,697	2.99E-14	57,463	7.11E-10	56,438	7.26E-16	61,251	2.43E-15	61,251	1.68E-14	59,788	7.11E-10	56,438
Th229	2.13E-08	58,644	8.53E-11	58,819	4.22E-10	58,776	3.62E-12	59,558	7.60E-12	59,558	3.21E-10	59,316	8.88E-06	58,635	1.50E-09	58,776	3.14E-09	58,776	4.77E-08	58,775	9.13E-06	58,639
Th230	2.39E-08	63,604	5.12E-12	63,604	4.92E-10	63,552	2.44E-12	64,649	1.16E-16	64,649	3.95E-10	64,395	1.04E-05	63,604	9.39E-10	63,552	4.47E-14	63,552	5.59E-08	63,552	1.07E-05	63,603
Th232	2.62E-12	56,509	5.69E-16	56,512	6.07E-17	61,321	2.63E-16	57,771	9.75E-19	57,771	4.25E-14	57,503	1.14E-09	56,509	1.16E-16	61,321	4.31E-19	61,321	1.65E-14	58,194	1.14E-09	56,509
Pa231	3.23E-09	52,582	8.66E-12	52,602	6.66E-10	51,968	4.13E-11	53,845	2.45E-13	53,845	3.83E-08	53,845	2.55E-07	52,769	1.03E-08	51,968	6.13E-11	51,968	9.53E-06	51,968	9.96E-06	51,977
U233	1.17E-08	50,550	2.82E-11	50,550	4.28E-09	50,550	3.43E-11	50,600	1.15E-14	50,600	2.02E-09	50,550	2.22E-07	50,550	1.65E-08	50,550	5.55E-12	50,550	4.48E-07	50,550	2.01E-06	50,550
U234	9.93E-08	58	2.41E-10	58	3.81E-08	58	1.68E-10	125	1.77E-13	125	1.14E-08	74	1.87E-06	58	1.47E-07	58	1.55E-10	58	3.99E-06	58	1.78E-05	58
U235	9.84E-09	51,167	2.83E-11	51,167	3.59E-09	50,600	3.82E-11	51,237	1.68E-11	51,237	1.93E-09	51,199	1.88E-07	51,167	1.51E-08	50,600	6.67E-09	50,600	3.72E-07	50,600	1.67E-06	50,600
U236	4.38E-10	50,550	1.06E-12	50,550	1.60E-10	50,550	1.29E-12	50,600	1.28E-15	50,600	7.60E-11	50,550	8.35E-09	50,550	6.20E-10	50,550	6.16E-13	50,550	1.68E-08	50,550	7.54E-08	50,550
U238	1.01E-07	58	2.56E-10	58	3.92E-08	58	2.18E-10	125	2.10E-10	125	1.17E-08	75	1.90E-06	58	1.90E-07	58	1.84E-07	58	4.09E-06	58	1.84E-05	58

Rad.	Angler		River Paddler		Mire Mudder		Park User (Field)		Con. Worker (Field)		Farmer (Field)		Smallholder (Field)		Park User (Land/Mire)		Con. Worker (Land/Mire)		Farmer (Land/Mire)		Smallholder (Land/Mire)	
	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)	Peak Dose (mSv y^{-1})	Time of Peak (y)
Np237	2.24E-11	1,050	3.01E-14	1,032	2.40E-12	1,046	6.55E-15	1,069	1.91E-15	1,069	1.91E-13	1,068	8.56E-11	1,051	2.06E-12	1,046	6.01E-13	1,046	5.76E-11	1,046	1.62E-10	1,048
Pu238	2.98E-09	213	5.32E-13	213	6.83E-11	213	1.97E-15	292	9.49E-20	292	2.63E-13	262	1.22E-08	213	4.23E-12	213	2.04E-16	213	3.66E-10	213	1.33E-08	213
Pu239	1.59E-07	335	2.83E-11	335	3.63E-09	334	3.00E-13	606	3.51E-17	606	3.09E-11	567	6.51E-07	335	2.25E-10	334	2.63E-14	334	1.95E-08	334	7.06E-07	335
Pu240	1.71E-07	334	3.05E-11	334	3.91E-09	334	3.20E-13	601	1.47E-17	601	3.29E-11	562	7.03E-07	334	2.42E-10	334	1.12E-14	334	2.10E-08	334	7.62E-07	334
Pu241	6.44E-12	90	1.15E-15	90	1.47E-13	90	1.03E-18	109	5.83E-22	109	2.99E-16	95	2.64E-11	90	9.14E-15	90	5.16E-18	90	7.91E-13	90	2.87E-11	90
Pu242	1.13E-09	52,577	2.01E-13	52,577	2.05E-11	52,484	3.89E-15	53,000	9.75E-19	53,000	3.98E-13	52,964	4.63E-09	52,577	1.27E-12	52,484	3.18E-16	52,484	1.10E-10	52,484	4.94E-09	52,569
Am241	4.48E-07	409	2.01E-11	411	1.92E-09	408	9.80E-13	677	1.47E-14	677	7.48E-11	582	5.44E-07	409	2.32E-09	408	3.49E-11	408	9.40E-08	408	8.44E-07	409
Am243	1.87E-16	3,375	2.26E-19	3,590	7.74E-19	3,355	6.73E-21	8,940	2.17E-20	8,940	1.36E-19	8,860	2.25E-16	3,370	3.28E-18	3,355	1.06E-17	3,355	3.91E-17	3,355	3.62E-16	3,365
Cm243	2.12E-21	235	2.05E-22	234	8.37E-23	291	6.05E-24	270	1.76E-23	270	2.07E-22	264	9.26E-21	233	8.55E-22	291	2.49E-21	291	2.24E-20	291	6.58E-20	282
Cm244	1.91E-15	128	1.80E-16	128	2.81E-14	128	1.30E-18	153	4.33E-23	153	1.34E-16	147	9.10E-15	129	1.08E-13	128	3.59E-18	128	7.98E-12	128	1.97E-11	128

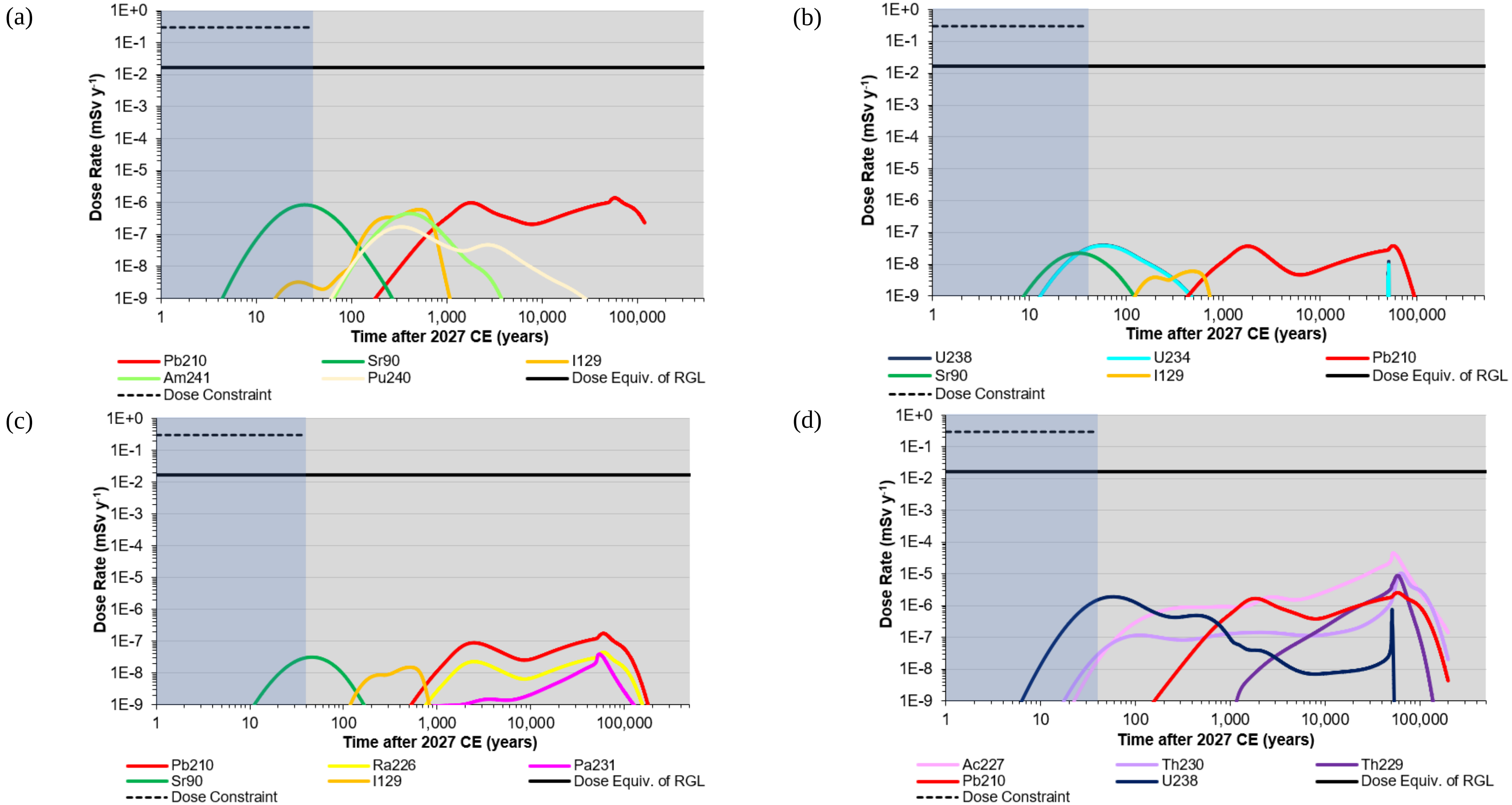

Figure 10.7: Dose rates for the top five dose-contributing radionuclides for the Reference Case assessment: (a) Angler RP; (b) Mire Mudder RP; (c) Farmer (Field) RP; and (d) Smallholder (Field) RP.

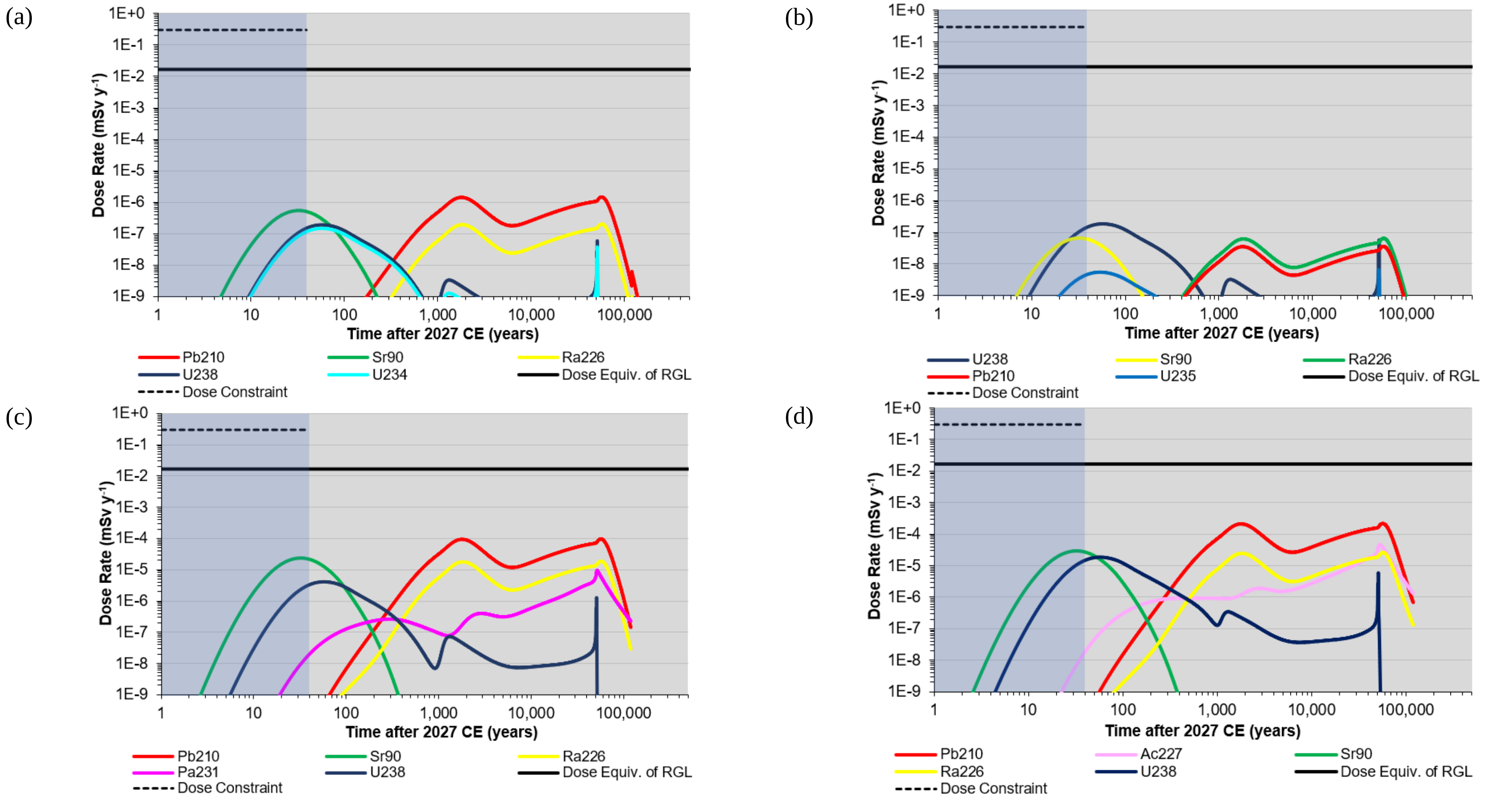

Figure 10.8: Dose rates for the top five dose-contributing radionuclides for the Reference Case assessment: (a) Park User (Land/Mire) RP; (b) Construction Worker (Land/Mire) RP; (c) Farmer (Land/Mire) RP; and (d) Smallholder (Land/Mire) RP.

Feature-specific Impacts

492 Table 10.3 presents the dose rates resulting from natural evolution of each modelled feature group and individual feature, including any emplaced contaminated infill, for the Reference Case assessment, while Figure 10.9 to Figure 10.12 present the same for the four RPs with the highest peak dose in Figure 10.4 (Smallholder (Land/Mire), Farmer (Land/Mire), Smallholder (Field) and Park User (Land/Mire) RPs). Note that the Dragon reactor complex features do not contribute to the Mire Mudder, Park User (Land/Mire) and Construction Worker (Land/Mire) RPs, as there is no transport path from Dragon to the Land/Mire compartment. However, the Dragon reactor complex feature group does contribute to the Farmer and Smallholder (Land/Mire) RPs through releases to the River compartment, the water from which is then consumed by livestock and used to grow aquatic crops (watercress). Figure 10.13 and Figure 10.14 present the top five dose-contributing radionuclides to the Smallholder RP in both the Land/Mire and Field compartments when individually considering the SGHWR and Dragon reactor complex disposals.

493 The results show that, of the three feature groups, SGHWR is the dominant dose-contributing feature to the peak dose for all RPs except for the Mire Mudder and Construction Worker (Land/Mire) RPs, where the OoS A59 area feature group dominates. The A59 feature group is also the dominant contributor to dose in the first 1,000 years for all RPs. The Dragon reactor complex feature group is always the smallest dose contributor. The dominant dose-contributing radionuclides from the SGHWR are primarily ^{210}Pb, ^{226}Ra, ^{227}Ac, ^{231}Pa, ^{229}Th, ^{230}Th and ^{238}U. The SGHWR feature group peak dose occurs between 50,000 and 60,000 years after model start and is associated with concrete chemical degradation, but a comparable peak primarily due to the same radionuclides is also observed between 1,000 and 2,000 years after model start when the concrete is assumed to be hydraulically degraded. The time of peak dose for the A59 feature group occurs much earlier, between 30 and 120 years after the IEP, and is dominated by ^{90}Sr and ^{238}U. The SGHWR ^{238}U inventory is more than double that of the A59 feature group and the ^{90}Sr inventory is more than an order of magnitude greater, but the lack of attenuating and sorbing concrete structure means that releases from the OoS A59 area can occur earlier.

494 When considering the individual features, the SGHWR bioshield has the highest total inventory in the Reference Case (3.6E5 MBq; Table 3.9) but forms one of the lowest contributors to dose due to the time required for release of the activity from the bioshield and through the SGHWR Region 1 structure. The highest dose-contributing features are generally SGHWR Region 1, and the SGHWR South and North Annexes with ^{210}Pb and actinides, and the A59 Other feature, with ^{90}Sr and actinides. SGHWR Region 1 has the second-highest inventory of all the features (2.0E5 MBq), containing the Primary Containment, Ponds and Mortuary Tubes. The other three SGHWR features have relatively large inventories, although at least an order of magnitude lower than that of SGHWR Region 1. The concrete in the SGHWR Annexes is assumed to be hydraulically degraded from the model start, but as they are above the groundwater table releases are limited by infiltration through the cap. The A59 Other inventory is slightly smaller than that of either SGHWR Annexe, but is not contained by a concrete

structure, has the shortest release pathway to the receptors and is already in contact with groundwater.

495 All other features contribute to the overall calculated full-site dose rates, but do not greatly influence the patterns of dose rate observed (Figure 10.4).

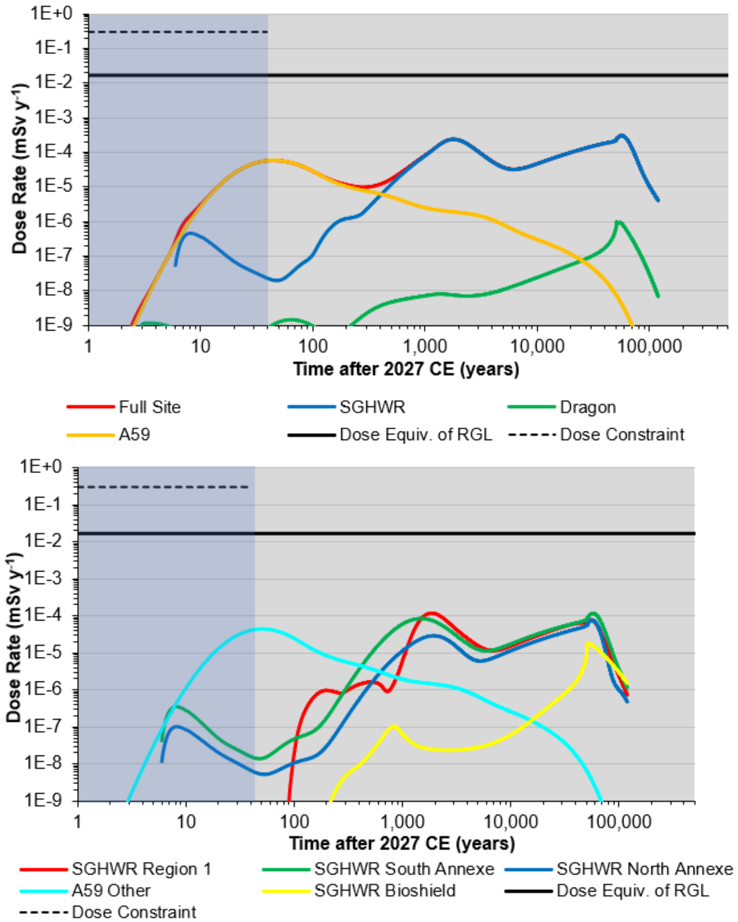

Figure 10.9: Dose rates for the three feature groups (top) and the top five dose-contributing individual features (bottom) for the Smallholder (Land/Mire) RP in the Reference Case assessment.

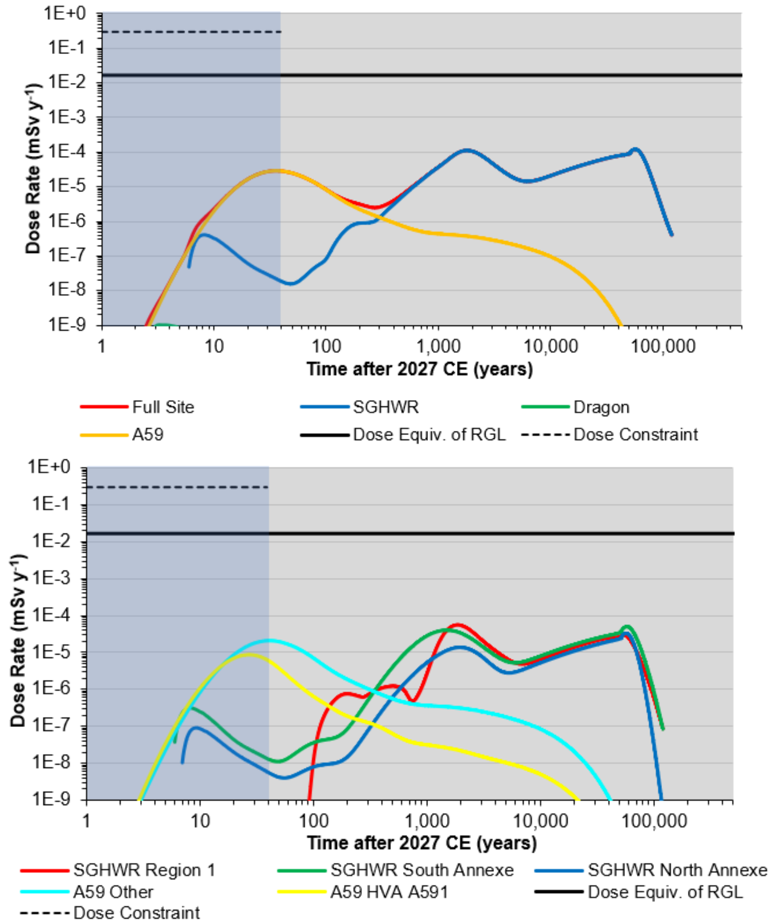

Figure 10.10: Dose rates for the three feature groups (top) and the top five dose-contributing individual features (bottom) for the Farmer (Land/Mire) RP in the Reference Case assessment.

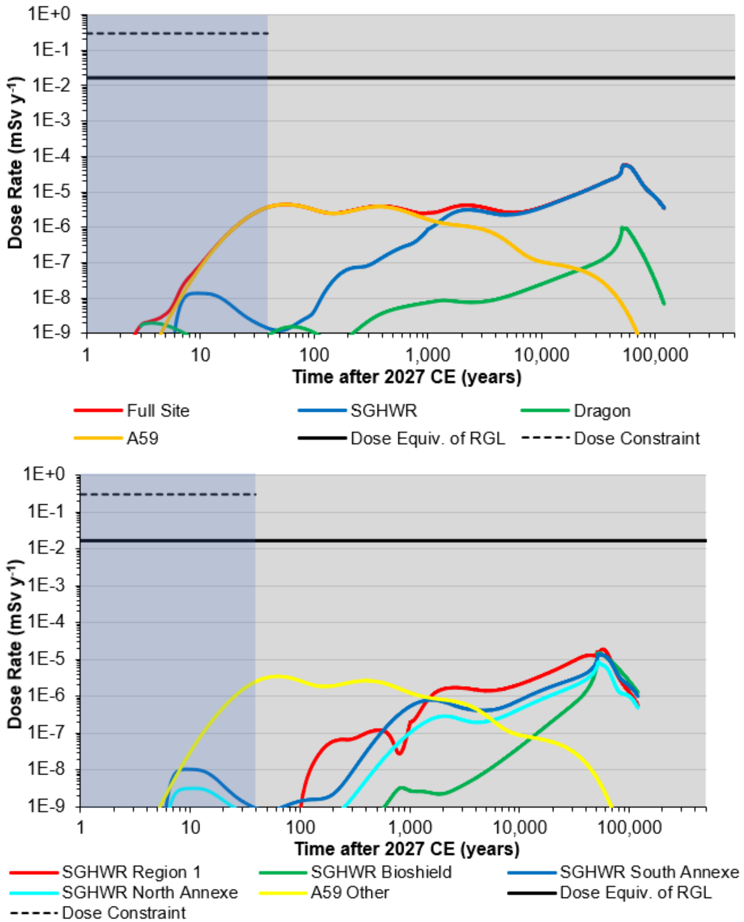

Figure 10.11: Dose rates for the three feature groups (top) and the top five dose-contributing individual features (bottom) for the Smallholder (Field) RP in the Reference Case assessment.

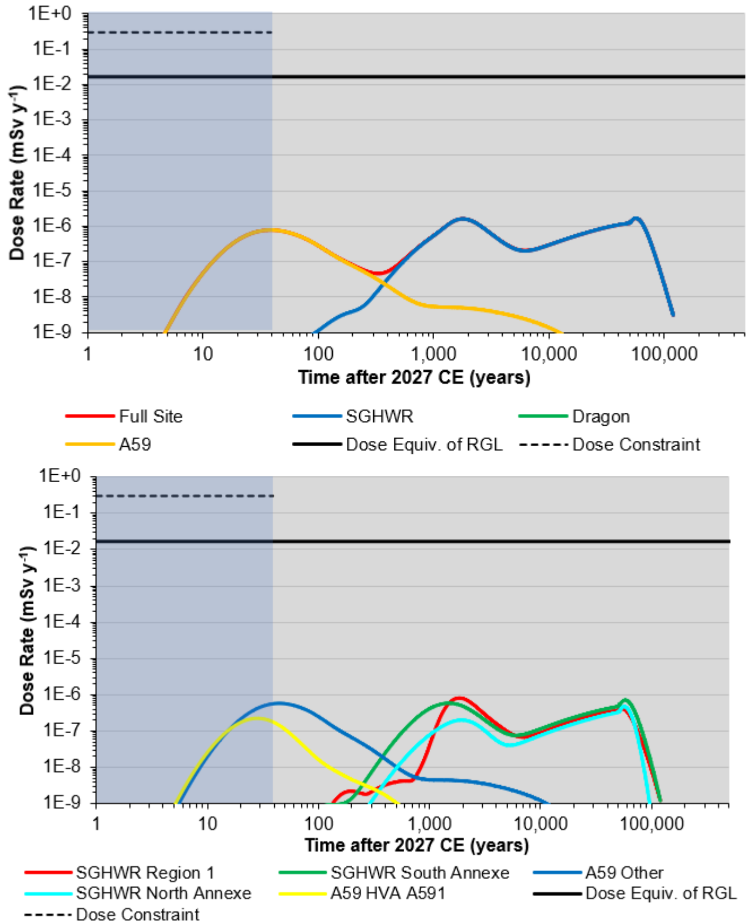

Figure 10.12: Dose rates for the three feature groups (top) and the top five dose-contributing individual features (bottom) for the Park User (Land/Mire) RP in the Reference Case assessment.

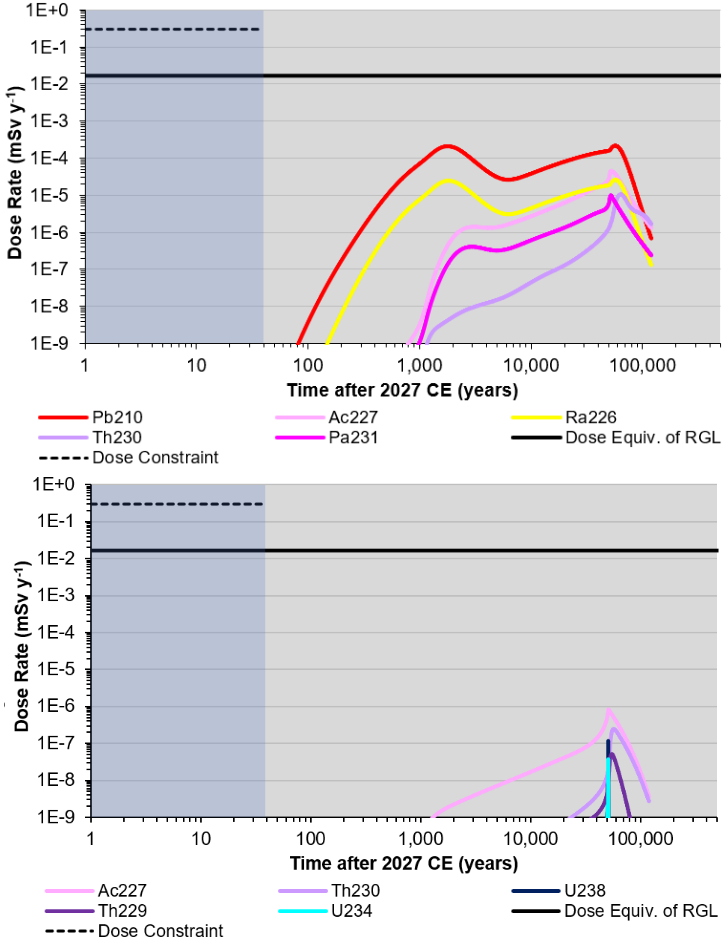

Figure 10.13: Top five dose-contributing radionuclides for SGHWR (top) and the Dragon (bottom) disposals for the Smallholder (Land/Mire) RP in the Reference Case.

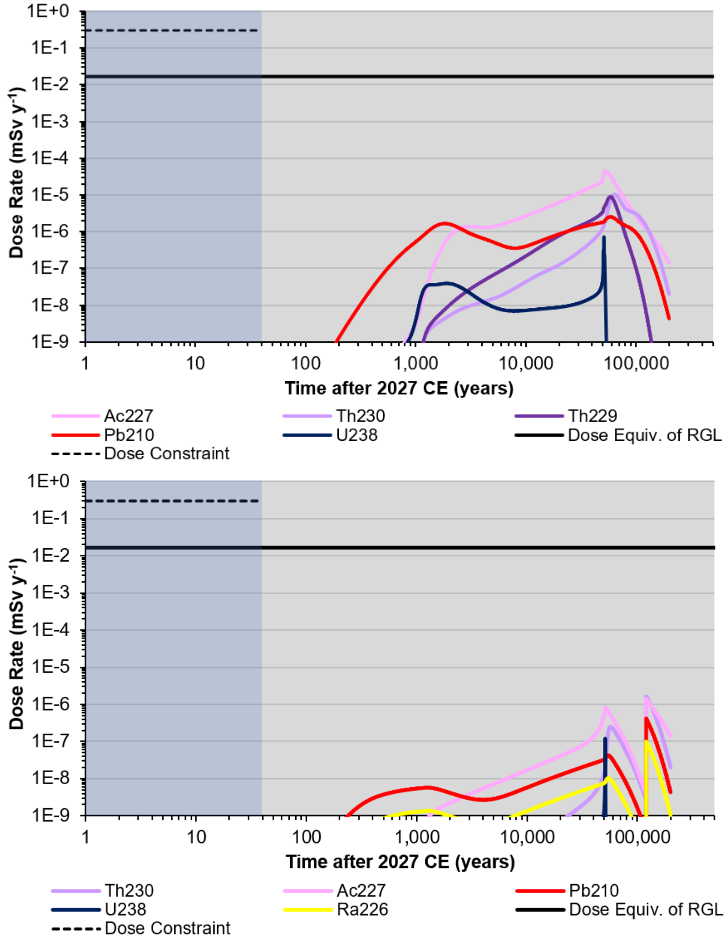

Figure 10.14: Top five dose-contributing radionuclides for SGHWR (top) and the Dragon (bottom) disposals for the Smallholder (Field) RP in the Reference Case.

Table 10.3: Peak dose rate, per feature, to each RP considered in the Reference Case assessment. The time of peak dose rate after 2027 CE, associated with each feature, is also shown. Green (low) to red (high) shading is used to identify features with a higher dose contribution (considered separately for each RP for the three feature groups and the 13 individual features). Note that in some cases the dominant radionuclide is not the main dose-contributing radionuclide at the time of the overall peak dose rate. Grey shading indicates there is no dose pathway for the relevant disposal feature and RP. *Page set to A3 size.*

Feature Types	Feature	Angler			River Paddler			Mire Mudder			Park User (Field)			Con. Worker (Field)		
		Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.
Full Site	Full Site	1.52E-06	58272	Pb210	7.06E-10	51176	Pb210	9.36E-08	52	U238	3.05E-09	59669	Pb210	3.31E-10	51246	U238
Feature Groups	SGHWR	1.50E-06	58378	Pb210	6.89E-10	51184	Pb210	5.82E-08	51181	Pb210	3.01E-09	59759	Pb210	3.16E-10	51258	U238
	Dragon R.C.	3.07E-08	51076	Pb210	3.32E-11	51075	U238	0.00E+00	0	H3	6.12E-11	51132	Pb210	2.35E-11	51131	U238
	A59	9.66E-07	35	Sr90	6.09E-10	52	U238	9.35E-08	52	U238	7.80E-10	55	Sr90	2.29E-10	108.5	U238
Individual Features	SGHWR Region 1	6.09E-07	517	I129	2.40E-10	50550	Pb210	2.14E-08	50550	Pb210	7.55E-10	57764	Pb210	8.88E-11	50600	U238
	SGHWR Bioshield	1.65E-08	844	Ca41	4.53E-11	51445	Ac227	3.25E-09	50600	U235	4.92E-11	51489	U235	1.44E-11	50750	U235
	SGHWR Region 2	8.98E-08	58406	Pb210	4.09E-11	50450	Pb210	4.37E-09	50450	Pb210	1.82E-10	59769	Pb210	2.27E-11	50500	U238
	SGHWR South Annexe	6.16E-07	59670	Pb210	2.70E-10	51191	Pb210	2.96E-08	51188	Pb210	1.25E-09	61027	Pb210	1.46E-10	51268	U238
	SGHWR North Annexe	3.99E-07	58279	Pb210	1.52E-10	51165	Pb210	1.54E-08	51162	Pb210	8.08E-10	59622	Pb210	7.60E-11	51238	Ra226
	Dragon Inside Wall C	7.87E-10	571	Pb210	7.30E-13	3.954	H3				7.55E-13	51132	Pb210	1.52E-13	51131	U238
	Dragon Bioshield	1.69E-10	643	Ca41	1.76E-14	16	H3				1.93E-14	537	Cl36	2.88E-16	499	Cl36
	Dragon Walls A-C	2.89E-08	51076	Pb210	3.24E-11	51075	U238				5.85E-11	51132	Pb210	2.32E-11	51131	U238
	Dragon Primary Mortuary Holes	1.32E-09	53714	Pb210	8.79E-13	55031	Th229				2.13E-12	55003	Pb210	1.85E-13	55581	Ra226
	Dragon B78 floor slab	4.36E-10	1145	Pb210	1.78E-13	3.026	H3				4.21E-13	1610	Pb210	3.09E-14	50050	Ra226
	A59 PSA Pit 3	2.24E-07	376	Am241	4.26E-11	57	U238	6.54E-09	56.5	U238	4.25E-11	64	Sr90	1.65E-11	113	U238
	A59 HVA A591	2.96E-07	26.5	Sr90	1.39E-10	35.5	U238	2.13E-08	35.5	U234	2.00E-10	40	Sr90	3.82E-11	53	U238
	A59 Other	6.91E-07	39.5	Sr90	4.76E-10	58	U238	7.32E-08	58	U238	5.81E-10	61	Sr90	1.86E-10	116	U238

Feature Types	Feature	Farmer (Field)			Smallholder (Field)			Park User (Land/Mire)			Con. Worker (Land/Mire)			Farmer (Land/Mire)			Smallholder (Land/Mire)		
		Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.
Full Site	Full Site	2.49E-07	58872	Pb210	5.58E-05	55768	Ac227	1.67E-06	57047	Pb210	2.29E-07	50.5	U238	1.21E-04	56743	Pb210	2.99E-04	56777	Pb210
Feature Groups	SGHWR	2.45E-07	58965	Pb210	5.49E-05	55838	Ac227	1.67E-06	57047	Pb210	1.42E-07	51181	Ra226	1.21E-04	56743	Pb210	2.99E-04	56790	Pb210
	Dragon R.C.	4.37E-09	51095	Pb210	1.00E-06	51088	Ac227	0.00E+00	0	H3	0.00E+00	0	H3	1.01E-09	3.6	H3	9.96E-07	51088	Ac227
	A59	5.13E-08	52.5	Sr90	4.39E-06	56.5	U238	7.81E-07	39	Sr90	2.29E-07	50.5	U238	2.89E-05	36	Sr90	5.81E-05	44.5	Sr90
Individual Features	SGHWR Region 1	6.09E-08	57178	Pb210	1.88E-05	57723	Ac227	8.05E-07	1865	Pb210	4.91E-08	1875	Ra226	5.55E-05	1865	Pb210	1.17E-04	1865	Pb210
	SGHWR Bioshield	1.34E-08	53942	Pa231	1.49E-05	52268	Ac227	1.75E-08	50650	U235	6.06E-09	50600	U235	3.43E-06	51564	Pa231	1.83E-05	52031	Ac227
	SGHWR Region 2	1.43E-08	59032	Pb210	2.24E-06	52161	Ac227	1.02E-07	56995	Pb210	1.12E-08	50450	U238	7.23E-06	56703	Pb210	1.69E-05	56641	Pb210
	SGHWR South Annexe	9.77E-08	60385	Pb210	1.36E-05	52990	Ac227	7.06E-07	58218	Pb210	7.35E-08	51188	U238	5.00E-05	57991	Pb210	1.15E-04	57975	Pb210
	SGHWR North Annexe	6.22E-08	59020	Pb210	8.16E-06	52546	Ac227	4.66E-07	57079	Pb210	3.75E-08	51162	Ra226	3.28E-05	56831	Pb210	7.44E-05	56801	Pb210
	Dragon Inside Wall C	3.18E-10	3.946	H3	1.29E-08	54716	Ac227							1.83E-10	3.788	H3	1.28E-08	51100	Ac227
	Dragon Bioshield	7.92E-12	16	H3	3.26E-11	653	C14							4.51E-12	16	H3	2.88E-11	661	C14
	Dragon Walls A-C	4.16E-09	51095	Pb210	9.72E-07	51088	Ac227							8.17E-10	51074	H3	9.65E-07	51087	Ac227
	Dragon Primary Mortuary Holes	1.57E-10	54981	Pb210	6.63E-08	55234	Th229							1.54E-11	50100	U234	6.60E-08	55234	Th229
	Dragon B78 floor slab	7.73E-11	3.293	H3	5.57E-09	50050	Ac227							4.55E-11	3.026	H3	5.51E-09	50050	Ac227
	A59 PSA Pit 3	3.01E-09	57.5	Sr90	7.93E-07	351	Pu239	4.46E-08	45.5	Sr90	1.62E-08	56	U238	1.52E-06	41.5	Sr90	3.68E-06	51	U238
	A59 HVA A591	1.27E-08	38.5	Sr90	9.41E-07	38	U234	2.23E-07	28	Sr90	5.25E-08	34.5	U238	8.67E-06	27	Sr90	1.51E-05	30.5	Sr90
	A59 Other	3.87E-08	58	Sr90	3.47E-06	62.5	U238	5.75E-07	44.5	Sr90	1.79E-07	57	U238	2.08E-05	41	Sr90	4.40E-05	50.5	Sr90

Summary

496 In summary, the following key observations are made regarding the Reference Case assessment:

- Dose rates to all RPs are more than an order of magnitude below the dose rate equivalent of the RGL.
- Dose rates are highest for the Smallholder (Land/Mire) RP; these are primarily associated with the ingestion of foodstuffs contaminated with ^{90}Sr, ^{210}Pb, ^{226}Ra, ^{234}U and ^{238}U, with the peak exposure occurring 56,800 years after 2027 CE. Ingestion of contaminated animal and plant foodstuffs are the largest contributors to the peak dose rate.
- Dose rates are dominated by the ingestion of contaminated foodstuffs for all RPs that consider the ingestion exposure pathway.
- Peaks in dose rates at early times are generally associated with ^{90}Sr, whilst later peaks tend to be associated with certain actinides and the assumed time of complete concrete chemical degradation. However, some actinides contribute to peaks at early times and those are generally associated with releases from the A59 feature group. Differences in the time of the peaks are associated with the half-life and near-field sorption potential of the dominant dose-contributing radionuclides, and the presence and degradation status of the concrete structures.
- Of the three feature groups, the SGHWR is the dominant dose-contributing feature to the peak dose rate for all RPs except for the Mire Mudder and Construction Worker (Land/Mire) RPs, where the OoS A59 area feature group dominates. In the first 1,000 years the A59 feature group is the dominant contributor to dose rate for all RPs.
- The highest dose-contributing individual features are generally SGHWR Region 1, the SGHWR South and North Annexes, and the A59 Other feature.

10.1.3 Alternative Assessment Cases

497 As discussed above and in Section 4, alternative assessment cases have been defined to investigate the impact of parameter value uncertainty in the Reference Case assessment. The Reference Case is a deterministic assessment that considers the realistic, best estimate or mean of the range of possible parameter values, where possible and appropriate, for comparison with the quantitative GRR requirements, which is recommended in the GRR as the more appropriate measure to use [7, ¶A4.40]. The alternative cases can be thought of as similar to the end members of the range of a parameter value distribution in a probabilistic assessment, but instead of accounting for the probability of occurrence, they are considered singly in individual deterministic alternative assessment calculations that are conservatively assumed to occur.

498 Table 10.4 and Figure E.1 to Figure E.18 (Appendix E.1) present the total dose rates calculated for the proposed Winfrith on-site disposals for the alternative assessment cases. The Smallholder (Land/Mire) RP continues to receive the highest dose rate of

all the RPs, across every assessment case considered where this RP is possible. However, in all but one of the cases considered dose rates to all RPs remain below the dose rate equivalent of the RGL. Dose rates are highest for the case considering maximum foodstuff biosphere uptake factors, which conservatively assumes the maximum value for every radionuclide, with the peak dose rate for the Farmer and Smallholder RPs in the Land/Mire compartment exceeding the dose rate equivalent of the RGL by about a factor of ten after 1,000 years. Discussion of the impacts of the parameter changes considered in the alternative assessment cases, relative to the Reference Case assessment, is presented below.

Alternative Inventories (Cases EE 1.1 and EE 1.2)

499 The alternative inventory cases consider uncertainty in the inventory derived for each feature. The Case EE 1.1 alternative inventory estimate has been conservatively developed considering a range of factors for each feature such as the maximum characterisation result for each radionuclide, assuming lower decontamination factors are achieved, and/or applying alternative fingerprints (see Section 3.3.4). Case EE 1.2 considers a second alternative inventory, which is the same as Case EE 1.1 for all features except for the Dragon reactor complex, where an alternative Pu-containing fingerprint is applied for the B70 and B78 building general contamination inventory component. As the alternative inventories typically assume higher activities for each feature, it is unsurprising that the calculated peak dose for all RPs increases by almost an order of magnitude, rising to 1.8E-03 mSv y^{-1} in both cases for the Smallholder (Land/Mire) RP, but this still remains below the dose rate equivalent of the RGL. For all RPs the changes in the composition of the inventory estimates are not so great that the dominant radionuclide has changed, except for the Construction Worker RP (from ^{238}U to ^{226}Ra for both Land/Mire and Field) and the Mire Mudder RP (from ^{238}U to ^{210}Pb). The time of peak dose also remains essentially unchanged. The Mire Mudder RP and Construction Worker (Land/Mire) RP peak dose occurs substantially later, but this is simply due to a fractional difference in the relative magnitude of the later peak associated with release from SGHWR exceeding the earlier peak due to releases from the OoS A59 area (Figure E.1), but there is no meaningful difference. Similarly, the Park User (Land/Mire) RP peak dose occurs substantially earlier for the same (reversed) reason.

Near-field Sorption (Cases EE 1.3 and EE 1.4)

500 A decrease in near-field sorption increases peak dose rates by a factor of two to three for the Angler, Park User (Land/Mire), Farmer (Land/Mire) and Smallholder (Land/Mire) RPs, with the other RPs seeing increases less than this (and the Construction Worker (Field) seeing a small decrease of 7%). Increasing near-field sorption decreases peak dose rates (by up to 44%) for most RPs, although there is an insignificant change in the peak dose rates for the Mire Mudder and Construction Worker (Land/Mire) RPs. However, the differences in the dose rates equate to less than 1 μSv y^{-1} for all RPs, with the Smallholder (Land/Mire) RP peak dose increasing to 7.6E-04 mSv y^{-1} for the minimum sorption case (remaining well below the dose rate equivalent of the RGL) and decreasing to 1.8E-04 mSv y^{-1} for the maximum sorption case. Near-field sorption is a key control on the rate and timing of release of

radionuclides from the disposals, with reduced sorption leading to reduced decay before radionuclide release, which generally results in the time of peak dose occurring slightly earlier. Reduced sorption also results in less retention of longer-lived nuclides (such as ^{210}Pb and the actinides) in near-field concrete prior to complete leaching; thus, the release pulse of the nuclides when degradation completes is smaller such that the peak dose is reduced and occurs earlier for all the RPs except the Mire Mudder and Construction Worker (Land/Mire), which already have early peak doses in the Reference Case.

Concrete and Rubble Porosity (Cases EE 1.5 and EE 1.6)

501 A decrease in the rubble and initial intact concrete porosity reduces peak dose rates by around 10% to 60% for all RPs (a difference of less than 1 μSv y^{-1}), except the Mire Mudder and Construction Worker (Land/Mire). The time of the peak dose moves to within the initial hundreds of years for the Angler, River Paddler, Construction Worker (Field and Land/Mire) and Park User (Land/Mire) RPs, with the earlier peaks dominated by releases from the OoS A59 area. The peak doses for the Mire Mudder and Construction Worker (Land/Mire) RPs are not impacted by this change since their Reference Case peak dose is dominated by releases from the OoS A59 area, which does not contain concrete. An increase in the porosity also reduced peak dose rates for all RPs, except the Mire Mudder and Construction Worker (Land/Mire), but by a smaller amount of up to 13% – the time of peak dose remains approximately the same for most RPs and the dominant radionuclides remain the same as for the Reference Case. There is less of a difference when increasing porosity as the intact concrete is simply assumed to start with its final degraded porosity value, leading to a small shift in the time of the peak impact.

Bulk Concrete Density (Cases EE 1.7 and EE 1.8)

502 Changes in the intact concrete density to account for uncertainty in its initial value have negligible impact on the peak dose rates, reducing by around 1% when the density is reduced and increasing by less than 1% when the density is increased.

Geosphere Sorption (Cases EE 1.9 and EE 1.10)

503 A decrease in geosphere sorption tends to increase peak dose rates (by up to a factor of eight for some of the RPs) and brings forward the time of occurrence of each peak, with the peak for the Park User and Construction Worker Land/Mire RPs occurring within the first ten years. The Smallholder (Land/Mire) RP continues to have the greatest peak dose, doubling from the Reference Case value to 7.6E-04 mSv y^{-1} but remaining more than an order of magnitude beneath the dose rate equivalent to the RGL. Reductions in the sorption potential of radionuclides to Poole Formation material leads to their more rapid transport through the geosphere, which results in an increase in peak dose rates for the RPs where the primary dose-contributing radionuclides are relatively short-lived. In the case of an increase in geosphere sorption, the process outlined above is reversed, with peak doses reducing by around 80-90% (but equivalent to a reduction in dose of less than 1 μSv y^{-1}).

Biosphere Sorption (Cases EE 1.11 and EE 1.12)

504 A decrease in biosphere sorption leads to decreases in the peak dose rates of up to an order of magnitude for all RPs (but peak doses remain less than 1 μSv), except the River Paddler RP (11% reduction) and the Angler and Mire Mudder RPs (increase by 16% and 3%, respectively). For the land-based RPs this is due to a decrease in the sorption potential of radionuclides to soil, allowing for radionuclides to be more rapidly transported out of the system. However, the impact on the peak dose for the water-based RPs (Angler, River Paddler and Mire Mudder) is different as the decrease in the sorption potential of radionuclides to soil/sediment increases their activity concentration in the water of the river and mire. In the case of an increase in biosphere sorption, the process outlined above is generally reversed, but larger increases of peak dose rates are observed, with the dose rates for some RPs increasing by more than an order of magnitude (although the largest increase, for the Smallholder (Land/Mire) RP, is only 8 μSv y^{-1} and the resulting peak dose rate of 8.7E-03 mSv y^{-1} remains beneath the RGL; Figure E.12).

Child and Infant RPs (Cases EE 1.13 and EE 1.14)

505 The Reference Case calculates dose rates for adults, as this is deemed to be the most representative age range for the considered RPs. However, it is likely that children and infants will paddle in the river, play in a park or be part of a smallholder family. The occupancy times were kept as for adult RPs, but the consumption rates and dose coefficient factors adjusted for children and infants. The Park User RP peak dose reduces by around 70% for children and increases by 20% for infants, for both Field and Land/Mire compartments. The River Paddler RP peak dose increases by almost a factor of two for children and infants. These changes are driven by the relative balance of reduced consumption rates against higher dose coefficient values. For the Smallholder RP, the child peak dose is reduced by 99% (Field) and 31% (Land/Mire) compared to that for an adult but increases by 78% (Field) and decreases by 1% (Land/Mire) for an infant – these differences are primarily due to the Winfrith habits survey data recording watercress consumption for infants but not children, high uptake factors for aquatic plants, and the greater dominance of animal and terrestrial plant foodstuff ingestion pathways for the Land/Mire compartment. However, in all cases, the time of peak dose rate remains roughly the same and the dominant radionuclides remain ^{210}Pb or ^{227}Ac (except for the child Smallholder (Field) RP that changes from ^{227}Ac to ^{210}Pb). In all cases the change in peak dose is much less than 1 μSv y^{-1} and the dose rates are well below the dose equivalent of the RGL.

Biosphere Uptake Factors (Cases EE 1.15 and EE 1.16)

506 Varying the biosphere uptake factors has no impact on the River Paddler, Mire Mudder and Construction Worker (Field and Land/Mire) RPs, as they do not ingest contaminated foodstuffs. For the remaining RPs there is a direct correlation between dose and uptake factors; assuming minimum uptake factors reduces the peak dose rate by about an order of magnitude and increases it by more than two orders of magnitude for the maximum uptake factors. This leads to the Farmer and Smallholder RPs in the Land/Mire compartment having peak dose rates of 5.3E-02 mSv y^{-1} and

7.5E-02 mSv y^{-1}, respectively (Figure 10.15). These dose rates are comparable to, but in excess of, the dose rate equivalent of the RGL (1.7E-02 mSv y^{-1}). However, it is important to recognise the uncertainty in the uptake factors for various foodstuffs – this calculation considers the extreme of the parameter value range for every radionuclide. In addition, these calculations assume that the RP scenarios occur; as discussed above, the probability of a smallholder living directly on the contaminated area in the future is expected to be much less than one. Whilst farming in the area is a probable activity, doing so on the contaminated area is less likely, as is assuming that the Farmer RP's entire meat and vegetable intake is contaminated.

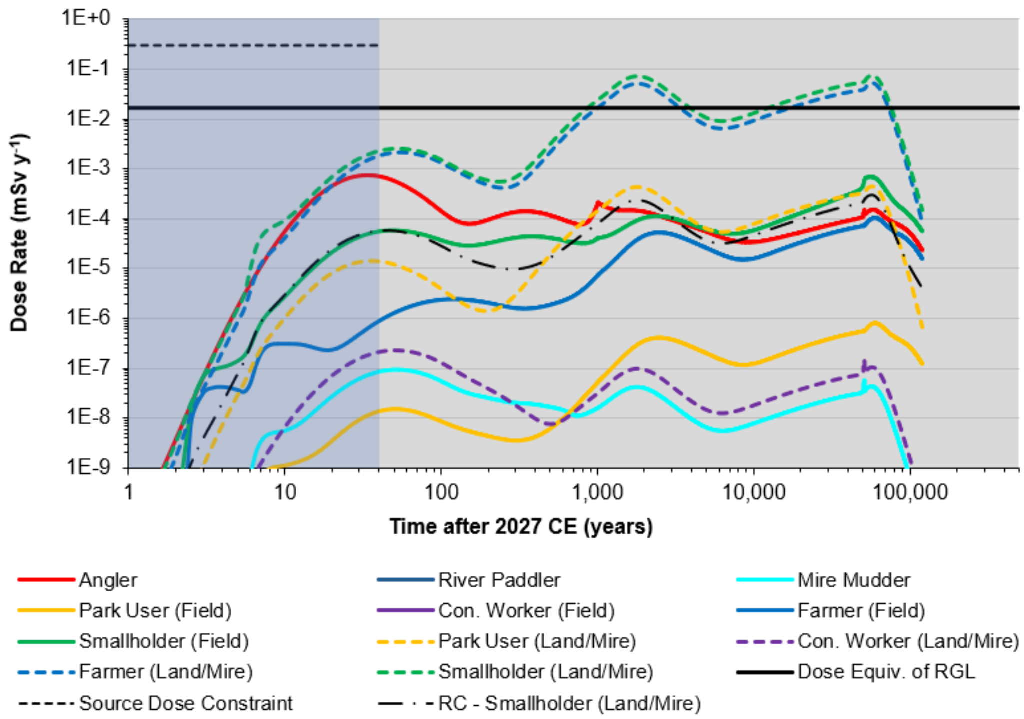

Figure 10.15: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.16 (maximum biosphere uptake factors). The Reference Case (RC) Smallholder (Land/Mire) RP dose rate is shown for comparison.

Mire Outflow Rate (Cases EE 1.17 and EE 1.18)

507 The flow rate through the mire will vary considerably over time, from effectively zero during extended dry periods to hundreds of cubic metres per day or more during extreme flood events (PA-023). The average annual flow in the mire is expected to be low; a value of 0.05 m s^{-1} is assumed for the Reference Case (see Table D.47). Reducing the assumed outflow rate by an order of magnitude leads to increases in peak dose rate by a factor of up to seven for the RPs based on the Land/Mire compartment due to radionuclides remaining in the compartment for longer. However, this also reduces the total peak dose rate by 10% to 20% for most of the other RPs, as the radionuclide concentration in the River and Field compartments is reduced. The reverse

occurs when the flow rate is increased by an order of magnitude, with the additional water volumes passing through the compartment leading to peak dose rate reductions in the five Land/Mire compartment RPs by up to 90% and an increase of 1% to 17% for the other RPs (excluding the Smallholder (Field) RP which also sees a 7% reduction). However, these changes in peak dose are less than 1 μSv y^{-1}, except for the Smallholder (Land/Mire) RP which increases by just over 1 μSv y^{-1} to 1.8E-03 mSv y^{-1} when the mire outflow rate is reduced.

Summary

508 In summary, dose rates to all RPs remain below the dose rate equivalent of the RGL for all alternative assessment cases considered except when biosphere uptake factors are maximised, which leads to conditional peak doses exceeding the RGL for the Land/Mire Farmer and Smallholder RPs 1,000 years in the future. The alternative assessment cases suggest that uncertainty in the following parameters has the greatest impact on RP dose rates:

- alternative inventories;
- radioelement partition coefficients for concrete, Poole Formation material and biosphere soil and sediment;
- biosphere uptake factors for radionuclide transfer from the environment into food products; and
- average annual mire outflow rates to the river.

Table 10.4: Peak dose rate to each RP for the alternative assessment cases considered in the Winfrith NE assessment. The time of peak dose rate after 2027 CE is also shown. Blue shading is used to denote dose rates that are two (pale blue) to ten or more times (dark blue) higher than the Reference Case Smallholder (Land/Mire) peak dose. Note that in some cases the dominant radionuclide is not the main dose-contributing radionuclide at the time of the overall peak dose rate. *Page set to A3 size.*

Assessment Case	Angler			River Paddler			Mire Mudder			Park User (Field)			Con. Worker (Field)			Farmer (Field)			Smallholder (Field)			Park User (Land/Mire)			Con. Worker (Land/Mire)			Farmer (Land/Mire)			Smallholder (Land/Mire)		
	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.
EE.1.0 Ref. Case	1.52E-06	58272	Pb210	7.06E-10	51176	Pb210	9.36E-08	52	U238	3.05E-09	59669	Pb210	3.31E-10	51246	U238	2.49E-07	58872	Pb210	5.58E-05	55768	Ac227	1.67E-06	57047	Pb210	2.29E-07	50.5	U238	1.21E-04	56743	Pb210	2.99E-04	56777	Pb210
EE.1.1 Alt. inventories	8.56E-06	58063	Pb210	3.94E-09	51182	Pb210	3.16E-07	51182	Pb210	1.76E-08	59310	Pb210	1.76E-09	51250	Ra226	1.50E-06	58434	Pb210	3.84E-04	52395	Ac227	9.54E-06	1770	Pb210	7.41E-07	51182	Ra226	7.00E-04	56384	Pb210	1.77E-03	56237	Pb210
EE.1.2 Alt. (Pu) Dragon inventory	8.49E-06	58126	Pb210	3.90E-09	51184	Pb210	3.16E-07	51182	Pb210	1.75E-08	59367	Pb210	1.74E-09	51254	Ra226	1.49E-06	58489	Pb210	3.82E-04	52400	Ac227	9.54E-06	1770	Pb210	7.41E-07	51182	Ra226	7.00E-04	56384	Pb210	1.77E-03	56243	Pb210
EE.1.3 Min. near-field sorption	3.47E-06	1235	Pb210	1.11E-09	1275	Pb210	1.35E-07	1255	Pb210	4.23E-09	1805	Pb210	3.07E-10	1805	U238	3.10E-07	1795	Pb210	7.00E-05	51497	Ac227	5.21E-06	1265	Pb210	3.21E-07	1265	Ra226	3.59E-04	1265	Pb210	7.57E-04	1265	Pb210
EE.1.4 Max. near-field sorption	1.02E-06	754	Sr90	6.10E-10	52	U238	9.35E-08	52	U238	1.70E-09	60932	Pb210	2.95E-10	51375	U238	1.45E-07	58685	Pb210	4.45E-05	52525	Ac227	9.37E-07	58256	Pb210	2.29E-07	50.5	U238	6.84E-05	56878	Pb210	1.79E-04	56924	Pb210
EE.1.5 Min. concrete & rubble porosity	1.377E-06	446	Sr90	6.097E-10	52	U238	9.354E-08	52	U238	1.212E-09	57752	Pb210	2.289E-10	108.5	U238	1.134E-07	57267	Pb210	4.723E-05	57268	Ac227	8.268E-07	1850	Pb210	2.289E-07	50.5	U238	5.71E-05	1855	Pb210	1.40E-04	55867	Pb210
EE.1.6 Max. concrete & rubble porosity	1.404E-06	58523	Pb210	6.538E-10	51176	Pb210	9.356E-08	52	Pb210	2.814E-09	59896	Pb210	3.117E-10	51244	U238	2.278E-07	58985	Pb210	4.873E-05	55025	Ac227	1.799E-06	1795	Pb210	2.289E-07	50.5	U238	1.24E-04	1795	Pb210	2.70E-04	56848	Pb210
EE.1.7 Min. dry bulk concrete density	1.514E-06	58228	Pb210	6.984E-10	51174	Pb210	9.356E-08	52	U238	3.038E-09	59619	Pb210	3.266E-10	51243	U238	2.478E-07	58800	Pb210	5.526E-05	52754	Ac227	1.665E-06	57014	Pb210	2.289E-07	50.5	U238	1.20E-04	56700	Pb210	2.98E-04	56714	Pb210
EE.1.8 Max. dry bulk concrete density	1.521E-06	58300	Pb210	7.102E-10	51178	Pb210	9.356E-08	52	U238	3.054E-09	59700	Pb210	3.34E-10	51247	U238	2.496E-07	58917	Pb210	5.62E-05	55948	Ac227	1.675E-06	57067	Pb210	2.289E-07	50.5	U238	1.21E-04	56770	Pb210	3.01E-04	56816	Pb210
EE.1.9 Min. geosphere sorption	1.22E-05	5.597	Sr90	3.92E-09	7.443	Sr90	6.05E-07	7.404	Sr90	4.94E-09	51107	Pb210	8.22E-10	48.5	U238	3.86E-07	51066	Pb210	1.48E-04	51605	Th229	8.60E-06	5.793	Sr90	1.58E-06	6.983	Sr90	3.62E-04	1003	Sr90	7.60E-04	1002	Pb210
EE.1.10 Max. geosphere sorption	3.81E-07	639	I129	1.16E-10	61470	Pb210	1.45E-08	536	Pb210	4.84E-10	112613	Pb210	5.58E-11	52528	U238	4.11E-08	66576	Pb210	2.54E-05	62233	Ac227	3.10E-07	116588	Pb210	2.29E-08	453	U238	2.16E-05	115651	Pb210	5.12E-05	64216	Pb210
EE.1.11 Min. biosphere sorption	1.76E-06	57712	Pb210	6.28E-10	46.5	Pb210	9.66E-08	46.5	Pb210	9.31E-11	56150	Pb210	6.83E-12	54415	Ac227	2.16E-08	51174	H3	3.07E-05	57095	Ac227	2.93E-08	55572	Pb210	1.65E-09	51187	Ac227	4.05E-06	52220	Pa231	3.60E-05	56634	Ac227
EE.1.12 Max. biosphere sorption	2.95E-06	65477	Pb210	1.32E-08	53232	Th229	4.56E-08	51395	Pb210	3.16E-08	87247	Pb210	4.55E-09	58132	U238	2.30E-06	86844	Pb210	8.71E-04	52530	Th230	5.57E-05	61825	Pb210	7.82E-06	51386	U238	3.89E-03	61818	Pb210	8.75E-03	61998	Pb210
EE.1.13 Child RP				1.28E-09	58261	Pb210				9.28E-10	59733	Pb210							3.83E-07	59627	Pb210	5.07E-07	57085	Pb210							2.06E-04	57033	Pb210
EE.1.14 Infant RP				1.31E-09	58301	Pb210				3.60E-09	59773	Pb210							9.96E-05	52717	Ac227	2.02E-06	57061	Pb210							2.95E-04	56527	Pb210
EE.1.15 Min. uptake factors	4.49E-08	1013	C14	7.06E-10	51176	Pb210	9.36E-08	52	U238	3.97E-10	58042	Pb210	3.31E-10	51246	U238	1.31E-08	57828	Pb210	5.57E-06	55755	Ac227	1.87E-07	56458	Pb210	2.29E-07	50.5	U238	5.09E-06	56058	Pb210	2.35E-05	56660	Pb210
EE.1.16 Max. uptake factors	7.42E-04	34	Sr90	7.06E-10	51176	Pb210	9.36E-08	52	U238	8.01E-07	59887	Pb210	3.31E-10	51246	U238	1.04E-04	59880	Pb210	6.88E-04	56697	Ac227	4.45E-04	57115	Pb210	2.29E-07	50.5	U238	5.29E-02	57185	Pb210	7.48E-02	57158	Pb210
EE.1.17 Min. mire outflow rate	1.21E-06	59587	Pb210	6.19E-10	51217	Pb210	5.74E-07	84.5	U238	2.69E-09	60672	Pb210	3.01E-10	51288	U238	2.21E-07	59636	Pb210	6.02E-05	53024	Ac227	1.18E-05	57895	Pb210	1.38E-06	81.5	U238	8.67E-04	57455	Pb210	1.78E-03	57684	Pb210
EE.1.18 Max. mire outflow rate	1.78E-06	57814	Pb210	7.55E-10	51172	Pb210	9.70E-09	47	Pb210	3.12E-09	59524	Pb210	3.35E-10	51241	U238	2.54E-07	58757	Pb210	5.18E-05	56616	Ac227	2.07E-07	56811	Pb210	2.38E-08	46	U238	1.47E-05	56566	Pb210	8.16E-05	56642	Ac227

10.2 Natural Evolution - Variant Scenarios

509 The 18 variant scenarios considered in the Winfrith NE assessment can be split between the 13 that investigate uncertainty in the conceptual model, including uncertainty in the future evolution of the proposed on-site disposals and their setting, and the five that consider uncertainty in the configuration of the disposals; these are discussed in Sections 10.2.1 and 10.2.2, respectively.

10.2.1 Variant Concept Scenarios

510 Table 10.5 and Figure E.19 to Figure E.28 (Appendix E.2) present the total dose rates calculated for natural evolution of the proposed Winfrith on-site disposals in the variant concept scenarios. In all but one of these scenarios, peak dose rates to all RPs remain below the dose rate equivalent of the RGL. Dose rates are highest for the Well Abstractor RP in the A59 groundwater abstraction variant scenario, where an RP is assumed to abstract and consume groundwater released from a well 1 m down-gradient of the OoS A59 area feature group. The peak dose rate exceeds the dose rate equivalent of the RGL by almost an order of magnitude in the first 100 years, but this conditional dose does not reflect the probability of drilling such a well nor the fact that, for the first 40 years, the higher source dose constraint applies as NRS will still retain control of the site and drilling a well will not be possible (see further discussion in sub-section Groundwater Well Abstraction below).

511 Discussion of each of the variant concept scenarios presented in Table 10.5, relative to the Reference Case assessment, is presented below.

Shorter Concrete Chemical Degradation Duration (Scenario VA.1)

512 Reducing the chemical degradation duration from 50,000 years to 1,000 years (consistent with the assumed hydraulic degradation period) leads to increases in peak dose for most RPs of up to around 1.5 times, although the Angler RP sees an increase of an order of magnitude to 1.6E-05 mSv y^{-1}. However, there are decreases of around 10% to 50% in the Park User, Farmer and Smallholder RP peak doses for the Field compartment. The Smallholder (Land/Mire) RP remains the most limiting RP, but with a dose rate below that equivalent of the RGL. The peak dose increases arise due to a pulse of radionuclides flushed from the SGHWR shortly after the concrete has degraded, containing radionuclides that have had less time to decay, such that ^{14}C is the dominant radionuclide for many RPs along with ^{238}U and ^{210}Pb. The time of the peak also occurs at around 1,300 years to 2,300 years for all RPs.

Varying Intact Concrete Initial Hydraulic Conductivity and Shorter Degradation Period (Scenarios VA.2 and VA.3)

513 Assuming a minimum initial hydraulic conductivity of 1E-12 m s^{-1} (Scenario VA.2) leads to no meaningful change in the peak dose (Figure E.20). There is a maximum peak dose reduction of up to 4% for all RPs, no change in the dominant radionuclide and effectively no change in the time of the peak.

514 Assuming a maximum initial hydraulic conductivity for the intact concrete of 1E-9 m s^{-1} and reducing the hydraulic degradation period from 1,000 years to 300 years (Scenario VA.3) leads to a change in the peak dose for all RPs of no more than 2%, except for the Angler RP. For the latter, there is a 33% increase in peak dose to 2.0E-06 mSv y^{-1}, the dominant radionuclide changes from ^{210}Pb to ^{129}I and the time of peak dose occurs much earlier, around 200 years after model start – however, this is simply due to a fractional difference in the magnitude of the later peak being exceeded by the earlier peak, with no meaningful difference. There is no change in the dominant radionuclides and effectively no change in the time of the peak for the other RPs.

Cap Degradation Time (Scenario VA.4)

515 Scenario VA.4 considers the impact of cap degradation commencing 125 years after the Disposal Start Date, rather than 250 years, and doubling the rate of degradation such that the maximum infiltration rate is reached by 500 years after the Disposal Start Date (compared with 1,000 years in the Reference Case). Overall, this scenario has limited impact, with the peak dose changing by less than 4%. The only slight exception is the Angler RP where the peak dose increases by 12% to 1.7E-06 mSv y^{-1} and the time of peak dose occurs slightly earlier (but there is no change in the dominant radionuclide, ^{210}Pb) – this is simply because the fractional increase in the later peak associated with release from SGHWR is exceeded by the earlier peak due to releases from OoS A59 area, but there is no meaningful difference. The Smallholder (Land/Mire) RP remains limiting with a peak dose of 3.0E-04 mSv y^{-1}, orders of magnitude beneath that equivalent of the RGL.

Geosphere Flow Path Proportions (Scenarios VA.5, VA.6 and VA.7)

516 These scenarios consider the radiological impact of changes in the proportion of releases from the SGHWR and OoS A59 area feature groups; the Reference Case assumes 50% of these releases travel to the River Frome and 50% to the Land/Mire. All releases from the Dragon reactor complex travel to the River Frome.

- Scenario VA.5 - Assuming 100% of SGHWR and OoS A59 area releases to the River Frome leads to no dose to the Mire Mudder RP and Land/Mire Park User and Construction Worker RPs, as the Land/Mire does not become contaminated. The peak dose for the Land/Mire Farmer and Smallholder RPs also reduces by more than an order of magnitude as no dose is received from the contaminated Land/Mire (these RPs still receive a dose through consumption of animal products where the animals have consumed water from the River). The time of peak dose is also reached earlier and the dominant radionuclides change from ^{210}Pb to ^{3}H and ^{227}Ac, respectively. The peak dose for the other RPs, except the Smallholder (Field), increases by between 1% and 50% and occurs slightly later, but with no change in the dominant radionuclide. The Smallholder (Field) RP sees an 11% reduction in the peak dose (a change of less than 1 μSv) and the time of the peak occurs a few thousand years earlier, but the dominant radionuclide remains ^{227}Ac. Increased peaks doses are generally due to the increase in SGHWR releases to the river, and the later peak times are driven primarily by the delay in releases from OoS A59 area reaching the river (the path length from OoS A59 area to the mire is 25 m, but 350 m to the river). In this scenario the Smallholder (Field) RP is the limiting RP with a peak dose rate of 5.0E-05 mSv y^{-1}.

- Scenario VA.6 - Assuming 100% of SGHWR and OoS A59 area releases are directed to the Land/Mire leads to increases in the peak dose for all RPs, with the peak dose rate for those RPs associated with the Field increasing by a factor of 1.5-2.0 and all other RPs increasing by a factor of 2.5-3.5. The Smallholder (Land/Mire) RP remains the limiting RP with a peak dose rate of 8.1E-04 mSv y^{-1}, more than an order of magnitude beneath the dose rate equivalent of the RGL. This overall increase occurs because, after being released to the Land/Mire, no delay for subsequent release to the River Frome is assumed; thus, release to the Land/Mire effectively acts in the NE model as a short-cut to the river (300 m compared to 1,350 m for SGHWR and 25 m compared with 350 m for A59), leading to less sorption and decay. The time of the peak for the non-Field compartment RPs moves significantly earlier, with limited change for the other RPs. The dominant radionuclides remain the same, except for the Mire Mudder RP which switches from ^{238}U to ^{210}Pb.
- Scenario VA.7 - Assuming 100% of SGHWR release is directed to the Dragon reactor complex, to join its release path to the River Frome, results in peak dose rate increases of up to a factor of two for the River and Field RPs. Similar to the previous scenario, the increase occurs because the combined path length from SGHWR to the Dragon reactor complex and on to the River Frome is 1,050 m, compared with 1,350 m for SGHWR direct to the River, which results in less sorption and decay. There is no change in the peak dose rate for the Mire Mudder and Construction Worker (Land/Mire) RPs because these are dominated by OoS A59 area releases to the Land/Mire at early times, rather than releases from SGHWR. The Land/Mire compartment Park User, Farmer and Smallholder RPs, for which the peak doses are dominated by SGHWR releases in the Reference Case, all see a reduction in the peak dose rate of 53% to 81%, the time of the peak shifting significantly earlier from over 50,000 years to less than 50 years after model start, and the dominant radionuclide changing from ^{210}Pb to ^{90}Sr or ^{227}Ac. In this scenario the Smallholder (Field) RP is the limiting RP with a peak dose rate of 5.8E-05 mSv y^{-1}.

Increased Rate of Rainfall Infiltration Through the Soil Above A59 (Scenario VA.8)

517 Increasing the recharge through the A59 near-field area by 10% has no noticeable impact on any of the receptors. This shows that the change is too small to have any impact on the other receptors compared to the dominant releases from the other feature groups at later times.

Reasonable Worst Case Future Groundwater Levels (Scenario VA.9)

518 Increased groundwater elevation to reflect a potential future climate with a higher water table leads to negligible difference in radiological impact as compared to the Reference Case for most of the RPs, with the diluting effect of the increased water volumes balancing the greater fraction of the in-situ features that is below the water table and

available to be released as the structures degrade. The Mire Mudder and Construction Worker (Land/Mire) RPs see a 20% increase in peak dose rate (a difference of <<1 μSv y^{-1}) due to the higher water level enabling a slightly bigger fraction of the OoS A59 inventory to be available earlier, but the dominant radionuclide (^{238}U) and time of peak (~50 years) remain unchanged. The Smallholder (Land/Mire) RP remains the limiting RP with a peak dose rate of 3.0E-04 mSv y^{-1}.

Reasonable Worst Case Future Groundwater Levels with Seasonal Fluctuation (Scenario VA.10)

519 As discussed in Section 3.4, it is expected that there will be wetter winters and warmer summers in the future. This could result in seasonal fluctuation in water levels, with water entry into some features potentially occurring occasionally in wet winters. Based on the RWC climate simulation water is modelled to enter the SGHWR South Annexe for 12% and the Dragon reactor for 9% of the period modelled (to 2100) [148, Tab.614/1]; other climate simulations show lower frequencies for water entry and lower water levels. Some climate simulations mean that groundwater levels could be lower than in the Reference Case.

520 The GoldSim NE assessment model cannot directly implement a water level that fluctuates every few months over a 100,000-year period, especially a fluctuation of varying magnitude. However, a conservative estimate of the impact has been undertaken by running the NE model for a water level equivalent to the maximum modelled winter water level (the average RWC groundwater level plus an additional water volume associated with that modelled to periodically enter the SGHWR Annexe and Dragon reactor). The peak dose calculated in the NE model has then been scaled by a volume enhancement factor. The enhancement factor aims to account for the smaller volume of water that would annually flow through the additional winter-saturated layer, as compared to assuming that the layer is saturated for the entire year. This also accounts for the fact that water is only predicted to periodically enter the modelled features (a frequency of groundwater infiltration was not calculated for the A59 area so 20% has been arbitrarily assumed).

521 Based on the feature void volumes and heights, modelled water elevations and the Poole Formation flow rate, indicative enhancement factors of 37x for SGHWR, 145x for the Dragon reactor complex and 6x for A59 have been derived[44]. Applying these to the three feature group components of the Smallholder (Land/Mire) RP peak dose suggests that the peak dose could be ~37 times higher across all the features at 1.1E-02 mSv y^{-1} (it is overwhelmingly dominated by releases from SGHWR at the time of the peak), which is slightly lower than the dose equivalent of the RGL.

522 This calculation to capture the potential effect of fluctuating groundwater levels is considered to be bounding because:

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[44] The notable differences in the enhancement factors derived depends partly of the size of the feature and the height of the fluctuating water level compared to the feature base, but is also strongly affected by the hydraulic gradient in the area of the feature. The hydraulic gradient is smallest (0.005) in the A59 area and greatest near the Dragon reactor complex (0.025) – see Paragraph 103.

- the Reasonable Worst Case groundwater levels are assumed rather than the Cautious Central Estimate groundwater levels;
- does not account for the impact of changing rainfall rates which would be associated with higher groundwater levels;
- assumes that any reduction in water volume directly correlates to an increase in dose, without accounting for differences in potential attenuation, dilution or decay before reaching receptors;
- assumes that the same total activity would be released from the additional layer when it saturated for part of the time compared to when it is permanently saturated;
- assumes that the concrete structure is fully degraded and so models the maximum hydraulic conductivity;
- the entire additional water layer is assumed to outflow each year and be replaced; and
- the scaling factor has been applied to the peak dose derived from a calculation where water levels are held constant – periodic water ingress into the features means that it will take longer for radionuclides to diffuse through the partially saturated structure and be released to groundwater, which would lead to lower peak impacts spread out over a longer period. This would also mean greater decay would be expected before reaching the receptors.

Groundwater Well Abstraction

523 The final set of variant concept scenarios consider groundwater abstraction, with the Well Abstractor RP conservatively assumed to abstract and consume groundwater released from a well 1 m down-gradient of each of the three feature groups (scenarios VA.11, VA.12 and VA.13 as presented in Figure 10.16). The figure shows that the conditional dose rate for the Well Abstractor RP for a well located downstream of the SGHWR and Dragon reactor complex feature groups is always below the dose equivalent of the RGL, and so there is no exceedance associated with the proposed disposals.

524 As discussed in Sections 1.3 and 3.3.3, the A59 feature group inventory modelled satisfies RSR OoS criteria and so does not form part of the RSR permit application. However, it has been included in the PA to ensure a robust transparent assessment. The conditional dose rate for the Well Abstractor RP for a well associated with the A59 feature group exceeds the dose equivalent of the RGL in the first 100 years after 2027, with a peak dose of 1.6E-1 mSv y^{-1} within two years. The dominant radionuclides are ^{90}Sr and ^{238}U. However, for the first ~40 years, in the period to the SRS (2066), NRS will retain control of the site and drilling a borehole would not be permitted. In addition, as shown on Figure 10.16, the GRR dose constraint applies in this period and the calculated dose is less than this. Therefore, only the post-RSR period is relevant, where the peak dose rate has reduced to approximately double that equivalent of the RGL (4.1E-02 mSv y^{-1} at 2066).

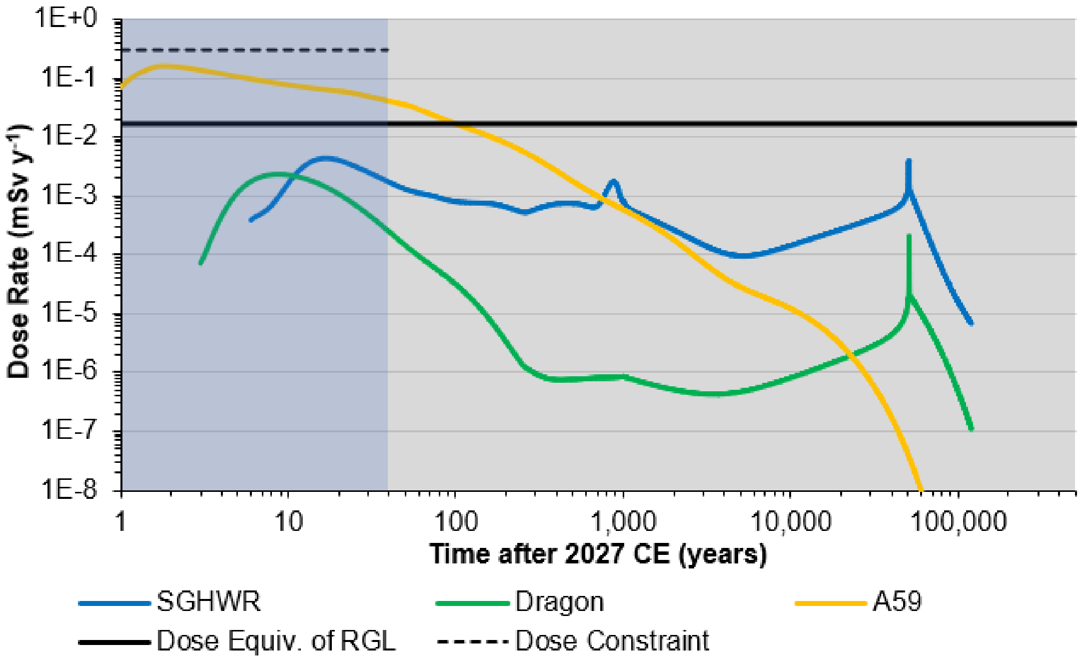

Figure 10.16: Dose rates for the Well Abstractor RP in the variant concept scenarios, with a well located 1 m down-gradient of each feature group. NRS will retain control over the site in the period to the SRS such that it will not be possible to drill a well (the blue shaded period on the plot).

525 Nonetheless, when considering such modelled impacts, it is important to note that the probability of a dose being received has been cautiously assumed to be unity (i.e. it is a conditional dose). It is considered unlikely that an RP would receive a radiological impact in excess of the RGL because:

- During the period of RSR, drilling a well immediately downstream of the on-site disposals will be prevented by NRS control of the site.
- After the period of RSR, the CEFAS regional habits surveys suggest construction of a residential well is relatively uncommon. The 2003 CEFAS habits survey [59, p.35] recorded only one household within a 5-km radius of the site whose sole water supply was from a borehole, and two properties near the Winfrith site had capped or disused wells in their gardens. The 2019 survey noted human consumption of groundwater via boreholes at “several” farmhouses [60, §5.1], but the exact number of farmhouses was not stated.
- There are commercial groundwater abstraction wells in the area. WSP [43, §6.3.2] report a number of groundwater abstraction wells within 5 km of the site, mostly small to medium sized, abstracting less than 2,500 m^3/day. The closest of these to the site is located at Broompound Dairy, approximately 0.9 km north of the site. There are three locations with groundwater abstraction greater than 2,500 m^3/day; the two Wessex Water public water supplies (located 3.2 km south-east of the site), and one associated with a watercress farm located 3.8 km to the north-west of the site. However, Schedule 2 of the Water Supply (Water Quality) Regulations 2018 requires that radioactivity is monitored (i.e.

the indicator standards are gross alpha 0.1 Bq l^{-1} and gross beta of 1.0 Bq l^{-1}). Therefore, any radioactive contamination present would be identified.

- On the basis of current water abstractions and given the proximity to nearby rivers, it is most likely that an abstraction borehole would be drilled into the confined Chalk aquifer below the London Clay, rather than potentially contaminated groundwater in the Poole Formation. Additionally, some of the land between the north boundary of the site and the River Frome is currently designated as a SSSI due to the presence of groundwater-supported aquatic and bankside vegetation [43, §6.3.2]. The undesignated woodland that is located between the site and the River Frome SSSI also has the potential to support a groundwater dependent terrestrial ecosystem (GWDTE). As such, groundwater abstractions within this area would have the potential to cause the deterioration of designated habitat communities. There is also a sewage treatment works located between the site and the River Frome SSSI that would make this area a less favourable location for a water supply source. Furthermore, any shallow well near to the on-site disposals might exhibit a mild reduction in water quality (e.g. suspended solids, slight colour) owing to the presence of the concrete structures. Site worker knowledge suggests shallow water may be naturally reducing with elevated levels of iron and/or manganese, which could affect the flavour, colour and potability of abstracted water. These factors combined make it unlikely that a future groundwater abstraction would be located on the site or between the site and the River Frome, at least in the near-term.
- Given the large land area over which a well could be located, it is even less probable that a well would be drilled such that it intercepts exactly the migrating contamination, at the location of highest concentration. The calculations presented above are bounding, assuming that the well is drilled immediately adjacent to (1 m downstream of) each modelled feature and do not account for transverse dispersion in the groundwater. The intercepted concentration will reduce with distance from the feature.
- The modelled Well Abstractor RP behaviour is bounding with an assumption that the receptor meets their entire annual drinking water needs from the one well.
- The exceedance calculated above occurs over a relatively narrow time interval (about the first 60 years after the proposed SRS date). The above figure shows that, over the majority of the modelled timeframe, calculated dose rates associated with drinking groundwater downstream of OoS A59 area are below the dose rate equivalent of the RGL.

526 Regarding the low probability argument above, the 2011 LLWR environmental safety case incorporated explicit quantification of the probability of a dose being received, based on the probability that one or more wells would be present in the area of contamination. This was calculated as follows [149, p.9]:

$$P(A) = 1 - \exp(-\mu A) \quad (10.1)$$

$$\text{If the product } \mu A \ll 1\text{, then } P(A) \approx \mu A \quad (10.2)$$

where:

- $P(A)$ Probability that one or more wells are present within the contaminated area A.
- A Contaminated area (m^2).
- μ Well probability per unit area (per m^2).

527 This same approach can be applied at Winfrith. The 2003 and 2019 CEFAS habits surveys for Winfrith [59; 60] suggest a value of three residential wells in the survey area (three in a circle of radius 5 km, or one well per 2.6E+07 m^2). The area that could become contaminated by aqueous releases from SGHWR can be approximated by the width of the facility perpendicular to groundwater flow and the groundwater path length to the River Frome (81 m x 1350 m = 1.1E+05 m^2), although this conservatively assumes a larger area than that immediately downstream of the facility where the highest concentration would be located. This calculation yields an annual[45] probability of just 4E-03 for drilling a well into the area of contamination between the SGHWR and the River Frome. Equivalent values for wells associated with the Dragon reactor complex and A59 are 6E-04 and 1E-03, respectively. When multiplied by the calculated peak dose rate, this would greatly reduce the associated peak risk, falling to at least two orders of magnitude below the RGL (1E-09 y^{-1} for SGHWR, 9E-11 y^{-1} for the Dragon reactor complex and 9E-09 y^{-1} for A59).

Summary

528 In summary, of the 13 variant concept scenarios discussed above, those with the most significant impact are the groundwater well abstraction scenario, seasonally fluctuating groundwater levels and assuming the entire flow path from SGHWR and OoS A59 area reaches the Land/Mire compartment. Conditional dose rates to all RPs remain below the dose rate equivalent of the RGL except for the low-probability event of drinking water from a well located immediately downstream of the A59 feature, which narrowly exceeds the dose equivalent of the RGL for a relatively short period of time.

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[45] The calculation of the probability of drilling a well in the region of interest is relatively simple and is assumed to be constant with time. It does not attempt to account for the cumulative probability of drilling wells in the area over the assessment period of tens of thousands of years, nor the finite operational lifetime of such wells or the impact on the location of subsequent wells. This is consistent with the assessment by LLWR [149, §2.3] and is considered to be a proportionate approach for this assessment given the conservative assumptions made (e.g. that the RP consumes their entire annual water supply from the well and that the well is located 1 m downstream of each feature) and the short period where the dose rate is calculated to exceed that equivalent of the RGL.

Table 10.5: Peak dose rate to each RP for the variant concept scenarios considered in the Winfrith NE assessment. The time of peak dose rate after 2027 CE is also shown. Blue shading is used to denote dose rates that are two (pale blue) to ten or more times (dark blue) higher than the Reference Case Smallholder (Land/Mire) peak dose. Note that in some cases the dominant radionuclide is not the main dose-contributing radionuclide at the time of the overall peak dose rate. *Page set to A3 size.*

Assessment Case	Angler			River Paddler			Mire Mudder			Park User (Field)			Con. Worker (Field)			Farmer (Field)			Smallholder (Field)			Park User (Land/Mire)			Con. Worker (Land/Mire)			Farmer (Land/Mire)			Smallholder (Land/Mire)		
	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.
EE.1.0 Ref. Case	1.52E-06	58272	Pb210	7.06E-10	51176	Pb210	9.36E-08	52	U238	3.05E-09	59669	Pb210	3.31E-10	51246	U238	2.49E-07	58872	Pb210	5.58E-05	55768	Ac227	1.67E-06	57047	Pb210	2.29E-07	50.5	U238	1.21E-04	56743	Pb210	2.99E-04	56777	Pb210
VA.1 Shorter chemical degradation duration	1.55E-05	1325	C14	1.15E-09	2195	Pb210	1.24E-07	2203	Pb210	2.72E-09	2292	Pb210	5.33E-10	2281	U238	1.91E-07	1325	C14	3.03E-05	1325	C14	2.30E-06	1800	Pb210	2.75E-07	2202	U238	1.59E-04	1830	Pb210	3.56E-04	2009	Pb210
VA.2 Min. initial hydraulic conductivity	1.52E-06	58396	Pb210	6.92E-10	51186	Pb210	9.36E-08	52	U238	3.04E-09	59772	Pb210	3.20E-10	51260	U238	2.48E-07	58986	Pb210	5.49E-05	55977	Ac227	1.67E-06	57057	Pb210	2.29E-07	50.5	U238	1.21E-04	56757	Pb210	2.99E-04	56815	Pb210
VA.3 Max. initial hydraulic conductivity & shorter degradation	2.01E-06	206	I129	7.00E-10	51175	Pb210	9.49E-08	53	U238	3.04E-09	59669	Pb210	3.25E-10	51243	U238	2.48E-07	58872	Pb210	5.54E-05	55586	Ac227	1.67E-06	57035	Pb210	2.29E-07	50.5	U238	1.20E-04	56732	Pb210	2.99E-04	56747	Pb210
VA.4 Shorter cap degradation time	1.70E-06	346	Pb210	7.14E-10	50700	Pb210	9.36E-08	52	Pb210	3.03E-09	59410	Pb210	3.36E-10	50750	U238	2.47E-07	58626	Pb210	5.48E-05	52361	Ac227	1.73E-06	1730	Pb210	2.29E-07	50.5	U238	1.20E-04	56408	Pb210	2.98E-04	56497	Pb210
VA.5 SGHWR & A59 groundwater pathway to River Frome	2.26E-06	65899	Pb210	7.92E-10	65895	Pb210	0.00E+00	0	H3	3.81E-09	67716	Pb210	3.36E-10	51445	U238	2.92E-07	66932	Pb210	4.97E-05	53500	Ac227	0.00E+00	0	H3	0.00E+00	0	H3	1.80E-08	247	H3	4.93E-05	53492	Ac227
VA.6 SGHWR & A59 groundwater pathway to mire	3.71E-06	1350	Pb210	1.58E-09	29.5	Pb210	2.43E-07	29.5	Pb210	4.95E-09	55316	Pb210	6.28E-10	51158	U238	3.94E-07	55026	Pb210	1.10E-04	55208	Ac227	5.60E-06	1355	Pb210	6.05E-07	28.5	U238	3.86E-04	1355	Pb210	8.13E-04	1355	Pb210
VA.7 SGHWR groundwater pathway to Dragon R.C.	2.87E-06	59848	Pb210	1.09E-09	51234	Pb210	9.35E-08	52	U238	4.82E-09	61591	Pb210	4.88E-10	51301	U238	3.72E-07	61118	Pb210	5.82E-05	52333	Ac227	7.81E-07	39	Sr90	2.29E-07	50.5	U238	2.89E-05	36	Sr90	5.81E-05	44.5	Ac227
VA.8 Increased rate of rainfall infiltration through soil	1.52E-06	58273	Pb210	7.06E-10	51176	Pb210	9.44E-08	52	U238	3.05E-09	59669	Pb210	3.31E-10	51246	U238	2.49E-07	58872	Pb210	5.58E-05	55768	Ac227	1.67E-06	57047	Pb210	2.31E-07	51	U238	1.21E-04	56743	Pb210	2.99E-04	56777	Pb210
VA.9 RWC groundwater levels	1.52E-06	58249	Pb210	7.45E-10	52	Pb210	1.14E-07	52	U238	3.05E-09	59643	Pb210	3.31E-10	51246	U238	2.49E-07	58840	Pb210	5.61E-05	55719	Ac227	1.67E-06	57024	Pb210	2.80E-07	51	U238	1.21E-04	56715	Pb210	3.00E-04	56749	Pb210
VA.10 RWC groundwater levels with seasonal fluctuation	1.73E-06	472	Pb210	6.85E-10	69	Pb210	1.05E-07	68	U238	2.78E-09	57947	Pb210	2.90E-10	114	U238	2.35E-07	57031	Pb210	6.38E-05	52119	Ac227	2.02E-06	1705	Pb210	2.53E-07	66	U238	1.39E-04	1710	Pb210	2.95E-04 1.08E-02	1710	Pb210

10.2.2 Variant Configuration Scenarios

529 Table 10.6 and Figure E.29 to Figure E.33 (Appendix E.3) present the total peak dose rates calculated in the variant configuration scenarios. All of these scenarios have negligible impact on the peak dose rates for all RPs and dose rates to all RPs remain below the dose rate equivalent of the RGL.

530 Discussion of variant configuration scenarios, relative to the Reference Case assessment, is presented below:

- Greater void spacing between blocks (Scenario VB.1) – Increasing the spacing between blocks from 10 vol% to 20 vol% has negligible impact, leading to an increase in peak dose of no more than 0.1% and no real change in the time of peak dose or dominant radionuclides.
- All SGHWR and Dragon disposal voids filled with rubble (Scenario VB.2) – Replacing the concrete block infill layers in SGHWR Region 1 and Dragon Inside Wall C with rubble has negligible impact, with a maximum change of up to 4% (<<1 μSv y^{-1}).
- All SGHWR and Dragon disposal voids filled with grout (Scenario VB.3) – This scenario models the grouting of emplaced infill material in the SGHWR and Dragon disposal voids. The impact on dose rate is negligible, also with a maximum change of up to 4% (<<1 μSv y^{-1}). The time of peak dose rate and dominant radionuclide remains unchanged from that of the Reference Case for all RPs.
- Minimum and maximum concrete block size (Scenarios VB.4 and VB.5) – Reducing the block size to 0.5 m^3 and increasing it to 2.4 m^3 has negligible impact, with insignificant peak dose rate changes of around 0.1% for each RP.

Table 10.6: Peak dose rate to each RP for the variant configuration scenarios considered in the Winfrith NE assessment. The time of peak dose rate after 2027 CE is also shown. Blue shading is used to denote dose rates that are two (pale blue) to ten or more times (dark blue) higher than the Reference Case Smallholder (Land/Mire) peak dose (none of the variant configuration scenarios register on this scale). Note that in some cases the dominant radionuclide is not the main dose-contributing radionuclide at the time of the overall peak dose rate. *Page set to A3 size.*

Assessment Case	Angler			River Paddler			Mire Mudder			Park User (Field)			Con. Worker (Field)			Farmer (Field)			Smallholder (Field)			Park User (Land/Mire)			Con. Worker (Land/Mire)			Farmer (Land/Mire)			Smallholder (Land/Mire)		
	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.
EE.1.0 Ref. Case	1.52E-06	58272	Pb210	7.06E-10	51176	Pb210	9.36E-08	52	U238	3.05E-09	59669	Pb210	3.31E-10	51246	U238	2.49E-07	58872	Pb210	5.58E-05	55768	Ac227	1.67E-06	57047	Pb210	2.29E-07	50.5	U238	1.21E-04	56743	Pb210	2.99E-04	56777	Pb210
VB.1 Greater void spacing between blocks	1.519E-06	58281	Pb210	7.057E-10	51177	Pb210	9.356E-08	52	U238	3.049E-09	59677	Pb210	3.312E-10	51246	U238	2.491E-07	58878	Pb210	5.59E-05	55770	Ac227	1.672E-06	57056	Pb210	2.289E-07	50.5	U238	1.21E-04	56750	Pb210	3.00E-04	56785	Pb210
VB.2 Entirely rubble infill	1.50E-06	58553	Pb210	6.95E-10	51176	Pb210	9.36E-08	52	Pb210	3.01E-09	59971	Pb210	3.29E-10	51245	U238	2.46E-07	59125	Pb210	5.69E-05	55665	Ac227	1.74E-06	1780	Pb210	2.29E-07	50.5	U238	1.20E-04	1780	Pb210	2.98E-04	57029	Pb210
VB.3 Grouting of entire volume	1.45E-06	58923	Pb210	6.97E-10	51182	Pb210	9.42E-08	52	U238	2.92E-09	60378	Pb210	3.41E-10	51252	U238	2.38E-07	59574	Pb210	5.38E-05	56160	Ac227	1.63E-06	1795	Pb210	2.29E-07	50.5	U238	1.16E-04	57406	Pb210	2.87E-04	57360	Pb210
VB.4 Min. block size	1.52E-06	58274	Pb210	7.061E-10	51176	Pb210	9.356E-08	52	U238	3.05E-09	59670	Pb210	3.314E-10	51246	U238	2.49E-07	58872	Pb210	5.582E-05	55756	Ac227	1.672E-06	57048	Pb210	2.289E-07	50.5	U238	1.21E-04	56744	Pb210	3.00E-04	56777	Pb210
VB.5 Max. block size	1.518E-06	58271	Pb210	7.053E-10	51176	Pb210	9.356E-08	52	U238	3.046E-09	59668	Pb210	3.31E-10	51246	U238	2.487E-07	58873	Pb210	5.575E-05	55779	Ac227	1.67E-06	57046	Pb210	2.289E-07	50.5	U238	1.21E-04	56742	Pb210	2.99E-04	56777	Pb210

10.3 Natural Evolution - "What-If" Scenarios

531 Table 10.7 and Figure E.34 to Figure E.35 (Appendix E.4) present the total peak dose rates calculated in the "what-if" scenarios. In these scenarios dose rates to all RPs remain below the dose rate equivalent of the RGL.

532 Discussion of the "what-if" scenarios, relative to the Reference Case assessment, is presented below:

- Instantaneous hydraulic degradation (Scenario WI.1) – This scenario considers instantaneous hydraulic failure of the concrete structures in the near field, assumed to occur directly at the Disposal Start Date for the relevant feature group. Such a situation could potentially result from a large earthquake damaging the near field, which in view of the local seismic setting, is considered highly unlikely. In this scenario, peak doses for most RPs increase, with the greatest impact an increase by a factor of 2.8 for the Angler RP. This is a result of the hydraulic failure leading to greater flow rates through the near field in the first few decades, which results in the earlier release of radionuclides such as ^{3}H and ^{129}I. However, the limiting RP remains the Smallholder (Land/Mire) RP with a small increase in the peak dose rate to 3.2E-4 mSv y^{-1}.
- Extreme climate change with groundwater to 1 m below surface-level (Scenario WI.2) – This scenario arbitrarily assumes that groundwater reaches 1 m below the ground surface, leading to groundwater-driven releases from all modelled features and an increase in the height of the geosphere segments. Peak dose rates decrease by up to 21% for the River Paddler, Park User (Field), Construction Worker (Field) and Farmer (Field) RPs. Reasons for this include increased sorption due to the increase in the height of the modelled geosphere pathways (with more material to sorb to), as well as increased dilution. The peak dose rate increases for the Angler, Mire Mudder, Smallholder (Field) and the four Land/Mire RPs by between 5% and 67%. This is driven by the increased releases from the A59 area than for the Reference Case (as groundwater now reaches most of the feature). However, the limiting RP remains the Smallholder (Land/Mire) RP with less than a 1 μSv y^{-1} increase in the peak dose rate to 4.1E-4 mSv y^{-1}.

Table 10.7: Peak dose rate to each RP for the "What-if" scenarios considered in the Winfrith NE assessment. The time of peak dose rate after 2027 CE is also shown. Note that in some cases the dominant radionuclide is not the main dose-contributing radionuclide at the time of the overall peak dose rate. *Page set to A3 size.*

Assessment Case	Angler			River Paddler			Mire Mudder			Park User (Field)			Con. Worker (Field)			Farmer (Field)			Smallholder (Field)			Park User (Land/Mire)			Con. Worker (Land/Mire)			Farmer (Land/Mire)			Smallholder (Land/Mire)		
	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.	Peak Dose (mSv y^{-1})	Time Peak (y)	Dom. Rad.
EE.1.0 Ref. Case	1.52E-06	58272	Pb210	7.06E-10	51176	Pb210	9.36E-08	52	U238	3.05E-09	59669	Pb210	3.31E-10	51246	U238	2.49E-07	58872	Pb210	5.58E-05	55768	Ac227	1.67E-06	57047	Pb210	2.29E-07	50.5	U238	1.21E-04	56743	Pb210	2.99E-04	56777	Pb210
WI.1 Instantaneous hydraulic degradation	4.20E-06	22.5	I129	9.26E-10	6.689	H3	1.46E-07	6.681	H3	2.98E-09	60294	Pb210	3.16E-10	51242	U238	4.12E-07	6.827	H3	5.36E-05	52729	Ac227	2.20E-06	1175	Pb210	2.34E-07	52	U238	1.52E-04	1175	Pb210	3.21E-04	1175	Pb210
WI.2 Extreme climate change	1.92E-06	1580	Pb210	6.58E-10	64.5	Pb210	9.94E-08	60.5	Pb210	2.62E-09	2160	Pb210	2.82E-10	112	U238	1.97E-07	53759	Pb210	5.89E-05	51627	Ac227	2.79E-06	1585	Pb210	2.41E-07	58.5	U238	1.92E-04	1590	Pb210	4.06E-04	1590	Pb210

10.4 Site Occupancy

533 The results of MicroShield® calculations are given as dose rates (mSv h^{-1})[46]. The dose rates can be multiplied by the annual number of hours of exposure considered likely for a given scenario or RP. Appendix C.2.2 lists activities and RPs identified for potential inclusion in the site occupancy exposure pathways assessment and presents a screening justification.

534 For the time between the IEP and the SRS, where it is assumed that the public will be able to access the site for recreational use but it is still controlled by NRS, two RPs have been identified for inclusion in the site occupancy assessment: a dog walker and a camper. For a dog walker, an average occupancy time of 470 hours per year is assumed based on an analysis of questionnaire data collected by wardens on Dorset's Urban Heaths [127]. For a camper, an occupancy time of 384 hours per year is assumed based upon four trips of four nights each on contaminated land per year, assuming 24-hour occupancy.

535 For the period after the SRS when no access control of the site is assumed, three RPs have been identified for inclusion in the assessment: a dog walker, a camper and a caravan (static-home) dweller. Less likely, but possible, activities leading to direct radiation doses include housing and industrial developments and farming above the buried contamination. However, larger buildings and/or shorter exposure times suggest that the long-term consequences of RPs undertaking these activities are likely to be no greater than for a caravan dweller. It is assumed that the caravan is conservatively located on top of the buried contamination and is lived in year-round. The IAEA suggest a realistic exposure time of 4,500 hours for a house resident and a low probability exposure time of 8,760 hours (an entire year of exposure) [150]; conservatively, the larger exposure time is assumed here. Dog walker and camper occupancy times are assumed to be the same as for the pre-SRS receptors.

536 The site occupancy calculations for the dog walker do not take account of the movement of a walker over the site and therefore represent a bounding worst-case scenario for each feature (i.e. they are assumed to spend their entire walk above a single feature).

537 The site occupancy calculations for the caravan dweller do not take credit for any shielding from the floor of the caravan.

538 As stated in Section 6.2.3, the effective doses presented here are for the AP geometry (i.e. person lying face first towards the ground), as this geometry gives the highest reported dose rates. This is conservative as the RPs would not spend all their time lying down when present on the site.

539 External irradiation doses are highly dependent on the assumed distance from the source to the calculated dose point. Doses reported here assume that the dose point is

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[46] Note that MicroShield® calculates absorbed dose to each organ as well as the "effective dose equivalent rate" reported here.

1 m from the closest shield or source for the dog walker and caravan dweller; this is consistent with the position of an individuals' organs relative to the ground whilst walking or whilst standing, seated or sleeping in a bed in the caravan. For the camper, doses reported here assume that the dose point is at the surface of the closest shield or source; this is consistent with the position of an individuals' organs relative to the ground whilst sleeping in a tent.

540 Calculations have been carried out for the Reference Case configuration and for variant cases. The Reference Case configuration assumes the reference inventory for each feature and the following engineered cap/cover material thicknesses: SGHWR 4.0 m thick cap; Dragon reactor complex 3.8 m thick cap; and A59 0.5 m thick cover material. Variant cases address uncertainties in the inventory and in the cover material thickness, and consider thinner engineered cap thicknesses to support future optimisation assessments.

541 The probability of an RP being located above a given feature would be proportional to the horizontal cross-sectional area of the feature/component – the probability that an RP remains in the same location (central to the feature/component) for prolonged periods of time is low and would not be considered normal behaviour. The overall probability of an RP receiving an annual effective dose equal to those reported here is therefore expected to be low. However, the probability of the assessed scenarios has not been considered and they are simply assumed to occur.

10.4.1 Reference Case

542 Table 10.8 presents the calculated hourly dose rate above buried features which is used to calculate the annual dose to the RP based on occupancy time. The site occupier is assumed to be located relative to the feature of interest as follows:

- For SGHWR Region 1 it is assumed that the site occupier is located above the reactor bioshield and for the North and South Annexes it is assumed that the site occupier is over the centre of each annexe (Region 2 exposure is bounded by the greater inventory of Region 1).
- For the Dragon reactor complex feature group it is assumed that the site occupier is located above the reactor bioshield, and for the B78 floor slab and Dragon primary mortuary holes it is assumed that the site occupier is over the centre of each feature.
- For each feature area of the OoS A59 area feature group the site occupier is assumed to be located at a central point.

543 Figure 10.17 presents the annual effective doses for RPs in 2036 (the IEP date) and Figure 10.18 presents the same for 2066 (the SRS date). The calculated annual effective doses to all RPs are at least an order of magnitude below the dose rate equivalent of the RGL for both years. Due to the very low calculated doses at 2066, doses that would be received by a site occupier located above features at subsequent dates are not assessed (as decay and leaching over time would lead to smaller calculated doses). The key results are summarised as follows:

- For SGHWR the largest calculated doses are a result of exposure to Region 1: 6.05E-14 mSv y^{-1} to a dog walker in 2036 and 2.39E-13 mSv y^{-1} to a caravan dweller in 2066. The primary contributor to dose is ^{152}Eu in the bioshield in both years.
- For the Dragon reactor complex the largest calculated doses are a result of exposure to the infilled reactor bioshield: 5.49E-14 mSv y^{-1} to a dog walker in 2036 and 1.14E-12 mSv y^{-1} to a caravan dweller in 2066. The primary contributors to dose are ^{232}Th, ^{226}Ra and ^{228}Ra in 2036 and ^{232}Th in 2066.
- For A59 the largest calculated doses are a result of exposure to the remediated A591/HVA land area: 9.49E-06 mSv y^{-1} to a dog walker in 2036 and 1.03E-04 mSv y^{-1} to a caravan dweller in 2066. The primary contributor to dose is ^{137}Cs in both years.

Table 10.8: Reference Case dose rate (mSv h^{-1}) above buried in-situ features.

Year		**2036**	**2066**
Structure		**mSv h^{-1}**	
SGHWR Region 1	Surface	1.48E-16	2.99E-17
	1 m	1.29E-16	2.72E-17
North Annexe	Surface	2.12E-18	2.08E-18
	1 m	2.09E-18	2.05E-18
South Annexe	Surface	3.35E-18	3.30E-18
	1 m	3.08E-18	3.03E-18
Dragon Reactor	Surface	2.35E-17	2.45E-17
	1 m	1.17E-16	1.30E-16
Dragon B78	Surface	9.52E-18	1.06E-17
	1 m	9.48E-18	1.05E-17
Dragon Mortuary Holes	Surface	9.43E-22	2.23E-22
	1 m	9.33E-22	2.20E-23
A591/HVA	Surface	2.04E-08	1.19E-08
	1 m	2.02E-08	1.17E-08
PSA/Pit 3	Surface	8.01E-09	4.40E-09
	1 m	7.93E-09	4.36E-09
A59 Other Areas	Surface	6.87E-09	4.04E-09
	1 m	6.90E-09	4.05E-09

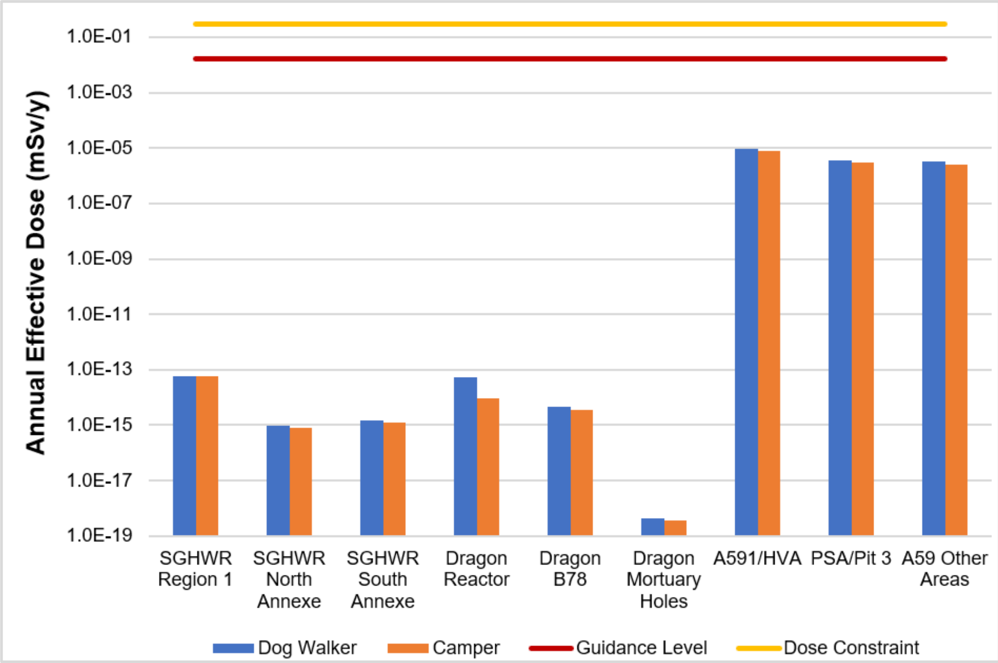

Figure 10.17: Annual effective dose (mSv y^{-1}) to site occupiers located above buried in-situ features for the Reference Case in 2036. The yellow line indicates the R9 dose constraint and the red line indicates the dose rate equivalent of the RGL (R10). Note the logarithmic scale for annual effective dose.

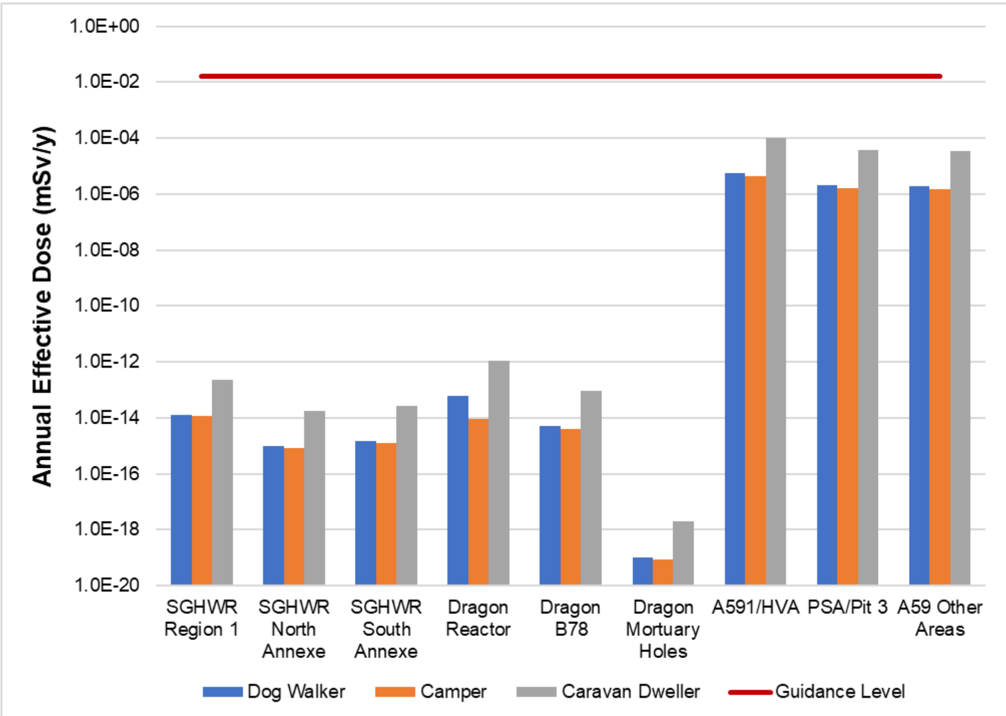

Figure 10.18: Annual effective dose (mSv y^{-1}) to site occupiers located above buried in-situ features for the Reference Case in 2066. The red line indicates the dose rate equivalent of the RGL (R10). Note the logarithmic scale for annual effective dose.

10.4.2 Alternative Assessment Case

544 As discussed above, alternative assessment cases have been defined to investigate the impact of parameter value uncertainty in the Reference Case assessment. Alternative inventories (cases HI.1.2 and HI.1.3, Table 8.3) are considered here.

545 Figure 10.19 presents the annual effective doses for RPs in 2036 (the IEP date) and in 2066 (the SRS date) for the more conservative alternative inventory and the reference cap/clean cover thicknesses (4.0 m for SGHWR, 3.8 m for Dragon reactor complex and 0.5 m for A59). Dose rates (mSv h^{-1}) are tabulated in Table F.1. Calculated annual effective doses are higher for the variant alternative inventory compared to the reference inventory but are all below the dose rate equivalent of the RGL.

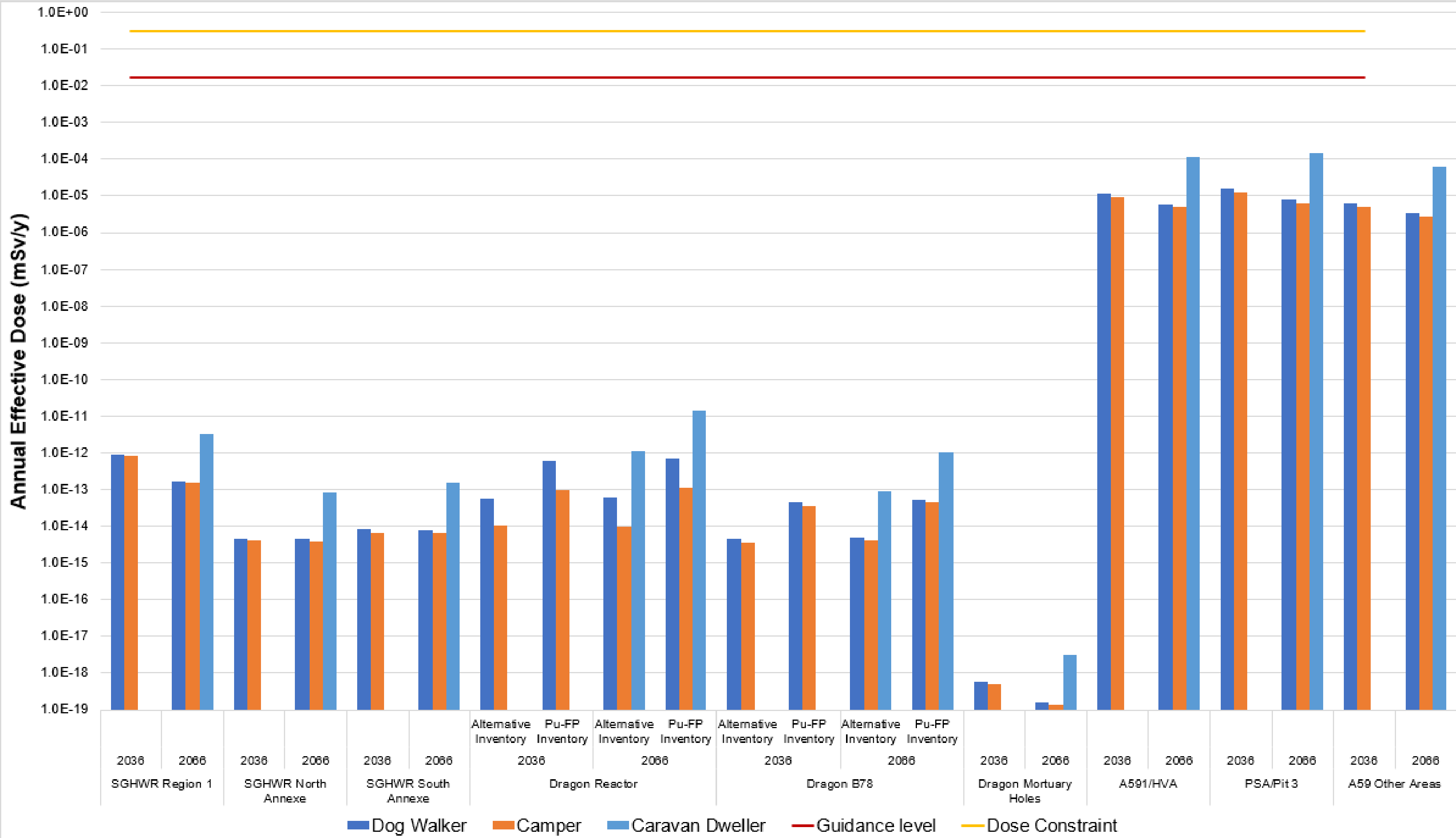

Figure 10.19: Annual effective dose (mSv y^{-1}) to site occupiers located above buried end state features for alternative inventories assuming a cap thickness of 4.0 m. The yellow line indicates the R9 dose constraint applicable prior to the SRS (i.e. 2036 results) and the red line indicates the dose rate equivalent of the R10 RGL (i.e. applicable to the 2066 results).

10.4.3 Variant Configuration Scenario

546 As discussed above, variant configuration scenarios have been defined to investigate the impact of conceptual model uncertainty in the Reference Case assessment. Cap/cover thickness (cases HI.VB.1, HI.VB.2 and HI.VB.3, Table 8.3) is considered here.

547 Figure 10.20 presents the annual effective doses for RPs for alternative cap thicknesses above SGHWR and Dragon structures, assuming the reference inventory. Calculated annual effective doses are many orders of magnitude below the dose rate equivalent of the RGL for all cap thicknesses considered.

548 Figure 10.21 presents the annual effective doses for RPs for varying thicknesses of clean cover material above the OoS A59 area, assuming the reference inventory. The calculated annual effective doses to the dog walker and camper RPs are below the dose rate equivalent of the RGL for both years even if the contamination is present at the surface. Only when considering the unrealistic scenario of a caravan dweller lying horizontally for an entire year with no cover material directly above the remediated A591/HVA land area in 2066 is a dose comparable to that of the RGL calculated (2.4E-2 mSv y^{-1} compared to 1.7E-2 mSv y^{-1}). Even discounting how unrealistic this scenario is, the ground survey that will be completed as part of remediation of the A59 area and the site closure process will ensure that there is appropriate clean cover material in place.

549 Dose rates (mSv h^{-1}) are tabulated in Table F.2.

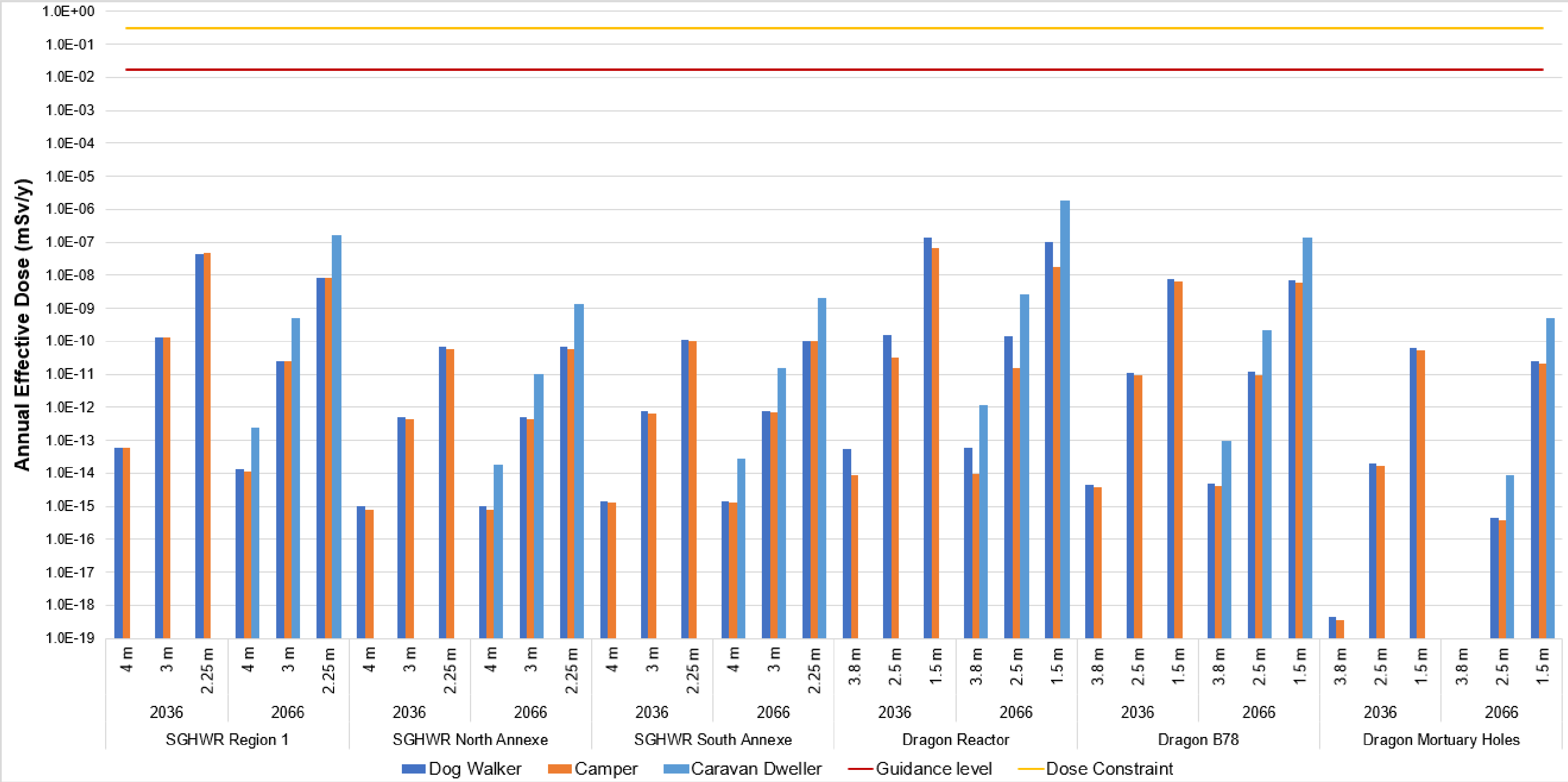

Figure 10.20: Annual effective dose (mSv y^{-1}) to site occupiers located above buried in-situ SGHWR and Dragon reactor complex features for varying cap thicknesses assuming the reference inventory. The yellow line indicates the R9 dose constraint applicable prior to the SRS (i.e. 2036 results) and the red line indicates the dose rate equivalent of the R10 RGL (i.e. applicable to the 2066 results).

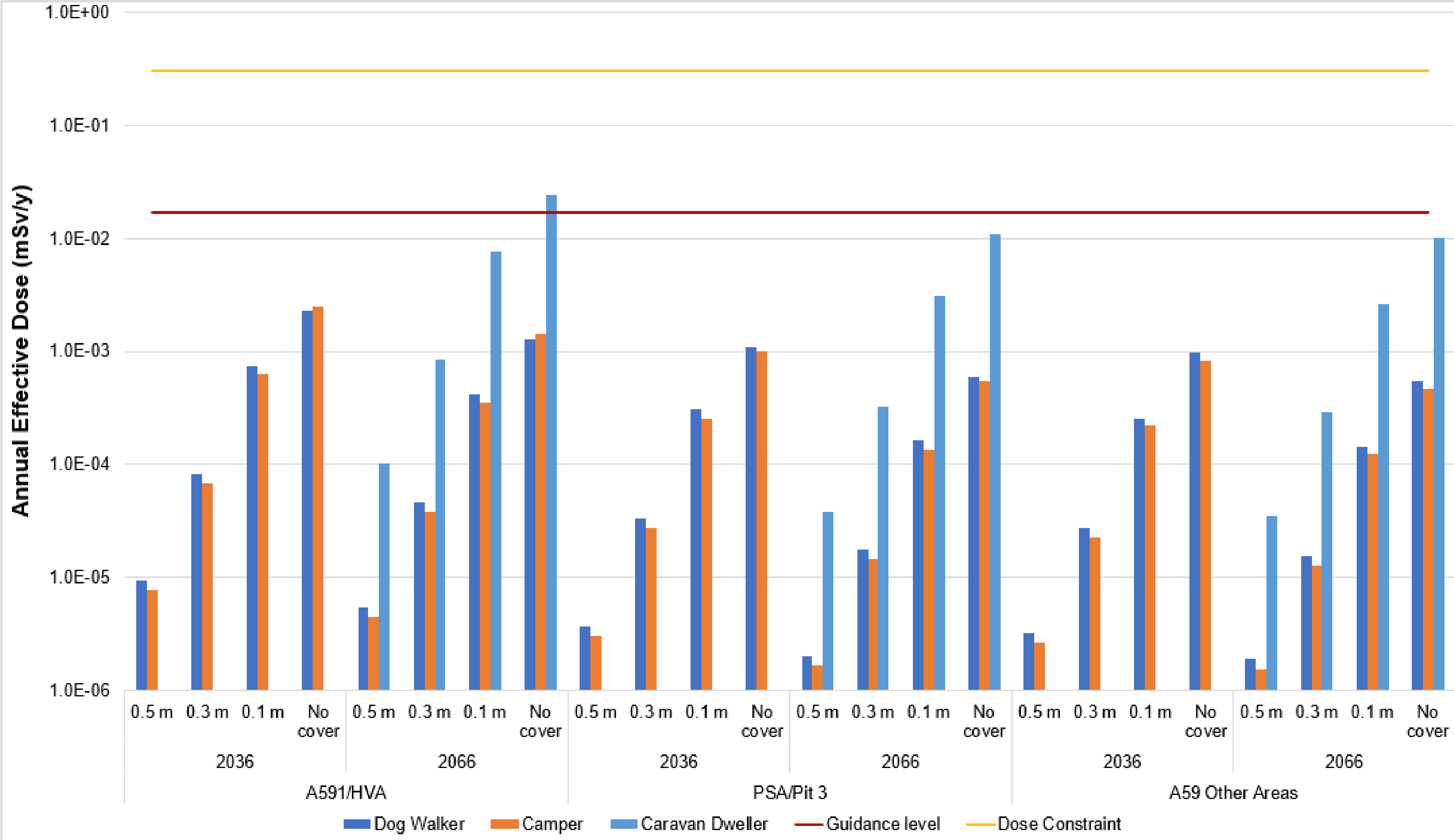

Figure 10.21: Annual effective dose (mSv y^{-1}) to site occupiers located above OoS A59 area for varying clean cover material thicknesses assuming the reference inventory. The yellow line indicates the R9 dose constraint applicable prior to the SRS (i.e. 2036 results) and the red line indicates the dose rate equivalent of the R10 RGL (i.e. applicable to the 2066 results).

10.5 Inadvertent Human Intrusion

550 This section presents the results of the human intrusion calculations undertaken. The section is split into two: Section 10.5.1 documents the Reference Case calculations, whilst Section 10.5.2 documents the variant calculations undertaken. The figures and tables in this section compare the calculated doses to the GRR lower dose guidance level (3 mSv y^{-1}) for prolonged exposures (for example, an infant living on contaminated material) and to the GRR upper dose guidance level (20 mSv in total) for transitory exposures (such as for a borehole driller or site excavator).

551 Doses to excavation workers are presented as well as doses to infants using the excavated material following the intrusion; doses to adults using the excavated material are not presented as they are bounded by the infant doses. For use of land following the excavation, the two most bounding GIM scenarios are presented: ‘play area user’ and ‘land use’[47]. These correspond to the ‘play area’ and ‘farm/smallholding’ referred to in Table 7.1. The GIM ‘aggregate in house building material’ scenario (corresponding to ‘housing development’ in Table 7.1) is not presented here as doses from this scenario are bounded by those from the play area and land use scenarios.

10.5.1 Reference Case

SGHWR

552 The annual effective doses from human intrusions into SGHWR features in 2066 are summarised in Table 10.9 for the reference inventory and reference cap thickness (4.0 m). Doses from intrusions into SGHWR features are also summarised in Figure 10.22 (worst-case only for each intrusion type).

553 The largest calculated doses are to an infant land user as a result of a large deep and borehole intrusions into Region 1 assuming residual inventory in the SGHWR mortuary tubes. The paragraphs following this table discuss the key results for each SGHWR feature.

[47] Note that in GIM this is referred to as “material spread”.

Table 10.9: Calculated doses to receptors from intrusions into SGHWR for the Reference Case at 2066. Case numbers refer to the list of intrusion cases in Table 7.4, Table 7.5 and Table 7.6. Highlighting in pink indicates where the GRR dose guidance level for prolonged exposures (3 mSv y^{-1}) has been exceeded for relevant receptors. None of the calculated doses to excavators exceed the GRR dose guidance level for transitory exposures (20 mSv y^{-1}). Case 2 and 6 include an estimate for residual inventory remaining in the SGHWR mortuary tubes after characterisation and cleaning, whereas the other cases exclude the tubes.

Region	Case	Receptor	Intrusion	Components intercepted by the intrusion[48]	Dose (mSv y^{-1})
Region 1	1	Excavator	Large, deep (exc. mortuary tubes)	Whole bioshield, part of the primary containment, part of the secondary containment, backfill	5.46E-02
		Infant, play area user	Large, deep (exc. mortuary tubes)		2.32E-02
		Infant, land use	Large, deep (exc. mortuary tubes)		8.49E-02
	2	Excavator	Large, deep (inc. mortuary tubes)		6.08E+00
		Infant, play area user	Large, deep (inc. mortuary tubes)		7.25E-01
		Infant, land use	Large, deep (inc. mortuary tubes)		2.38E+01
	3	Excavator	Large, deep	Secondary containment, backfill	3.23E-02
		Infant, play area user	Large, deep		9.79E-03
		Infant, land use	Large, deep		7.13E-02
	4	Excavator	Pile array (40)[49]	Backfill	1.42E-02
		Infant, play area user	Pile array (40)		1.15E-02
		Infant, land use	Pile array (40)		1.57E-02
	5[50]	Excavator	Total Boreholes (exc. mortuary tubes) (5)	5 boreholes: 1. Backfill and primary containment floor 2. Backfill and secondary containment floor 3. Bioshield wall and primary containment floor 4. Backfill, pond wall and pond floor	1.63E-02
		Infant, play area user	Total Boreholes (exc. mortuary tubes) (5)		1.66E-02
		Infant, land use	Total Boreholes (exc. mortuary tubes) (5)		2.97E-02

48 See Table 7.4, Table 7.5 and Table 7.6 for area of overlap.
49 The pile array intersects the Region 1 backfill only and so is not impacted by whether or not the mortuary tubes are included.
50 Table 10.9 only presents the doses resulting from the total array of five boreholes; doses from each individual borehole considered in the array are presented in Appendix G.1.

Region	Case	Receptor	Intrusion	Components intercepted by the intrusion[48]	Dose (mSv y^{-1})
				5. Backfill, pond wall and pond floor	
	6[50]	Excavator	Total Boreholes (inc. mortuary tubes) (5)	5 boreholes: 1. Backfill and primary containment floor 2. Backfill and secondary containment floor 3. Bioshield wall and primary containment floor 4. Backfill, pond wall and pond floor 5. Mortuary tubes and primary containment floor	2.33E+00
		Infant, play area user	Total Boreholes (inc. mortuary tubes) (5)		6.09E-01
		Infant, land use	Total Boreholes (inc. mortuary tubes) (5)		3.58E+00
North Annexe	7	Excavator	Large, deep	Secondary containment (walls and floor), backfill	2.54E-02
		Infant, play area user	Large, deep		5.33E-03
		Infant, land use	Large, deep		4.52E-02
	8	Excavator	Large, deep	Part of the North Annexe walls and floor, part of the primary containment walls of Region 1, backfill	2.35E-02
		Infant, play area user	Large, deep		4.56E-03
		Infant, land use	Large, deep		4.27E-02
	9	Excavator	Pile array (40)	North Annexe floor, backfill	1.32E-02
		Infant, play area user	Pile array (40)		5.86E-03
		Infant, land use	Pile array (40)		9.90E-03
	10	Excavator	Single Borehole		5.14E-04
		Infant, play area user	Single Borehole		2.06E-04
		Infant, land use	Single Borehole		3.48E-04
		Excavator	Total Boreholes (5)		2.57E-03
		Infant, play area user	Total Boreholes (5)		1.03E-03
		Infant, land use	Total Boreholes (5)		1.74E-03
Region 2 and South Annexe	11	Excavator	Large, deep	Part of the South Annexe walls, backfill	4.01E-02
		Infant, play area user	Large, deep		9.74E-03
		Infant, land use	Large, deep		9.53E-02
	12	Excavator	Pile array (40)		2.00E-02

Region	Case	Receptor	Intrusion	Components intercepted by the intrusion[48]	Dose (mSv y^{-1})
		Infant, play area user	Pile array (40)	South Annexe floor, South Annexe “local” backfill	1.19E-02
		Infant, land use	Pile array (40)		2.11E-02
	13	Excavator	Single Borehole		1.35E-03
		Infant, play area user	Single Borehole		7.75E-04
		Infant, land use	Single Borehole		1.37E-03
		Excavator	Total Boreholes (5)		6.73E-03
		Infant, play area user	Total Boreholes (5)		3.87E-03
		Infant, land use	Total Boreholes (5)		6.86E-03
	14	Excavator	Pile array (40)	Secondary containment floor, Region 2 “local” backfill	7.09E-02
		Infant, play area user	Pile array (40)		6.47E-02
		Infant, land use	Pile array (40)		7.71E-02
	15	Excavator	Single Borehole		7.90E-03
		Infant, play area user	Single Borehole		8.11E-03
		Infant, land use	Single Borehole		9.66E-03
		Excavator	Total Boreholes (5)		3.95E-02
		Infant, play area user	Total Boreholes (5)		4.06E-02
		Infant, land use	Total Boreholes (5)		4.83E-02

Region 1

554 For Region 1, the only doses exceeding the dose guidance level are those to infant land users associated with intrusions into the residual inventory estimated to remain in the mortuary tubes (Cases 2 and 6); all intrusion cases excluding the mortuary tubes are below the dose guidance level (Figure 10.22).

555 For the two cases exceeding the dose guidance level in 2066, doses have also been calculated assuming intrusion occurs at later dates. These are presented in Table 10.10, illustrating when the dose falls below the dose guidance level. There is large uncertainty associated with the SGHWR mortuary tubes inventory estimate due to the inability to access them at this time for characterisation and cleaning. The mortuary tube inventory estimate is regarded as preliminary, conservatively derived based on the potential sources of contamination and what could remain at the end state, but without direct characterisation data (see the End State Radiological Inventory Report [84] for further details on this). Characterisation and cleaning of this feature is planned once it is accessible, with the level of clean-up to be optimised once characterisation data are available.

556 Considering the cases where the mortuary tubes are included with the assumed residual inventory, the largest doses arise from the large, deep excavations (Case 2) with the

infant land user receiving the greatest dose (23.8 mSv y^{-1} at 2066). The primary dose pathway is ingestion and the dose is dominated by ^{90}Sr, which forms over 98% of the total dose. The dose reduces by approximately 20% after 10 years and by approximately an order of magnitude after 90 years, which is strongly tied to the half-life of ^{90}Sr (29 years). After 90 years (at 2156) the dose is below the dose guidance level. Similarly for the Case 6 infant land user following borehole intrusions, the dose is also dominated by ^{90}Sr and reduces by approximately 20% after 10 years, by which time it is below the dose guidance level.

Table 10.10: Calculated doses to receptors for those intrusions into SGHWR Region 1 that exceeded the dose guidance level at 2066 assuming the reference inventory (including the residual mortuary tube inventory) and a cap thickness of 4.0 m. Presented dates after 2066 indicate where doses fall below the dose guidance level. Highlighting in pink indicates where the GRR dose guidance level value for prolonged exposures (3 mSv y^{-1}) is exceeded.

Case	Receptor	Intrusion	Dose (mSv y^{-1})			
		Year of intrusion:	2066	2076	2146	2156
2	Infant, land use	Large, deep (inc. mortuary tubes)	2.38E+01	1.87E+01	3.57E+00	2.83E+00
6	Infant, land use	Total Boreholes (inc. mortuary tubes) (5)	3.58E+00	2.82E+00	Not needed	

557 For cases where the SGHWR mortuary tubes residual inventory is excluded, the largest doses arise from the large, deep excavations (Case 1) with the infant land user receiving the greatest dose (0.08 mSv y^{-1} at 2066). The primary dose pathway is ingestion of crops and animals grown/reared on contaminated land and the dose is dominated by ^{90}Sr, which contributes approximately 67% of the total, and ^{3}H, which contributes approximately 19%.

North Annexe

558 The calculated doses from intrusions into the North Annexe are all at least an order of magnitude below the GRR dose guidance level. The largest doses arise from the large, deep excavations (Cases 7 and 8) with the infant land user being the receptor receiving the greatest dose (0.05 mSv y^{-1} at 2066). This dose is dominated by ^{90}Sr, which provides approximately 92% of the total.

Region 2 and the South Annexe

559 The calculated doses from intrusions into Region 2 and the South Annexe are all at least an order of magnitude below the dose guidance level. The largest doses arise from the large, deep excavations (Case 11) with the infant land user receiving the greatest dose (0.10 mSv y^{-1} at 2066). This is dominated by ^{90}Sr which contributes approximately 94% to the total.

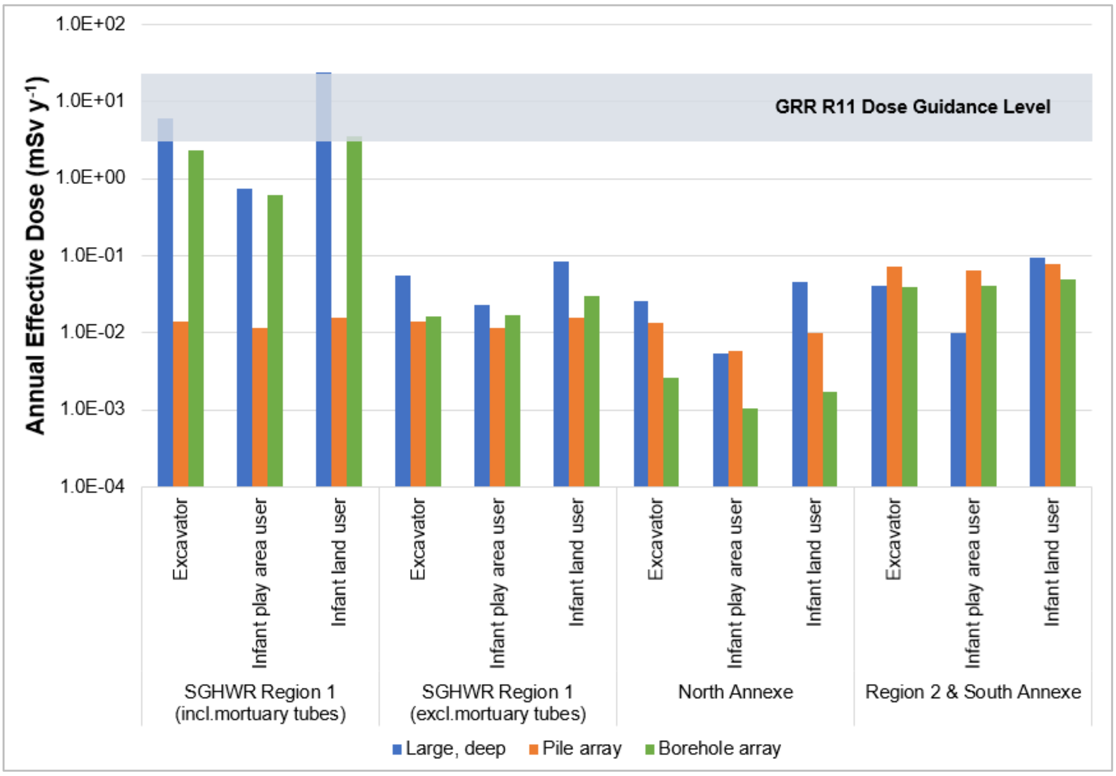

Figure 10.22: Doses to receptors from human intrusion into SGHWR features for the Reference Case at 2066. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

Dragon Reactor Complex

560 The annual effective doses from intrusions into the Dragon reactor complex structures in 2066 are shown in Table 10.11 for the Reference Case. Note that no doses are presented for the shallow intrusions (Cases 17 and 18 in Table 7.7, Cases 25 and 26 in Table 7.8 and Cases 30 and 31 in Table 7.9) as the thickness of the reference cap (3.8 m) exceeds the depth of these intrusions (2 m). A summary of the calculated doses is presented in Figure 10.23.

561 Due to the steel composition of the mortuary holes and therefore all contamination being present within steel rather than concrete, appropriate scenarios for the use of contamination following an excavation are not the same as those considered for other Dragon reactor complex and SGHWR calculations. Therefore, instead of assessing the infant ‘play area’ and infant ‘land use’ GIM scenarios, which are assumed not to make use of steel excavated material, the GIM ‘off-site metal recycling’ scenario has been assessed. The receptor in this scenario is a worker.

562 None of the calculated doses exceed the GRR dose guidance level. The largest calculated doses are to an excavator (0.43 mSv y^{-1}) and an infant land user

(0.60 mSv y^{-1}) as a result of a large deep intrusion into the Dragon reactor building. For the excavator the dominant pathway is inhalation. For the infant land user the dominant pathway is ingestion of crops and animals grown/reared on contaminated land. The key results for each feature can be summarised as follows:

- **Dragon reactor building:**
  - The results show that all of the calculated doses are below the dose guidance level. The largest dose arises from the large, deep intrusion (Case 16) with the infant land user receiving the greatest dose. The dose is dominated by ^{90}Sr, which contributes approximately 97%.
  - As discussed in Section 7.6.1, the borehole arrays considered in Cases 21 and 22 are low probability intrusions due to the areal extent of the PGPC spill and the Betalite store. However, they still result in doses significantly below the dose guidance level for intrusions in 2066.
- **B78 building floor slab:**
  - The calculated doses from intrusions are over three orders of magnitude below the dose guidance level for the reference inventory. The largest doses arise from the large, deep excavations (Case 24) with the infant land user receiving the greatest dose (1.6E-03 mSv y^{-1} at 2066). The dose is dominated by ^{90}Sr, which contributes over 97% to the total.
- **Mortuary holes:**
  - The calculated doses from intrusions are all significantly below the dose guidance level (by over four orders of magnitude). The largest dose arises from the array of five boreholes (Case 32) with the excavator receiving the dose (the excavator is the only receptor considered for this borehole array as GIM does not report doses to off-site metal workers from borehole excavations). The greatest dose is 3.3E-05 mSv y^{-1} at 2066. This dose is dominated by ^{241}Am, which contributes approximately 49% to the total, and ^{238}Pu which contributes approximately 25%.

Table 10.11: Calculated doses to receptors from intrusions into the Dragon reactor building in 2066 for the Reference Case. Case numbers refer to the list of intrusion cases in Table 7.7, Table 7.8 and Table 7.9.

Feature	Case	Receptor	Intrusion	Components intercepted by the intrusion[51]	Dose (mSv y^{-1})
Reactor Building	16	Excavator	Large, deep	Bioshield, general building contamination, backfill	4.32E-01
		Infant, play area user	Large, deep		2.49E-02
		Infant, land use	Large, deep		5.99E-01

[51] See Table 7.7, Table 7.8 and Table 7.9 for the area of overlap.

Feature	Case	Receptor	Intrusion	Components intercepted by the intrusion[51]	Dose (mSv y^{-1})
	19	Excavator	Pile array (40)	Backfill	2.22E-01
		Infant, play area user	Pile array (40)		2.31E-02
		Infant, land use	Pile array (40)		9.89E-02
	20	Excavator	Single Borehole into backfill and floor slab	Backfill, floor slab	1.77E-02
		Infant, play area user	Single Borehole into backfill and floor slab		2.02E-03
		Infant, land use	Single Borehole into backfill and floor slab		8.67E-03
		Excavator	Total Boreholes (5)		8.84E-02
		Infant, play area user	Total Boreholes (5)		1.01E-02
		Infant, land use	Total Boreholes (5)		4.33E-02
	21	Excavator	Single Borehole into backfill and PGPC spill	Backfill, floor slab (at the location of the PGPC contaminated water spill)	1.91E-02
		Infant, play area user	Single Borehole into backfill and PGPC spill		8.63E-03
		Infant, land use	Single Borehole into backfill and PGPC spill		9.47E-03
		Excavator	Total Boreholes (5)		9.55E-02
		Infant, play area user	Total Boreholes (5)		4.31E-02
		Infant, land use	Total Boreholes (5)		4.73E-02
	22	Excavator	Single Borehole into backfill and Betalite store	Backfill, Betalite store	1.80E-02
		Infant, play area user	Single Borehole into backfill and Betalite store		2.03E-03
		Infant, land use	Single Borehole into backfill and Betalite store		8.67E-03

Feature	Case	Receptor	Intrusion	Components intercepted by the intrusion[51]	Dose (mSv y^{-1})
		Excavator	Total Boreholes (5)		8.98E-02
		Infant, play area user	Total Boreholes (5)		1.01E-02
		Infant, land use	Total Boreholes (5)		4.34E-02
	23	Excavator	Mixed borehole array (5)	1 borehole into the bioshield and floor slab 1 borehole into the backfill and floor slab (where the PGPC spill is) 1 borehole into the backfill and Betalite store 2 boreholes into the backfill and floor slab	7.25E-02
	23	Infant, play area user	Mixed borehole array (5)		1.48E-02
	23	Infant, land use	Mixed borehole array (5)		3.55E-02
B78 Floor Slab	24	Excavator	Large, deep	B78 floor slab	1.17E-03
B78 Floor Slab	24	Infant, play area user	Large, deep	B78 floor slab	6.76E-05
B78 Floor Slab	24	Infant, land use	Large, deep	B78 floor slab	1.63E-03
B78 Floor Slab	27	Excavator	Pile array (40)	B78 floor slab	2.50E-04
B78 Floor Slab	27	Infant, play area user	Pile array (40)	B78 floor slab	2.20E-05
B78 Floor Slab	27	Infant, land use	Pile array (40)	B78 floor slab	9.42E-05
B78 Floor Slab	28	Excavator	Single Borehole	B78 floor slab	6.39E-06
B78 Floor Slab	28	Infant, play area user	Single Borehole	B78 floor slab	5.50E-07
B78 Floor Slab	28	Infant, land use	Single Borehole	B78 floor slab	2.35E-06
B78 Floor Slab	28	Excavator	Total Boreholes (5)	B78 floor slab	3.20E-05
B78 Floor Slab	28	Infant, play area user	Total Boreholes (5)	B78 floor slab	2.75E-06
B78 Floor Slab	28	Infant, land use	Total Boreholes (5)	B78 floor slab	1.18E-05
Mortuary Holes	29	Excavator	Large, deep	The mortuary hole structure	9.56E-06
Mortuary Holes	29	Worker, off-site metal recycling	Large, deep	The mortuary hole structure	1.29E-06
Mortuary Holes	32	Excavator	Single Borehole	Mortuary holes	6.51E-06
Mortuary Holes	32	Excavator	Total Boreholes (5)	Mortuary holes	3.26E-05

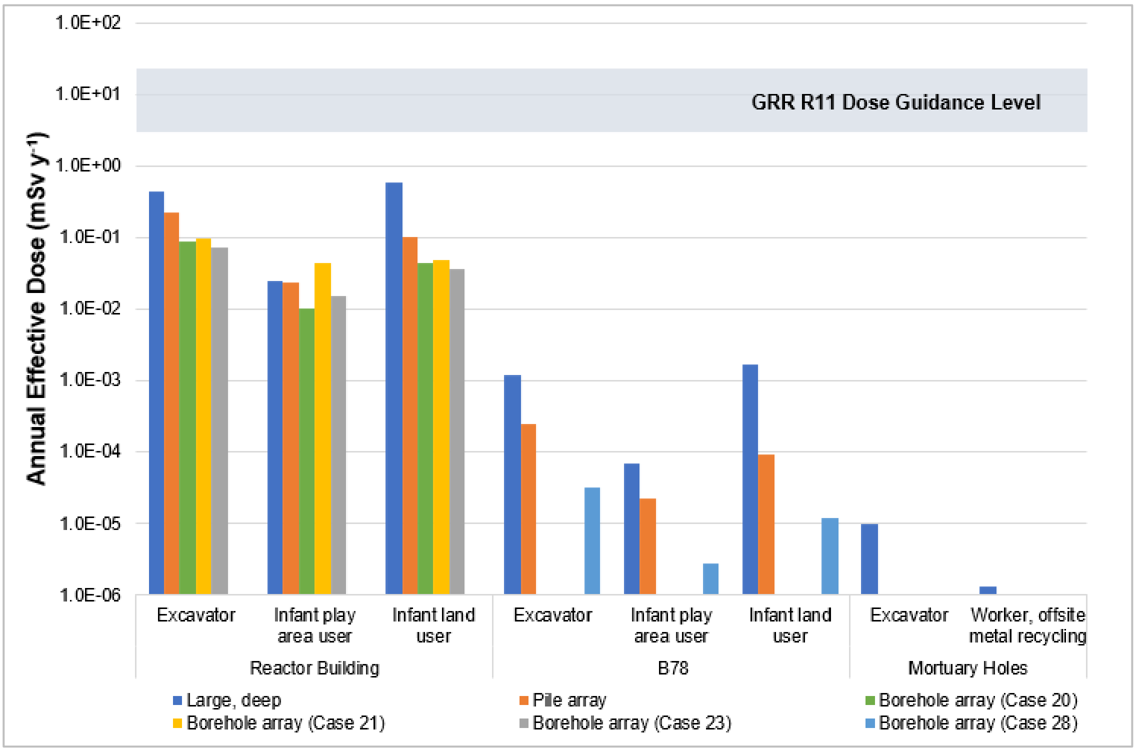

Figure 10.23: Doses to receptors from intrusions into the Dragon reactor building in 2066 for the Reference Case. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

A59

563 The annual effective doses from human intrusions into the A59 in 2066 are shown in Table 10.12 and summarised in Figure 10.24 assuming the reference inventory and reference cover material thickness (0.5 m).

564 None of the calculated doses exceed the GRR dose guidance level. The largest calculated doses are to an infant land user as a result of large shallow intrusions into the A59 Other Areas (0.02 mSv y^{-1}) and the combined remediated A591/HVA land area and surrounding A59 Other Areas (0.04 mSv y^{-1}). For the infant land user the dominant pathway is ingestion of crops and animals grown/reared on contaminated land. The key results are summarised as follows:

- **A59 Other Areas:**
  - The results show all calculated doses to be at least two orders of magnitude below the dose guidance level. The largest doses arise from the large, shallow (Case 34) intrusion with the infant land user receiving the greatest dose (0.02 mSv y^{-1} at 2066). The dose is dominated by ^{90}Sr, which contributes over 98% to the total.

- **A591/HVA remediated area:**
  - The results show all calculated doses to be at least an order of magnitude below the dose guidance level. The largest doses arise from the large, shallow intrusion (Case 39) with the infant land user receiving the greatest dose (0.04 mSv y^{-1} at 2066). The dose is dominated by ^{90}Sr, which contributes over 98% to the total.
- **PSA/Pit 3 remediated area:**
  - As discussed in Section 7.7.3, only one intrusion case has been assessed for the PSA/Pit 3 Area. The results show doses from this case to be significantly below the dose guidance level at 2066, with the infant land user receiving the greatest dose (5.7E-04 mSv y^{-1} at 2066). The dose is dominated by ^{90}Sr, which contributes over 93% to the total.

565 As noted in Appendix B.2, the limited list of radionuclides included in the GIM tool means that only 76.1% of the A59 Other Areas reference inventory is accounted for (uncertainty PA-001). This occurs primarily because the uranium isotopes form a larger fraction of the A59 inventory (19.9%) compared with the SGHWR and Dragon reactor complex inventories (less than 1% for each), yet uranium isotopes are not included in GIM. An estimate of the potential impact of this on the calculated dose can be made by considering comparable dose coefficients. For the Case 34 highest dose using the reference inventory, the greatest receptor is an infant land user, which is a pathway dominated by ingestion. Review of the infant ingestion dose coefficients in GIM indicates that ^{241}Am is the closest to those for the ^{234}U, ^{235}U, ^{236}U and ^{238}U isotopes – scaling the ^{241}Am dose contribution by 1.5 would roughly account for the missing uranium isotopes in terms of the ingestion dose coefficient. There is also a factor of ~15.2 difference in the reference inventory content. Applying these two factors would suggest that the missing radionuclides would contribute an additional 6E-04 mSv y^{-1}. Whilst this in an indicative estimate of the missing contribution, it does suggest that the impact is sufficiently small that it would not change the conclusions drawn here.

Table 10.12: Calculated doses to receptors from intrusions into the OoS A59 area in 2066 assuming the reference inventory and a cover material thickness of 0.5 m. Case numbers refer to the list of intrusion cases in Table 7.10, Table 7.11 and Table 7.12.

Area	Case	Receptor	Intrusion	Components intercepted by the intrusion[52]	Dose (mSv y^{-1})
Other Areas	33	Excavator	Large, deep	A59 other areas (excluding APCs)	3.29E-03
		Infant, play area user	Large, deep		2.36E-04
		Infant, land use	Large, deep		1.27E-02

[52] See Table 7.10, Table 7.11 and Table 7.12 for the area of overlap.

Area	Case	Receptor	Intrusion	Components intercepted by the intrusion[52]	Dose (mSv y^{-1})
	34	Excavator	Large, shallow		4.38E-04
		Infant, play area user	Large, shallow		3.54E-04
		Infant, land use	Large, shallow		1.91E-02
	35	Excavator	Small, shallow		5.17E-06
		Infant, play area user	Small, shallow		1.77E-04
		Infant, land use	Small, shallow		1.70E-03
	36	Excavator	Pile array (40)		6.89E-04
		Infant, play area user	Pile array (40)		7.41E-05
		Infant, land use	Pile array (40)		7.12E-04
	37	Excavator	Single Borehole		1.72E-05
		Infant, play area user	Single Borehole		1.85E-06
		Infant, land use	Single Borehole		1.78E-05
		Excavator	Total Boreholes (5)		8.62E-05
		Infant, play area user	Total Boreholes (5)		9.26E-05
		Infant, land use	Total Boreholes (5)		8.90E-05
A591/HVA	38	Excavator	Large, deep	The whole A591/HVA area, and surrounding A59 other areas	6.63E-03
		Infant, play area user	Large, deep		5.52E-04
		Infant, land use	Large, deep		3.18E-02
	39	Excavator	Large, shallow		7.60E-04
		Infant, play area user	Large, shallow		7.15E-04
		Infant, land use	Large, shallow		4.12E-02
A591/HVA and surrounding	40	Excavator	Single pile (A591/HVA area)	11 piles into the A591/HVA area, 29	8.30E-05

Area	Case	Receptor	Intrusion	Components intercepted by the intrusion[52]	Dose (mSv y^{-1})
A59 Other Areas		Infant, play area user	Single pile (A591/HVA area)	piles into the A59 other areas	1.14E-05
		Infant, land use	Single pile (A591/HVA area)		1.20E-04
		Excavator	Single pile (A59 other areas)		1.72E-05
		Infant, play area user	Single pile (A59 other areas)		1.85E-06
		Infant, land use	Single pile (A59 other areas)		1.78E-05
		Excavator	Pile array (40)		1.41E-03
		Infant, play area user	Pile array (40)		1.79E-04
		Infant, land use	Pile array (40)		1.84E-03
A591/HVA	41	Excavator	Small, shallow	A591/HVA area	1.46E-05
		Infant, play area user	Small, shallow		6.41E-04
		Infant, land use	Small, shallow		6.74E-03
	42	Excavator	Single Borehole		8.30E-05
		Infant, play area user	Single Borehole		1.14E-05
		Infant, land use	Single Borehole		1.20E-04
		Excavator	Total Boreholes (5)		4.15E-04
		Infant, play area user	Total Boreholes (5)		5.71E-05
		Infant, land use	Total Boreholes (5)		6.00E-04
PSA/ Pit 3	43	Excavator	Small, shallow	PSA/ Pit 3 area	2.20E-05
		Infant, play area user	Small, shallow		3.46E-04
		Infant, land use	Small, shallow		5.69E-04

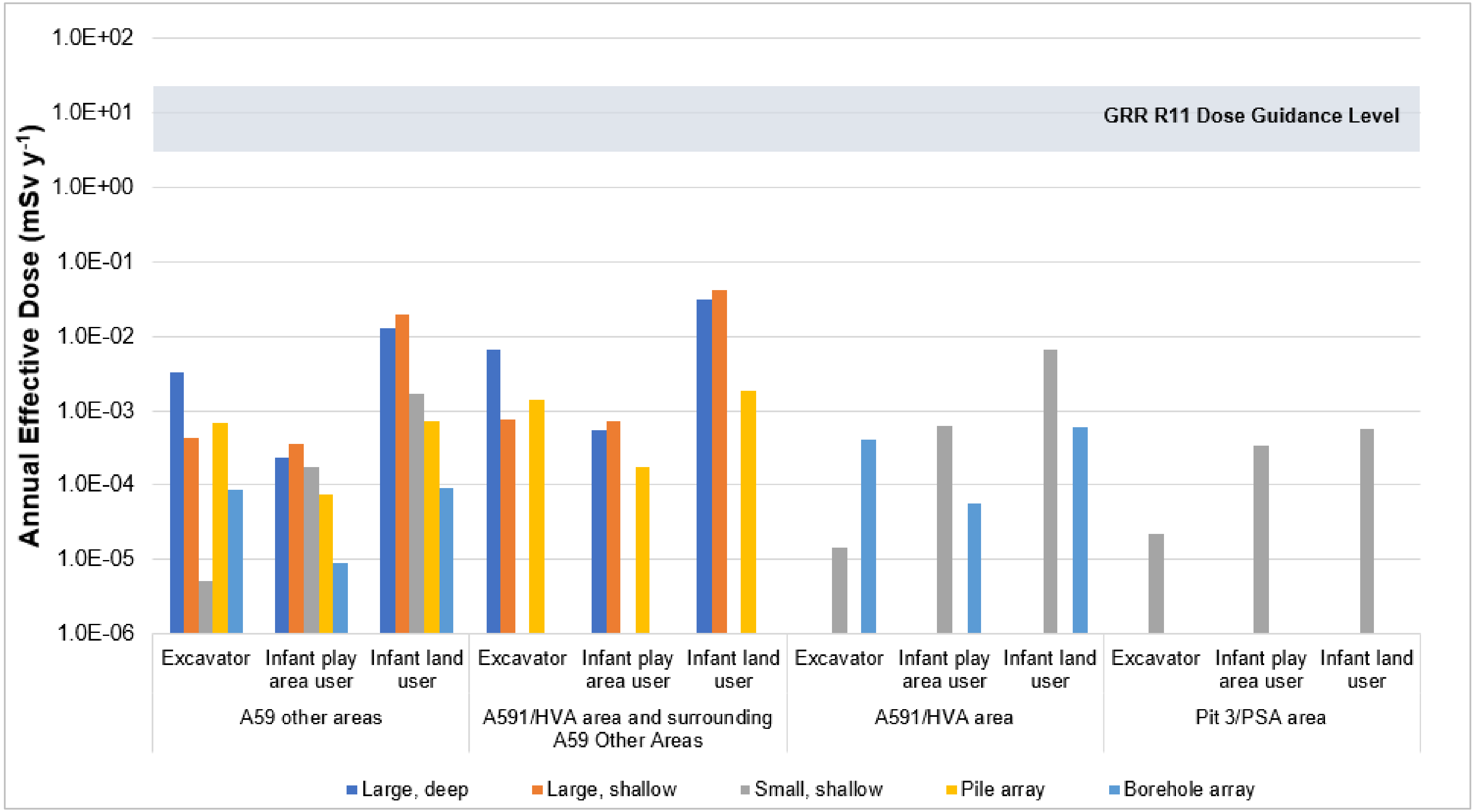

Figure 10.24: Doses to receptors from intrusions into the OoS A59 area in 2066 for the Reference Case. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

Summary

566 In summary, the following observations are made regarding the human intrusion Reference Case assessment:

- If the residual inventory assumed for the SGHWR Region 1 mortuary tubes is excluded, then all intrusion cases into Region 1 are below the dose guidance level in 2066 for the reference inventory with the reference cap (4.0 m thick, 1,500 kg m^{-3} waste density). The largest doses arise from the large, deep excavations with the infant land user receiving the greatest dose (0.08 mSv y^{-1} at 2066).
- Including the estimate for the residual inventory remaining in the SGHWR mortuary tubes leads to doses from the large, deep excavation and borehole array to infant land users that are above the dose guidance level in 2066 for the reference inventory and cap thickness (4.0 m). For the large, deep intrusion, the dose falls below the dose guidance level by 2156. For the borehole array, the dose is below the dose guidance level by 2076. There is large uncertainty associated with the mortuary tubes inventory estimate due to the inability to access them at this time. Characterisation and cleaning of this feature is planned once it is accessible, with the level of clean-up to be optimised once characterisation data are available.
- All intrusions into the SGHWR North Annexe, Region 2 and the South Annexe result in doses that are at least an order of magnitude below the dose guidance level in 2066. The largest doses arise from the large, deep excavations with the infant land user receiving the greatest dose.
- All intrusions into the Dragon reactor complex in 2066 result in doses that are below the dose guidance level. The largest doses arise from the large, deep excavations with the infant land user receiving the greatest dose. The assessed borehole arrays are considered to have a low probability due to the limited areal extent of features such as the PGPC spill and the Betalite store; however, these still result in doses significantly below the dose guidance level in 2066.
- All intrusions into the various parts of the A59 area in 2066 are significantly below the dose guidance level assuming the reference inventory and reference cover material thickness (0.5 m). The largest doses for the A59 Other Areas and remediated A591/HVA area arise from the large, shallow excavations with the infant land user receiving the greatest dose. Only small, shallow excavations were assessed for the remediated PSA/Pit 3 area and again the infant land user was found to receive the greatest dose.
- The receptor subject to the greatest dose is generally the infant via ingestion from land use.
- For the intrusions resulting in the greatest dose (frequently to infant land users from large excavations), the largest radionuclide dose contributor is typically ^{90}Sr.

10.5.2 Alternative Assessment Cases

567 As discussed above, alternative assessment cases have been defined to investigate the impact of parameter value uncertainty in the Reference Case assessment. An alternative intrusion

date (HI.1.4, Table 8.3) and alternative inventories (cases HI.1.2 and HI.1.3, Table 8.3) are considered here.

568 In this section only intrusions that lead to the highest doses are presented; intrusions that result in lower doses are presented in Appendix F.

SGHWR

Region 1 - Earlier Intrusion

569 Inadvertent human intrusion prior to the SRS date (2066) is not expected as NRS will retain control of the site. However, doses have been calculated and are presented here at an arbitrary date of 10 years prior to this (2056) to inform NRS decision-making regarding the length of the control period. Therefore, the annual effective doses from human intrusions into SGHWR Region 1 in 2056 are illustrated in Figure 10.25 and Figure 10.26. These assume the reference inventory and reference cap thickness (4.0 m). The same intrusion cases and receptors are presented as in the Reference Case.

570 As for intrusions in 2066, the results of intrusions in 2056 show that the only doses exceeding the dose guidance level assuming the reference inventory are those to infant land users associated with intrusions into the SGHWR mortuary tubes (Cases 2 and 6); all intrusion cases excluding the mortuary tubes residual inventory estimate are below the dose guidance level. Therefore, a future unforeseen need to shift to an earlier SRS date (between 2056 and 2066) is not constrained by human intrusion into SGHWR so long as the mortuary holes are characterised and cleaned as necessary.

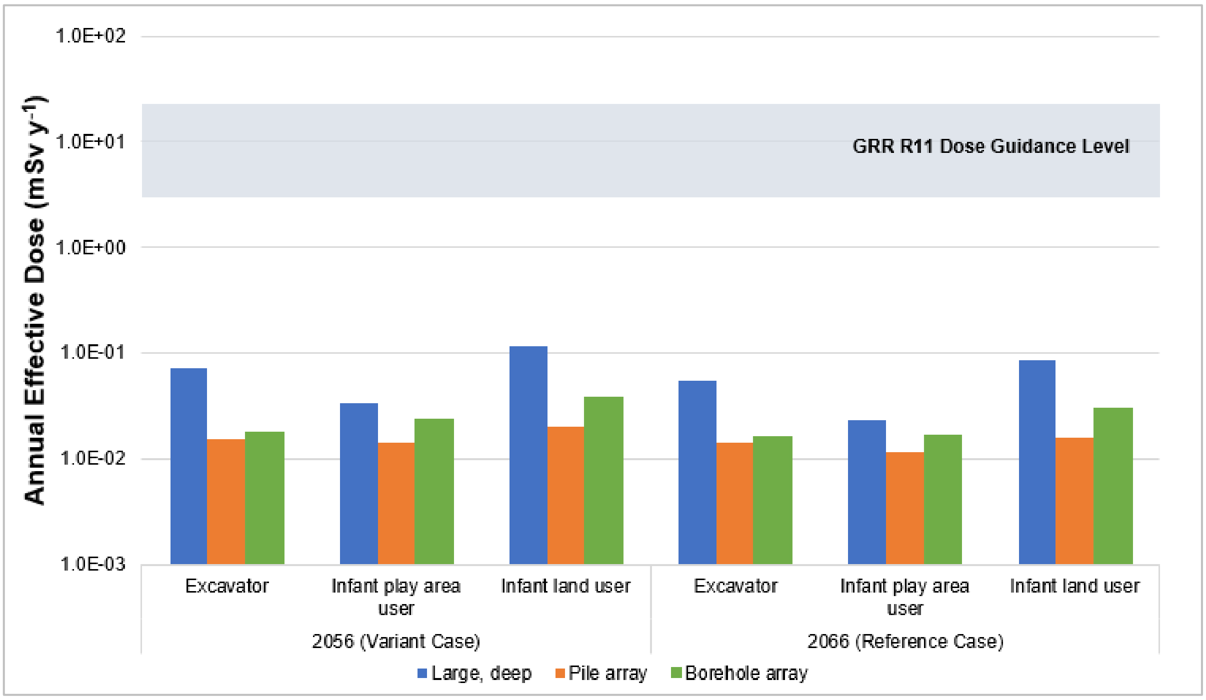

Figure 10.25: Doses to receptors from intrusions into SGHWR Region 1 in 2056 excluding the residual mortuary tubes inventory. Results shown assume the reference inventory and a cap thickness of 4.0 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

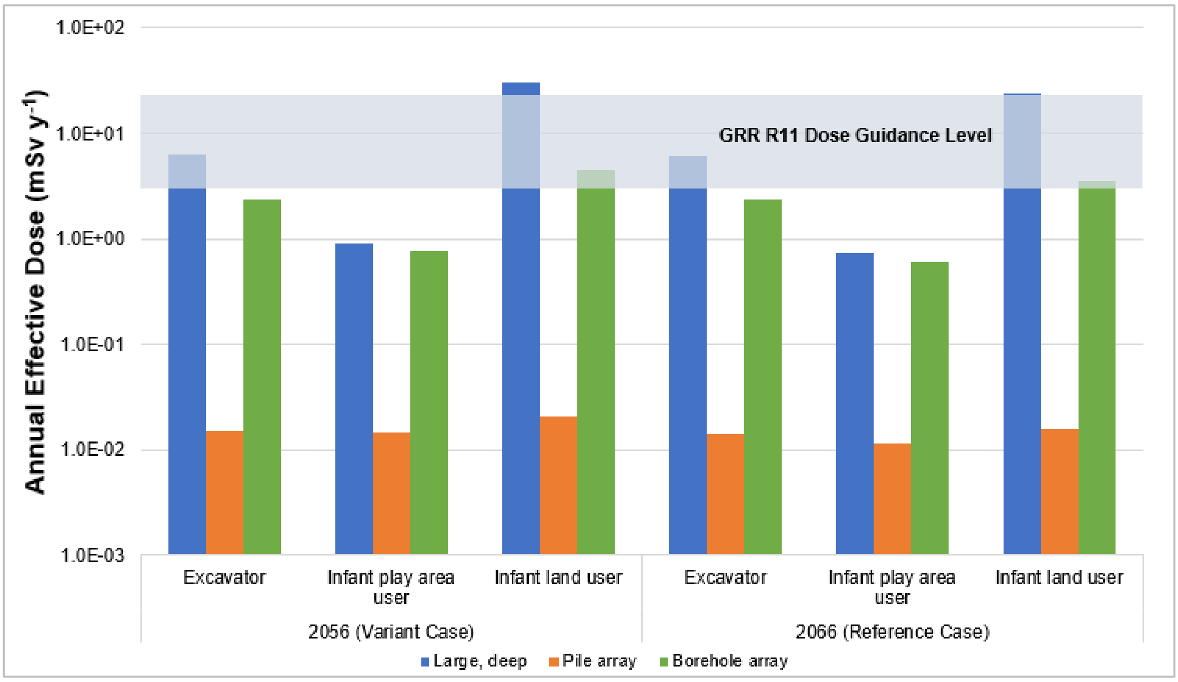

Figure 10.26: Doses to receptors from intrusions into SGHWR Region 1 in 2056 including the residual mortuary tubes inventory. Results shown assume the reference inventory and a cap thickness of 4.0 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

Region 1 - Alternative Inventory

571 The annual effective doses from human intrusions into SGHWR Region 1 in 2066 assuming the more conservative alternative inventory and the reference cap thickness (4.0 m) are summarised in Figure 10.27 and Figure 10.28.

572 Adopting the alternative inventory results in an increase in calculated doses. However, even with this assumption, the calculated doses remain below the dose guidance level as long as the estimated residual SGHWR mortuary tube inventory is excluded. As for the reference inventory, the calculated doses exceed the dose guidance level with the alternative inventory for infant land users where the intrusion is into the mortuary tubes (Cases 2 and 6). As noted previously, there is significant uncertainty associated with the SGHWR mortuary tubes inventory estimate and work is planned to characterise and clean this feature once waste has been removed and access is possible.

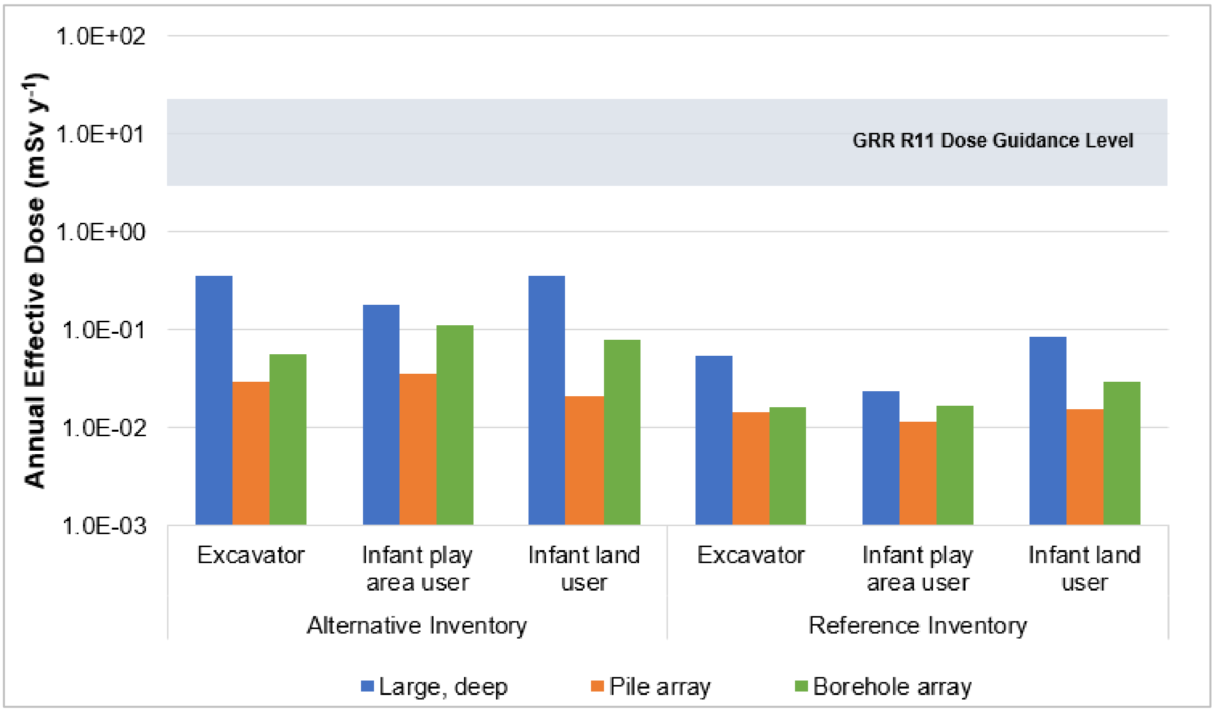

Figure 10.27: Doses to receptors from intrusions into SGHWR Region 1 in 2066 assuming the alternative inventory (excluding the mortuary tubes residual inventory estimate) and reference cap thickness (4.0 m). Results are also shown assuming the reference inventory for comparison. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

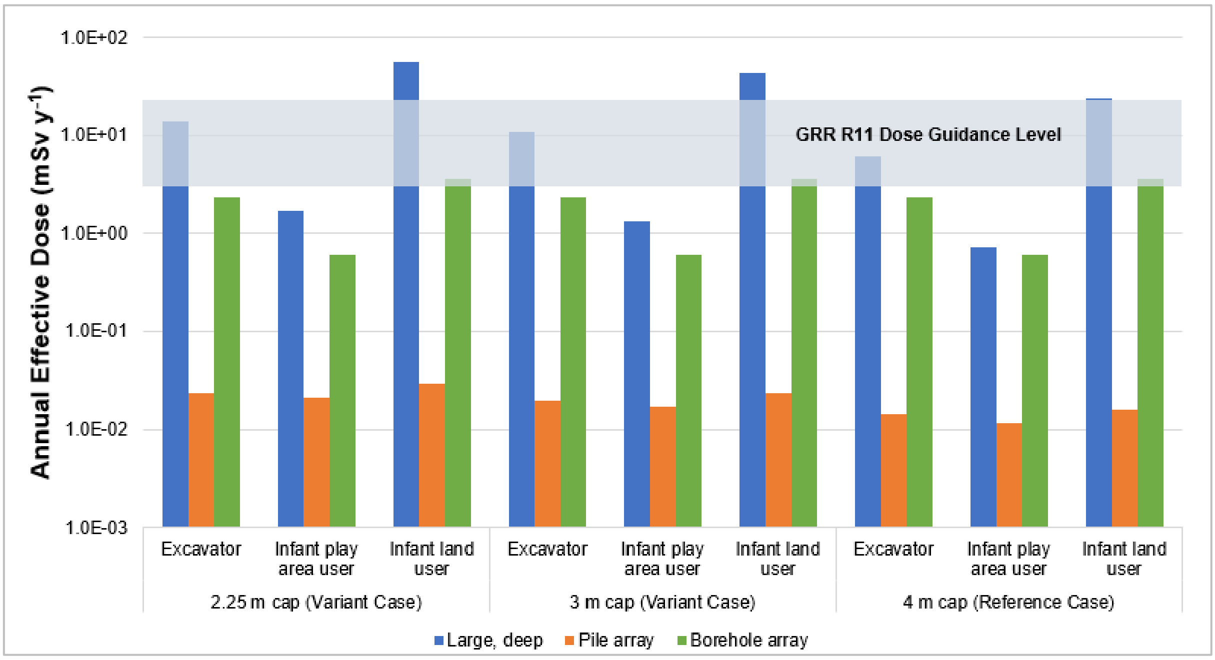

Figure 10.28: Doses to receptors from intrusions into SGHWR Region 1 in 2066 assuming the alternative inventory (including the mortuary tubes residual inventory estimate) and reference cap thickness (4.0 m). Results are also shown assuming the reference inventory for comparison. The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

North Annexe

573 The results show that all doses for alternative assessment case intrusions into the SGHWR North Annexe remain below the GRR dose guidance level, as summarised in: Figure G.1 for intrusions in 2056; and in Figure G.3 for the more conservative alternative inventory.

Region 2 and the South Annexe

574 The results show that all doses for alternative assessment case intrusions into SGHWR Region 2 and the South Annexe remain below the GRR dose guidance level, as summarised in Figure G.4 for intrusions in 2056; and in Figure G.6 for the more conservative alternative inventory.

Dragon Reactor Complex

Reactor Building – Earlier Intrusion

575 As for SGHWR, calculations have been undertaken for intrusions into the Dragon reactor complex prior to the SRS date. Whilst intrusion prior to the SRS is not expected, doses are presented at an arbitrary earlier date (2056) to inform NRS decision-making. Therefore, the annual effective doses from human intrusions into the Dragon reactor building in 2056 are

illustrated in Figure 10.29. These assume the reference inventory and reference cap thickness (3.8 m). The same intrusion cases and receptors are presented as in the Reference Case. The results show doses from intrusions in 2056 to be slightly increased compared to 2066, but they remain below the dose guidance level in all cases. Therefore, a future unforeseen need to shift to an earlier SRS date (between 2056 and 2066) is not constrained by human intrusion into the Dragon reactor complex.

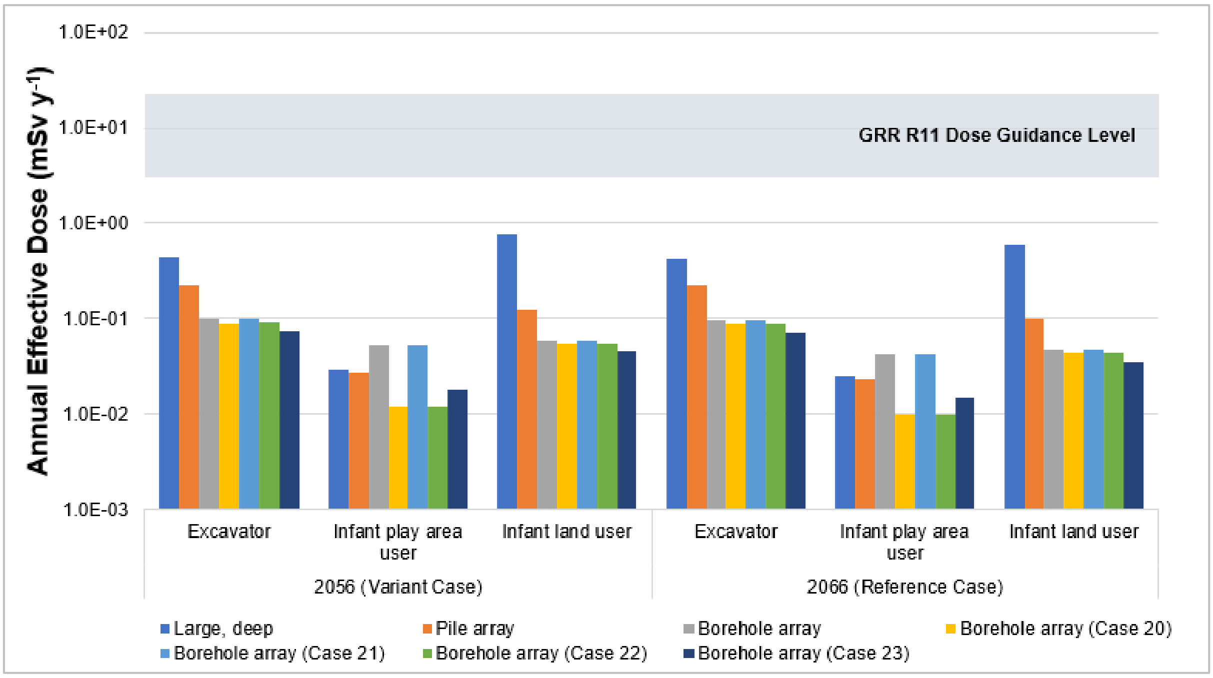

Figure 10.29: Doses to receptors from intrusions into the Dragon reactor building in 2056. Results shown assume the reference inventory and a cap thickness of 3.8 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

Reactor Building – Alternative Inventories

576 The annual effective doses arising from intrusions into the Dragon reactor building in 2066 assuming the alternative inventory and, separately, the alternative plutonium inventory, are summarised in Figure 10.30. The results show very few differences in calculated dose when assuming the alternative inventories compared to the reference inventory. The bioshield feature has the greatest difference in activity concentrations between these two inventories, with the biggest difference being in the tritium activity concentration. For the backfill and general building contamination, only the tritium activity concentration (of the nuclides included in GIM) is different between the two inventories and this difference is very minor. For the PGPC spill there are no differences between the inventories and for the Betalite store the differences are very minor. This is why the only differences in doses are for the intrusions excavating part of the bioshield: the large, deep intrusion, and the mixed borehole array. As the large, deep intrusion only intersects a small volume of bioshield concrete in comparison to the total volume of the excavation, the differences in doses are small.

Similarly, only one borehole out of the five boreholes within the mixed borehole array intersects the bioshield and hence the differences in doses are minor.

577 As the alternative plutonium inventory is based on the same total activity as the alternative inventory, the bioshield is again the feature for which there are the greatest differences in activity concentrations compared to the reference inventory. For the reactor building general contamination, the alternative Pu-containing fingerprint means that more radionuclides (notably the plutonium isotopes) are included at low activity concentrations, but the activity concentrations of other radionuclides have also decreased compared to the reference inventory as a consequence. The overall impact of these changes is that the doses are reduced when assuming the alternative plutonium inventory compared to the reference inventory. (GIM includes plutonium isotopes, so there is no reduction due to any decrease in the proportion of the inventory covered by GIM.)

578 In summary, all doses from all intrusion cases are below the dose guidance level in 2066 assuming a 3.8 m cap and any of the three inventories assessed (alternative, alternative plutonium, and reference).

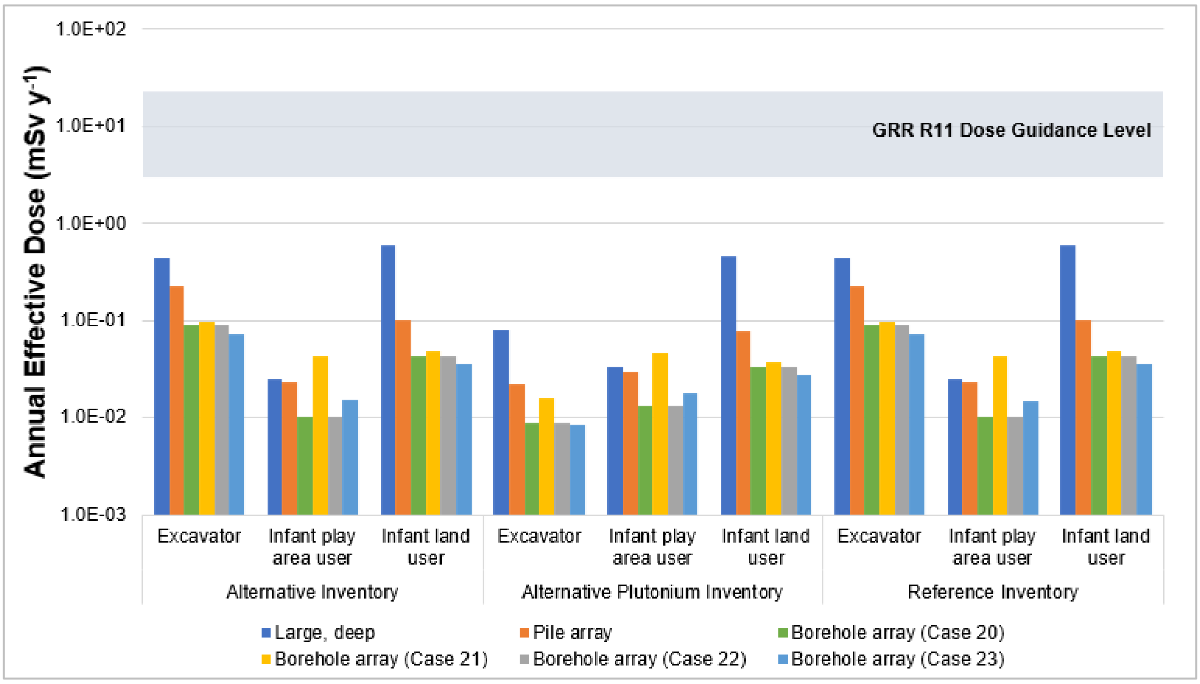

Figure 10.30: Doses to receptors from intrusions into the Dragon reactor building in 2066 assuming the alternative inventory and the alternative plutonium inventory. Results are also shown assuming the reference inventory for comparison. All cases shown assume the reference cap thickness (3.8 m). The R11 dose guidance level range is indicated by the grey shaded band.

B78 Building Floor Slab

579 The annual effective doses from intrusions into the B78 building floor slab in 2056 are shown in Figure G.7 for the reference inventory and reference cap thickness (3.8 m). All doses remain below the GRR dose guidance level.

580 Results for the alternative inventory and the alternative plutonium inventory cases are summarised in Figure G.9:

- There are no changes to the calculated doses when assuming the alternative inventory compared to the reference inventory. The only difference in activity concentrations between these two inventories is for tritium and the difference is very small. The difference does not impact the GIM results.
- As for the reactor building, doses decrease when considering the alternative plutonium inventory compared to those calculated for the reference inventory for the same reason: whilst more nuclides are included than in the reference inventory (notably the plutonium isotopes), the activity concentrations for the newly included nuclides are small and activity concentrations for other nuclides already present in the reference inventory have decreased.
- In summary, all doses from all intrusion cases are below the dose guidance level in 2066 assuming a 3.8-m-thick cap and any of the three inventories assessed (alternative, alternative plutonium, and reference).

Primary Mortuary Holes

581 The results show that all doses for alternative assessment case intrusions into the Dragon primary mortuary hole structure at earlier times remain below the GRR dose guidance level, as summarised in Figure G.10 for intrusions in 2056.

582 The annual effective doses from human intrusions into the Dragon primary mortuary hole structure in 2066 assuming the alternative inventory and the reference cap thickness (3.8 m) are summarised in Figure G.12; these are all well below the GRR dose guidance level. The alternative plutonium inventory is not applicable to the mortuary hole structure.

A59

Earlier Intrusion

583 As for SGHWR and the Dragon reactor complex, calculations have been undertaken for intrusions into A59 prior to 2066 (the SRS date). The annual effective doses from human intrusions into the A59 Other Areas and the remediated A591/HVA area in 2056 are illustrated in Figure 10.31. For the remediated PSA/Pit 3 area, results are shown in Figure G.13. These assume the reference inventory and reference cover material thickness of 0.5 m.

584 The same intrusion cases and receptors are presented as in the Reference Case. The results show doses from intrusions in 2056 to be slightly increased compared to 2066, but doses remain below the dose guidance level in all cases.

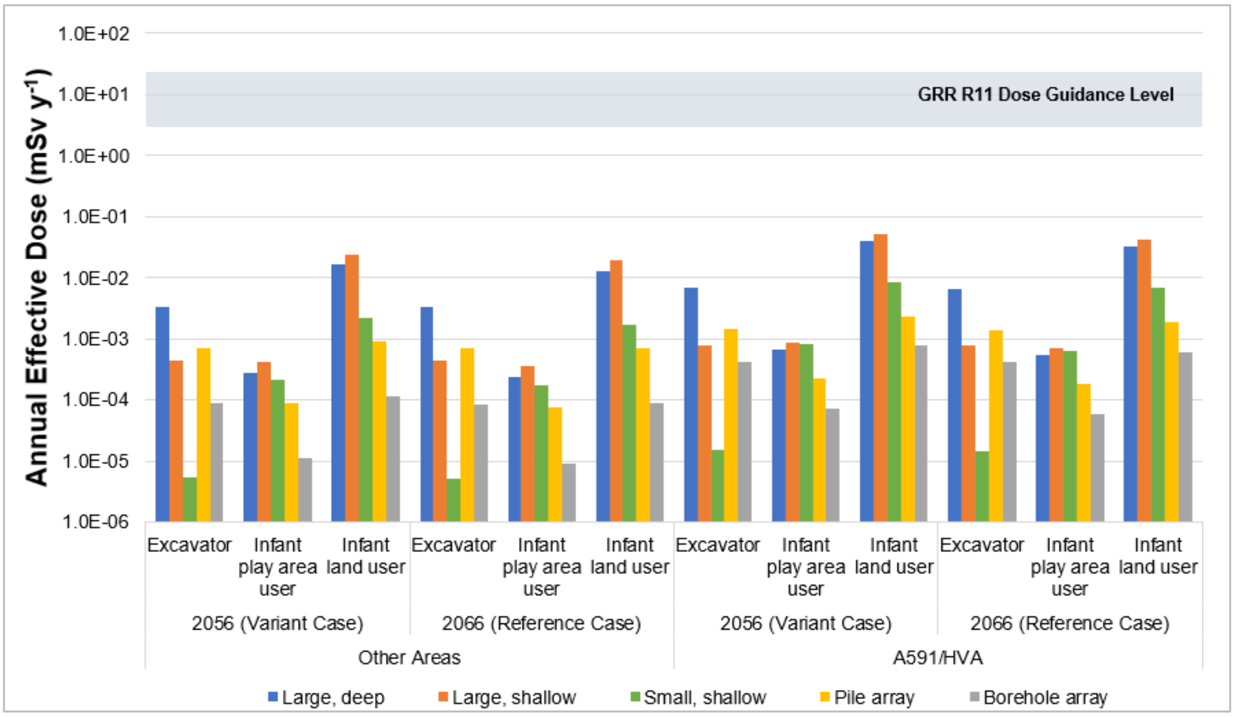

Figure 10.31: Doses to receptors from intrusions into the A59 OoS area in 2056. Results shown assume the reference inventory and reference cover material thickness of 0.5 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

Alternative Inventory

585 The annual effective doses from human intrusions into the A59 Other Areas and the remediated A591/HVA area in 2066 assuming the alternative inventory and the reference cover material thickness (0.5 m) are summarised in Figure 10.32. For the remediated PSA/Pit 3 area, results are shown in Figure G.15. The results show doses from all intrusion cases increase when assuming the alternative inventory compared to the reference inventory, but all doses remain below the dose guidance level.

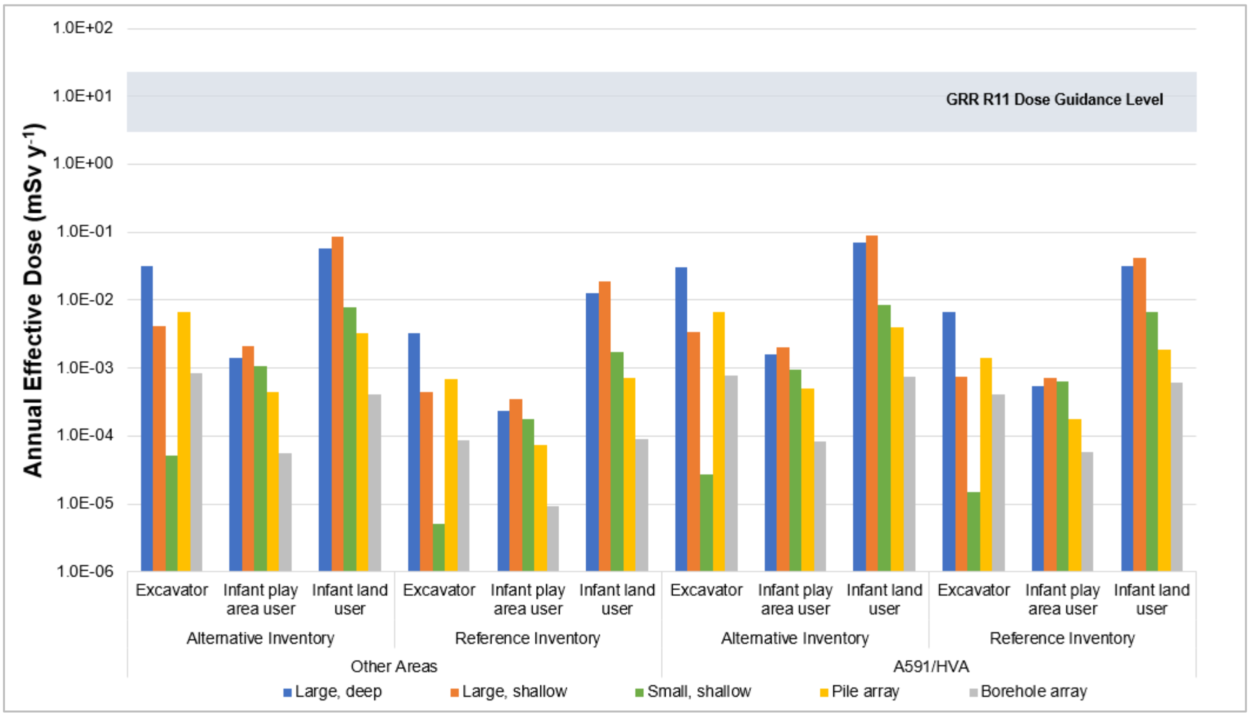

Figure 10.32: Doses to receptors from intrusions into the OoS A59 area in 2066 assuming the alternative inventory and reference cover material thickness (0.5 m). Results are also shown assuming the reference inventory for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

10.5.3 Variant Configuration Scenarios

586 Variant configuration scenarios have been defined to investigate the impact of conceptual model uncertainty in the Reference Case assessment. Cap/cover thickness (cases HI.VB.1, HI.VB.2 and HI.VB.3, Table 8.3) is considered here.

587 In this section only intrusions that lead to the highest doses are presented; intrusions that result in lower doses are presented in Appendix F.

SGHWR

Region 1

588 As the cap thickness is to be optimised, variant intrusion cases have considered alternative cap thicknesses. For SGHWR, there are two possible alternative cap thicknesses: 3.0 m and 2.25 m (see Section 3.3.1). It is understood that 2.25 m is the minimum thickness that is required for the cap to perform its functions (including drainage, anti-intrusion and landscaping) and it is considered unlikely that the cap will be this thin. The thickness of the cap means that shallow intrusions will not excavate any radioactive material. However, if during optimisation/detailed design it is considered appropriate to reduce the cap thickness below 2.25 m the human intrusion assessment will be revisited.

589 Annual effective doses from intrusions into SGHWR Region 1 in 2066 for the two alternative cap thicknesses assuming the reference inventory are summarised in Figure 10.33 and Figure 10.34.

590 The results show doses increase with decreasing cap thickness, except for the borehole scenarios – doses to receptors from borehole intrusions are not influenced by the cap thickness and remain the same. This is because, due to the depth of borehole intrusions, the same amount of clean and contaminated material is excavated for any of the assessed cap thicknesses, with the clean soil just extracted in different proportions from above and below the in-situ disposals depending on the cap thickness assumed.

591 The overall conclusions are the same for all three of the cap thicknesses assessed: all intrusions excluding the SGHWR mortuary tubes residual inventory are below the dose guidance level. The only doses exceeding the dose guidance level are those to infant land users associated with intrusions into the mortuary tubes containing the estimated residual inventory (Case 2, 4.3E+01 mSv y^{-1} for 3 m cap and 5.5E+01 mSv y^{-1} for 2.25 m cap, and Case 6, 3.6E+00 mSv y^{-1} for all cap thicknesses considered).

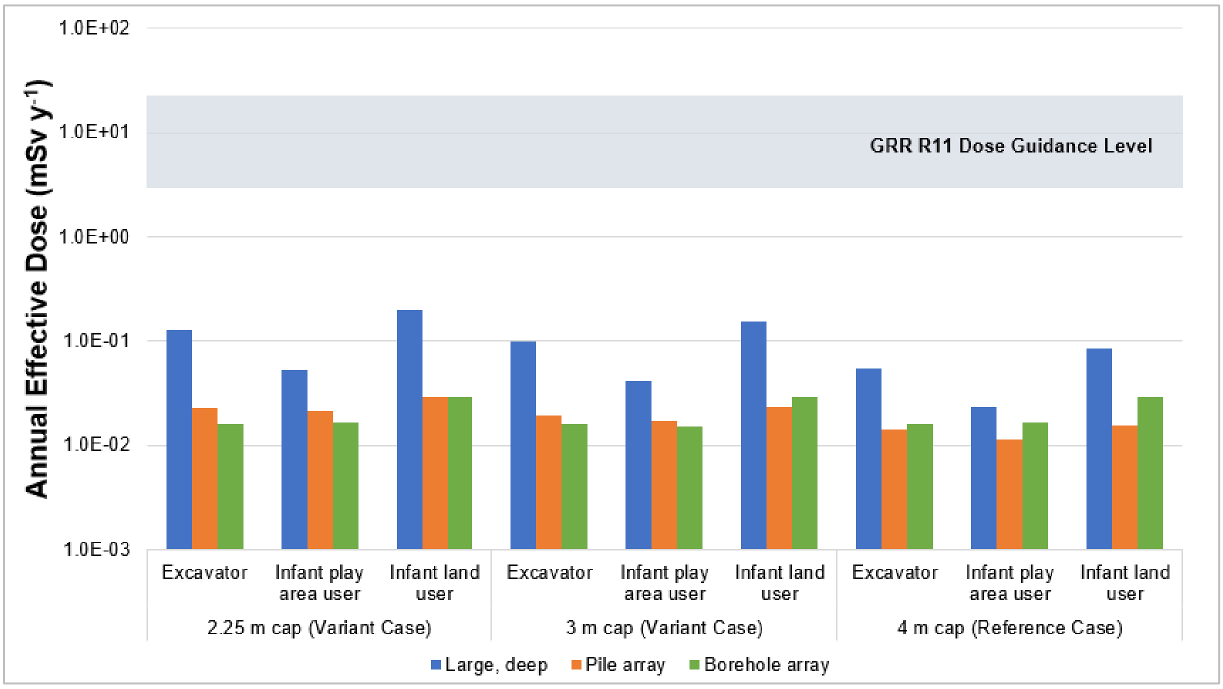

Figure 10.33: Doses to receptors from intrusions into SGHWR Region 1 in 2066 assuming the reference inventory (excluding the mortuary tubes residual inventory estimate). Results are shown for the two alternative cap thicknesses (2.25 m and 3.0 m) and the reference cap thickness (4.0 m). The R11 dose guidance level range is indicated by the grey shaded band.

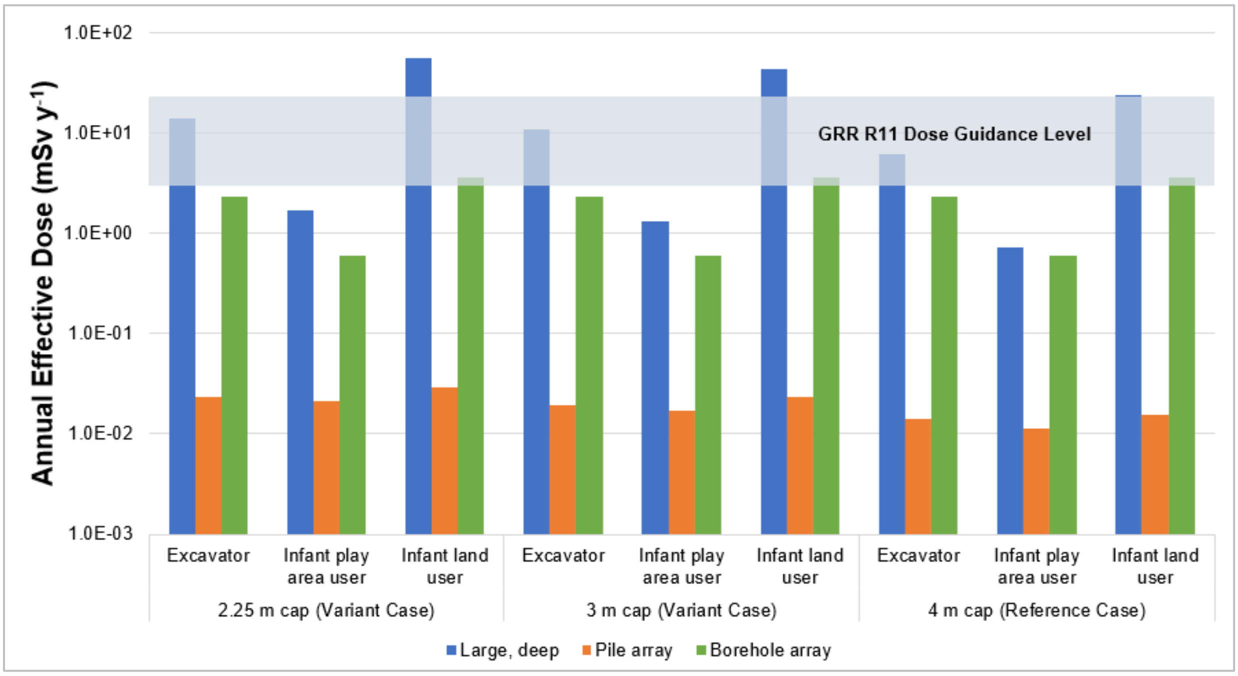

Figure 10.34: Doses to receptors from intrusions into SGHWR Region 1 in 2066 assuming the reference inventory (including the mortuary tubes residual inventory estimate). Results are shown for the two alternative cap thicknesses (2.25 m and 3.0 m) and the reference cap thickness (4.0 m). The R11 dose guidance level range is indicated by the grey shaded band. Doses to a site excavator are transitory and should be compared to the upper end (20 mSv in total) of the dose guidance level range, while doses to land users may be prolonged and should be compared to the lower end of the range (3 mSv y^{-1}).

North Annexe

592 The results show that all doses for variant case intrusions into the SGHWR North Annexe remain below the GRR dose guidance level, as summarised in Figure G.2 for two alternative cap thicknesses.

Region 2 and the South Annexe

593 The results show that all doses for variant case intrusions into SGHWR Region 2 and the South Annexe remain below the GRR dose guidance level, as summarised in Figure G.5 for two alternative cap thicknesses.

Dragon Reactor Complex

Reactor Building

594 As for SGHWR, the Dragon reactor complex cap thickness will be optimised. Therefore, variant intrusion cases have considered alternative cap thicknesses. For the Dragon reactor complex, there are two possible alternative cap thicknesses: 2.5 m and 1.5 m (see Section 3.3.2). Annual effective doses from human intrusions into the Dragon reactor

building in 2066 for the two alternative cap thicknesses assuming the reference inventory are summarised in Figure 10.35.

595 The results show that, even assuming thinner cap thicknesses, the doses from all cases remain below the dose guidance level in 2066. Note that only the thinnest cap considered (1.5 m thick) gives doses from the shallow intrusions due to the intrusion depth assumed in GIM (2.0 m). Doses to receptors from borehole intrusions are not influenced by the cap thickness and remain the same for all three thicknesses considered due to the depth of the boreholes (see Paragraph 590).

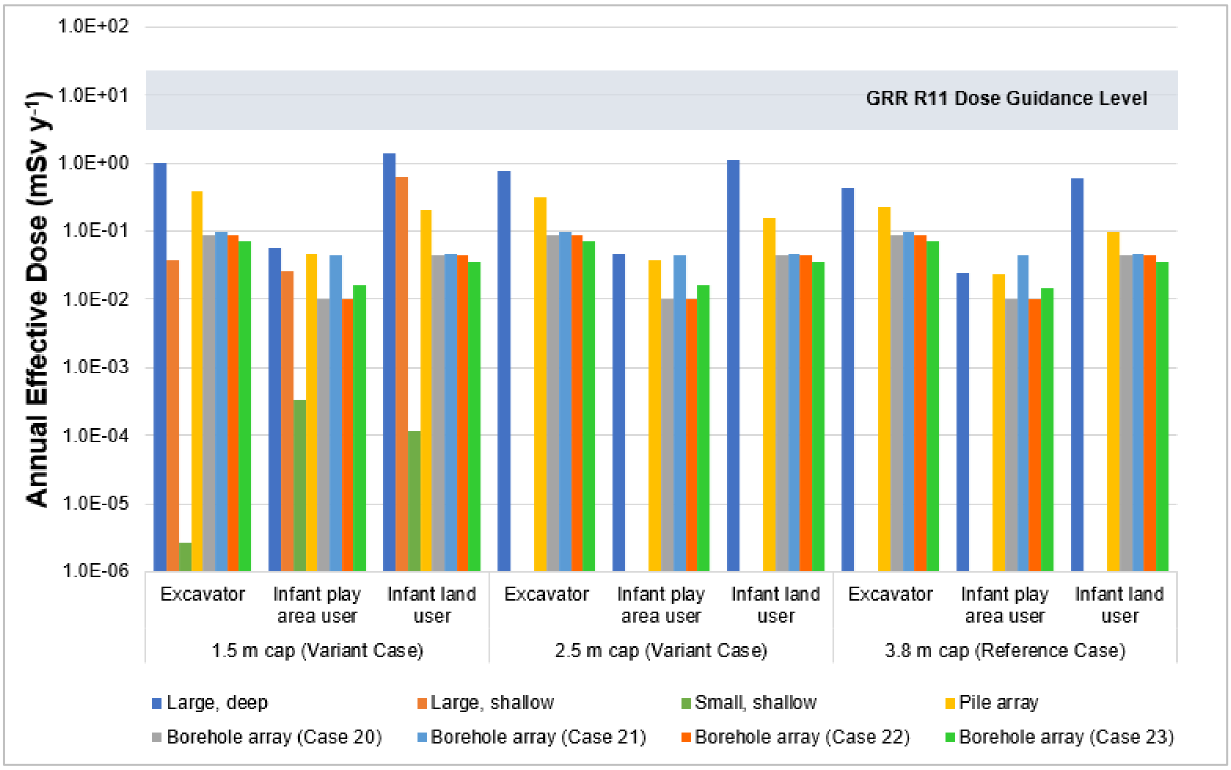

Figure 10.35: Doses to receptors from intrusions into the Dragon reactor building in 2066 assuming the reference inventory. Results are shown for the two alternative cap thicknesses (1.5 m and 2.5 m) together with the reference cap thickness (3.8 m) for comparison. Note that doses from the shallow intrusions only occur when assuming the thinnest cap (1.5 m) due to the depth of the shallow intrusions (2 m). The R11 dose guidance level range is indicated by the grey shaded band.

B78 Building Floor Slab

596 The annual effective doses from intrusions into the B78 building floor slab in 2066 for the two alternative cap thicknesses assuming the reference inventory are summarised in Figure G.8. The results show all doses are below the GRR dose guidance level. Note that the doses to receptors from the large, deep intrusions, pile array and borehole arrays are all insensitive to the cap thicknesses considered. This is because the depth of all of these intrusions exceeds the thickness of the cap and the in-situ disposals combined for all three

cap thicknesses. Therefore, exactly the same amount of clean and contaminated material is excavated for any of the assessed cap thicknesses; the clean soil is just extracted in different proportions from above and below the in-situ disposals depending on the cap thickness assumed.

Primary Mortuary Holes

597 The results show that all doses for variant case intrusions into the Dragon primary mortuary hole structure at earlier times and assuming thinner caps remain below the GRR dose guidance level, as summarised in Figure G.11 for the two alternative cap thicknesses.

A59

598 Variant intrusion cases for the OoS A59 area have considered alternative thicknesses of cover material in order to understand the impact of uncertainty in cover material thickness and to support future decision-making. The variant thicknesses considered are 0 m, 0.1 m and 0.3 m. Annual effective doses from human intrusions into the A59 Other Areas and the remediated A591/HVA area in 2066 for the three alternative cover material thicknesses assuming the reference inventory are summarised in Figure 10.36. For the remediated PSA/Pit 3 area, results are shown in Figure G.14.

599 The results for doses from the large, deep intrusions as well as the pile array and borehole array are insensitive to the cover material thicknesses considered and are therefore not included in Figure 10.36. This is because the depth of all of these intrusion cases exceeds the thickness of the cover material and the in-situ disposals combined for all four cover material thicknesses. Therefore, exactly the same amount of clean and contaminated material is excavated for any of the assessed cover material thicknesses; the clean soil is just extracted in different proportions from above and below the in-situ disposals depending on the cover material thickness assumed.

600 Doses from the small, shallow and large, shallow intrusions increase slightly with reducing cover material thickness. None of the calculated doses exceed the GRR dose guidance level.

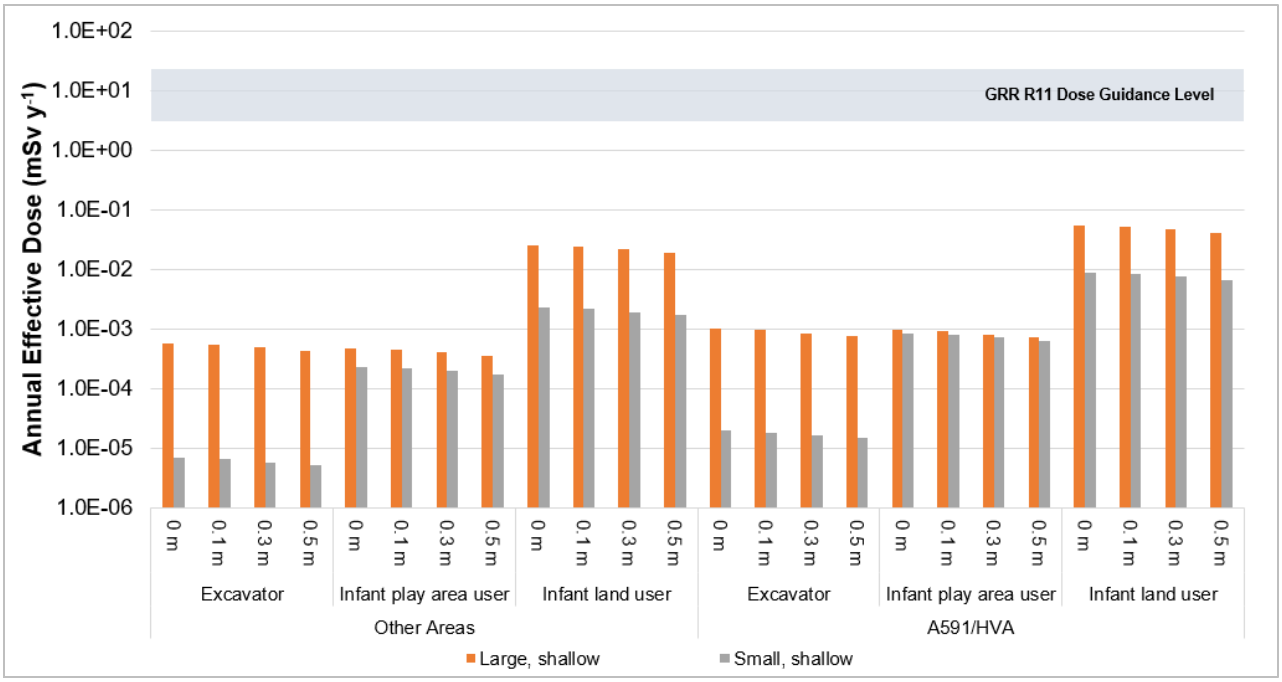

Figure 10.36: Doses to receptors from intrusions into the OoS A59 area in 2066 assuming the reference inventory. Results are shown for the three alternative cover material thicknesses (0 m, 0.1 m and 0.3 m) together with the reference cover material thickness (0.5 m) for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

10.5.4 Summary

601 In summary, the following observations are made regarding the human intrusion variant case assessment:

- For the SGHWR feature group:
  - For SGHWR Region 1, the overall conclusions for each variant case considered are the same as for the Reference Case: all doses are below the dose guidance level when the residual SGHWR mortuary tube inventory estimate is excluded. If the SGHWR mortuary tube inventory estimate is included, then doses from the large, deep excavation and borehole array to infant land users are above the dose guidance level value associated with prolonged exposures (3 mSv y^{-1}) for each variant case.
  - For SGHWR North Annexe, Region 2 and the South Annexe, none of the variant cases assessed resulted in a change to the overall conclusions compared to the Reference Case – all doses remain below the dose guidance level for all variant cases assessed.
  - Doses from borehole intrusions into SGHWR features are insensitive to cap thickness due to the depth of the intrusion exceeding the combined depth of the cap and in-situ disposals for all cap thicknesses assessed.

- For the Dragon reactor complex, doses are below the dose guidance level for all variant cases assessed.
  - Doses from boreholes into the Dragon reactor building, and from large, deep intrusions, boreholes and piles into the B78 building floor slab are insensitive to cap thickness due to the depth of these intrusions exceeding the depth of the cap and in-situ disposals combined for all cap thicknesses assessed.
  - Assessment of the alternative inventory for the Dragon reactor building resulted in very minor increases in dose compared with the reference inventory. The greatest increase in activity concentrations between the reference inventory and the alternative inventory is associated with the reactor bioshield. For the reactor building general contamination (and for the B78 floor slab), the only nuclide to increase in the alternative inventory (of those included in GIM) is tritium, and that by an amount leading to insignificant dose increases. There is no difference in the reference and alternative inventories for the PGPC spill. Therefore, an observable difference in dose only occurs for intrusion cases excavating part of the bioshield.
  - Assessment of the alternative plutonium inventory for the Dragon reactor building and B78 building floor slab result in a decrease in dose compared with the reference inventory. This is because, whilst more nuclides are included than in the reference inventory (notably the plutonium isotopes), the activity concentrations for the newly included nuclides are small and activity concentrations for other nuclides already present in the reference inventory have decreased.
  - Assessment of the alternative inventory for the Dragon primary mortuary holes increased doses by an order of magnitude, as the activity concentrations for the alternative inventory are an order of magnitude greater than those for the reference inventory. However, the doses are still significantly below the dose guidance level.
- For the OoS A59 area, doses are below the dose guidance level for all variant cases assessed.
  - Doses from large, deep intrusions, piles and boreholes into the OoS A59 area are insensitive to the thickness of cover material due to the depth of these intrusions exceeding the depth of the cover material and in-situ disposals combined for all cover material thicknesses assessed.

10.6 Non-Human Biota

602 The results of the Tier 2 ERICA assessment are presented in the following sections for each of the modelled biosphere compartments: Field, Land/Mire, and River Frome. In each case, results are shown for both the reference inventory and the alternative inventory. The assessment was also run for the alternative inventory using the Pu fingerprint for Dragon general building contamination; however, these results are not reported as (to at least two significant figures) they are the same as for the alternative inventory. This is expected, since

the assessment considers all envisaged disposals together and is therefore dominated by SGHWR and (for the mire, particularly at early times) A59, neither of which change between the two alternative inventories.

603 The input values for the assessment (environmental activity concentrations in the modelled compartments at the time of peak dose) are presented in Appendix D, together with the time of the peak for each radionuclide (Table D.114 for the reference inventory and Table D.115 for the alternative inventory). Appendix D also includes a list of the ERICA reference organisms in terrestrial and freshwater ecosystems (Table D.113).

10.6.1 Field Compartment

604 A terrestrial Tier 2 assessment was undertaken using the peak soil concentrations in the Field compartment as output from the natural evolution model. Results are presented in Table 10.13 and show that, for all organisms and for both reference and alternative inventories, dose rates are well below the default ERICA dose rate screening criterion of 10 µGy h^{-1}, and both expected and conservative RQ values (calculated using a UF of 3) are several orders of magnitude less than one[53]. Therefore, the Tier 2 screening level is not exceeded, the risk to non-human biota can be considered to be trivial, and no further assessment is required.

605 For most organisms in the Field compartment for the reference inventory, the largest contribution to dose comes from ^{226}Ra. For the bird and the tree, the largest contribution comes from ^{14}C, with the second largest from ^{226}Ra. For lichens and bryophytes, which have the highest dose rates and RQ values in the Field compartment, significant contributions to dose also come from ^{234}U, ^{238}U, ^{210}Pb and ^{227}Ac.

Table 10.13: Total dose rates (internal and external summed) per organism, and expected and conservative RQ values for the Field compartment (soil) of the Winfrith biosphere, assessed against the 10 µGy h^{-1} screening criterion.

Organism	Reference Inventory			Alternative Inventory		
	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)
Amphibian	5.51E-06	5.51E-07	1.65E-06	2.88E-05	2.88E-06	8.63E-06
Bird	2.12E-06	2.12E-07	6.36E-07	9.12E-06	9.12E-07	2.74E-06
Mollusc - gastropod	2.73E-06	2.73E-07	8.18E-07	1.25E-05	1.25E-06	3.76E-06
Reptile	5.44E-06	5.44E-07	1.63E-06	2.81E-05	2.81E-06	8.42E-06
Annelid	6.83E-06	6.83E-07	2.05E-06	3.59E-05	3.59E-06	1.08E-05
Arthropod - detritivorous	8.84E-06	8.84E-07	2.65E-06	4.45E-05	4.45E-06	1.34E-05

53 As explained in Section 9.1.2, the unitless Risk Quotient (RQ) is defined in Tier 2 by dividing the estimated total dose rate for each reference organism by the screening level. The conservative RQ multiplies the expected RQ by un uncertainty factor (UF). A UF of 3 tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential. When a UF of 3 or higher is used, Tier 2 conservative RQ values below one indicate that there is low probability that the estimated dose rate exceeds the screening dose rate and the risk to non-human biota can be considered to be trivial, based on analyses of effects data conducted to derive the ERICA screening dose rate.

Organism	Reference Inventory			Alternative Inventory		
	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)
Flying insects	2.23E-06	2.23E-07	6.70E-07	1.13E-05	1.13E-06	3.38E-06
Grasses & Herbs	7.72E-06	7.72E-07	2.32E-06	3.58E-05	3.58E-06	1.07E-05
Lichen & Bryophytes	4.63E-05	4.63E-06	1.39E-05	2.18E-04	2.18E-05	6.55E-05
Mammal - large	3.16E-06	3.16E-07	9.47E-07	1.48E-05	1.48E-06	4.45E-06
Mammal – small, burrowing	3.24E-06	3.24E-07	9.71E-07	1.53E-05	1.53E-06	4.59E-06
Shrub	9.56E-06	9.56E-07	2.87E-06	4.92E-05	4.92E-06	1.47E-05
Tree	1.78E-06	1.78E-07	5.35E-07	7.00E-06	7.00E-07	2.10E-06

10.6.2 Land/Mire Compartment

606 Two Tier 2 assessments, one for a terrestrial ecosystem and one for a freshwater ecosystem, were undertaken using the peak water and soil/sediment concentrations in the Land/Mire compartment as output from the natural evolution model. Results are presented in Table 10.14 and Table 10.15.

607 In all cases (whether modelled as a freshwater or terrestrial ecosystem, and for both reference and alternative inventories), dose rates to all organisms are below the default ERICA dose rate screening criterion of 10 µGy h^{-1}, and both expected and conservative RQ values (calculated using a UF of 3) are less than one. When modelled as a terrestrial ecosystem, the expected and conservative RQ values are several orders of magnitude below one, but when modelled as a freshwater ecosystem, some RQ values (notably for gastropod and bivalve molluscs, insect larvae and zooplankton) are relatively close to one. Nevertheless, the Tier 2 screening level is not exceeded, the risk to non-human biota can be considered to be negligible, and no further assessment is required. In support of this conclusion, the following contextual points are noted:

- When calculated relative to the higher IAEA/UNSCEAR-derived screening criteria available in ERICA [144; 145], the conservative RQ values are at least one order of magnitude below one for all organisms when the mire is modelled as a freshwater ecosystem. As explained in Section 9.1.1, these criteria are 40 µGy h^{-1} for terrestrial birds, animals, amphibians and reptiles and 400 µGy h^{-1} for fish and other aquatic organisms, and constitute scientifically-underpinned benchmarks below which non-human populations are unlikely to be harmed. Additionally, the 40 µGy h^{-1} limit is recognised by the UK environment agencies as an appropriate limit to assess dose rate effects to wildlife inhabiting Natura 2000 sites [146].
- It is only the alternative inventory for which the conservative RQ values are relatively close to one when calculated relative to the more stringent screening level of 10 µGy h^{-1}. There are significant conservatisms in this inventory and it does not represent a realistic estimate of the activity present.

- As noted in Section 9.3, the mire is expected to be ephemeral and to dry out entirely for significant periods of time. Modelling it as a freshwater rather than terrestrial ecosystem therefore represents the upper bound of the long-term expected impacts to non-human biota if it were to remain permanently wet; actual impacts are likely to be less significant.
- Several other conservatisms are built into this assessment, as listed in Section 9.3. In particular, the assumption that peak media concentrations will occur at the same time for all radionuclides is unrealistic. Different radionuclides peaking at different times over many years (as modelled in the natural evolution assessment) would have the effect of reducing overall dose rates and impacts to individuals and populations of non-human biota at any given time.

For a majority of organisms in the Land/Mire compartment, the largest contribution to dose comes from ^{226}Ra when it is modelled as a freshwater ecosystem, using the reference inventory. However, for several organisms the largest dose contributor is a different radionuclide: ^{90}Sr (benthic and pelagic fish; reptile), ^{234}U (mammal; vascular plant), ^{241}Am (crustacean), and ^{227}Ac (phytoplankton). When the land/mire compartment is modelled as a terrestrial ecosystem, ^{226}Ra is the largest dose contributor for all but two of the organisms; the exceptions are the gastropod mollusc and lichen and bryophytes, for which ^{234}U is the largest dose contributor.

Table 10.14: Total dose rates (internal and external summed) per organism, and expected and conservative RQ values for the Land/Mire compartment (mire water and mire soil/sediment) of the Winfrith biosphere, modelled as a freshwater ecosystem and assessed against the 10 µGy h^{-1} screening criterion.

Organism	Modelled as a Freshwater Ecosystem					
	Reference Inventory			Alternative Inventory		
	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)
Amphibian	2.47E-02	2.47E-03	7.42E-03	1.17E-01	1.17E-02	3.51E-02
Benthic fish	3.62E-02	3.62E-03	1.09E-02	9.44E-02	9.44E-03	2.83E-02
Bird	4.10E-02	4.10E-03	1.23E-02	1.82E-01	1.82E-02	5.45E-02
Crustacean	6.71E-02	6.71E-03	2.01E-02	2.50E-01	2.50E-02	7.51E-02
Insect larvae	4.92E-01	4.92E-02	1.48E-01	1.93E+00	1.93E-01	5.78E-01
Mammal	3.05E-02	3.05E-03	9.16E-03	9.37E-02	9.37E-03	2.81E-02
Mollusc - bivalve	4.99E-01	4.99E-02	1.50E-01	1.84E+00	1.84E-01	5.51E-01
Mollusc - gastropod	3.94E-01	3.94E-02	1.18E-01	1.57E+00	1.57E-01	4.71E-01
Pelagic fish	3.57E-02	3.57E-03	1.07E-02	9.23E-02	9.23E-03	2.77E-02
Phytoplankton	2.27E-02	2.27E-03	6.80E-03	9.21E-02	9.21E-03	2.76E-02
Reptile	5.11E-02	5.11E-03	1.53E-02	1.66E-01	1.66E-02	4.98E-02
Vascular plant	8.06E-02	8.06E-03	2.42E-02	2.77E-01	2.77E-02	8.30E-02
Zooplankton	4.04E-01	4.04E-02	1.21E-01	1.62E+00	1.62E-01	4.87E-01

Table 10.15: Total dose rates (internal and external summed) per organism, and expected and conservative RQ values for the Land/Mire compartment (mire soil/sediment) of the Winfrith biosphere, modelled as a terrestrial ecosystem and assessed against the 10 µGy h^{-1} screening criterion.

Organism	Modelled as a Terrestrial Ecosystem					
	Reference Inventory			Alternative Inventory		
	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)	Dose Rate (µGy/h)	RQ (expected)	RQ (conservative; UF=3)
Amphibian	2.31E-03	2.31E-04	6.94E-04	1.21E-02	1.21E-03	3.64E-03
Bird	7.24E-04	7.24E-05	2.17E-04	3.29E-03	3.29E-04	9.86E-04
Mollusc - gastropod	1.50E-03	1.50E-04	4.50E-04	5.09E-03	5.09E-04	1.53E-03
Reptile	2.28E-03	2.28E-04	6.83E-04	1.18E-02	1.18E-03	3.55E-03
Annelid	3.43E-03	3.43E-04	1.03E-03	1.63E-02	1.63E-03	4.90E-03
Arthropod - detritivorous	4.86E-03	4.86E-04	1.46E-03	2.02E-02	2.02E-03	6.06E-03
Flying insects	9.74E-04	9.74E-05	2.92E-04	4.52E-03	4.52E-04	1.36E-03
Grasses & Herbs	4.24E-03	4.24E-04	1.27E-03	1.47E-02	1.47E-03	4.42E-03
Lichen & Bryophytes	2.96E-02	2.96E-03	8.87E-03	9.69E-02	9.69E-03	2.91E-02
Mammal - large	1.22E-03	1.22E-04	3.65E-04	5.89E-03	5.89E-04	1.77E-03
Mammal - small-burrowing	1.25E-03	1.25E-04	2.76E-04	6.10E-03	6.10E-04	1.83E-03
Shrub	4.69E-03	4.69E-04	1.41E-03	2.17E-02	2.17E-03	6.52E-03
Tree	5.86E-04	5.86E-05	1.76E-04	2.31E-03	2.31E-04	6.94E-04

10.6.3 River Frome Compartment

608 A freshwater Tier 2 assessment was undertaken using the peak water and sediment concentrations in the River Frome compartment as output from the natural evolution model. Results are presented in Table 10.16 and show that, for all organisms, dose rates are well below the default ERICA dose rate screening criterion of 10 µGy h^{-1}, and both expected and conservative RQ values (calculated using a UF of 3) are several orders of magnitude less than one. Therefore, the Tier 2 screening level is not exceeded, the risk to non-human biota can be considered to be trivial, and no further assessment is required.

609 For a majority of organisms in the River compartment for the reference inventory, the largest contribution to dose comes from ^{226}Ra. However, for several organisms the largest dose contributor is a different radionuclide: ^{90}Sr (benthic and pelagic fish; reptile), ^{227}Ac (phytoplankton; vascular plant), ^{234}U (mammal), and ^{241}Am (crustacean).

Table 10.16: Total dose rates (internal and external summed) per organism, and expected and conservative RQ values for the River Frome compartment (river water and river sediment) of the Winfrith biosphere, assessed against the 10 µGy h^{-1} screening criterion.

Organism	Reference Inventory			Alternative Inventory		
	Dose Rate (µGy/h)	**RQ (expected)**	**RQ (conservative; UF=3)**	**Dose Rate (µGy/h)**	**RQ (expected)**	**RQ (conservative; UF=3)**
Amphibian	2.31E-04	2.31E-05	6.92E-05	1.14E-03	1.14E-04	3.41E-04
Benthic fish	2.61E-04	2.61E-05	7.83E-05	7.78E-04	7.78E-05	2.33E-04
Bird	3.42E-04	3.42E-05	1.03E-04	1.62E-03	1.62E-04	4.85E-04
Crustacean	7.16E-04	7.16E-05	2.15E-04	3.24E-03	3.24E-04	9.73E-04
Insect larvae	3.93E-03	3.93E-04	1.18E-03	1.70E-02	1.70E-03	5.10E-03
Mammal	2.50E-04	2.50E-05	7.51E-05	9.12E-04	9.12E-05	2.74E-04
Mollusc - bivalve	3.90E-03	3.90E-04	1.17E-03	1.61E-02	1.61E-03	4.84E-03
Mollusc - gastropod	3.11E-03	3.11E-04	9.32E-04	1.37E-02	1.37E-03	4.11E-03
Pelagic fish	2.56E-04	2.56E-05	7.68E-05	7.57E-04	7.57E-05	2.27E-04
Phytoplankton	2.34E-04	2.34E-05	7.02E-05	1.14E-03	1.14E-04	3.41E-04
Reptile	3.96E-04	3.96E-05	1.19E-04	1.47E-03	1.47E-04	4.42E-04
Vascular plant	8.03E-04	8.03E-05	2.41E-04	3.66E-03	3.66E-04	1.10E-03
Zooplankton	3.28E-03	3.28E-04	9.85E-04	1.47E-02	1.47E-03	4.41E-03

10.6.4 Summary

610 The above discussion shows that, for all organisms in all three compartments (Field, River Frome and Land/Mire, whether modelled as a freshwater or terrestrial ecosystem) and for both the reference and alternative inventories, estimated dose rates are below the 10 µGy h^{-1} screening criterion, and expected and conservative RQ values are at least an order of magnitude below one. The highest values are seen in the Land/Mire compartment when modelled as a freshwater ecosystem, and the lowest values in the Field compartment.

611 The Tier 2 screening level is not exceeded in any case even with the conservative assessment undertaken. Therefore, it is considered that the risk to non-human biota in all biosphere compartments is negligible for the assumed inventories and site end state configuration, and no further assessment is required.

11 Quality Assurance and Verification of Assessment

612 This report presents the compiled radiological assessment of natural evolution, site occupancy, human intrusion and non-human biota for the proposed Winfrith on-site disposals, which have been systematically quality assurance checked and verified, as described in this section.

11.1 Software Used

613 The following software has been used to undertake the quantitative assessments in this work:

- The commercial GoldSim-RT (Version 14.0 R2 Build #412) simulation software package for dynamic modelling and contaminant transport has been used for the natural evolution assessment (see Section 5.1).
- The commercial MicroShield® (version 11) photon/gamma-ray shielding and dose assessment program has been used for the site occupancy calculations (see Section 6).
- The "Generic Intrusion Methodology" (GIM) tool (Version 2.1.3) developed on behalf of NRS by Eden Nuclear and Environment Ltd has been used for the human intrusion assessment (see Section 7).
- The freely available "Environmental Risk from Ionising Contaminants: Assessment and Management" (ERICA) assessment tool (Version 2.0.228), originally developed under the EC 6th Framework Programme Euratom project and maintained by the ERICA consortium, has been used for the non-human biota assessment (see Section 9).

Data has also been processed and analysed using Microsoft Excel, the use of which has also been subject to appropriate management and verification (Section 11.3).

11.2 Software Quality Assurance

614 Released versions of GoldSim, which has been in development and use for over 20 years, are verified by the software developers. Extensive documentation and user guides are available [104; 105]. GoldSim is developed and maintained according to a rigorous set of software configuration management procedures to ensure quality. These procedures include requirements for: source code revision control; change control and tracking; testing and verification; and documentation[54].

615 MicroShield® has been developed by Grove Software and is subjected to their internal Quality Assurance (QA) processes. It continues to be updated on a regular basis to add new functionality, ensure compatibility with windows updates and update parameters to align with current industry standards.

[54] Further details are available on the relevant page of the GoldSim website: https://www.goldsim.com/Web/Products/GoldSim/FAQ/#GoldSimQualityAssurance

616 The GIM spreadsheet tool and associated manual has been developed by Eden Nuclear and Environment Ltd for NRS and subjected to their internal QA processes. The GIM spreadsheet is currently at Version 2.1.3. GIM Version 2.0 was the subject of a satisfactory closed-out Quality and Verification Plan from Eden Nuclear and Environment Ltd (Magnox Ref: DD/VP/0031 Issue 1) which includes the plan and outcome of independent testing by GSL of a pre-issue version of GIMv2.0 (GSL's close-out letter is included in DD/VP/0031 Issue 1). Up issues to GIM Version 2.1.3 have included some minor updates; the GIM Version 2.1.3 spreadsheet tool and associated user document have been accepted for use (for its stated purpose) by a NRS Subject Matter Expert (SME) as a relevant Authorised IC (IC12.00 - Radiological Safety, Radiation and Environment). All updates are recorded along with a review record in the "Version History" sheet of the GIM spreadsheet.

617 The ERICA assessment tool was originally developed under the EC 6th Framework Programme Euratom project, which ran from 2004 to 2007. For the last two years of the project the tool was available as a prototype and was continuously improved through comments received from both inside and outside the consortium. The ERICA tool is now maintained by a consortium led by the Norwegian Radiation and Nuclear Safety Authority (DSA), with QA undertaken by organisations including RadEcol Consulting Ltd[55].

11.3 Verification

618 Internal independent verification of input data, model-supporting spreadsheets and the models themselves has been undertaken according to a process set out in a project-specific procedure (PSP) forming part of GSL's Quality Management System. Model supporting spreadsheets include feature-specific workbooks containing parameter value documentation sheets (PVDS), a Model Record Management System (MRMS) sheet and model output sheets, and the GIM spreadsheets. Each workbook includes a dedicated QA sheet, containing a Review Form (RF) relevant to the current version of the workbook, that documents the verification checks that have been made, the results of these and the actions that were taken in response.

11.3.1 Data Verification

619 The parameter value document spreadsheet (PVDS), from which parameter data is directly uploaded into the GoldSim model and used in the GIM, MicroShield and ERICA models, is designed to record the model parameters and support the development, testing and documentation of the model. The PVDS describes each parameter, explains why a given value has been selected and its scope of use, and records the source references. The PVDS includes a dedicated quality assurance sheet, containing a Review Form (RF) relevant to the current version of the spreadsheet, that documents the verification checks that have been made, the results of these and the actions that were taken in response.

620 As detailed in the PSP and RFs, the checks undertaken for each version of the PVDS include:

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55 www.erica-tool.com/about

- A check that all raw (hardcoded) data in the spreadsheet are appropriately referenced, have been correctly transferred from their original sources and are used appropriately.
- A sense check that all assumptions and inferences made in order to perform calculations within the spreadsheet (prior to upload into the GoldSim model) are appropriate, justified and fully documented.
- A comprehensive check of formulae and calculations. This includes a review of coding and formulae to ensure appropriate calculations are being undertaken and that they have been correctly implemented, with independent calculations being made where necessary.
- A review of spreadsheet organisation, supporting information and formatting to ensure clarity and transparency, with a focus on the cover sheet and all titles, comments, descriptions/explanations and references.

621 As required by the PSP, verification checks were carried out by a competent GSL staff member independent of the specific spreadsheet development process. Updates to the spreadsheet by the developer in response to verification checks were checked and signed off by the verifier and project manager. This process is documented in the RFs.

11.3.2 Model Verification

622 As with the PVDS, the Winfrith NE GoldSim model has undergone testing by a competent GSL staff member, who was independent of the GoldSim model development process. This has been undertaken to verify that the conceptual and mathematical construction of the model is as documented. This verification exercise checked the implementation of the model, mathematical expressions used, and calls to the input parameter spreadsheet. Updates to the spreadsheet by the developer in response to verification checks were reviewed and signed off by the tester and project manager. This process is documented in Model Verification Forms.

11.4 Model Run Management

623 The run management system records the details of each calculation or run that has been used to support the presentation and interpretation of the Winfrith NE assessment in this report. This enables each run to be repeated and the results to be reproduced. This is presented in Appendix H.

11.5 NRS Checks and Input

624 Throughout the process of developing the PA, NRS subject-matter experts have been consulted and involved to ensure that the parameter data used and assessment cases considered align with current understanding of decommissioning activities and optimisation plans, and that assumptions and inferences made are credible. Previous assessments and optimisation carried out by GSL between 2016 (draft GRR trial) and 2019 (assessment against issued 2018 GRR) have been used to inform the assessments reported here.

11.6 Peer Review

625 The development of this PA has built upon a multi-year programme of work initiated as part of a “lead and learn” exercise trialling the Draft GRR (the 2016 consultation document) and continued following formal issue of the GRR in 2018. This has included gaining feedback on the programme of work from those in the environment agencies who have been tasked with developing and planning the implementation of the GRR. In addition, this assessment itself is subject to independent peer review [151].

12 Summary and Conclusions

626 This report presents an assessment against the quantitative GRR Requirements of the potential radiological impacts arising from the proposed Winfrith on-site disposals once decommissioning activities are complete and the proposed end state for each radioactive feature has been implemented. The scope of this PA includes radiological impacts arising from:

- natural evolution of the disposals through aqueous release of radionuclides to areas where a representative person might become exposed in the future (GRR Requirements R9 and R10);
- direct external irradiation of a representative person where sub-surface contamination remains in-situ and undisturbed (GRR Requirements R9 and R10);
- inadvertent human intrusion and the subsequent exposure of a representative person to radioactivity (GRR Requirement R11);
- radiological impacts arising from natural disruptive processes which expose radioactive waste or contamination, or impair protective barriers (GRR Requirement R12); and
- radiological impacts to non-human biota (GRR Requirement R14).

627 Three radiological site features are considered in this assessment: the SGHWR; the Dragon reactor complex; and the OoS A59 area. Each feature comprises discrete contaminated structures or areas with an explicit inventory that are individually modelled. The two reactor buildings form the principal disposal structures, the below-ground voids of which will be filled with radioactive and non-radioactive wastes and then covered with engineered caps. The A59 area does not form part of the RSR permit application but has been included in the PA, albeit with a radiological inventory that is OoS of RSR, to ensure a robust transparent assessment.

628 The Reference Case calculations presented in this report assume a cautious, but credible, reference estimate for the radioactive inventory and activity concentrations of the features. The estimates are based on existing characterisation data, provenance information and/or cautious assumptions, depending on the availability of relevant information. The end state inventory is dominated by the SGHWR feature group (98% of the total radioactivity) over that of the Dragon reactor complex and OoS A59 area (around 1% each).

629 The identified gaps, uncertainties and assumptions in the inventory have been used to support derivation of alternative, more conservative, inventory estimates. The alternative inventory estimates assume the maximum, rather than average, characterisation data by default, but alternative assumptions have been made where there are other sources of uncertainty. The alternative inventory accounts for variations in possible fingerprints and radionuclide content, or contamination volume/surface area, for components where this is considered appropriate. A second alternative inventory, which considers a Pu-containing fingerprint for the Dragon B70 and B78 building general contamination is also assessed in a further variant case.

630 Understanding of the proposed disposals and the site, its environment and how it is expected to evolve in the long-term, as well as uncertainties in that knowledge, have been used to identify a set of alternative cases and variant scenarios that have been considered as appropriate in each of the following pathway assessments.

631 Assessment of natural disruptive processes on the site, such as erosion, flooding, earthquakes and climate change, has informed both the scenario and assessment case identification approach and development of the natural evolution assessment model. No natural processes that would disrupt the site and that would also lead to exposed radioactive materials have been identified. Where justified, the impact of natural disruptive processes on the disposals has been quantitatively assessed through the consideration of variant scenarios (e.g. the impact of a major earthquake) and the incorporation of processes into the natural evolution assessment conceptual models (e.g. groundwater level rises).

12.1 Natural Evolution Assessment

632 In the Reference Case assessment assuming the reference inventory and best estimate parameter values, the total calculated peak dose rates for all of the RPs resulting from natural evolution of the proposed on-site disposals are more than an order of magnitude below the dose rate equivalent of the GRR risk guidance level (1.7E-02 mSv y^{-1}). The highest peak dose rate (3.0E-04 mSv y^{-1} occurring around 56,800 years in the future) is associated with the Smallholder (Land/Mire) RP, who is assumed to reside, grow and consume vegetables and fruit, and raise and consume livestock, on land contaminated by groundwater releases from the SGHWR and OoS A59 area feature groups. Peak dose rates for the other RPs are up to five orders of magnitude lower than the peak Smallholder (Land/Mire) RP dose rate. All peak dose rates occur more than 50,000 years in the future except for the Mire Mudder and Construction Worker (Land/Mire) RPs, which occur after 50 years and are associated with A59 releases to the Land/Mire model compartment (but which have peak dose rates orders of magnitude lower than the Smallholder RP).

633 Dose rates are dominated by the ingestion of contaminated foodstuffs for all RPs that consider the ingestion exposure pathway. Dose rates for the Smallholder (Land/Mire) RP are primarily associated with the ingestion of foodstuffs contaminated with ^{90}Sr, ^{210}Pb, ^{226}Ra, ^{234}U and ^{238}U. Ingestion of animal foodstuffs and terrestrially-grown plants are the dominant contributors, but ingestion of contaminated aquatic plant foodstuffs (watercress) is a significant contributor.

634 Peaks in dose rates at early times are generally associated with ^{90}Sr, whilst later peaks tend to be associated with ^{210}Pb, ^{226}Ra and the actinides. However, some actinides contribute to peaks at early times and those are generally associated with releases from the OoS A59 area feature group. Differences in the timing of the peaks are associated with the half-life and near-field sorption potential of the dominant dose-contributing radionuclides, and the presence and degradation status of the concrete structures.

635 Of the three feature groups, the SGHWR is the dominant dose-contributing feature to the peak dose rate for all RPs except for the Mire Mudder and Construction Worker (Land/Mire) RPs, where the OoS A59 area feature group dominates. In the first 1,000 years the OoS A59 area feature group is the dominant contributor to dose rate for all RPs. The highest dose-

contributing individual features are generally SGHWR Region 1, the SGHWR South and North Annexes, and the A59 Other Areas feature.

636 The Reference Case is a deterministic assessment that considers the realistic or best estimate of the range of possible parameter values, where possible and appropriate, for comparison with the quantitative GRR requirements. To explore uncertainties in the natural evolution model, the effects of uncertainties have been considered through additional deterministic calculations: 18 alternative assessment cases, 18 variant scenarios and two "what-if" scenarios.

637 The 18 alternative assessment cases consider the potential effects of parameter uncertainty (including inventory uncertainty) on calculated dose rates by undertaking deterministic calculations assuming parameter values at the extremes of their ranges. The Smallholder (Land/Mire) RP continues to receive the highest dose rate of all the RPs, across every alternative assessment case considered. In all but one of the alternative assessment cases considered peak dose rates to all RPs remain below the dose rate equivalent of the RGL. The exception relates to biosphere food uptake factors, which specify what proportion of a radionuclide in water or soil will be taken up by a plant or animal foodstuff. The Reference Case considered best estimate food uptake factors for every radionuclide. In the alternative case that considers maximum values for foodstuff biosphere uptake factors, the peak dose rate for the Farmer and Smallholder RPs in the Land/Mire compartment exceeds the dose rate equivalent of the RGL by about a factor of about five after 1,000 years (peaking at 7.5E-02 mSv y^{-1} for the Smallholder RP). However, it is important to recognise that this calculation considers the extreme of the value range for every food product uptake factor for every radionuclide. In addition, these calculations assume that the RP scenarios occur; the probability of a smallholder living directly on the contaminated area in the future would be expected to be less than one. Whilst farming in the area is a probable activity, doing so on the contaminated area is less likely, as is assuming that the Farmer RP's entire meat and vegetable intake is contaminated. The results suggest that uncertainty in the following parameters could most influence dose rates: inventory; biosphere pathway food product uptake factors; radioelement partition coefficients for concrete, Poole Formation material, soil and sediment; and average annual outflow rates from the proposed mire to the River Frome.

638 The 18 variant scenarios considered in the Winfrith NE assessment can be split between the 13 that consider uncertainty in the conceptual model, including uncertainty in the future evolution of the proposed on-site disposals and their setting, and the five that consider uncertainty in the configuration of the features:

- In all but one of the variant concept scenarios, peak dose rates to all RPs remain below the dose rate equivalent of the RGL. Dose rates are highest for a Well Abstractor RP in the groundwater abstraction variant scenario, where an RP is assumed to abstract and consume groundwater released from a well 1 m down-gradient of each radioactive feature. The peak conditional dose for both the SGHWR and Dragon reactor complex Well Abstractor RPs is below the dose equivalent of the RGL for the entire assessment period. The modelled A59 area inventory satisfies RSR OoS criteria and this feature does not form part of the RSR permit application, but it was included as part of a robust assessment. The OoS A59 area feature peak dose rate exceeds the dose rate equivalent of the RGL by a factor of about two in the first 60 years after the SRS. However, the calculated conditional dose does not account for likelihood – the probability of drilling such a well and its use as a sole drinking source is low. Based on the number of wells in the region and the area of potential contamination between the A59 area and the River Frome, an annual probability of 1E-03 has been estimated. When multiplied with the calculated peak dose rate, this would greatly reduce the associated peak risk, falling to two orders of magnitude below the RGL.

- Of the other variant concept scenarios, which have peak dose rates less than the RGL, those with the most significant impact are seasonally fluctuating groundwater levels on top of the Reasonable Worst Case groundwater levels, and assuming the entire flow path from SGHWR and the OoS A59 area reaches the Land/Mire compartment.
- The five variant configuration scenarios considered (e.g. changing concrete block size, replacing blocks with rubble, or grouting all voids) have negligible impact on the peak dose rates for all RPs and dose rates to all RPs remain below the dose rate equivalent of the RGL.

639 The two "what-if" scenarios consider highly speculative situations that are not deemed to be credible future outcomes. As such, they do not reflect the general uncertainty in the evolution of the disposal system but can be used to bound worst-case events. The what-if cases are instantaneous hydraulic failure of the concrete structures from the start of disposal implementation (e.g. due to an earthquake) and extreme climate change with groundwater to 1 m below surface-level. In both of these scenarios, peak dose rates to all RPs remain below the dose rate equivalent of the RGL.

640 In summary, the Reference Case NE assessment results for all RPs are at least an order of magnitude beneath the Requirement R9 dose constraint and the dose equivalent of the Requirement R10 risk guidance level for the entire assessment period. Consideration of uncertainties in parameter values, conceptual uncertainties and disposal system configuration identifies the assumptions and processes that the system is most sensitive to. The variant scenario calculations that lead to higher dose rates are associated with low probability scenarios that combine conservative assumptions and values at the extreme of the identified parameter ranges.

12.2 Site Occupancy Assessment

641 Assessments of the potential dose impacts from site occupancy above on-site disposals on the Winfrith site in the years 2036 (the assumed site IEP date) and 2066 (the SRS date) have been made for the Reference Case and variant cases. Assessments have used MicroShield® and considered exposure of RPs to radioactivity as a result of walking a dog, camping and living in a caravan above buried structures (worst-case site occupancy scenarios). NRS will retain control over the site between the IEP and the SRS such that it would not be possible to live on the site; therefore, a caravan dweller receptor is not considered in the calculations at 2036, only those at 2066. In addition, the higher GRR source dose constraint Requirement R9 would apply prior to the SRS, but the calculated Reference Case doses are all below the lower dose equivalent of the RGL (Requirement R10) anyway.

642 The key results can be summarised as follows:

- For the Reference Case (which assumes the reference inventory and the following engineered cap/cover material thicknesses: SGHWR 4.0 m thick cap; Dragon reactor complex 3.8 m thick cap; and A59 0.5 m thick cover material) the calculated annual effective doses to all receptors are at least an order of magnitude below the dose rate equivalent of the RGL for all modelled features in 2036 and 2066.
- For alternative assessment cases that assume the more conservative alternative inventory, the calculated annual effective doses to all receptors are many orders of magnitude below the dose rate equivalent of the RGL for all modelled features in 2036 and 2066.
- Variant configuration cases have been considered to inform future optimisation of the engineered caps above the reactor structures and to assess the impact of uncertainty in the thickness of cover material above the OoS A59 area feature group. For variant cases that assume the reference inventory and a thinner layer of engineered cap or clean cover material:
  - The calculated annual effective doses to all RPs are many orders of magnitude below the dose rate equivalent of the RGL for the SGHWR and Dragon reactor complex structures in 2036 and 2066 for all cap thicknesses considered.
  - For the OoS A59 area features, calculated annual effective doses to the dog walker and camper RPs are below the dose rate equivalent of the RGL in 2036 and 2066 even if no cover material is assumed. Only when considering the unrealistic scenario of a caravan dweller lying horizontally for an entire year with no cover material directly above the remediated A591/HVA area in 2066 is a dose comparable to that of the RGL calculated. The ground survey that will be completed as part of the site closure process will ensure that there is appropriate clean cover material in place.

12.3 Inadvertent Human Intrusion Assessment

643 Assessments of the potential dose impacts from inadvertent human intrusion into the proposed Winfrith on-site disposals have been made using the NRS Generic Intrusion Methodology (GIM) tool. This considers exposure of intruders and the subsequent exposure of a representative person to radioactivity as a result of various stylised intrusion scenarios.

644 The Reference Case calculations assume that intrusion occurs in 2066 (when the SRS is reached) and consider the reference inventory and reference thickness for the engineered cap/cover material above each feature group. In cases where the GRR Requirement R11 dose guidance level is exceeded with these assumptions, further calculations have been undertaken at dates beyond 2066 to identify when the calculated dose falls below the dose guidance level.

645 The calculated doses are compared to the GRR Requirement R11 dose guidance level, which is specified as a range of around 3 mSv y^{-1} to around 20 mSv in total. Values towards the lower end of this range are applicable to prolonged exposures (for example, an infant living

on contaminated material), while values towards the upper end of the range are applicable only to transitory exposures (such as for workers excavating material).

646 Key points from the GIM intrusion calculations for the Reference Case are as follows:

- All doses from intrusions into all parts of the SGHWR feature group in 2066 are below the dose guidance level if the SGHWR mortuary tube residual inventory estimate is excluded. The largest doses arise from the large, deep excavations with the infant land user receiving the greatest dose.
- The SGHWR mortuary tubes contents do not form part of the end state and are planned to be removed, packaged and transported off-site prior to the IEP. There is significant uncertainty associated with the residual SGHWR mortuary tubes inventory estimate due to the inability to access them at this time. If the SGHWR mortuary tube residual inventory estimate is included in the intrusion calculations, then doses from the large, deep excavation and borehole array to infant land users are above the dose guidance level in 2066 in the Reference Case. For the large, deep intrusion, the dose falls below the dose guidance level by 2156. For the borehole array, the dose is below the dose guidance level by 2076. These results support the planned work to empty, clean and characterise this feature during decommissioning to better constrain, and optimise as appropriate, the residual inventory.
- All Reference Case intrusions into the Dragon reactor building in 2066 are below the dose guidance level. The largest doses arise from the large, deep excavations with the infant land user receiving the greatest dose. The assessed borehole arrays are considered to have a low probability due to the limited areal extent of features such as the PGPC spill and the Betalite store; however, these still result in doses significantly below the dose guidance level in 2066. All intrusions into the Dragon B78 building floor slab and the mortuary hole structure in 2066 are significantly below the dose guidance level.
- All intrusions in 2066 into the various parts of the A59 area are significantly below the dose guidance level. The largest doses for the A59 Other Areas and remediated A591/HVA area arise from large, shallow excavations with the infant land user receiving the greatest dose. Only small, shallow excavations were assessed for the remediated PSA/Pit 3 area and again the infant land user was found to receive the greatest dose.
- The receptor subject to the greatest dose is generally the infant via ingestion from land use and the dominant radionuclide dose contributor is typically ^{90}Sr.

647 Alternative assessment cases and variant configuration case calculations have been undertaken to consider: intrusion prior to 2066 (to inform optimisation of the SRS date); thinner cap/cover material thicknesses (to inform optimisation of the engineered caps and to consider uncertainty in the thickness of cover material above the OoS A59 area); and alternative inventory cases to consider the impact of uncertainty in the reference disposal inventory estimate. The key findings are as follows:

- None of the calculations undertaken result in a change to the overall conclusions for SGHWR, the Dragon reactor complex or the OoS A59 area. If the SGHWR mortuary tubes are excluded, all doses are below the dose guidance level in all cases.

If the SGHWR mortuary tubes residual inventory estimate is included, then doses from the large, deep excavation and borehole array to infant land users are above the dose guidance level value for prolonged exposures (3 mSv y^{-1}) for each variant case.

- Doses from borehole intrusions into SGHWR and the Dragon reactor building are insensitive to cap thickness due to the depth of the intrusion exceeding the depth of the cap and disposals combined for all cap thicknesses assessed. Doses from large, deep intrusions, boreholes and piles into the B78 building floor slab are insensitive to cap thickness for the same reason.
- Doses from large, deep intrusions, piles and boreholes into the OoS A59 area are insensitive to the thickness of cover material due to the depth of these intrusions exceeding the depth of the cover material and modelled feature combined for all cover material thicknesses assessed.

648 Therefore, subject to future characterisation and optimisation of the SGHWR mortuary tubes, the human intrusion calculations show that there is no need for a control period beyond 2066.

12.4 Non-human Biota Assessment

649 Assessments of potential dose to non-human biota have been made using the ERICA assessment tool (Version 2.0). A Tier 2 assessment was run against the most conservative default ERICA dose rate screening criterion of 10 µGy h^{-1}, with the full suite of ERICA reference organisms for the appropriate ecosystem, for three separate biosphere compartments: Field, Land/Mire and River Frome. The Land/Mire was modelled both as a terrestrial ecosystem and as a freshwater ecosystem, bounding the expected impacts. Several other conservatisms were built into the assessment, including the assumption that (in the absence of detailed ecological data) sensitive ecological receptors would be exposed to the maximum environmental media concentrations. This level of conservatism is considered appropriate in light of the proximity of statutory designations and notable habitats and species on and near to the site.

650 Tier 2 results are reported both as dose rates and as unitless Risk Quotient (RQ) values for each organism. Two RQ values are calculated: an expected value equal to the estimated total dose rate for each reference organism divided by the screening level, and a conservative RQ which multiplies the expected RQ by un uncertainty factor (UF). A UF of 3 tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential. When a UF of 3 or higher is used, Tier 2 conservative RQ values below one indicate that there is low probability that the estimated dose rate exceeds the screening dose rate and the risk to non-human biota can be considered to be trivial, based on analyses of effects data conducted to derive the ERICA screening dose rate.

651 The results from the Winfrith non-human biota assessment show that, for all organisms in all three compartments (Field, River Frome and Land/Mire, whether modelled as a freshwater or terrestrial ecosystem) and for both the reference and alternative inventories, estimated dose rates are below the 10 µGy h^{-1} screening criterion, and expected and conservative RQ values are at least an order of magnitude below one. The highest values

are seen in the Land/Mire compartment when modelled as a freshwater ecosystem, and the lowest values in the Field compartment.

652 The Tier 2 screening level is not exceeded in any case even with the assessment taking into account many conservatisms. These conservatisms include the assumption that peak media concentrations will occur at the same time for all radionuclides, the low screening dose rate, conservative alternative inventory estimate, and expected absence of some freshwater ecosystem organisms in a shallow, ephemeral mire during periods when it dries out entirely. Therefore, it is considered that the risk to non-human biota in all biosphere compartments is negligible for the assumed inventories and site end state configuration, and no further assessment is required.

12.5 Conclusion

653 Based on the results of the deterministic calculations reported here and comparison with the relevant quantitative GRR Requirements, this radiological performance assessment supports the conclusion that the Reference Case for the proposed on-site disposals will provide an appropriate degree of environmental safety, from the point of implementation of the end state for each radioactive feature to long after release of the site from RSR. Table 12.1 summarises the peak doses for each pathway for the Reference Case. The aqueous release results indicate that changing the infill concrete block or rubble proportions, or grouting the infill, has no notable impact and therefore puts no requirements, from a post-IEP radiological risk viewpoint, on the end state engineering and backfill optimisation. The human intrusion and site occupancy calculations favour thicker caps and additional ground cover but show that thinner caps would still comply with GRR Requirements. Calculational results also identify where future characterisation and clean-up should be prioritised.

Table 12.1: Summary of peak doses for each dose pathway for the Reference Case. Note only a subset of RPs are considered possible in the period of RSR while NRS retains direct control over the site.

Pathway	Period of RSR (2036 - 2066)				After RSR (2066 and beyond)				
	Peak dose (mSv y^{-1})	RP	Dominant nuclides	Relevant guidance level	Peak dose (mSv y^{-1})	Time of peak dose	RP	Dominant nuclides	Relevant guidance level[56]
SGHWR									
Natural evolution	1.4E-08 mSv y^{-1}	Smallholder (Field)	H-3	0.3 mSv y^{-1}	3.0E-04 mSv y^{-1}	56,800 y	Smallholder (Land/Mire)	Pb-210	0.017 mSv y^{-1}
Site Occupancy	6.0E-14 mSv y^{-1}	Dog walker	Eu-152	0.3 mSv y^{-1}	2.3E-13 mSv y^{-1}	Dose assessed at 2066	Caravan dweller	Eu-152	0.017 mSv y^{-1}
Inadvertent human intrusion	N/A	N/A	N/A	N/A	8.5E-02 mSv y^{-1} (exc. mortuary holes)	Dose assessed at 2066	Infant land user	Sr-90, H-3	3 mSv y^{-1}
Dragon Reactor Complex									
Natural evolution	2.0E-9 mSv y^{-1}	Smallholder (Field)	H-3	0.3 mSv y^{-1}	1.0E-06 mSv y^{-1}	51,100 y	Smallholder (Field)	Ac-227	0.017 mSv y^{-1}
Site Occupancy	5.5E-14 mSv y^{-1}	Dog walker	Th-232, Ra-226, Ra-228	0.3 mSv y^{-1}	1.1E-12 mSv y^{-1}	Dose assessed at 2066	Caravan dweller	Th-232	0.017 mSv y^{-1}
Inadvertent human intrusion	N/A	N/A	N/A	N/A	6.0E-01 mSv y^{-1}	Dose assessed at 2066	Infant land user	Sr-90	3 mSv y^{-1}
A59									
Natural evolution	3.6E-06 mSv y^{-1}	Smallholder (Field)	U-238	0.3 mSv y^{-1}	5.8E-05 mSv y^{-1}	45 y	Smallholder (Land/Mire)	Sr-90	0.017 mSv y^{-1}
Site Occupancy	9.5E-06 mSv y^{-1}	Dog walker	Cs-137	0.3 mSv y^{-1}	1.0E-04 mSv y^{-1}	Dose assessed at 2066	Caravan dweller	Cs-137	0.017 mSv y^{-1}

[56] As discussed in Section 2.1.1, the GRR Requirement R10 guidance level after the period of RSR is stated in terms of risk. In this table, a dose rate equivalent of the risk guidance level is presented, which is conditional on the assumption that the exposure is certain to occur.

Pathway	Period of RSR (2036 - 2066)				After RSR (2066 and beyond)				
	Peak dose (mSv y^{-1})	RP	Dominant nuclides	Relevant guidance level	Peak dose (mSv y^{-1})	Time of peak dose	RP	Dominant nuclides	Relevant guidance level[56]
Inadvertent human intrusion	N/A	N/A	N/A	N/A	4.1E-02 mSv y^{-1}	Dose assessed at 2066	Infant land user	Sr-90	3 mSv y^{-1}
Full site									
Natural evolution	3.6E-06 mSv y^{-1}	Smallholder (Field)	U-238	0.3 mSv y^{-1}	3.0E-04 mSv y^{-1}	56,800 y	Smallholder (Land/Mire)	Pb-210	0.017 mSv y^{-1}

13 References

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Appendix A Uncertainties Assessment/Assumptions and Gaps

A1 Table A.1 summarises the safety-related uncertainties identified in the development of this report proposed for inclusion in the NRS Uncertainties Management Database (UMD). Uncertainties and gaps listed here are not modelling assumptions; however, they may result in a modelling assumption being required or amended. Uncertainties listed below relate directly to information required for the modelling approach. More detailed uncertainties surrounding the inventory and site characteristics are presented in the relevant reports and are not restated here. The systematic consideration and treatment in this PA of all relevant identified uncertainties (both those identified during PA development as in the table below, and those from relevant strands of previous work including the Radiological Inventory, Site Description and Conceptual Site Model (CSM) reports) is presented in Table C.8.

Table A.1: Uncertainties identified during development of the Winfrith PA. Superseded references refer to those listed in the Phase 2 PA report. Relevant uncertainties that originate from other documents (such as the Radiological Inventory Report, Site Description Report, CSM Report) are not included in this table; however, uncertainties reported in the CSM that originate from the Phase 2 PA (i.e. have PA-XXX-000 reference numbers) are included, with updated reference numbers.

GSL Reference No.	GSL Reference No. of Superseded Uncertainty	Feature, Event or Process subject to Uncertainty	Description of Uncertainty	Treatment of Uncertainty / Statement of Assumption	Originator's Rating of Potential Significance/ Impact (H/M/L)	Originator's Recommended Action
PA-001	PA-Approach-007	Radionuclide screening	The radionuclides assessed in the PA natural evolution model are based on the Winfrith End State Radiological Inventory Report, with those that cannot contribute significantly to future radiological impacts (due to, for example, being present with low activities and/or having short half-lives) screened out. The impact of screening out radionuclides on calculated doses is uncertain. The GIM tool used in the human intrusion model does not include all radionuclides in the screened list for the natural evolution model; the impact of this on calculated doses is uncertain.	The uncertainty in the natural evolution model is tolerated, as it is expected that screened-out radionuclides would not make a significant contribution and the overall impact would be minimal. The uncertainty in the human intrusion model is tolerated because it is not possible to add additional radionuclides to GIM. See Table C.8.	Low	Review if Radiological Inventory Report is updated, or if more radionuclides become available in future versions of GIM.
PA-002	PA-Approach-005 PA-Approach-006	Decommissioning timescales	Winfrith decommissioning timescales (including dates of the IEP and SRS) are uncertain and may be revised.	Cautious modelling and consideration of alternative assessment cases to determine the potential impact of the uncertainty – see Table C.8.	Low	None: potential impact considered through alternative assessment cases.
PA-003	PA-SGHWR-008 PA-Dragon-009	All radioactive source areas in the decommissioned facility	The inventory, materials, and water associated with the facility are not distributed homogeneously in the PA source areas. This is partly because the decommissioned facilities will retain some structure, but also due to the nature of backfilling operations and the distribution of inventory on the engineered structures and backfill material. Localised features could have a significant impact on processes such as aqueous chemistry, activity release, sorption and flows.	Cautious modelling – see Table C.8. Remaining uncertainty in natural evolution model tolerated as not expected to be significant. Explicit consideration of localised features that represent areas of elevated activity in human intrusion and site occupancy models.	Low	None: conservative approach used.
PA-004	PA-SGHWR-007 PA-Dragon-008	Sorption properties in the near field	There are limited site-specific data to describe the sorption properties of the cement-based materials in the SGHWR and Dragon reactor.	Consideration of alternative assessment cases to determine the potential impact of the uncertainty – see Table C.8.	Low	None: potential impact considered through alternative assessment cases.
PA-005	-	Radionuclide solubility	The role of solubility in limiting radionuclide transport in the near field is uncertain.	Cautious modelling with no solubility limitation – see Table C.8.	Low	None: due to the relatively low activity of the proposed on-site disposals, they are not expected to be solubility limited.
PA-006	-	Chemical degradation of concrete, grout, cap	The evolution of chemical properties associated with the in-situ structures, any grouted demolition arisings, and the engineered cap are uncertain.	Consideration of a variant scenario to determine the potential impact of the uncertainty – see Table C.8.	Low	None: cautious alternative chemical degradation approach modelled in a variant scenario.
PA-007	PA-SGHWR-005 PA-Dragon-006	Release of radionuclides from source areas	The release mechanisms that will act within the SGHWR and Dragon reactor source areas are uncertain. A variety of mechanisms and rates of release are possible, depending on the nature and location of the activity (activation- or	Cautious modelling assuming diffusion only towards advective flows, and	Low	None: conservative approach used.

GSL Reference No.	GSL Reference No. of Superseded Uncertainty	Feature, Event or Process subject to Uncertainty	Description of Uncertainty	Treatment of Uncertainty / Statement of Assumption	Originator's Rating of Potential Significance/ Impact (H/M/L)	Originator's Recommended Action
			contaminated-induced; on the surface or within the solid matrix), and localised chemical conditions.	instantaneous release following saturation – see Table C.8.		
PA-008	-	Hydraulic properties of intact concrete and rubble demolition arisings	The density and hydraulic conductivity of intact concrete (in-situ structures, concrete block infill and grout monolith infill) and demolition arisings placed in the SGHWR and Dragon reactor voids as rubble backfill is uncertain.	Consideration of variant scenarios to determine the potential impact of the uncertainty in density, porosity, and hydraulic conductivity – see Table C.8.	Low	None: potential impact considered through alternative assessment cases (where relevant).
PA-009	-	Integrity of in-situ structures	The potential for the integrity of the existing structures to be compromised by a natural disruptive event is uncertain.	Consideration of a "what-if" scenario to determine the potential impact of the uncertainty – see Table C.8.	Low	None: such an event is believed to be highly unlikely and its impact is considered through the "what-if" scenario.
PA-010	PA-SGHWR-001 PA-SGHWR-003 PA-SGHWR-006 PA-Dragon-001 PA-Dragon-004 PA-Dragon-007	Availability of water and flows within the facility	Flows through the SGHWR and Dragon reactor complex structures are uncertain and will change with time; in particular, the water level over time (reflecting the balance between infiltration through the cap and leakage through the walls/floor) is uncertain. Although initial modelling has shown that bathtubbing of void spaces above the water table (which could occur if inflows exceed outflows for a prolonged period) is unlikely, it cannot be entirely ruled out.	Consideration of variant scenarios and a "what-if" scenario to determine the potential impact of the uncertainty – see Table C.8.	Medium	None: potential impact considered through variant and "what-if" scenarios.
PA-011	-	Degree of homogenisation of demolition arisings used as backfill within each reactor complex	It is uncertain whether the demolition arisings from specific components (e.g. bioshield) will be emplaced separately in local voids or whether there will be mixing of the arisings from different components of each reactor complex (and to what degree) before emplacement in the voids.	Cautious modelling assuming that demolition arisings from individual components are emplaced separately in local voids – see Table C.8.	Low	None: conservative approach used.
PA-012	PA-SGHWR-009	Groundwater release locations (SGHWR)	Groundwater from the SGHWR is expected to reach both the River Frome and the Land/Mire compartment. Under some conditions, groundwater may also flow towards the Dragon reactor complex. There is uncertainty regarding the distribution of flow over the range of possible pathways, particularly for assumptions about a wetter future climate. The extent of the proposed mire may be subject to further optimisation when implemented at the end state.	Consideration of variant scenarios to determine the potential impact of the uncertainty – see Table C.8.	Medium	Potential impact considered through variant scenarios, but future versions of RMP to be monitored to check mire assumptions are conservative.
PA-013	-	Groundwater release locations (A59)	Groundwater from the A59 area is expected to reach both the River Frome and the Land/Mire compartment. There is uncertainty over the proportion reaching each location under different conditions, and also uncertainty over the location and extent of the mire.	Consideration of variant scenarios to determine the potential impact of the uncertainty – see Table C.8.	Medium	Potential impact considered through variant scenarios, but future versions of RMP to be monitored to check mire assumptions are still conservative.
PA-014	PA-Dragon-010	Groundwater release locations (Dragon)	Groundwater from the Dragon reactor structures is expected to reach the River Frome. However, groundwater modelling of the Winfrith end state suggests there could be releases to marshy land near to the Frome in the future.	The uncertainty is tolerated as such land is considered to be an extension of the river. Additionally, the Park User RP accounts for doses received via the interaction of river water with adjacent land. See Table C.8.	Low	Potentially consider modelling this in a future iteration of the PA.
PA-015	-	Groundwater levels	The impact of seasonally fluctuating groundwater into the SGHWR Annexes and Dragon reactor basement is uncertain.	Consideration of variant scenario to determine the potential impact of the uncertainty – see Table C.8.	Medium	None: potential impact considered through variant scenarios.
PA-016	-	Sorption in the geosphere/biosphere	There are limited/no site-specific data to describe the sorption properties of the Winfrith site geosphere and biosphere elements (soil, mire sediments, fluvial sediments).	Consideration of alternative assessment cases to determine the potential impact of the uncertainty – see Table C.8.	Low	None: potential impact considered through alternative assessment cases

GSL Reference No.	GSL Reference No. of Superseded Uncertainty	Feature, Event or Process subject to Uncertainty	Description of Uncertainty	Treatment of Uncertainty / Statement of Assumption	Originator's Rating of Potential Significance/ Impact (H/M/L)	Originator's Recommended Action
PA-017	-	Heathland fire	Heathlands have a high risk of fire; as the planned end state for the Winfrith site is heathland, the possibility of a significant fire cannot be ruled out.	The uncertainty is tolerated on the basis that its impact is likely to be bounded by pathways already considered – see Table C.4 and Table C.8.	Low	None: the impact of such an event is considered to be bounded by pathways already considered.
PA-018	-	Groundwater abstraction	As groundwater abstraction via wells is an observed present-day habit in the wider area, the possibility of such a well in the future intersecting contaminated groundwater cannot be ruled out. If this were to happen close to any of the source terms it could potentially lead to an RP receiving a relatively significant dose.	Consideration of variant scenarios to determine the potential impact of the uncertainty – see Table C.8.	Medium	None: potential impact considered through variant scenarios.
PA-019	-	Age of RPs	The age of the RPs receiving doses via the pathways identified in Appendix C.2 is uncertain.	Consideration of alternative assessment cases to determine the potential impact of the uncertainty – see Table C.8.	Low	None: potential impact considered through alternative assessment cases
PA-020	-	Uptake of contaminants into the food chain	There is significant uncertainty in the uptake factors controlling the transfer of contaminants from model compartments into foodstuffs consumed by animals or RPs.	Consideration of alternative assessment cases to determine the potential impact of the uncertainty – see Table C.8.	Low	None: potential impact considered through alternative assessment cases
PA-021	-	Geometry of structures	There are various uncertainties in the geometry of structures in both the SGHWR and Dragon reactor complex; both those that will form in-situ disposals and those that will be demolished and used to fill voids (DfaP). These include: • The SGHWR and Dragon bioshields do not have a reported plan area; the effective calculated area is used in the PA instead. • For the Dragon reactor, there is a discrepancy in that the reported plan area calculated from the Wall A exterior diameter is smaller than if the void infill volume were divided by the height, implying there is a discrepancy in at least one of the dimensions. However, this difference is small and is neglected in the PA. • For the Dragon B78 floor slab, there is a discrepancy between the thickness indicated on engineering drawings and that calculated based on the floor slab area and in-situ volume supplied by NRS. The latter is used in the PA. • Simplified assumptions are used for the contaminated layer thicknesses of individual features. These are set out in full in the Appendix D.2.4; simplifications are always conservative.	The uncertainty is tolerated on the basis that its impact is likely to be minimal (see details for individual uncertainties to left and Table C.8), but will be kept under review.	Low	Review treatment of uncertainty if significant changes to the geometry assumed in this PA are identified in future.
PA-022	-	Geometry simplification in MicroShield®	MicroShield® includes built in source (radioactively contaminated/activated structure) geometries. These geometries are simple rectangular, cylindrical and conical volumes. Structures at the Winfrith sites have more complex geometries but have been simplified/approximated to allow for modelling to be carried out. The impact of this simplification on site occupancy doses is uncertain.	The uncertainty is tolerated on the basis that its impact is likely to be minimal in comparison to the uncertainties in radiological inventory and thickness of contaminated/activated layers, but will be kept under review (as per Table C.8).	Low	Review treatment of uncertainty if significant changes to the geometry assumed in this PA are identified in future.
PA-023	-	Mire outflow	There is uncertainty in the average annual rate of outflow from the mire to the River Frome.	Consideration of alternative assessment cases to determine the potential impact of the uncertainty – see Table C.8.	Medium	None: potential impact considered through alternative assessment cases.
PA-024	-	Separate modelling of features	The Winfrith assessment separately models each feature within the on-site disposals and thus assumes there are no interactions between the features that could give rise to situations (radionuclide fluxes or concentrations) for RPs higher than the appropriate sum of those from the individual features.	The uncertainty is tolerated on the basis that the approach is adopted specifically to understand the impacts from the heterogenous distribution of radioactivity across disparate parts of the site – see Table C.8. Combination of releases from	Low	None: approach deliberately adopted to help inform prioritisation of future radiological characterisation and design optimisation.

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				individual sources in the geosphere and biosphere is accounted for in the NE model.		
PA-025	-	Integrity of Dragon Wall A	It is uncertain whether Wall A of the Dragon reactor building can be considered to offer a barrier to groundwater flow as, being a conventional concrete structure, it is expected to crack during end state implementation.	Cautious modelling assumes that Wall A will offer no barrier to groundwater flow after the IEP – see Table C.8.	Low	None: conservative approach used.
PA-026	-	A59 cover	It is uncertain how much clean cover material is/will be emplaced over ground contamination in the A59 area.	Consideration of variant configuration scenarios to determine the potential impact of the uncertainty – see Table C.8.	Medium	None: potential impact considered through alternative assessment cases.
PA-027	-	Groundwater emergence points to each location	Contaminated groundwater is likely to emerge at several points across the same feature, particularly after artificial drainage ceases to operate, thereby diluting the impact calculated for a single location. Distinct groundwater flow pathways from different feature groups may also enter the River Frome at different points.	Cautious modelling assuming that all of the groundwater emerges at a single place to a surface water feature or piece of land, and that the distinct groundwater flow pathways from all feature groups join the River Frome at the same point	Low	None: conservative approach used.

Appendix B Radionuclide Screening

B.1 Natural Evolution Radionuclide Screening

B1 The Radiological Inventory Report [152] indicates that 60 radionuclides are expected to be present in the radioactive end state features on the Winfrith site, encompassing SGHWR, the Dragon reactor complex and A59 at 1 January 2027. These radionuclides are presented in Table B.1(a). Table B.1(b) presents a longer list of the inventory radionuclides augmented with decay chain progeny, totalling 117 radionuclides. Many of these radionuclides are present with low activities and/or have short half-lives, such that they cannot contribute significantly to future radiological impacts. It is good practice and efficient to screen out radionuclides of lesser importance, enabling effort to be targeted at obtaining data for a sub-set of potentially significant radionuclides. Radionuclide screening was undertaken using the criteria described below. Decay chain diagrams encompassing the 117 identified radionuclides are presented in Figure B.1 to Figure B.6, with colour-coding indicating those radionuclides screened in or out, while Table B.3 provides additional detail about each radionuclide and its screening result.

B2 For the purposes of the natural evolution model, radionuclides with a half-life less than one year (365.25 days) are considered to be short lived and thus were excluded as follows:

- Short-lived daughter radionuclides in secular equilibrium with a longer-lived parent do not need to be explicitly accounted for, as aggregated dose coefficients for the parent radionuclide can also implicitly account for its short-lived progeny. Table B.2 identifies daughters considered to be in secular equilibrium with their parent radionuclide, as well as their respective decay chains and branching ratios; or
- Short-lived radionuclides that decay to a stable daughter (possibly via intermediate short-lived daughters). Many more than ten half-lives will have elapsed prior to any releases from the disposals via the groundwater pathway. The highest individual contribution to total activity in the inventory from these short-lived radionuclides (after ten half-lives) is only 933 Bq from ^{57}Co. As such, the activity contribution from short-lived radionuclides is considered to be negligible.

B3 Extremely long-lived radionuclides are considered to be effectively stable when their half-lives are greater than the age of the Earth (>1×10^{14} years). Thus, any such radionuclides have been screened out as they are not relevant to the timescale of interest in the PA. This includes ^{113}Cd and the daughters of ^{152}Eu (^{152}Gd, ^{148}Sm and ^{144}Nd).

B4 Radionuclides with a very low overall contribution to the inventory were also screened out. Radionuclides calculated to have a maximum activity concentration less than 1% of the out-of-scope values listed in the Environmental Protection Regulations 2016 (as amended in 2018) [153; 154], which do not also possess a parent radionuclide in the inventory, were excluded. Radionuclides excluded on this basis were ^{252}Cf and its daughter isotopes ^{248}Cm, ^{244}Pu, ^{240m}Np, ^{240}Np and ^{240}U. Potassium-40 is excluded under the same legislation as a radionuclide of natural terrestrial origin, which has not been deliberately processed on the Winfrith site. The noble gas radionuclides ^{39}Ar and ^{85}Kr were screened out from the LLWR safety assessment [155] due to their low impact. Argon-39 is calculated to be present only in the SGHWR bioshield, while ^{85}Kr is calculated to only be present in the SGHWR mortuary tubes in the alternative scenario estimate. Given their small contribution to the SGHWR end state total activity (0.27% and 0.00032%, respectively, at 01/01/2027) and the fact that they are estimated to be present with less or comparable activity than in the LLWR vaults (the Winfrith inventory is approximately 0.2 times that of the LLWR inventory for ^{39}Ar in the Reference Case, and more than 7,700 times smaller for ^{85}Kr), they have been screened out of the Winfrith PA.

B5 The remaining 51 radionuclides, shown unshaded in Table B.1(b), have been retained and are explicitly included in the natural evolution PA model. The radionuclides retained in the model account for 99.5% of the SGHWR reference inventory and effectively 100% of the Dragon reactor complex and OoS A59 area reference inventories.

B6 The impact of this radionuclide screening on calculated doses is noted as an uncertainty (PA-001).

Table B.1: Screened list of radionuclides considered in the PA. Part (a) lists radionuclides reported in the Winfrith end state inventory [152]. Part (b) augments the inventory radionuclides with those present in the relevant decay chains. Colour-coding: blue shading indicates exclusion from the PA based on short half-life (< 1 yr); orange represents radionuclides in secular equilibrium with their parents and which are accounted for using aggregated dose coefficients for the parent radionuclide; green indicates those excluded due to an extremely long half-life (>1x10^{14} yr) and purple indicates radionuclides excluded due to their low impact (either out of scope (<1% EPR16 OoS values) and have no parent present in the inventory or are noble gases with low inventory).

A) Radionuclides reported in the Winfrith end state inventory		b) Radionuclides in (a) augmented with decay chain progeny			
H-3	Hf-178n	H-3	Sm-148	Po-215	Pa-234
C-14	Pt-193	C-14	Sm-151	Po-216	Pa-234m
Cl-36	Tl-204	Cl-36	Eu-152	Po-218	U-233
Ar-39	Pb-210	Ar-39	Eu-154	At-217	U-234
K-40	Po-210	K-40	Eu-155	At-218	U-235
Ca-41	Ra-226	Ca-41	Gd-152	At-219	U-235m
Fe-55	Ra-228	Fe-55	Hf-178m	Rn-217	U-236
Co-57	Ac-227	Co-57	Hf-178n	Rn-218	U-237
Co-60	Th-228	Co-60	Pt-193	Rn-219	U-238
Ni-59	Th-229	Ni-59	Tl-204	Rn-220	U-240
Ni-63	Th-230	Ni-63	Tl-207	Rn-222	Np-237
Kr-85	Th-232	Kr-85	Tl-208	Fr-221	Np-239
Sr-90	Pa-231	Sr-90	Tl-209	Fr-223	Np-240
Zr-93	U-233	Y-90	Tl-210	Ra-223	Np-240m
Nb-93m	U-234	Zr-93	Pb-209	Ra-224	Pu-238
Nb-94	U-235	Nb-93m	Pb-210	Ra-225	Pu-239
Tc-99	U-236	Nb-94	Pb-211	Ra-226	Pu-240
Cd-113m	U-238	Tc-99	Pb-212	Ra-228	Pu-241
Sn-121m	Np-237	Cd-113	Pb-214	Ac-225	Pu-242
Sb-125	Pu-238	Cd-113m	Bi-210	Ac-227	Pu-244
I-129	Pu-239	Sn-121	Bi-211	Ac-228	Am-241
Cs-134	Pu-240	Sn-121m	Bi-212	Th-227	Am-243
Cs-137	Pu-241	Sb-125	Bi-213	Th-228	Cm-242
Ba-133	Pu-242	Te-125m	Bi-214	Th-229	Cm-243
Sm-148	Am-241	I-129	Bi-215	Th-230	Cm-244
Sm-151	Am-243	Cs-134	Po-210	Th-231	Cm-248
Eu-152	Cm-242	Cs-137	Po-211	Th-232	Cf-252
Eu-154	Cm-243	Ba-133	Po-212	Th-234	
Eu-155	Cm-244	Ba-137m	Po-213	Pa-231	
Gd-152	Cf-252	Nd-144	Po-214	Pa-233	

Table B.2: Short-lived daughters considered to be in secular equilibrium with their parents for the purposes of the PA. Branching ratios were taken from ICRP Publication 107 [156]. Minor branches (<10^{-5}) are not reported. The full decay chains are presented in Figure B.1 to Figure B.6.

Parent	**Secular equilibrium daughters and their branching ratios**													
Sr-90	Y-90	1.00E+00												
Sn-121m	Sn-121	7.76E-01												
Sb-125	Te-125m	2.31E-01												
Cs-137	Ba137m	9.44E-01												
Hf-178n	Hf-178m	1.00E+00												
Pb-210	Bi-210	1.00E+00	Po-210	1.00E+00										
Ra-226	Rn-222	1.00E+00	Po-218	1.00E+00	Pb-214	1.00E+00	Bi-214	1.00E+00	Po-214	1.00E+00				
									Tl-210	2.10E-04				
					At-218	2.00E-04	Bi-214	9.99E-01	Po-214	1.00E+00				
									Tl-210	2.10E-04				
							Rn-218	1.00E-03	Po-214	1.00E+00				
Ac-227	Th-227	9.86E-01	Ra-223	1.00E+00	Rn-219	1.00E+00	Po-215	1.00E+00	Pb-211	1.00E+00	Bi-211	1.00E+00	Tl-207	9.97E-01
													Po-211	2.76E-03
	Fr-223	1.38E-02	Ra-223	1.00E+00	Rn-219	1.00E+00	Po-215	1.00E+00	Pb-211	1.00E+00	Bi-211	1.00E+00	Tl-207	9.97E-01
													Po-211	2.76E-03
			At219	6.00E-05	Bi-215	9.70E-01	Po-215	1.00E+00	Pb-211	1.00E+00	Bi-211	1.00E+00	Tl-207	9.97E-01
													Po-211	2.76E-03
					Rn-219	3.00E-02	Po-215	1.00E+00	Pb-211	1.00E+00	Bi-211	1.00E+00	Tl-207	9.97E-01
													Po-211	2.76E-03
Ra-228	Ac-228	1.00E+00												
Th-228	Ra-224	1.00E+00	Rn-220	1.00E+00	Po-216	1.00E+00	Pb-212	1.00E+00	Bi-212	1.00E+00	Po-212	6.41E-01		
											Tl-208	3.59E-01		

Parent	Secular equilibrium daughters and their branching ratios													
Th-229	Ra-225	1.00E+00	Ac-225	1.00E+00	Fr-221	1.00E+00	At-217	1.00E+00	Bi-213	1.00E+00	Po-213	9.79E-01	Pb-209	1.00E+00
											Tl-209	2.09E-02	Pb-209	1.00E+00
									Rn-217	1.20E-04	Po-213	1.00E+00	Pb-209	1.00E+00
U-235	Th-231	1.00E+00												
U-238	Th-234	1.00E+00	Pa-234m	1.00E+00	Pa-234	1.60E-03								
Np-237	Pa-233	1.00E+00												
Pu-239	U-235m	9.99E-01												
Pu-241	U-237	2.45E-05												
Am-243	Np-239	1.00E+00												

Table B.3: Radionuclide data for the full list of 117 radionuclides developed from the 60 radionuclides reported in the Winfrith end state radiological inventory (including the alternative inventory scenarios) [152] and augmented with decay chain progeny radionuclides. Colour-coding: blue indicates exclusion on the basis of short half-life (< 1 yr); orange radionuclides are assumed to be in secular equilibrium and are accounted for with their parents; green indicates exclusion due to an extremely long half-life (>1x10^{14} yr); and purple indicates radionuclide exclusion due to low impact. Half-lives, branching ratios and decay chain data are from ICRP Publication 107 [156], unless indicated otherwise. Minor branches (those with branching ratios <10^{-5}) are not reported, neither is decay via spontaneous fission (this is a minor decay route for some of the heavier radionuclides such as ^{252}Cf). Note that some of the branching ratios do not sum to exactly one, due to rounding and uncertainties in the data, but the maximum impact of this is 0.006% error in the branching ratios.

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
H-3	1.23E+01	He-3	1.00E+00	Yes						
C-14	5.70E+03	N-14	1.00E+00	Yes						
Cl-36	3.01E+05	Ar-36	9.81E-01	Yes	S-36	1.90E-02	Yes			
Ar-39	2.69E+02	K-39	1.00E+00	Yes						Neglect initial inventory on the basis of low impact and exclude nuclide.
K-40	1.25E+09	Ca-40	8.91E-01	Yes	Ar-40	1.09E-01	Yes			Excluded on the basis of natural terrestrial origin and not processed on site (categorised as low impact).
Ca-41	1.02E+05	K-41	1.00E+00	Yes						
Fe-55	2.74E+00	Mn-55	1.00E+00	Yes						
Co-57	7.44E-01	Fe-58	1.00E+00	Yes				SL		Neglect initial inventory and exclude as short-lived; decays straight to stable.
Co-60	5.27E+00	Ni-60	1.00E+00	Yes						
Ni-59	1.01E+05	Co-59	1.00E+00	Yes						
Ni-63	1.00E+02	Cu-63	1.00E+00	Yes						
Kr-85	1.08E+01	Rb-85	1.00E+00	Yes						Neglect initial inventory on the basis of low impact and exclude nuclide.
Sr-90	2.88E+01	Y-90	1.00E+00						Y-90	
Y-90	7.31E-03	Zr-90	1.00E+00	Yes				SL		Assume in secular equilibrium with parent Sr-90.
Zr-93	1.53E+06	Nb-93m	9.75E-01		Nb-93	2.50E-02	Yes			

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
Nb-93m	1.61E+01	Nb-93	1.00E+00	Yes						
Nb-94	2.03E+04	Mo-94	1.00E+00	Yes						
Tc-99	2.11E+05	Ru-99	1.00E+00	Yes						
Cd-113	7.70E+15	In-113	1.00E+00	Yes						Excluded as an extremely long-lived isotope (>1E14 y).
Cd-113m	1.41E+01	In-113	9.99E-01	Yes	Cd-113	1.40E-03				
Sn-121	3.08E-03	Sb-121	1.00E+00	Yes				SL		Assume in secular equilibrium with parent Sn-121m.
Sn-121m	4.39E+01	Sn-121	7.76E-01		Sb-121	2.24E-01	Yes		Sn-121	
Sb-125	2.76E+00	Te-125m	2.31E-01		Te-125	7.69E-01	Yes		Te-125m	
Te-125m	1.57E-01	Te-125	1.00E+00	Yes				SL		Assume in secular equilibrium with parent Sb-125.
I-129	1.57E+07	Xe-129	1.00E+00	Yes						
Cs-134	2.06E+00	Ba-134	1.00E+00	Yes						Minor (3E-6) branch to Xe-134 is excluded. Xe-134 also has an extremely long half-life (6E22 y).
Cs-137	3.02E+01	Ba137m	9.44E-01		Ba-137	5.60E-02	Yes		Ba-137m	
Ba-133	1.05E+01	Cs-133	1.00E+00	Yes						
Ba-137m	4.85E-06	Ba-137	1.00E+00	Yes				SL		Assume in secular equilibrium with parent Cs-137.
Nd-144	2.29E+15	Ce-140	1.00E+00	Yes						Excluded as an extremely long-lived isotope (>1E14 y).
Sm-148	7.00E+15	Nd-144	1.00E+00	Yes						Excluded as an extremely long-lived isotope (>1E14 y).
Sm-151	9.00E+01	Eu-151	1.00E+00	Yes						
Eu-152	1.35E+01	Gd-152	2.79E-01		Sm-152	7.21E-01	Yes			
Eu-154	8.59E+00	Gd-154	1.00E+00	Yes	Sm-154	2.00E-04	Yes			
Eu-155	4.76E+00	Gd-155	1.00E+00	Yes						
Gd-152	1.08E+14	Sm-148	1.00E+00							Excluded as an extremely long-lived isotope (>1E14 y).
Hf-178m	1.27E-07	Hf-178	1.00E+00	Yes				SL		Assume in secular equilibrium with Hf-178n. Half-life and decay path data taken from NNDC ENSDF NuDat database (https://www.nndc.bnl.gov/, accessed 06/06/23).

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
Hf-178n	3.10E+01	Hf-178m	1.00E+00						Hf-178m	Note that the state is labelled as Hf-178m in ICRP107, but the notation indicating that the 31 y state is labelled Hf-178n is used here. Decay path data taken from NNDC ENSDF NuDat database (https://www.nndc.bnl.gov/, accessed 06/06/23).
Pt-193	5.00E+01	Ir-193	1.00E+00	Yes						
Tl-204	3.78E+00	Pb-204	9.71E-01	Yes	Hg-204	2.90E-02	Yes			
Tl-207	9.07E-06	Pb-207	1.00E+00	Yes				SL		Assume in secular equilibrium with Ac-227 (via Th-227, Ra-223, Rn-219, Po-215, Fr-223, At-219, Bi-215, Pb-211, Bi-211).
Tl-208	5.80E-06	Pb-208	1.00E+00	Yes				SL		Assume in secular equilibrium with Th-228 (via Ra-224, Rn-220, Po-216, Pb-212, Bi-212).
Tl-209	4.11E-06	Pb-209	1.00E+00					SL		Assume in secular equilibrium with Th-229 (via Ra-225, Ac-225, Fr-221, At-217, Bi-213).
Tl-210	2.47E-06	Pb-210	1.00E+00					SL		Assume in secular equilibrium with Ra-226 (via Rn-222, Po-218, Pb-214, At-218, Bi-214).
Pb-209	3.71E-04	Bi-209	1.00E+00	Yes				SL		Assume in secular equilibrium with Th-229 (via Ra-225, Ac-225, Fr-221, At-217, Rn-217, Bi-213, Po-213, Tl-209).
Pb-210	2.22E+01	Bi-210	1.00E+00						Bi-210, Po-210	Minor decay branch to Hg-206 (1.9E-8) is neglected.
Pb-211	6.86E-05	Bi-211	1.00E+00					SL		Assume in secular equilibrium with Ac-227 (via Th-227, Ra-223, Rn-219, Po-215, Fr-223, At-219, Bi-215).
Pb-212	1.21E-03	Bi-212	1.00E+00					SL		Assume in secular equilibrium with Th-228 (via Ra-224, Rn-220, Po-216).
Pb-214	5.10E-05	Bi-214	1.00E+00					SL		Assume in secular equilibrium with Ra-226 (via Rn-222, Po-218).
Bi-210	1.37E-02	Po-210	1.00E+00					SL		Assume in secular equilibrium with parent Pb-210. Minor decay branch to Tl-206 (1.32E-06) ignored.

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
Bi-211	4.07E-06	Tl-207	9.97E-01		Po-211	2.76E-03		SL		Assume in secular equilibrium with Ac-227 (via Th-227, Ra-223, Rn-219, Po-215, Fr-223, At-219, Bi-215, Pb-211).
Bi-212	1.15E-04	Po-212	6.41E-01		Tl-208	3.59E-01		SL		Assume in secular equilibrium with Th-228 (via Ra-224, Rn-220, Po-216, Pb-212).
Bi-213	8.67E-05	Po-213	9.79E-01		Tl-209	2.09E-02		SL		Assume in secular equilibrium with Th-229 (via Ra-225, Ac-225, Fr-221, At-217).
Bi-214	3.78E-05	Po-214	1.00E+00		Tl-210	2.10E-04		SL		Assume in secular equilibrium with Ra-226 (via Rn-222, Po-218, Pb-214).
Bi-215	1.44E-05	Po-215	1.00E+00					SL		Assume in secular equilibrium with Ac-227 (via Fr-223, At-219).
Po-210	3.79E-01	Pb-206	1.00E+00	Yes				SL		Assume in secular equilibrium with Pb-210 (via Bi-210).
Po-211	1.64E-08	Pb-207	1.00E+00	Yes				SL		Assume in secular equilibrium with Ac-227 (via Th-227, Ra-223, Rn-219, Po-215, Fr-223, At-219, Bi-215, Pb-211, Bi-211).
Po-212	9.47E-15	Pb-208	1.00E+00	Yes				SL		Assume in secular equilibrium with Th-228 (via Ra-224, Rn-220, Po-216, Pb-212, Bi-212).
Po-213	1.33E-13	Pb-209	1.00E+00					SL		Assume in secular equilibrium with Th-229 (via Ra-225, Ac-225, Fr-221, At-217, Rn-217, Bi-213).
Po-214	5.21E-12	Pb-210	1.00E+00					SL		Assume in secular equilibrium with Ra-226 (via Rn-222, Po-218, At-218, Pb-214, Bi-214, Rn-218).
Po-215	5.64E-11	Pb-211	1.00E+00					SL		Assume in secular equilibrium with Ac-227 (via Th-227 / Fr-223, Ra-223, Rn-219).
Po-216	4.59E-09	Pb-212	1.00E+00					SL		Assume in secular equilibrium with Th-228 (via Ra-224, Rn-220).
Po-218	5.89E-06	Pb-214	1.00E+00		At-218	2.00E-04		SL		Assume in secular equilibrium with Ra-226 (via Rn-222).
At-217	1.02E-09	Bi-213	1.00E+00		Rn-217	1.20E-04		SL		Assume in secular equilibrium with Th-229 (via Ra-225, Ac-225, Fr-221). ICRP107 shows 99.988% decay

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
										from At-217 to Bi-213; the remaining fraction is identified as decay to Rn-217 using NNDC NuDat (accessed 06/06/23).
At-218	4.75E-08	Bi-214	9.99E-01		Rn-218	1.00E-03		SL		Assume in secular equilibrium with Ra-226 (via Rn-222, Po-218).
At-219	1.77E-06	Bi-215	9.70E-01		Rn-219	3.00E-02		SL		Assume in secular equilibrium with Ac-227 (via Fr-223). ICRP107 shows 97% decay from At-219 to Bi-215; the remaining 3% is identified as decay to Rn-219 using NNDC NuDat (accessed 06/06/23).
Rn-217	1.71E-11	Po-213	1.00E+00					SL		Assume in secular equilibrium with Th-229 (via Ra-225, Ac-225, Fr-221, At-217).
Rn-218	1.11E-09	Po-214	1.00E+00					SL		Assume in secular equilibrium with Ra-226 (via Rn-222, Po-218, At-218).
Rn-219	1.25E-07	Po-215	1.00E+00					SL		Assume in secular equilibrium with Ac-227 (via Th-227 / Fr-223, Ra-223).
Rn-220	1.76E-06	Po-216	1.00E+00					SL		Assume in secular equilibrium with Th-228 (via Ra-224).
Rn-222	1.05E-02	Po-218	1.00E+00					SL		Assume in secular equilibrium with parent Ra-226.
Fr-221	9.32E-06	At-217	1.00E+00					SL		Assume in secular equilibrium with Th-229 (via Ac-225, Ra-225).
Fr-223	4.18E-05	Ra-223	1.00E+00		At219	6.00E-05		SL		Assume in secular equilibrium with parent Ac-227.
Ra-223	3.13E-02	Rn-219	1.00E+00					SL		Assume in secular equilibrium with Ac-227 (via Th-227 / Fr-223).
Ra-224	1.00E-02	Rn-220	1.00E+00					SL		Assume in secular equilibrium with parent Th-228.
Ra-225	4.08E-02	Ac-225	1.00E+00					SL		Assume in secular equilibrium with parent Th-229.
Ra-226	1.60E+03	Rn-222	1.00E+00						Rn-222, Po-218, Pb-214, Bi-214, Tl-210, At-218, Rn-218, Po-214	Minor decay branch to Pb212 excluded.
Ra-228	5.75E+00	Ac-228	1.00E+00						Ac-228	

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
Ac-225	2.74E-02	Fr-221	1.00E+00					SL		Assume in secular equilibrium with Th-229 (via Ra-225).
Ac-227	2.18E+01	Th-227	9.86E-01		Fr-223	1.38E-02			Th-227, Fr-223, Ra-223, Rn-219, Po-215, At-219, Bi-215, Pb-211, Bi-211, Tl-207, Po-211	
Ac-228	7.02E-04	Th-228	1.00E+00					SL		Assume in secular equilibrium with parent Ra-228.
Th-227	5.11E-02	Ra-223	1.00E+00					SL		Assume in secular equilibrium with parent Ac-227.
Th-228	1.91E+00	Ra-224	1.00E+00						Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208, Po-212	
Th-229	7.34E+03	Ra-225	1.00E+00						Ra-225, Ac-225, Fr-221, At-217, Bi-213, Rn-217, Po-213, Tl-209, Pb-209	
Th-230	7.54E+04	Ra-226	1.00E+00							
Th-231	2.91E-03	Pa-231	1.00E+00					SL		Assume in secular equilibrium with parent U-235.
Th-232	1.41E+10	Ra-228	1.00E+00							
Th-234	6.60E-02	Pa-234m	1.00E+00					SL		Assume in secular equilibrium with parent U-238.
Pa-231	3.28E+04	Ac-227	1.00E+00							
Pa-233	7.38E-02	U-233	1.00E+00					SL		Assume in secular equilibrium with parent Np-237.
Pa-234	7.64E-04	U-234	1.00E+00					SL		Assume in secular equilibrium with U-238 (via Th-234, Pa-234m).
Pa-234m	2.22E-06	U-234	9.98E-01		Pa-234	1.60E-03		SL		Assume in secular equilibrium with U-238 (via Th-234).
U-233	1.59E+05	Th-229	1.00E+00							

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
U-234	2.46E+05	Th-230	1.00E+00							
U-235	7.04E+08	Th-231	1.00E+00						Th-231	
U-235m	4.94E-05	U-235	1.00E+00					SL		Assume in secular equilibrium with parent Pu-239.
U-236	2.34E+07	Th-232	1.00E+00							
U-237	1.85E-02	Np-237	1.00E+00					SL		Assume in secular equilibrium with parent Pu-241.
U-238	4.47E+09	Th-234	1.00E+00						Th234, Pa-234m, Pa-234	Minor spontaneous fission decay route is ignored.
U-240	1.61E-03	Np-240m	1.00E+00					SL		Excluded as low impact – no initial inventory and head of chain excluded based on low impact (concentration < 1% of EPR OoS value). Short-lived and assumed to be in secular equilibrium with parent Pu-244.
Np-237	2.14E+06	Pa-233	1.00E+00						Pa-233	
Np-239	6.45E-03	Pu-239	1.00E+00					SL		Assume in secular equilibrium with parent Am-243.
Np-240	1.18E-04	Pu-240	1.00E+00					SL		Excluded as low impact – no initial inventory and head of chain excluded based on low impact (concentration < 1% of EPR OoS value). Short-lived and assumed to be in secular equilibrium with parent Pu-244 (via U-240).
Np-240m	1.37E-05	Pu-240	9.99E-01		Np-240	1.10E-03		SL		Excluded as low impact – no initial inventory and head of chain excluded based on low impact (concentration < 1% of EPR OoS value). Short-lived and assumed to be in secular equilibrium with parent Pu-244 (via U-240).
Pu-238	8.77E+01	U-234	1.00E+00							Minor spontaneous fission decay route is ignored.
Pu-239	2.41E+04	U-235m	9.99E-01		U-235	6.00E-04			U-235m	
Pu-240	6.56E+03	U-236	1.00E+00							Minor spontaneous fission decay route is ignored.
Pu-241	1.44E+01	Am-241	1.00E+00		U-237	2.45E-05			U-237	
Pu-242	3.75E+05	U-238	1.00E+00							Minor spontaneous fission decay route is ignored.
Pu-244	8.00E+07	U-240	9.99E-01						U-240, Np-240m, Np-240	Excluded as low impact – no initial inventory and parent excluded based on low impact (concentration <

Nuclide	Half-life (yr)	Daughter 1	Branching Ratio 1	Decay straight to stable?	Daughter 2	Branching Ratio 2	Decay straight to stable?	Short-lived (<365.25 days)	Secular equilibrium daughters	Comment
										1% of EPR OoS value). Spontaneous fission decay route is ignored.
Am-241	4.32E+02	Np-237	1.00E+00							
Am-243	7.37E+03	Np-239	1.00E+00						Np-239	
Cm-242	4.46E-01	Pu-238	1.00E+00					SL		Excluded as a very short-lived isotope and no inventory of parent Am-242m is reported. Minor spontaneous fission decay route is ignored.
Cm-243	2.91E+01	Pu-239	9.98E-01		Am-243	2.40E-03				
Cm-244	1.81E+01	Pu-240	1.00E+00							Minor spontaneous fission decay route is ignored.
Cm-248	3.48E+05	Pu-244	9.16E-01							Excluded as low impact – no initial inventory and parent excluded based on low impact (concentration < 1% of EPR OoS value). Spontaneous fission decay route is ignored.
Cf-252	2.65E+00	Cm-248	9.97E-01							Excluded as low impact – maximum concentration < 1% of EPR OoS value and no parent present in the inventory. Spontaneous fission decay route is ignored.

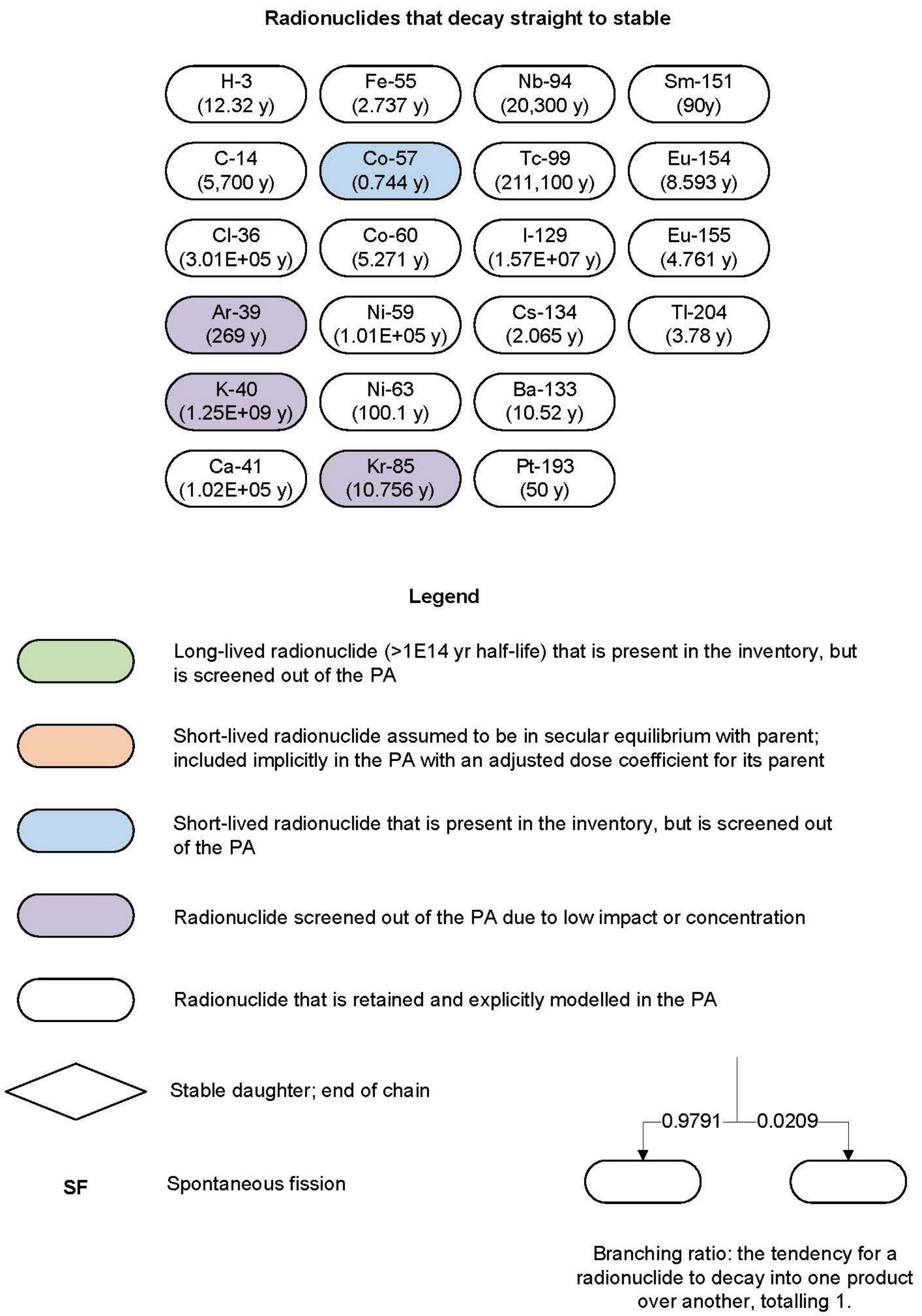

Figure B.1: Schematic of radionuclides considered in the Winfrith PA radionuclide screening analysis that decay straight to table (top), and a legend (bottom) for decay chains presented subsequently (Figure B.2 to Figure B.6).

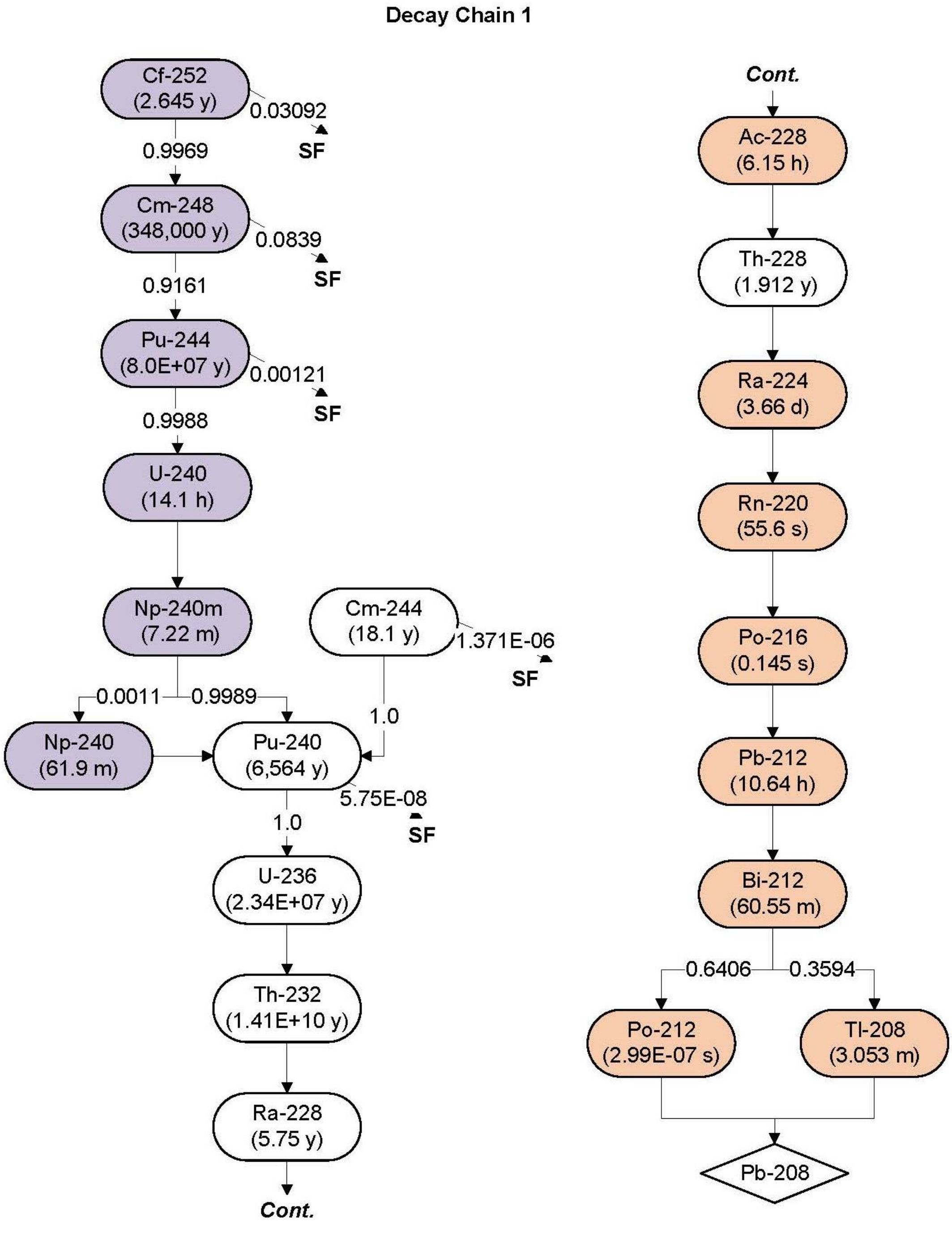

Figure B.2: Decay chain of ^{252}Cf and associated daughter nuclides considered in the Winfrith PA radionuclide screening analysis.

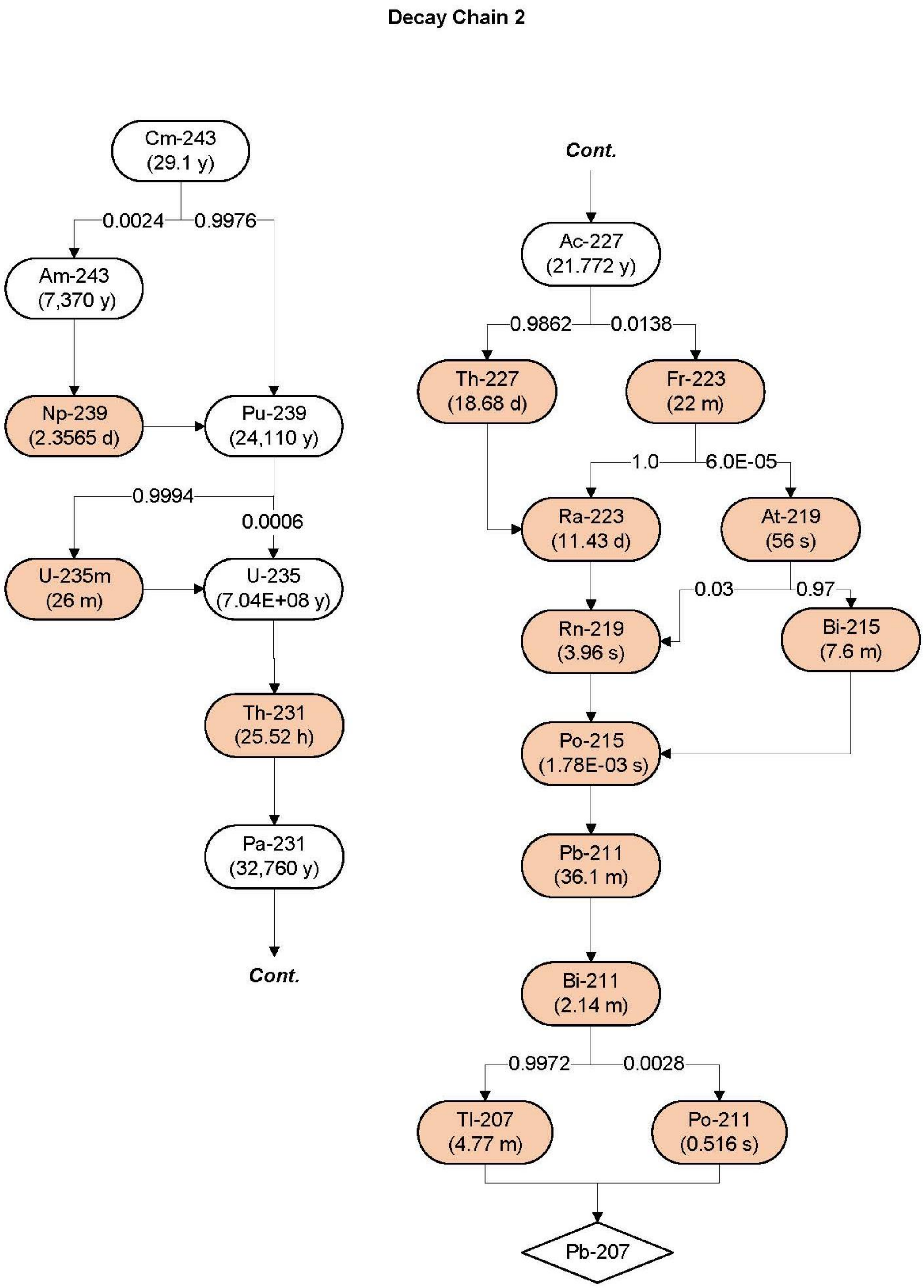

Figure B.3: Decay chain of ^{243}Cm and associated daughter nuclides considered in the Winfrith PA radionuclide screening analysis.

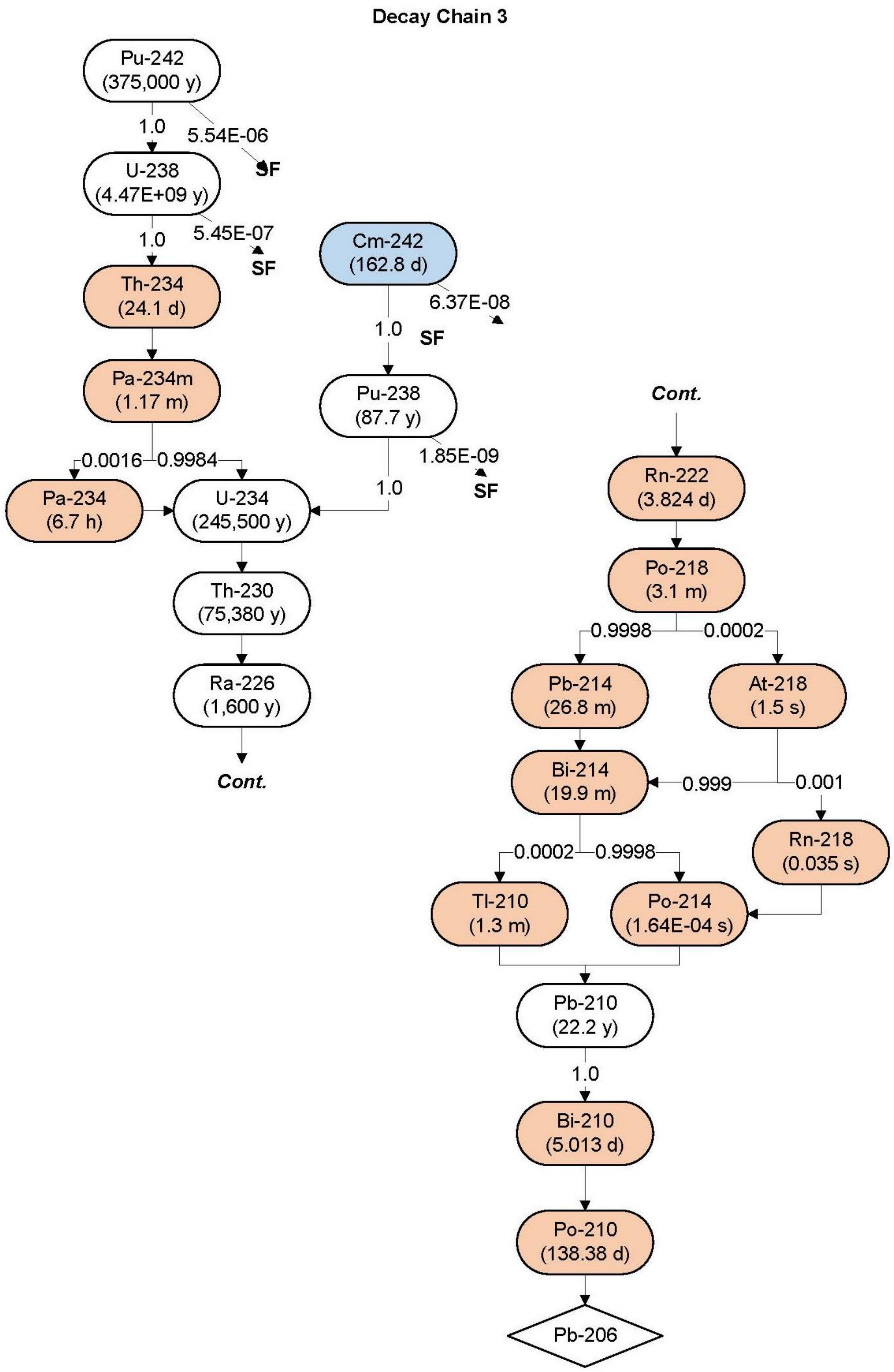

Figure B.4: Decay chain of ^{242}Pu and associated daughter nuclides considered in the Winfrith PA radionuclide screening analysis.

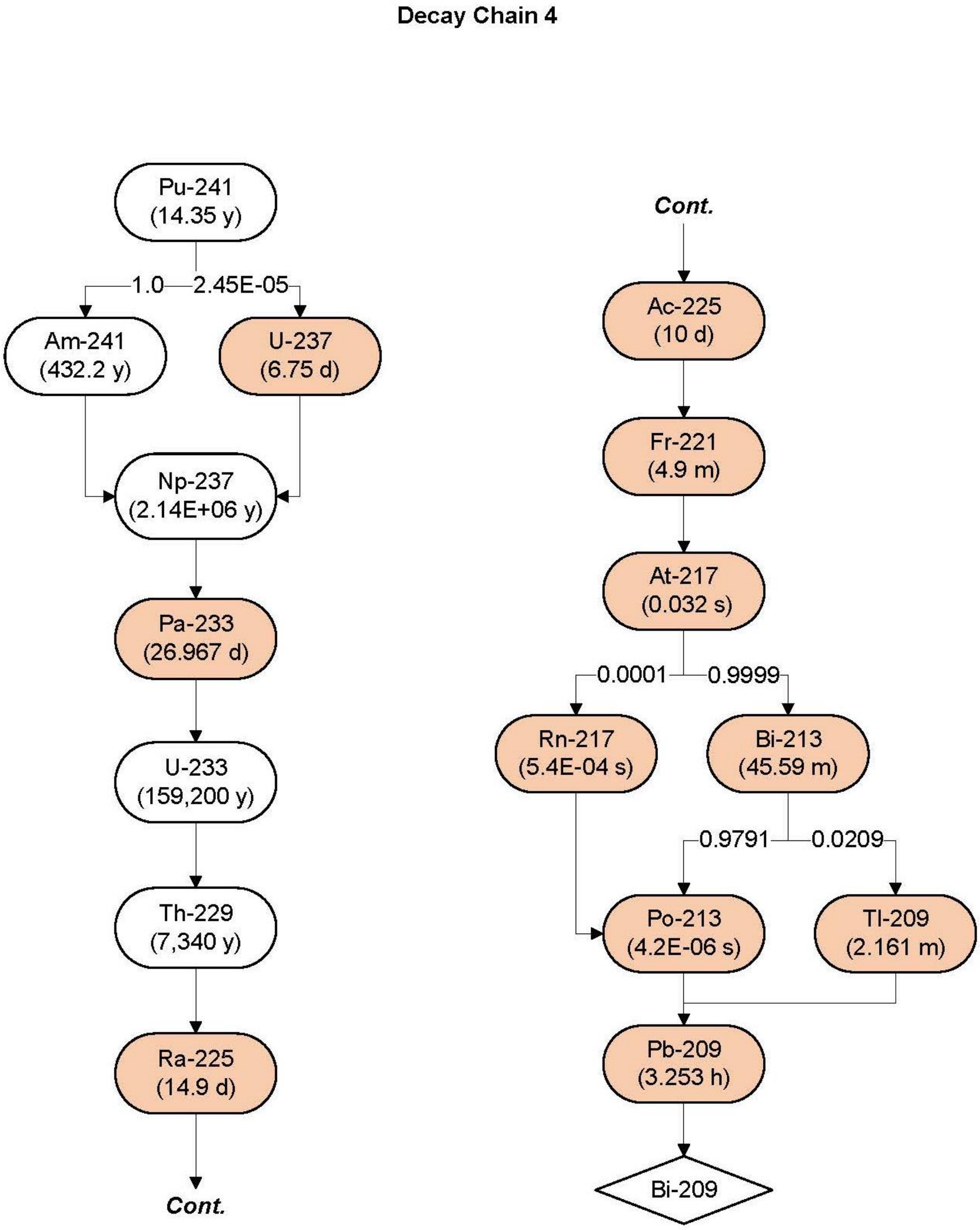

Figure B.5: Decay chain of ^{241}Pu and associated daughter nuclides considered in the Winfrith PA radionuclide screening analysis.

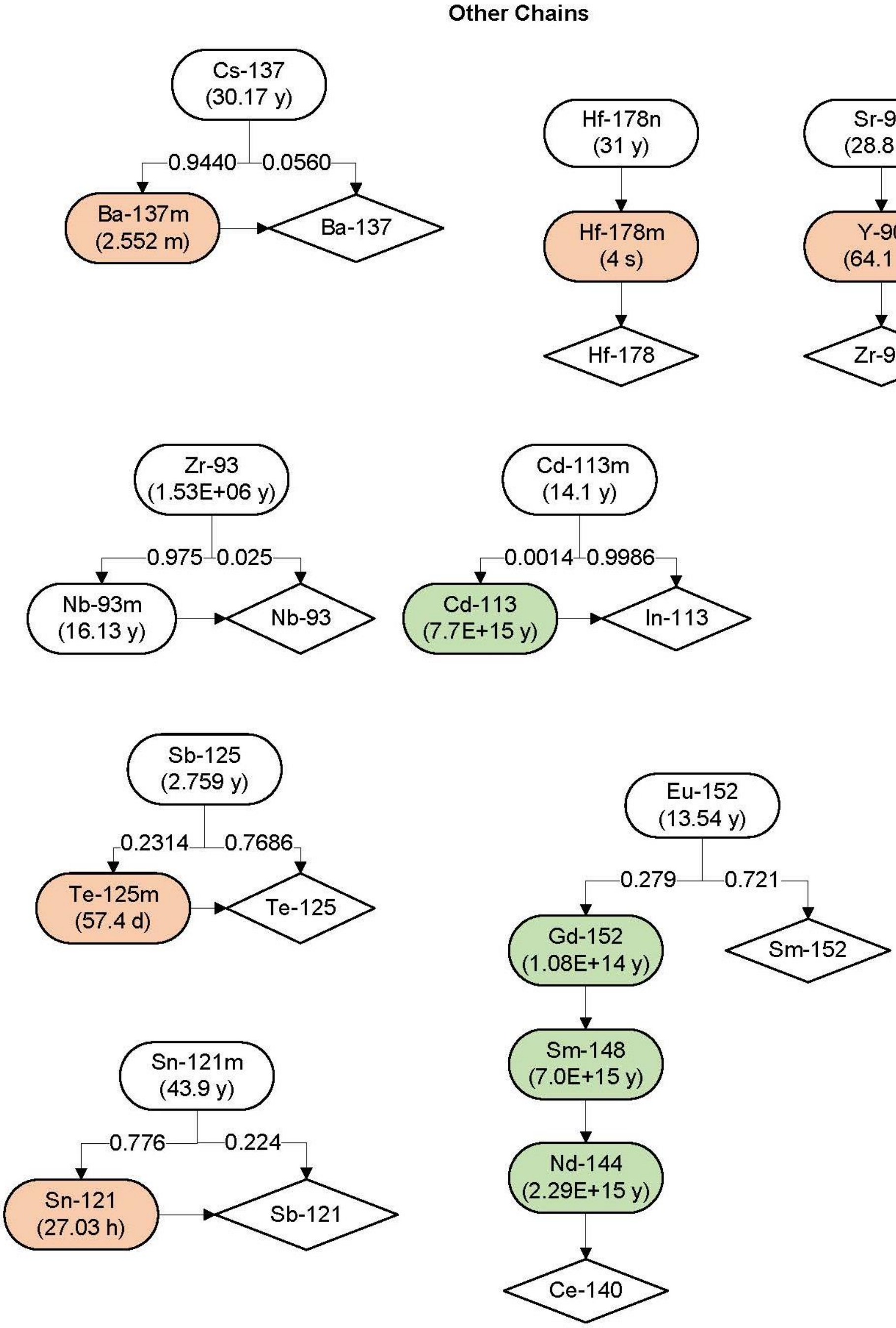

Figure B.6: Short decay chains and associated daughter nuclides considered in the Winfrith PA radionuclide screening analysis.

B.2 Human Intrusion Radionuclide Screening

B7 The Generic Intrusion Tool (GIM) [157] used to undertake the human intrusion calculations (as discussed in Sections 7 and 10.5) supports assessment of the following 18 radionuclides:

H-3, C-14, Cl-36, Ca-41, Fe-55, Co-60, Ni-59, Ni-63, Sr-90, Y-90, Cs-137, Eu-152, Eu-154, Pu-238, Pu-239, Pu-240, Pu-241 and Am-241.

B8 Radionuclides were selected based on the most significant radionuclides anticipated to be present in candidate material for on-site disposal at NRS sites.

B9 Of these radionuclides, 17 are included in the screened list of radionuclides to be modelled in the Winfrith natural evolution assessment. Yttrium-90 is not explicitly included in the natural evolution assessment as it is assumed to be in secular equilibrium with its parent ^{90}Sr (i.e. ^{90}Y is not modelled explicitly, but exposure to ^{90}Y is accounted for with exposure to its parent ^{90}Sr).

B10 The radionuclides that are modelled in GIM represent 97.5% of the total Winfrith radiological end state reference inventory. Of this, only 79.8% of the OoS A59 area reference inventory (and only 76.1% when considering the A59 Other Areas reference inventory) is covered by GIM, primarily because the uranium isotopes form a larger fraction of the A59 inventory (19.9%) compared with SGHWR and Dragon (less than 1% for each), yet uranium isotopes are not included in GIM. The impact of this missing inventory in the human intrusion assessment is considered in Section 10.5.1 and is noted as an uncertainty (PA-001).

B11 Radioactive decay and ingrowth is included in the natural evolution modelling (see Sections 5 and 10) by specifying the parent-daughter chains (as detailed in Table B.3). Decay is captured in the GIM model by specification of the input inventory activity, and the impact of ingrowth is captured in a few cases in the dose coefficients used (the dose coefficients consider a period of 100 years ingrowth).

B.3 References

152 GSL, *Winfrith Site: End State Radiological Inventory*, Galson Sciences Ltd and NNL, NRS Reference ES(19)P281, GSL Report 1624-10, Version 2, December 2024.

153 TSO, *The Environmental Permitting (England and Wales) Regulations 2016* (S.I. 2016/1154), The Stationery Office Limited, December 2016.

154 TSO, *The Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018* (S.I. 2018/428), The Stationery Office Limited, March 2018.

155 LLWR, *The 2011 Environmental Safety Case, Assessment of Long-term Radiological Impacts*, LLWR/ESC/R(11)10028, May 2011.

156 ICRP, *Nuclear Decay Data for Dosimetric Calculations*, International Commission on Radiological Protection, Publication 107, Ann. ICRP 38 (3), 2008.

157 Eden, *Generic Intrusion Methodology (GIM) for Radiological Assessment of Nuclear Site End States: GIMv2.1.3*, Eden Nuclear and Environment, Report ENE-0174/B15/2022/D1, Issue 1.4, March 2022.

Appendix C Scenario and Assessment Case Identification

C.1 Approach to Scenario Development

C.1.1 International Guidance

C1 The key objectives of scenario development are to [158]:

- Demonstrate completeness or sufficiency in the scope of an assessment.
- Decide which FEPs to include in an assessment and how to treat them.
- Provide traceability from data and information to the assessment scenarios, models, parameter values, and assessment cases.
- Promote transparency and improve understanding of the assessment and the associated results.
- Guide decisions concerning future work.

C2 Two methods of scenario development are promoted by the IAEA [159, ¶5.40] and NEA [160, §5.3], although there is considerable overlap between them:

- "Bottom-up" development based on screening of FEPs. For this approach, a comprehensive list of FEPs is developed as a starting point. This may involve the use of generic FEP lists (from internationally agreed lists, for example NEA [161], or regulatory guidance) that can be adapted to consider site- and system-specific FEPs. This is followed by a screening process to exclude FEPs from further consideration that would have either a very small impact on the disposal system or a very low probability of occurrence. For the relevant FEPs, a thorough examination of interactions between them and their combination within suitable scenarios is performed. This approach was promoted by the IAEA Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM) project [162] and has been used in the development of scenarios for UK near-surface disposal facility assessments.
- "Top-down" development, based on analyses of how the safety functions of the disposal system may be affected by safety-relevant uncertainties. Safety functions describe the long-term functioning of the disposal concept and its components in support of environmental safety. Such top-down functional systems analysis, which may involve derivation of hierarchical failure modes, may be followed by a process of auditing the scenarios developed against an appropriate FEP list. Approaches similar to this have been employed in the development of scenarios for European waste disposal facilities (e.g. SFR [163]).

C3 International guidance [159, ¶5.42] notes that, regardless of the method used for developing the scenarios, all FEPs that could significantly influence the performance of the disposal system should be addressed. It should be shown that all potentially significant migration pathways from the facility have been considered and that possible evolutions of the system have been taken into account.

C.1.2 Approach Taken in This Assessment

C4 In this PA for the Winfrith site, four types of scenarios are defined. These and their relationship to underlying assessment cases are as follows:

- A single ***"expected evolution" scenario***, encompassing:
  - The *"reference" assessment case (henceforth called the Reference Case)*, considering the expected evolution (as described in Section 3) of the Winfrith site as based on current understanding of the proposed on-site disposals, site characteristics and the surrounding region, and its robust model implementation. The reference case includes both natural evolution of the site and a range of appropriate inadvertent human intrusion and site occupancy activities.
  - *"Alternative" assessment cases*, investigating the impact of parameter uncertainty in the reference assessment case. Each alternative assessment case investigates the effect of varying a single parameter or a set of related parameters.
- Several ***"variant configuration" scenarios***, which investigate potential options for the configuration of the proposed on-site disposals, including in-situ, backfill and engineered components. *Each variant configuration scenario typically consists of a single assessment case.*
- Several ***"variant concept" scenarios***, which investigate uncertainty in the conceptual model, including different interpretations of climate change. *Each variant concept scenario typically consists of a single assessment case*. While all variant concept scenarios are considered credible, each has a different probability of occurrence.
- Several ***"what-if" scenarios***, which are not considered to represent likely evolutions and do not reflect general system uncertainty but can be used to explore the system response to hypothetical events and situations, including extreme climate change. *Each "what-if" scenario typically consists of a single assessment case*.

C5 For this Winfrith PA, a "top-down" approach has been used, as summarised in Figure 4.1. This approach aligns with international best practice guidance (Section C.1.1) and is analogous to that used in the natural evolution assessment for the Trawsfynydd Ponds Complex in 2023 [164]. It draws on experience gained through previous GRR work for NRS and ESC development for UK near-surface disposal facilities.

C6 The scenario development process outlined in in Figure 4.1 has four steps:

1) Identification of relevant dose pathways (Section C.2). This is undertaken based on the requirements of the GRR [165] and an understanding of the system description, such as the configuration of the proposed on-site disposals, the

associated radiological inventory, and the characteristics of the Winfrith site and surrounding region. In this assessment, relevant dose pathways are identified for the following circumstances:

- Site occupancy (direct irradiation from buried contamination with no intrusion).
- Natural (passive) evolution of the site, including pathways involving groundwater and gas.
- Natural disruptive events, including pathways involving seismicity, erosion, and flooding.
- Groundwater abstraction via a well.
- Human intrusion directly into radioactive waste.

2) Definition of the key environmental safety functions (Section C.3) provided by the near field of the proposed on-site disposals, the geosphere and the biosphere, for the relevant dose pathways. As with Step 1, these are defined based on an understanding of the system description.

3) This step consists of two main tasks:

   - Consideration of how safety-related uncertainties (as identified and recorded during the development of GRR-related documentation, including this PA, as per the NRS GRR Uncertainties Management Methodology (UMM)) [166] could affect the key environmental safety functions provided by the near field of the proposed on-site disposals, the geosphere and the biosphere (Section C.4).
     - For each uncertainty a treatment is defined that is based on the expected impact of the uncertainty on the associated environmental safety function.
     - For a sub-set of the uncertainties, treatment is best achieved through definition of one or more assessment cases and/or scenarios that can be used to assess possible impact, such as end members to bracket the variation, or using alternative assumptions. For the remaining uncertainties, alternative treatment approaches can be employed, such as toleration or cautious parameterisation/modelling (or planning of work to reduce uncertainty, which is not within the scope of this report).
   - Identification of a set of bounding scenarios capturing current uncertainty in the configuration of the proposed on-site disposals. This is undertaken through review of possible design variations that have been identified as part of optimisation of the Winfrith end state.

The output of these two tasks is a set of scenarios, and underlying assessment cases[57], that captures all current uncertainty in both the configuration of proposed on-site disposals and in the conceptual model, as well as unlikely but hypothetically possible worst-case evolutions. These are presented in Section C.4.2.

4) Comparative review of the set of scenarios and assessment cases against:

   - Assessment cases considered in the ESCs of other UK near-surface disposal facilities [167; 168].
   - The Dounreay Low Level Waste (LLW) FEP List [169, Appendix 1]. Whilst this list was developed specifically for Dounreay LLW disposal facilities, it outlines all the FEPs presented in the NEA International FEP List[58] [170] and the ISAM FEP List [162].

   Through this step, any gaps in the initial set of assessment cases are identified and a final set defined.

C7 Sections C.2 to C.5 describe and present the results of Steps 1, 2, 3 and 4 of the scenario and assessment case identification approach, respectively.

C.2 Identification of Relevant Dose Pathways

C8 A "dose pathway" is to the route through which representative persons (RPs) and/or other receptors potentially receive a radiation dose. Three overarching dose pathways through which RPs could be exposed to a dose have been identified:

- **Direct radiation from a source**. This occurs when RPs occupy or use the site (for residential, occupational or recreational purposes), and is considered in Section C.2.2.
- **Migration of radionuclides from a source**. This occurs when radionuclides travel and are released to the accessible environment where RPs are exposed, via the migration of either groundwater (aqueous release) or gas (gaseous release). These are both considered under the assessment of natural evolution (Section C.2.3).
  - Exposure of RPs via abstraction of groundwater from a well also occurs as a result of radionuclide migration. This is considered separately (Section C.2.4) because it does not occur only as a consequence of natural evolution but also requires human action (that does not fall into the category of intrusion directly into radioactive waste).

[57] See Section 4.1 for definitions of the different types of scenarios and assessment cases, and the relationships between them used in this assessment.

[58] Note that the NEA International FEP list has since been updated; the latest issue, Version 3, was published in 2019 [161]. However, it is noted in Version 3 that near-surface disposal is beyond the scope of the list [161,§1.2], which is not the case for Version 1 [170, Table 3].

- **Disruption of a source**. There are two types of source disruption via which radioactive waste or contamination may become exposed and/or protective barriers impaired:
  - Natural disruptive events, including pathways involving seismicity, erosion and flooding. These are considered in Section C.2.5.
  - Human intrusion directly into radioactive waste, as considered in Section C.2.6.

C9 Within these categories, specific dose pathways and RPs have been identified by considering the likely source-pathway-receptor[59] linkages for each of the overarching pathways, and then screened using expert review of their applicability to the Winfrith site.

C10 Note that while the planned end state of the Winfrith site is heathland open to the public for recreational purposes, all alternative credible future uses of the site have been considered when identifying and screening pathways. However, to keep the number of pathways manageable, a pathway has not been defined for each possible use; rather, a representative set of pathways and RPs that bound the exposures that might occur through the complete range of possible activities has been identified. This approach means that an activity or RP can be screened as "bounded" by another and, therefore, not retained specifically for calculation. In doing this, care must be taken that the "lifestyle" (range of uses) represented by a modelled RP is bounding compared to any other lifestyle that might theoretically involve a different set of activities.

C11 The remainder of this section presents the identification and screening of dose pathways in each of the categories identified above, to ensure comprehensive modelling of potential exposures of RPs on the Winfrith site.

C.2.2 Dose Pathways for Assessment of Direct Radiation (Site Occupancy)

C12 The most likely future direct exposures to buried contamination are through activities associated with the next planned use of the Winfrith site (i.e. heathland open to the public for recreational purposes). However, once control over the site under RSR is removed after reaching the SRS, it cannot be ruled out that the site might be developed for other purposes. Although such development might be prevented by controls such as planning regulations, no reliance on such controls is assumed here. Further, there are currently uncertainties over future developments that may incorporate part of the site. Possible activities for the site occupancy exposure pathways assessment are limited to those that involve human activities but without any intrusion into the buried

[59] "Receptor" is a commonly used term in performance assessment documentation and may refer either to a compartment via which radioactivity reaches the accessible environmental (such as a water body or crops), or to the person, animal or plant that receives a dose from interacting with such a compartment. In this assessment (other than when discussing impacts on non-human biota), all receptors are RPs, and environmental elements are considered to be part of the pathway. To minimise confusion, the term "receptor" is avoided and "RP" (or non-human biota) used instead.

contamination. The significance of the impacts is, therefore, assessed against the risk guidance level of GRR Requirement R10.

C13 Table C.1 lists activities and RPs identified for potential inclusion in the site occupancy exposure pathways assessment and presents a screening justification. It is noted that the activities listed in Table C.1 might equally take place over ground that contamination has migrated to via aqueous release (Section C.2.3). However, the highest doses would occur when the site occupant is assumed to be located directly over the disposals (before there has been any migration of radioactivity).

C14 Figure C.1 illustrates the source-pathway-RP linkages screened in for the site occupancy exposure pathways assessment.

Table C.1: Exposure activities and RPs considered for inclusion in the site occupancy assessment, where the exposure pathway for each activity is external irradiation from buried contamination, and screening justification (applicable to SGHWR, Dragon and the OoS A59 area). Note that housing and industrial developments typically involve significant disruption of the ground and would likely result in contact with the waste; this is not in the scope of the direct radiation assessment but is discussed in relation to human intrusion pathways (Section C.2.6).

Activity	Description	RPs	Screening Decision and Justification
Recreational walking	Walking above buried contamination without intruding into it.	Dog walker	✓ Given the planned end state for the site of heathland with public access, exposure to buried contamination via external irradiation when walking over the site is the most likely exposure activity both before and after the SRS. Exposure time would be less than for a caravan dweller. However, before the SRS, residency in a caravan on the site is not considered credible as the site will still be under NRS control, and so this activity is screened in for quantitative assessment.
Recreational camping	Camping above buried contamination without intruding into it.	Camper	✓ Given the planned end state of the site is heathland with public access, occasional recreational camping above buried contamination is a credible activity both before and after the SRS. Occupancy/exposure time would be different than for the recreational walking activity (less frequently, but for a greater period of time on each occasion). Exposure time would be less than for a caravan dweller (who is assumed not to receive any shielding from the caravan), and so this activity is bounded by caravan dwelling. However, before the SRS, residency in a caravan on the site is not considered credible as the site will still be under NRS control, and so this activity is screened in for quantitative assessment.
Caravan dwelling	Living above buried contamination without intruding into it.	Caravan Dweller	✓ Whilst the planned end state for the Winfrith site is heathland open to the public, development of a caravan park on the site or an individual taking up unauthorised residency in a caravan on site is a credible future use. Occupancy/exposure time would be greater than for the recreational walking activity or recreational camping, and would also bound residency in a housing development, workers in an office building and farm work.
Housing development	A resident family occupies a house with garden above buried contaminated material.	Resident	✗ Whilst the planned end state for the Winfrith site is heathland open to the public, development of housing on the site is a credible future use. Regulations such as planning legislation might restrict such development, but no credit is taken for such controls beyond the period of RSR. While public access will be permitted from the IEP, NRS will retain control over the start such that development would not be possible until after the SRS. Therefore, this activity is possible after the SRS, but larger buildings

Activity	Description	RPs	Screening Decision and Justification
			would suggest that long-term consequences are likely to be no greater than for a caravan dweller, so this activity is excluded from quantitative assessment.
Light industrial development	Office workers in a building above buried contamination.	Office worker	✗ A credible future use for part of the site involves expansion of the technology/business park. However, shorter worker occupancy times and larger buildings would suggest that long-term consequences are likely to be no greater than for a caravan dweller, so this activity is excluded from quantitative assessment.
Heavy or high-rise development	Residents in a high-rise or workers in a heavy industrial development above buried contamination.	Resident/ worker	✗ Development of high-rise buildings is considered unlikely given there are few high-rise developments in this area and because thorough geotechnical investigations that would precede any development of this type would reveal the site as artificially made ground; the presence of the waste is also likely to be discovered. Therefore, this activity is excluded from quantitative assessment.
Farm / smallholding	A farmer working in fields above buried contamination.	Farmer	✗ Farming is a current activity in the area, such that farmers could potentially undertake activities above the contamination. However, occupancy time above the contamination is expected to be bounded by that of a caravan dweller and so this activity is excluded from quantitative assessment.

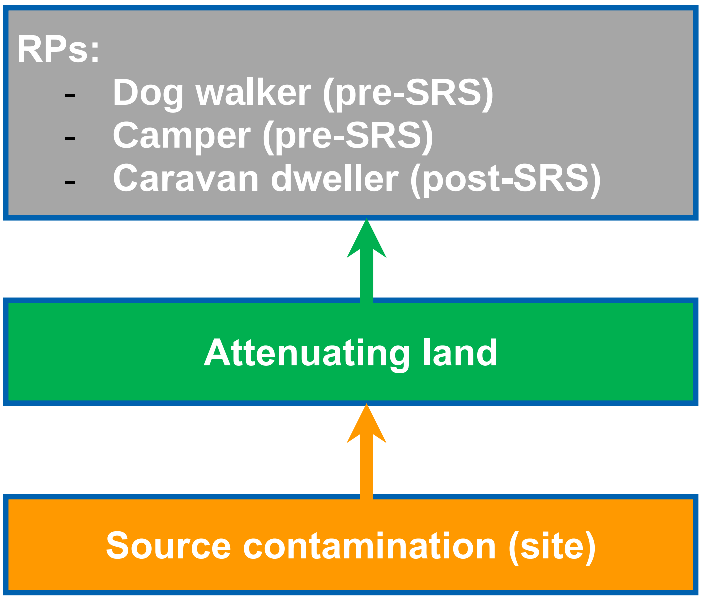

Figure C.1: Schematic showing source-pathway-RP linkages screened in for the site occupancy direct irradiation pathway.

C.2.3 Dose Pathways for Assessment of Natural Evolution

C15 The GRR requirements [165] of relevance to natural evolution of the proposed Winfrith site end state are:

- Requirement R9, focused on doses to RPs during the period of RSR, which requires that "assessment of effective dose should take into account both direct radiation from each source on-site and radiation from current discharges attributable to that source" [165, ¶A4.26].
- Requirement R10, associated with risks to RPs after release from RSR, which requires the assessment of "risks from radioactive substances dispersed in the accessible environment (arising from radioactive waste or radioactive contamination) due to the migration or uncovering of radioactive substances by natural processes" [165, ¶A4.33].

C16 The dose pathways of relevance for assessment of the natural evolution of the Winfrith site against GRR Requirements R9 and R10 are through exposure to radionuclides migrating from on-site disposals of radioactive features into the geosphere and biosphere via groundwater and gas.

Aqueous Release

C17 For the proposed on-site disposals, aqueous release of radionuclides is expected following implementation of the end state, when active management of the interaction between groundwater and areas of residual contamination will cease. For SGHWR and Dragon, saturation of the portion of the structures located below the water table will occur as a result of groundwater flowing sub-horizontally and vertical infiltration of water through the cap. However, water ingress will be slow owing to the low permeability of the structures.

C18 Over time, contamination will be released to groundwater either via water infiltrating vertically downwards from the surface or sub-horizontally at depth once structures have resaturated below the water table. Release of contamination will be slow; water inflow will be impeded by the low permeability of capping materials and the concrete reactor walls, and a large proportion of the contamination will be bound to the solid material where it currently resides. However, inevitably given the long half-lives of some contamination (thousands to millions of years) compared to the durability of engineered structures (hundreds to thousands of years), there will be some release. The release will be by a combination of mechanisms, reflecting the range of contaminant properties. Some contamination will be released instantly to water from solid surfaces, with the release rate determined only by the water flow rate and the affinity of the contaminant for the solid surface (as represented using a distribution coefficient). Other contamination will have diffused into the solid and will only be released by the same slow diffusive process. Still other contamination might be tightly bound in the solid and will only be released by very slow processes such as solid dissolution or metal corrosion.

C19 Once in the groundwater, the contamination will become dispersed across the groundwater flow path until it is released at the point where the groundwater emerges at the surface, either in a river/stream or to marshy ground (a mire). The migration of contamination in the groundwater might be retarded by partitioning between the groundwater and the solid material it is flowing through.

C20 Humans might be exposed to the contamination via natural evolution pathways by using land or surface waters affected by the contaminated groundwater. As noted in Section C.2.2, site occupancy activities (as listed in Table C.1) could also take place above contaminated land, but associated doses will be bounded by such activities occurring directly over the disposals. Table C.2 lists activities and RPs identified for potential inclusion in the natural evolution aqueous release exposure pathways assessment, and Table C.3 presents the screening justification for each activity.

C21 Figure C.2 illustrates the source-pathway-RP linkages screened in for the natural evolution aqueous release exposure pathways assessment.

C22 Humans may also be directly exposed to the contamination through groundwater abstraction, natural disruptive events or inadvertent intrusion; these pathways are considered in Sections C.2.4 to C.2.6.

Table C.2: Exposure activities and RPs considered for inclusion in the aqueous release assessment.

Activity	Description	RPs	Exposure Pathways
Angling	Releases to groundwater join a local stream, canal, river or pond. Recreational fishing involves catching and consuming contaminated fish.	Angler	Ingestion of contaminated freshwater fish and inadvertent ingestion of contaminated river water and sediment. External irradiation from radionuclides in bank sediments and from contaminated water on the skin.
Stream water abstraction	Releases to groundwater join a local stream or river, from which contaminated water is abstracted for drinking.	Stream Abstractor	Ingestion of contaminated water.
Recreation (water body)	Releases to groundwater join a local stream, canal, river or pond. The waterbody is used for swimming, boating or other sports or games.	River Paddler	Inadvertent ingestion of contaminated river water and sediment. External irradiation from water and sediment on the skin.
Recreation (mire)	Releases to groundwater emerge at an area of marshy ground (a mire). The contaminated mire is used for a recreational event such as a Tough Mudder.	Mire Mudder	Inadvertent ingestion of contaminated mire mud and/or water. External irradiation from mud and water on the skin.
Recreation (land)	Contaminated river or borehole water is used to irrigate "park" grass, or the grass is contaminated via fluvial or groundwater flooding. The contaminated area is used for a recreational "park".	Park User / Park Worker	External irradiation from the ground and from contaminated soil and water on the skin. Inadvertent ingestion of contaminated soil and/or dust. Inhalation of contaminated dust. Ingestion of contaminated wild berries.
Construction	An area for development is contaminated via irrigation from groundwater or surface water contact. The contaminated area is developed over the course of a year for residential or commercial purposes. This activity need not occur above the buried contamination, so does not include penetration into the waste (this is considered in Section C.2.6).	Construction worker	External irradiation from the ground and from contaminated soil and water on the skin. Inhalation of contaminated dust. Inadvertent ingestion of contaminated soil and/or dust.

Activity	Description	RPs	Exposure Pathways
Crop consumption	A garden or smallholding growing fruit and vegetables is contaminated via irrigation from groundwater or surface water.	Smallholder – crop	Ingestion of contaminated crops. Inadvertent ingestion of contaminated soil and/or dust.
Animal product consumption	Livestock consumes contaminated water either through drinking or through eating vegetation which has taken up contaminated water.	Smallholder – animal	Ingestion of contaminated animal produce (milk or meat).
Land worker	A farmer uses contaminated water to irrigate a crop or feed animals, or ploughs a field of contaminated soil.	Farmer	External irradiation from the ground and from contaminated soil and water on the skin. Inhalation of contaminated dust. Inadvertent ingestion of contaminated soil.
Resident smallholding	A smallholder uses a contaminated area for farming of both crops and animals, including manual working and ploughing the ground, and lives in a house built on contaminated land.	Smallholder	External irradiation from the ground and from contaminated soil and water on the skin. Inhalation of contaminated dust. Inadvertent ingestion of contaminated soil and/or dust. Ingestion of contaminated crops and animal produce.

Table C.3: Screening and justification of the activities to be modelled in the aqueous release exposure pathways assessment.

Activity	Screening Decision and Justification
Angling	✓Angling and consumption of freshwater fish has been reported further downstream from the site in the River Frome [172]. Therefore, angling in a stretch of the river beside the site where each of the disposal features are assumed to enter the River (where the contamination is highest) is included in the assessment and offers a worst case for the observed behaviour of water being used downstream in the River Frome, where it will be more diluted.
Stream water abstraction	× Given that the Winfrith area is relatively flat, the River Frome is relatively slow flowing, and land use in the area (predominantly farming, with some industry and housing) is likely to result in various pollutants entering it, it is considered very unlikely that anyone would use the River Frome as a direct drinking water supply. This exposure pathway is therefore excluded from the assessment. In addition, this pathway is bounded by consumption of contaminated groundwater abstracted from a well immediately downstream of each disposal feature, where the concentration will be higher (see Section C.2.4).

Activity	Screening Decision and Justification
Recreation (water body)	✓Although the 2019 CEFAS survey [171] does not identify any recreational activities taking place in the River Frome, the 2003 survey [172] notes some use of the area around the River Frome for paddling and playing. Such activity cannot be ruled out in future; therefore, it is included in the assessment with the conservative assumption that all activities take place at the point of groundwater entry to the River (where the contamination is highest).
Recreation (mire)	✓The Winfrith Restoration Management Plan (RMP) [173] includes the creation of a mire downstream of SGHWR and close to A59. This is considered to be a default location for groundwater flowing from SGHWR and A59. Recreational uses of such a mire (such as a Tough Mudder-style event) cannot be ruled out; therefore, this activity is included in the assessment.
Recreation (land)	✓ This exposure pathway includes external irradiation to a recreational user from ground contaminated by water released to the mire, to the River Frome or (during wet periods) directly to land west of the Monterey roundabout. The planned end state for the site is heathland with public access, which is unlikely to be deliberately irrigated as a formal or cultivated "park", but the land may be contaminated via flooding and this pathway is therefore included in the assessment. The assumed behaviour is use of the land for recreation, rather than a worker with responsibility for maintenance of the land, as active management of heathland will be minimal.
Construction	✓ The planned end state for the site is heathland with public access. However, any possible future use of the site must be considered. Therefore, construction on areas of the site where land is contaminated by flooding from the mire or River Frome cannot be ruled out.
Crop consumption	✗ The 2003 and 2019 CEFAS surveys [172; 171] identified an average of three (and a maximum of four) farms producing salad crops and one producing watercress for the area surrounding the Winfrith site. Therefore, use of contaminated water for irrigation of crops for human consumption is an expected activity. However, this exposure pathway is bounded by the resident smallholder and standalone crop consumption is therefore excluded from quantitative assessment.
Animal product consumption	✗ CEFAS surveys [172; 171] for the area surrounding the Winfrith site both identify 35 working farms of various types, both arable and pastoral. Therefore, use of contaminated water for livestock and grazing is an expected activity. However, this exposure pathway is bounded by the resident smallholder and standalone animal product consumption is therefore excluded from quantitative assessment.
Land agricultural worker / Farmer	✓ CEFAS surveys [172; 171] for the area surrounding the Winfrith site both identify 35 working farms of various types, both arable and pastoral. Land workers are considered separately from the resident smallholder, as exposure times and patterns will be different. Therefore, use of land contaminated by flooding from the mire or River Frome for farming is included in the assessment.

Activity	Screening Decision and Justification
Resident smallholder	✓ Contaminated water from the River Frome may be used to irrigate fields, and contamination of land in the Frome Valley may also arise when the River Frome floods. Contaminated land may also arise from the drying out of the mire. Use of such contaminated land for a smallholding cannot be ruled out. Maximum use of the contaminated land for subsistence (i.e. growing fruit and vegetables and rearing animals) is considered as a cautious bounding case. The smallholder might also live in a house built on the contaminated land, but external exposure while indoors will be minor owing to the shielding offered by the building and so this is not modelled.

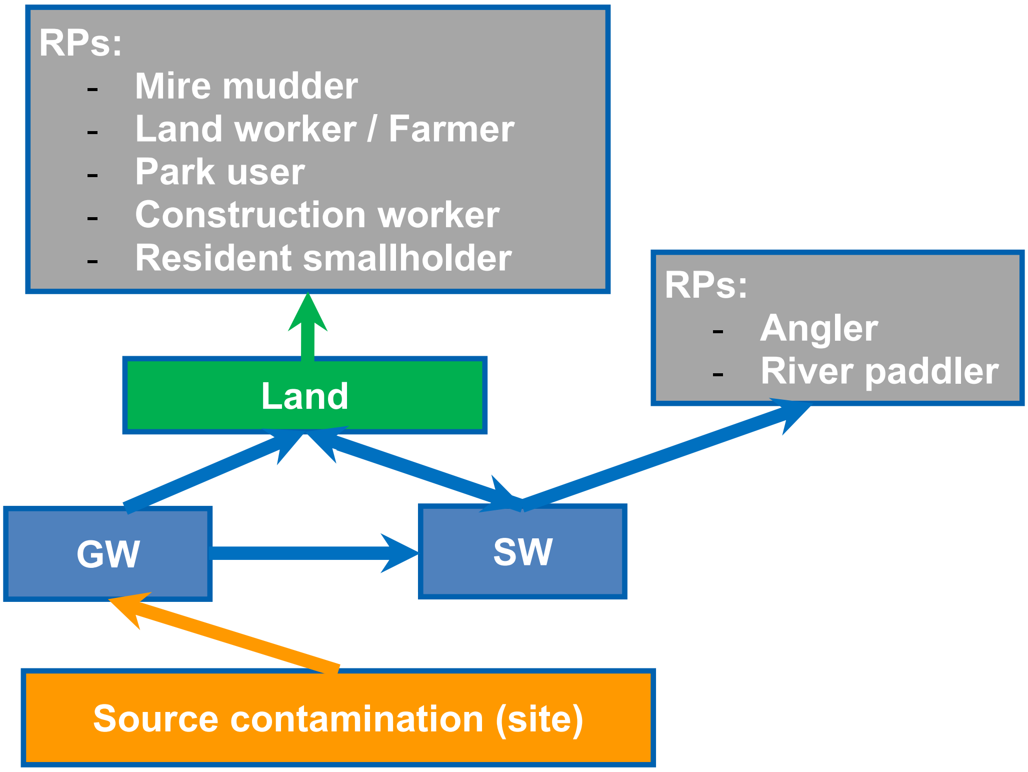

Figure C.2: Schematic showing the source-pathway-RP linkages screened in for exposure to contamination down-gradient of the source features at the Winfrith site via the aqueous release pathway. Key: GW=groundwater; SW=surface water. As explained in Section 5.4.1, the mire is considered to be land that is sometimes wet, rather than a surface water feature. Groundwater reaches the River Frome both directly and via the mire.

Gaseous Release

C23 LLWR assessments, together with monitoring results from LLWR and other waste storage and disposal sites, have shown that the radionuclides of concern in regards to gaseous release are those that can constitute bulk gases produced within the disposals and those that are themselves gases [174, §6.1.1]. Potentially significant releases of radioactive gases to the atmosphere from Winfrith disposals are as follows:

- Tritium (^{3}H) may be released either directly as a gas or as tritiated water vapour (HTO). The ^{3}H reference disposal inventory at 2027 is 492 GBq ([84], Section 3.3.4), with ^{3}H forming 80% of the SGHWR inventory and 59% of the Dragon inventory (no tritium is associated with A59). Due to its relatively short half-life (12.3 y), tritium is primarily of concern during the operational period and early post-closure period only.
  - Tritium may be substituted for stable hydrogen, either in hydrogen gas produced from metallic corrosion, or in methane produced from organic degradation. The vast majority of the inventory is associated with concrete, with only a small steel content (e.g. encased reinforcement bar and mortuary tubes) and negligible presence of organic material. As

such, the volume of tritium gas and ^{3}H-labelled methane produced in the disposals will be low.

- Evaporation of tritiated water (HTO) vapour could occur at low rates over the first few decades after the disposals are implemented, although this will be limited by the low temperatures within the materials left on site and due to the depth of soil overlying the disposals.

- The above assessment is supported by scoping calculations reported for the LLWR [175, §5.1.2]. These calculations show that a peak emission rate of 4.4 TBq y^{-1} corresponds to an annual average air concentration of 0.46 Bq m^{-3} at ground level, 400 m from the point of release, on the basis of a point source release at ground level with no plume buoyancy and a standard Gaussian plume atmospheric dispersion model. The calculated peak annual dose for inhalation of tritium (HTO) by a permanent site resident at this concentration for an entire year is 0.082 μSv. The annual tritium release used in this calculation for the LLWR is an order of magnitude greater than the entire Winfrith inventory of tritium. Even if a direct gaseous release mechanism were identified for HTO at Winfrith (the LLWR waste materials and disposal concept are very different), the consequent radiological impacts would be insignificant.

- Based on the above, tritium-bearing gas production from the Winfrith disposals is screened out of the PA. This decision is further supported by comparison of the disposal inventory with the current permitted annual discharge limits for the Winfrith site. The site EPR Permit [11, Sch.3] constrains atmospheric tritium discharges to 49.5 TBq per year, two orders of magnitude greater than the entire tritium disposal inventory.

- Carbon-14 (^{14}C), can substitute for stable carbon isotopes in methane (CH_4) and in carbon dioxide (CO_2), gases produced by organic degradation. The estimated ^{14}C reference disposal inventory in 2027 is 5.62 GBq, with ^{14}C comprising ca. 0.9% of the total SGHWR activity and ca. 0.5% of the total Dragon activity ([84], Section 3.3.4). There is no ^{14}C associated with A59.

  - Methane and carbon dioxide are generated from the degradation of organic wastes mainly within the first few hundred years, after which readily degradable organic material would be exhausted. As CO_2 may be taken up as carbonate within cement grout in the disposals, CH_4 would be the main gas to evolve. Carbon-14-labelled methane would be expected to migrate by diffusion, aided by buoyancy, within the unsaturated disposals and profiling to beneath the cap, and then diffuse through the cap.

  - A key feature of this pathway is that production of ^{14}C-labelled methane from the disposals requires both degradation of organic materials and that ^{14}C is at the same time being released from the waste. The vast majority of the Winfrith disposal inventory is associated with concrete and masonry, with negligible presence of organic materials, and so there is limited potential for organic gas production. In addition, the ^{14}C inventory is primarily associated with activation (typically of the bioshields) rather than contamination, and so will be released slowly as it must diffuse through the concrete structure. As there is also no inorganic mechanism for carbon oxidation at the low temperatures within the materials left on site gaseous release of ^{14}C is screened out of the PA.

- Isotopes of the noble gas radon: ^{222}Rn and ^{220}Rn.
  - Radon (^{222}Rn) has a half-life of 3.8 days and is generated from the decay of ^{226}Ra (half-life 1,600 y). Radium-226 is a very minor constituent of the 2027 reference end state inventory, representing ca. 0.08% of the total SGHWR activity and ca. 0.01% of the total Dragon activity ([84], Section 3.3.4). The ^{226}Ra activity for A59 is similarly small (<0.00001%). Therefore, the amount of ^{222}Rn gas generated is expected to be insignificant.
  - Thoron (^{220}Rn) has a half-life of 56 seconds and is generated from the decay of ^{228}Th (half-life 1.9 y) and its parents ^{228}Ra (half-life 5.8 y) and ^{232}Th (half-life 1.41 x 10^{10} y). The end state inventory for SGHWR and A59 does not contain ^{228}Th, ^{228}Ra or ^{232}Th ([84], Section 3.3.4). The combined 2027 reference end state inventory for Dragon for ^{228}Th, ^{228}Ra and ^{232}Th is only 0.03 MBq.
  - Given the small inventories, and that the half-lives of ^{222}Rn and ^{220}Rn are too short for any significant migration from the site of production, release of radon and thoron is excluded from the assessment.

C24 As set out above, no gaseous exposure pathways have been identified that could lead to significant doses.

C.2.4 Dose Pathway for Assessment of Groundwater Abstraction

C25 The GRR notes that the requirements of the European Groundwater Directive 2006 should be taken into account in the development of the SWESC [165, ¶5.2.7]. The GRR sets out the approach to the protection of groundwater with regard to radioactive substances [165, ¶5.2.9]. The approach to groundwater protection more broadly in England under EPR16 is set out by the Environment Agency in a collection of guidance material including [176] and [177]. In all cases a risk assessment and a risk-based approach is required.

C26 The groundwater in the Poole Formation at Winfrith is a secondary aquifer. Drilling a groundwater abstraction well into contaminated groundwater is not considered as part of natural evolution and it would not count as human intrusion because the well does not intrude directly into the source contamination. Therefore, abstraction of contaminated groundwater via a well is considered separately here. Drilling a well will not be allowed during the period of RSR, so compliance need only be assessed against the risk guidance level set out under Requirement R10 in the GRR after the SRS.

C27 Drilling a well into contaminated groundwater could lead to exposure from radionuclides through use of well water for drinking and irrigation [178]. The 2003 and 2019 CEFAS habits surveys [172; 171] record several instances of wells and boreholes used for water consumption in the survey area, but do not note any wells that could be contaminated by groundwater releases from the Winfrith site. On the basis of current water abstractions, a borehole is most likely to be drilled into the confined White Chalk aquifer below the London Clay, rather than potentially contaminated groundwater in the Poole Formation. Further, any shallow well near to SGHWR or Dragon might exhibit a mild reduction in water quality (e.g. suspended solids, slight colour) due to the concrete reactor structures. Nevertheless, a water well pathway is included to consider the hypothetical situation where a shallow well is drilled into the Poole Formation, intercepting contaminated groundwater (PA-018). The abstractor is assumed to draw sufficient water from the well for their entire annual water consumption.

C28 Figure C.3 illustrates the source-pathway-RP linkage for the groundwater abstraction pathway.

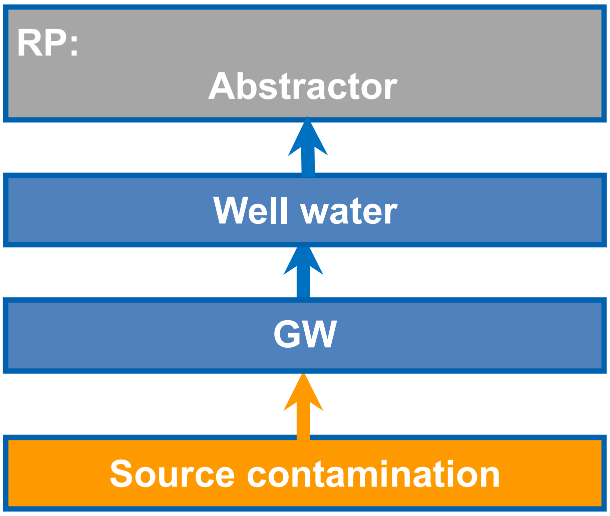

Figure C.3: Schematic showing the source-pathway-RP linkage for the groundwater (GW) abstraction pathway.

C.2.5 Dose Pathways for Assessment of Natural Disruptive Events

C29 Requirement R12 of the GRR [165] concerns natural disruptive processes after the release of a site from RSR. To comply, it is necessary to show that "people will be adequately protected in the case of natural disruptive processes which expose radioactive waste or contamination, or impair protective barriers" [165, ¶A4.84].

C30 The potential for natural disruptive events and processes at the Winfrith site is considered in the Winfrith Site Description report [179]. These are summarised and screened in Table C.4. As set out in the table, no natural events or processes have been identified that could lead to disruption of the site or any exposure pathways.

Table C.4: Identification, screening and justification of natural disruptive events and processes.

Event / Process	Description	Screening Decision and Justification
Seismic events	Rapid relative movements within the Earth's crust usually along existing faults or geological interfaces. The accompanying release of energy may result in ground movement and/or ruptures (e.g. earthquakes). Most common in tectonically or volcanically active regions.	× The UK, including the Winfrith site, is in a geologically inactive setting, situated far from plate boundaries, and levels of seismicity are typically low (Section 3.2.2). Reactor engineering was constructed to a design basis to withstand anticipated seismic events. Possible impacts from seismic activity in terms of degraded engineering and faster flows will be captured in assessment cases identified from uncertainty analysis. Other potential extreme seismic events leading to cataclysmic failure and impacts on groundwater and surface water (e.g. a sudden release of significant inventory to the geosphere) are not considered, on the basis of low likelihood.
Glaciation	Erosion and deposition of material as glaciers move across the surface and impact of the weight of glacial ice sheets causing depression and then rebound as the ice is removed.	× There is considerable uncertainty in the timescale over which the global surface air temperature will remain elevated compared to present and how far into the future it might be until the next glacial period. The IAEA [98] suggests two potential future timings of the next glacial inception: around 50,000 years after present and around 100,000 years after present. However, icesheets did not reach as far south as Winfrith at the last global maximum and any future glaciation event is expected to have a similar pattern. Therefore, glaciation is not expected to impact the proposed disposals.
Coastal erosion	Erosion of material from a coastal region.	× The site is situated around four miles from the coast (Section 3.2.1), with a ridge of chalk downs situated between the site and the coast. Conclusions given in the Winfrith Site Description Report [179] are that the site is not currently vulnerable to coastal erosion. Therefore, pathways created as a result of coastal erosion can be excluded from assessment.

Event / Process	Description	Screening Decision and Justification
Surface erosion	Surface erosion includes soil erosion, through heathland fire, wind or rainfall, and fluvial erosion, through incision or migration.	× Mapping by the European Soil Data Centre [180] indicates soil erosion rates of less than 5 te ha^{-1} yr^{-1} by water in the Dorset region [179], the lowest category of surface erosion. The River Frome is the largest river close to the site; however, based on its distance from the site (approximately 300 m, Section 3.2.3), relatively small size, and lack of credible mechanism for a significant increase in its erosive power, the site is not considered to be vulnerable to fluvial erosion either now or over the assessment timescale. There is potential for localised surface erosion to soil surrounding the site through trampling or other processes, but this is not expected to impact any made ground, capped features or large areas of the site to a significant extent. Heathland fires affecting the site cannot be ruled out but are not expected to significantly increase surface erosion rates from wind, rainfall or trampling, as burned heather should continue to protect the soil until regrowth is established (PA-017). Overall, low rates of surface erosion and lack of mechanism for rapid erosion events mean that there is very low likelihood of waste being exposed by surface erosion over the assessment timescale and other effects will be negligible. Therefore, pathways created as a result of surface erosion can be excluded from assessment.
Coastal flooding	High tides, storm surges and wave action, often acting in combination, flooding low-lying coastal land.	× Winfrith is not vulnerable to coastal flooding since the site is at an elevation of approximately 20 m AOD, with ground rising towards the western boundary of the site to close to 50 m AOD (Section 3.2.1).
Fluvial flooding	Flooding resulting from nearby rivers when the amount of water exceeds the channel capacity of the watercourse.	× The Environment Agency's Flood Map for Planning [181] shows that the elevated parts of the Winfrith site around SGHWR and Dragon are not at significant risk of fluvial flooding [182]; there is no likelihood of the actual disruption of the contamination sources themselves by fluvial flooding. The potential for contaminated land arising from fluvial flooding of land adjacent to the River Frome is considered as part of natural evolution under R10 (Section C.2.3), rather than as a separate natural disruptive event under R12.
Groundwater flooding	Flooding caused when groundwater levels rise above ground level following prolonged rainfall.	× The potential for groundwater flooding on the Winfrith site following the IEP has been modelled [182] and is considered as part of natural evolution under R10 (Section C.2.3), rather than as a separate natural disruptive event under R12.

C.2.6 Dose Pathways for Assessment of Human Intrusion

C31 Requirement R11 of the GRR [165] concerns inadvertent human intrusion following release of a site from RSR. It requires assessment of “the potential consequences of inadvertent human intrusion into any local concentrations of radioactive substances” and defines dose guidance limits for the assessment of effective dose to RPs during and after the assumed intrusion [165, ¶A4.56].

C32 The GRR notes that there may be a period of control following the completion of activities involving radioactive substances to restrict human activities that could lead to exposure from any residual radioactivity. Following release from RSR the GRR assumes that there will be unrestricted use of the site, although the land owner and/or the planning regime may limit the intended use of the site.

C33 The planned end state for the Winfrith site is heathland with public access. After the SRS, use of the site may continue to be subject to planning controls, such as designation as public open space, but release from RSR means here that use must be assumed to be unrestricted. The assumption of unrestricted use leads to the possibility of human intrusion, and therefore the potential for both direct exposure to contamination and the re-use of contaminated material from excavations. It is assumed that human intrusion is prevented in the period between the IEP and SRS, when public access will be allowed but NRS will retain control of the site and it will still be subject to RSR.

C34 Activities that might lead to intrusion are conjectural, but the GRR requires their consideration on the basis that they are likely to occur at some point in time. The potential radiological impacts of human intrusion are calculated in the PA from the assumed the SRS date, but variant calculations consider earlier intrusion to inform optimisation of the SRS.

C35 The GRR provides further guidance on the assumptions to be made with respect to assessments of human intrusion. Human intrusion activities fall into three classes, two of which constitute inadvertent intrusion and should be considered in the assessment: (1) intrusion without prior knowledge of the radioactive substances; and (2) intrusion with knowledge of the existence of past human activity at that location but without understanding its nature [165, §A4.58 to §A4.60]. In each case, pathways should be identified based on human actions that use technology and practices similar to those that currently exist, or that have historically existed, in similar geological and geographical settings anywhere in the world. The assumed habits and behaviour of people should be based on present and past human habits and behaviour that have been observed and are judged relevant.

C36 The approach used here is to identify activities considered in appropriate methodologies and other assessments [178, 183, 184, 185, 186] and then to screen these, using expert review, for their applicability to each of the sources anticipated to be left at the Winfrith site. As human intrusion activities are necessarily somewhat stylised, they can be considered in a generic way and it is therefore appropriate to use existing assessment methodologies as a starting point. The initial set of activities identified from other assessments is presented in Table C.5 together with the relevant RPs and pathways.

C37 Table C.6 presents the screening assessment for these activities for each of the Winfrith sources, providing justification for their inclusion or omission in the radiological safety assessments. The screened activities and RPs are also shown schematically in Figure C.4.

Table C.5: Human intrusion activities considered for inclusion in the PA, and reference to other assessments and guidance that consider these exposure activities.

Activities	Description	RPs	Exposure Pathways	References
Excavation Events				
Exploratory borehole drilling	Drilling of an exploratory borehole that intersects contaminated material.	Workers drilling the borehole	External irradiation Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil	[178;185]
Geotechnical investigations	Geotechnical investigations involving interactions with contaminated material, including borehole drilling, trial pit excavation and laboratory analysis of cores and samples.	Technically qualified investigators	External irradiation Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil	[178;185]
		Laboratory analyst	External irradiation from contaminated material Skin exposure to contaminated material Inhalation of radon gas	
Excavation (construction site)	Excavation of contaminated land for construction during development for either residential or commercial use. Use of the excavated material is considered in the material use events.	Excavators	External irradiation Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil	[178; 183]
Technical or archaeological excavation	Exposed wastes may become a target for archaeological excavations and local authorities may send a technically qualified person to investigate if it becomes obvious that something is being eroded that has some manmade structure.	Archaeologists /technically qualified excavators	External irradiation from the ground Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil	[178;185]

Activities	Description	RPs	Exposure Pathways	References
Road development	Development of a road cutting through the site, at underpass level, intersecting contaminated material.	Construction workers Members of the public	External irradiation from the ground Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil External irradiation from the ground	[184, p.22; 185]
Aircraft crash	An aircraft crash penetrating to the depth of the buried waste. This would lead to contaminated material on the ground surface and contaminated dust generation.	Members of the public	External irradiation Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil	[178]
Informal scavenging	Occasional scavenging of waste, following exposure of the waste due to erosion.	Members of the public	External irradiation from the ground Skin exposure to soil/dust and scavenged items Inhalation of dust Inadvertent ingestion of soil	[178]
Local organised material recovery	Organised recovery of exposed waste. Recovered metals could then be sent to a foundry for smelting. Recovered hard-core could be used locally on tracks or to cover public places or as aggregate for use in construction.	Members of the local community or contractors	External irradiation from the ground Skin exposure to soil/dust and recovered material Inhalation of dust Inadvertent ingestion of soil	[178]

Activities	Description	RPs	Exposure Pathways	References
Commercial excavation	Organised recovery of exposed waste on a large scale which could then be used in any of the development scenarios. This would most likely be preceded by site investigations that would reveal the presence of waste and potentially hazardous contents.	Commercial excavators	External irradiation from the ground Skin exposure from handling excavated material Inhalation of dust Inadvertent ingestion of soil	[178]
Material Use Events				
Housing development	A housing development built using contaminated rubble and/or on land shaped using contaminated radioactive material.	Residents	External irradiation from the building and/or ground Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil Ingestion of contaminated foodstuffs	[178; 183;185; 187; 188]
Leisure development	Leisure facilities (e.g. a sports centre or golf course) built using contaminated rubble.	Members of the public	External irradiation from the building	[178]
School	A school built using contaminated rubble.	Adult workers School children	External irradiation from the building	[183]
Industrial/ office use	An industrial/commercial site built using contaminated rubble.	Office workers	External irradiation from the building	[183]
Heavy or high-rise development	Heavy or high-rise developments for use as flats or offices built using contaminated rubble.	Residents/workers	External irradiation from the building	[178]
Building with cellar	Building with a cellar built into contaminated land.	Residents	External irradiation from the cellar walls Inhalation of radon gas	[178]

Activities	Description	RPs	Exposure Pathways	References
Play area	Contaminated aggregate spread on land which is then used for a play area. Construction workers spreading the aggregate to construct the playground are not considered here, but such exposure would be bounded by the original excavation event.	Members of the public (all ages) using the park for playing or walking	External irradiation from the ground Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil	[183]
Farm/ smallholding	Development of a farm or smallholding on contaminated rubble. It is assumed that sufficient degradation of the rubble and mixing with other materials occurs to allow crops to be grown and animals grazed. More intensive use of land for food compared to residential housing development.	Farmers working and living on the site and their families	External irradiation from the ground Skin exposure to soil/dust Inhalation of dust Inadvertent ingestion of soil Ingestion of contaminated foodstuffs	[178;185]

Table C.6: Screening and justification of the human intrusion activities modelled in the PA.

Activities	Screening decisions		
	SGHWR	Dragon	A59
Excavation Events			
Exploratory borehole drilling	✓Drilling a well (borehole) for exploratory purposes through radioactive material left on site is included in the human intrusion assessment, whilst consideration of abstraction and use of water from a well intercepting radioactivity in groundwater is considered in the groundwater abstraction pathway (Section C.2.4).		
Geotechnical investigations	✓Geotechnical investigations such as drilling boreholes may reach radioactive material at depths below those reached by excavations and therefore are included in this assessment. Site-based investigators are assumed to be exposed to larger quantities of radioactive material than the laboratory analysts and are the only exposed group considered.		

Activities	Screening decisions		
	SGHWR	Dragon	A59
Excavation (construction site)	✓Building or development at the Winfrith site will involve the excavation of foundations and/or the installation of piles, and this scenario is included in the assessment. The scale of the excavation, in terms of area and depth, is dependent on the type of building or development. This scenario is only concerned with excavation activities and their impacts - use of the building or development, and use of the excavated material are considered under other scenarios.		
Technical or archaeological excavation	✗Technical or archaeological excavations into radioactive material left on site would probably involve smaller or similarly sized excavations to those required for housing development, and certainly smaller excavations than those for larger-scale developments. Technical or archaeological excavations into radioactive material excavated from the site and distributed elsewhere would expose workers for shorter periods than residents on such material. The impacts of this scenario can therefore be assumed to be bounded by the impacts from other scenarios and it is excluded.		
Road development	✗The topography of the Winfrith site is such that construction of a road would not involve deep cuttings into radioactive material left on site but might require shallower excavations similar to other developments. The area of excavation may be larger, in which case a greater number of workers would be involved rather than extended exposure times. Further, once constructed, exposure times to members of the public using the road would be much shorter than to residents of a house. The impacts of this scenario can therefore be assumed to be bounded by the impacts from other scenarios and it is excluded.		
Aircraft crash	✗With a cap at least 1 m thick (in all scenarios) above both the SGHWR and Dragon, a light aircraft crash would not penetrate to waste depth. A large commercial or military aircraft crash could penetrate to waste depth but is highly unlikely to occur. On the basis that there is no more than one such event in the UK per year, that the area of the SGHWR is around 0.004 km^2 and that the area of the UK is 244,000 km^2 [189, p.89], the annual probability of a disruptive aircraft crash is less than 10^{-7}. This assumes equal probability of aircraft crash across the UK, although crashes may be more likely to occur along the path of an air traffic corridor (no data for Winfrith). Further, the impact of this scenario on members of the public are considered to be bounded by doses calculated from the construction and development scenarios. Therefore, this scenario is excluded.		✗There will be no cap over the A59 area and so a light aircraft crash could penetrate the feature, but this is still highly unlikely to occur. As the total contaminated A59 area is approximately 0.004 km^2 [195, Tab.4.11], the same arguments apply as for SGHWR: the probability of an aircraft crash is extremely low and doses to members of the public are considered to be bounded by the construction and development scenarios.

Activities	Screening decisions		
	SGHWR	Dragon	A59
Informal scavenging	×Due to the location of the Winfrith site, there is a very low possibility of radioactive material becoming exposed due to natural disruption and available for scavenging (see Section C.2.5). If exposed as a result of other human activities, the consequences to people engaged in small-scale recovery would be bounded by doses to excavators and people exposed to larger volumes of material.		
Local organised material recovery	×Due to the location of the Winfrith site, there is a very low possibility of radioactive material becoming exposed due to natural disruption. If exposed as a result of other human activities, the impacts to people engaged in recovery and processing of such material would be bounded by those to the excavators and to people exposed to the re-used materials for longer periods.		
Commercial excavation	×Radioactive material that is proposed to be left on site includes mass concrete and broken concrete that could be commercially recovered and reused if discovered. However, the impacts to people engaged in recovery and processing of such concrete would be bounded by the impacts to workers excavating material for large-scale buildings or developments and to people exposed to the re-used materials for longer periods.		
Material Use Events			
Housing development	✓House foundations would involve shallow excavations that could nevertheless reach radioactive material left on site and doses to workers excavating such foundations are considered under the excavation scenario. This scenario considers residents in a house constructed using contaminated material. Exposure to external irradiation only is considered. The growing and eating of crops on soil contaminated by radioactive material in a garden is not considered as this pathway is bounded by the farm/smallholding scenario. Residence in a house built on land shaped using contaminated radioactive material (on or off-site) is bounded by site occupancy activities (see Table C.1).		
Leisure development	×Excavations for construction of buildings to contain leisure facilities are considered under the excavation scenario. Once built, the occupancy times for leisure facilities are likely to be less than that of a house and radiological impacts from the use of leisure facilities are likely to be bounded by those from a housing development. The leisure development scenario is therefore excluded.		
School	×Excavations for construction of a school are considered under the excavation scenario. The occupancy times for a school will be less than that for a house, and doses from the use of a school are likely to be bounded by those from a housing development. The school scenario is therefore excluded.		

Activities	Screening decisions		
	SGHWR	Dragon	A59
Industrial /office use	×Foundations are likely to be deeper for an industrial building than those for a housing development and are considered under the excavation scenario. The occupancy times for an industrial building are less than those for a house, and doses from the use of an industrial building are likely to be bounded by those from a housing development. The industrial scenario is therefore excluded.		
Heavy or high-rise development	×Foundations are likely to be deeper for heavy or high-rise development than those for a housing development and are considered under the excavation scenario. The occupancy times for heavy or high-rise development are less than those for a house, and doses from the use of heavy or high-rise development are likely to be bounded by those from a housing development. The heavy or high-rise development scenario is therefore excluded.		
Building with cellar	×A building with a cellar may require deeper excavations than typical for a housing development and these are considered under the excavation scenario. Exposures to site occupants could be higher than for a house without a cellar due to doses from radon. However, the limited inventory for the parent radionuclides of radon being considered for on-site disposal at the Winfrith site (see discussion in Appendix C.2.3) allows this exposure pathway and hence the building with cellar scenario to be excluded.		
Play area	✓Radioactive material excavated from the Winfrith site could be re-used as aggregate either on or off site. The radiological impacts from use of aggregate as a base for a play area are likely to bound the impacts from any other use and this scenario is considered in the assessments.		
Farm /smallholding	✓Occupancy of a farm or smallholding would be similar to that for a housing development, but additional exposure pathways are associated with the consumption of contaminated foodstuffs derived intensively from the site and this scenario is included.		

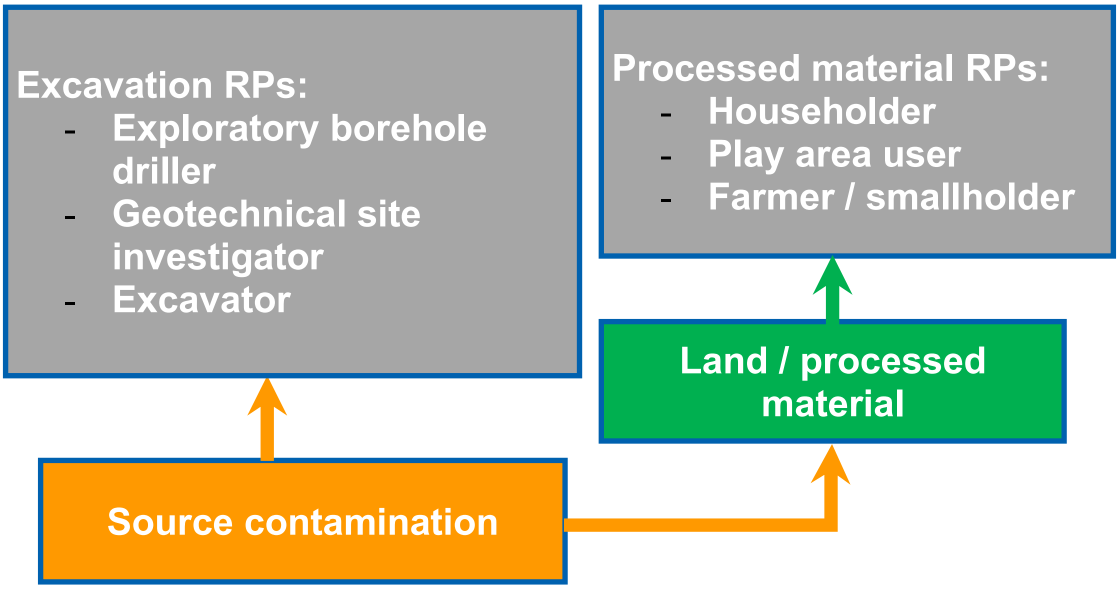

Figure C.4: Schematic showing the source-pathway-RP linkages screened in for human intrusion pathways.

C.2.7 Summary of Dose Pathways and RPs

C38 Table C.7 summarises the dose pathway screening for the PA, listing the pathways and RPs considered for the three sources (SGHWR, Dragon and A59). The GRR requirement against which the results for each pathway are compared is also presented.

C39 Assumptions made regarding exposure pathways, consumption and habits for each of the RPs to be modelled are set out in Section 5.4 (biosphere model for natural evolution and groundwater abstraction), Section 6 (site occupancy model), and Section 7 (human intrusion model). It is assumed that site occupancy scenarios involving living on the site and human intrusion are prevented in the period between the IEP and SRS, when public access will be allowed but NRS will retain control of the site and it will still be subject to RSR.

C40 With the exception of the groundwater well abstraction pathway, all of the dose pathways and RPs listed in Table C.7 are considered in the reference assessment case and all of the alternative assessment cases and scenarios identified in Sections C.4 and C.4.2. The groundwater well abstraction pathway is considered as a variant concept scenario.

Table C.7: Dose pathways and RPs screened in for quantitative assessment in the PA against the GRR dose constraint (DC; if the scenario is assumed to occur before the SRS), and the risk or dose guidance level after the SRS (RGL or DGL). There are no differences in the dose pathways and RPs considered for SGHWR, Dragon and A59; that is, all pathways are relevant for all sources. Note that, in the natural evolution model, a subset of RPs (the park user (AR4), construction worker (AR5), farmer (AR6) and smallholder (AR7)) are duplicated; one set interacts with an off-site contaminated field and the other with the on-site contaminated Land/Mire compartment (see Section 5.4.1).

Dose Pathway (and RPs)	DC / RGL / DGL
Site Occupancy Pathway	
SO1 Recreational walker above buried contamination (Dog Walker)	DC & RGL
SO2 Recreational camper above buried contamination (Camper)	DC & RGL
SO3 Caravan dwelling above buried contamination (Caravan Dweller)	RGL
Natural Evolution – Aqueous Release Pathway	
AR1 Angling in contaminated surface water (Angler)	DC & RGL
AR2 Recreation in contaminated water (River Paddler)	DC & RGL
AR3 Recreation in contaminated mire (Mire Mudder)	DC & RGL
AR4 Recreation on contaminated land (Park User)	DC & RGL
AR5 Construction on contaminated land (Construction Worker)	DC & RGL
AR6 Land agriculture involving contaminated water/soil (Farmer)	DC & RGL
AR7 Resident smallholding on contaminated area (Smallholder)	DC & RGL
Natural Evolution – Gas Exposure Pathway	
None screened in	
Groundwater Abstraction Well	
AW1 Groundwater abstraction well (Well Abstractor) – variant concept scenario	RGL
Natural Disruptive Events	
None screened in	
Human Intrusion	
HI1 Exploratory borehole drilling into contaminated material (Driller)	DGL
HI2 Geotechnical investigations involving contaminated material, with multiple boreholes (Investigator)	DGL
HI3 Excavation of contaminated land for residential or commercial development (Excavator)	DGL
HI4 Housing development built on/using contaminated rubble (Resident Family)	DGL
HI5 Play area built on contaminated aggregate (Play Area User)	DGL
HI6 Farm/smallholding built on/using contaminated rubble (Land User)	DGL

C.3 Definition of Environmental Safety Functions

C41 This section sets out how Step 2 of the scenario development process (Figure 4.1) has been implemented.

C42 The IAEA defines a safety function as *"a specific purpose that must be accomplished for safety for a facility or activity to prevent or to mitigate radiological consequences of normal operation, anticipated operational occurrences and accident conditions"* [190].

C43 The definition of the term "safety function" means its use is generally restricted to functions provided by an engineered facility. However, there are also characteristics and processes that occur in the geosphere and biosphere that may also mitigate the radiological consequences, in terms of doses/risks to RPs. This is acknowledged in the GRR, which uses the term "environmental safety functions", which is defined as:

> *"The various ways in which components of the disposal system may contribute towards environmental safety, such as the geology providing a physical barrier function and also having chemical properties that help to retard the migration of radionuclides."*

C44 The proposed on-site disposals and near-field are expected to provide four top-level environmental safety functions, identified through consideration of their estimated inventory, configuration and expected characteristics in terms of exposure pathways (see Sections 3 and 5). These are:

- The relatively small radioactive inventory (in comparison to existing near-surface waste disposal facilities) associated with the proposed on-site disposals is expected to limit associated radiological consequences. Although not strictly a function, the inventory can be managed and is still considered to be a contribution that the source term provides towards achieving safety; it is therefore treated as an environmental safety function for the purposes of this discussion.
- The hydraulic characteristics of the proposed on-site disposals (including caps over SGHWR and Dragon) are expected to limit the transport of radionuclides to the geosphere and biosphere.
- The chemical characteristics of the proposed on-site disposals are expected to provide containment (retardation) of some key radionuclides, and thus limit their mobility.
- The caps over SGHWR and the Dragon reactor complex are expected to provide shielding from external irradiation emanating from the proposed on-site disposals, and also reduce the likelihood of some inadvertent human intrusion activities by increasing isolation from the surface. The clean cover over the A59 area also provides shielding.

C45 The local geosphere and biosphere are expected to provide two top-level environmental safety functions, defined based on an understanding of the geological and environmental characteristics of the Winfrith site and wider surrounding region (e.g. [179]). These are:

- The hydrological conditions of the geosphere and biosphere are expected to promote dilution and dispersion of radionuclides.
- The sorption of radionuclides on to geosphere materials is expected to provide retardation (and in some cases attenuation) within the geosphere.

C46 Additionally, interaction between human receptors and the environment dictates the dose/risk received. This cannot be controlled and is therefore not an environmental safety function, but local survey data can be used as an additional safety argument.

C47 The underlying processes that contribute to these two sets of top-level environmental safety functions are discussed in Appendix C.3.1 to C.3.3, and form the basis for the consideration of uncertainties in Section C.4.

C.3.1 Environmental Safety Functions of the Proposed On-site Disposals

C48 The proposed on-site disposals are expected to consist of a mix of in-situ disposal of structures, disposal for a purpose (DfaP) of infill (use as DfR), and caps over SGHWR and the Dragon reactor complex. This forms the near-field module of the natural evolution assessment model, as reported in Section 5.

C49 As outlined above, four top-level environmental safety functions have been identified for the proposed on-site disposals:

- The radioactive inventory associated with the proposed on-site disposals is expected to be relatively small, and thus limit associated radiological consequences (**Inventory**). This is associated with:
  - The disposed material having a relatively low radionuclide activity (**Activity**) – The total activity of the proposed on-site disposals directly impacts the doses/risks received by the RPs, with lower activities, generally, proportionally decreasing doses/risks when considered on a per radionuclide basis. When considered against UK LLW near-surface disposal facilities (such as LLWR and D3100) and landfill sites suitable for the disposal of very low level radioactive waste (such as Lillyhall see [187]), the cautious total activity estimate for the proposed on-site disposals (Section 3.3.4) is relatively small (as shown in Table C.1).
  - The activity within the disposed material rapidly decaying (**Decay**) – A significant proportion of the activity reported in the Winfrith inventory is associated with relatively short-lived radionuclides. For example, 79% of the total 2027 inventory activity is associated with ^{3}H (12-year half-life). This means that the total activity of the proposed on-site disposals will decrease rapidly; there is expected to be substantial radioactive decay of shorter-lived radionuclides, and hence a reducing radiological hazard, between the assumed inventory date of 2027 and the peak release of radionuclides out of the near field (due to the containment environmental safety functions detailed below).

- As set out in the Winfrith Design Substantiation Report [191], the hydraulic characteristics of the proposed on-site disposals are expected to limit radionuclide transport to the geosphere (**Hydraulic Containment**). This is associated with:
  - The hydraulic properties of intact concrete, associated with the in-situ disposals, limiting radionuclide diffusion and advection (**Transport**) – For the aqueous release dose pathway, radionuclides can be transported by advection in flowing water or diffusion along concentration gradients (from areas of high to low concentration).

    For in-situ disposals, the radioactive inventory is in most cases expected to be present within a low permeability near-surface contaminated layer of concrete. Thus, radionuclides other than those actually on surfaces will not be instantly available for transport by advection; diffusion to the surface of the contaminated layer will first be required.

    Intact undegraded concrete structures generally have hydraulic properties that greatly limit advection, especially very low hydraulic conductivity (unless specifically designed not to – as with porous concrete). Thus, whilst undegraded:
    - The SGHWR and Dragon reactor complex caps should limit infiltration (from rainfall) entering the parts of the near field containing most of the disposed inventory.
    - In-situ disposals which will consist of intact concrete structures, should limit advection into (from groundwater) and out of (from groundwater and infiltration) the near field.
  - The majority of the proposed on-site disposals being positioned above the water table (i.e. above the zone of saturation), and thus limiting radionuclide diffusion and advection (**Saturation**) – Across most of the Winfrith site, the water table is found to be significantly below the level of the ground surface and is expected to remain so (Section 3.4.2). This is expected to result in the majority of the proposed on-site disposals remaining above the water table, and thus only ever partially saturated, even with increased infiltration over time (Section 5.3.1). For such disposals:
    - The lower degree of saturation will tend to limit rates of diffusion out of near-surface contaminated layers (associated with in-situ disposals).
    - The rate of radionuclide advection will differ to below the water table, as it will be driven by the downward infiltration of rainwater, which is expected to be initially limited by the SGHWR and Dragon reactor complex caps.
  - The hydraulic degradation rate of intact concrete being sufficiently low to limit radionuclide transport (**Degradation**) – Over time, in-situ structures (and caps) will degrade through both physical and chemical processes (Section 3.4.1). Such degradation is likely to alter the

hydraulic properties (especially porosity and hydraulic conductivity) of intact concrete, leading to higher rates of infiltration into and flows of leachate out of the proposed on-site disposals. Hydraulic concrete degradation has been reviewed in support of environmental safety case development for various near-surface disposal facilities; when not accelerated by external events or processes, it is expected to occur relatively slowly, over hundreds to thousands of years (Table 5.2).

- The chemical characteristics of the proposed on-site disposals are expected to provide containment (retardation) of radionuclides, and thus limit their mobility out of the proposed on-site disposals (**Chemical Containment**). This is associated with:
  - The concentrations of some radionuclides within porewater being solubility limited, reducing dissolution and subsequent advective transport of radionuclides (**Solubility**) – Within the near field environment of radioactive waste disposals, the maximum concentrations of certain radionuclides in porewater may be solubility limited, dependent on speciation and the potential presence of complexing agents in solution. This will act to limit the dissolution and subsequent advective transport of such radionuclides.
  - The sorption of some key radionuclides on to disposed materials, which will act to contain them within the proposed on-site disposals (**Sorption**) – As outlined in Sections 3.4.1 and 5.2.1, sorption describes the partitioning of dissolved contaminants between a fluid (porewater) and the mineralogical constituents of a solid material (e.g. concrete), which increases the travel time of contaminants along a pathway (retardation). It is expected that radionuclides that sorb strongly to concrete, which is expected to the make up the majority of the proposed disposals/emplacements (Section 3.3.4), will have lower or limited mobility.
  - The chemical degradation rate of concrete and its constituent minerals being sufficiently low to continue to contain radionuclides that sorb strongly to concrete (**Degradation**) – As outlined in Sections 3.4.1 and 5.2.1, leaching of concrete involves gradual removal of the mineralogical components of the concrete as a result of interaction with flowing water. As leaching progresses, there are changes in the sorption properties of the concrete. For the concrete associated with the proposed on-site disposals, it is expected that these changes will occur over hundreds to thousands of years, primarily due to the hydraulic properties of intact concrete initially limiting water flow rates (see above).
- The SGHWR and Dragon reactor complex caps and the clean cover over A59 are expected to provide shielding from external irradiation (shine) emanating from the radioactive features (**Shielding**) – The caps/cover will act to attenuate shine from the SGHWR and Dragon reactor complex in-situ structures and A59 area of contaminated land. The degree of attenuation achieved has the potential

to vary greatly based on the characteristics (e.g. thickness, density and extent) of the caps/cover.

Table C.1: Comparison of the Winfrith end state radiological inventory [192] in relation to Trawsfynydd DAIS[60] inventory [164, Tab. C-1] and the permitted inventories of existing waste disposal facilities. Note the values for the existing waste disposal facilities are indicative; details on their estimation are reported in [193].

Site/Facility	Total Activity (TBq)	Volume (m^3)	Activity Concentration ($MBq\ m^{-3}$)
Winfrith	0.6 (2027)	66,000	9
Trawsfynydd (DAIS)	0.2 (2022)	5,200	40
Lillyhall	5	582,000	10
Clifton Marsh	80	210,000	380
LLWR	22,000	1,400,000	15,700
D3100	15	175,000	90

C.3.2 Environmental Safety Functions of the Geosphere

C50 As identified in Appendix C.2, radionuclide transport from the proposed on-site disposals will occur through aqueous release. Radionuclides, released from the proposed on-site disposals, will enter saturated portions of the near field and will be transported downgradient in groundwater (Sections 3.4.2 and 5.3.1).

C51 For the geosphere, two top-level environmental safety functions have been defined:

- The hydrological conditions of the geosphere are expected to lead to dilution and dispersion of radionuclides. This is associated with:
  - The dilution of radionuclides in groundwater (**Dilution**) – The flow rate through the geosphere will directly impact the dilution of radionuclides in the groundwater, with higher flow rates decreasing radionuclide concentrations at the groundwater emergence point.
  - The dispersion of radionuclides along the geosphere flow path(s) (**Dispersion**) – The dimensions of the geosphere flow path will alter the dispersion potential of radionuclides and thus their downgradient concentrations, with the magnitude of dispersion often related to the length of a pathway, and radionuclide sorption (see below).
- The sorption of radionuclides on to geosphere materials is expected to lead to their retardation (and in some cases attenuation through decay) within the geosphere (**Sorption**) – Some radionuclides are expected to sorb strongly to

[60] Disposal Area Interim State: the area (primarily the Ponds Complex) and configuration covered by the Trawsfynydd site's 2023 application for on-site disposal.

geosphere materials; concentrations of such radionuclides in groundwater will reduce over the geosphere pathlength (when emanating from a source) as they partition between the solid and aqueous phases. If they also happen to be relatively short-lived, decay could lead to significant attenuation of activity prior to biosphere release.

C.3.3 Environmental Safety Functions of the Biosphere

C52 Dependent on the groundwater release point, biosphere transport processes and considerations of future local land use and habits, RPs may receive doses as a result of radionuclides entering the biosphere (Section 5.4.1).

C53 For the biosphere, two top-level environmental safety functions have been defined:

- The hydrological conditions of the biosphere are expected to lead to dilution and dispersion of radionuclides. This is associated with:
  - The dilution of radionuclides in the biosphere (**Dilution**) – Biosphere transport processes are primarily hydraulically driven, and include soil infiltration, throughflow and stream transport (Section 5.4.1). These transport processes will dilute radionuclide concentrations within the biosphere.
  - The dispersion of radionuclides in the biosphere (**Dispersion**) – A range of transport processes (as detailed in Section 5.4.1) will disperse activity over different parts of the local biosphere.
- The sorption of radionuclides to biosphere materials, which will influence their rate of transport out of the local biosphere (**Sorption**) – Some radionuclides are expected to sorb strongly to biosphere materials, such as the soils and sediments in the region surrounding the site. For the proposed on-site disposals and geosphere, sorption aids in limiting the migration of strongly sorbing radionuclides from entering the biosphere and thus generally decreasing doses/risks to RPs. Conversely, sorption within the biosphere will generally act to limit dilution and dispersion of radionuclides and thus could increase doses/risks to RPs that interact with relevant materials (directly or via food chains).

C54 As an additional safety argument, the interaction between human receptors and the environment dictates the dose/risk received (**RPs**) – The radiological impacts to an RP will vary greatly dependent on the nature of the exposure to contamination. Exposure pathways can include the ingestion of radionuclides in contaminated foodstuffs and/or water, inhalation of radionuclides in air potentially containing radionuclide-bearing dust and external irradiation from contaminated media, including soil, sediment and water.

C.4 Definition of Assessment Cases and Scenarios

C.4.1 Consideration of Uncertainties

C55 As noted in Appendix C.1, Step 3 of the scenario development process involves identification of a set of scenarios, and associated underlying assessment cases, through consideration of safety-related uncertainties that could impact the environmental safety functions (as identified in Appendix C.3) and uncertainties associated with the configuration of the proposed on-site disposals. These considerations are made separately against the Reference Case assessments for the aqueous release dose pathway, and the human intrusion and site occupancy dose pathways, respectively. The human intrusion and site occupancy dose pathways are grouped together because there are strong similarities between these assessments (they both consider only in-situ radioactivity at fixed points in time and use much simpler, more constrained models than the natural evolution assessment). Many of the uncertainties considered are only relevant to the natural evolution model, and those that are relevant to all three assessments tend to be treated the same in the human intrusion and site occupancy assessments, but often differently in the natural evolution assessment.

C56 The Reference Case assessment considers a cautiously realistic representation of the expected evolution of the Winfrith site, defined based on the current understanding of the system comprising the proposed on-site disposals, site characteristics and the local surrounding region (Section 3). Further details on the Reference Case assumptions are presented within the descriptions of the conceptual models that underpin the assessment (see Sections 5 and 6).

C57 Safety- and configuration-related uncertainties associated with the requirements of the GRR have been captured for the Winfrith site through implementation of the GRR UMM developed by NRS [166]. Central to the methodology is the systematic recording of GRR-related uncertainties identified during development of GRR-related documentation together with identification of the planned NRS uncertainty treatment (and, where possible, the ultimate close-out justifications for the uncertainties). Uncertainties are generally collated in an Appendix in each GRR-related report, with the aim of populating a central database. The key reports and uncertainties used to inform this step of the Winfrith radiological assessment scenario development process are:

- The Winfrith Conceptual Site Model [194, §10].
- The Winfrith Radiological Inventory Report [192, App.A].
- The A59 Inventory Report [195, App.A]
- The Winfrith Site Description Report [179, App.A].
- The Phase 2 Draft Winfrith Performance Assessment Report [196, App.B].

C58 Table C.8 maps the safety- and configuration-related uncertainties reported in these documents, along with additional uncertainties identified during the methodological development of this Winfrith performance assessment (Appendix A), to the environmental safety functions identified in Appendix C.3. Each uncertainty is discussed in terms of its treatment in the performance assessment, with four approaches considered:

- *Tolerate based on qualitative or bounding arguments*. For some uncertainties it can be argued qualitatively that they are unlikely to negatively influence the radiological performance of the disposal system or that their likely impact, in terms of radiological performance, can be implicitly bounded by quantitative assessment cases developed for other uncertainties[61]. Thus, the uncertainty can be tolerated without specific quantitative consideration. Within Table C.8, uncertainties that can be tolerated in this way are identified with orange shading[62].
- *Cautious parameterisation or modelling*. For uncertainties that are difficult to constrain, those associated with complex processes that can be cautiously simplified, or associated with processes that are unlikely to have a significant radiological impact, cautious parameterisation or modelling can be used to bound their influence. Within Table C.8, uncertainties that are managed through the use of cautious parameterisation or modelling are identified with blue shading.
- *Explore through additional assessment cases or scenarios*. The radiological impact of some uncertainties can only be sufficiently captured by undertaking one or more additional assessment cases or scenarios. For this treatment approach, four options are identified:
  - “Alternative” assessment cases. These assessment cases investigate the impact of parameter uncertainty in the Reference Case assessment. All alternative assessment cases, and the Reference Case assessment itself, are part of the “expected evolution” scenario. Within Table C.8, uncertainties explored through definition of alternative cases are shaded light green.
  - “Variant concept” scenarios. These scenarios investigate uncertainty in the conceptual model, including uncertainty in the future evolution of the proposed on-site disposals and their setting. It is important to highlight that whilst they are all considered credible, the probability of occurrence of each is not the same, and is likely to vary greatly between the scenarios. Within Table C.8, uncertainties explored through definition of variant concept scenarios are shaded a dark green.
  - “Variant configuration” scenarios. To address Requirement R13 of the GRR [165], an optimisation exercise is being undertaken to determine the configuration of individual features. The most likely configuration is used in the expected evolution scenario, and variant scenarios are used to investigate the impact of different potential configurations. Within

61 For example, the size and shape of rubble particles is expected to influence radionuclide leaching and transport in the near-field. However, this uncertainty can be explored and bounded through alternative assessment cases considering density and porosity (see Table C.8 for further discussion).

62 Note that this use of the word “tolerate” is narrower than the definition used in the NRS UMM.

Table C.8, uncertainties explored through definition of variant configuration scenarios are shaded a mid-green.

– “What-if” scenarios. These scenarios are considered to be highly speculative and are not deemed credible future outcomes. They do not reflect the general uncertainty in the evolution of the disposal system, but can be used to explore the system performance in particular hypothetical situations. Within Table C.8, uncertainties explored through definition of what-if scenarios are shaded bright green.

Table C.8: Safety- and configuration-related uncertainties, and their treatment in the Winfrith performance assessment, mapped to the FEPs associated with the environmental safety functions identified in Appendix C.3. Colour shading denotes the treatment approach outlined above, and can be summarised as "tolerate", "cautious parameterisation or modelling", "alternative" assessment cases, "variant concept" scenarios, "variant configuration" scenarios and "what-if" scenarios. All uncertainties identified during the methodological development of this Winfrith performance assessment (i.e. those with a reference number starting "PA" in the right-most column) are also captured in Appendix A.

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA		Reference no. and relevant reports
					Natural evolution model	Human intrusion and site occupancy models	
Near-field	Radiological inventory	Activity (SGHWR)	SGHWR outbuildings, subsurface and contaminated land	Other outbuildings and structures exist in close proximity to the SGHWR, as well as the subsurface beneath the SGHWR which is inaccessible. Contaminating events with a ground impact have taken place historically in and around the SGHWR and whether a residual inventory exists as a result is uncertain.	It is assumed that any radiological inventory associated with external SGHWR outbuildings and structures is negligible, or that these features will be removed prior to the IEP. Any existing contaminated land inventory beneath the SGHWR is assumed to be OoS. These features are not considered in the PA.		INV-SGHWR-001 [192]
			SGHWR estimated inventory	Uncertainties associated with the derived SGHWR inventory estimates: • Uncertainties in the application of waste fingerprints and whether they capture all radionuclides. • Material densities used to derive activity estimates are not based on site measurements. • Although a significant quantity of radiological characterisation data was used to derive the inventory, no statistical analysis of robustness (including spatial distribution) has been undertaken. • Only two cores define the contamination profile in the bioshield. • Some rooms in the SGHWR have not been characterised at all.	The Reference Case uses a cautious best estimate inventory for SGHWR features. For the bioshield estimate, conservative assumptions and simplifications were made and activation modelling was also used. The rooms with no characterisation data typically have no process history and are assumed to be inactive. However, inventories for uncharacterised rooms with a process history (or other likely contamination pathways) have been derived based on data for rooms expected to have a similar contamination profile and pathway. To account for these uncertainties, the PA includes calculations to assess alternative, more conservative, inventory estimates of components (alternative assessment case EE1.1 in Table C.9 and alternative assessment case HI.1.1 in Table C.10). The alternative inventory estimates were derived in the Radiological Inventory Report.		INV-SGHWR-002 INV-SGHWR-003 INV-SGHWR-004 INV-SGHWR-005 INV-SGHWR-006 INV-SGHWR-007 INV-SGHWR-010 [192]
			SGHWR ongoing and future contamination	Ongoing and planned activities in the SGHWR may contribute to the overall disposal inventory. Segmentation of the reactor core will involve activities in a number of areas spanning the primary and secondary containments as well as parts of the ancillary areas. The contribution to the final inventory of these activities is not accounted for in the disposal inventory assessed in the PA.	For some rooms with ongoing or planned active operations, no inventory contribution has been derived. It is assumed any contamination arising in these areas will be decontaminated to OoS prior to demolition and disposal. In other areas, the inventory is based on what is currently known and takes no account of potential additional inventory from ongoing activities. However, any additional inventory is assumed to be bounded by the alternative assessment cases assessing the alternative inventory estimates (EE.1.1 in Table C.9 and HI.1.1 in Table C.10).		INV-SGHWR-009 [192]
			SGHWR mortuary tubes characterisation	The SGHWR mortuary tubes contain active items that are yet to be removed. There are no sampling data from the mortuary tubes on which to base an inventory and the amount of contamination remaining following the removal of the items is unknown.	The mortuary tube inventory estimate adopted in the PA Reference Case is regarded as preliminary, a speculative inventory conservatively derived based on the potential sources of contamination. The preliminary nature of this inventory estimate is accounted for in the alternative assessment cases assessing the alternative inventory estimates (EE.1.1 in Table C.9 and HI.1.1 in Table C.10).		INV-SGHWR-011 [192]
		Activity (Dragon)	Dragon characterisation data	Uncertainties associated with Dragon inventory estimates: • Although a significant quantity of radiological characterisation data was used to derive the inventory, no statistical analysis of robustness (including spatial distribution) has been undertaken. • Some areas have not been characterised at all. • The proportion of surface contamination present is thought to be low, but there is no data to confirm this. • There is currently limited characterisation data for residual contamination from the PGPC spill. Regarding the bioshield inventory estimate: • No samples from areas known to contain barytes concrete, which may be indicative of higher activation levels.	The Reference Case uses a cautious best estimate inventory for Dragon reactor complex features. Areas with no characterisation data are typically low-risk in relation to their potential radiological impact on the inventory. To account for these uncertainties, the PA includes calculations to assess alternative, more conservative, inventory estimates of components (alternative assessment case EE.1.1 in Table C.9 and alternative assessment case HI.1.1 in Table C.10). The alternative inventory estimates were derived in the End State Radiological Inventory Report.		INV-DRAGON-002 INV-DRAGON-004 INV-DRAGON-005 INV-DRAGON-006 INV-DRAGON-007 INV-DRAGON-010 [192]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
				• No activation modelling of the Dragon bioshield has been undertaken; activation modelling of the SGHWR bioshield supports the inventory derivation. • The specification and extent of the ordinary concrete, barytes concrete and rebar in the bioshield is not known.			
			Remaining Dragon structures and contaminated land	Other plant, outbuildings and external structures exist as part of the Dragon Complex, for which no inventory has been derived. No inventory associated with contaminated land surrounding the Dragon Complex has been derived. Within B70 there is the potential for some low-level actinide contamination beneath the fuel carousel and fission product contamination in the steel-lined sump beneath the reactor; these areas can only be characterised once accessible. No inventory associated with the additional mortuary hole system, the metal lining of the storage pit, or the bulk concrete into which the primary mortuary hole structure is set, is derived.	It is assumed in both the Radiological Inventory Report and the PA that such components are either radiologically uncontaminated, OoS of RSR, or will be decontaminated prior to their demolition and removal from site.		INV-DRAGON-001 INV-DRAGON-009 [192]
			Dragon mortuary hole characterisation	There is uncertainty associated with the Dragon mortuary hole system inventory estimate following the 2023 characterisation campaign: • The fingerprint of the fixed contamination and the ratio of loose to fixed contamination in the Dragon mortuary holes is uncertain. • The pick-up efficiency of smears and the appropriate surface area for the full-height smears are uncertain. • There has been no direct characterisation of some parts of the system including bottom cross vents.	The mortuary hole inventory estimate adopted in the PA Reference Case is regarded as a cautious best estimate. With medium confidence in the inventory estimate following the systematic 2023 characterisation campaign, the mortuary holes contribute less than 1% to the overall Dragon inventory preliminary and is therefore considered to be a relatively low risk component. Remaining uncertainties accounted for in the alternative assessment cases assessing the alternative inventory estimates (EE.1.1 in Table C.9 and HI.1.1 in Table C.10).		INV-DRAGON-008 [192]
			Dragon general building contamination	The possibility of Pu isotopes being included in the Dragon general building contamination cannot be ruled out.	The Radiological Inventory Report derives an alternative inventory for Dragon (separate to those in alternative assessment cases EE.1.1 and HI.1.1, but equivalent in total activity) that includes Pu isotopes. Although this is based on items removed during decommissioning and is therefore not considered a realistic fingerprint for the on-site disposals, assessment of this alternative inventory allows exploration of the impact of the potential presence of Pu isotopes on doses. This is considered in alternative assessment case EE.1.2 in Table C.9 and alternative assessment case HI.1.2 in Table C.10.		INV-DRAGON-007 [192]
		Activity (A59)	A59 characterisation data	Although the current reference inventory estimate suggests that all A59 features are already OoS, there remain many uncertainties in this estimate (listed below) and future characterisation may show otherwise. If needed, the A59 area (in particular the two current APCs) will be remediated to OoS. Uncertainties associated with the A59 inventory estimate: • The inclusion of pre-remediation samples cannot be excluded, and the approach taken to verify the success of the remediation may not be robust. • A59 waste fingerprints may not be fully representative of the residual contamination, and the presence of mobile contaminants is uncertain. • The dataset includes many elevated LOD values. • Radioactive decay over the period of sample collection and analysis is not taken into account. • Density and moisture content of the contaminated soil are not based on site-specific values.	The Reference Case uses a cautious best estimate inventory for A59, as described in the A59 Inventory Report [195], which is already OoS. Conservative assumptions have been made where appropriate and a variety of approaches used to fill gaps in the dataset. To account for the remaining uncertainties, the PA includes calculations to assess alternative, more conservative, inventory estimate(s) for A59 features (alternative assessment case EE.1.1 in Table C.9 and alternative assessment case HI.1.1 in Table C.10). The alternative inventory estimate(s) were derived in the A59 Inventory Report [195] and are also summarised in the Winfrith Radiological Inventory Report [192]. They assume maximum instead of average activity concentrations and are then scaled so that activities just meet OoS criteria.		A59-001 A59-003 A59-004 A59-005 A59-006 A59-007 A59-008 A59-011 A59-013 A59-015 A59-016 [195] INV-A59-001 [192]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA		Reference no. and relevant reports
					Natural evolution model	Human intrusion and site occupancy models	
				• Lack of characterisation data for the infill. • The contribution to the inventory of background radioactivity is not well constrained. • No statistical analysis of robustness (including spatial distribution) of the dataset has been undertaken.			
			Contaminated land near A59	Contamination has been inferred to be present adjacent to/under the road/hard-surfacing area at the edge of A59, near Area 4/HVA. This is excluded from the A59 inventory estimate.	It is assumed in both the Inventory Reports and the PA that this area will be remediated as part of final site clearance, and that shallow material does not migrate into the A59 area.		A59-002 [195]
			Geometry and distribution of contamination (both in-situ and infill)	Both the lateral and vertical distribution of contamination is uncertain: contaminant concentrations are known to be "spotty" and no bottom depth has been determined. The proportion of remediated soil removed from site/used for infill, and the volume of material used to backfill the different A59 areas, are uncertain.	The Reference Case uses a cautious best estimate inventory for A59. A method accounting for the "spottiness" of contamination has been developed and applied to reduce the impact of over-representing zones of elevated contamination, and conservative assumptions have been made regarding depth of contamination and infill volumes.		A59-009 A59-010 A59-012 A59-014 A59-017 [195]
		Activity	Radionuclides	The radionuclides assessed in the PA are based on the Winfrith End State Radiological Inventory Report, with those that cannot contribute significantly to future radiological impacts (due to, for example, being present with low activities and/or having short half-lives) screened out. The screening exercise was performed separately for natural evolution and human intrusion. The impact of screening out radionuclides on calculated doses is uncertain. The GIM tool used in the human intrusion model does not include all radionuclides in the screened list for the natural evolution model; the impact of this on calculated doses is uncertain.	The PA natural evolution model adopts the screened lists of radionuclides in the assessment calculations, on the basis that the screened-out radionuclides would not make a significant contribution and the overall impact would be minimal.	The human intrusion model uses the list of radionuclides available in the GIM tool. This uncertainty is tolerated because it is not possible to add additional radionuclides to GIM.	PA-001
			Soil radiochemistry	The average levels of Pb-210, Ra-226 and Th-232 in the soil are elevated (greater than EPR16 levels); the reason for this elevation is uncertain.	All assessment cases and scenarios of the PA includes assessment of these nuclides as per the radionuclide screening exercise. The dose impact of the elevated levels is assessed.		SD-008 [179]
		Decay	Decommissioning timescales	Winfrith decommissioning timescales (including dates of the IEP and SRS) are uncertain and may be revised.	The Reference Case for the natural evolution assessment adopts a start date (and point at which releases from A59 are modelled) of 1 January 2027. The Dragon and SGHWR end states are assumed to be implemented in 2029 and 2032 respectively, at which point degradation, saturation, and radionuclide release are possible. The model cautiously assumes immediate unrestricted use of the site/exposure to contamination. However, results are considered in the context of an assumed IEP date of 2036 and an assumed SRS date of 2066, and it is acknowledged that some RP activities would not be possible before the SRS. The dose constraint (GRR Requirement R9) applies until the SRS and the risk guidance level (GRR Requirement R10) thereafter.	The Reference Case assumes that no site occupancy activities involving living on the site, and no human intrusion activities, could take place before the assumed SRS date of 2066. Other site occupancy activities are assessed at the assumed IEP date of 2036. In the human intrusion assessment, further calculations have been undertaken at dates earlier than 2066 (to inform NRS decision making) and, where the GRR Requirement R11 dose guidance level is exceeded at the SRS, beyond 2066 (to identify when the calculated dose falls below the dose guidance level). These are covered by alternative assessment case HI.1.3 in Table C.10.	PA-002
		Heterogeneity	All radioactive source areas in the	The inventory, materials, and water associated with the facility are not distributed homogeneously in the PA source areas. This is partly because the decommissioned facilities will retain some	Assessment models typically use a limited number of "cells" for which it is assumed that materials and inventory are always in contact and homogeneous. For most features, events and processes this is a conservative approach.		PA-003

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA		Reference no. and relevant reports
					Natural evolution model	Human intrusion and site occupancy models	
			decommissioned facility	structure, but also due to the nature of backfilling operations and the distribution of inventory on the engineered structures and backfill material. Localised features could have a significant impact on processes such as aqueous chemistry, activity release, sorption and flows.	It is assumed that features, events and processes for which this assumption may not be conservative (for example areas of higher activity, preferential flow within the facility) are not significant for the groundwater pathway. For the groundwater model, the inventory is assumed to be evenly distributed within source areas defined to reflect the main structures and zones of activity (e.g. bioshield, annexes).	In the human intrusion and site occupancy assessments, localised features that represent areas of elevated activity are explicitly considered, with intrusion cases designed to be worst cases (i.e. intersect the most active features).	
	Radionuclide containment	Sorption	Sorption properties in the near field	There are limited site-specific data to describe the sorption properties of the cement-based materials in the SGHWR and Dragon reactor.	The PA uses generic sorption data for cementitious materials. To account for uncertainties, a range of K_d values are used; two alternative assessment cases (Cases EE.1.3 and EE.1.4 in Table C.9) within the expected evolution scenario adopt minimum and maximum values, while the Reference Case uses a mid-range "most likely" value.	Not relevant to human intrusion or site occupancy models	PA-004
		Solubility	Radionuclide solubility	The role of solubility in limiting radionuclide transport in the near field is uncertain.	Following the approach taken in the 2023 natural evolution assessment for the Trawsfynydd Ponds Complex [164], the PA cautiously assumes unlimited solubility.		PA-005
		Chemical degradation of materials	Chemical degradation of concrete, grout, cap	The evolution of chemical properties associated with the in-situ structures, any grouted demolition arisings, and the engineered cap are uncertain.	In the Reference Case, the duration of chemical degradation is assumed to be 50,000 years. The rate of concrete leaching, which is judged to be the most important chemical degradation process, is assumed to be linear with time over this period. To bound the uncertainty, a variant scenario is assessed assuming that chemical degradation takes place on the same timescale as hydraulic degradation (1,000 years) (Scenario VA.1 in Table C.9).		PA-006 CSM [194, §5.1]
	Hydraulic containment	Radionuclide mobilisation	Release from source areas	The release mechanisms that will act within the SGHWR and Dragon reactor source areas are uncertain. A variety of mechanisms and rates of release are possible, depending on the nature and location of the activity (activation- or contaminated-induced; on the surface or within the solid matrix), and localised chemical conditions.	Release of radionuclides is cautiously modelled in the PA. The Reference Case assumes diffusive release of contaminants from the source area to the surrounding pore water from the current date, and instantaneous release of activity following saturation. Diffusive transport is cautiously modelled through only considering diffusion towards advective flows (i.e. no diffusion further into the concrete structure). These approaches are considered bounding.	Not relevant to human intrusion or site occupancy models	PA-007
				The role of contaminant diffusion through the walls and base of the SGHWR and Dragon reactor End States is uncertain.	The PA does not model diffusion through the walls and base of the structures to the outside of the void: contamination is assumed to diffuse from the inner contaminated surface into the void pore water and then be advected through assumed cracks to the outside of the void. Advection is assumed to dominate and diffusion is assumed to be negligible. This approach is conservative as it leads to earlier release of contaminants than only considering diffusion through the floor/wall thickness.		CSM6.2 [194]
			Hydraulic properties of intact, undegraded concrete in in-situ structures and concrete blocks used as backfill	The porosity of concrete (in blocks and in-situ) in the SGHWR and Dragon reactors is uncertain.	The Reference Case assumes the porosity of concrete (in blocks and in-situ) in the SGHWR and Dragon reactor is 15% v/v as determined in a review of the porosity of structural concrete by SKB [197]. To bound the impact of uncertainty in porosity in blocks and in-situ concrete, two alternative assessment cases are conducted considering minimum and maximum porosity values; these cases also consider minimum and maximum values for porosity in demolition arisings (Cases EE.1.5 and EE.1.6 in Table C.9).	In the human intrusion and site occupancy assessments, the relevant parameter affected by porosity and density is the mass of contaminated material present (a greater mass would lead to greater doses). Assuming a constant volume (as defined by void dimensions), either decreasing the porosity or increasing the density would result in a greater mass of contaminated material being present. In the models, this	CSM2.11 [194] [194, Table 606/5]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
				The dry bulk density of the concrete (in blocks and in-situ) in the SGHWR and Dragon reactors is not based on site-specific data.	The Reference Case assumes the dry bulk density is 2,400 kg/m^3 as determined in a review of the dry bulk density of structural concrete by SKB [197]. To bound the impact of uncertainty in dry bulk concrete density, two alternative assessment cases are conducted considering minimum and maximum density values; these cases also consider minimum and maximum values for density of demolition arisings (Cases EE.1.7 and EE.1.8 in Table C.9).	impact is controlled by density. In all cases and scenarios, a higher density results in higher doses and is therefore conservative. The Reference Case uses a density of 2,400 kg/m^3 for both intact concrete and rubble infill, which is considered to be bounding of the uncertainty in the properties of intact concrete and all possible infill options.	CSM2.12 [194] INV-SGHWR-003 [192] [194, Table 606/5]
				The initial hydraulic conductivity of in-situ concrete structures and concrete blocks is uncertain.	See subsequent row considering hydraulic degradation and conductivity.		
			Hydraulic properties of rubble demolition arisings used as backfill	The porosity of demolition arisings when placed in the SGHWR and Dragon reactor voids as rubble backfill is uncertain.	The Reference Case assumes the porosity of demolition arisings is 30% v/v based on the minimum void space between spherical particles being 26% and random packing of equal spheres having a porosity of around 36%. To bound the impact of uncertainty in porosity of emplaced demolition arisings, two alternative assessment cases are conducted considering minimum and maximum rubble porosity values; these cases also consider minimum and maximum values for porosity in intact concrete (Cases EE.1.5 and EE.1.6 in Table C.9).	The discussion in the rows concerning porosity and density of undegraded concrete also applies here.	CSM2.17 [194] [194, Table 606/5]
				The density of demolition arisings when placed in the SGHWR and Dragon reactor voids as rubble backfill is uncertain.	Rubble density is a function of intact concrete density and rubble porosity. Uncertainties in rubble density are therefore covered by the alternative assessment cases considering these parameters (Cases EE.1.5, EE.1.6, EE1.7 and EE1.8 in Table C.9).		PA-008
				The hydraulic conductivity of demolition arisings when placed in the SGHWR and Dragon reactor voids as rubble backfill is uncertain.	Hydraulic conductivity of rubble is not used in the PA, as there is no need to use Darcy's law to calculate the flow across the rubble as it is not treated as a structure/wall. Therefore, this uncertainty does not affect the PA results.	Not relevant to human intrusion or site occupancy models	PA-008
			Separate modelling of features	The Winfrith assessment separately models each feature within the on-site disposals and thus assumes there are no interactions between the features that could give rise to situations (radionuclide fluxes or concentrations) for RPs higher than the appropriate sum of those from the individual features.	The Winfrith PA separately models each feature within the on-site disposals and, due to the modelling approach employed, does not consider the possible impacts from interactions between features. This approach of considering features as separate sources, rather than as a single amalgamated source for the whole of the site, is adopted specifically to understand the impacts from the heterogenous distribution of radioactivity across disparate parts of the site. The understanding gained from this approach is expected to help inform prioritisation of future radiological characterisation and design optimisation. Therefore, this uncertainty is tolerated in the Winfrith PA.		PA-024
		Saturation	Integrity of existing structures following demolition and backfilling	The damage to the SGHWR North Annexe and South Annexe caused by the placement of demolition material is uncertain.	The Reference Case assumes that, due to the damage sustained during demolition and placement of arisings, the North Annexe and South Annexe End States will not retain water from the outset (after the IEP). This treatment is assumed to be bounding and no alternative cases are defined specifically to address this uncertainty.	Not relevant to human intrusion or site occupancy models	CSM5.1 [194]
				It is uncertain whether Wall A of the Dragon reactor will suffer loss of integrity during demolition and backfilling due to its conventional structure.	The Reference Case assumes that Wall A will not offer any barrier to groundwater flow after the feature end state is implemented. This treatment is assumed to be bounding and no alternative cases are defined specifically to address this uncertainty.		CSM5.2 [194] PA-025 [198]
				Changes to the integrity of the SGHWR structure as a result of works to prepare the SGHWR for decommissioning (as detailed in the Winfrith Structural Integrity Assessment) are uncertain.	The works are not expected to, and are assumed in the Reference Case not to, demolish any part of the structure other than the core segmentation or result in any damage to the SGHWR structure. The possibility of damage to the integrity of the SGHWR structure is covered by the hydraulic degradation and conductivity variant scenarios discussed below (Scenarios VA.2 and VA.3 in Table C.9), and (in the worst case)		CSM5.3 [194] [199]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
					bounded by the "what-if" scenario of instantaneous hydraulic degradation also discussed below (Scenario WI.1 in Table C.9).		
				Processes affecting structural integrity and gross hydraulic conductivity have been considered for the SGHWR primary containment structure. It is uncertain whether these findings are equally applicable to other structures.	The Reference Case assumes that the processes and effects are applicable to other parts of SGHWR Regions 1 and 2. As this is considered very likely, no alternative cases are defined specifically to address this uncertainty.		CSM5.4 [194] [200]
				The potential for the integrity of the existing structures to be compromised by a natural disruptive event is uncertain.	Following the approach taken in the 2023 natural evolution assessment for the Trawsfynydd Ponds Complex [164], a "what-if" scenario is undertaken that aims to bound the worst-case impact of a natural hazard on the hydraulic properties of the near field. This scenario assumes the hydraulic properties instantly transition to degraded values at the end state (Scenario WI.1 in Table C.9).		PA-009
			Availability of water and flows within the facility	Flows through the SGHWR and Dragon structures will change with time due to changes in rainfall, groundwater levels and degradation of the engineered structures including the cap. In particular, the position of the water level over time is uncertain. It will reflect the balance between infiltration through the cap and leakage through the side walls and floors. It is conceivable that unfavourable hydraulic properties of the engineered cap, or its premature failure, could lead to infiltration rates through the cap exceeding outflow rates from the near field. Under such circumstances, some parts of the SGHWR and Dragon void spaces located above the water table could begin to saturate, and potentially "bathtub" if inflows continue to exceed outflows, which could alter radionuclide transport processes within the near field. Although initial modelling has shown bathtubbing to be unlikely, it cannot be entirely ruled out.	It is likely that, in the long term, the water level will be slightly higher than the regional water table. In the shorter term, while some of the side walls maintain a low permeability, the water level might rise such that there is spill over to the annexes. The Reference Case assumes that the cap engineering promotes this overspill rather than water reaching the ground surface. The remaining uncertainty is captured in the hydraulic degradation and conductivity and future groundwater level variant scenarios discussed below (Scenarios VA.2 and VA.3 in Table C.9). The possibility of bathtubbing is covered by the extreme climate change "what-if" scenario assuming that the water table is 1 m below the ground surface (Scenario WI.2 in Table C.9).	Not relevant to human intrusion or site occupancy models	PA-010 CSM7.1 [194]
		Hydraulic degradation and conductivity	Degradation of in-situ structures, concrete blocks and grout	The initial effective hydraulic conductivity of the SGHWR structures and Wall B of the Dragon reactor, any concrete blocks placed in their voids, and any grouted demolition arisings, is uncertain. Subsequent evolution of the hydraulic conductivity is also uncertain; this includes: • the final effective hydraulic conductivity at the point when further loss in integrity of the structures leads to no further increase in effective hydraulic conductivity, and • the point in time at which this is reached.	The Reference Case assumes that the initial effective hydraulic conductivity of SGHWR structures and Dragon Wall B is 4.4×10^{-11} m/s, based on the current rate of water ingress. It is assumed that the point in time when loss of integrity of the structures leads to no further increase in effective hydraulic conductivity is 1,000 years from the start of the model, and that the effective hydraulic conductivity at this time (i.e. the final hydraulic conductivity) is 2.7×10^{-4} m/s (the mid-point of the range of estimates for the Poole Formation), following a linear evolution. To bound the uncertainty, two variant scenarios are assessed: • A variant scenario in which the initial hydraulic conductivity is assumed to be a minimum value of 1×10^{-12} m/s. The final hydraulic conductivity and degradation time are assumed to be the same as in the Reference Case, and the hydraulic conductivity is assumed to evolve linearly (as in the Reference Case). This is Scenario VA.2 in Table C.9. • A variant scenario in which the initial hydraulic conductivity is assumed to be a maximum value of 1×10^{-9} m/s. The final hydraulic conductivity is assumed to be the same as in the Reference Case and the hydraulic conductivity is assumed to evolve linearly (as in the Reference Case), but the final hydraulic conductivity is reached after 300 years. This is Scenario VA.3 in Table C.9.	Not relevant to human intrusion or site occupancy models	CSM5.5, CSM5.6 CSM5.7, CSM7.1 [194] CSM [194, §5.1] [168]
		Cap design	Cap design optimisation	The disposals/deposits at the SGHWR and the Dragon reactor will be covered by an engineered cap. The current concept cap	Although the details of cap design and A59 cover are uncertain, these are not expected to have significant	Variant configuration scenarios (Scenarios HI.VB.1 and, HI.VB.2 in Table C.10) use	CSM5.8 [194]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
	Engineered cap/cover material (A59)			design, including thickness, will be subject to future optimisation. The A59 area may have clean cover material emplaced on top of it. Its thickness will be subject to future optimisation.	effects on radiological impacts via the groundwater pathway.	thinner caps for SGHWR and Dragon, and thinner cover for A59, than the Reference Case to account for uncertainty in this parameter. A further scenario, HI.VB.3 in Table C.10, considers the impact of no clean cover over the A59 area. Other cap design details are not expected to have any impact on human intrusion doses.	PA-026
		Cap performance	Cap infiltration rate	For the engineered caps, both the initial (design) cap infiltration rate and the long-term cap infiltration rate are uncertain.	For the engineered caps, the Reference Case conservatively assumes an initial (design) infiltration rate of 5 mm/year and a long-term infiltration rate of 43 mm/year, which is the calculated infiltration rate of the mineral liner component (i.e. assuming failure/degradation of geomembrane and geosynthetic clay liner components). The A59 cover material is assumed to have the infiltration properties of soil.	Not relevant to human intrusion or site occupancy models	CSM5.9, CSM5.11 [194]
			Cap membrane liner degradation	The time to onset, and rate of, degradation of the flexible membrane liner of the cap is uncertain.	The Reference Case assumes the time to onset of degradation is 250 years. A linear increase in infiltration rate between the initial infiltration rate and the long-term infiltration rate is assumed for the period of 250 years to 1,000 years. To bound the uncertainty in these parameters, a variant scenario is conducted in which the time to the onset of degradation is halved to 125 years, and the rate of degradation is doubled compared to the Reference Case, such that the long-term infiltration rate is reached 500 years after installation (Scenario VA.4 in Table C.9).		CSM5.10 [194] [194, Section 5.3]
	Configuration	Structures	Geometry	During preparation of this PA, various uncertainties have been identified in the geometry of structures in both the SGHWR and Dragon reactor complexes; both those that will form in-situ disposals and those that will be demolished and used to fill voids (DfaP). These are listed in full in Table A.1.	The geometries adopted in the PA reflect current best available knowledge regarding the structures in question. They are considered to be sufficiently accurate to support mathematical model development, and it is believed that small changes are unlikely to significantly affect calculated radiological impacts. Therefore, this uncertainty is tolerated in the Winfrith PA, but will be kept under review and its treatment will be reconsidered if significant changes to geometry are identified in future.		INV-DRAGON-011 [192] PA-021
				MicroShield® includes built in source (radioactively contaminated/activated structure) geometries. These geometries are simple rectangular, cylindrical and conical volumes. Structures at the Winfrith sites have more complex geometries but have been simplified/approximated to allow for modelling to be carried out. The impact of this simplification on site occupancy doses is uncertain.	Not relevant to natural evolution model	The uncertainty is tolerated on the basis that its impact is likely to be minimal in comparison to the uncertainties in radiological inventory and thickness of contaminated/activated layers.	PA-022
		Voids	Void volumes	Void volumes have been estimated by scaling from drawings and without the benefit of a three-dimensional computer model. These estimates are for the purposes of conceptualisation to support mathematical model development and are not for underpinning detailed design.	The estimated volumes for SGHWR voids are within approximately 5% of those determined by UKAEA using a three-dimensional computer model prior to subdivision of the SGHWR regions. Based on this comparison, the estimated void volumes for both SGHWR and Dragon are deemed sufficiently accurate to support mathematical model development.		CSM2.2 [194] [201]
				There is uncertainty associated with the space occupied by internal structures, such as walls and floors, in the SGHWR and Dragon reactors. The volume of internal structures is uncertain, and this impacts the available void volumes.	The void volumes adopted in the PA account for the volumes occupied by internal structures. For SGHWR the volume of internal structures was calculated by a 2006 UKAEA assessment. For Dragon, the volume was calculated in the 2021 Waste Recovery Plan. These values for the volume of internal structures are considered to be sufficiently accurate to support mathematical model development.		CSM2.5, CSM2.6 [194] [201], [202]
			Void space between blocks	The amount of void space between the blocks placed in the SGHWR and Dragon reactors is uncertain.	The Reference Case assumes that the void space between the blocks is 10% of the total volume occupied by blocks; this is judged to be a conservative assumption. Increasing the void space between blocks could increase water flow and hence increase radionuclide leaching from the blocks. To explore this, a variant	Not relevant to human intrusion or site occupancy models	CSM2.8 [194] [203, Tab. 2 and 3]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
					scenario is undertaken assuming that the void space between the blocks is a greater proportion of the total volume occupied by the blocks (Scenario VB.1 in Table C.9).		
		SGHWR and Dragon backfill strategies	Relative use of blocks and demolition arisings as backfill	The relative volume of blocks versus demolition arisings (rubble) to be placed in the SGHWR, and their emplacement locations, is uncertain.	The Reference Case assumes blocks are placed in the deepest basal areas of the SGHWR Region 1. The volume of blocks is assumed to be 6,300 m^3. Demolition arisings are assumed to be placed above the blocks in the SGHWR Region 1, and in Region 2, the North Annexe and the South Annexe. A variant scenario is undertaken (Scenario VB.2 in Table C.9) assuming that no blocks are emplaced and the SGHWR voids are entirely filled with rubble.	Conservative density used (see discussion above).	CSM2.13, CSM2.14, CSM2.21 [194] INV-SGHWR-007, INV-SGHWR-008 [192]
				The relative volume of blocks demolition arisings (rubble) to be placed in the Dragon reactor, and their emplacement locations, is uncertain.	The Reference Case assumes blocks are placed in the deepest basal areas of the Dragon reactor within Wall C. The volume of blocks is assumed to be 400 m^3. Demolition arisings are assumed to be placed above the blocks within Wall C, and in all void space outside of Wall C. A variant scenario is undertaken (Scenario VB.2 in Table C.9) assuming that no blocks are emplaced and the Dragon voids are entirely filled with rubble.		CSM2.19, CSM2.20, CSM2.21 [194] INV-DRAGON-002 INV-DRAGON-003 [192]
			Degree of homogenisation of demolition arisings used as backfill within each reactor complex	It is uncertain whether the demolition arisings from specific components (e.g. bioshield) will be emplaced separately in local voids or whether there will be mixing of the arisings from different components of each reactor complex (and to what degree) before emplacement in the voids.	It is assumed in the PA that demolition arisings from individual components are emplaced separately in local voids. This is considered to be conservative as it maximises the backfill activity for the most active features.		PA-011
			Grout used with backfill	The extent to which grout will be used with the demolition arisings and blocks emplaced in the SGHWR and Dragon voids has yet to be optimised.	The Reference Case assumes that no grout is used with either the demolition arisings and blocks used as backfill. A variant scenario considers the impact of grouting the entire volume following backfilling (Scenario VB.3 in Table C.9). In this case, the grouted backfill is assumed to have the same hydraulic properties as the in-situ structures and concrete blocks.	Conservative density used (see discussion above).	CSM2.4 [194]
			Backfill material properties	The shape of the blocks to be placed in the SGHWR and Dragon reactor is uncertain and will be determined by the wireline cutting design and the part of the structure being demolished.	Due to modelling constraints, all blocks are assumed to have a cubic shape. The main impact of different and/or uneven block shapes would be to increase the void space between blocks, which is already accounted for in the PA by a variant scenario (Scenario VB.1 in Table C.9).	Not relevant to human intrusion or site occupancy models	CSM2.9 [194]
				The size of the blocks placed in the SGHWR and Dragon reactor will vary: up to 2.4 m^3 for SGHWR and up to 1 m^3 for Dragon.	In the Reference Case, all blocks are assumed to have a volume of 1 m^3. A smaller block size would be expected to result in greater radionuclide leaching from the blocks. To bound the uncertainty, variant scenarios are conducted using a small (0.5 m^3) and large (2 m^3) block size (Scenarios VB.4 and VB.5 in Table C.9).		CSM2.10 [194]
				The shape of particles of demolition arisings to be emplaced in the SGHWR and Dragon reactor (both generated in-situ from above-ground structures and taken from the D630 stockpile) is unknown, and there is variation in the particle size distribution.	Due to modelling constraints, the shape and size of rubble particles is not modelled explicitly; instead, the rubble backfill is assumed to be concrete with an appropriate density and porosity (parameters which would be affected by particle size and shape).		CSM2.16, CSM2.18 [194]
					Uncertainty in particle size and shape is therefore covered by the alternative assessment cases considering density and porosity (Cases EE.1.5, EE.1.6, EE.1.7 and EE.1.8 in Table C.9).	Conservative density used (see discussion above).	

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
		Materials within the source area	Rebar	It is uncertain how much rebar will be removed from the arisings generated by SGHWR and Dragon demolition.	The radioactive material mass is assumed to be 100% concrete for the release of radioactivity. This is considered to be acceptable for the following reasons: It is intended to remove as much metal as possible from demolition arisings before emplacement in voids; any remaining metal will be a small volume so is unlikely to significantly impact the model results. The activation associated with the rebar is conservatively included in the inventory even though the metal is not modelled. It is also conservatively assumed that all contamination is in a thin surface layer; this is considered to more than bound the uncertainty relating to rebar removal.		CSM3.4, CSM3.9 [194]
Geosphere	Dispersion	Geosphere flow conditions	Longitudinal dispersion	There is uncertainty regarding the degree of longitudinal dispersion along the saturated and unsaturated pathways.	In the saturated and unsaturated pathways a longitudinal dispersivity of 10% of the pathway length is assumed. This is a standard approximation of the effects of longitudinal dispersion, as described in the GoldSim Contaminant Transport Module user's guide.	Not relevant to human intrusion or site occupancy models	CSM6.12 [194]
			Transverse dispersion	There is uncertainty regarding the degree of transverse (lateral and vertical) dispersion along the saturated and unsaturated pathways.	The effects of transverse dispersion are conservatively disregarded.		CSM6.13 [194]
				Lateral dispersion of contaminants may occur as they migrate through the unsaturated zone to the water table.	The width of the unsaturated pathway beneath the SGHWR annexes and the Dragon reactor is conservatively assumed to be limited to the footprint of the structure above.		CSM6.4 [194]
			Saturated pathway	Both the superficial deposits and the Poole Formation can be locally confined with depth or where extensive clay layers exist.	Both the superficial deposits and Poole Formation are conservatively assumed to be unconfined in the PA.		CSM6.3 [194] SD-023 [179]
		Release	Groundwater release locations – SGHWR	As explained in Section 5.3.1, groundwater flow across the Winfrith site is generally from topographic high areas in the west and southwest to topographic low areas in the northeast and east towards the River Frome [204]. After the IEP, groundwater from the SGHWR is modelled to flow towards the River Frome, emerging either in the river itself or in low-lying marshy land close to the river [204, Fig.604/51]. However, depending on the hydrological conditions (and the mire location and extent), emergence in the proposed mire location and/or to land west of the Monterey roundabout is possible. Therefore, both the River Frome and the combined Land/Mire compartment are considered to be default locations for groundwater releases from the SGHWR. Under some conditions, groundwater may also flow from SGHWR towards the Dragon area [173], where it would join with releases from Dragon, eventually entering the River Frome. Hence, there is uncertainty regarding the distribution of flow over the range of possible release pathways, particularly for assumptions about a wetter future climate.	The Reference Case assumes that 50% of groundwater from SGHWR flows towards and emerges in the River Frome, and 50% flows towards and emerges in the Land/Mire compartment. Three variant scenarios (VA.5, VA.6 and VA.7 in Table C.9) consider 100% of the groundwater flow from SGHWR going to the River Frome, the Land/Mire compartment, and the Dragon area respectively. (Scenarios VA.5 and VA.6 also assume 100% of groundwater flow from A59 goes to the River Frome and the mire respectively; this ensures use of the pathway is maximised. Scenario VA.7 continues to assume that 50% of groundwater flow from A59 goes to the River Frome and 50% to the mire, to identify the impact of the SGHWR change alone.) Between them, these variant scenarios are assumed to bound the range of possible groundwater release pathways from SGHWR. To simplify calculations, the possibility that, under wetter conditions, groundwater may emerge in marshy land next to the River Frome is not explicitly modelled. Such land is considered to be an extension of the river. Additionally, the Park User RP accounts for doses received via the interaction of river water with adjacent land.	Not relevant to human intrusion or site occupancy models	PA-012 [173], [204]
			Groundwater release locations – A59	As explained in Section 5.3.1 and based on flow modelling [173; 204], both the River Frome and the Land/Mire compartment are considered to be default locations for groundwater releases from the A59 area, but there is uncertainty over the proportion reaching each location under different conditions (in addition to uncertainty regarding the mire location and extent).	The Reference Case assumes that 50% of groundwater from the A59 area flows towards the River Frome and 50% flows towards the mire. Two variant scenarios (VA.5 and VA.6 in Table C.9) consider 100% of flow from A59 to the River Frome and the mire respectively. (These scenarios also assume 100% of groundwater flow from SGHWR goes to the River Frome and the mire respectively; this ensures use of the pathway is maximised.) These are assumed to bound the range of possible groundwater release pathways from A59.		PA-013 [173], [204]

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
			Groundwater release locations – Dragon	As explained in Section 5.3.1, groundwater release from the Dragon reactor structures is expected to join the River Frome [173; 204]. However, groundwater modelling of the Winfrith end state suggests there could be emergence to marshy land near to the Frome in the future.	The Reference Case assumes that 100% of groundwater from Dragon enters the River Frome. To simplify calculations, the possibility that, under wetter conditions, groundwater may emerge in marshy land in front of the River Frome is not explicitly modelled. Such land is considered to be an extension of the river. Additionally, the Park User RP accounts for doses received via the interaction of river water with adjacent land.		PA-014 [173], [204]
			Groundwater emergence points to each location	Contaminated groundwater is likely to emerge at several points across the same feature, particularly after artificial drainage ceases to operate, thereby diluting the impact calculated for a single location. Distinct groundwater flow pathways from different feature groups may also enter the River Frome at different points.	The natural evolution model cautiously assumes that all of the groundwater emerges at a single place to a surface water feature or piece of land, and that the distinct groundwater flow pathways from all feature groups join the River Frome at the same point.		PA-027
	Dilution	Water balance	Water flow beneath and around structures	The deepest parts of SGHWR Regions 1 and 2 rest on clay and Regions 1 and 2 are defined by structures with thick base slabs. There is uncertainty about how much water can move through the base slabs and into the clay.	Due to both geology and the base slab thickness, contaminants are assumed to migrate only through the sidewalls, and not the base slabs, of SGHWR Regions 1 and 2 structures to the saturated Poole Formation.	Not relevant to human intrusion or site occupancy models	CSM6.6 [194] SD-019 [179]
				The potential for groundwater to flow beneath or around all four regions of the SGHWR is uncertain.	Groundwater flow lines are likely to pass beneath one or two of the four regions of the SGHWR only. However, to ensure account is taken of the potential cumulative effect of leakage from all four regions, it will be assumed that there is a groundwater flow line that can pass beneath both the South Annexe and North Annexe as well as around or through Regions 1 and 2.		CSM6.8 [194] SD-019 [179]
			Unsaturated zone	The unsaturated zone beneath most of the plan area of the SGHWR annexes is the Poole Formation. However, there are also voids filled with gravel and zones of mass concrete.	The volumetrically smaller elements of the unsaturated zone are ignored for the purposes of the PA as they are expected to have a negligible impact; the unsaturated zone is assumed to consist only of the Poole Formation.		CSM6.7 [194]
			Saturated zone	There is uncertainty over the role of the "rubble" drains (open-channel ditches which collect, store and convey drained surface water) as preferential pathways for groundwater movement and contaminant transport.	It is intended that the "rubble" drains will either be removed or broken up to prevent them from acting as preferential pathways. It is therefore assumed in the PA that these will not become preferential pathways for groundwater movement and contaminant transport.		CSM6.9 [194]
			Impacts of climate change	The impact of climate change on regional groundwater levels, groundwater flows and future hydrogeological conditions is uncertain. The impact of seasonally fluctuating groundwater into the SGHWR Annexes and Dragon basement is uncertain.	Impacts of climate change are modelled in the PA via rainfall infiltration rates and groundwater levels. Due to the caps that will be constructed above the reactor complexes, infiltration rates for SGHWR and Dragon are a function of cap degradation (regardless of rainfall rates) and the impact of a higher infiltration rate is explored through the shorter cap degradation variant scenario (VA.4 in Table C.9). For A59, the impact of a higher infiltration rate is explored through a variant scenario with increased rainfall infiltration rate through soil (Scenario VA.8 in Table C.9). The Reference Case uses a cautious central estimate of future groundwater levels for SGHWR, Dragon and A59. A variant scenario (VA.9 in Table C.9) uses a reasonable worst-case estimate of future groundwater levels. A variant scenario (VA-10 in Table C.9) uses the same reasonable worst-case estimate of future groundwater levels and also considers seasonal fluctuations. An extreme climate change "what-if" scenario (WI.2 in Table C.9) considers the impact of the water table rising to 1 m below the ground surface.	Not relevant to human intrusion or site occupancy models	CSM6.5, CSM6.11, CSM7.1 [194] SD-033, SD-035, SD-037 [179] PA-015

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model	Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
				The future flood risk at the site is uncertain.	The future flood risk of the site is linked to climate change. This uncertainty is covered by the "what-if" extreme climate change scenario (WI.2 in Table C.9).		SD034 [179]
			Impacts of erosion	Rates of coastal erosion at Worbarrow Bay, and fluvial erosion rates by the River Frome, are poorly constrained.	The coast and the River Frome are both sufficiently far from the site that impacts will be negligible.	Not relevant to human intrusion or site occupancy models	SD-016, SD-018 [179]
				Surface erosion rates and specific soil vulnerability are unknown.	Heathland is vulnerable to erosion, particularly with increased public access. Surface erosion would result in an increased elevation of the water table relative to the land surface and shorter groundwater release pathways; these are bounded in the PA by the variant groundwater release scenarios (VA.5 to VA.7 in Table C.9), and the variant (VA.9 in Table C.9) and "what-if" groundwater level scenarios (WI.2 in Table C.9).	Surface erosion would reduce the thickness of material above the waste; this is bounded by variant configuration scenarios considering different cap thicknesses (HI.VB.1 and HI.VB.2 Table C.10).	SD-017 [179]
	Sorption	Sorption properties of the geosphere	Sorption in the geosphere	There are limited/no site-specific data to describe the sorption properties of the Poole Formation.	Generic sorption data for sand and clay materials are used in the absence of site-specific data. Alternative assessment cases using K_d values representing minimum and maximum geosphere sorption are undertaken to bound the uncertainty (Cases EE.1.9 and EE.1.10 in Table C.9).	Not relevant to human intrusion or site occupancy models	SD-011 [179]
	Geological configuration	Physical properties of geological layers	Thickness of geological layers	There are uncertainties associated with the thickness of the Poole Formation and London Clay. In particular, the variable lithology of the London Clay in the region results in uncertainties about the thickness of this unit.	The interpretation of the stratigraphy does not affect the nature of the material beneath the SGHWR (a thick clay aquitard, either a clay lens of the Poole Formation, or the top of the London Clay) and hence has negligible effect on the hydrogeological interpretation of the site or the PA results.		SD-009, SD-036 [179]
Biosphere	Sorption	Sorption properties of the biosphere	Sorption in the biosphere	There are limited/no site-specific data to describe the sorption properties of the Winfrith site biosphere elements (soil, mire sediments, fluvial sediments).	Sorption of radioelements to soil, lake sediments and fluvial sediments will control how quickly radioelements are dispersed into the wider biosphere. Following the approach taken in the 2023 natural evolution assessment for the Trawsfynydd Ponds Complex [164], the impact of this uncertainty is explored by undertaking two alternative assessment cases that consider estimated minimum and maximum partition coefficients for soils and sediments (Cases EE.1.11 and EE.1.12 in Table C.9).	Not relevant to human intrusion or site occupancy models	PA-016
	RPs	Scenario-specific RPs	Natural disruptive events – heathland fire	Heathlands have a high risk of fire; as the planned end state for the Winfrith site is heathland, the possibility of a significant fire cannot be ruled out.	A fire would generate significant quantities of dust, leading to increased uptake of dust by all RPs with an inhalation pathway. However, a fire would cover a much larger area than just the on-site disposals, and the additional dust inhaled would be a mixture of clean and contaminated material. It is considered that this situation would be bounded by an RP working on contaminated land and inhaling only contaminated dust.		PA-017
			Groundwater abstraction	As groundwater abstraction via wells is an observed present-day habit in the wider area, the possibility of such a well in the future intersecting contaminated groundwater cannot be ruled out. If this were to happen close to any of the source terms it could potentially lead to an RP receiving a relatively significant dose.	Three variant scenarios (VA.11, VA.12 and VA.13 in Table C.9) consider the impact of a scenario-specific RP (Well Abstractor) drinking contaminated groundwater. The Well Abstractor RP is conservatively assumed to drill a borehole immediately (1 m) downstream of each of the disposals (SGHWR, Dragon and A59) to obtain a bounding dose for consumption of well water. It is considered unrealistic to assume that the Well Abstractor RP drinks from all three wells, and so the dose resulting from drinking from each feature well is considered separately.		PA-018

Model region	Model component or process		Feature, event or process subject to uncertainty	Description of uncertainty	Treatment of uncertainty in the PA: Natural evolution model		Treatment of uncertainty in the PA: Human intrusion and site occupancy models	Reference no. and relevant reports
		RPs	Age of RPs	The age of the RPs receiving doses via the pathways identified in Appendix C.2 is uncertain.	The Reference Case uses an adult RP for all pathways. As the physiology and habits of the RP affects the dose received, two alternative assessment cases (EE.1.13 and EE.1.14 Table C.9) are undertaken using child and infant RPs for all pathways respectively.	The RPs considered in the human intrusion assessment Reference Case already cover a range of ages. For the site occupancy assessment, MicroShield uses conversion tables in ICRP Publication 51 to convert photon fluence rate to units of exposure. These tables are applicable to adult members of the public as well as workers, however they are not, generally, applicable to children. To undertake such an assessment would therefore require significant effort and is considered to be disproportionate.		PA-019
	Food chain	Uptake factors	Uptake of contaminants into the food chain	There is significant uncertainty in the uptake factors controlling the transfer of contaminants from model compartments into foodstuffs consumed by animals or RPs.	The Reference Case uses “most likely” uptake factors based on a range of literature. Two alternative assessment cases (E.1.15 and E.1.16 in Table C.9) are also undertaken, using “minimum” and “maximum” uptake factors to bound the uncertainty. These are taken directly from the literature where available, and are otherwise set at one order of magnitude below and above the most likely value, respectively.		Not relevant to human intrusion or site occupancy models	PA-020
	Dispersion	Biosphere flow conditions	Mire outflow	There is uncertainty in the rate of outflow from the mire to the River Frome.	Two alternative assessment cases (EE.1.17 and EE.1.18 in Table C.9), considering a minimum and maximum mire outflow rate, bound this uncertainty.		Not relevant to human intrusion or site occupancy models	PA-023

C.4.2 Assessment Cases and Scenarios

Natural Evolution Assessment Cases and Scenarios

C59 Based on the treatment approaches for uncertainties outlined in Appendix C.4, Table C.9 presents the set of scenarios and assessment cases developed for the Winfrith PA natural evolution assessment.

Table C.9: Set of assessment cases and scenarios proposed for the Winfrith PA natural evolution assessment, derived from the light green, mid-green, dark green and bright green shaded cells in the relevant column of Table C.8.

Scenario	Assessment Case	Differences to the Reference Case
EE.1 Expected evolution	EE.1.0 Reference Case	-
	EE.1.1 Alternative inventories	Assessment of alternative SGHWR, Dragon and OoS A59 inventory estimates as derived in the Radiological Inventory Report.
	EE.1.2 Alternative (Pu) Dragon inventory	Assessment of alternative Dragon inventory including a general building contamination inventory derived using a Pu-containing fingerprint.
	EE.1.3 Minimum near-field sorption	Minimum partition coefficients (K_d values) for concrete in the near field
	EE.1.4 Maximum near-field sorption	Maximum partition coefficients (K_d values) for concrete in the near field
	EE.1.5 Minimum concrete and rubble porosity	Minimum porosity of undegraded concrete in blocks and in other demolition arisings in the SGHWR and Dragon reactor complexes. Minimum rubble porosity based on the minimum void space between spherical particles being 26%.
	EE.1.6 Maximum concrete and rubble porosity	Maximum porosity of undegraded concrete in blocks and in other demolition arisings in the SGHWR and Dragon reactor complexes. Maximum rubble porosity based on maximum void based on random packing of equal spheres having a porosity of around 36%.
	EE.1.7 Minimum dry bulk concrete density	Minimum density of in-situ concrete and concrete blocks.
	EE.1.8 Maximum dry bulk concrete density	Maximum density of in-situ concrete and concrete blocks.
	EE.1.9 Minimum geosphere sorption	Minimum partition coefficients for the geosphere (Poole Formation).
	EE.1.10 Maximum geosphere sorption	Maximum partition coefficients for the geosphere (Poole Formation).
	EE.1.11 Minimum biosphere sorption	Minimum partition coefficients for the biosphere (soil and sediments).
	EE.1.12 Maximum biosphere sorption	Maximum partition coefficients for the biosphere (soil and sediments).
	EE.1.13 Child RP	Child RP assumed for all pathways, rather than adult RP as in the Reference Case.

Scenario	Assessment Case	Differences to the Reference Case
	EE.1.14 Infant RP	Infant RP assumed for all pathways, rather than adult RP as in the Reference Case.
	EE.1.15 Minimum uptake factors	Minimum uptake factors for transfer of contaminants into the food chain.
	EE.1.16 Maximum uptake factors	Maximum uptake factors for transfer of contaminants into the food chain.
	EE.1.17 Minimum mire outflow rate	Order of magnitude decrease in the average annual outflow rate from the Land/Mire compartment to the River compartment.
	EE.1.18 Maximum mire outflow rate	Order of magnitude increase in the average annual outflow rate from the Land/Mire compartment to the River compartment.
Variant concept (VA) scenarios		
VA.1 Shorter chemical degradation duration		Chemical degradation takes place on the same timescale as hydraulic degradation (1,000 years), instead of 50,000 years.
VA.2 Minimum initial hydraulic conductivity for SGHWR and Dragon structures		Lower initial hydraulic conductivity for the degraded structures ($1x10^{-12}$ m/s instead of $4.4x10^{-11}$ m/s).
VA.3 Maximum initial hydraulic conductivity and shorter degradation period		Higher initial hydraulic conductivity for the degraded structures ($1x10^{-9}$ m/s instead of $4.4x10^{-11}$ m/s), followed by linear degradation to reach the final hydraulic conductivity after 300 years instead of 1000 years.
VA.4 Shorter cap degradation time		Time to onset of degradation is halved (to 125 years) compared to the Reference Case. Rate of degradation is doubled compared to the Reference Case (so that the maximum infiltration rate is reached after 500 years, rather than after 1,000 years).
VA.5 SGHWR and A59 groundwater release to River Frome		Assume 100% of groundwater flow from SGHWR and 100% of groundwater flow from A59 enters the River Frome, rather than 50% from each to the Frome and 50% from each to the mire as in the Reference Case.
VA.6 SGHWR and A59 groundwater release to Land/Mire		Assume 100% of groundwater flow from SGHWR and 100% of groundwater flow from A59 emerges in the Land/Mire, rather than 50% from each to the Frome and 50% from each to the mire as in the Reference Case.
VA.7 SGHWR groundwater release to Dragon and A59 groundwater release to River Frome		Assume 100% of groundwater from SGHWR flows to Dragon, where it would join with releases from Dragon and eventually enter the River Frome. Continue to assume the Reference Case position for A59 (50% to the River Frome and 50% to the mire).
VA.8 Increased rate of rainfall infiltration through soil above A59		Higher rate of rainfall infiltration through soil (recharge) for the A59 area.
VA.9 Reasonable worst-case future groundwater levels		Reasonable worst-case estimate of future groundwater levels assumed, instead of cautious central estimate.

Scenario	Assessment Case	Differences to the Reference Case
VA.10 Reasonable worst-case future groundwater levels with seasonal fluctuation		Groundwater is assumed to seasonally fluctuate into the SGHWR Annexes and the Dragon basement, in addition to the use of reasonable worst-case estimate groundwater levels.
VA.11 Groundwater abstraction (SGHWR)		RP drinking radioactively-contaminated groundwater from a well 1 m downstream of SGHWR.
VA.12 Groundwater abstraction (Dragon)		RP drinking radioactively-contaminated groundwater from a well 1 m downstream of Dragon.
VA.13 Groundwater abstraction (A59)		RP drinking radioactively-contaminated groundwater from a well 1 m downstream of A59.
Variant configuration (VB) scenarios		
VB.1 Greater void spacing between blocks		Blocks in both SGHWR and Dragon are assumed to be more widely spaced, leading to increased void space between them (greater than 10% of the total volume occupied by the blocks).
VB.2 Entirely rubble infill		No blocks are emplaced and entire void space in both SGHWR and Dragon assumed to be filled with rubble.
VB.3 Grouting of entire volume		Entire remaining void space in both SGHWR and Dragon assumed to be grouted following backfilling.
VB.4 Minimum block size		Block volume for both SGHWR and Dragon is assumed to be 0.5 m^3 instead of 1 m^3.
VB.5 Maximum block size		Block volume for both SGHWR and Dragon is assumed to be 2 m^3 instead of 1 m^3.
"What-if" scenarios		
WI.1 Instantaneous hydraulic degradation, i.e. instantaneous failure of the proposed on-site disposals and cap to limit flows. This could result from a natural disruptive event such as a large earthquake.		Instantaneous hydraulic degradation of the near field; hydraulic properties instantly transition to degraded values at the end state.
WI.2 Extreme climate change		Water table assumed to be 1 m below ground surface.

Human Intrusion and Site Occupancy Assessment Cases and Scenarios

C60 The Reference Case and all alternative assessment cases and variant scenarios for human intrusion all include the same range of "intrusion types" considering different types of intrusion into different parts of the radioactive features remaining on the Winfrith site at the end state and different uses of the excavated material. Because these apply to all scenarios and assessment cases, they are not included in the following tables, but they are defined in Sections 7.5, 7.6 and 7.7 for SGHWR, the Dragon reactor complex and the OoS A59 area respectively.

C61 Based on the treatment approaches for uncertainties outlined in Appendix C.4, Table C.10 presents the set of scenarios and assessment cases developed for the Winfrith PA human intrusion and site occupancy assessments.

Table C.10: Set of assessment cases and scenarios proposed for the Winfrith PA human intrusion and site occupancy assessments, derived from the light green, mid-green and dark green shaded cells in the relevant column of Table C.8 (there are no "what-if" scenarios in these assessments).

Scenario	Assessment Case	Differences to the Reference Case
HI.1 Expected evolution	HI.1.0 Reference Case	-
	HI.1.1 Alternative inventories	Assessment of alternative SGHWR, Dragon and A59 inventory estimates as derived in the Radiological Inventory Report.
	HI.1.2 Alternative (Pu) Dragon inventory	Assessment of alternative Dragon inventory including a general building contamination inventory derived using a Pu-containing fingerprint.
	HI.1.4 Alternative human intrusion dates	In the human intrusion assessment, further cases examine intrusion at dates earlier than 2066 (to inform NRS decision making) and, where GRR Requirement R11 dose guidance level is exceeded at the SRS in the Reference Case, beyond 2066 (to identify when the calculated dose falls below the dose guidance level).
Variant configuration (VB) scenarios		
HI.VB.1 Mid-thickness cap/cover		Mid-thickness cap assumed for SGHWR and Dragon (3.0 m and 2.5 m respectively), instead of the thick cap assumed in the Reference Case (4.0 m and 3.8 m respectively). Mid-thickness cover layer assumed for A59 (0.3 m instead of 0.5 m assumed in the Reference Case).
HI.VB.2 Low-thickness cap/cover		Low-thickness cap assumed for SGHWR and Dragon (2.25 m and 1.5 m respectively), instead of the thick cap assumed in the Reference Case (4.0 m and 3.8 m respectively). Low-thickness cover layer assumed for A59 (0.1 m instead of 0.5 m assumed in the Reference Case).
HI.VB.3 No A59 cover		No clean cover material assumed for the A59 area.

C.5 Comparative Review of Scenarios and Assessment Cases

C62 This section describes how Step 4 of the scenario development process set out in Section C.1 has been implemented for the natural evolution assessment[63]. The set of scenarios and assessment cases (Table C.9), along with the uncertainty treatment approaches (Table C.8), are reviewed against the assessment cases considered in the assessments of UK near-surface disposal facilities and the Dounreay LLW FEP List; this is to ensure identification of an appropriate and comprehensive set of scenarios and assessment cases. It is noted that uncertainties of importance will differ for valid

[63] An equivalent process is not deemed necessary to report at this stage for the human intrusion and site occupancy assessments, since these are more straightforward and the software used to implement them is much more constrained than for the natural evolution assessment. Nevertheless, previous similar assessments have been reviewed and used to inform the approach taken for Winfrith, as discussed in the text of Sections 6 and 7.

reasons with each situation considered, and thus so may scenarios and assessment cases. The assessment approach used to identify them may also be different in important respects. Some differences are therefore to be expected, and these are noted and justified in the discussion and tables below.

C.5.2 Comparative Review Against Assessment Cases of UK Near-surface Disposal Facilities

C63 The assessment cases considered in the LLWR and Dounreay D3100 Disposal Facilities assessments have been reviewed and collated to allow for a cross-check against the set of assessment cases presented in Table C.9, defined through application of Step 3 of the scenario and assessment case identification approach. As can be seen in Table C.11, the assessment cases considered in the LLWR and D3100 assessments align well with the set proposed for the Winfrith assessment, suggesting the latter is relatively comprehensive. Only a few outliers are noticeable:

- Enhanced modelling of ^{14}C releases to groundwater (LLWR) – This is associated with the relatively large ^{14}C inventory and wide range of disposed material types at LLWR. For the Winfrith assessment, enhanced modelling of ^{14}C release is not required due to the relatively small ^{14}C inventory and disposed of materials being primarily concrete and masonry.
- Consideration of solubility assessment cases (LLWR) – In the Winfrith assessment, unlimited radionuclide solubility is cautiously assumed.
- Consideration of coastal erosion assessment cases (LLWR and D3100) – Coastal erosion is not relevant for Winfrith as it is an inland nuclear site.
- No assessment cases associated with alternative facility configurations (LLWR and D3100) – Both LLWR and D3100 are relatively mature facilities with established (and implemented) disposal facility designs that no longer need to assess the impact of alternative configurations. However, the Winfrith on-site disposals are at an earlier design stage, albeit that the location and basic structures are fixed, and the PA is being used to inform optimisation and design work; it is appropriate to consider alternative configurations at this stage.

Table C.11: Assessment cases, associated with the aqueous release pathway, considered in the assessments of LLWR and D3100, in comparison to the set of assessment cases proposed for the Winfrith natural evolution assessment (Table C.9). Text within brackets for the LLWR and D3100 columns denotes the case number.

Comp.	Environmental Safety Function		LLWR 2011 Groundwater assessment [167, §6.2]	D3100 Run 5 assessment [168, Appendix E]	Winfrith Assessment Cases
Near field	Inv.	Activity	• Alternative inventory estimates (R5 to R10). • Upper estimate inventory (95^{th} %) (R22).	• 2020 upper estimate inventory (2). • 2009 inventory estimate (3).	• VA.1 Alternative inventories. • VA.2 Pu-fingerprint alternative Dragon inventory.
	Hyd. Con..	Transport	• Increased C14 release to groundwater (R2).		• EE.1.3 Minimum rubble and concrete porosity. • EE.1.4 Maximum rubble and concrete porosity. • EE.1.5 Minimum dry bulk concrete density • EE.1.6 Maximum dry bulk concrete density • VA.10 Increased rainfall infiltration above A59. • VA.11, VA.12 Reasonable worst-case future groundwater levels, +/- seasonal fluctuations.
		Saturation	• Reduced leachate management period (R13).		• VA.10 Increased rainfall infiltration above A59. • VA.11, VA.12 Reasonable worst-case future groundwater levels, +/- seasonal fluctuations. • W1.2 Extreme climate change.
		Degrad.	• Rapid hydraulic degradation (through hydraulic conductivities) (R21).	• Rapid hydraulic degradation (through degradation rate) (4).	• VA.4 Minimum initial hydraulic conductivity. • VA.5 Maximum initial hydraulic conductivity and shorter degradation period. • VA.6 Shorter cap degradation time. • WI.1 Instantaneous hydraulic degradation.
	Chem. Con.	Solubility	• Limited solubility for plutonium (R11). • Unlimited solubility for uranium (R14).		
		Sorption	• Near field K_d values set to zero (R12).	• Minimum concrete K_d values (5). • Maximum concrete K_d values (6).	• EE.1.1 Minimum near-field sorption. • EE.1.2 Maximum near-field sorption.
		Degrad.			• VA.3 Shorter chemical degradation.
Geo.	Dilution		• Minimum geosphere path length (R18). • Delayed coastal erosion (R3 & R4).	• Minimum fracture spacing (7). • Maximum fracture spacing (8). • Moderate coastal erosion (14). • High coastal erosion (15). • No coastal erosion (16).	• VA.10 Increased rainfall infiltration above A59. • VA.11, VA.12 Reasonable worst-case future groundwater levels, +/- seasonal fluctuations.

Comp.	Environmental Safety Function	LLWR 2011 Groundwater assessment [167, §6.2]	D3100 Run 5 assessment [168, Appendix E]	Winfrith Assessment Cases
	Dispersion	• Variant geosphere flow conditions. Changes to flow rates and flow cross-sections (R16).	• Variant geosphere flow conditions (9).	• VA.10 Increased rainfall infiltration above A59. • VA.11, VA.12 Reasonable worst-case future groundwater levels, +/- seasonal fluctuations. • VA.7, VA.8, VA.9 Multiple geosphere flow pathways. • WI.2 Extreme climate change.
	Sorption		• Minimum geosphere K_d values (10). • Maximum geosphere K_d values (11).	• EE.1.7 Minimum geosphere sorption. • EE.1.8 Maximum geosphere sorption.
Bio.	Dilution			• VA.10 Increased rainfall infiltration above A59. • VA.11, VA.12 Reasonable worst-case future groundwater levels, +/- seasonal fluctuations.
	Dispersion			• VA.7, VA.8, VA.9 Multiple geosphere flow pathways.
	Sorption		• Minimum soil K_d values (12). • Maximum soil K_d values (13).	• EE.1.9 Minimum biosphere sorption. • EE.1.10 Maximum biosphere sorption.
	RPs	• Increased probability of water abstraction wells (R20).	• Geosphere water abstraction "what-if" calculation.	• EE.1.11 Child RP. • EE.1.12 Infant RP. • EE.1.13 Minimum uptake factors. • EE.1.14 Maximum uptake factors. • VA.13, VA.14, VA.15 Groundwater abstraction.
Assessment cases associated with uncertainty in the Winfrith end state configuration				
				• VB.1 Greater spacing between blocks. • VB.2 Entirely rubble infill. • VB.3 Grouting of entire volume. • VB.4 Minimum block size. • VB.5 Maximum block size.

C.5.3 Comparative Review Against the Dounreay LLW FEP List

C64 The Dounreay LLW FEP List has been developed to support scenario development for the D3100 assessment. As stated in Appendix C.1, it is based on the generic NEA International FEP List [170] and ISAM FEP List [162]. Its last full iteration, Version 3, was presented in Appendix 1 of the D3100 Run 3 assessment [169]; rescreening of this list was last undertaken for the Run 5 assessment [168]. The screening assessment has five categories:

- **O** – FEP can be excluded from the assessment on the basis that they are **O**utside the scope of the Winfrith assessment.
- **SO-P** – FEP is **S**creened **O**ut of the assessment on the basis of low **P**robability of occurrence over a timescale of significance to the calculated performance of the disposal system.
- **SO-C** – FEP is **S**creened **O**ut of the assessment on the basis of having a low **C**onsequence to the calculated performance of the disposal system.
- **UP** – FEP is expected to occur and has a significant contribution to the **U**ndisturbed **P**erformance (i.e. natural evolution) of the disposal system.
- **DP** – FEP is associated with **D**isturbed **P**erformance; this could be human intrusion or natural FEPs that disrupt the disposal system (e.g. erosion). Such FEPs are not certain to occur within a specific timeframe and, if they do occur, the effect on the disposal system is to bypass or eliminate one or more disposal system barriers.

C65 To assist with confirming that the set of scenarios and assessment cases for the Winfrith natural evolution assessment (Table C.9) is comprehensive, the full list of FEPs has been reviewed against the system description associated with the envisaged on-site disposals (as summarised in Section 3). This review is summarised in Table C.12, which presents:

- Discussion of the first and second level-one categories of FEPs, focused on “assessment context” and “repository issues”, which do not form part of the screening exercise as they are all deemed relevant to the envisaged on-site disposals.
- FEPs that are screened in for the envisaged on-site disposals from the third level-one category onwards: For the remaining ~170 FEPs in the Dounreay LLW FEP List, a judgement has been made on whether each should be screened in (UP and DP categories) for the envisaged on-site disposals, independent of whether it is screened in or out for D3100. FEPs that are screened in are discussed with regard to how they are accounted for through the “top-down” consideration of uncertainties presented in Appendix C.4.
- The FEPs screened out for the envisaged on-site disposals, but screened in for D3100: Due to system description differences between the sites (e.g. Winfrith is inland whilst Dounreay is coastal), some of the FEPs screened in for D3100 are not relevant here. Table C.12 identifies these FEPs and discusses the reasons for the differences in screening results.

Table C.12: Consolidated list of FEPs relevant to either the Winfrith site or Dounreay D3100 LLW Disposal Facilities. For the Winfrith screening, differences from the D3100 screening are highlighted in blue shading. Titles and screening decisions in italics are associated with unnumbered Dounreay FEP list sub-divisions of the NEA FEPs.

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
1	**Assessment Basis**			
1.01	Impacts of concern	No Screening		The impacts of concern for the Winfrith natural evolution assessment are outlined in Section 2. The impacts of concern are: 1) The dose rate from the envisaged on-site disposals to RPs prior to release of the Winfrith site from RSR (GRR Requirement R9), 2) Radiological risk (or its dose rate equivalent) from the envisaged on-site disposals to RPs after release of the Winfrith site from RSR (GRR Requirement R10), and 3) to show that people will be adequately protected in the case of natural disruptive processes (GRR Requirement R12).
1.02	Timescales of concern			The assessment timeframe is defined in Section 2.2; it extends from 2027 to until the time of peak dose/risk has been passed.
1.03	Spatial domain of concern			This FEP is concerned with the spatial domain over which a significant human health or environmental hazard may be present. For the Winfrith assessment, the spatial domain of concern is the Winfrith site and the local surrounding region; this is introduced in Section 3, with details on how it is modelled presented in Section 5.
1.04	Repository assumptions			Details on the assumptions associated with the envisaged on-site disposals, such as their inventory and configuration, are presented in Section 3.2.9. Assumptions associated with modelling the envisaged on-site disposals are outlined in Section 5.2.
1.05	Future human action assumptions			In accordance with the GRR, the Winfrith assessment considers doses/risks to RPs. Each represents "an individual receiving a dose that is representative of the more highly exposed individuals in the population". As proposed in the GRR [165, ¶A4.50], the RPs are defined "based on present and past habits and behaviour that have been observed and that are judged relevant". Further details on the RPs considered in the Winfrith assessment are presented in Section 5.4.1. Future human actions that could directly intrude into the envisaged on-site disposals are considered in Section 7.
1.06	Future human behaviour (target group) assumptions			
1.07	Dose response assumptions			Based on recommendations outlined in the GRR [165, ¶A4.35 and App.B2], a dose to risk conversion factor (risk coefficient) of 0.06 per Sv is used for situations in which the effective dose rate is less than 100 mSv per year and the estimated equivalent dose to each tissue is below the relevant threshold for deterministic effects.
1.08	Aims of the assessment			The aims of the Winfrith assessment are outlined in Sections 1 and 2.
1.09	Regulatory requirements and exclusions			As outlined in Sections 1 and 2, the Winfrith assessment addresses the radiological impacts from natural evolution of the envisaged on-site disposals and how they compare to associated GRR requirements (R9, R10 and R12); radiological impacts resulting from direct external irradiation of RPs from the envisaged on-site disposals; radiological impacts from human intrusion into the envisaged on-site disposals; and radiological impacts to non-human biota.

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
1.10	Model and data issues			Details on the natural evolution conceptual models and their implementation in GoldSim are presented in Section 5, whilst details on parameter and model verification are presented in Section 11. Treatment of key uncertainties, and how they have fed into defining assessment cases, are outlined in Appendix C.4.
2	**Repository Issues**			
2.01	Site investigation (knowledge)	No Screening		On-site disposal on the Winfrith site is supported by a wealth of information that has been collected since the site was commissioned. This includes photographs of the construction of the reactors; geological, hydrogeological and geochemical investigations; environmental surveys; and groundwater monitoring. This information, along with other publicly-available information sources on the environmental conditions in the local region, have been used to develop an understanding of the site characteristics, as summarised in Section 3.2.
2.02	Excavation/construction			The approach to demolition of the SGHWR and Dragon reactors, emplacement of demolition arisings in voids and capping has yet to be finalised. Uncertainties associated with the potential configuration of the disposals have been considered as part of scenario identification, as detailed in Appendix C.4 and Table C.8, with multiple variant configuration scenarios identified (Table C.9).
2.03	Emplacement of wastes and backfilling			
2.04	Closure and repository sealing			
2.05	Records and markers, repository			The Winfrith assessment makes no assumptions about the nature of the controls that might be put in place or their effectiveness after release of the site from RSR. The Winfrith assessment also makes no assumptions about future precautionary measures, other than those planned to be included within the design of the disposals (e.g. SGHWR and Dragon caps), that could act to limit human interactions with the envisaged on-site disposals or their releases.
2.06	Waste allocation (waste types and amounts)			The envisaged on-site disposals will contain radioactive waste, made up primarily of concrete and masonry, in-situ or sourced from elsewhere on the site. Details on the estimated radioactive inventory of this waste and its assumed distribution across the disposals are presented in Section 3.2.9. There is significant uncertainty associated with how demolition arisings are likely to be emplaced within below-ground voids. The current most likely configuration is assumed in the Reference Case assessment (Section 3.2.9) and this uncertainty is bounded by several variant scenarios considering different possible configuration options (Table C.8; Table C.9).
2.07	Repository design			As outlined above, uncertainties associated with the potential configuration of the disposals have been considered as part of scenario identification (Appendix C.4 and Table C.8, with multiple variant configuration scenarios identified (Table C.9).
2.08	Quality control			The GRR requires [165, ¶A3.31] that operators maintain a positive environmental safety culture and that their management system and organisational structure provide quality management (amongst other things). This is to be discussed in the SWESC.
2.09	Schedule and planning			Key dates are identified and discussed in Section 2. The site IEP is assumed to be reached in 2036; small changes in this date are not considered to affect long-term performance. Up until release of the site from RSR, the site will be under regulatory controls. As outlined in Section 2.2, it is cautiously assumed in the Winfrith assessment that release of the site from RSR will coincide with the site end state.
2.10	Administrative control, repository site			

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
2.11	Monitoring of repository			The Winfrith assessment takes no credit for any future monitoring of the envisaged on-site disposals. Specific guidance on monitoring is outlined in the GRR (Requirement R8), and is to be discussed in the SWESC.
2.12	Accidents and unplanned events			The Winfrith Reference Case assessment assumes that the site remains under control until release from RSR and that the works undertaken to achieve the IEP will meet specifications (i.e. be completed without errors). As noted in the Dounreay LLW FEP List, *"accidents are events that are outside the range of normal operations… should be anticipated in repository operational planning*"; such unplanned events occurring during operation of the site are not captured in Table C.8. Several of the alternative assessment cases and variant scenarios set out in Table C.8 and Table C.9 cover situations where works to achieve the IEP are not completed to specification. The timescale between now and the IEP is considered to be sufficiently short that no unplanned events of greater significance during operations need be considered.
2.13	Retrievability			The expected design of the envisaged on-site disposals is such that waste retrieval will be possible, if considered necessary. Therefore, there is no need to consider special design, emplacement, operational or administrative measures associated with retrievability in the Winfrith assessment.
3	**External Factors**			
3.1	**Geological Processes and Effects**			
3.1.03	Seismicity *faulting/rupture*	*DP*	*DP*	Impact of seismicity potentially degrading the near field is considered through the instantaneous hydraulic degradation scenario (WI.1 in Table C.9).
3.1.07	Erosion and sedimentation	SO-C	DP	Surface erosion could potentially remove any clean landscaping cover materials emplaced over the SGHWR and Dragon caps; however, no benefit from this material is accounted for in the Winfrith assessment. Even at relatively high surface erosion rates (which are not expected based on current surface erosion rates and consideration of possible mechanisms), exposure of the envisaged on-site disposals over the next few hundred years is unlikely and other effects are expected to be negligible.
3.2	**Climatic Processes and Effects**			
3.2.01	Climate change, global	UP	UP	The greatest impacts of climate change at Winfrith are expected to be primarily through modification of the local hydrological regime (see FEP 3.2.07).
3.2.02	Climate change, regional and local	UP	UP	
3.2.03	Sea-level change	SO-C	UP	Due to Winfrith being an inland nuclear site at around 40 m AoD, changes in sea level are of low consequence.
3.2.07	Hydrological/hydrogeological response to climate changes	UP	SO-C	This FEP has been screened in for the Winfrith assessment. Uncertainty in this is bounded through variant scenarios considering changes in infiltration rate, groundwater levels and flow paths, and the "what-if" assessment case considering extreme climate change (groundwater extending to 1 m below the surface) (Table C.8; VA.7 to VA.12 and WI.2 in Table C.9).
3.3	**Future Human Actions**			
3.3.01	Human influences on climate	UP	UP	Related to FEPs 3.2.01, 3.2.02 and 3.2.07 – see relevant discussions.
3.3.02	Motivation and knowledge issues (inadvertent/deliberate human actions)	O	DP	

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
3.3.04	Drilling activities including fracking (human intrusion)	O	DP	FEPs relevant to the inadvertent human intrusion assessment – not considered in this screening exercise (see footnote 63).
3.3.06	Surface environment, human activities	O	DP	
3.3.07	Water management (wells, reservoirs, dams) *surface water management* *groundwater extraction*	 *UP* *DP*	 *UP* *DP*	Water management at the Winfrith site is relatively important due to the intention to create a mire as part of site restoration, the proximity of the River Frome, and the habits of local inhabitants (Section 3). This FEP is managed through consideration of a broad range of RPs, including an angler, river paddler, mire mudder and well water abstractor (the latter through variant scenarios), and appropriate consideration in the model of water compartments of the local biosphere
3.3.11	Explosions and crashes	O	DP	Impacts are considered to be implicitly bounded by the intrusions considered as part of the inadvertent human intrusion assessment.
4	**Disposal System Domain: Environmental Factors**			
4.1	**Wastes and Engineered Features**			
4.1.01	Inventory, radionuclide and other material *radionuclide inventory* *other material inventory*	 *UP* *O*	 *UP* *UP*	Uncertainty in the radioactive inventory is accounted for by cautiously realisitc assumptions in the reference inventory, and further by variant scenarios (VA.1 and VA.2 in Table C.9) considering alternative inventories, which are expected to significantly overestimate the true levels of radioactivity for the envisaged on-site disposals. Other material inventories (e.g. non-radiological contamination) is beyond the scope of the Winfrith PA, and is to be addressed in the SWESC.
4.1.02	Wasteform materials and characteristics *hydrological and mechanical characteristics* *chemical characteristics* *cracking* *waste heterogeneity*	 *UP* *UP* *UP* *UP*	 *UP* *UP* *UP* *SO-C*	Uncertainties associated with the key characteristics of the envisaged on-site disposals are explored in alternative assessment cases that consider sorption, bulking and compaction, grouting, layering and saturation (Table C.8; Table C.9). Waste heterogeneity is captured in the Winfrith assessment through a granular near field, separately modelling the distinct regions of the reactor complexes and A59 area relevant to natural evolution.
4.1.03	Container materials and characteristics	*O*	UP	As no containers, in a traditional sense, will be used, this FEP is screened as outside of the scope of the Winfrith assessment.
4.1.04	Buffer/backfill materials and characteristics	UP	UP	No buffer or backfill materials, in a traditional sense, will be used. However, there is potential for below-ground void spaces to be grouted through permeation grouting of emplaced demolition arisings. The radiological impact of this is considered in a variant configuration scenario (VB.3, Table C.9), and is expected to be explored further as part of optimisation work that will feed into the WMP and SWESC.
4.1.05	Seals, cavern/tunnel/shaft	UP	UP	The only structures of relevance for this FEP are the SGHWR and Dragon caps. Uncertainties associated with cap design are not expected to have significant impacts via the groundwater pathway; those relating to its infiltration rate and degradation are explored though cautious parameterisation and a variant scenario (VA.6) respectively (Table C.8).
4.1.06	Other engineered features materials and characteristics *drainage system*	 *SO-C*	 *SO-C*	The envisaged on-site disposals are expected to be predominantly formed of concrete. Therefore, they are expected to initially inhibit flows as well as provide a relatively favourable chemical environment (e.g. through promoting

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
	hydrological characteristics – floors and walls *chemical characteristics – floors and walls*	*UP* *UP*	*UP* *UP*	sorption) (Section 5.2.1). Uncertainties associated with their hydraulic and chemical properties and concrete degradation rates are explored through multiple assessment cases and scenarios (Table C.8; Table C.9). No drainage systems that could affect the radiological impacts on the disposals are expected to remain on the Winfrith site at the IEP.
4.1.08	Hydraulic/hydrogeological processes and conditions (in wastes and engineered barrier systems)	UP	UP	Uncertainty in the hydraulic conductivity of the near field and the hydraulic degradation rate of intact concrete is explored through two alternative assessment cases (Table C.8; VA.4 and VA.5, Table C.9).
4.1.09	Chemical/geochemical processes and conditions (in wastes and EBS) *chemical conditioning – LLW* *dissolution and sorption* *redox*	 *UP* *UP* *UP*	 *UP* *UP* *UP*	Chemical degradation of concrete and radionuclide solubility are cautiously considered through assuming relatively rapid degradation (and loss of conditioning impacts – e.g., pH) and unlimited solubility, respectively (Table C.8). For the Winfrith assessment, oxidising conditions are cautiously assumed to persist over the model duration, as this generally increases radionuclide mobility. Uncertainty in radioelement sorption to concrete is considered as part of two alternative assessment cases (Table C.8; EE.1.1 and EE.1.2, Table C.9).
4.1.10	Biological/biochemical processes and conditions (in wastes and EBS) *microbial degradation* *chemical effects*	 *SO-C* *SO-C*	 *UP* *UP*	Due to organic materials being expected to form only a minor disposal constituent (Section 3.2.9), microbial degradation, and its associated impact on the chemical environment, is expected to have a low consequence on radiological performance.
4.1.12	Gas sources and effects (in wastes and EBS)	SO-C	UP	Whilst relatively small amounts of gas could potentially be generated through radiolysis and alpha-decay, the radioactivity of the waste is likely insufficient to produce meaningful volumes of gas (Appendix C.2.3). For near-surface disposal facilities, the generic main gas pathways are associated with the microbial degradation of organic material and the corrosion of metals. Due to organic materials and metals being expected to form only a minor constituent of the envisaged on-site disposals, gas generation is expected to be minimal and thus have a low consequence on radiological performance (Appendix C.2.3).
4.2	**Geological Environment**			
4.2.02	Host rock	UP	UP	The "host rock" (bedrock – Poole Formation) and its characteristics are summarised in Sections 3.2.2 and 3.2.5 and accounted for in the geosphere conceptual model.
4.2.03	Geological units, other	UP	UP	The superficial deposits that overlie the bedrock and their characteristics are summarised in Sections 3.2.2 and 3.2.5 and accounted for in the geosphere conceptual model.
4.2.04	Discontinuities, large scale (in geosphere)	O	UP	No large structural discontinuities are believed to extend under the Winfrith site. This FEP is therefore screened out.
4.2.05	Contaminant transport path characteristics (in geosphere)	UP	UP	The hydraulically conductive transport pathways, as described Section 3.2.5, are accounted for in the Winfrith assessment geosphere conceptual model. The impacts from multiple geosphere flow paths are considered in variant scenarios (Table C.8; VA.7 to VA.9, Table C.9).
4.2.07	Hydraulic/hydrogeological processes and conditions (in geosphere)	UP	UP	The hydrogeological conditions at the Winfrith site are described in Section 3.2.5 and accounted for in the geosphere conceptual model. Uncertainty in infiltration rate, geosphere flow paths and groundwater levels are considered through as range of variant scenarios (Table C.8; VA.7 to VA.12, Table C.9).

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
4.2.08	Chemical/geochemical processes and conditions (in geosphere)	UP	UP	The geochemical conditions at the Winfrith site are summarised in Section 3.2.6. The key chemical process of relevance is geosphere sorption, which is accounted for in the geosphere conceptual model. As with the near field (FEP 4.1.09), oxidising conditions are cautiously assumed to persist over the model duration, as this generally increases radionuclide mobility. Uncertainty in radioelement sorption to made ground is considered as part of two alternative assessment cases (Table C.8; EE.1.7 and EE.1.8, Table C.9).
4.2.13	Geological resources *groundwater for drinking*	*DP*	*DP*	Geological resources in and around the Winfrith site are described in the Site Description Report [179]. Groundwater abstraction in the region around the Winfrith site occurs at a range of scales for personal and commercial purposes [179]. Within the Winfrith natural evolution assessment, the impact of this potential exposure pathway is captured through consideration of three groundwater abstraction variant scenarios (Table C.8; VA.13 to VA.15, Table C.9).
	flagstones (mineral resources)	*SO-P*	*DP*	There is no history of local quarrying or indication of particular mineralogical or lithological properties that would make the bedrock at the site (Poole Formation) a particular target for mining or quarrying [179]. Due to this, and that any potential future extraction of the bedrock is primarily relevant to the inadvertent human intrusion assessment, this FEP is screened out for the Winfrith natural evolution assessment on the basis of its low probability of occurrence.
4.3	**Surface Environment**			
4.3.01	Topography and morphology	UP	UP	The topography in and around the Winfrith site is summarised in Section 3.2.1 and is accounted for in the geosphere and biosphere conceptual models.
4.3.02	Soil and sediment	UP	UP	The soil in and around the Winfrith site is described in the Site Description Report [179] and accounted for in the biosphere conceptual model. Sediments in the local environment are less well understood, but are considered in the biosphere conceptual model based on generic parameterisation. Uncertainties associated with radioelement sorption to soils and sediments is considered through two alternative assessment cases (Table C.8; EE.1.9 and EE.1.10, Table C.9).
4.3.03	Aquifers and water-bearing features, near surface	UP	UP	Related to FEPs 4.2.05, 4.2.07 and 4.2.13 – see relevant discussions.
4.3.04	Lakes, rivers, streams and springs	UP	UP	The surface hydrology in and around the Winfrith site is summarised in Section 3.2.3 and accounted for in the Winfrith assessment biosphere conceptual model. Potential future changes in the surface hydrology are considered in variant scenarios exploring increased rainfall infiltration and higher groundwater levels (leading to greater emergence) (Table C.8; VA.10 to VA.12, Table C.9).
4.3.05	Coastal features	O	UP	As the Winfrith site is located inland, there are no coastal or marine features present in the vicinity.
4.3.06	Marine features	O	UP	
4.3.07	Atmosphere	UP	UP	The atmosphere is relevant to the performance of the disposal system only in terms of its capacity to transport contaminants. Atmospheric transport of radionuclides (e.g. particulates) is accounted for in the Winfrith assessment biosphere conceptual model.

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
4.3.08	Vegetation	UP	UP	The type of vegetation present around the Winfrith site, both currently and in the future, is relevant to considerations of human habits, such as through influencing land use. A range of vegetation types (e.g. heathland, grass, crops) are considered in the Winfrith assessment biosphere conceptual model.
4.3.09	Animal populations	UP	UP	The potential future use of land in the vicinity of the Winfrith site for animal husbandry and the presence of fish in the River Frome are both accounted for in the Winfrith assessment biosphere conceptual model.
4.3.10	Meteorology	UP	UP	The climate of the Winfrith site is described in the Site Description Report [179] and accounted for in the assessment conceptual models. The impact of potential future changes in climate is captured in in variant scenarios exploring increased rainfall infiltration and higher groundwater levels (Table C.8; VA.10 to VA.12, Table C.9).
4.3.11	Hydrological regime and water balance (near-surface)	UP	UP	Related to FEPs 4.2.05, 4.2.07 and 4.2.13 – see relevant discussions.
4.3.12	Erosion and deposition *coastal erosion* *other erosion processes*	 *O* *SO-C*	 *UP* *SO-C*	Related to FEP 3.1.07 – see relevant discussion.
4.3.13	Ecological/biological/microbial systems	UP	UP	Related to FEP 4.3.08 and 4.3.09 – see relevant discussions. Direct impacts of radionuclide release on non-human biota are considered in Section 8.
4.4	**Human Behaviour**			
4.4.01	Human characteristics (physiology, metabolism)	UP	UP	Local human behaviour is considered in the Winfrith assessment biosphere conceptual model through the definition of a range of RPs, with the exposure pathways and associated parameters based on local human habits (Section 3.2.8).
4.4.03	Diet and fluid intake	UP	UP	
4.4.04	Habits (non-diet-related behaviour)	UP	UP	
4.4.07	Dwellings	UP	UP	
4.4.08	Wild and natural land and water use *wild water use*	 *UP*	 *UP*	
4.4.09	Rural and agricultural land and water use (incl. fisheries) *land agriculture* *fisheries*	 *UP* *UP*	 *UP* *SO-C*	
5	**Radionuclide/Contaminant Factors**			
5.1	**Contaminant Characteristics**			
5.1.01	Radioactive decay and in-growth	UP	UP	Radioactive decay and in-growth of long-lived daughter radionuclides are explicitly modelled in the Winfrith assessment. The radiological impact of short-lived daughters is also implicitly considered by cautiously adding the dose coefficients (taking account of decay branching ratios) of the daughters to that of the parent (see Appendix D.3).

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
5.1.04	Volatiles and potential for volatility *radioactive methane, hydrogen and radon*	*SO-C*	*UP*	Due to the material and radionuclide make-up of the envisaged on-site disposals, as outlined in the Winfrith inventory, radionuclide-containing gases are not expected to be generated (see Appendix C.2.3).
5.2	**Contaminant Release/Migration Factors**			
5.2.01	Dissolution, precipitation and crystallisation, contaminant *dissolution*	*UP*	*UP*	Related to FEP 4.1.09 – see relevant discussion. Release of activity from disposals is cautiously modelled in the Winfrith assessment through assuming unlimited solubility (Table C.8).
5.2.02	Speciation and solubility, contaminant	UP	UP	
5.2.03	Sorption/desorption processes, contaminant	UP	UP	Related to FEP 4.1.09 – see relevant discussion. Radioelement sorption to concrete, geosphere, soil and freshwater sediment is considered in the Winfrith assessment model; uncertainty in this is considered as part of multiple alternative assessment cases (Table C.8; Table C.9).
5.2.06	Microbial/biological/plant-mediated processes, contaminant	SO-C	UP	Related to FEP 4.1.10 – see relevant discussion.
5.2.07	Water-mediated transport of contaminants *advection and diffusion* *dispersion and matrix diffusion*	 *UP* *UP*	 *UP* *UP*	The dose pathways of relevance for natural evolution of the envisaged on-site disposals are reviewed in Appendix C.2.3.
5.2.08	Solid-mediated transport of contaminants	UP	UP	
5.2.09	Gas-mediated transport of contaminants *radioactive gases*	*SO-C*	*UP*	
5.2.10	Atmospheric transport of contaminants	UP	UP	
5.2.12	Human-action-mediated transport of contaminants *intrusive human actions*	*O*	*DP*	FEP relevant to the inadvertent human intrusion assessment, not part of this screening exercise (see footnote 63).
5.2.13	Food chains, uptake of contaminants in	UP	UP	Uptake of radionuclides into foodstuffs is considered in the Winfrith assessment biosphere conceptual model. Uptake factors (concentration ratios) consider the uptake from soil into plants, from plants and soil into animals, and from animals (livestock) into humans. Animals may also uptake radioactivity by drinking contaminated water (e.g. abstracted from contaminated streams). There is inherent uncertainty associated with the use of uptake factors to derive dose rates. Key drivers for this uncertainty include the characteristics of the radionuclide itself and the specifics of the uptake pathway (e.g. modes of uptake, characteristics of the up-taking organism). Usage of uptake factors to derive dose rates is standard practice in natural evolution assessment models (e.g. [167; 168]) and DPUR tools (e.g. [205]). In the Winfrith assessment, most likely values from international databases have generally been used, where available, with data gaps filled using values from other natural evolution assessment models, and two alternative assessment cases (EE.1.13 and EE.1.14) consider minimum and maximum uptake factors (see Appendix D.4.3).

D3100 FEP No.	FEP Title	Winfrith Screen.	D3100 Screen.	Winfrith Screening Discussion
5.3	**Exposure Factors**			
5.3.01	Drinking water, foodstuffs and drugs, contaminant concentrations in	UP	UP	The Winfrith assessment considers radionuclide concentrations in consumed human foodstuffs. The possible use (e.g. consumption) of contaminated water as drinking water is considered through a groundwater abstractor RP, considered in three variant scenarios (Table C.8; VA.13 to VA.15, Table C.9).
5.3.02	Environmental media, contaminant concentrations in	UP	UP	The Winfrith assessment considers the potential for radioactivity to contaminate a range of environmental media, including soil, sediments and water, identified based on the current biosphere and its possible future evolution.
5.3.04	Exposure modes	UP	UP	A range of exposure modes are considered in the Winfrith assessment biosphere conceptual model, identified through consideration of the local biosphere compartments susceptible to contamination and local human habits that lead to interactions with these compartments.
5.3.05	Dosimetry	UP	UP	Dosimetry is accounted for in the Winfrith assessment through the dose coefficients used in the biosphere conceptual model. Uncertainty in the internationally recommended dose coefficients is considered to be outside the scope of the assessment.
5.3.06	Radiological toxicity/effects	UP	UP	The Winfrith assessment considers radiological risk, derived from the “effective dose” of radiation exposure. The concept of “effective dose” was developed by the ICRP as a risk-adjusted whole body dosimetric quantity for managing stochastic effects of low levels of radiation exposure, principally cancer, enabling comparison of received doses with dose guidance levels. Effective doses are converted to risks using a risk coefficient of 0.06 per Sv, as outlined in the GRR [165, ¶A4.35].
5.3.08	Radon and radon daughter exposure	SO-C	UP	Related to FEP 5.1.04 – see relevant discussion.

C66 Through this exercise all FEPs considered relevant to either the Winfrith site or the Dounreay D3100 LLW Disposal Facilities have been individually reviewed and recorded. Overall, this process has confirmed the comprehensiveness of the scenarios and assessment cases presented in Table C.9.

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Appendix D Model Parameterisation

D1 This appendix summarises the database of input parameters used within this performance assessment. Default parameters for the assessment are reported in Sections D.1 to D.6, which provide inputs to the groundwater modelling, site occupancy, human intrusion and ERICA models. Unless stated otherwise, parameter values are for the Reference Case. Overarching general parameters are reported in Section D.1. Near-field parameters are reported in Section D.2, including the configuration, geometries and material form of the contaminated site features, both at the IEP and in the future. The radiological inventory is reported, as well as hydrological parameters such as groundwater levels and rainfall infiltration levels. Section D.3 reports the geological parameters associated with the site and relevant surroundings. Section D.4 reports biosphere-related parameters, including parameterisation of Representative Persons (RPs) such as consumption and occupancy habits, elemental uptake factors, radionuclide dose coefficients and soil partition coefficients. Section D.5 reports parameters associated with the human intrusion model, while Sections D.6 and D.7 report parameters associated with site occupancy modelling and ERICA modelling respectively. A list of the references cited in this appendix are provided in Section D.8. Some values reported in Appendix D are rounded for presentational purposes.

D.1 General Parameters

Table D.1: Key Winfrith site decommissioning and management dates

Parameter	Value	Reference/Justification
NE Model Start Date	2027	Date of activity estimates in the End State Radiological Inventory [206]. NE assessment model start date; radioactive decay of all feature inventory estimates commences.
SGHWR Disposal Start Date	2032	The year in which the end state is implemented for each disposal feature (facility decommissioned, waste emplaced in below-ground voids and engineered cap implemented). The below-ground structures are assumed to be dry to this point.
Dragon Disposal Start Date	2029	
A59 Disposal Start Date	2027	
Interim End Point (IEP)	2036	Site IEP achieved and public access permitted. NRS retains sufficient control to prevent inadvertent intrusion and site residency, but members of the public can access the site and may be subject to external irradiation from sub-surface contamination.
Site Reference State (SRS)	2066	Site Reference State achieved (marks transition between GRR Requirements R9 and R10). Human intrusion is assumed to be possible. Site occupancy model considers the potential for site residency, as well as general site access.

Table D.2: Hydrological and hydrogeological parameters that are common to one or more GoldSim NE modules.

Parameter	**Value**	**Reference/Justification**
Reference diffusivity for water ($m^2\ s^{-1}$)	1.00E-09	Default value for water, as suggested by GoldSim-RT [207, p.65].
Partial Saturation Diffusion Exponent (-)	3.33	Suggested in GoldSim-RT [208, p.135; 207, p.143] as appropriate for modelling aqueous diffusion. Based on Millington and Quirk [209].
Density of water ($kg\ m^{-3}$)	1000	Approximate value.
Longitudinal dispersivity (fraction)	0.1	Based on typical longitudinal dispersion values, as suggested by GoldSim-RT [207, p.178].

Table D.3: Radionuclides species list used by GoldSim in the NE assessment, as detailed in Appendix B.

Radionuclide	**Atomic Weight ($g\ mol^{-1}$)**	**Half-life (years)**	**Modelled Daughter(s)**	**Branching fraction**	**Comment**
H3	3.016	1.232E+01			
C14	14.003	5.700E+03			
Cl36	35.968	3.010E+05			
Ca41	40.962	1.020E+05			
Fe55	54.938	2.737E+00			
Co60	59.934	5.271E+00			
Ni59	58.934	1.010E+05			
Ni63	62.930	1.001E+02			
Sr90	89.908	2.879E+01			
Zr93	92.906	1.530E+06	Nb93m	1	
Nb93m	92.906	1.613E+01			
Nb94	93.907	2.030E+04			
Tc99	98.906	2.111E+05			
Cd113m	112.904	1.410E+01			
Sn121m	120.904	4.390E+01			
Sb125	124.905	2.759E+00			
I129	128.905	1.570E+07			
Cs134	133.907	2.065E+00			
Cs137	136.907	3.017E+01			
Ba133	132.906	1.052E+01			
Sm151	150.920	9.000E+01			
Eu152	151.922	1.354E+01			
Eu154	153.923	8.593E+00			
Eu155	154.923	4.761E+00			
Hf178n	177.944	3.100E+01			
Pt193	192.963	5.000E+01			
Tl204	203.974	3.780E+00			

Radionuclide	Atomic Weight (g mol^{-1})	Half-life (years)	Modelled Daughter(s)	Branching fraction	Comment
Pb210	209.984	2.220E+01			
Ra226	226.025	1.600E+03	Pb210	1	
Ra228	228.031	5.750E+00	Th228	1	
Ac227	227.028	2.177E+01			
Th228	228.029	1.912E+00			
Th229	229.032	7.340E+03			
Th230	230.033	7.538E+04	Ra226	1	
Th232	232.038	1.405E+10	Ra228	1	
Pa231	231.036	3.276E+04	Ac227	1	
U233	233.040	1.592E+05	Th229	1	
U234	234.041	2.455E+05	Th230	1	
U235	235.044	7.040E+08	Pa231	1	
U236	236.046	2.342E+07	Th232	1	
U238	238.051	4.468E+09	U234	1	
Np237	237.048	2.144E+06	U233	1	
Pu238	238.050	8.770E+01	U234	1	
Pu239	239.052	2.411E+04	U235	1	
Pu240	240.054	6.564E+03	U236	1	
Pu241	241.057	1.435E+01	Am241	0.99998	Branching
			Np237	0.00002	
Pu242	242.059	3.750E+05	U238	1	
Am241	241.057	4.322E+02	Np237	1	
Am243	243.061	7.370E+03	Pu239	1	
Cm243	243.061	2.910E+01	Pu239	0.9976	Branching
			Am243	0.0024	
Cm244	244.063	1.810E+01	Pu240	1	

D.2 Near-field Parameters

D.2.1 Configuration

D2 Table D.4 lists all the features and components modelled within the Winfrith PA and their associated configuration.

Table D.4: Winfrith end state features and their associated key characteristics specified in the NE model Reference Case.

Feature No.	Feature Name	Infill Material	Initial Intact Concrete Hydraulic Status	Comment
1	SGHWR Region 1	Intact Concrete (Blocks) and Granular Concrete	Hydraulically Undegraded	Regions 1 and 2 (R1/R2) sit on a clay layer such that there is no GW transfer through the floor.
2	SGHWR Bioshield	Intact Concrete (Grouted)	Hydraulically Undegraded	The bioshield sits within R1 and is assumed to have the same water level as R1. It can only be assumed to be hydraulically intact at model start.
3	SGHWR Region 2	Granular Concrete	Hydraulically Undegraded	R1 and R2 sit on a clay layer such that there is no GW transfer through the floor.
4	SGHWR South Annexe	Granular Concrete	Hydraulically Degraded	Base of the Annexe is assumed to be cracked, with the hydraulic conductivity properties of degraded concrete.
5	SGHWR North Annexe	Granular Concrete	Hydraulically Degraded	Base of the Annexe is assumed to be cracked, with the hydraulic conductivity properties of degraded concrete.
6	Dragon Inside Wall C	Intact Concrete (Blocks) and Granular Concrete	Hydraulically Undegraded	Wall C is assumed to be hydraulically degraded/not present a barrier to flow and so the internal water level will be determined by the flow across Wall A.
7	Dragon Bioshield	Intact Concrete (Grouted)	Hydraulically Undegraded	The bioshield is assumed to have the same water level as that inside Wall C. It can only be assumed to be hydraulically intact at model start.
8	Dragon Walls A-C Up-gradient	Granular Concrete	Hydraulically Degraded	Wall A is assumed to be hydraulically degraded/fractured. The infill material between Wall A and C can only be rubble or grout.
9	Dragon Walls A-C Down-gradient	Granular Concrete	Hydraulically Degraded	
10	Dragon Mortuary Holes	N/A	Hydraulically Degraded	The mortuary holes will be filled with clean grout, with the contamination held up in the metal tubes themselves, but the feature is modelled as a single block of degraded contaminated concrete.
11	Dragon B78 floor slab	N/A	Hydraulically Degraded	The floor slab is modelled as a single block of degraded contaminated concrete. There is no infill.
12	A59_PSA_Pit 3	N/A	N/A	The OoS A59 areas are modelled as contaminated blocks of soil. There is no infill assigned in the model.
13	A59_HVA_A591	N/A	N/A	
14	A59_Other	N/A	N/A	

D.2.2 Radiological Inventories

D3 The tables contained in this section present the radionuclide inventories used in the groundwater model, the human intrusion model and the site occupancy model. The inventory is derived from the Winfrith Site End State Radiological Inventory [206], although for the purposes of PA modelling the inventory has been screened to a shorter list of radionuclides, as described in Appendix B. Table D.5 and Table D.6 report the reference total inventory (MBq) for in-situ structures and infill respectively. Table D.7 and Table D.8 report equivalent total inventories for the alternative inventory. Table D.9 and Table D.10 report a third inventory which uses an alternative plutonium fingerprint for Dragon reactor building contamination. Table D.11 to Table D.18 report the specific activity concentration values (Bq g^{-1}) derived for the features and regions of the SGHWR and Dragon reactors and the OoS A59 areas, as used in the human intrusion and site occupancy assessments.

Table D.5: Reference case total activity for the in-situ below-ground end state features (underground concrete structures and contaminated land) of the Winfrith site in MBq. *Note this page is set to A3 size.*

Rads.	SGHWR In-situ Features					Dragon In-situ Features						A59 In-situ Features		
	Region 1 (excl. bioshield)	Bioshield	Region 2	South Annexe	North Annexe	Inside Wall C	Bioshield	Walls A-C Up-gradient	Walls A-C Down-gradient	Mortuary Holes	B78 floor slab	PSA/ Pit 3	A591/ HVA	Other areas
H3	1.15E+05	3.08E+05	2.56E+03	9.69E+03	2.40E+03	1.69E+02	1.25E+03	4.22E+02	2.09E+02	1.88E-01	3.82E+01	0.00E+00	0.00E+00	0.00E+00
C14	2.41E+03	8.42E+02	1.15E+02	2.25E+02	6.56E+01	1.02E-01	1.21E+01	7.31E-01	1.26E-01	4.69E-01	4.04E-02	0.00E+00	0.00E+00	0.00E+00
Cl36	1.08E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.27E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	0.00E+00	4.11E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.91E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe55	3.93E+02	1.77E+03	5.19E+00	9.75E+00	4.23E+00	0.00E+00	1.03E+00	0.00E+00	0.00E+00	4.63E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	5.48E+02	1.55E+03	5.26E+01	5.99E+00	1.46E+00	2.44E-02	2.71E+00	1.09E-01	3.01E-02	2.57E-02	9.68E-03	1.46E+00	1.50E+01	1.27E+01
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	4.12E+03	7.11E+03	7.55E+02	2.12E+03	2.30E+01	7.13E-02	4.27E+01	2.95E-01	8.78E-02	1.56E-02	2.82E-02	4.81E+01	9.88E+02	1.62E+03
Sr90	7.70E+03	9.34E-01	4.78E+01	1.42E+02	5.44E+00	1.75E+00	0.00E+00	8.96E+00	2.15E+00	8.37E+00	6.93E-01	4.62E+01	1.13E+02	7.80E+02
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb94	5.41E+00	0.00E+00	3.08E-02	6.72E-01	1.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	2.99E+01	0.00E+00	1.56E+00	6.00E-02	1.23E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	2.58E+00	1.25E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb125	9.22E-01	0.00E+00	6.83E-02	7.01E-01	3.63E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-02	0.00E+00	0.00E+00
I129	1.23E+02	0.00E+00	3.34E+00	1.29E-01	2.63E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs134	2.04E-02	6.50E-02	9.99E-03	6.87E-02	1.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs137	1.17E+04	6.23E+03	3.33E+03	1.46E+03	6.40E+01	1.27E+00	1.36E-02	9.39E+02	1.57E+00	1.87E+01	5.05E-01	4.61E+01	3.45E+01	2.70E+02
Ba133	1.08E+01	3.91E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	0.00E+00	3.07E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.42E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu152	7.43E+01	1.86E+04	4.09E+00	1.59E+01	4.07E+00	0.00E+00	1.16E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu154	2.92E+01	8.24E+02	8.51E-01	3.56E+00	9.06E-01	0.00E+00	3.19E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	3.23E+00	3.24E+01	5.97E-02	1.22E+00	2.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	2.56E+00	1.24E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.92E-02	0.00E+00	5.68E-02	3.59E-02	4.02E-10	1.16E-02	0.00E+00	0.00E+00	0.00E+00
Ra226	1.48E+02	0.00E+00	1.18E+01	1.01E+02	1.24E+01	5.58E-02	0.00E+00	1.09E-01	6.87E-02	1.16E-08	2.21E-02	2.27E-05	3.43E-05	2.83E-04
Ra228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.41E-04	0.00E+00	1.44E-03	9.13E-04	8.30E-15	2.94E-04	0.00E+00	0.00E+00	0.00E+00
Ac227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-06	0.00E+00	2.47E-06	1.56E-06	1.14E-08	5.03E-07	3.81E-04	5.91E-04	2.66E-03
Th228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.69E-04	0.00E+00	1.11E-03	7.00E-04	2.68E-15	2.25E-04	0.00E+00	0.00E+00	0.00E+00
Th229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-14	0.00E+00	2.77E-14	1.75E-14	1.59E-04	5.64E-15	0.00E+00	0.00E+00	0.00E+00
Th230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-03	0.00E+00	2.76E-03	1.75E-03	1.55E-05	5.63E-04	5.79E-03	8.76E-03	7.21E-02
Th232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-03	0.00E+00	2.20E-03	1.40E-03	4.55E-14	4.49E-04	0.00E+00	0.00E+00	0.00E+00
Pa231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.92E-06	0.00E+00	1.93E-05	1.22E-05	2.15E-07	3.93E-06	1.59E-03	2.46E-03	1.11E-02
U233	5.42E+02	0.00E+00	8.11E-01	0.00E+00	5.66E-01	5.19E-11	0.00E+00	1.01E-10	6.39E-11	4.88E-01	2.06E-11	0.00E+00	0.00E+00	0.00E+00
U234	1.89E+02	0.00E+00	3.30E+01	2.37E+02	7.86E+01	1.68E-01	0.00E+00	3.27E-01	2.07E-01	4.88E-01	6.66E-02	3.47E+01	5.25E+01	4.32E+02
U235	4.48E+01	2.34E+02	2.79E+00	1.78E+01	5.85E+00	5.33E-02	0.00E+00	1.04E-01	6.57E-02	2.95E-03	2.11E-02	4.13E+00	6.40E+00	2.89E+01
U236	1.76E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.67E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U238	1.53E+02	0.00E+00	2.72E+01	1.97E+02	8.88E+01	2.08E-01	0.00E+00	4.04E-01	2.56E-01	2.88E-03	8.23E-02	3.83E+01	5.16E+01	4.43E+02
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-06	0.00E+00	5.39E-06	3.41E-06	1.10E-06	1.10E-06	1.28E-04	7.27E-05	3.39E-04
Pu238	2.21E+01	8.72E-02	2.15E+00	5.06E+01	8.08E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.35E-01	0.00E+00	1.94E+00	7.05E-01	5.75E+00
Pu239	3.57E+02	1.75E-02	2.19E+00	5.80E+01	1.04E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-01	0.00E+00	2.37E+01	8.26E-01	3.04E+01
Pu240	2.91E+02	1.75E-02	1.79E+00	4.71E+01	8.83E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-01	0.00E+00	1.79E+01	1.26E+00	4.24E+01
Pu241	1.33E+03	8.11E-01	5.14E+01	1.63E+02	1.07E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E+00	0.00E+00	5.58E+01	1.39E+01	1.20E+02
Pu242	1.70E+00	0.00E+00	8.58E-01	0.00E+00	5.66E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	3.11E+02	6.25E+01	6.77E+00	6.96E+01	2.81E+01	9.66E-01	0.00E+00	1.88E+00	1.19E+00	9.85E-01	3.83E-01	2.27E+01	1.25E+01	5.93E+01
Am243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.66E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	1.37E-01	0.00E+00	1.24E-02	2.37E-02	1.09E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.27E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm244	5.30E+00	0.00E+00	4.93E-01	3.15E+00	5.17E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.84E-02	0.00E+00	4.09E-01	7.04E-01	1.88E+01

Table D.6: Reference Case total activity for the infill inventory (concrete blocks and rubble to fill void spaces) assigned to each end state feature in MBq. *Note this page is set to A3 size.*

Rads.	SGHWR infill Regions and Features					Dragon infill Regions and Features						A59 infill		
	Region 1 (excl. bioshield)	Bioshield	Region 2	South Annexe	North Annexe	Inside Wall C	Bioshield	Walls A-C Up-gradient	Walls A-C Down-gradient	Mortuary Holes	B78 floor slab	PSA/ Pit 3	A591/ HVA	Other areas
H3	3.90E+04	0.00E+00	1.70E+03	5.64E+03	2.98E+03	9.42E+02	0.00E+00	6.16E+02	6.16E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	1.21E+03	0.00E+00	6.45E+01	2.88E+02	3.70E+02	9.11E+00	0.00E+00	5.89E+00	5.89E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cl36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.47E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe55	9.22E+00	0.00E+00	1.36E+00	1.49E+00	4.73E+00	7.77E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	9.99E+01	0.00E+00	8.96E+00	1.69E+01	7.76E+00	2.04E+00	0.00E+00	1.48E+00	1.48E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	1.39E+03	0.00E+00	1.54E+02	3.93E+02	1.72E+02	3.21E+01	0.00E+00	3.36E+01	3.36E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr90	2.25E+03	0.00E+00	6.78E+02	1.81E+03	6.15E+02	0.00E+00	0.00E+00	1.71E+02	1.71E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb94	2.70E+01	0.00E+00	0.00E+00	5.12E-02	2.53E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	1.33E+01	0.00E+00	4.90E-04	3.62E-02	2.26E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb125	1.38E-02	0.00E+00	4.10E-03	2.05E-01	4.67E-01	0.00E+00	0.00E+00	1.03E-03	1.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	1.11E-01	0.00E+00	1.05E-03	7.76E-02	4.85E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs134	7.87E-03	0.00E+00	5.62E-04	2.12E-02	1.90E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs137	8.62E+03	0.00E+00	2.99E+03	5.06E+03	1.78E+03	1.03E-02	0.00E+00	4.64E+02	4.64E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba133	4.97E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.19E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.08E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu152	1.67E+02	0.00E+00	2.84E+00	1.97E+01	1.25E+01	8.75E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu154	2.47E+01	0.00E+00	6.39E-01	4.33E+00	2.81E+00	2.40E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	1.63E+00	0.00E+00	0.00E+00	2.63E-01	3.69E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-01	1.12E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra226	9.10E+01	0.00E+00	9.00E+00	5.83E+01	4.00E+01	0.00E+00	0.00E+00	2.15E-01	2.15E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.85E-03	2.85E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ac227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-06	4.89E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.19E-03	2.19E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.48E-14	5.48E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.47E-03	5.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.37E-03	4.37E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.82E-05	3.82E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	2.21E+00	0.00E+00	1.84E-01	0.00E+00	5.65E-01	0.00E+00	0.00E+00	2.00E-10	2.00E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U234	1.36E+02	0.00E+00	4.21E+01	1.91E+02	1.62E+02	0.00E+00	0.00E+00	3.34E+00	3.34E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	3.88E+01	0.00E+00	7.94E+00	3.07E+01	1.72E+01	0.00E+00	0.00E+00	1.55E+00	1.55E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U236	5.96E-02	0.00E+00	0.00E+00	4.16E-01	3.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U238	3.07E+02	0.00E+00	9.01E+01	3.08E+02	2.08E+02	0.00E+00	0.00E+00	1.69E+01	1.69E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-05	1.07E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu238	1.77E+01	0.00E+00	5.07E+00	1.76E+01	1.47E+01	0.00E+00	0.00E+00	1.17E+00	1.17E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu239	8.10E+01	0.00E+00	2.37E+01	6.94E+01	3.44E+01	0.00E+00	0.00E+00	5.86E+00	5.86E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu240	1.12E+02	0.00E+00	3.28E+01	9.33E+01	4.08E+01	0.00E+00	0.00E+00	8.15E+00	8.15E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu241	3.49E+02	0.00E+00	1.07E+02	3.22E+02	2.25E+02	0.00E+00	0.00E+00	2.32E+01	2.32E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu242	5.74E-01	0.00E+00	1.84E-01	1.85E-01	6.17E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	1.78E+02	0.00E+00	5.18E+01	1.56E+02	8.41E+01	0.00E+00	0.00E+00	1.60E+01	1.60E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	1.04E-02	0.00E+00	3.83E-03	7.54E-03	1.40E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm244	5.50E+01	0.00E+00	1.63E+01	4.46E+01	1.56E+01	0.00E+00	0.00E+00	4.06E+00	4.06E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.7: Alternative case total activity for the in-situ below-ground end state features (underground concrete structures and contaminated land) of the Winfrith site in MBq. *Note this page is set to A3 size.*

Rads.	SGHWR In-situ Features					Dragon In-situ Features						A59 In-situ Features		
	Region 1 (excl. bioshield)	Bioshield	Region 2	South Annexe	North Annexe	Inside Wall C	Bioshield	Walls A-C Up-gradient	Walls A-C Down-gradient	Mortuary Holes	B78 floor slab	PSA/ Pit 3	A591/ HVA	Other areas
H3	2.85E+05	4.56E+06	3.41E+03	2.16E+04	3.00E+03	5.90E+02	5.64E+03	4.60E+03	7.26E+02	2.50E-01	1.83E+02	0.00E+00	0.00E+00	0.00E+00
C14	8.79E+03	1.24E+04	4.28E+02	1.03E+03	5.27E+02	2.04E+00	3.15E+01	4.36E+00	2.51E+00	9.62E-01	8.09E-01	0.00E+00	0.00E+00	0.00E+00
Cl36	1.17E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.56E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	0.00E+00	6.11E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.88E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe55	1.40E+02	2.64E+04	1.03E+01	2.15E+01	5.99E+00	0.00E+00	2.43E+00	0.00E+00	0.00E+00	7.41E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	3.61E+03	2.30E+04	2.55E+02	5.25E+01	2.29E+01	4.89E-01	8.10E+00	9.77E-01	6.02E-01	3.83E-02	1.94E-01	3.05E+00	1.74E+01	4.68E+01
Ni59	6.55E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	2.08E+04	1.02E+05	1.60E+03	4.58E+03	8.84E+01	1.43E+00	1.14E+02	2.83E+00	1.76E+00	2.03E-02	5.65E-01	2.33E+02	1.31E+03	6.05E+03
Sr90	1.26E+04	9.34E-01	3.80E+02	9.73E+02	9.78E+01	3.50E+01	0.00E+00	7.11E+01	4.31E+01	1.14E+01	1.39E+01	9.00E+01	1.37E+02	1.73E+03
Zr93	1.23E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	2.90E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb94	3.28E+02	0.00E+00	3.49E-02	1.22E+00	2.48E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	4.17E+01	0.00E+00	5.04E+00	3.00E-01	4.22E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	3.89E-01	1.86E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	3.43E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb125	2.89E+01	0.00E+00	9.55E-02	1.43E+00	4.78E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.20E-02	0.00E+00	0.00E+00
I129	1.43E+02	0.00E+00	1.08E+01	6.42E-01	9.05E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs134	7.57E+00	9.55E-01	1.45E-02	1.81E-01	4.09E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs137	5.78E+04	1.08E+04	1.70E+04	1.57E+04	9.74E+02	2.55E+01	1.36E-02	9.84E+02	3.14E+01	2.64E+01	1.01E+01	2.05E+02	4.64E+01	5.58E+02
Ba133	2.06E+02	5.80E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	0.00E+00	4.56E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu152	3.26E+02	2.76E+05	2.06E+01	7.12E+01	2.42E+01	0.00E+00	3.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu154	7.24E+01	1.22E+04	4.54E+00	1.50E+01	5.05E+00	0.00E+00	8.89E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	4.59E+00	4.81E+02	8.91E-02	2.45E+00	3.27E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	6.84E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	7.35E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	2.97E+01	1.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.83E-01	0.00E+00	1.09E+00	7.19E-01	9.02E-10	2.31E-01	2.93E-06	2.37E-06	5.07E-05
Ra226	9.50E+02	0.00E+00	8.54E+01	6.85E+02	9.42E+01	1.12E+00	0.00E+00	2.09E+00	1.37E+00	2.61E-08	4.42E-01	1.78E-05	1.44E-05	3.08E-04
Ra228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E-02	0.00E+00	2.78E-02	1.83E-02	8.30E-15	5.87E-03	0.00E+00	0.00E+00	0.00E+00
Ac227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.54E-05	0.00E+00	4.76E-05	3.12E-05	2.44E-08	1.01E-05	3.55E-04	2.10E-04	3.35E-03
Th228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-02	0.00E+00	2.13E-02	1.40E-02	2.68E-15	4.51E-03	0.00E+00	0.00E+00	0.00E+00
Th229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.85E-13	0.00E+00	5.34E-13	3.50E-13	3.57E-04	1.13E-13	0.00E+00	0.00E+00	0.00E+00
Th230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.84E-02	0.00E+00	5.33E-02	3.50E-02	3.48E-05	1.13E-02	4.55E-03	3.67E-03	7.85E-02
Th232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-02	0.00E+00	4.25E-02	2.79E-02	4.55E-14	8.98E-03	0.00E+00	0.00E+00	0.00E+00
Pa231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-04	0.00E+00	3.72E-04	2.44E-04	4.61E-07	7.86E-05	1.48E-03	8.72E-04	1.40E-02
U233	5.85E+02	0.00E+00	8.58E-01	0.00E+00	5.66E-01	1.04E-09	0.00E+00	1.95E-09	1.28E-09	1.09E+00	4.11E-10	0.00E+00	0.00E+00	0.00E+00
U234	1.51E+03	0.00E+00	3.00E+02	1.85E+03	3.97E+02	3.36E+00	0.00E+00	6.30E+00	4.14E+00	1.09E+00	1.33E+00	2.72E+01	2.20E+01	4.70E+02
U235	2.58E+02	3.45E+03	2.33E+01	1.42E+02	3.00E+01	1.07E+00	0.00E+00	2.00E+00	1.31E+00	6.30E-03	4.23E-01	3.85E+00	2.27E+00	3.63E+01
U236	2.62E+01	0.00E+00	4.88E-02	1.38E-01	5.23E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.67E-04	0.00E+00	2.86E-05	8.32E-07	1.20E-04
U238	1.38E+03	0.00E+00	2.77E+02	1.60E+03	3.92E+02	4.16E+00	0.00E+00	7.79E+00	5.12E+00	6.16E-03	1.65E+00	3.04E+01	2.17E+01	4.83E+02
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.54E-05	0.00E+00	1.04E-04	6.82E-05	1.36E-06	2.19E-05	3.02E-04	1.43E-04	1.21E-03
Pu238	2.27E+02	8.72E-02	2.97E+01	4.37E+02	4.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+00	0.00E+00	5.07E+00	7.65E-01	2.14E+01
Pu239	6.70E+02	1.75E-02	3.58E+01	5.04E+02	4.94E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-01	0.00E+00	6.81E+01	1.01E+00	1.60E+02
Pu240	5.48E+02	1.75E-02	2.95E+01	4.11E+02	4.12E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-01	0.00E+00	5.31E+01	1.55E+00	2.23E+02
Pu241	2.18E+03	8.11E-01	1.06E+02	3.84E+02	1.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.36E+00	0.00E+00	1.32E+02	9.54E+00	4.22E+02
Pu242	2.42E+00	0.00E+00	8.80E-01	6.13E-02	5.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	5.44E+02	9.20E+02	1.85E+01	2.08E+02	4.81E+01	1.93E+01	0.00E+00	3.62E+01	2.38E+01	1.22E+00	7.66E+00	5.33E+01	2.42E+01	2.11E+02
Am243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.57E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	3.07E-01	0.00E+00	3.27E-02	6.22E-02	1.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm244	5.56E+01	0.00E+00	2.84E+00	2.70E+01	2.42E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-02	0.00E+00	3.71E-01	9.30E-01	6.70E+01

Table D.8: Alternative case total activity for the alternative case infill inventory (concrete blocks and rubble to fill void spaces) assigned to each end state feature in MBq. *Note this page is set to A3 size.*

Rads.	SGHWR infill Regions and Features					Dragon infill Regions and Features						A59 infill		
	Region 1 (excl. bioshield)	Bioshield	Region 2	South Annexe	North Annexe	Inside Wall C	Bioshield	Walls A-C Up-gradient	Walls A-C Down-gradient	Mortuary Holes	B78 floor slab	PSA/ Pit 3	A591/ HVA	Other areas
H3	1.14E+05	0.00E+00	2.37E+03	6.13E+03	3.32E+03	4.25E+03	0.00E+00	2.25E+03	2.25E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	4.25E+03	0.00E+00	1.94E+02	6.61E+02	1.97E+03	2.37E+01	0.00E+00	1.43E+01	1.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cl36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe55	1.90E+01	0.00E+00	2.74E+00	3.46E+00	1.02E+01	1.83E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	6.42E+02	0.00E+00	1.73E+01	2.64E+01	3.27E+01	6.10E+00	0.00E+00	3.27E+00	3.27E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	3.32E+03	0.00E+00	2.35E+02	4.97E+02	4.12E+02	8.55E+01	0.00E+00	3.88E+01	3.88E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr90	2.56E+03	0.00E+00	8.78E+02	1.97E+03	6.81E+02	0.00E+00	0.00E+00	2.99E+02	2.99E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb94	6.80E+01	0.00E+00	0.00E+00	7.68E-02	3.16E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	1.66E+01	0.00E+00	1.06E-02	1.32E-01	5.14E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb125	1.38E-02	0.00E+00	4.10E-03	2.61E-01	6.14E-01	0.00E+00	0.00E+00	1.03E-03	1.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	3.24E-01	0.00E+00	2.28E-02	2.84E-01	1.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs134	2.65E-02	0.00E+00	2.59E-03	5.55E-02	5.20E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs137	2.78E+04	0.00E+00	9.32E+03	5.39E+03	2.76E+03	1.03E-02	0.00E+00	5.57E+02	5.57E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba133	4.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu152	4.81E+02	0.00E+00	1.39E+01	6.06E+01	3.03E+01	2.70E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu154	6.88E+01	0.00E+00	3.08E+00	1.26E+01	6.06E+00	6.70E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	4.10E+00	0.00E+00	0.00E+00	3.32E-01	4.17E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.25E+00	2.25E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra226	5.21E+02	0.00E+00	5.67E+01	2.07E+02	1.17E+02	0.00E+00	0.00E+00	4.30E+00	4.30E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-02	5.71E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ac227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.77E-05	9.77E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E-02	4.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-12	1.10E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-01	1.09E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.73E-02	8.73E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.64E-04	7.64E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	2.79E+00	0.00E+00	1.84E-01	0.00E+00	5.65E-01	0.00E+00	0.00E+00	4.00E-09	4.00E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U234	1.01E+03	0.00E+00	2.21E+02	7.72E+02	4.72E+02	0.00E+00	0.00E+00	1.77E+01	1.77E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	1.68E+02	0.00E+00	2.52E+01	8.56E+01	4.33E+01	0.00E+00	0.00E+00	6.49E+00	6.49E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U236	2.16E-01	0.00E+00	3.28E-02	5.08E-01	3.95E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U238	1.27E+03	0.00E+00	3.00E+02	9.59E+02	5.63E+02	0.00E+00	0.00E+00	4.46E+01	4.46E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E-04	2.13E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu238	1.06E+02	0.00E+00	2.34E+01	7.01E+01	3.84E+01	0.00E+00	0.00E+00	1.17E+00	1.17E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu239	1.88E+02	0.00E+00	4.57E+01	1.32E+02	6.50E+01	0.00E+00	0.00E+00	5.86E+00	5.86E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu240	2.00E+02	0.00E+00	5.09E+01	1.45E+02	6.65E+01	0.00E+00	0.00E+00	8.15E+00	8.15E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu241	5.25E+02	0.00E+00	1.39E+02	4.21E+02	3.21E+02	0.00E+00	0.00E+00	2.32E+01	2.32E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu242	7.69E-01	0.00E+00	1.99E-01	2.26E-01	6.32E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	2.16E+02	0.00E+00	5.85E+01	1.77E+02	1.05E+02	0.00E+00	0.00E+00	8.68E+01	8.68E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	8.29E-02	0.00E+00	7.35E-03	1.17E-02	1.92E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm244	6.29E+01	0.00E+00	1.75E+01	4.77E+01	1.70E+01	0.00E+00	0.00E+00	4.06E+00	4.06E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.9: Total activity for the alternative Pu fingerprint inventory for the in-situ below-ground end state features (underground concrete structures and contaminated land) of the Winfrith site in MBq (changes impact Dragon). *This page is set to A3 size.*

Rads.	SGHWR in-situ Regions and Features					Dragon in-situ Regions and Features						A59 in-situ		
	Region 1 (excl. bioshield)	Bioshield	Region 2	South Annexe	North Annexe	Inside Wall C	Bioshield	Walls A-C Up-gradient	Walls A-C Down-gradient	Mortuary Holes	B78 floor slab	PSA/ Pit 3	A591/ HVA	Other areas
H3	2.85E+05	4.56E+06	3.41E+03	2.16E+04	3.00E+03	5.83E+02	5.64E+03	4.59E+03	7.19E+02	2.50E-01	1.80E+02	0.00E+00	0.00E+00	0.00E+00
C14	8.79E+03	1.24E+04	4.28E+02	1.03E+03	5.27E+02	3.30E+00	3.15E+01	5.92E+00	4.07E+00	9.62E-01	1.31E+00	0.00E+00	0.00E+00	0.00E+00
Cl36	1.17E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E+00	1.56E+00	5.85E+00	5.85E+00	0.00E+00	1.88E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	0.00E+00	6.11E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.88E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe55	1.40E+02	2.64E+04	1.03E+01	2.15E+01	5.99E+00	2.67E-02	2.43E+00	3.28E-02	3.28E-02	7.41E-03	1.06E-02	0.00E+00	0.00E+00	0.00E+00
Co60	3.61E+03	2.30E+04	2.55E+02	5.25E+01	2.29E+01	3.20E-01	8.10E+00	7.70E-01	3.95E-01	3.83E-02	1.27E-01	3.05E+00	1.74E+01	4.68E+01
Ni59	6.55E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	2.08E+04	1.02E+05	1.60E+03	4.58E+03	8.84E+01	8.50E+00	1.14E+02	1.15E+01	1.05E+01	2.03E-02	3.37E+00	2.33E+02	1.31E+03	6.05E+03
Sr90	1.26E+04	9.34E-01	3.80E+02	9.73E+02	9.78E+01	1.89E+01	0.00E+00	5.14E+01	2.33E+01	1.14E+01	7.51E+00	9.00E+01	1.37E+02	1.73E+03
Zr93	1.23E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	2.90E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb94	3.28E+02	0.00E+00	3.49E-02	1.22E+00	2.48E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	4.17E+01	0.00E+00	5.04E+00	3.00E-01	4.22E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	3.89E-01	1.86E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	3.43E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb125	2.89E+01	0.00E+00	9.55E-02	1.43E+00	4.78E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.20E-02	0.00E+00	0.00E+00
I129	1.43E+02	0.00E+00	1.08E+01	6.42E-01	9.05E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs134	7.57E+00	9.55E-01	1.45E-02	1.81E-01	4.09E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs137	5.78E+04	1.08E+04	1.70E+04	1.57E+04	9.74E+02	5.06E+01	1.36E-02	1.02E+03	6.23E+01	2.64E+01	2.01E+01	2.05E+02	4.64E+01	5.58E+02
Ba133	2.06E+02	5.80E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	0.00E+00	4.56E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu152	3.26E+02	2.76E+05	2.06E+01	7.12E+01	2.42E+01	3.75E+00	3.58E+02	4.62E+00	4.62E+00	0.00E+00	1.49E+00	0.00E+00	0.00E+00	0.00E+00
Eu154	7.24E+01	1.22E+04	4.54E+00	1.50E+01	5.05E+00	3.54E-01	8.89E+00	4.36E-01	4.36E-01	0.00E+00	1.40E-01	0.00E+00	0.00E+00	0.00E+00
Eu155	4.59E+00	4.81E+02	8.91E-02	2.45E+00	3.27E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	6.84E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	7.35E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	2.97E+01	1.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E-09	0.00E+00	3.76E-01	2.49E-09	9.02E-10	8.02E-10	2.93E-06	2.37E-06	5.07E-05
Ra226	9.50E+02	0.00E+00	8.54E+01	6.85E+02	9.42E+01	2.37E-08	0.00E+00	7.18E-01	2.92E-08	2.61E-08	9.41E-09	1.78E-05	1.44E-05	3.08E-04
Ra228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.62E-01	0.00E+00	3.32E-01	3.22E-01	8.30E-15	1.04E-01	0.00E+00	0.00E+00	0.00E+00
Ac227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E-06	0.00E+00	2.27E-05	6.38E-06	2.44E-08	2.05E-06	3.55E-04	2.10E-04	3.35E-03
Th228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-01	0.00E+00	2.55E-01	2.47E-01	2.68E-15	7.96E-02	0.00E+00	0.00E+00	0.00E+00
Th229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-14	0.00E+00	1.96E-13	1.25E-14	3.57E-04	4.03E-15	0.00E+00	0.00E+00	0.00E+00
Th230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-05	0.00E+00	1.83E-02	1.54E-05	3.48E-05	4.94E-06	4.55E-03	3.67E-03	7.85E-02
Th232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-01	0.00E+00	5.07E-01	4.93E-01	4.55E-14	1.59E-01	0.00E+00	0.00E+00	0.00E+00
Pa231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.05E-05	0.00E+00	1.78E-04	4.99E-05	4.61E-07	1.61E-05	1.48E-03	8.72E-04	1.40E-02
U233	5.85E+02	0.00E+00	8.58E-01	0.00E+00	5.66E-01	3.75E-11	0.00E+00	7.14E-10	4.62E-11	1.09E+00	1.49E-11	0.00E+00	0.00E+00	0.00E+00
U234	1.51E+03	0.00E+00	3.00E+02	1.85E+03	3.97E+02	1.54E-01	0.00E+00	2.35E+00	1.90E-01	1.09E+00	6.11E-02	2.72E+01	2.20E+01	4.70E+02
U235	2.58E+02	3.45E+03	2.33E+01	1.42E+02	3.00E+01	2.18E-01	0.00E+00	9.55E-01	2.68E-01	6.30E-03	8.63E-02	3.85E+00	2.27E+00	3.63E+01
U236	2.62E+01	0.00E+00	4.88E-02	1.38E-01	5.23E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.67E-04	0.00E+00	2.86E-05	8.32E-07	1.20E-04
U238	1.38E+03	0.00E+00	2.77E+02	1.60E+03	3.92E+02	2.70E-01	0.00E+00	3.01E+00	3.33E-01	6.16E-03	1.07E-01	3.04E+01	2.17E+01	4.83E+02
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.04E-06	0.00E+00	3.82E-05	2.51E-06	1.36E-06	8.09E-07	3.02E-04	1.43E-04	1.21E-03
Pu238	2.27E+02	8.72E-02	2.97E+01	4.37E+02	4.00E+01	3.44E-01	0.00E+00	4.24E-01	4.24E-01	1.28E+00	1.36E-01	5.07E+00	7.65E-01	2.14E+01
Pu239	6.70E+02	1.75E-02	3.58E+01	5.04E+02	4.94E+01	1.46E-01	0.00E+00	1.80E-01	1.80E-01	1.74E-01	5.80E-02	6.81E+01	1.01E+00	1.60E+02
Pu240	5.48E+02	1.75E-02	2.95E+01	4.11E+02	4.12E+01	1.08E-01	0.00E+00	1.33E-01	1.33E-01	1.74E-01	4.28E-02	5.31E+01	1.55E+00	2.23E+02
Pu241	2.18E+03	8.11E-01	1.06E+02	3.84E+02	1.98E+02	4.67E+00	0.00E+00	5.75E+00	5.75E+00	3.36E+00	1.85E+00	1.32E+02	9.54E+00	4.22E+02
Pu242	2.42E+00	0.00E+00	8.80E-01	6.13E-02	5.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	5.44E+02	9.20E+02	1.85E+01	2.08E+02	4.81E+01	7.50E-01	0.00E+00	1.34E+01	9.24E-01	1.22E+00	2.97E-01	5.33E+01	2.42E+01	2.11E+02
Am243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.57E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	3.07E-01	0.00E+00	3.27E-02	6.22E-02	1.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm244	5.56E+01	0.00E+00	2.84E+00	2.70E+01	2.42E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-02	0.00E+00	3.71E-01	9.30E-01	6.70E+01

Table D.10: Total activity for the alternative Pu fingerprint infill inventory (concrete blocks and rubble to fill void spaces) assigned to each end state feature in MBq (changes only impact Dragon). *Note this page is set to A3 size.*

Rads.	SGHWR infill Regions and Features					Dragon infill Regions and Features						A59 infill		
	Region 1 (excl. bioshield)	Bioshield	Region 2	South Annexe	North Annexe	Inside Wall C	Bioshield	Walls A-C Up-gradient	Walls A-C Down-gradient	Mortuary Holes	B78 floor slab	PSA/ Pit 3	A591/ HVA	Other areas
H3	1.14E+05	0.00E+00	2.37E+03	6.13E+03	3.32E+03	4.25E+03	0.00E+00	2.22E+03	2.22E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C14	4.25E+03	0.00E+00	1.94E+02	6.61E+02	1.97E+03	2.37E+01	0.00E+00	1.92E+01	1.92E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cl36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E+00	0.00E+00	1.83E+01	1.83E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe55	1.90E+01	0.00E+00	2.74E+00	3.46E+00	1.02E+01	1.83E+00	0.00E+00	1.03E-01	1.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co60	6.42E+02	0.00E+00	1.73E+01	2.64E+01	3.27E+01	6.10E+00	0.00E+00	2.62E+00	2.62E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni63	3.32E+03	0.00E+00	2.35E+02	4.97E+02	4.12E+02	8.55E+01	0.00E+00	6.60E+01	6.60E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr90	2.56E+03	0.00E+00	8.78E+02	1.97E+03	6.81E+02	0.00E+00	0.00E+00	2.38E+02	2.38E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb94	6.80E+01	0.00E+00	0.00E+00	7.68E-02	3.16E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	1.66E+01	0.00E+00	1.06E-02	1.32E-01	5.14E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb125	1.38E-02	0.00E+00	4.10E-03	2.61E-01	6.14E-01	0.00E+00	0.00E+00	1.03E-03	1.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I129	3.24E-01	0.00E+00	2.28E-02	2.84E-01	1.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs134	2.65E-02	0.00E+00	2.59E-03	5.55E-02	5.20E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs137	2.78E+04	0.00E+00	9.32E+03	5.39E+03	2.76E+03	1.03E-02	0.00E+00	6.54E+02	6.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba133	4.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu152	4.81E+02	0.00E+00	1.39E+01	6.06E+01	3.03E+01	2.70E+02	0.00E+00	1.45E+01	1.45E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu154	6.88E+01	0.00E+00	3.08E+00	1.26E+01	6.06E+00	6.70E+00	0.00E+00	1.36E+00	1.36E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu155	4.10E+00	0.00E+00	0.00E+00	3.32E-01	4.17E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pb210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.79E-09	7.79E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra226	5.21E+02	0.00E+00	5.67E+01	2.07E+02	1.17E+02	0.00E+00	0.00E+00	9.14E-08	9.14E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+00	1.01E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ac227	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-05	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.74E-01	7.74E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.92E-14	3.92E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.80E-05	4.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E+00	1.54E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.56E-04	1.56E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	2.79E+00	0.00E+00	1.84E-01	0.00E+00	5.65E-01	0.00E+00	0.00E+00	1.45E-10	1.45E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U234	1.01E+03	0.00E+00	2.21E+02	7.72E+02	4.72E+02	0.00E+00	0.00E+00	5.36E+00	5.36E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	1.68E+02	0.00E+00	2.52E+01	8.56E+01	4.33E+01	0.00E+00	0.00E+00	3.22E+00	3.22E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U236	2.16E-01	0.00E+00	3.28E-02	5.08E-01	3.95E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U238	1.27E+03	0.00E+00	3.00E+02	9.59E+02	5.63E+02	0.00E+00	0.00E+00	2.96E+01	2.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E+00	1.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu238	1.06E+02	0.00E+00	2.34E+01	7.01E+01	3.84E+01	0.00E+00	0.00E+00	1.74E+00	1.74E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu239	1.88E+02	0.00E+00	4.57E+01	1.32E+02	6.50E+01	0.00E+00	0.00E+00	6.27E+00	6.27E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu240	2.00E+02	0.00E+00	5.09E+01	1.45E+02	6.65E+01	0.00E+00	0.00E+00	2.61E+01	2.61E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu241	5.25E+02	0.00E+00	1.39E+02	4.21E+02	3.21E+02	0.00E+00	0.00E+00	2.32E+01	2.32E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu242	7.69E-01	0.00E+00	1.99E-01	2.26E-01	6.32E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am241	2.16E+02	0.00E+00	5.85E+01	1.77E+02	1.05E+02	0.00E+00	0.00E+00	1.52E+01	1.52E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am243	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	8.29E-02	0.00E+00	7.35E-03	1.17E-02	1.92E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm244	6.29E+01	0.00E+00	1.75E+01	4.77E+01	1.70E+01	0.00E+00	0.00E+00	4.06E+00	4.06E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.11: Reference Case specific activity for the four main modelled SGHWR regions in Bq g^{-1}. *Note this page is set to A3 size.*

Rads.	Region 1			Region 2			North Annexe			South Annexe		
	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ
H3	3.69E+01	4.73E+01	1.09E+01	6.51E+00	5.83E+00	7.88E+00	2.22E+00	2.62E+00	1.98E+00	3.21E+00	3.56E+00	2.74E+00
C14	3.56E-01	3.63E-01	3.38E-01	2.73E-01	2.61E-01	2.99E-01	1.80E-01	7.15E-02	2.46E-01	1.07E-01	8.27E-02	1.40E-01
Cs134	7.44E-06	9.54E-06	2.20E-06	1.61E-05	2.27E-05	2.60E-06	1.35E-05	1.51E-05	1.26E-05	1.88E-05	2.53E-05	1.03E-05
Cs137	2.12E+00	2.01E+00	2.40E+00	9.63E+00	7.56E+00	1.38E+01	7.63E-01	6.99E-02	1.19E+00	1.36E+00	5.36E-01	2.46E+00
Co57	4.76E-08	6.67E-08	3.53E-11	7.26E-07	1.08E-06	1.97E-11	1.45E-06	1.68E-06	1.31E-06	9.95E-07	1.31E-06	5.78E-07
Co60	1.75E-01	2.34E-01	2.79E-02	9.39E-02	1.20E-01	4.15E-02	3.81E-03	1.59E-03	5.17E-03	4.79E-03	2.20E-03	8.21E-03
Am241	4.41E-02	4.18E-02	4.97E-02	8.94E-02	1.54E-02	2.40E-01	4.63E-02	3.06E-02	5.59E-02	4.72E-02	2.56E-02	7.58E-02
Nb94	2.59E-03	6.05E-04	7.54E-03	4.69E-05	7.00E-05	0.00E+00	1.86E-04	2.16E-04	1.68E-04	1.51E-04	2.47E-04	2.49E-05
Sb125	7.47E-05	1.03E-04	3.86E-06	1.11E-04	1.55E-04	1.90E-05	3.43E-04	3.96E-04	3.11E-04	1.89E-04	2.57E-04	9.95E-05
Eu152	1.50E+00	2.09E+00	4.65E-02	1.06E-02	9.30E-03	1.31E-02	6.83E-03	4.44E-03	8.30E-03	7.43E-03	5.83E-03	9.55E-03
Eu154	7.01E-02	9.54E-02	6.90E-03	2.27E-03	1.94E-03	2.96E-03	1.53E-03	9.88E-04	1.87E-03	1.65E-03	1.31E-03	2.10E-03
Eu155	2.97E-03	3.98E-03	4.55E-04	9.11E-05	1.36E-04	0.00E+00	2.72E-04	3.16E-04	2.46E-04	3.11E-04	4.49E-04	1.28E-04
Fe55	1.74E-01	2.42E-01	2.57E-03	9.99E-03	1.18E-02	6.31E-03	3.70E-03	4.61E-03	3.15E-03	2.35E-03	3.58E-03	7.23E-04
Ni63	1.01E+00	1.25E+00	3.89E-01	1.39E+00	1.72E+00	7.13E-01	8.05E-02	2.51E-02	1.14E-01	5.27E-01	7.81E-01	1.91E-01
Sr90	7.94E-01	8.61E-01	6.27E-01	1.11E+00	1.09E-01	3.14E+00	2.57E-01	5.94E-03	4.10E-01	4.08E-01	5.20E-02	8.79E-01
Pu241	1.34E-01	1.49E-01	9.73E-02	2.41E-01	1.17E-01	4.95E-01	1.37E-01	1.17E-01	1.50E-01	1.02E-01	6.00E-02	1.57E-01
Ba133	3.13E-01	4.38E-01	1.39E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	3.45E-03	3.34E-03	3.71E-03	2.38E-03	3.54E-03	2.27E-06	1.44E-05	1.34E-05	1.51E-05	2.01E-05	2.20E-05	1.76E-05
I129	9.84E-03	1.38E-02	3.10E-05	5.10E-03	7.60E-03	4.87E-06	3.09E-05	2.87E-05	3.23E-05	4.31E-05	4.72E-05	3.77E-05
Cl36	8.64E-03	1.21E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	4.34E-02	6.06E-02	6.16E-04	1.52E-03	1.85E-03	8.54E-04	4.68E-04	6.18E-04	3.76E-04	0.00E+00	0.00E+00	0.00E+00
U234	2.60E-02	2.12E-02	3.80E-02	1.15E-01	7.50E-02	1.95E-01	9.93E-02	8.57E-02	1.08E-01	8.93E-02	8.69E-02	9.25E-02
U235	2.54E-02	3.12E-02	1.08E-02	1.64E-02	6.34E-03	3.68E-02	9.53E-03	6.39E-03	1.14E-02	1.02E-02	6.56E-03	1.49E-02
U236	1.41E-03	1.96E-03	1.66E-05	0.00E+00	0.00E+00	0.00E+00	1.49E-04	0.00E+00	2.40E-04	8.70E-05	0.00E+00	2.02E-04
U238	3.67E-02	1.71E-02	8.55E-02	1.79E-01	6.19E-02	4.18E-01	1.23E-01	9.68E-02	1.39E-01	1.06E-01	7.23E-02	1.50E-01
Pu238	3.18E-03	2.48E-03	4.93E-03	1.10E-02	4.89E-03	2.35E-02	9.43E-03	8.81E-03	9.80E-03	1.43E-02	1.86E-02	8.57E-03
Pu239	3.50E-02	3.99E-02	2.26E-02	3.95E-02	4.99E-03	1.10E-01	1.85E-02	1.13E-02	2.29E-02	2.67E-02	2.13E-02	3.37E-02
Pu240	3.21E-02	3.26E-02	3.11E-02	5.27E-02	4.07E-03	1.52E-01	2.05E-02	9.63E-03	2.71E-02	2.94E-02	1.73E-02	4.53E-02
Pu242	1.81E-04	1.90E-04	1.60E-04	1.59E-03	1.95E-03	8.54E-04	4.89E-04	6.18E-04	4.10E-04	3.87E-05	0.00E+00	8.98E-05
Cm243	1.18E-05	1.53E-05	2.89E-06	2.48E-05	2.82E-05	1.78E-05	1.03E-05	1.19E-05	9.32E-06	6.54E-06	8.72E-06	3.66E-06
Cm244	4.81E-03	5.92E-04	1.53E-02	2.57E-02	1.12E-03	7.57E-02	6.67E-03	5.64E-04	1.04E-02	9.99E-03	1.16E-03	2.17E-02
Ra226	1.91E-02	1.65E-02	2.54E-02	3.18E-02	2.69E-02	4.17E-02	2.17E-02	1.36E-02	2.66E-02	3.33E-02	3.70E-02	2.83E-02
K40	4.34E-02	3.27E-02	7.03E-02	1.55E-01	1.50E-01	1.66E-01	1.04E-01	6.89E-02	1.25E-01	1.41E-01	1.17E-01	1.72E-01
Ar39	1.32E-01	1.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	3.28E-01	4.59E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	1.20E-03	1.69E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	2.45E-01	3.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	1.19E-03	1.67E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm242	3.11E-10	3.06E-10	3.22E-10	3.47E-10	3.33E-10	3.74E-10	7.61E-12	1.00E-11	6.12E-12	1.04E-13	0.00E+00	2.40E-13
Cf252	7.71E-06	7.93E-06	7.16E-06	7.32E-05	7.35E-05	7.26E-05	5.99E-06	7.90E-06	4.81E-06	7.83E-07	0.00E+00	1.82E-06

Table D.12: Reference Case specific activity for the SGHWR components modelled in Bq g^{-1}. *Note this page is set to A3 size.*

Rads.	Bioshield			Ponds			Mortuary Tubes			Primary (excluding bioshield, mortuary tubes and ponds)			Secondary		
	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ
H3	4.03E+02	4.03E+02	0.00E+00	8.20E-01	8.20E-01	0.00E+00	1.61E+02	1.61E+02	0.00E+00	1.63E+01	1.95E+01	1.03E+01	3.13E+00	3.00E+00	3.33E+00
C14	1.10E+00	1.10E+00	0.00E+00	9.61E-02	9.61E-02	0.00E+00	1.67E+01	1.67E+01	0.00E+00	4.20E-01	4.35E-01	3.92E-01	1.60E-01	1.00E-01	2.48E-01
Cs134	8.50E-05	8.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.85E-06	1.57E-06	2.36E-06	2.04E-05	2.48E-05	1.39E-05
Cs137	8.15E+00	8.15E+00	0.00E+00	2.93E+00	2.93E+00	0.00E+00	8.54E+02	8.54E+02	0.00E+00	9.15E-01	9.90E-01	7.74E-01	1.32E+00	1.38E+00	1.23E+00
Co57	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-06	1.73E-06	0.00E+00	8.30E-12	6.59E-12	1.15E-11	1.32E-06	1.47E-06	1.10E-06
Co60	2.03E+00	2.03E+00	0.00E+00	2.13E-02	2.13E-02	0.00E+00	2.44E+01	2.44E+01	0.00E+00	5.85E-02	7.44E-02	2.89E-02	2.25E-02	3.38E-02	5.94E-03
Am241	8.17E-02	8.17E-02	0.00E+00	1.28E-01	1.28E-01	0.00E+00	4.75E+01	4.75E+01	0.00E+00	1.39E-03	1.11E-03	1.92E-03	3.23E-02	2.93E-02	3.67E-02
Nb94	0.00E+00	0.00E+00	0.00E+00	2.10E-03	2.10E-03	0.00E+00	4.90E-01	4.90E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.21E-03	5.98E-04	9.51E-03
Sb125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E-02	1.59E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	4.78E-04	2.30E-04
Eu152	2.43E+01	2.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.94E-01	7.94E-01	0.00E+00	1.06E-02	9.33E-03	1.29E-02	2.84E-02	1.10E-02	5.39E-02
Eu154	1.08E+00	1.08E+00	0.00E+00	1.05E-02	1.05E-02	0.00E+00	1.84E+00	1.84E+00	0.00E+00	1.59E-03	1.29E-03	2.17E-03	4.80E-03	2.41E-03	8.32E-03
Eu155	4.23E-02	4.23E-02	0.00E+00	1.16E-03	1.16E-03	0.00E+00	1.39E-01	1.39E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.52E-04	7.28E-04	7.88E-04
Fe55	2.32E+00	2.32E+00	0.00E+00	2.45E-02	2.45E-02	0.00E+00	1.23E+02	1.23E+02	0.00E+00	3.27E-03	3.80E-03	2.27E-03	4.94E-03	5.86E-03	3.59E-03
Ni63	9.29E+00	9.29E+00	0.00E+00	1.82E-01	1.82E-01	0.00E+00	1.40E+02	1.40E+02	0.00E+00	5.15E-01	6.03E-01	3.49E-01	5.12E-01	8.05E-01	8.28E-02
Sr90	1.22E-03	1.22E-03	0.00E+00	3.50E+00	3.50E+00	0.00E+00	1.28E+03	1.28E+03	0.00E+00	1.05E-02	1.19E-02	7.83E-03	1.19E-01	3.07E-02	2.49E-01
Pu241	1.06E-03	1.06E-03	0.00E+00	6.74E-01	6.74E-01	0.00E+00	1.52E+02	1.52E+02	0.00E+00	7.67E-03	7.46E-03	8.05E-03	9.69E-02	8.86E-02	1.09E-01
Ba133	5.11E+00	5.11E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.66E-03	2.66E-03	0.00E+00	2.07E-03	2.17E-03	1.87E-03	0.00E+00	0.00E+00	0.00E+00
Tc99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.54E-03	5.82E-03	5.00E-03	3.81E-04	6.25E-04	2.46E-05
I129	0.00E+00	0.00E+00	0.00E+00	1.03E-01	1.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E-04	1.65E-04	2.39E-05	8.18E-04	1.34E-03	5.27E-05
Cl36	0.00E+00	0.00E+00	0.00E+00	9.29E-02	9.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	0.00E+00	0.00E+00	0.00E+00	4.62E-01	4.62E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.34E-04	7.70E-04	6.68E-04	4.05E-04	4.00E-04	4.14E-04
U234	0.00E+00	0.00E+00	0.00E+00	9.46E-03	9.46E-03	0.00E+00	1.56E+00	1.56E+00	0.00E+00	1.73E-02	1.28E-02	2.57E-02	7.88E-02	7.10E-02	9.03E-02
U235	3.06E-01	3.06E-01	0.00E+00	9.57E-03	9.57E-03	0.00E+00	6.58E-02	6.58E-02	0.00E+00	3.96E-03	3.14E-03	5.51E-03	9.13E-03	7.82E-03	1.11E-02
U236	0.00E+00	0.00E+00	0.00E+00	9.57E-03	9.57E-03	0.00E+00	6.58E-02	6.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.88E-04	1.48E-03	2.69E-04
U238	0.00E+00	0.00E+00	0.00E+00	6.67E-03	6.67E-03	0.00E+00	4.93E-01	4.93E-01	0.00E+00	1.42E-02	1.06E-02	2.11E-02	7.57E-02	5.88E-02	1.01E-01
Pu238	1.14E-04	1.14E-04	0.00E+00	7.84E-03	7.84E-03	0.00E+00	1.68E+00	1.68E+00	0.00E+00	3.56E-04	3.27E-04	4.10E-04	7.70E-03	8.22E-03	6.93E-03
Pu239	2.29E-05	2.29E-05	0.00E+00	1.24E-01	1.24E-01	0.00E+00	7.43E+01	7.43E+01	0.00E+00	3.25E-04	2.86E-04	3.97E-04	1.13E-02	9.09E-03	1.44E-02
Pu240	2.28E-05	2.28E-05	0.00E+00	1.01E-01	1.01E-01	0.00E+00	6.05E+01	6.05E+01	0.00E+00	2.67E-04	2.36E-04	3.26E-04	1.11E-02	7.41E-03	1.66E-02
Pu242	0.00E+00	0.00E+00	0.00E+00	8.29E-04	8.29E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.67E-05	5.98E-05	5.10E-05	4.60E-04	4.42E-04	4.86E-04
Cm243	0.00E+00	0.00E+00	0.00E+00	8.78E-05	8.78E-05	0.00E+00	2.74E-03	2.74E-03	0.00E+00	3.29E-06	3.36E-06	3.17E-06	1.17E-05	1.36E-05	8.98E-06
Cm244	0.00E+00	0.00E+00	0.00E+00	3.33E-03	3.33E-03	0.00E+00	1.03E-01	1.03E-01	0.00E+00	1.32E-04	1.34E-04	1.28E-04	2.83E-03	6.32E-04	6.04E-03
Ra226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.09E-02	1.82E-02	2.60E-02	3.28E-02	3.41E-02	3.10E-02
K40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E-02	1.13E-02	5.42E-02	1.39E-01	1.38E-01	1.42E-01
Ar39	2.17E+00	2.17E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	5.37E+00	5.37E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	1.64E-02	1.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.40E-01	9.40E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	4.01E+00	4.01E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	1.62E-02	1.62E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.31E-01	9.31E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm242	0.00E+00	0.00E+00	0.00E+00	7.20E-12	7.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.76E-10	4.99E-10	4.33E-10	7.14E-11	9.73E-11	3.36E-11
Cf252	0.00E+00	0.00E+00	0.00E+00	4.57E-06	4.57E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.63E-06	9.04E-06	7.85E-06	1.29E-05	1.43E-05	1.08E-05

Table D.13: Alternative case specific activity for the four main SGHWR modelled regions in Bq g^{-1}. *Note this page is set to A3 size.*

Rads.	Region 1			Region 2			North Annexe			South Annexe		
	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ
H3	3.96E+02	5.42E+02	3.18E+01	8.82E+00	7.76E+00	1.10E+01	2.61E+00	3.27E+00	2.21E+00	5.80E+00	7.94E+00	2.98E+00
C14	2.03E+00	2.37E+00	1.19E+00	9.49E-01	9.73E-01	9.01E-01	1.03E+00	5.74E-01	1.31E+00	3.54E-01	3.78E-01	3.21E-01
Cs134	6.83E-04	9.53E-04	7.40E-06	2.61E-05	3.30E-05	1.20E-05	3.84E-05	4.46E-05	3.46E-05	4.95E-05	6.66E-05	2.69E-05
Cs137	7.69E+00	7.67E+00	7.74E+00	4.02E+01	3.87E+01	4.32E+01	1.54E+00	1.06E+00	1.84E+00	4.41E+00	5.77E+00	2.62E+00
Co57	1.40E-07	1.96E-07	9.56E-11	9.88E-07	1.47E-06	8.43E-11	3.32E-06	3.85E-06	3.00E-06	2.32E-06	3.06E-06	1.35E-06
Co60	2.17E+00	2.97E+00	1.79E-01	4.15E-01	5.79E-01	8.02E-02	2.30E-02	2.50E-02	2.18E-02	1.65E-02	1.93E-02	1.28E-02
Am241	1.34E-01	1.64E-01	6.03E-02	1.17E-01	4.21E-02	2.71E-01	6.34E-02	5.25E-02	7.00E-02	8.06E-02	7.64E-02	8.62E-02
Nb94	3.16E-02	3.66E-02	1.90E-02	5.32E-05	7.93E-05	0.00E+00	2.33E-04	2.70E-04	2.10E-04	2.72E-04	4.50E-04	3.73E-05
Sb125	2.31E-03	3.23E-03	3.86E-06	1.52E-04	2.17E-04	1.90E-05	4.51E-04	5.22E-04	4.09E-04	3.54E-04	5.27E-04	1.27E-04
Eu152	2.21E+01	3.09E+01	1.34E-01	5.27E-02	4.69E-02	6.45E-02	2.25E-02	2.64E-02	2.02E-02	2.76E-02	2.62E-02	2.94E-02
Eu154	9.87E-01	1.37E+00	1.92E-02	1.16E-02	1.03E-02	1.43E-02	4.59E-03	5.51E-03	4.03E-03	5.77E-03	5.50E-03	6.14E-03
Eu155	3.91E-02	5.43E-02	1.14E-03	1.36E-04	2.03E-04	0.00E+00	3.08E-04	3.57E-04	2.78E-04	5.83E-04	9.02E-04	1.61E-04
Fe55	2.12E+00	2.96E+00	5.29E-03	1.98E-02	2.33E-02	1.27E-02	6.70E-03	6.53E-03	6.79E-03	5.22E-03	7.90E-03	1.68E-03
Ni63	1.01E+01	1.38E+01	9.27E-01	2.80E+00	3.64E+00	1.09E+00	2.07E-01	9.64E-02	2.74E-01	1.06E+00	1.68E+00	2.42E-01
Sr90	1.21E+00	1.41E+00	7.13E-01	1.92E+00	8.64E-01	4.07E+00	3.22E-01	1.07E-01	4.53E-01	6.16E-01	3.57E-01	9.59E-01
Pu241	2.16E-01	2.44E-01	1.46E-01	3.74E-01	2.41E-01	6.44E-01	2.15E-01	2.16E-01	2.14E-01	1.68E-01	1.41E-01	2.05E-01
Ba133	4.65E+00	6.51E+00	1.24E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc99	4.66E-03	4.66E-03	4.64E-03	7.71E-03	1.15E-02	4.93E-05	3.87E-05	4.61E-05	3.42E-05	9.03E-05	1.10E-04	6.43E-05
I129	1.15E-02	1.60E-02	9.04E-05	1.65E-02	2.46E-02	1.06E-04	8.29E-05	9.87E-05	7.33E-05	1.94E-04	2.36E-04	1.38E-04
Cl36	9.31E-03	1.30E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	4.69E-02	6.54E-02	7.79E-04	1.59E-03	1.95E-03	8.54E-04	4.68E-04	6.18E-04	3.76E-04	0.00E+00	0.00E+00	0.00E+00
U234	2.01E-01	1.69E-01	2.82E-01	7.96E-01	6.83E-01	1.03E+00	3.59E-01	4.33E-01	3.14E-01	5.48E-01	6.78E-01	3.75E-01
U235	3.10E-01	4.15E-01	4.68E-02	7.40E-02	5.30E-02	1.17E-01	3.03E-02	3.27E-02	2.88E-02	4.76E-02	5.21E-02	4.16E-02
U236	2.11E-03	2.93E-03	6.03E-05	1.24E-04	1.11E-04	1.52E-04	1.85E-04	5.71E-05	2.63E-04	1.35E-04	5.07E-05	2.47E-04
U238	2.11E-01	1.54E-01	3.53E-01	8.79E-01	6.29E-01	1.39E+00	3.95E-01	4.28E-01	3.75E-01	5.36E-01	5.89E-01	4.66E-01
Pu238	2.66E-02	2.54E-02	2.96E-02	8.10E-02	6.76E-02	1.08E-01	3.24E-02	4.36E-02	2.55E-02	1.06E-01	1.60E-01	3.40E-02
Pu239	6.85E-02	7.49E-02	5.24E-02	1.24E-01	8.14E-02	2.12E-01	4.73E-02	5.39E-02	4.32E-02	1.33E-01	1.85E-01	6.43E-02
Pu240	5.97E-02	6.12E-02	5.57E-02	1.23E-01	6.71E-02	2.36E-01	4.45E-02	4.49E-02	4.43E-02	1.16E-01	1.51E-01	7.06E-02
Pu242	2.55E-04	2.71E-04	2.14E-04	1.65E-03	2.00E-03	9.22E-04	5.05E-04	6.43E-04	4.21E-04	6.01E-05	2.25E-05	1.10E-04
Cm243	3.11E-05	3.43E-05	2.31E-05	6.11E-05	7.44E-05	3.41E-05	1.45E-05	1.72E-05	1.28E-05	1.55E-05	2.29E-05	5.68E-06
Cm244	9.45E-03	6.21E-03	1.75E-02	3.11E-02	6.46E-03	8.12E-02	8.02E-03	2.64E-03	1.13E-02	1.56E-02	9.92E-03	2.32E-02
Ra226	1.17E-01	1.06E-01	1.45E-01	2.17E-01	1.94E-01	2.63E-01	8.73E-02	1.03E-01	7.80E-02	1.87E-01	2.52E-01	1.01E-01
K40	2.80E-01	2.39E-01	3.83E-01	1.07E+00	9.96E-01	1.21E+00	4.12E-01	4.75E-01	3.73E-01	6.67E-01	7.34E-01	5.79E-01
Ar39	1.96E+00	2.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	4.87E+00	6.82E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	1.49E-02	2.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	3.63E+00	5.09E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	1.71E-02	2.39E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	2.32E-01	3.25E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	5.46E-03	7.65E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr85	1.51E-03	2.11E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	5.22E-03	7.32E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	5.86E-03	8.22E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	2.73E-02	3.83E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	9.83E-03	1.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm242	4.68E-10	4.56E-10	5.00E-10	3.51E-10	3.39E-10	3.74E-10	7.65E-12	1.01E-11	6.15E-12	1.61E-13	6.03E-14	2.94E-13
Cf252	1.12E-05	1.14E-05	1.08E-05	7.66E-05	7.79E-05	7.39E-05	6.31E-06	8.42E-06	5.02E-06	1.22E-06	4.56E-07	2.22E-06

Table D.14: Alternative case specific activity for the SGHWR inventory features modelled in Bq g^{-1}. *Note this page is set to A3 size.*

Rads.	Bioshield			Ponds			Mortuary Tubes			Primary (excluding bioshield, mortuary tubes and ponds)			Secondary		
	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ	Entire structure	In-situ	Above in-situ
H3	5.97E+03	5.97E+03	0.00E+00	8.17E-01	8.17E-01	0.00E+00	1.60E+02	1.60E+02	0.00E+00	4.70E+01	5.24E+01	3.68E+01	4.76E+00	5.06E+00	4.33E+00
C14	1.62E+01	1.62E+01	0.00E+00	9.90E-02	9.90E-02	0.00E+00	2.40E+02	2.40E+02	0.00E+00	1.42E+00	1.47E+00	1.33E+00	6.30E-01	3.83E-01	9.93E-01
Cs134	1.25E-03	1.25E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.72E+00	2.72E+00	0.00E+00	5.60E-06	5.53E-06	5.73E-06	5.40E-05	6.69E-05	3.52E-05
Cs137	1.41E+01	1.41E+01	0.00E+00	5.60E+00	5.60E+00	0.00E+00	8.54E+02	8.54E+02	0.00E+00	8.01E+00	8.39E+00	7.30E+00	7.22E+00	9.23E+00	4.28E+00
Co57	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-06	1.73E-06	0.00E+00	4.16E-11	4.18E-11	4.13E-11	3.04E-06	3.38E-06	2.53E-06
Co60	3.01E+01	3.01E+01	0.00E+00	4.13E-02	4.13E-02	0.00E+00	5.44E+02	5.44E+02	0.00E+00	2.69E-01	2.94E-01	2.23E-01	1.29E-01	2.03E-01	2.05E-02
Am241	1.20E+00	1.20E+00	0.00E+00	2.45E-01	2.45E-01	0.00E+00	4.75E+01	4.75E+01	0.00E+00	3.54E-03	3.37E-03	3.86E-03	5.26E-02	5.83E-02	4.43E-02
Nb94	0.00E+00	0.00E+00	0.00E+00	2.94E-03	2.94E-03	0.00E+00	1.17E+02	1.17E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-02	8.73E-04	2.38E-02
Sb125	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+01	1.01E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.75E-04	7.62E-04	3.01E-04
Eu152	3.61E+02	3.61E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.94E-01	7.94E-01	0.00E+00	4.13E-02	4.13E-02	4.13E-02	6.47E-02	2.23E-02	1.27E-01
Eu154	1.60E+01	1.60E+01	0.00E+00	1.66E-02	1.66E-02	0.00E+00	1.84E+00	1.84E+00	0.00E+00	4.39E-03	4.27E-03	4.63E-03	1.03E-02	4.48E-03	1.88E-02
Eu155	6.29E-01	6.29E-01	0.00E+00	1.64E-03	1.64E-03	0.00E+00	1.39E-01	1.39E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E-03	1.19E-03	1.69E-03
Fe55	3.45E+01	3.45E+01	0.00E+00	2.50E-02	2.50E-02	0.00E+00	2.28E+01	2.28E+01	0.00E+00	5.76E-03	6.41E-03	4.54E-03	8.18E-03	1.00E-02	5.51E-03
Ni63	1.34E+02	1.34E+02	0.00E+00	2.71E-01	2.71E-01	0.00E+00	4.32E+03	4.32E+03	0.00E+00	1.24E+00	1.36E+00	1.01E+00	1.11E+00	1.76E+00	1.65E-01
Sr90	1.22E-03	1.22E-03	0.00E+00	6.77E+00	6.77E+00	0.00E+00	1.28E+03	1.28E+03	0.00E+00	2.08E-02	2.28E-02	1.72E-02	2.05E-01	1.24E-01	3.24E-01
Pu241	1.06E-03	1.06E-03	0.00E+00	1.05E+00	1.05E+00	0.00E+00	1.52E+02	1.52E+02	0.00E+00	1.49E-02	1.50E-02	1.48E-02	1.33E-01	1.28E-01	1.40E-01
Ba133	7.59E+01	7.59E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.13E+01	4.13E+01	0.00E+00	1.80E-02	1.87E-02	1.67E-02	0.00E+00	0.00E+00	0.00E+00
Tc99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.85E-03	7.19E-03	6.23E-03	1.63E-03	2.69E-03	6.97E-05
I129	0.00E+00	0.00E+00	0.00E+00	1.03E-01	1.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-04	2.03E-04	3.64E-05	3.49E-03	5.77E-03	1.49E-04
Cl36	0.00E+00	0.00E+00	0.00E+00	9.31E-02	9.31E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	0.00E+00	0.00E+00	0.00E+00	4.63E-01	4.63E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.72E-04	1.02E-03	8.88E-04	4.28E-04	4.37E-04	4.14E-04
U234	0.00E+00	0.00E+00	0.00E+00	1.26E-02	1.26E-02	0.00E+00	1.56E+00	1.56E+00	0.00E+00	2.63E-02	2.22E-02	3.40E-02	1.89E-01	1.85E-01	1.94E-01
U235	4.52E+00	4.52E+00	0.00E+00	9.91E-03	9.91E-03	0.00E+00	6.58E-02	6.58E-02	0.00E+00	2.46E-02	2.46E-02	2.46E-02	1.93E-02	1.84E-02	2.07E-02
U236	0.00E+00	0.00E+00	0.00E+00	9.91E-03	9.91E-03	0.00E+00	6.58E-02	6.58E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-03	3.19E-03	2.81E-04
U238	0.00E+00	0.00E+00	0.00E+00	7.64E-03	7.64E-03	0.00E+00	4.93E-01	4.93E-01	0.00E+00	2.16E-02	1.82E-02	2.79E-02	1.80E-01	1.60E-01	2.10E-01
Pu238	1.14E-04	1.14E-04	0.00E+00	1.13E-02	1.13E-02	0.00E+00	2.56E+01	2.56E+01	0.00E+00	6.90E-04	6.77E-04	7.14E-04	1.89E-02	2.19E-02	1.47E-02
Pu239	2.29E-05	2.29E-05	0.00E+00	2.36E-01	2.36E-01	0.00E+00	7.43E+01	7.43E+01	0.00E+00	8.78E-04	8.62E-04	9.07E-04	2.46E-02	2.50E-02	2.39E-02
Pu240	2.28E-05	2.28E-05	0.00E+00	1.92E-01	1.92E-01	0.00E+00	6.05E+01	6.05E+01	0.00E+00	7.21E-04	7.08E-04	7.44E-04	2.21E-02	2.05E-02	2.44E-02
Pu242	0.00E+00	0.00E+00	0.00E+00	1.10E-03	1.10E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.75E-05	1.02E-04	8.88E-05	4.68E-04	4.47E-04	5.00E-04
Cm243	0.00E+00	0.00E+00	0.00E+00	9.43E-05	9.43E-05	0.00E+00	2.74E-03	2.74E-03	0.00E+00	3.02E-05	3.11E-05	2.83E-05	2.20E-05	2.89E-05	1.19E-05
Cm244	0.00E+00	0.00E+00	0.00E+00	3.57E-03	3.57E-03	0.00E+00	1.32E+01	1.32E+01	0.00E+00	1.19E-03	1.23E-03	1.12E-03	3.67E-03	1.71E-03	6.54E-03
Ra226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E-01	1.05E-01	1.00E-01	7.51E-02	8.35E-02	6.27E-02
K40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-02	2.30E-02	5.73E-02	3.26E-01	3.45E-01	2.96E-01
Ar39	3.22E+01	3.22E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ca41	7.99E+01	7.99E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cd113m	2.43E-01	2.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-01	1.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm151	5.96E+01	5.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tl204	2.41E-01	2.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E+01	1.08E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb93m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+03	1.06E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hf178n	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.49E+01	2.49E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.86E+00	6.86E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ni59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E+01	2.38E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt193	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.67E+01	2.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn121m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E+02	1.25E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zr93	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.48E+01	4.48E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm242	0.00E+00	0.00E+00	0.00E+00	7.06E-12	7.06E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.34E-10	7.67E-10	6.73E-10	7.29E-11	9.97E-11	3.36E-11
Cf252	0.00E+00	0.00E+00	0.00E+00	4.48E-06	4.48E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E-05	1.39E-05	1.22E-05	1.38E-05	1.58E-05	1.09E-05

Table D.15: Reference Case specific activity for the Dragon features modelled in Bq g^{-1}. *Note this page is set to A3 size.*

Radionuclide	In-situ below cutline inventory						Infill (above cutline) inventory						
	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	Stockpile rubble
H3	4.86E+00	4.74E+00	1.88E+01	9.45E+01	2.89E-03	4.75E+00	4.86E+00	4.74E+00				4.75E+00	2.61E-02
C14	4.70E-02	2.27E-01	2.27E-01	6.73E+00	7.21E-03	2.27E-01	4.70E-02	2.27E-01				2.27E-01	5.07E-03
Cl36	2.82E-03						2.82E-03						
Ca41	7.41E-02						7.41E-02						
Fe55	4.01E-03				7.13E-05		4.01E-03						
Co60	1.05E-02	5.42E-02	5.42E-02	7.73E-01	3.96E-04	5.42E-02	1.05E-02	5.42E-02				5.42E-02	1.28E-03
Ni59													
Ni63	1.66E-01	1.58E-01	1.58E-01	1.98E+00	2.41E-04	1.58E-01	1.66E-01	1.58E-01				1.58E-01	3.08E-02
Sr90		3.88E+00	3.88E+00	7.02E+01	1.29E-01	3.88E+00		3.88E+00				3.88E+00	1.52E-01
Zr93													
Nb93m													
Nb94													
Tc99													
Cd113m													
Sn121m													
Sb125													9.51E-07
I129													
Cs134													
Cs137	5.29E-05	2.83E+00	2.83E+00	1.18E+04	2.88E-01	2.83E+00	5.29E-05	2.83E+00				2.83E+00	4.24E-01
Ba133	2.16E-01						2.16E-01						
Sm148	4.14E-30						4.14E-30						
Sm151	2.10E-02						2.10E-02						
Gd152	8.91E-15						8.91E-15						
Eu152	4.51E-01						4.51E-01						
Eu154	1.24E-02						1.24E-02						
Eu155													
Hf178n													
Pt193													
Tl204													
Pb210		6.48E-02	6.48E-02		6.19E-12	6.48E-02		6.48E-02				6.48E-02	
Ra226		1.24E-01	1.24E-01		1.79E-10	1.24E-01		1.24E-01				1.24E-01	
Ra228		1.65E-03	1.65E-03		1.28E-16	1.65E-03		1.65E-03				1.65E-03	
Ac227		2.82E-06	2.82E-06		1.76E-10	2.82E-06		2.82E-06				2.82E-06	
Th228		1.26E-03	1.26E-03		4.12E-17	1.26E-03		1.26E-03				1.26E-03	
Th229		3.16E-14	3.16E-14		2.45E-06	3.16E-14		3.16E-14				3.16E-14	
Th230		3.15E-03	3.15E-03		2.39E-07	3.15E-03		3.15E-03				3.15E-03	
Th232		2.52E-03	2.52E-03		7.00E-16	2.52E-03		2.52E-03				2.52E-03	
Pa231		2.20E-05	2.20E-05		3.32E-09	2.20E-05		2.20E-05				2.20E-05	
U233		1.15E-10	1.15E-10		7.51E-03	1.15E-10		1.15E-10				1.15E-10	
U234		3.73E-01	3.73E-01		7.51E-03	3.73E-01		3.73E-01				3.73E-01	2.49E-03
U235		1.18E-01	1.18E-01		4.54E-05	1.18E-01		1.18E-01				1.18E-01	1.24E-03
U236					4.10E-06								
U238		4.61E-01	4.61E-01		4.44E-05	4.61E-01		4.61E-01				4.61E-01	1.49E-02
Np237		6.15E-06	6.15E-06		1.69E-08	6.15E-06		6.15E-06				6.15E-06	
Pu238					1.29E-02								1.08E-03
Pu239					1.74E-03								5.41E-03
Pu240					1.74E-03								7.53E-03
Pu241					4.29E-02								2.14E-02

Radionuclide	In-situ below cutline inventory						Infill (above cutline) inventory						
	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	Stockpile rubble
Pu242													
Pu244													
Am241		2.15E+00	2.15E+00		1.52E-02	2.15E+00		2.15E+00				2.15E+00	1.14E-02
Am243					4.10E-10								
Cm243					5.04E-04								
Cm244					4.37E-04								3.75E-03

Table D.16: Alternative case specific activity for the Dragon modelled regions in Bq g^{-1}. *Note this page is set to A3 size.*

Radionuclide	In-situ below cutline inventory						Infill (above cutline) inventory						
	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	Stockpile rubble
H3	2.19E+01	5.04E+00	3.91E+02	9.45E+01	3.84E-03	5.26E+00	2.19E+01	5.04E+00				5.26E+00	7.95E-02
C14	1.22E-01	2.27E-01	2.04E-01	6.73E+00	1.48E-02	2.27E-01	1.22E-01	2.27E-01				2.27E-01	5.99E-03
Cl36	6.05E-03						6.05E-03						
Ca41	2.28E-01						2.28E-01						
Fe55	9.42E-03				1.14E-04		9.42E-03						
Co60	3.15E-02	5.42E-02	4.89E-02	7.73E-01	5.90E-04	5.42E-02	3.15E-02	5.42E-02				5.42E-02	1.28E-03
Ni59													
Ni63	4.41E-01	1.58E-01	1.43E-01	1.98E+00	3.12E-04	1.58E-01	4.41E-01	1.58E-01				1.58E-01	3.08E-02
Sr90		3.88E+00	3.50E+00	7.02E+01	1.76E-01	3.88E+00		3.88E+00				3.88E+00	1.52E-01
Zr93													
Nb93m													
Nb94													
Tc99													
Cd113m													
Sn121m													
Sb125													9.51E-07
I129													
Cs134													
Cs137	5.29E-05	2.83E+00	2.55E+00	1.18E+04	4.07E-01	2.83E+00	5.29E-05	2.83E+00				2.83E+00	4.24E-01
Ba133	6.75E-01						6.75E-01						
Sm148	1.28E-29						1.28E-29						
Sm151	6.58E-02						6.58E-02						
Gd152	2.75E-14						2.75E-14						
Eu152	1.39E+00						1.39E+00						
Eu154	3.45E-02						3.45E-02						
Eu155													
Hf178n													
Pt193													
Tl204													
Pb210		6.48E-02	5.84E-02		1.39E-11	6.48E-02		6.48E-02				6.48E-02	
Ra226		1.24E-01	1.12E-01		4.01E-10	1.24E-01		1.24E-01				1.24E-01	
Ra228		1.65E-03	1.48E-03		1.28E-16	1.65E-03		1.65E-03				1.65E-03	
Ac227		2.82E-06	2.54E-06		3.76E-10	2.82E-06		2.82E-06				2.82E-06	
Th228		1.26E-03	1.14E-03		4.12E-17	1.26E-03		1.26E-03				1.26E-03	
Th229		3.16E-14	2.85E-14		5.50E-06	3.16E-14		3.16E-14				3.16E-14	
Th230		3.15E-03	2.84E-03		5.36E-07	3.15E-03		3.15E-03				3.15E-03	

Radionuclide	In-situ below cutline inventory						Infill (above cutline) inventory						
	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	Stockpile rubble
Th232		2.52E-03	2.27E-03		7.00E-16	2.52E-03		2.52E-03				2.52E-03	
Pa231		2.20E-05	1.99E-05		7.09E-09	2.20E-05		2.20E-05				2.20E-05	
U233		1.15E-10	1.04E-10		1.68E-02	1.15E-10		1.15E-10				1.15E-10	
U234		3.73E-01	3.37E-01		1.68E-02	3.73E-01		3.73E-01				3.73E-01	4.40E-03
U235		1.18E-01	1.07E-01		9.70E-05	1.18E-01		1.18E-01				1.18E-01	2.20E-03
U236					4.10E-06								
U238		4.61E-01	4.16E-01		9.48E-05	4.61E-01		4.61E-01				4.61E-01	2.64E-02
Np237		6.15E-06	5.55E-06		2.09E-08	6.15E-06		6.15E-06				6.15E-06	
Pu238					1.98E-02								1.08E-03
Pu239					2.68E-03								5.41E-03
Pu240					2.68E-03								7.53E-03
Pu241					5.18E-02								2.14E-02
Pu242													
Pu244													
Am241		2.15E+00	1.94E+00		1.88E-02	2.15E+00		2.15E+00				2.15E+00	1.14E-02
Am243					5.49E-10								
Cm243					6.75E-04								
Cm244					6.00E-04								3.75E-03

Table D.17: Alternative case (Pu fingerprint) specific activity for the Dragon modelled regions in Bq g^{-1}. *Note this page is set to A3 size.*

Radionuclide	In-situ below cutline inventory						Infill (above cutline) inventory						
	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	Stockpile rubble
H3	2.19E+01	4.33E+00	3.91E+02	9.45E+01	3.84E-03	4.55E+00	2.19E+01	4.33E+00				4.55E+00	7.95E-02
C14	1.22E-01	3.67E-01	2.04E-01	6.73E+00	1.48E-02	3.67E-01	1.22E-01	3.67E-01				3.67E-01	5.99E-03
Cl36	6.05E-03	5.28E-01				5.28E-01	6.05E-03	5.28E-01				5.28E-01	
Ca41	2.28E-01						2.28E-01						
Fe55	9.42E-03	2.96E-03			1.14E-04	2.96E-03	9.42E-03	2.96E-03				2.96E-03	
Co60	3.15E-02	3.56E-02	4.89E-02	7.73E-01	5.90E-04	3.56E-02	3.15E-02	3.56E-02				3.56E-02	1.28E-03
Ni59													
Ni63	4.41E-01	9.44E-01	1.43E-01	1.98E+00	3.12E-04	9.44E-01	4.41E-01	9.44E-01				9.44E-01	3.08E-02
Sr90		2.10E+00	3.50E+00	7.02E+01	1.76E-01	2.10E+00		2.10E+00				2.10E+00	1.52E-01
Zr93													
Nb93m													
Nb94													
Tc99													
Cd113m													
Sn121m													
Sb125													9.51E-07
I129													
Cs134													
Cs137	5.29E-05	5.62E+00	2.55E+00	1.18E+04	4.07E-01	5.62E+00	5.29E-05	5.62E+00				5.62E+00	4.24E-01
Ba133	6.75E-01						6.75E-01						
Sm148	1.28E-29						1.28E-29						
Sm151	6.58E-02						6.58E-02						
Gd152	2.75E-14						2.75E-14						
Eu152	1.39E+00	4.17E-01				4.17E-01	1.39E+00	4.17E-01				4.17E-01	

Radionuclide	In-situ below cutline inventory						Infill (above cutline) inventory						
	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	B70 Bioshield	B70 Building Contam (excl. Betalite store)	B70 Building Contam (Betalite store)	PGPC Spill	Primary Mortuary Hole Structure	B78	Stockpile rubble
Eu154	3.45E-02	3.93E-02				3.93E-02	3.45E-02	3.93E-02				3.93E-02	
Eu155													
Hf178n													
Pt193													
Tl204													
Pb210		2.25E-10	5.84E-02		1.39E-11	2.25E-10		2.25E-10				2.25E-10	
Ra226		2.64E-09	1.12E-01		4.01E-10	2.64E-09		2.64E-09				2.64E-09	
Ra228		2.91E-02	1.48E-03		1.28E-16	2.91E-02		2.91E-02				2.91E-02	
Ac227		5.75E-07	2.54E-06		3.76E-10	5.75E-07		5.75E-07				5.75E-07	
Th228		2.23E-02	1.14E-03		4.12E-17	2.23E-02		2.23E-02				2.23E-02	
Th229		1.13E-15	2.85E-14		5.50E-06	1.13E-15		1.13E-15				1.13E-15	
Th230		1.38E-06	2.84E-03		5.36E-07	1.38E-06		1.38E-06				1.38E-06	
Th232		4.44E-02	2.27E-03		7.00E-16	4.44E-02		4.44E-02				4.44E-02	
Pa231		4.50E-06	1.99E-05		7.09E-09	4.50E-06		4.50E-06				4.50E-06	
U233		4.17E-12	1.04E-10		1.68E-02	4.17E-12		4.17E-12				4.17E-12	
U234		1.71E-02	3.37E-01		1.68E-02	1.71E-02		1.71E-02				1.71E-02	4.40E-03
U235		2.42E-02	1.07E-01		9.70E-05	2.42E-02		2.42E-02				2.42E-02	2.20E-03
U236					4.10E-06			0.00E+00				0.00E+00	
U238		3.00E-02	4.16E-01		9.48E-05	3.00E-02		3.00E-02				3.00E-02	2.64E-02
Np237		2.27E-07	5.55E-06		2.09E-08	2.27E-07		2.27E-07				2.27E-07	
Pu238		3.82E-02			1.98E-02	3.82E-02		3.82E-02				3.82E-02	1.08E-03
Pu239		1.63E-02			2.68E-03	1.63E-02		1.63E-02				1.63E-02	5.41E-03
Pu240		1.20E-02			2.68E-03	1.20E-02		1.20E-02				1.20E-02	7.53E-03
Pu241		5.19E-01			5.18E-02	5.19E-01		5.19E-01				5.19E-01	2.14E-02
Pu242													
Pu244													
Am241		8.33E-02	1.94E+00		1.88E-02	8.33E-02		8.33E-02				8.33E-02	1.14E-02
Am243					5.49E-10								
Cm243					6.75E-04								
Cm244					6.00E-04								3.75E-03

Table D.18: Specific activity for the both the Reference Case and alternative case A59 area modelled features in Bq g^{-1}.

Radionuclide	Reference Case Activity Concentration				Alternative Case Activity Concentration			
	PSA/Pit 3	A591/HVA	A59 Other Areas	Infill	PSA/Pit 3	A591/HVA	A59 Other Areas	Infill
Co60	4.97E-04	2.14E-02	6.17E-04	6.34E-04	4.36E-04	2.53E-02	3.54E-03	4.97E-03
Ni63	0.00E+00	1.41E+00	7.84E-02	8.19E-02	0.00E+00	1.91E+00	4.57E-01	6.42E-01
Sr90	1.27E-02	1.58E-01	4.00E-02	3.12E-02	2.86E-02	1.98E-01	1.82E-01	9.03E-02
Sb125	8.10E-06	0.00E+00	0.00E+00	0.00E+00	4.79E-05	0.00E+00	0.00E+00	0.00E+00
Cs137	1.72E-02	4.74E-02	1.29E-02	1.41E-02	1.02E-01	6.70E-02	5.83E-02	2.90E-02
Ra226	7.72E-09	4.79E-08	1.49E-08	9.74E-09	3.29E-09	2.07E-08	1.01E-08	1.02E-08
Ac227	1.73E-07	8.51E-07	1.65E-07	1.06E-07	7.32E-08	3.03E-07	1.10E-07	1.11E-07
Th230	1.97E-06	1.22E-05	3.80E-06	2.48E-06	8.38E-07	5.28E-06	2.58E-06	2.59E-06
Pa231	7.22E-07	3.54E-06	6.86E-07	4.41E-07	3.05E-07	1.26E-06	4.58E-07	4.61E-07
U234	1.18E-02	7.32E-02	2.28E-02	1.49E-02	5.02E-03	3.17E-02	1.54E-02	1.55E-02
U235	1.88E-03	9.22E-03	1.79E-03	1.15E-03	7.94E-04	3.28E-03	1.19E-03	1.20E-03
U238	1.33E-02	7.18E-02	2.34E-02	1.53E-02	5.71E-03	3.14E-02	1.58E-02	1.59E-02
Np237	5.50E-08	1.03E-07	1.76E-08	1.26E-08	1.48E-07	2.08E-07	1.76E-07	1.97E-08
Pu238	8.19E-04	9.79E-04	2.92E-04	2.42E-04	2.44E-03	1.10E-03	2.83E-03	7.80E-04
Pu239	1.03E-02	9.13E-04	1.42E-03	1.76E-03	3.26E-02	1.20E-03	1.41E-02	1.63E-02
Pu240	7.46E-03	1.43E-03	1.97E-03	2.45E-03	2.37E-02	1.87E-03	1.97E-02	2.27E-02
Pu241	2.41E-02	1.92E-02	6.13E-03	4.83E-03	5.97E-02	1.37E-02	5.59E-02	1.50E-02
Am241	9.72E-03	1.77E-02	3.08E-03	2.21E-03	2.61E-02	3.52E-02	3.06E-02	3.60E-03
Cm244	0.00E+00	9.03E-04	9.80E-04	6.97E-04	0.00E+00	1.34E-03	9.79E-03	1.02E-03

D.2.3 Materials

D4 Parameterisation of the feature material properties, such as concrete porosity, density and radionuclide partition coefficients are reported here. Table D.19 reports intact concrete parameters, Table D.20 reports granular concrete parameters and Table D.21 reports parameters associated with concrete degradation processes.

D5 Partition coefficients for cement in various stages of degradation are reported in Table D.22, Table D.23 and Table D.24. Note that where multiple oxidation states are reported in the underpinning references, the value associated with the highest oxidation state is used here because the geosphere, and thus the near field, is primarily oxic in nature. The values reported here are multiplied by the cement paste proportion in concrete (Table D.21) in the model.

Table D.19: Material properties associated with initially intact concrete structures.

Parameter	Value		Source
	Undegraded	Degraded	
Porosity (-)	0.15	0.26	In the Winfrith Conceptual Site Model (CSM), WSP [210] assumes the undegraded value quoted by SKB [211] for structural concrete. WSP [210] calculated the degraded value based on Wexham Developments Limited [212], which found the average cement content of samples of concrete from the SGHWR to be around 250 kg m^{-3}. If the cement is assumed to be comprised of portlandite and, using a bulk density for portlandite of 2230 kg m^{-3} (e.g. Mindat [213]), it can be calculated that the cement has a volume of 0.11 m^3 m^{-3} concrete. The fully degraded value is therefore 0.15+0.11=0.26 v v^{-1}.
Bulk Density (kg m^{-3})	2400	2150	WSP [210] assumes a value between two undegraded values from SKB [211, 214] for structural concrete, and calculates the degraded value based on Wexham Developments Limited [212], which found the average cement content of samples of concrete from the SGHWR to be around 250 kg m^{-3}. The fully degraded dry bulk density is therefore 2400-250=2150 kg m^{-3}.
Hydraulic conductivity (m s^{-1})	4.4E-11	2.7E-04	WSP [210] estimates the current effective hydraulic conductivity of the SGHWR Regions 1 and 2 structure to be 4.4×10^{-11} m s^{-1} based on the current rate of reported water ingress. To allow for uncertainty, minimum and maximum conductivities of 1×10^{-12} m s^{-1} and 1×10^{-9} m s^{-1}, respectively, are also considered in variant cases. It is assumed that hydraulic degradation of the concrete structure will mean that ultimately the concrete structure provides no resistance to water flow and that the effective hydraulic conductivity will become approximately that of the Poole Formation. The results of large-scale tests for hydraulic conductivity in geological strata beneath the site range between 7×10^{-5} m s^{-1} to 4.7×10^{-4} m s^{-1}, with the mid-point at 2.7×10^{-4} m s^{-1}. This is also approximately the hydraulic conductivity required for the Poole

Parameter	Value		Source
	Undegraded	Degraded	
			Formation if rainfall infiltration upgradient of the SGHWR is to flow under the measured hydraulic gradient in the vicinity of the SGHWR.
Tortuosity (-)	0.01	0.1	WSP [210, §5.1]: The undegraded value is chosen to give an effective diffusion coefficient consistent with saturated structurally intact concrete of around 10^{-11} m^2 s^{-1} [211]. The degraded value is based on Dounreay "Demolition LLW", a porous broken concrete, similar to what intact concrete is expected to be like when the cement components have been removed and it has become sufficiently cracked, and is chosen to give an effective diffusion coefficient of around 10^{-10} m^2 s^{-1} [216, App.D.1.3, p.290].
Saturation below the water table (-)	1	1	Fraction of porosity. Assumed to be fully saturated, independent of degradation state.
Saturation above the water table / Initial state (-)	0.8	0.58	Undegraded value based on a review of intact concrete saturation levels (SCK CEN [215, "Conclusions"] states "83% as an initial value for the degree of saturation"). Degraded value is assumed to be the same as for granular concrete (see Table D.20).

Table D.20: Material properties associated with granular concrete.

Parameter	Value	Source
Bulking and Compaction Factor (-)	1.31	The bulking and compaction factor (which defines the increase in bulk volume of demolished material after it has been demolished and emplaced) assumed for the granular concrete infill associated with some rooms/voids of SGHWR and Dragon. Bulking increases volume by 60% and compaction in turn reduces volume by 18%, leading to an overall default combined bulking and compaction factor of 1.312, based on WSP [210, footnote C to Tab.606/7].
Porosity (-)	0.30	Based on WSP [210, Tab.606/6], porosity of emplaced demolition arising. Assumption based on the minimum void space between spherical particles being 26% and random packing of equal spheres having a porosity of around 36%.
Bulk Density (kg m^{-3})	1680	Calculated based on the rubble porosity and intact concrete density.

Parameter	Value	Source
Tortuosity (-)	0.1	Based on “Demolition LLW” in Herbert et al. 2021 [216, App.D.1.3, p.290].
Saturation below the water table (-)	1	Assumed to be fully saturated.
Saturation above the water table / Initial state (-)	0.58	The mean moisture by mass in the NRS D630 analysis [217, p.112] is 9.4%. Saturated fraction by volume of the available porosity calculated based on density of rubble and water, and rubble porosity.

Table D.21: Parameters associated with concrete degradation.

Parameter	Value	Source
Hydraulic degradation time (y)	1,000	The time assumed for the concrete to hydraulically degrade has been assessed by reference to hydraulic degradation rates assumed for concrete barriers in safety assessments for near-surface disposal facilities [210, §5.1.4], with 1,000 years judged to be a reasonable modelling assumption. The Reference Case value assumed here is 1,000 years, but a variant case also considers 300 years, which has been assumed in other safety assessments [210, §5.1.4].
Chemical degradation time (y)	50,000	WSP [210, §5.1.5] calculates an estimate for the time required for complete cement dissolution based on the mass of concrete present in SGHWR, the maximum cap infiltration rate and the volume of water passing through the cement to be over 50,000 years. For simplicity, this value is assumed for the Reference Case, but sensitivity analysis assumes the same timescale as the hydraulic degradation (1,000 years).
Cement paste proportion (-)	0.15	Cautiously realistic cement paste proportion for concrete drawing on [218, Tab 36; 219, Tab 7-8; 216, App.D.1.3, p.283].
Hydraulic conductivity exponential growth rate (-)	1.58E-02	WSP [210, §5.1.4] considers it reasonable to assume that degradation of the structure will accelerate with time, so the effective hydraulic conductivity is modelled to change in an exponential fashion over the concrete degradation period.

Table D.22: Partition coefficients for cement paste (m^3 kg^{-1}), concrete chemical degradation Stages 2 and 3b (see discussion in Section 3.4.1), as reported by SKB [219, Tab.7-5 & 7-7], unless stated otherwise in the comment column. *Note this page is set to A3 size.*

Element	Stage 2			Stage 3b			Comment
	Minimum	Most Likely	Maximum	Minimum	Most Likely	Maximum	
Ac	1.00E+00	1.00E+01	5.00E+03	3.00E+00	1.00E+01	5.00E+03	Values are derived by analogy to lanthanides [219, §7.9, p.98].
Am	1.00E+00	1.00E+01	5.00E+03	3.00E+00	1.00E+01	5.00E+03	-
Ba	5.00E-03	3.00E-02	1.00E-01	1.00E-02	1.00E-01	3.00E+00	Values derived through analogy to Sr [219, §7.9, p.98].
C	2.00E+00	5.00E+00	2.00E+01	1.00E-01	7.00E-01	2.00E+00	Data for carbon in the form of carbonate species are used here.
Ca	1.23E-04	3.09E-03	7.72E-03	1.87E-03	4.67E-02	1.17E-01	-
Cd	2.00E-02	6.00E-02	2.00E-01	2.00E-02	6.00E-02	2.00E-01	Values derived through analogy to Pb, but conservatively using Pb state I and reducing the values by a factor of 5 [219, §7.9, p.100].
Cl	2.00E-04	1.00E-03	1.00E-02	2.00E-04	1.00E-03	1.00E-02	-
Cm	1.00E+00	1.00E+01	5.00E+03	3.00E+00	1.00E+01	5.00E+03	Values derived through analogy to Am [219, §7.9, p.101].
Co	1.60E-02	4.00E-02	4.00E-01	1.60E-02	4.00E-02	4.00E-01	Value derived through analogy to Ni but has been cautiously reduced by a factor of five [219, §7.9, p.101].
Cs	1.00E-04	2.00E-03	5.00E-02	1.00E-03	2.00E-02	3.00E-01	-
Eu	1.00E+00	1.00E+01	5.00E+03	3.00E+00	1.00E+01	5.00E+03	Values derived through analogy to Am [219, §7.9, p.101].
Fe	6.00E-01	6.00E+00	6.00E+01	6.00E-02	6.00E-01	6.00E+00	Best estimate values for cementitious material, degradation stages II and III oxidising conditions [220, Tab.14] - converted from mL g^{-1}. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
H	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	No value reported by SKB 219]; assumed to not sorb. This aligns with partition coefficient data for H reported in [218, Tab.34 & 43].
Hf	1.00E-01	1.00E+01	1.00E+02	1.00E+00	1.00E+02	5.00E+02	GTK [221] states that the geochemical properties of Hf and Zr are very similar due to their almost identical ionic radius, all Zr minerals contain Hf and pure Hf minerals are not commonly known. The concentration of Hf in minerals rarely exceeds Zr. Thus, the values here are those reported for Zr.
I	0.00E+00	1.00E-03	1.00E-02	0.00E+00	1.00E-03	1.00E-02	-
Nb	1.00E+00	5.00E+01	1.00E+03	1.00E-01	5.00E+00	1.00E+02	-
Ni	5.44E-01	1.66E+00	4.88E+00	5.44E-01	1.66E+00	4.88E+00	-
Np	7.10E-02	1.00E-01	1.40E-01	7.10E-02	1.00E-01	1.40E-01	Multiple oxidation states reported. The highest, Np(V), is used here.
Pa	5.00E-01	1.00E+01	1.00E+03	5.00E-01	1.00E+01	1.00E+03	Values derived through analogy to Pb [219, §7.9, p.103], with the best estimate and upper limit selected for Pb directly accepted. For the lower limit, the corresponding values for Pb were reduced by an order of magnitude. Multiple oxidation states reported. The highest, Pa(V), is used here.
Pb	1.00E+00	3.00E+00	1.00E+01	1.00E+00	3.00E+01	1.00E+02	-
Pt	4.00E-01	4.00E+00	4.00E+01	4.00E-02	4.00E-01	4.00E+00	Best estimate values for cementitious material, degradation stages II and III (oxidising conditions) [220, Tab.14] - converted from mL g^{-1}. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Pu	3.00E+00	3.00E+01	3.00E+02	1.00E+01	3.00E+01	3.00E+02	Multiple oxidation states reported. The highest, Pu(VI), is used here.
Ra	1.00E-03	1.00E-01	1.00E+00	8.00E-02	8.00E-01	8.00E+00	-
Sb	3.00E-02	3.00E-01	3.00E+00	1.00E-02	1.00E-01	1.00E+00	Best estimate values for cementitious material, degradation stages II and III (oxidising conditions) [220, Tab.14] - converted from mL g^{-1}. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Sm	1.00E+00	1.00E+01	5.00E+03	3.00E+00	1.00E+01	5.00E+03	Values derived through analogy to Am [219, §7.9, p.101].
Sn	1.00E+01	2.00E+01	2.00E+02	2.00E+00	4.00E+00	2.00E+02	-
Sr	5.00E-03	3.00E-02	1.00E-01	1.00E-02	1.00E-01	3.00E+00	-
Tc	1.00E-04	1.00E-03	1.00E-02	0.00E+00	0.00E+00	0.00E+00	Multiple oxidation states reported. The highest, Tc(VII), is used here.
Th	1.00E+00	1.00E+02	1.00E+03	1.00E+00	1.00E+02	1.00E+03	-
Tl	2.00E-02	2.00E-01	2.00E+00	8.00E-03	8.00E-02	8.00E-01	Best estimate values for cementitious material, degradation stages II and III (oxidising conditions) [220, Tab.14] - converted from mL g^{-1}. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
U	3.00E+00	2.00E+01	3.00E+02	3.00E+00	2.00E+01	3.00E+02	Multiple oxidation states reported. The highest, U(VI), is used here.
Zr	1.00E-01	1.00E+01	1.00E+02	1.00E+00	1.00E+02	5.00E+02	-

Table D.23: Partition coefficients for cement paste ($m^3\ kg^{-1}$), concrete chemical degradation Stage 4 (see discussion in Section 3.4.1), as reported in ONDRAF/NIRAS [218, Tab.34 & 43] unless stated otherwise in the comment column. Values converted from $l\ kg^{-1}$. *Note this page is set to A3 size.*

Element	Stage 4			Comment
	Minimum	Most Likely	Maximum	
Ac	3.00E+00	1.00E+01	5.00E+03	Not reported in ONDRAF/NIRAS [218]. Value is for late Stage 3 degraded cement [219, Tab.7-7].
Am	3.00E+00	1.00E+01	5.00E+03	-
Ba	1.00E-02	1.00E-01	3.00E+00	Not reported in ONDRAF/NIRAS [218]. Value is for late Stage 3 degraded cement [219, Tab.7-7].
C	1.00E-04	3.16E-03	1.00E-01	No best estimate value for Stage 4 is reported in [218, Tab.34]. The best estimate has been set at the geometric mean of the minimum and maximum values.
Ca	1.30E-02	4.00E-02	1.30E-01	-
Cd	2.00E-02	6.00E-02	2.00E-01	Not reported in ONDRAF/NIRAS [218]. Value is for late Stage 3 degraded cement [219, Tab.7-7].
Cl	0.00E+00	0.00E+00	0.00E+00	-
Cm	3.00E+00	1.22E+02	5.00E+03	No best estimate value for Stage 4 is reported in [218, Tab.34]. Minimum and maximum values have been derived through analogy to Am (ONDRAF/NIRAS [218, Tab.44]. The best estimate has been set at the geometric mean of the minimum and maximum values.
Co	1.60E-02	4.00E-02	4.00E-01	Not reported in ONDRAF/NIRAS [218]. Value is for late Stage 3 degraded cement [219, Tab.7-7].
Cs	0.00E+00	0.00E+00	0.00E+00	No best estimate value for Stage 4 is reported in [218, Tab.34]. As noted in ONDRAF/NIRAS [218, Tab.44], no values have been assumed for the minimum and maximum values. As such, the best estimate has also been set to zero.
Eu	3.00E+00	1.00E+01	5.00E+03	Not reported in ONDRAF/NIRAS [218]. Value is for late Stage 3 degraded cement [219, Tab.7-7].
Fe	6.00E-02	6.00E-01	6.00E+00	Not reported in ONDRAF/NIRAS [218]. Value is for Stage 3 degraded cement: mean value for cementitious material, degradation states II and III [220, Tab.14, oxidising conditions] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
H	0.00E+00	0.00E+00	0.00E+00	-
Hf	3.00E-04	5.48E-01	1.00E+03	GTK [221] states that the geochemical properties of Hf and Zr are very similar due to their almost identical ionic radius, all Zr minerals contain Hf and pure Hf minerals are not commonly known. The concentration of Hf in minerals rarely exceeds Zr. Thus, the values here are those reported for Zr.
I	0.00E+00	4.00E-04	4.00E-03	No lower bound value is given; this is assumed to be zero (this is consistent with SKB [219]).
Nb	5.00E-02	5.00E-01	5.00E+00	-
Ni	5.00E-04	5.00E-03	5.00E-02	As noted in ONDRAF/NIRAS [218, Tab.44], minimum and maximum values have been derived through decreasing and increasing the best estimate value by an order of magnitude, respectively.
Np	1.00E-01	1.00E+01	1.00E+03	Multiple oxidation states reported. The highest, Np(V), is used here. No best estimate value for Stage 4 is reported in [218, Tab.34]. The best estimate has been set at the geometric mean of the minimum and maximum values. As noted in ONDRAF/NIRAS [218, Tab.44], the maximum value is derived through analogy to Th.
Pa	1.00E-02	3.00E-01	1.00E+01	Multiple oxidation states reported. The highest, Pa(V), is used here.
Pb	2.00E-01	8.00E-01	2.00E+00	-
Pt	4.00E-02	4.00E-01	4.00E+00	Not reported in ONDRAF/NIRAS [218]. Value is for Stage 3 degraded cement: mean value for cementitious material, degradation states II and III [220, Tab.14, oxidising conditions] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Pu	3.00E-02	5.00E-02	1.00E+03	Multiple oxidation states reported. The highest, Pu(VI), is used here. As noted in ONDRAF/NIRAS [218, Tab.44], the minimum and maximum values are derived through analogy to Th.
Ra	1.00E-04	1.00E-03	3.00E-02	-
Sb	1.00E-02	1.00E-01	1.00E+00	Not reported in ONDRAF/NIRAS [218]. Value is for Stage 3 degraded cement: mean value for cementitious material, degradation states II and III [220, Tab.14, oxidising conditions] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Sm	3.00E+00	1.00E+01	5.00E+03	Not reported in ONDRAF/NIRAS [218]. Value is for late Stage 3 degraded cement [219, Tab.7-7].
Sn	3.00E-04	3.00E-03	3.00E-02	No best estimate value for Stage 4 is reported in [218, Tab.34]. The best estimate has been set at the geometric mean of the minimum and maximum values.
Sr	1.00E-04	1.00E-03	3.00E-02	-
Tc	1.00E-04	1.00E-03	1.00E-02	Multiple oxidation states reported. The highest, Tc(VII), is used here. As noted in ONDRAF/NIRAS [218, Tab.44], minimum and maximum values have been derived through decreasing and increasing the best estimate value by an order of magnitude, respectively.
Th	3.00E-02	3.00E+01	1.00E+03	-
Tl	8.00E-03	8.00E-02	8.00E-01	Not reported in ONDRAF/NIRAS [218]. Value is for Stage 3 degraded cement: mean value for cementitious material, degradation states II and III [220, Tab.14, oxidising conditions] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
U	5.00E-03	5.00E-02	5.00E-01	Multiple oxidation states reported. The highest, U(VI), is used here.
Zr	3.00E-04	5.48E-01	1.00E+03	No best estimate value for Stage 4 is reported in [218, Tab.34]. The best estimate has been set at the geometric mean of the minimum and maximum values.

Table D.24: Granite rock matrix partition coefficients ($m^3\ kg^{-1}$) at pH < 10 values from [219, Tab.8-8] unless stated otherwise. These values are used for fully degraded concrete. *Note this page is set to A3 size.*

Element	pH < 10			Comment
	Minimum	Most Likely	Maximum	
Ac	5.70E-04	1.50E-02	3.80E-01	No change with pH, set at the pH > 10 value.
Am	5.70E-04	1.50E-02	3.80E-01	No change with pH, set at the pH > 10 value.
Ba	1.70E-03	1.40E-02	1.10E-01	Value for "periglacial" (fresh) groundwater of pH < 10
C	0.00E+00	0.00E+00	0.00E+00	No change with pH, set at the pH > 10 value.
Ca	0.00E+00	0.00E+00	0.00E+00	
Cd	2.10E-05	7.40E-04	2.70E-02	No change with pH, set at the pH > 10 value.
Cl	0.00E+00	0.00E+00	0.00E+00	No change with pH, set at the pH > 10 value.
Cm	5.70E-04	1.50E-02	3.80E-01	
Co	2.10E-05	7.40E-04	2.70E-02	
Cs	2.20E-04	3.00E-03	4.00E-02	Value for "periglacial" (fresh) groundwater of pH < 10
Eu	5.70E-04	1.50E-02	3.80E-01	No change with pH, set at the pH > 10 value.
Fe	2.00E-02	2.00E-01	2.00E+00	Lacking data for granite, a mean value for a sandy sediment environment has been assumed [220, Tab.13] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
H	0.00E+00	0.00E+00	0.00E+00	No change with pH, set at the pH > 10 value.
Hf	4.50E-03	2.10E-02	1.00E-01	GTK [221] states that the geochemical properties of Hf and Zr are very similar due to their almost identical ionic radius, all Zr minerals contain Hf and pure Hf minerals are not commonly known. The concentration of Hf in minerals rarely exceeds Zr. Thus, the values here are those reported for Zr.
I	0.00E+00	0.00E+00	0.00E+00	No change with pH, set at the pH > 10 value.
Nb	1.10E-03	2.00E-02	3.50E-01	
Ni	2.10E-05	7.40E-04	2.70E-02	
Np	1.50E-05	4.10E-04	1.20E-02	
Pa	6.80E-03	5.90E-02	5.10E-01	
Pb	2.00E-03	2.50E-02	3.10E-01	
Pt	7.00E-04	7.00E-03	7.00E-02	Lacking data for granite, a mean value for a sandy sediment environment has been assumed [220, Tab.13] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Pu	5.70E-04	1.50E-02	3.80E-01	Value for "all" groundwater of pH < 10.
Ra	1.70E-03	1.40E-02	1.10E-01	Value for "periglacial" (fresh) groundwater of pH < 10.
Sb	3.00E-01	3.00E+00	3.00E+01	Lacking data for granite, a mean value for a sandy sediment environment has been assumed [220, Tab.13] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Sm	5.70E-04	1.50E-02	3.80E-01	No change with pH, set at the pH > 10 value.
Sn	4.50E-02	1.60E-01	5.60E-01	Value for "all" groundwater of pH < 10.
Sr	1.30E-05	2.00E-04	3.10E-03	Value for "periglacial" (fresh) groundwater of pH < 10
Tc	0.00E+00	0.00E+00	0.00E+00	No change with pH, set at the pH > 10 value.
Th	2.80E-03	5.30E-02	9.80E-01	
Tl	3.00E-03	3.00E-02	3.00E-01	Lacking data for granite, a mean value for a sandy sediment environment has been assumed [220, Tab.13] – converted from $mL\ g^{-1}$. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
U	5.50E-06	1.10E-04	2.10E-03	No change with pH, set at the pH > 10 value.
Zr	4.50E-03	2.10E-02	1.00E-01	No change with pH, set at the pH > 10 value.

D.2.4 Geometries

D6 Geometric parameters associated with the modelled features are reported here, including concrete features and void spaces, in Table D.25 to Table D.27. Table D.28 and Table D.29 report the contamination depth and volume of concrete features throughout the site. Table D.30 reports the geometries of concrete blocks modelled to fill the void spaces.

Table D.25: Elevation, plan area and void volume values for Winfrith modelled end state features (calculated plan areas are based on void volume and height and void volume). Comments relate to reported values in columns to the left-hand side. *Note this page is set to A3 size.*

Feature No.	Feature Name	Top Elevation / Cutline (m AOD)	Comment	Top of floor slab elevation (m AOD)	Floor slab thickness (m)	Comment	Calculated plan area (m^2) [210]	Calculated plan area* (m^2)	Void volume† (m^3)	Comment
1	SGHWR Region 1	40.61	SGHWR cutline is 1m below ground surface (40.61 mAOD) - WSP [210, Tab.606/2].	28.8	2.74	WSP [210, Tab.606/1].	1265.0	986.4	11649.0	WSP [210, Tab.606/4].
2	SGHWR Bioshield	40.61		33.62	0	Floor slab elevation calculated from the bioshield wall height and the fact that the cutline is coincident with the top of the bioshield. There is no additional floor under the bioshield; redundant plant under it will be removed and its geometry is calculated as a hollow cylinder.	-	31.6	0	The internal void in the centre of the bioshield will be filled with blocks/rubble; this volume is assumed to be included in the Region 1 void infill volume. The plan area subtracts the inner core area (calculated from inner and outer diameters).
3	SGHWR Region 2	40.61		30.6	1.68	WSP [210, Tab.606/1, Fig.606/4 and Tab.606/4]. Floor slab thickness and elevation vary across the rooms within Region 2 (turbine hall, delay tank room and steam labyrinth). A value for the floor slab thickness has been calculated by weighting the three different thicknesses by the room surface areas to provide a proportional estimate. For the floor elevation, the lowest value has been chosen to maximise the time when groundwater may saturate the lower part of this region.	618.0	342.2	3425.0	WSP [210, Tab.606/4].
4	SGHWR South Annexe	40.61		35.4	0.23	WSP [210, Tab.606/1 and Fig.606/4]. Top of floor slab elevation is stated to range between 35.4 m AOD and 36.6 m AOD; the lower value is chosen so that increasing groundwater levels intersect the Annexe at earlier times. The floor slab thickness is stated to range between 0.23 m and 0.53 m; the thinner value is conservatively assumed to hasten release of contamination.	2202.0	2015.5	10501.0	
5	SGHWR North Annexe	40.61		37.8	0.33	WSP [210, Tab.606/1].	1593.0	1481.9	4164.0	
6	Dragon Inside Wall C	35.05	Dragon cutline is at ground surface (35.05 mAOD) - WSP [210, Tab.606/2].	27.34	3.7	WSP [210, §2.2.2].	262.7	245.3	1891.0	WSP [210, Tab.606/7]. There is a discrepancy in that the reported plan area calculated from the Wall A exterior diameter is smaller than if the infill volume were divided by the height - implies there is an error in at least one of the dimensions. However, this discrepancy is small and is neglected in the PA. This uncertainty is recorded in the uncertainty register (PA-021).
7	Dragon Bioshield	35.05		27.88	3.7	WSP [210, §2.2.2] and using the provided bioshield height value.	-	35.7	0	The internal void in the centre of the bioshield will be filled with blocks/rubble; this volume is assumed to be included in the Inside Wall C void infill volume. The plan area subtracts the inner core area (calculated from inner and outer diameters).
8	Dragon Walls A-C Up-gradient	35.05		27.34	2.775	WSP [210, §2.2.2] gives the floor as 3.7 m thick (12 ft). However, between Walls C and A the base slab is angled with reducing thickness towards the exterior. The final thickness is not stated on drawing AE133370 Mod M [229] but appears to be about half the original thickness. Therefore, an average thickness of 9ft is assumed for the base slab as it transitions from 12ft to 6ft thick.	310.1	301.8	2236.5	WSP [210, Tab.606/7] (outside Wall C value halved).
9	Dragon Walls A-C Down-gradient	35.05		27.34	2.775		310.1	301.8	2236.5	

Feature No.	Feature Name	Top Elevation / Cutline (m AOD)	Comment	Top of floor slab elevation (m AOD)	Floor slab thickness (m)	Comment	Calculated plan area (m^2) [210]	Calculated plan area* (m^2)	Void volume† (m^3)	Comment
10	Dragon Mortuary Holes	35.05		29.87	0	Feature is modelled as a contaminated block of concrete from the ground surface. The top of the floor slab elevation parameter is taken to be the bottom of the contaminated block.	87.65	87.65	454.2	Plan area calculated from width and length, where UKAEA engineering drawing AE184218 [222] indicates that the base slab length, including walls, is 37'0" (11.28 m). The volume of the steel mortuary holes to be filled with grout is 27.1 m^3 [210, §2.4.3], but the volume reported here is for the entire concrete block modelled in GoldSim (derived using the plan area and thickness).
11	Dragon B78 floor slab	35.05		34.34	0	Feature is modelled as a contaminated block of concrete from the ground surface so no floor slab is modelled. The top of the floor slab elevation parameter is taken to be the bottom of the contaminated block.	709.5	709.5	505.13	NRS [223] confirmed that the in-situ volume of the B78 foundations is 505.13 m^3. The void volume parameter represents the entire contaminated block volume modelled. Plan area of the floor is estimated to be 709.5 m^2 [224, B78-Building tab, cell O75].
12	A59_PSA_Pit 3	25.0	GSL [225, Fig.2.8] – based on GIS-09-06-014, the average ground level in the A59 area is estimated to be 25 mAOD. The remaining contamination is assumed to extend from the excavation surface to ground level.	22.5	0	This feature is contaminated land so does not have a floor slab. The top of the floor slab elevation parameter is taken to be the bottom of the contaminated block.	440.0	440.0	1100.00	GSL [226, Zones+Volumes tab; 225, Tab.4.11]. Data originally supplied by NRS from GIS data for the A59 site investigation zones. Void volume parameter represents the entire contaminated block volume modelled, based on surface area and contamination thickness/depth.
13	A59_HVA_A 591	25.0		20.75	0		81.73	81.73	347.35	
14	A59_Other	25.0		22.5	0		3228.85	3228.85	8072.13	

* Calculated based on void volume and height - accounts for subtracted internal structures.
† Accounts for internal structures.

Table D.26: Volume of infill blocks and volume available for rubble infill for the Winfrith modelled features.

Feature No.	Feature Name	Volume of infill blocks (m^3)	Volume available for rubble infill (m^3)	Comment
1	SGHWR Region 1	6,300	5,349	WSP [210, Tab.606/7]
2	SGHWR Bioshield	0	0	The core void at the centre of the bioshield is not modelled; the volume is covered by the Region 1 infill.
3	SGHWR Region 2	0	3,425	WSP [210, Tab.606/7].
4	SGHWR South Annexe	0	10,501	
5	SGHWR North Annexe	0	4,164	
6	Dragon Inside Wall C	400	1,491	WSP [210, Tab.606/7].
7	Dragon Bioshield	0	0	The core void at the centre of the bioshield is not modelled; the volume is covered by the Inside Wall C infill.
8	Dragon Walls A-C Up-gradient	0	2,326.5	WSP [210, Tab.606/7] (outside Wall C value halved).
9	Dragon Walls A-C Down-gradient	0	2,326.5	
10	Dragon Mortuary Holes	0	0	WSP [210, §2.4.3] - to be filled with clean grout.
11	Dragon B78 floor slab	0	0	This is modelled as a block of concrete without a volume to fill.
12	A59_PSA_Pit 3	0	0	This is modelled as a block of contaminated soil without a volume to fill.
13	A59_HVA_A591	0	0	
14	A59_Other	0	0	

Table D.27: Modelled feature boundary wall thickness, height and width. *Note this page is set to A3 size.*

Feature No.	Feature Name	Wall thickness (m)	Comment	Wall height (m)	Comment	Wall Width (m) *perpendicular to flow*	Comment
1	SGHWR Region 1	1.2	WSP [210, §2.3.1]. Minimum wall thickness.	11.81	Calculated difference between top elevation (cutline) and floor slab elevation.	42.0	Measured from technical drawing 1W936655, SGHWR "124' 0" AOD Floor Level (Level 3)", Issue G, 4 December 2008 [228].
2	SGHWR Bioshield	1.55	GSL [206, Tab.2.7] and GSL [227, sheet "Bioshield Dimensions and Volume", cell B23]. Minimum wall thickness is 1.2 m, but ranges to 1.56 m. The average activation thickness assumed is 1.55 m so this is assumed for the bioshield thickness.	6.99	GSL [206, Tab.2.7].	8.05	GSL [206, Fig.2.10]. Distance to flex cell joint and maximum extent of the bioshield activation assumed in the Radiological Inventory Report. Calculated in GSL [227, sheet "Bioshield Dimensions and Volume", cell B25].
3	SGHWR Region 2	0.30	The wall thickness varies across the rooms within Region 2 (turbine hall, delay tank room and steam labyrinth), with walls of the order of 1+m for the condenser cell in the turbine hall (Magnox technical drawing 1W936655 [228] "124'0"" AOD floor level (level 3) to walls of relatively standard construction (such walls may have thicknesses of the order of 0.3 m). As thinner walls will lead to earlier contaminant release and reduced opportunity for sorption, walls 0.3 m thick are assumed.	10.01	Calculated difference between top elevation (cutline) and floor slab elevation.	39.2	Measured from technical drawing 1W936655, SGHWR "124' 0" AOD Floor Level (Level 3)", Issue G, 4 December 2008 [228].
4	SGHWR South Annexe	0.30	While some areas in the annexes have thick walls, the annexes generally comprise relatively standard construction and so the walls are assumed to be 0.3m thick.	5.21		81.2	Calculated from the sum of the Region 1 and 2 widths; slightly overestimates the width but maximises groundwater intersection.
5	SGHWR North Annexe	0.30		2.81		81.2	
6	Dragon Inside Wall C	0.46	Technical drawing AE133370 Mod M [229]; wall C is 1 ft 6" thick.	7.71	Calculated difference between top elevation (cutline) and floor slab elevation.	18.3	Based on diameter values.
7	Dragon Bioshield	1.75	GSL [206].	7.17	GSL [206, Tab.3.1].	8.2	
8	Dragon Walls A-C Up-gradient	0.61	WSP [210, §2.3.5].	7.71	Calculated difference between top elevation (cutline) and floor slab elevation	33.5	
9	Dragon Walls A-C Down-gradient	0.61		7.71		33.5	
10	Dragon Mortuary Holes	0	No walls are modelled for these contaminated blocks.	5.18	Dragon Storage Block For 50 Irradiated Fuel Elements engineering diagram [230], indicates that the mortuary hole concrete structure is 15' 6" deep, with drawing AE184218 [222] indicating that there is 1' 6" of concrete below this.	7.77	UKAEA engineering drawing AE184218 [222] indicates that the base slab width, including walls, is (3'0" + 21'0"+1'6"). GSL [206, cell D153].
11	Dragon B78 floor slab	0		0.71	UKAEA engineering diagram, Dragon Storage Building (B78) – Plan & Sections [231], indicates that the floor slab is 6" [15cm] thick (neglecting foundation blocks). However, based on the floor slab area and in-situ volume supplied by NRS, then the floor thickness needs to be of the order 0.7 m thick. As the plan area was used in derivation of the radioactive inventory, and NRS have specified that the in-situ volume is 505 m^3, then the equivalent calculated slab thickness has been assumed here. This uncertainty is recorded in the uncertainty register.	22.50	GSL [224, B78-Building tab, plan view from UKAEA, Drawing 0W20040336]. The total width is the sum of the widths of areas E and F shown in the plan diagram.
12	A59_PSA_Pit 3	0	There are no walls for this remediated land area.	2.5	Parameter used to represent contaminated layer thickness. [206, Zones+Volumes tab; 225, Tab.4.11] – data originally supplied by NRS from GIS data.	13.8	The feature width perpendicular to groundwater flow is estimated from GSL [225, Fig.2.9].
13	A59_HVA_A59 1	0		4.25		15.9	
14	A59_Other	0		2.5		72.8	

Table D.28: In-situ contamination depth and surface area for Winfrith modelled features. Explanatory comments pertain to values to the left of each comment. *Note this page is set to A3 size.*

Feature No.	Feature Name	In-situ Structure Contaminated Layer Thickness (m)	Comment	In-situ structure contaminated surface area (m^2)			Walls Surface Area (m^2) for Darcy Law Calculation	Comment
				Floor	4 Walls / cylinder	Comment		
1	SGHWR Region 1	0.10	GSL [206] reports characterisation data with contamination depths ranging from a few mm to ~150 mm in different parts of the SGHWR complex. In the PA model, it is assumed that the entire contamination inventory is held within the first 100 mm – this relatively thin layer conservatively leads to shorter diffusion paths and earlier release times than if a thicker contamination layer were assumed.	1097.67	1590.08	Calculated assuming a cuboid of 4 walls and a floor. Width and length not equal, so plan area and width used to calculate length rather than assume a cube.	1262.71	Assume no transfer across R1/R2 wall so only count 3 walls (subtract length).
2	SGHWR Bioshield	0.75	GSL [206, Tab.2.7] and GSL [227, sheet " Bioshield Dimensions and Volume", cell B23]. The minimum wall thickness is 1.2 m, but ranges to 1.56 m. Activation was observed in the Radiological Inventory Report to 1.55 m, but clear signs of activation reduced after 1 m. Conservatively, a thinner activation depth of 0.75 m is assumed for the PA.	0.00	317.23	Calculated from geometry data, whereby the entire cylinder (inner and outer) and one ends is contaminated. There is a gap underneath the bioshield, so that end could be contaminated; the top will be cut to the demolition cutline and so should present a non-contaminated surface, so the value includes one end in with the walls.	317.23	Value not used - The water level in the bioshield is assumed to equal that inside the Region 1 void - no additional time delay to resaturate the void is accounted for.
3	SGHWR Region 2	0.10	GSL [206] reports characterisation data with contamination depths ranging from a few mm to ~150 mm in different parts of the SGHWR complex. In the PA model, it is assumed that the entire contamination inventory is held within the first 100 mm in Regions 1 and 2 - this relatively thin layer conservatively leads to shorter diffusion paths and earlier release times than if a thicker contamination layer were assumed. Due to the different use, a thinner contamination layer of 50 mm has been assumed for the annexes.	585.38	1076.38	Calculated assuming a cuboid of 4 walls and a floor. Width and length not equal, so plan area and width used to calculate length rather than assume a cube.	924.58	Assume no transfer across R1/R2 wall so only count 3 walls (subtract length).
4	SGHWR South Annexe	0.05		2137.37	1116.17		696.25	Assume no transfer across R1/R2 wall so only count 3 walls (subtract width).
5	SGHWR North Annexe	0.05		1532.87	559.85		333.37	Assume no transfer across R1/R2 wall so only count 3 walls (subtract width).
6	Dragon Inside Wall C	0.03	GSL [206] reports characterisation data with contamination depths ranging from a few mm to ~50 mm in different parts of Dragon reactor complex. For the purposes of the PA, it is assumed that the entire contamination inventory is held within the first 30 mm - this relatively thin layer conservatively leads to shorter diffusion paths and earlier release times than if a thicker contamination layer were assumed.	237.07	863.78	Calculated assuming a cylinder and a floor, but both sides of the cylinder are contaminated and are accessible for diffusion. This neglects the surface area of any other structures remaining in-situ and so under-estimates the actual contaminated surface area, but the total contamination activity will be included in the model - this will have the impact of increasing the concentration in the contaminated volume, and so will over-estimate the rate of contamination diffusion out of the structure, leading to earlier releases than would occur in reality.	863.78	Assume fluid flow across all of Wall C. Value not used - The water level inside Wall C is assumed to equal that across the outside Wall C void - no additional time delay to resaturate inside Wall C void is accounted for.
7	Dragon Bioshield	0.50	GSL [206] - the inventory estimate was developed assuming an activation depth of 0.75 m based on the results of bioshield cores. However, a conservatively thinner depth of 0.5 m has been assumed for the PA.	0.00	291.79	Calculated from geometry data, whereby the entire cylinder inner and outer wall is assumed to be contaminated (the outer wall would be contaminated rather than activated, but the same contamination depth as for activation is assumed for model simplification). The ends of the bioshield are not assumed to have a contamination layer as they are coincident with the floor and will be cut to ground level at the top.	291.79	Value not used – The water level in the bioshield is assumed to equal that inside the Wall C void – no additional time delay to re-saturate the void is accounted for.
8	Dragon Walls A-C Up-gradient	0.03	GSL [206] reports characterisation data with contamination depths ranging from a few mm to ~50 mm in different parts of Dragon reactor complex. For the purposes of the PA, it is assumed that the entire contamination inventory is held within the first 30 mm - this relatively thin layer conservatively leads to shorter diffusion paths and earlier release times than if a thicker contamination layer were assumed.	278.58	612.77	Calculated assuming a cylinder for inside Wall A and one for outside Wall C, and a floor. Value is halved to split to over the up- and down-gradient components. This neglects the surface area of any other structures remaining in-situ and so under-estimates the actual contaminated surface area, but the total contamination activity will be included in the model – this will have the impact of increasing the concentration in the contaminated volume, and so will over-estimate the rate of contamination diffusion out of the structure, leading to earlier releases than would occur in reality.	391.29	Assume fluid flow across all of Wall A (halved for up- and down-gradient)
9	Dragon Walls A-C Down-gradient	0.03		278.58	612.77		391.29	
10	Dragon Mortuary Holes	0	No structure contamination layer is modelled – assumed to be a well-mixed block.	0	0	No structure contamination layer is modelled – assumed to be a well-mixed block.	0	n/a

Feature No.	Feature Name	In-situ Structure Contaminated Layer Thickness (m)	Comment	In-situ structure contaminated surface area (m²)			Walls Surface Area (m²) for Darcy Law Calculation	Comment
				Floor	4 Walls / cylinder	Comment		
11	Dragon B78 floor slab	0		0	0		0	
12	A59 PSA Pit 3	0	No structure contamination layer is modelled – assumed to be a well-mixed block.	0	0	No structure contamination layer is modelled – assumed to be a well-mixed block.	0	n/a
13	A59 HVA A591	0		0	0		0	
14	A59 Other	0		0	0		0	

Table D.29: In-situ structure contamination volume for Winfrith modelled features.

Feature No.	Feature Name	In-situ structure contaminated volume (m^3)		
		Floor	Walls	Comment
1	SGHWR Region 1	109.77	159.01	Calculated assuming a cuboid of 4 walls and a floor, and using the assumed contamination depth.
2	SGHWR Bioshield	0.00	221.24	Treat entire volume as walls (no floor). Entire modelled volume is activated/contaminated (uncontaminated concrete volume is accounted for within the Region 1 infill).
3	SGHWR Region 2	58.54	107.64	Calculated assuming a cuboid of 4 walls and a floor, and using the assumed contamination depth.
4	SGHWR South Annexe	106.87	55.81	
5	SGHWR North Annexe	76.64	27.99	
6	Dragon Inside Wall C	7.11	25.9	Calculated assuming a cylinder and a floor, and using the assumed contamination depth.
7	Dragon Bioshield	0.00	145.9	Calculated assuming a cylinder with no floor, and using the assumed contamination/activation depth. Entire modelled volume is activated/contaminated (uncontaminated concrete bioshield volume is accounted for within the inside Wall C infill).
8	Dragon Walls A-C Up-gradient	8.36	18.4	Calculated assuming a cylinder for inside Wall A and one for outside Wall C, and a floor, and the assumed contamination depth. Value is halved to split to over the up- and down-gradient components.
9	Dragon Walls A-C Down-gradient	8.36	18.4	
10	Dragon Mortuary Holes	0	0	n/a
11	Dragon B78 floor slab	0	0	
12	A59_PSA_Pit 3	0	0	n/a
13	A59_HVA_A591	0	0	
14	A59_Other	0	0	

Table D.30: Volumes and surface areas associated with concrete blocks infill for Winfrith modelled features for the Reference Case. The block displacement volume stated here is smaller than the volume of block infill in Table D.26 because this value excludes the void space between the emplaced blocks.

Feature No.	Feature Name	Total Block Displacement Volume (m^3)	Number of Blocks (-)	Total Block Surface Area (m^2)	Total Block Contaminated Layer Volume (m^3)	Comment
1	SGHWR Region 1	5727.3	5727.3	11454.5	1145.5	Block infill assumed to be in the form of regular cubes. Assume that, on average, only two sides of each block are contaminated (opposing sides are assumed since it is expected that the blocks would come from walls/floors where either side could be contaminated).
2	SGHWR Bioshield	-	-	-	-	n/a – There is no block infill.
3	SGHWR Region 2	-	-	-	-	n/a – There is no block infill.
4	SGHWR South Annexe	-	-	-	-	n/a – There is no block infill.
5	SGHWR North Annexe	-	-	-	-	n/a – There is no block infill.
6	Dragon Inside Wall C	363.6	363.6	727.3	72.7	Block infill assumed to be in the form of regular cubes. Assume that, on average, only two sides of each block are contaminated (opposing sides are assumed since it is expected that the blocks would come from walls/floors where either side could be contaminated).
7	Dragon Bioshield	-	-	-	-	n/a – There is no block infill.
8	Dragon Walls A-C Up-gradient	-	-	-	-	n/a – There is no block infill.
9	Dragon Walls A-C Down-gradient	-	-	-	-	n/a – There is no block infill.
10	Dragon Mortuary Holes	-	-	-	-	n/a – There is no block infill.
11	Dragon B78 floor slab	-	-	-	-	n/a – There is no block infill.
12	A59_PSA_Pit 3	-	-	-	-	n/a – There is no block infill.
13	A59_HVA_A591	-	-	-	-	
14	A59_Other	-	-	-	-	

D.2.5 Hydrological

D7 Parameters associated with groundwater levels and water infiltration rates in the near field are presented here. Table D.31 and Table D.32 report future groundwater level estimates. Table D.33 and Table D.34 report future rainfall infiltration through feature (reactor) caps and un-capped land (A59 area) respectively.

Table D.31: Future groundwater level estimates associated with the modelled feature groups – cautious central estimate (CCE) and reasonable worst case (RWC) estimates. *Note this page is set to A3 size.*

Estimate type	Years after model start:			Cautious Central Estimate of Future Groundwater Levels			Reasonable Worst Case Estimate of Future Groundwater Levels		
Feature Group Name	**SGHWR**	**Dragon**	**A59**	**SGHWR**	**Dragon**	**A59**	**SGHWR**	**Dragon**	**A59**
Groundwater Level at Disposal Start Date (m AOD)	5	2	0	33.1	24.5	23.0	33.1	24.5	23.0
Groundwater Level at 2050s (m AOD)	23	23	23	33.6	24.9	23.4	34.1	25.3	23.8
Groundwater Level at 2080s (m AOD)	53	53	53	34.0	25.1	23.6	34.1	25.3	23.8
Comment				NRS [232].	NRS [232] and Golder [233, Tab.614/1].	WSP [234, Fig.604/29] indicates that the GW elevation in the region of A59 on 1 April 2003 was 23.0 mAOD; this value is assumed for the model start for A59 (and for the reactor end states). Modelling by Arcadis for the period post-IEP implementation on the site suggests similar GW levels for drier periods but ~0.4 m increase during wet winters [235]; a GW level increase of 0.4 m is assumed for the 2050s. This estimate does not account for increases due to climate change, but such changes have not been calculated for the OoSA59 area. As A59 is in a shallower area than Dragon, it would be expected that the GW increase would not be as great (0.6 m from the IEP), but this is conservatively assumed for A59 from the 2080s onwards.	NRS [232], RWC. No value was calculated for the 2050s so the value at 2080 has been assumed.	NRS [232] and Golder [233, Tab.614/1]. No value was calculated for the 2050s so the value at 2080 has been assumed.	WSP [234, Fig.604/29] indicates that the GW elevation in the region of A59 on 1 April 2003 was 23.0 mAOD; this value is assumed for the model start for A59 (and for the reactor end states). Changes in GW level in the OoS A59 area due to climate change have not been calculated. As A59 is in a shallower area than Dragon, it would be expected that the GW increase would not be as great (0.8m from the IEP), but this is conservatively assumed for A59 from the 2050s onwards.

Table D.32: Future groundwater level estimates associated with the modelled feature groups – variant scenario arbitrary groundwater levels and additional seasonal water volumes used for what-if calculation of fluctuating groundwater levels.

Estimate type	Years after model start:			Arbitrary Groundwater Levels						Additional seasonal water volume to add to RCW after 2050 for what-if calculation of fluctuating GW levels		
Feature Group Name	**SGHWR**	**Dragon**	**A59**	**SGHWR**		**Dragon**		**A59**		**SGHWR**	**Dragon**	**A59**
Groundwater Level at Disposal Start Date (m AOD)	5	2	0	33.1		24.5		23.0		0	0	0
Groundwater Level at 2050s (m AOD)	23	23	23	33.6		24.9		23.4		2.90	3.94	0.50
Groundwater Level at 2080s (m AOD)	53	53	53	39.61	37.0	34.05	2.90	3.94	0.50	2.90	3.94	0.50
Comment				Arbitrary values are used to consider different model aspects in variant scenario assessment cases. Note that the cutline heights of the disposal features are: SGHWR = 40.61m; Dragon = 35.05m; and A59 ground level = 25m. When consider 1m bgl case, then SGHWR = 39.61m, Dragon = 34.05m and A59 = 24.0m. When consider case where hold at top of seasonal water level, then SGHWR = 37.0m, Dragon = 29.24m and (arbitrary) A59 = 24.2m.						WSP [236] sets out the maximum modelled thickness of saturated infill material of 1.6 m for the SGHWR South Annexe and 1.9 m for the Dragon reactor, based on the RWC GW levels for the 2080s. The floor elevation of these features has been used here to calculate the additional water height that needs to be added to the RCW GW levels for alternate 6-month periods (half-year to represent winter highs and summer lows) in the model. Data are not available for A59; to indicatively consider the impact of seasonal fluctuation in this area, an additional 0.5 m variation is assumed (the GW level is already near the surface at A59 so only a small fluctuation is considered).		

Table D.33: Rainfall infiltration rate through the engineered cap for reactor structures (SGHWR and Dragon) for baseline and variant scenarios.

Elapsed time from Disposal Start Date (y)	Infiltration rate (mm y^{-1})		Elapsed time from Disposal Start Date (y)	Infiltration rate (mm y^{-1})	
	Baseline			Variant	
	SGHWR	Dragon		SGHWR	Dragon
0	5	5	0	5	5
250	5	5	125	5	5
1,000	43	43	500	43	43
			1,000	43	43
WSP [210, §5.3 & Fig.606/21]. Linear degradation between 250 and 1,000 years is assumed. The final infiltration rate remains less than the recharge rate because cap infiltration continues to be limited by the cap mineral layer once the flexible membrane and geosynthetic clay layer fail. No chemical degradation mechanism for the mineral layer has been identified [237].			WSP [210, §5.3 & Fig.606/21]. Linear degradation between 125 and 500 years is assumed.		

Table D.34: Rainfall infiltration rate through soil (applies to the OoS A59 area as no engineered cap is present).

Time Period	Infiltration rate (mm/y)	
	Baseline	Variant
Recharge at model start (2027)	279	279
Recharge at 2085	326	358.6
Comment	WSP [234, §3.3], based on 30 y mean average data from BGS for 2020 and 2085.	As a variant case, the recharge is arbitrarily assumed to increase by 10% from 2085 onwards.

D.3 Geosphere Parameters

D8 Table D.35 lists geometry values associated with the geosphere compartments modelled. A number of the length values used are taken directly from measured distances on maps, as displayed in Figure D.1 through Figure D.5. Table D.36 lists radionuclide partition coefficients used for the Poole Formation, while Table D.37 lists general parameters associated with the Poole Formation.

Table D.35: Geosphere compartment geometries and corresponding number of GoldSim cells with which they are modelled. *Note this page is set to A3 size.*

Feature Group	Geosphere Segments	Length (m) *From Feature Group*	Width (m)	Base Elevation of Flow Path (mAOD)	Source	Number of GoldSim mixing cells	Comment
SGHWR	Well	1	81.2	26.06	A drinking water well is assumed to be located just outside the structure, with an arbitrary distance of 1 m assumed. The width of the compartment in which the well is drilled is assumed to equal the full width of SGHWR. The height is assumed to be the difference between the base of the floor slab elevation of Region 1 (26.1 mAOD) and the external SGHWR GW level (this changes over time).	**5**	Compartment modelled using an Aquifer element. The minimum number of compartments suggested by GoldSim to accurately model dispersion is defined by the length divided by twice the dispersivity [207, p.178]. For a dispersivity of 10%, this equates to 5 compartments.
	River	1350			WSP [234, §10 / p.94] notes that GW elevation contours indicate that, generally, GW flow across the site is from topographic high areas in the W and SW to topographic low areas in the NE and E towards the River Frome. A default release pathway from SGHWR is assumed to be to the River Frome in a NNE direction. Measurement on Google Maps (Figure D.1) supports an indicative estimate of 1,350 m for the length of the release pathway. The width of the compartment is assumed to equal the full width of SGHWR. The height is assumed to be the difference between the base of the floor slab elevation of Region 1 (26.1 mAOD) and the external GW level (which changes over time). The height of the compartment at the point of release from SGHWR is assumed to remain constant over the flow path.	**27**	Compartment modelled using an Aquifer element. The minimum number of compartments suggested by GoldSim to accurately model dispersion is defined by the length divided by twice the dispersivity [207, p.178]. For a dispersivity of 10%, this equates to 5 compartments. A minimum length of 50 m per compartment is also assumed.
	Land/Mire	300			Under wet conditions, now and in the future, groundwater is modelled to emerge to the west of the roundabout on Monterey Avenue downgradient of the SGHWR [234, §10 / p.95]. Groundwater is also modelled to emerge in the ephemeral mire proposed in the RMP. The degree of groundwater released to the surface west of the roundabout and to the mire depends on the season and how wet the climate is; this affects whether there would be surface flow of contaminated water between the roundabout and mire. At times these areas could be dry. Release to an area of land from west of the roundabout to east of the mire, with the contaminant concentration averaged over this land area, is considered to be a default release pathway. Borehole OW44 is located approximately 350 m downgradient of SGHWR in the direction of location of groundwater emergence close to the roundabout [234, §9.4.1 / p.88]. Measurement on Google Maps (Figure D.2) supports an estimate of 350 m for the release pathway from SGHWR to land near Monterey Avenue roundabout, although WSP [234, §8.3 / p.79] estimates 300 m; conservatively, the smaller distance is assumed here. Potential releases to the River Frome valley land beside the river are assumed to be bounded by the shorter release pathway considered here. The width of the compartment is assumed to equal the full width of SGHWR. The height is assumed to be the difference between the base of the floor slab elevation of Region 1 (26.1 mAOD) and the external GW level (which changes over time). The height of the compartment at the point of release from SGHWR is assumed to remain constant over the flow path.	**6**	
	Dragon	550			Under some of the RMP GW modelling results [238, App.B, Fig.4-12], some flowlines occur from SGHWR to the Dragon reactor complex. Whilst groundwater is not expected to emerge at this point, it does mean that there is the potential for combination of contaminant release from both reactors. Therefore, an alternative pathway considers releases from SGHWR joining those from Dragon on the way to the River Frome. Measurement on Google Maps (Figure D.3) supports an estimate of ~550 m for the pathway between SGHWR and Dragon. The width of the compartment is assumed to equal the full width of SGHWR. The height is assumed to be the difference between the base of the floor slab elevation of Region 1 (26.1 mAOD) and the external GW level (which changes over time). The height of the compartment at the point of release from SGHWR is assumed to remain constant over the flow path (the height of the flowpath from Dragon onwards to the River Frome is then used – see below).	**11**	
Dragon	Well	1	33.5	19.5	A drinking water well is assumed to be located just outside the structure, with an arbitrary distance of 1 m assumed. The width of the compartment in which the well is drilled is assumed to equal the full width of the Dragon reactor, which is equal to the diameter of Wall A. The height, or thickness of the compartment, is assumed to be 5 m below the water table [210, p.115] at the IEP (which is 24.5 mAOD) – the base elevation of the pathway is thus 19.5 mAOD and the pathway height can change over time as the future water table changes.	**5**	Compartment modelled using an Aquifer element. The minimum number of compartments suggested by GoldSim to accurately model dispersion is defined by the length divided by twice the dispersivity [207, p.178]. For a dispersivity of 10%, this equates to 5 compartments.
	River	500			Measurement on Google Maps (Figure D.4 supports an estimate of 700 m for the release pathway from the Dragon reactor complex to the River Frome. However, the CSM [210, p.115] states the distance to be 500 m, and so the shorter distance is conservatively assumed here. The width of the compartment is assumed to equal the full width of the Dragon reactor. The height, or thickness of the compartment, is assumed to be 5 m below the water table [210, p.115] at the IEP	**10**	Compartment indirectly modelled using an Aquifer element. The minimum number of compartments suggested by GoldSim to accurately model dispersion is defined by the length divided by twice the dispersivity [207, p.178]. For a

Feature Group	Geosphere Segments	Length (m) *From Feature Group*	Width (m)	Base Elevation of Flow Path (mAOD)	Source	Number of GoldSim mixing cells	Comment
					(which is 24.5 mAOD) – the base elevation of the pathway is thus 19.5 mAOD and can change over time as the future water table changes.		dispersivity of 10%, this equates to 5 compartments. A minimum length of 50 m per compartment is also assumed.
A59	Well	1	72.8	20.8	A drinking water well is assumed to be located just outside the feature, with an arbitrary distance of 1 m assumed. The width of the compartment in which the well is drilled is assumed to equal the full width of the A59 area. The height is assumed to be the difference between the local GW level (this changes over time) and the base of the deepest part of A59 (the base elevation of the pathway is thus 20.8 mAOD).	**5**	Compartment modelled using an Aquifer element. The minimum number of compartments suggested by GoldSim to accurately model dispersion is defined by the length divided by twice the dispersivity [207, p.178]. For a dispersivity of 10%, this equates to 5 compartments.
	River	350			Measurement on Google Maps (Figure D.5) supports an estimate of 350 m for the release pathway from A59 to the River Frome. The width of the compartment is assumed to equal the full width of the A59 area. The height is assumed to be the difference between the local GW level (this changes over time) and the base of the deepest part of A59 (the base elevation of the pathway is thus 20.8 mAOD).	**7**	Compartment indirectly modelled using an Aquifer element. The minimum number of compartments suggested by GoldSim to accurately model dispersion is defined by the length divided by twice the dispersivity [207, p.178]. For a dispersivity of 10%, this equates to 5 compartments. A minimum length of 50 m per compartment is also assumed.
	Mire	25			An assumed default release pathway for A59 is to the ephemeral mire proposed in the RMP. Based on groundwater emergence modelling using the Cautious Central Estimate for climate change in the period to 2100 and considering results for the case with maximum groundwater discharge to the mire, a short pathway length of 25 m is assumed (based on indicative measurement between the position of A591 remediated land and the edge of groundwater emergence in WSP [238, App.B, Fig.4-6]). The width of the compartment is assumed to equal the full width of the A59 area orthogonal to flow to the River Frome. The height is assumed to be the difference between the local GW level (this changes over time) and the base of the deepest part of the OoS A59 area (the base elevation of the pathway is thus 20.8 mAOD).	**5**	

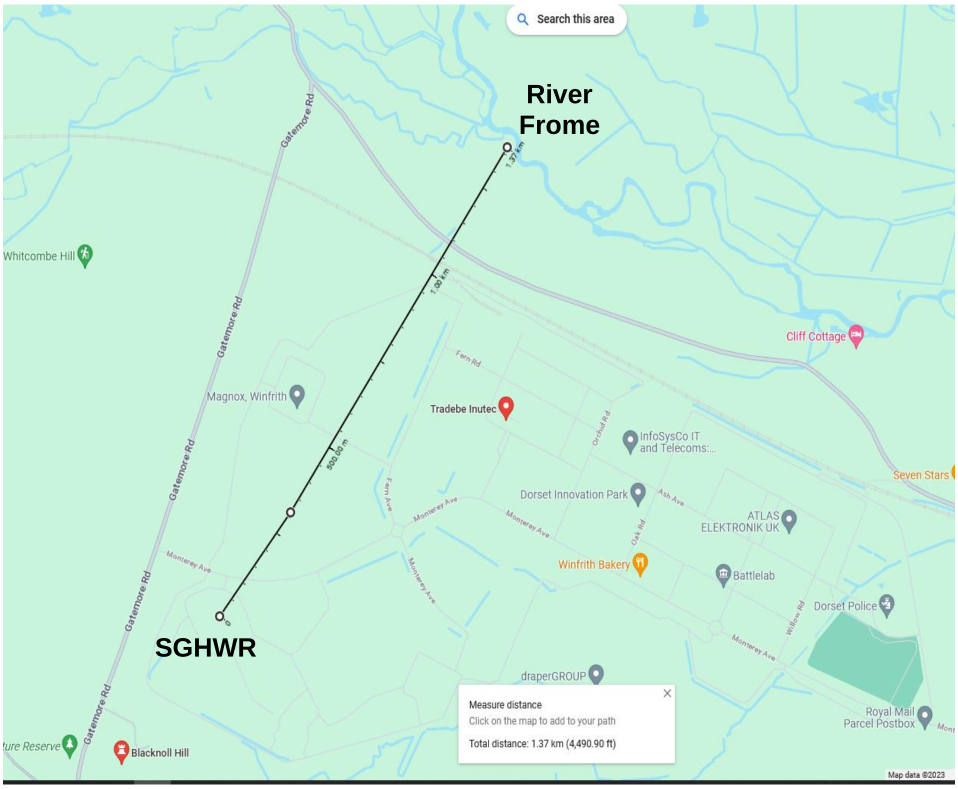

Figure D.1: Indicative release pathway length from SGHWR to River Frome as measured on Google Maps (~1350 m).

Figure D.2: Indicative release pathway length from SGHWR to point of land surface emergence as measured on Google Maps (~350 m).

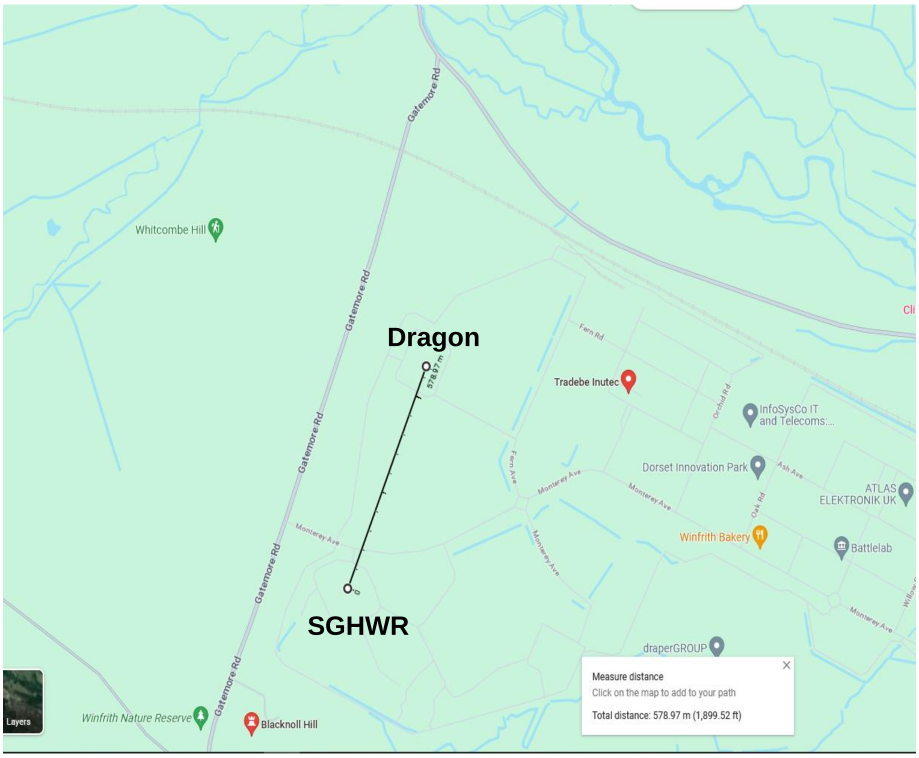

Figure D.3: Indicative release pathway length from SGHWR to the Dragon reactor complex as measured on Google Maps (~550 m).

Figure D.4: Indicative release pathway length from the Dragon reactor complex to the River Frome as measured on Google Maps (~700 m).

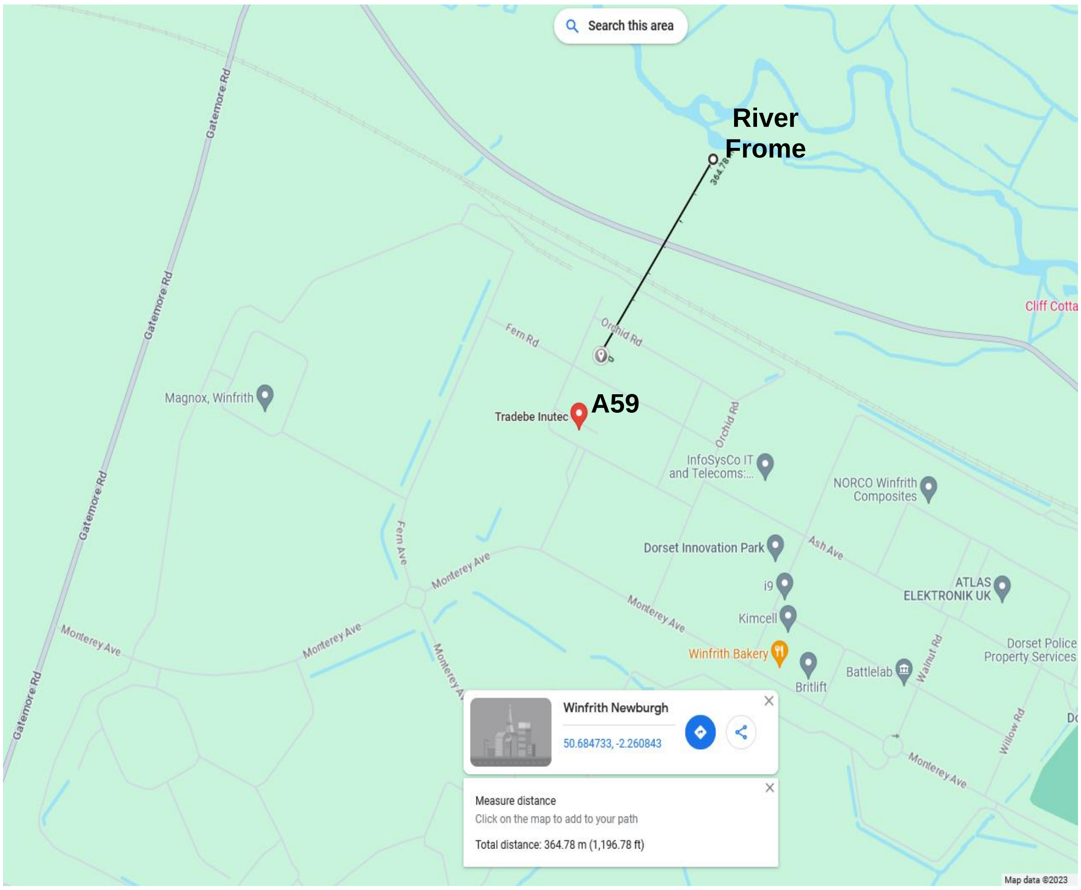

Figure D.5: Indicative release pathway length from the OoS A59 area to the River Frome as measured on Google Maps (~350 m).

Table D.36: Partition Coefficients used for the Poole Formation (predominantly sand and clay) – from LLWR [239, Tab.E6] (Unit B2 – clay rich tills, and sands and gravels), unless stated otherwise. Minimum and maximum values are derived by adjusting the most likely values by an order of magnitude either side (unless from other sources and then the range specified is used). *Note this page is set to A3 size.*

Elements	Partition Coefficients ($m^3\ kg^{-1}$)			Comment
	Minimum	Best	Maximum	
Ac	1.40E-02	1.40E-01	1.40E+00	-
Am	1.40E-02	1.40E-01	1.40E+00	-
Ba	4.00E-05	4.00E-04	4.00E-03	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14]. Lacking uncertainty range data, the minimum and maximum are assumed to be an order of magnitude different from the best estimate.
C	0.00E+00	0.00E+00	0.00E+00	-
Ca	1.20E-03	1.20E-02	1.20E-01	-
Cd	2.00E-03	1.50E-01	7.00E+00	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.12, corrigendum].
Cl	0.00E+00	0.00E+00	0.00E+00	-
Cm	1.40E-02	1.40E-01	1.40E+00	-
Co	1.40E-02	1.40E-01	1.40E+00	-
Cs	3.00E-02	3.00E-01	3.00E+00	-
Eu	2.00E-01	5.00E-01	9.00E-01	Value for sorption in freshwater sediments from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.54].
Fe	2.20E-01	8.80E-01	4.90E+00	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14].
H	0.00E+00	0.00E+00	0.00E+00	-
Hf	4.50E-01	2.50E+00	8.50E+00	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14].
I	1.10E-04	1.10E-03	1.10E-02	-
Nb	8.80E-02	8.80E-01	8.80E+00	-
Ni	4.00E-03	4.00E-02	4.00E-01	-
Np	1.40E-03	1.40E-02	1.40E-01	-
Pa	1.00E-02	1.00E-01	1.00E+00	-
Pb	4.00E-03	4.00E-02	4.00E-01	-
Pt	1.20E-02	2.40E-02	8.30E-02	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14].
Pu	1.00E-02	1.00E-01	1.00E+00	-
Ra	8.60E-03	8.60E-02	8.60E-01	-
Sb	6.00E-04	6.20E-02	2.10E+00	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14].
Sm	2.40E-01	9.30E-01	3.00E+00	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14].
Sn	1.30E-01	1.60E+00	3.10E+01	Value for sorption in soils from the IAEA Terrestrial and Freshwater Environments Parameter Value Handbook [240, Tab.14].
Sr	1.20E-03	1.20E-02	1.20E-01	-
Tc	1.00E-05	1.00E-04	1.00E-03	-
Th	8.80E-02	8.80E-01	8.80E+00	-
Tl	2.00E+00	2.00E+01	2.00E+02	Value for sorption in freshwater sediments (which is actually based on the value for saltwater due to limited data) from EA Initial Radiological Assessment Tool [241, Tab.F.4].
U	1.50E-03	1.50E-02	1.50E-01	-
Zr	8.80E-02	8.80E-01	8.80E+00	-

Table D.37: Parameters used to model transport through the Poole Formation.

Parameter	Value	Comment
Porosity (m^3 m^{-3})	0.2	Effective porosity for the Poole Formation as used previously by AEA and Amec and considered to be an appropriate average value in the Winfrith Hydrogeological Interpretation Report [234, §6.4].
Bulk Density (kg m^{-3})	2000	Bulk density for the Poole Formation as used previously by AEA and Amec and considered to be an appropriate average value in the Winfrith Hydrogeological Interpretation Report [234, §6.4].
Hydraulic conductivity (m s^{-1})	2.70E-04	The results of large-scale tests for hydraulic conductivity in geological strata beneath the site range between 7×10^{-5} m s^{-1} to 4.7×10^{-4} m s^{-1} [210; 234, §6.4], with the mid-point at 2.7×10^{-4} m s^{-1}. This is also approximately the hydraulic conductivity required for the Poole Formation if rainfall infiltration upgradient of the SGHWR is to flow under the measured hydraulic gradient in the vicinity of the SGHWR.
Tortuosity (-)	1	Cautious assumption – A tortuosity of 1 means a direct (straight) diffusive pathway is modelled [207, p.75].
Saturation (-)	1	As transport is assumed to occur in the saturated layer, a saturation of 1 is assumed.
Geosphere hydraulic gradient in the region of SGHWR (m m^{-1})	0.010	The contours show that hydraulic gradients in the west of the site in the region between the SGHWR and Dragon reactors are, on average, around 0.01 and are highest in the vicinity of the Dragon reactor, around 0.025 [234, §7.1.2, p.61]. The hydraulic gradient reduces to around 0.005 in the NE part of the site [234, §7.1.2, p.61], which covers the A59 area. The contours in [234, Fig.604/40] suggest that the hydraulic gradient may increase slightly in the region of A59 as a result of climate change/increased GW levels (the figure shows the highest May 2093 modelled cautious central estimate GW levels), but not significantly so, and also does not appear to indicate notable impacts in the region of SGHWR and Dragon. Therefore, these gradients are assumed for all climate scenarios. The average value of 0.01 is assumed for the longest transport paths from SGHWR across the site to the River Frome.
Geosphere hydraulic gradient in the region of Dragon (m m^{-1})	0.025	
Geosphere hydraulic gradient in the region of A59 (m m^{-1})	0.005	

D.4 Biosphere Parameters

D.4.1 Representative Person Behaviours

D9 Table D.38 reports the adult ingestion rates for each food group that each representative person (RP) consumes in the natural evolution model. The Smallholder RP diet was sense-checked against generic UK adult consumption data and the calorific value of the consumed food products to confirm that the modelled diet is reasonable in terms of calorific intake; this check is summarised in Table D.39, along with the record of which food products are assumed to derive from the potentially contaminated area or are assumed to be imported from elsewhere. Table D.40 reports the inadvertent ingestion rates of soil and river sediment, the consumption rate of well water, and inhalation rates for adults. Table D.41 reports the equivalent data for child and infant RPs. Adult occupancy rates are reported in Table D.42 and child and infant occupancy rates are reported in Table D.43. Table D.44 reports additional parameters used to calculate the dose to RPs.

Table D.38: Foodstuff ingestion rates assumed for the aqueous release pathway adult RPs; the consumption rates are based on the Winfrith radiological habits surveys and generic UK data (see Table D.39). *Note this page is set to print A3 size.*

Parameter		Modelled Representative Persons consumption rate (kg y^{-1}) or (l y^{-1})						
		Angler	**River Paddler**	**Mire Mudder**	**Park User**	**Cons. Worker**	**Farmer**	**Smallholder**
Food Group ingestion rate (kg yr^{-1}) or (l yr^{-1})	Green vegetables						23.3	23.3
	Other vegetables						33.9	33.9
	Root vegetables						31.3	31.3
	Potato						52.2	52.2
	Domestic fruit						30.3	30.3
	Cattle milk						117.3	117.3
	Cattle meat						42.7	42.7
	Pig meat							
	Sheep meat						14.1	14.1
	Goat meat							1.4
	Poultry							9.4
	Eggs							14.2
	Wild/free foods (berries)				4.6			4.6
	Rabbits/hares							
	Honey							
	Wild fungi							0.7
	Venison							
	Freshwater fish	20.0						0.5
	Freshwater plants							10.4
Comment		There was limited ingestion of freshwater fish observed in 2003 CEFAS survey (0.5 kg y^{-1}; Table D.39), with no consumption reported in the 2019 survey (although angling on the River Frome was observed using a catch-and-release system). The stretch of the River Frome near the site forms part of a number of chalk stream fishing beats offered by the neighbouring East Burton estate (http://eastburtonestate.co.uk/chalkstream-fishing/) for trout, grayling, salmon and eel. Following discussion with peer reviewers, it was decided to more conservatively assess the impact of angling on the Frome, which will help to account for future behaviour changes. Therefore, rather than use the low CEFAS ingestion data, the generic UK critical group intake value of 20 kg y^{-1} recommended by Smith and Jones [242, §3.4] has been used.	No food ingestion assumed.	No food ingestion assumed.	Consumption of wild berries whilst in the park is assumed.	No food ingestion assumed.	High meat (cattle and sheep) consumption assumed based on the mean high-rate consumer data observed in the Winfrith CEFAS surveys (Table D.39), plus milk and vegetable ingestion. There is limited uptake data for pig meat, so this is modelled as cattle meat.	Diet based on weighted average high-rate adult consumption values from the 2003 and 2019 CEFAS radiological habits surveys for Winfrith [245, Tab.2; 246, Tab.B & H]. The calorific value of the foods ingested was sense-checked against typical adult consumption values to ensure a realistic diet [244] and using UK generic consumption data (Smith and Jones, 2003) for foods imported from outside the area - this is analysed in Table D.39. There is limited uptake data for pig meat available, so this is treated as cattle meat. No consumption of venison, honey or rabbits/hares is included, as deer/bees/hares are assumed to roam over a large area (e.g. [243]) and therefore not be attributed directly to the potentially contaminated area. While rabbits do not typically roam over such a large area, the likelihood of ingesting wild rabbits originating 100% of the time from contaminated land is low. A more likely scenario is a larger hunting area than the contaminated area. Therefore rabbits, hares, venison and honey are assumed to be uncontaminated.

Table D.39: Smallholder RP diet constructed using the 2003 and 2019 Winfrith CEFAS radiological habits surveys and mean UK food consumption data. The consumption rates use the weighted average high-rate consumption data reported in the CEFAS surveys [245; 246] where it is available and fills the gaps using the UK mean consumption rate data [242, Tab.2]. There is some overlap between the food categories; this is noted where relevant in the table comments. The calorific value of the foods consumed is estimated from the data reported in the PHE Composition of Foods Integrated Dataset (CoFID) [244], with the average calorific value for multiple food types calculated based on the food proportions recorded in the CEFAS surveys (this is reported in detail in underpinning spreadsheet "CEFAS data collection v3.xlsx"; the resulting calorie value is reported here). Due to the construction of the diet, a sense check was performed against the mean calorific intake of adults to ensure that the diet is appropriate in terms of total food consumption. Smith and Jones [242, Tab.7] report the mean calorific intake for adults, which ranges from 1700 kcal/day for women to 2485 kcal/day for men (the mean for both sexes is 2093 kcal/day). The constructed Smallholder RP diet represents a daily intake of 2123 kcal; this is considered to be an appropriate diet and the consumption rates do not need to be adjusted. The foods are classed as being produced on the potentially contaminated land/river or sourced from outside the area (shaded blue); only those sourced from the contaminated area are carried into Table D.38 for inclusion in the NE GoldSim model. *Note this page is set to print A3 size.*

Food group	Calorific value (kcal/kg) [244, spreadsheet, Tab.1.3]	UK mean consumption rate per person [242, Tab.2] (kg y^{-1} or l y^{-1})	UK mean calories per person and foodstuff per day (kcal/day)	Winfrith weighted average high consumption rate [245, Tab.9; 246, Tab.B & H] (kg y^{-1} or l y^{-1})	Winfrith mean calories per person and foodstuff per day (kcal/day)	Consumption rate for Smallholder RP (kg y^{-1} or l y^{-1})	Winfrith Data	UK Data	Calories for Smallholder RP consumption rates (kcal/day)	Assume Contaminated Source	Assume Un-contaminated Source	Comment
Imported fruit	382	30	31.4			30.0		x	31.4		x	Assume imported fruit have same calorific value as domestic fruit.
Domestic fruit	382	20	20.9	30.3	31.7	30.3	x		31.7	x		All fruit assumed to be grown on land irrigated or intermittently flooded with contaminated river water.
Nuts	5810	3	47.7			3.0		x	47.7		x	Calorific value for "14-880 Nuts, mixed". Assumed to be sourced from outside the contaminated area.
Potatoes	750	50	102.7	52.2	107.2	52.2	x		107.2	x		All potatoes assumed to be grown on land irrigated or intermittently flooded with contaminated river water.
Root vegetables	353	10	9.7	31.3	30.2	31.3	x		30.2	x		All root vegetables assumed to be grown on land irrigated or intermittently flooded with contaminated river water
Green vegetables	224	15	9.2	23.3	14.3	23.3	x		14.3	x		All green vegetables assumed to be grown on land irrigated or intermittently flooded with contaminated river water.
Other domestic vegetables	284	20	15.6	33.9	26.4	33.9	x		26.4	x		All other vegetables assumed to be grown on land irrigated or intermittently flooded with contaminated river water.
Other imported vegetables	284	9	7.0			9.0		x	7.0		x	Assume imported vegetables have the same calorific value as other domestic vegetables.
Wild fungi	70	3	0.6	0.7	0.1	0.7	x		0.1			Assumes that the mushrooms are foraged from contaminated land.
Sugar	3940	15.0	161.8			15.0		x	161.8		x	Assumed to be sourced from elsewhere. Calorific value for "17-063 Sugar, white".
Honey	2880	2.5	19.7	4.8	38.0	4.8	x		38.0		x	Assumed to be uncontaminated as bees roam over a large area and therefore cannot be attributed directly to the contaminated area.
Pig meat	1929	15	79.2	12.6	66.5				0.0			There is limited uptake data for pig meat, so it is added to the consumption rate for, and modelled as, cattle meat in the NE model.
Cattle meat	2015	15	82.8	30.2	166.4	42.7	x		235.8	x		Livestock are assumed to be reared on land irrigated or intermittently flooded with contaminated river water.
Sheep meat	2163	8	47.4	14.1	83.5	14.1	x		83.5	x		Livestock are assumed to be reared on land irrigated or intermittently flooded with contaminated river water.
Offal	2163	5.5	32.6						0.0			PHE [244] does not have a generic category for offal. Calorific value for lamb in above table includes liver, heart, kidney and tongue, so this category is used here for "offal". The Winfrith CEFAS survey data does not explicitly identify offal; it is assumed that this is included in the consumption rates specified for cattle, pig, sheep and goat meat.
Poultry	1699	10	46.5	9.4	43.6	9.4	x		43.6	x		Poultry is assumed to be reared on land irrigated or intermittently flooded with contaminated river water.
Game	1660	6	27.3						0.0			Average calorific value of "18-387 Rabbit, raw, meat only", "18-390 Venison, meat only, raw", "18-383 Pheasant, meat only, roasted", "18-381 Partridge, meat only, roasted", "18-385 Pigeon, meat only, roasted" and "18-489 Duck, meat only, raw". CEFAS data does not have a generic "game" category, but individually reports rabbits/hares and venison, and includes partridge, pheasant, pigeon and duck in the "poultry" category.
Rabbits/hares	1370			2.2	8.3	2.2	x		8.3		x	Hares roam over a large area and therefore cannot be attributed directly to the contaminated area. While rabbits do not typically roam over such a large area, the likelihood of ingesting wild rabbits originating 100% of the time from contaminated land is low. A more likely scenario is a larger hunting area than the contaminated area. Therefore, rabbits and hares are assumed to be uncontaminated.

Food group	Calorific value (kcal/kg) [244, spreadsheet, Tab.1.3]	UK mean consumption rate per person [242, Tab.2] (kg y^{-1} or l y^{-1})	UK mean calories per person and foodstuff per day (kcal/day)	Winfrith weighted average high consumption rate [245, Tab.9; 246, Tab.B & H] (kg y^{-1} or l y^{-1})	Winfrith mean calories per person and foodstuff per day (kcal/day)	Consumption rate for Smallholder RP (kg y^{-1} or l y^{-1})	Winfrith Data	UK Data	Calories for Smallholder RP consumption rates (kcal/day)	Assume Contaminated Source	Assume Un-contaminated Source	Comment
Venison	1030			4.5	12.6	4.5	x		12.6		x	Assumed to be uncontaminated as deer roam over a large area and therefore cannot be attributed directly to the contaminated area.
Oil (non-dairy)	8990	10.0	246.1			10.0	x		246.1		x	Assumed to be sourced from elsewhere. Calorific value for "17-686 Oil, vegetable, average".
Milk (only)	631	95	164.2									Calorific value for food "12-596 Milk, whole, pasteurised, average". Overlaps with CEFAS category "milk", which also includes milk products.
Butter	7440	4.5	91.7									Calorific value for "17-661 Butter, unsalted". Overlaps with CEFAS category "milk", which also includes milk products.
Cheese	3810	8	83.4									Calorific value for "12-368 Cheese, white, average". Overlaps with CEFAS category "milk", which also includes milk products.
Other milk products	3526	15	144.8									Average calorific value of butter, milk, cheese, "12-334 Cream, fresh, double, including Jersey cream" and "12-184 Yogurt, whole milk, plain". Overlaps with CEFAS category "milk", which also includes milk products.
Milk & milk products				117.3	463.6	117.3	x		463.6	x		Assumed to come from cattle reared on contaminated ground and drinking contaminated river water. Data in the CEFAS survey is for milk and all milk products, but the breakdown is not provided. The number of calories is calculated based on the proportions of milk products identified in the generic UK data [242].
Eggs	1319	8.5	30.7	14.2	51.2	14.2	x		51.2	x		Assumed to derive from poultry reared on contaminated ground and drinking contaminated river water.
Fish (freshwater only)	1330			0.5	1.8	0.5	x		1.8	x		Assumed to be raised and caught in a contaminated stretch of the River Frome.
Fish (marine only)	1119			24.5	75.0	24.5	x		75.0		x	Marine fish are assumed to be obtained from an uncontaminated source.
Fish (unspecified)	1147	15	47.1									Overlaps with the separate freshwater and marine fish consumption categories in the CEFAS data.
Shellfish / Crustacea	843	3.5	8.1	17.4	40.2	17.4	x		40.2		x	Shellfish/crustacea are assumed to be obtained from an uncontaminated source.
Cereals	2587	50	354.1			50.0		x	354.1		x	Assumed to be sourced from elsewhere. Average calorific value of "11-763 Breakfast cereal, bran flakes, fortified", "11-971 Bread, brown, average" and "11-1145 Bread, white, average".
Goat meat	1030			1.4	3.9	1.4	x		3.9	x		No calorific data are reported in PHE [244] for goat meat, so the value for beef is assumed. Goats are assumed to be raised on contaminated land.
Wild/free foods	367			4.6	4.6	4.6	x		4.6	x		Assumed to consist of berries grown on contaminated land.
Plants (freshwater)	100			10.4	2.8	10.4	x		2.8	x		Watercress assumed to be grown in a contaminated stretch of the River Frome.
Total daily calorific intake (kcal)			**1912.1**		**1271.9**				**2123.0**			The total assumed daily calorific intake for the Smallholder RP is in line with mean UK adult female and male intake values.

Table D.40: Ingestion and inhalation rates for adult RPs. All rates are taken from Smith and Jones [242].

Parameter		Representative Persons consumption rate (kg y^{-1}) or (m^3 y^{-1})							
		Angler	**River Paddler**	**Mire Mudder**	**Park User**	**Construction Worker**	**Farmer**	**Smallholder**	**Well Abstractor**
Inadvertent ingestion	Soil (kg y^{-1})			0.0083	0.0083	0.0083	0.0083	0.0083	
	River/mire water (m^3 y^{-1})	0.0005	0.0005	0.0005					
Comment		Soil: generalised adult rate [242, Tab.11, critical group]. River water [242, Tab.12, high-rate group for sea swimmers] - conservative for the likely consumption by the angler.	River water: [242, Tab.12, high-rate group for sea swimmers] - conservative for the likely consumption by the river paddler.	Mire mud/soil: generalised adult rate [242, Tab.11, critical group]. River water: [242, Tab.12, high-rate group for sea swimmers] - conservative for the likely consumption by the mire mudder.	Soil: generalised adult rate, [242, Tab.11, critical group].	Soil: generalised adult rate [242, Tab.11, critical group].	Soil: generalised adult rate [242, Tab.11, critical group].	Soil: generalised adult rate [242, Tab.11, critical group].	
Borehole Abstraction	Water consumption (m^3 y^{-1})								0.6
Comment									Drinking rate is taken from [242, Tab.10].
		Representative Persons breathing rate (m^3 y^{-1})							
Inhalation	Breathing rate (m^3 y^{-1})	1.05E+04	1.48E+04	2.63E+04	1.05E+04	1.48E+04	1.48E+04	8.40E+03	
Comment		Adult worker breathing for light work [242, Tab.9].	Adult worker breathing rate for heavy work [242, Tab.9].	Adult heavy exercise breathing rate [242, Tab.9].	Adult worker breathing rate for light work [242, Tab.9]. The value for light work is used to reflect that the RP is engaged in potentially energetic recreation in the park.	Adult worker breathing rate for heavy work [242, Tab.9].	Adult worker breathing rate for heavy work [242, Tab.9] – the farmer is assumed not to live on the contaminated field.	Adult worker breathing rate for light work [242, Tab.9], with the value reflecting an individual who works and lives on contaminated land.	

Table D.41: Ingestion and inhalation rates for child and infant RPs. *Note this page is set to print A3 size.*

Parameter		Representative Persons consumption rate (kg y^{-1}) or (l y^{-1})					
		River Paddler		Park User		Smallholder	
		Infant	Child	Infant	Child	Infant	Child
Ingestion rate (kg yr^{-1}) or (l yr^{-1})	Green vegetables					3.0	7.9
	Other vegetables					3.2	8.1
	Root vegetables					0.5	9.3
	Potato					3.3	16.2
	Domestic fruit					3.5	4.2
	Cattle milk					0.0	96.8
	Cattle meat					8.9	14.1
	Pig meat					2.0	9.5
	Sheep meat					3.5	2.5
	Goat meat						
	Poultry					0.4	3.5
	Eggs					4.5	7.8
	Wild/free foods (berries)			0.9	0.6	0.9	0.6
	Rabbits/hares					0.0	0.0
	Honey					3.2	3.2
	Wild fungi					0.2	0.4
	Venison					1.6	3.3
	Freshwater fish					0.0	0.0
	Freshwater plants					5.2	0.0
Comment		River Paddler RP does not consume any food.		Park Users are assumed to consume wild berries - see Smallholder RP for value source.		Weighted average values of 2003 and 2019 mean infant (5 y in 2003 data, 0-5y in 2019 data) and child (10y in 2003 data, 6-15 y in 2019 data) consumption rates for high-rate groups for terrestrial food groups [245, Tab.11-12; 246, Tab.34-48, Tab.I & §5.4]. No consumption of goat meat, rabbits/hares and freshwater fish was observed. There is limited uptake data for pig meat available, so this is conservatively treated as cattle meat. No consumption of venison and honey is included, as deer and bees are assumed to roam over a large area and therefore not be attributed directly to the contaminated area.	
		Representative Persons consumption rate (kg y^{-1}) or (l y^{-1})					
Inadvertent ingestion	Soil (kg y^{-1})			4.40E-02	1.80E-02	4.40E-02	1.80E-02
	River/mire water (m^3y^{-1})	2.00E-04	5.00E-04				
Comment		The river paddler is assumed to inadvertently ingest some river water whilst playing. The ingestion rates assumed here, which are the generalised infant (1 y) and child (10 y) rates from Smith and Jones [242, Tab.12] for the high-rate group data for sea swimmers, are bounding of the likely consumption by river paddlers.		Conservatively assumed to inadvertently ingest park/field soil whilst playing/eating on site. Generalised infant (1 y) and child (10 y) critical group rates from Smith and Jones [242, Tab.11].		Conservatively assumed to inadvertently ingest soil/dust whilst playing in/gardening the smallholding. Generalised infant (1 y) and child (10 y) critical group rates from Smith and Jones [242, Tab.11].	
		Representative Persons breathing rate (m^3 y^{-1})					
Inhalation	Breathing rate (m^3 y^{-1})	1.90E+03	5.60E+03	1.90E+03	5.60E+03	1.90E+03	5.60E+03
Comment		General infant (1 y) and child (10 y) inhalation rate from Smith and Jones [242, Tab.8].		General infant (1 y) and child (10 y) inhalation rate from Smith and Jones [242, Tab.8].		General infant (1 y) and child (10 y) inhalation rate from Smith and Jones [242, Tab.8].	

Table D.42: Occupancy rates for adult Site Occupancy and Aqueous Release assessment RPs. Note that indoor occupancy is recorded separately to outdoor occupancy since the dose received while indoors is assumed to be attenuated by flooring materials. Where possible, occupancy is based upon the CEFAS habits survey data [245; 246]. Occupancy data from other sources are recorded in the comments. *Note that this page is set to print in A3.*

Occupancy ($h\ y^{-1}$)	Site Occupancy			Aqueous Release						
	Walker	**Camper**	**Resident**	**Angler**	**River Paddler**	**Mire Mudder**	**Park User**	**Construction Worker**	**Farmer**	**Smallholder**
Indoor			8760.0							4383.0
Outdoor	470.0	384.0					470.0	2080.0	4383.0	4253.0
Stream/river					81.1					
Riverbank				1000.0						130.0
Mire						6.0				
Comment	English Nature [248, Tab.5 & 10], combining frequency and duration values in a weighted average of the high-rate group (cut off method).	Assumed occupancy based upon four trips of four nights each on contaminated land per year, assuming 24 h occupancy.	The IAEA suggest a realistic exposure time of 4,500 hours for a house resident and a low probability exposure time of 8,760 hours (an entire year of exposure) [247].	No time was reported for freshwater fishing in the CEFAS surveys, although this was noted to occur (and a freshwater fish consumption rate given). The weighted average of the CEFAS high-rate groups for intertidal anglers [245, Tab.14; 246, Tab.11] was originally considered. However, the stretch of the River Frome near the site forms part of a number of chalk stream fishing beats offered by the neighbouring East Burton estate (http://eastburtonestate.co.uk/chalkstream-fishing/) for trout, grayling, salmon and eel. Following discussion with peer reviewers, it was decided to more conservatively assess the impact of angling on the Frome, which will help to account for future behaviour changes. Therefore, rather than use the CEFAS intertidal occupancy data, the generic UK generic adult critical group value of 1000 h y^{-1} recommended by [242, §4.2.2] has been assumed.	CEFAS 2003 [245, Tab.17]. Weighted average of eleven observations of people in the River Frome.	Assumed occupancy based upon 3 h in the mire per event; two events per year.	English Nature [248, Tab.5 & 10], combining frequency and duration values in a weighted average of the high-rate group (cut off method).	Assumed occupancy based on a construction worker working full time (8 h per day, 5 days per week, 52 weeks per year).	The CEFAS 2019 [246, Tab.50] highest outdoor occupancy values are associated with retired residents. The values for “tending cattle” and “farming” are very low (maximum 209 hours). Therefore, a value which represents 50% of the year spent outdoors is conservatively adopted. This occupancy value is multiplied by an adjustment factor to account for the proportion of time a farmer spends on contaminated land, but this is applied directly in the GoldSim model (depending on the size of the Field or Land/Mire compartment, the scaling factor typically reduces the occupancy time by <0.4).	Assumed that outdoor and indoor occupancy are equal (i.e. 50% of time spent indoors and 50% outdoors). The time spent on the riverbank fishing, which is based on the weighted average value for intertidal fishing observed in the Winfrith CEFAS surveys [245, Tab.14; 246, Tab.11], is subtracted from the outdoor occupancy time.

Table D.43: Occupancy rates for child and infant RPs.

Occupancy times ($hr\ y^{-1}$)	River Paddler		Park User		Smallholder	
	Infant	**Child**	**Infant**	**Child**	**Infant**	**Child**
Indoors					4383.0	4383.0
Outdoors			470.0	470.0	4383.0	4383.0
Stream/river	81.1	81.1				
Comment	CEFAS 2003 [245, Tab.17]. Weighted average of eleven observations of people in the River Frome - which were all children ranging in age from 8 y to 15 y.		Assume same occupancy for children as adults, which assumes the same occupancy as high rate weighted mean dog walkers [248, Tab.5 & 10]. Assumes a maximum frequency of 2 walks per day.		As for adults, assume that outdoor and indoor occupancy are equal (i.e. 50% of time spent indoors and outdoors).	

Table D.44: Additional parameters used to calculate the modelled dose to representative persons.

Parameter	Value	Comment
Thickness of a house concrete base slab (m)	0.1	This is assumed to attenuate external irradiation doses. Minimum thickness reported for a ground floor slab by the National House Building Council [249].
Stream geometry scaling factor (-)	0.25	Adjusts the external irradiation dose to account for the stream geometry. Based on the scaling factor converting external irradiation from a semi-infinite slab into a 1-m radius sphere at a distance of 1 m [250, Tab.3]. Assumed to apply equally to a mire.
Dose to risk conversion factor (Sv^{-1})	0.06	Probability that a dose will result in a serious health effect, as outlined in the GRR [251].
Indoor shielding factor (-)	0.1	Indoor shielding factor [252, p.118].
Thickness of contaminated layer on skin (m)	1.00E-04	Oatway *et al.* [253, Tab.D3].
Density of the contaminated material on the skin (kg m^{-3})	2000	Oatway *et al.* [253, Tab.D3].
Tissue weighting factor for ultraviolet (UV) exposed skin (-)	0.01	ICRP [254, Tab.2].
Fraction of UV exposed skin in contact with the contaminated dust (-)	0.5	Assumed, consistent with the Dounreay LLW Disposal Facilities PA [216].
Minimum topsoil density (kg m^{-3})	430	Model estimates of topsoil pH and bulk density [255] – first 0 -15 cm of topsoil.
Average topsoil density (kg m^{-3})	940	
Maximum topsoil density (kg m^{-3})	1160	

D.4.2 Materials

D10 The parameterisation of materials associated with the modelled biosphere includes the partition coefficients of radionuclides in freshwater sediments and soil, which are reported in Table D.45. Table D.46 records the geometry values of the biosphere compartments modelled. Table D.47 to Table D.51 report additional parameters associated with soil, sediment and hydrogeological aspects of the biosphere model.

Table D.45: Partition Coefficient (Kd) values for radionuclides in soil and freshwater sediments. Data is sourced from The Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments IAEA [240], ONDRAF/NIRAS [256] or as otherwise stated. *Note that this page is set to print A3 size.*

Element	Kd values ($m^3\ kg^{-1}$)							
	Soil			Source	Freshwater Sediment			Comment
	Minimum	Best	Maximum		Minimum	Best	Maximum	
Ac	4.50E-01	1.70E+00	5.40E+00	IAEA [240, Tab.14], value for "all soils".	4.00E+01	4.00E+02	4.00E+03	ONDRAF/NIRAS [256, Tab.166]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Am	5.00E-02	2.60E+00	1.10E+02	IAEA [240, Tab.14], value for "all soils".	2.50E+01	2.10E+02	1.90E+03	IAEA [240, Tab.53], adsorption experiment data.
Ba	4.00E-05	4.00E-04	4.00E-03	Best estimate value from IAEA [240, Tab.14], value for "all soils". No minimum and maximum values reported; values have been derived through increasing and decreasing the best estimate value by an order of magnitude.	2.50E-01	2.00E+00	1.60E+01	IAEA [240, Tab.53].
C	1.90E-03	1.66E-02	1.80E-01	ONDRAF/NIRAS [256, Tab.17]. Values for sandy soils.	2.00E-01	2.00E+00	2.00E+01	ONDRAF/NIRAS [256, Tab.22]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Ca	7.00E-04	8.00E-03	1.10E-01	IAEA [240, Tab.14], value for "all soils".	1.00E-01	1.00E+00	1.00E+01	ONDRAF/NIRAS [256, Tab.37].
Cd	2.00E-03	1.50E-01	7.00E+00	IAEA [240, Tab.12], value for "all soils".	5.00E-04	3.30E-03	7.30E-03	Allison and Allison [257, Tab.4].
Cl	4.00E-05	3.00E-04	1.20E-03	IAEA [240, Tab.14], value for "all soils".	1.00E-04	1.00E-03	1.00E-02	ONDRAF/NIRAS [256, Tab.30]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Cm	1.90E-01	9.30E+00	5.20E+01	IAEA [240, Tab.14], value for "all soils".	1.00E-02	5.00E+00	7.00E+01	IAEA [240, Tab.54].
Co	2.00E-03	4.80E-01	1.00E+02	IAEA [240, Tab.12], value for "all soils".	1.10E+00	4.30E+01	1.70E+03	IAEA [240, Tab.53], adsorption experiment data.
Cs	4.30E-03	1.20E+00	3.80E+02		3.70E-01	9.50E+00	1.90E+02	
Eu	3.00E-01	3.00E+00	3.00E+01	EA [241, Tab.G.5] - value for organic soil assuming Ce as an analogue (recommended in Table C.3). No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.	2.00E-01	5.00E-01	9.00E-01	IAEA [240, Tab.54]. The same best estimate value is also reported by the EA [241, Tab.F.4].
Fe	2.20E-01	8.80E-01	4.90E+00	IAEA [240, Tab.14], value for "all soils".	1.00E+00	5.00E+00	1.00E+01	IAEA [240, Tab.54].
H	1.00E-05	1.00E-04	1.00E-03	Best estimate value from IAEA [240, Tab.14], value for "all soils". No minimum and maximum values reported; values have been derived through increasing and decreasing the best estimate value by an order of magnitude.	0.00E+00	0.00E+00	0.00E+00	ONDRAF/NIRAS [256, §3.5]. Only best estimate value given; minimum and maximum values are assumed to be zero.
Hf	4.50E-01	2.50E+00	8.50E+00	IAEA [240, Tab.14], value for "all soils".	1.00E+00	1.00E+00	1.00E+01	GTK [221] states that the geochemical properties of Hf and Zr are very similar due to their almost identical ionic radius, all Zr minerals contain Hf and pure Hf minerals are not commonly known. The concentration of Hf in minerals rarely exceeds Zr. Thus, the values here are those reported for Zr by IAEA [240].
I	1.00E-05	6.90E-03	5.80E-01	IAEA [240, Tab.12], value for "all soils".	5.90E-02	4.40E+00	3.40E+02	IAEA [240, Tab.53].
Nb	1.60E-01	1.50E+00	8.40E+00	IAEA [240, Tab.12], value for "all soils".	5.00E-02	5.00E-01	5.00E+00	ONDRAF/NIRAS [256, Tab.76].
Ni	3.00E-03	2.80E-01	7.20E+00	IAEA [240, Tab.14], value for "all soils".	2.00E+00	2.00E+01	2.00E+02	ONDRAF/NIRAS [256, Tab.46]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Np	1.30E-03	3.50E-02	1.20E+00	IAEA [240, Tab.12], value for "all soils".	2.00E-04	1.00E-02	1.00E-01	IAEA [240, Tab.54].

Element	Kd values (m^3 kg^{-1})							
	Soil			Source	Freshwater Sediment			Comment
	Minimum	Best	Maximum		Minimum	Best	Maximum	
Pa	5.40E-01	2.00E+00	6.60E+00	IAEA [240, Tab.14], value for "all soils".	5.00E+00	5.00E+01	5.00E+02	ONDRAF/NIRAS [256, Tab.160]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Pb	2.50E-02	2.00E+00	1.30E+02		1.00E+00	1.00E+01	1.00E+02	ONDRAF/NIRAS [256, Tab.139]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Pt	1.20E-02	2.40E-02	8.30E-02		1.10E+01	3.20E+01	9.30E+01	Due to a lack of available data for platinum, ruthenium (Ru), a platinum-group metal, has been assumed as an analogue. Data from [240, Tab.53].
Pu	3.20E-02	7.40E-01	9.60E+00		2.10E+01	7.90E+01	2.90E+02	IAEA [240, Tab.53], adsorption experiment data.
Ra	1.20E-02	2.50E+00	9.50E+02		1.10E+00	7.40E+00	5.20E+01	IAEA [240, Tab.53].
Sb	6.00E-04	6.20E-02	2.10E+00		5.50E-01	5.00E+00	4.60E+01	
Sm	2.40E-01	9.30E-01	3.00E+00		9.10E+00	9.10E+01	9.10E+02	EA [241, Tab.F.4]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Sn	1.30E-01	1.60E+00	3.10E+01		3.00E+00	3.00E+01	3.00E+02	ONDRAF/NIRAS [256, Tab.111]. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
Sr	4.00E-04	5.20E-02	6.50E+00	IAEA [240, Tab.12], value for "all soils".	1.40E-02	1.90E-01	2.20E+00	IAEA [240, Tab.53], adsorption experiment data.
Tc	1.00E-05	2.30E-04	1.10E-02	IAEA [240, Tab.14], value for "all soils".	5.00E-04	5.00E-03	1.00E-01	IAEA [240, Tab.54]. No minimum value reported; value has been derived through decreasing the best estimate value by an order of magnitude.
Th	1.80E-02	1.90E+00	2.50E+02	IAEA [240, Tab.12], value for "all soils".	1.20E+00	1.90E+02	2.70E+04	IAEA [240, Tab.53].
Tl	7.00E-04	1.30E-02	9.10E-01	EA [258] recommends K as an analogue for Tl. Thus, the data presented here are for K from IAEA [240, Tab.14, "all soils"].	2.00E+00	2.00E+01	2.00E+02	EA [241, Tab.A.2 / Tab.F.4], value for ocean sediment due to lack of data for freshwater. No minimum and maximum values reported; values have been derived by increasing and decreasing the best estimate value by an order of magnitude.
U	7.00E-04	2.00E-01	6.70E+01	IAEA [240, Tab.12], value for "all soils".	2.00E-02	5.00E-02	1.00E+00	IAEA [240, Tab.54].
Zr	2.00E-03	4.10E-01	1.00E+01	IAEA [240, Tab.14], value for "all soils".	1.00E+00	1.00E+00	1.00E+01	

Table D.46: Geometry parameters associated with biosphere compartments.

Biosphere Compartment	Geometry			Comment
	Length (m)	Width (m)	Height (m)	
River Water	1100.0	10.0	0.90	The length of the river compartment that may receive contaminant releases from the site disposals, either directly or via the mire, is taken as the length of the site parallel to the river along the railway line, from Gatemore Road to the site boundary at Soldier's Bridge (see screenshot below from Google Maps, giving a length of 1.1 km). This conservatively neglects the winds in the river length that are present in reality and which extend the river length considerably. Estimates from Google Maps suggest the river is 14 m wide, but this is cautiously rounded down to 10 m wide to reduce the available volume of water for dilution and to account for uncertainties and variation in the width. Depth data (RiverLevels.co.uk, 2023) for the River Frome are available for the flow gauging station at East Stoke, approximately 6 km downstream of the site (EA Station No. 44207). The usual range is between 0.57 m and 1.42 m, although it has ranged between 0.62 m and 1.63 m over the last 12 months. Based on the data in the period 26/11/2012 to 21/11/2023, the mean daily depth is 0.90 m.
River Sediment	1100.0	10.0	0.3	Assume same length and width as for the river itself. No data obtained on riverbed sediment depth; arbitrary value of 0.3 m chosen for consistency with field soil depth and mire depth.
Field	1100.0	300.0	0.3	Indicative field width estimated from Google Maps. The field length is assumed to be equal to the length of the neighbouring River compartment. A field depth of 30 cm is generally assumed in dose assessments, which typically corresponds to the depth of turned soil in a ploughed field [183, App.B; 241, App.G].
Land/Mire	750.0	150.0	0.3	Contaminated groundwater may emerge west of the Monterey roundabout and in the mire (which will then be transported through the Frome Ditch to the River Frome). For the purposes of the PA calculations, the length of the contaminated land and mire is assumed to be 750 m, which is slightly less than the straight distance just west from the Monterey roundabout to the corner of the site at Soldier's Bridge. The width of the mire excavation is subject to optimisation, but the width of the wet ground will also depend on the season and climate, being smaller in drier periods and bigger in wetter. The width of the land and mire that may be contaminated by releases from SGHWR and A59 is arbitrarily assumed to be 150 m. The soil/peat depth assumed to form the bulk of the contaminated land and mire is 30 cm, consistent with the thickness of the layer assumed for soil in a field (above).

Table D.47: Biosphere hydrological, hydrogeological and sediment parameters.

Parameter	Water Outflow Rates ($m^3\ y^{-1}$)	Comment
River Water	2.12E+08	Flow data for the River Frome are available for the flow gauging station at East Stoke, approximately 6 km downstream of the site (EA Station No. 44001); based on the data in the period 1965 to 2021, the mean flow rate is 6.72 $m^3\ s^{-1}$ [259, § 5.2].
River Sediment	0	No outflow from the river sediment (it simply cycles with the river water compartment), so value set to zero.
Field	0	Discharge rate is the recharge over the field plan area plus the field irrigation/flood flow - calculated in the model.
Land/Mire	1.34E+06	EdenvaleYoung [260, §4.5] models *peak* flow velocities in the mire between about 0.05-0.2 $m\ s^{-1}$ (no climate change, 1 in 2 year return) and 0.1-2.0 $m\ s^{-1}$ (45% climate change, 1 in 100 y return). However, the average annual flow in the mire would be expected to be lower than this, so a value of 0.05 $m\ s^{-1}$ is assumed in the PA. This water will outflow into the Frome Ditch, although it is assumed that a restriction will be implemented [260, §3.1] to reduce peak flow. Thus, the annual outflow rate is estimated based on the reduced cross-sectional area of the pipe beneath the railway of 1.04 m diameter (the current pipe is 1.2 m in diameter and the area is assumed to be reduced by 25%). Variant cases consider an outflow rate a factor 10 higher and a factor 10 lower.

Table D.48: Other biosphere compartment values.

Parameter	Value	Comment
Inflow from the River Frome to the Field ($m^3\ y^{-1}$)	2.92E+04	The Field compartment is assumed to be contaminated by contact with contaminated river water, whether by the river flooding the field and/or the river water being abstracted and used to irrigate the field. **Potential water inflow due to flooding:** Apart from the functional floodplain of the River Frome (AEP>5%), the licensed site and majority of the surrounding area currently sit in Flood Zone 1, with an AEP<0.1% [259, §5.6]. Restoration of the site will be designed such that the flood risk is not impacted. However, as climate change takes place, wetter winters will increase the potential for flooding. Therefore, it is assumed that the River Frome floods for 1 week per year, which is equivalent to an AEP of 2% (less than a functional floodplain, but more often than is currently observed). Flow rate data for the River Frome from the CEH National River Flow Archive (https://nrfa.ceh.ac.uk/data/station/peakflow/44001) reports a QMED (median annual flood flow – a flood event with a 50% chance of occurrence in any given year) flow rate of 21.3 $m\ s^{-1}$. This would lead to a water volume into the field of 1.29E7 $m^3\ y^{-1}$. **Potential water inflow due to irrigation:** The actual volume of irrigation water used on a field depends on the season, climate, crop, soil and equipment. An indicative value can be calculated using data from [261], which states that in a dry year approximately 150,000 hectares of outdoor field crops are irrigated in the UK, and the annual spray irrigation demand in England and Wales ranges between 82 and 110 million m^3 (with an unconstrained volume of 200 Mm^3). For a field area of 135,000m^2, the irrigation volume would be 9,000 $m^3\ y^{-1}$. An upper estimate of 35,100 $m^3\ y^{-1}$ can be calculated by assuming a 10mm depth of water is added to the field each week for 6 months of the year (26 weeks). **Field water capacity and selected value:** The field is assumed is have a porosity of 40% and 90% saturation (see rows below). Therefore, the field water volume is 14,580m^3. Clearly the flood volume above would saturate the field many times over and would then run off back into the river; such a flood volume would also considerably dilute the contamination present in the river and field. The irrigation volumes range from roughly 60% to 250% of the capacity. Thus, as a conservative irrigation volume, but to also represent flooding of the field for a proportion of the year, it is assumed that the contaminated water volume to the field each year is twice the water capacity of the field (29,160 m^3), which means that the field water volume will be replaced with contaminated water twice each year.
Additional water volume assumed to be present in the Land/Mire compartment (m^3)	5.00E+03	The Land/Mire compartment will also contain a varying water volume as climate conditions vary and the mire slowly drains to the River Frome. The soil/mud and water are assumed to be equally mixed in the biosphere compartment in the GoldSim implementation and so an estimate for the average volume of additional water that may be present and held up in this compartment needs to be included. The water will be present in various ephemeral pools and dips. For the purposes of this PA it is arbitrarily assumed that this surface area is 500 m long by 50 m wide. Based on the surface water modelling work for the proposed mire, EdenvaleYoung [260, §5.2] predict that, for a 1 in 2 year return period event, surface water will have a typical depth of 0.1 m to

Parameter	Value	Comment
		0.2 m. Water depths for less frequent events, such as a 1 in 100-year-event, could be as high as 1.5 m. Therefore, an average water depth of 0.2 m is assumed to represent the average standing water depth over the long timescales of the natural evolution model.
Stream sediment deposition/resuspension rate (kg m^{-2} y^{-1})	1.00	Lacking any specific data for Winfrith, values for freshwater sediment used in the 2023 PA for Trawsfynnydd have been assumed, which are drawn from Westlakes [262, p.3]. This value is for deposition in a lake, which would be expected to have a lower flow than the River Frome. As such, deposition in the Frome would be expected to be lower than this, but the value is assumed to be conservative.
Stream suspended sediment concentration (kg m^{-3})	3.00E-03	Lacking any specific data for Winfrith, values for freshwater sediment used in the 2023 PA for Trawsfynnydd have been assumed, which are drawn from Westlakes [262, p.4].

Table D.49: Hydrological parameters.

Parameter	Value	Source
Effective recharge from rainfall (mm y^{-1})	326	WSP [234, §3.3 / p.18] reports estimates of the recharge based on UKCP SRES A1B projections, with mean values of 279 mm y^{-1} in 2020 and 326 mm y^{-1} in 2085. The range is 252 to 319 mm y^{-1} in 2020 and 247 to 383 mm y^{-1} in 2085. As contaminants will not reach the biosphere until after 2085, the mean recharge at this later date is assumed.

Table D.50: Soil physical parameters.

Parameter	Value	Comment
Porosity (-)	0.4	Consistent with the surface water modelling for the site by EdenvaleYoung [260, §A.4.7], a universal value of 40% porosity has been applied for all soils.
Bulk Density (kg m^{-3})	940	UK Soil Observatory [263] data for the area indicates the topsoil (0-15 cm deep) density ranges between 430 kg m^{-3} and 1160 kg m^{-3}, with a mean of 940 kg m^{-3}.
Saturation (-)	0.9	Consistent with the surface water modelling for the site by EdenvaleYoung [260, §A.4.7], soil voids are assumed to be 90% saturated.
Tortuosity (-)	1	Cautious assumption - A tortuosity of 1 means a direct (straight) diffusive pathway is modelled. In any case, no diffusion is modelled for soil.

Table D.51: Sediment physical parameters.

Parameter	Value	Comment
Porosity	0.75	Lacking any specific data for Winfrith, values for freshwater sediment used in the 2023 PA for Trawsfynydd have been assumed, which are drawn from Westlakes [262].
Bulk Density (kg/m3)	650	Lacking any specific data for Winfrith, values for freshwater sediment used in the 2023 PA for Trawsfynydd have been assumed, which are drawn from Westlakes [262, §3.1.1] and assume a grain density of 2600 kg m^{-3}.
Saturation (-)	1	The sediment in the mire is assumed to be fully saturated and equally mixed with the water layer present. The deposited sediment in the river is also assumed to be fully saturated.
Tortuosity	1	Cautious assumption - A tortuosity of 1 means a direct (straight) diffusive pathway is modelled. In any case, no diffusion is modelled for freshwater sediment.

D.4.3 Uptake Factors

D11 Uptake factors for a range of animals, plants and fungi relevant to the ingestion dose pathway are recorded. Table D.52 reports the conversion factors which convert uptake factors reported in dry weight values to fresh weight values. Uptake values are reported for freshwater fish (Table D.53), freshwater plants (Table D.54), beef cattle (Table D.55), cattle milk (Table D.56), sheep meat or mutton (Table D.57), goat meat (Table D.58), poultry (Table D.59), eggs (Table D.60), potatoes (Table D.61), green vegetables (Table D.62), root vegetables (Table D.63), fruit (Table D.64), mushrooms (Table D.65), berries (Table D.66) and pasture (Table D.67). Table D.68 reports animal consumption rates of water, pasture and soil. Uptake factor minimum and maximum values are taken from the source where values are stated (indicated by the presence of a geometric standard mean value or other commentary) and are otherwise taken to be one order of magnitude larger (maximum) or smaller (minimum).

Table D.52: Conversion factors for dry weight to fresh weight for common food groups considered in the model.

Food group	Conversion factor dry to fresh weight	Comment
Potatoes	0.21	Tables 82, 83 (for fruit) and 84 (for pasture) [240, App.I].
Green Veg (cabbage)	0.12	
Root Veg (carrots)	0.14	
Fruit (apples)	0.16	
Pasture	0.20	
Mushroom	0.1	IAEA [264, p.345].
Berries	0.14	IAEA [264, Tab.14]. Weighted average dry weight of berries native to UK, Europe temperate zones.

Table D.53: Uptake factors between water and fish, whole body values. Sourced from the IAEA Wildlife Transfer Parameter Database [265] unless stated otherwise. *Note that this page is set to print A3 size.*

Element	Uptake factor between water and fish (fresh) l kg^{-1} whole body values			
	Minimum	Most Likely	Maximum	Comment
Ac	1.50E+00	1.50E+01	1.50E+02	EA [241, Tab F4]. Sm recommended as analogue by source.
Am	2.40E+00	5.68E+02	1.50E+03	
Ba	2.95E-01	9.26E+01	1.37E+03	
C	1.00E+03	2.54E+03	3.95E+06	Best estimate calculated through assuming specific activity equilibrium, as advised IAEA [264, p.568]. A site-specific uptake factor is derived by dividing a unit C14 activity concentration (1 Bq L^{-1}) by the local mean dissolved inorganic carbon concentration (47.2 mg/L DIC at Holmebridge, River Frome [266]) and multiplying by the stable carbon concentration in Rainbow trout (1.20E+02 g[C]/kg FW [264, Tab.14]). Minimum and maximum values from the Wildlife Transfer Parameter Database [265].
Ca	1.65E+01	8.85E+02	1.58E+04	
Cd	5.65E+00	3.33E+02	1.06E+05	
Cl	1.25E+02	1.27E+03	1.83E+03	
Cm	2.40E-02	2.40E-01	2.40E+00	
Co	7.40E-01	7.44E+01	9.04E+03	
Cs	1.28E+01	1.73E+03	8.24E+04	
Eu	6.18E+00	4.52E+01	2.94E+02	
Fe	6.39E-01	2.40E+02	7.97E+03	
H	6.00E-01	8.74E-01	1.00E+00	Best estimate calculated by assuming specific activity equilibrium between tritiated water and fish, as advised in IAEA [264, p.561]. Impacts of tritium in water (HTO) and organically-bound tritium (OBT) are summed (eq 23 and 24). Calculated for a unit tritium activity concentration (1 Bq L^{-1}), using values outlined in [264, p.561]. Yields a value of 8.74E-1; the calculation is (=(1*0.78)+((1-0.78)*0.65*0.66*1)). Minimum and maximum values are from [267, Tab.XXII] [6e-1 to 1]. EA [241, Tab F.4] assumes a generic conservative carbon value (4E+5 l kg^{-1}) as an analogue for organically-bound tritium on the basis that the metabolism of hydrogen in such compounds is closely related to that of carbon. The EA notes that this is likely to be cautious, as the metabolism of such compounds is likely to result in some of the tritium being lost as tritiated water and only a limited fraction being incorporated into well-retained biochemical components of organs and tissues. However, this is considered to be overly conservative for releases from Winfrith disposals. Melintescu and Galeriu [268] state that the concentration factor is less than 1 if the contamination is due only to an initially HTO source (as is the case for Winfrith). Anomalously high concentration factors (>4e3) have been observed in marine biota in Cardiff Bay, but this is attributed to organic species of tritium in a mixture of compounds released by GE Healthcare (which is not applicable for Winfrith, where any releases would be in the form of HTO). Thus, the approach recommended by [264] is retained.
Hf	6.54E+01	6.54E+02	6.54E+03	
I	9.00E+00	1.98E+02	1.32E+03	
Nb	2.27E+01	3.05E+01	5.54E+01	
Ni	1.64E+00	9.85E+01	3.00E+03	
Np	1.00E+01	3.00E+01	3.00E+03	IAEA [267, Tab.XXII]. For edible portions of fish.
Pa	1.00E+00	1.00E+01	1.00E+02	US DOE [269, Tab.2.10], freshwater fish, muscle only.
Pb	1.98E+00	1.01E+02	9.31E+03	
Pt	9.90E+00	9.90E+01	9.90E+02	EA [241, Tab.A.6]. Benthic fish. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	4.00E-01	1.40E+02	4.66E+04	
Ra	1.44E-01	6.12E+01	4.80E+03	
Sb	2.43E-01	1.54E+01	7.52E+02	
Sm	4.38E+01	2.64E+02	7.72E+02	
Sn	1.92E+02	4.05E+02	1.05E+03	
Sr	3.84E+00	1.51E+02	1.23E+05	
Tc	5.29E+00	7.09E+01	1.98E+02	
Th	3.30E+01	1.17E+02	3.67E+04	
Tl	1.00E+02	3.09E+03	1.35E+04	
U	5.07E-01	1.03E+01	4.95E+03	
Zr	9.20E+00	5.11E+02	1.48E+04	

Table D.54: Uptake factors between water and freshwater aquatic plants. Sourced from EA [241], unless otherwise stated. *Note that this page is set to print A3 size.*

Element	Uptake factor between water and freshwater aquatic plants (l kg^{-1})			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	9.80E+03	9.80E+04	9.80E+05	
Am	1.30E+02	1.30E+03	1.30E+04	
Ba	4.50E+01	4.50E+02	4.50E+03	
C	8.80E+02	8.80E+03	8.80E+04	
Ca	2.50E+01	2.50E+02	2.50E+03	
Cd	1.10E+04	1.90E+04	2.30E+04	IAEA [240, Tab.55].
Cl	2.60E+01	2.60E+02	2.60E+03	
Cm	2.30E-01	2.30E+00	2.30E+01	
Co	9.30E+01	9.30E+02	9.30E+03	
Cs	3.60E+01	3.60E+02	3.60E+03	
Eu	2.30E+01	2.30E+02	2.30E+03	
Fe	5.10E+02	5.10E+03	5.10E+04	
H	1.00E-01	1.00E+00	1.00E+01	EA [241, Tab.A.6]. Vascular plant. Inorganic tritium (HTO) is listed as 1 l kg^{-1} while organic tritium is equivalent to the carbon value (8.8E+3 l kg^{-1}) as per EA [241] recommendation on use of analogues. Using the same argument as per Melintescu and Galeriu [268], Winfrith expects no organic tritium discharges, therefore the HTO tritium value is used.
Hf	9.90E+00	9.90E+01	9.90E+02	EA [241, Tab.A.6]. Vascular plant. Zirconium chosen as analogue. Both are group IV metals and typically have similar chemical behaviour.
I	5.40E+00	5.40E+01	5.40E+02	
Nb	3.80E+02	3.80E+03	3.80E+04	
Ni	5.20E+01	5.20E+02	5.20E+03	
Np	2.20E+01	2.20E+02	2.20E+03	
Pa	1.30E+02	1.30E+03	1.30E+04	EA [241, Tab.A.6]. Vascular plant. Americium chosen as analogue. Both are actinides and typically have similar chemical behaviour.
Pb	3.00E+01	3.00E+02	3.00E+03	
Pt	4.00E+00	4.00E+01	4.00E+02	EA [241, Tab.A.6]. Vascular plant. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	1.10E+02	1.10E+03	1.10E+04	
Ra	1.10E+02	1.10E+03	1.10E+04	EA [241, Tab.A.6]. Vascular plant. Radium other value used because only Ra226 and Ra228 are present in the inventory, not Ra223, which has a distinct uptake factor.
Sb	3.60E+00	3.60E+01	3.60E+02	
Sm	8.80E+01	8.80E+02	8.80E+03	
Sn	3.00E+01	3.00E+02	3.00E+03	EA [241, Tab.A.6]. Vascular plant. Lead chosen as analogue due to unavailability of Sn data - both are group 14 elements with similar chemical properties and thus similar fate and speciation in the biogeopshere.
Sr	1.80E+01	1.80E+02	1.80E+03	
Tc	4.00E+00	4.00E+01	4.00E+02	
Th	9.80E+03	9.80E+04	9.80E+05	
Tl	3.60E+01	3.60E+02	3.60E+03	
U	3.70E+01	3.70E+02	3.70E+03	
Zr	9.90E+00	9.90E+01	9.90E+02	

Table D.55: Uptake factors for cattle meat (beef). *Note that this page is set to print A3 size.*

Element	Uptake factor – cattle meat (d kg^{-1})			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	5.00E-06	5.00E-05	5.00E-04	LLWR [239, Tab.E14].
Am	5.00E-05	5.00E-04	5.00E-03	IAEA [240, Tab.30].
Ba	5.00E-05	1.40E-04	2.30E-04	IAEA [240, Tab.30].
C	7.50E-03	7.50E-02	7.50E-01	LLWR [239, Tab.E14].
Ca	1.00E-03	1.30E-02	6.10E-01	IAEA [240, Tab.30].
Cd	1.50E-04	5.80E-03	6.00E-02	IAEA [240, Tab.30].
Cl	1.70E-03	1.70E-02	1.70E-01	IAEA [240, Tab.30].
Cm	5.00E-06	5.00E-05	5.00E-04	LLWR [239, Tab.E14].
Co	1.30E-04	4.30E-04	8.40E-04	IAEA [240, Tab.30].
Cs	4.70E-03	2.20E-02	9.60E-02	IAEA [240, Tab.30].
Eu	4.71E-05	4.71E-04	4.71E-03	Watkins *et al*. [270].
Fe	9.00E-03	1.40E-02	2.50E-02	IAEA [240, Tab.30].
H	1.00E-03	1.00E-02	1.00E-01	LLWR [239, Tab.E14].
Hf	1.00E-04	1.00E-03	1.00E-02	US DOE [269, Tab.2.6]
I	2.00E-03	6.70E-03	3.80E-02	IAEA [240, Tab.30].
Nb	2.60E-08	2.60E-07	2.60E-06	IAEA [240, Tab.30].
Ni	1.00E-03	1.00E-02	1.00E-01	LLWR [239, Tab.E14].
Np	1.00E-05	1.00E-04	1.00E-03	LLWR [239, Tab.E14].
Pa	1.00E-04	1.00E-03	1.00E-02	LLWR [239, Tab.E14].
Pb	2.00E-04	7.00E-04	1.60E-03	IAEA [240, Tab.30].
Pt	5.00E-04	5.00E-03	5.00E-02	EA [241, Tab.D.7]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	8.80E-08	1.10E-06	3.00E-04	IAEA [240, Tab.30].
Ra	1.70E-04	1.70E-03	1.70E-02	IAEA [240, Tab.30].
Sb	1.10E-03	1.20E-03	1.30E-03	IAEA [240, Tab.30]. Young animals only.
Sm	5.11E-05	5.11E-04	5.11E-03	Watkins *et al*. [270].
Sn	8.00E-03	8.00E-02	8.00E-01	US DOE [269 Tab.2.6]
Sr	2.00E-04	1.30E-03	9.20E-03	IAEA [240, Tab.30].
Tc	7.50E-05	7.50E-04	7.50E-03	LLWR [239, Tab.E14].
Th	4.00E-05	2.30E-04	9.60E-04	IAEA [240, Tab.30].
Tl	4.00E-03	4.00E-02	4.00E-01	US DOE [269, Tab.2.6]
U	2.50E-04	3.90E-04	6.30E-04	IAEA [240, Tab.30].
Zr	1.20E-07	1.20E-06	1.20E-05	EA [241, Tab.D.7].

Table D.56: Uptake factors for cattle milk (bovine). *Note that this page is set to print A3 size.*

Element	Uptake factor – cattle milk (kg L^{-1})			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	2.00E-07	2.00E-06	2.00E-05	LLWR [239, Tab.E14].
Am	4.20E-08	4.20E-07	4.20E-06	IAEA [240, Tab.26].
Ba	3.80E-05	1.60E-04	7.30E-04	IAEA [240, Tab.26].
C	9.00E-04	9.00E-03	9.00E-02	LLWR [239, Tab.E14].
Ca	2.00E-03	2.00E-02	2.00E-01	LLWR [239, Tab.E14].
Cd	1.80E-06	1.90E-04	8.40E-03	IAEA [240, Tab.26].
Cl	2.00E-03	2.00E-02	2.00E-01	LLWR [239, Tab.E14].
Cm	2.00E-07	2.00E-06	2.00E-05	LLWR [239, Tab.E14].
Co	6.00E-05	1.10E-04	3.00E-04	IAEA [240, Tab.26].
Cs	6.00E-04	4.60E-03	6.80E-02	IAEA [240, Tab.26].
Eu	2.00E-06	2.00E-05	2.00E-04	Maul and Egan [271, Tab.E11].
Fe	1.00E-05	3.50E-05	9.70E-05	IAEA [240, Tab.26].
H	1.00E-03	1.00E-02	1.00E-01	LLWR [239, Tab.E14].
Hf	5.50E-07	3.60E-06	1.70E-05	IAEA [240, Tab.26]. Zirconium chosen as analogue as both are group IV elements therefore should exhibit similar properties.
I	4.00E-04	5.40E-03	2.50E-02	IAEA [240, Tab.26].
Nb	4.10E-08	4.10E-07	4.10E-06	IAEA [240, Tab.26].
Ni	6.50E-04	9.50E-04	1.30E-03	IAEA [240, Tab.26].
Np	5.00E-07	5.00E-06	5.00E-05	LLWR [239, Tab.E14].
Pa	1.00E-07	1.00E-06	1.00E-05	LLWR [239, Tab.E14].
Pb	7.30E-06	1.90E-04	1.20E-03	IAEA [240, Tab.26].
Pt	5.50E-07	5.50E-06	5.50E-05	UA DOE [269, Tab.2.8]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	1.00E-06	1.00E-05	1.00E-04	IAEA [240, Tab.26].
Ra	9.00E-05	3.80E-04	1.40E-03	IAEA [240, Tab.26].
Sb	2.00E-05	3.80E-05	1.10E-04	IAEA [240, Tab.26].
Sm	2.00E-06	2.00E-05	2.00E-04	Watkins *et al*. [270].
Sn	1.00E-04	1.00E-03	1.00E-02	US DOE [269, Tab.2.8].
Sr	3.40E-04	1.30E-03	4.30E-03	IAEA [240, Tab.26].
Tc	7.50E-05	7.50E-04	7.50E-03	LLWR [239, Tab.E14].
Th	1.00E-04	1.00E-03	1.00E-02	LLWR [239, Tab.E14].
Tl	2.00E-04	2.00E-03	2.00E-02	EA [241, Tab.D.7].
U	5.00E-04	1.80E-03	6.10E-03	IAEA [240, Tab.26].
Zr	5.50E-07	3.60E-06	1.70E-05	IAEA [240, Tab.26].

Table D.57: Uptake factors for sheep meat. *Note that this page is set to print A3 size.*

Element	Uptake factor – sheep meat (d kg^{-1})			
	Minimum	Most Likely	Maximum	Comment
Ac	4.71E-05	4.71E-04	4.71E-03	Run 1 Biosphere Database (Watkins *et al*. [270]).
Am	1.10E-05	1.10E-04	1.10E-03	IAEA [240, Tab.31].
Ba	9.90E-03	9.90E-02	9.90E-01	Derived through analogy to radium (following guidance in IAEA [240, Tab.25]).
C	1.70E-01	1.70E+00	1.70E+01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Ca	1.50E-02	1.50E-01	1.50E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cd	1.20E-04	1.20E-03	1.20E-02	IAEA [240, Tab.31].
Cl	6.21E-02	6.21E-01	6.21E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cm	3.00E-05	3.00E-04	3.00E-03	Run 1 Biosphere Database (Watkins *et al*. [270]).
Co	8.00E-03	1.20E-02	1.60E-02	IAEA [240, Tab.31].
Cs	5.30E-02	1.90E-01	1.30E+00	IAEA [240, Tab.31].
Eu	3.20E-05	3.20E-04	3.20E-03	Run 1 Biosphere Database (Watkins *et al*. [270]).
Fe	1.00E-03	1.00E-02	1.00E-01	EA [241, Tab.D.8]. Sheep meat.
H	4.09E-02	4.09E-01	4.09E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Hf	2.00E-02	4.50E-02	1.40E-01	IAEA [240, Tab.31]. Zirconium as analogue – both are group IV elements which typically exhibit similar chemical behaviour.
I	3.00E-03	3.00E-02	3.00E-01	IAEA [240, Tab.31].
Nb	2.00E-04	2.00E-03	2.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Ni	1.20E-02	1.20E-01	1.20E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Np	1.40E-05	1.40E-04	1.40E-03	Run 1 Biosphere Database (Watkins *et al*. [270]).
Pa	1.00E-04	1.00E-03	1.00E-02	LLWR [239, Tab.E14] value for beef used as analogue.
Pb	4.00E-03	7.10E-03	1.00E-02	IAEA [240, Tab.31].
Pt	5.00E-04	5.00E-03	5.00E-02	EA [241, Tab.D.8]. Sheep meat. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	2.00E-05	5.30E-05	8.50E-05	IAEA [240, Tab.31].
Ra	9.90E-03	9.90E-02	9.90E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Sb	1.00E-03	1.00E-02	1.00E-01	EA [241, Tab.D.8]. Sheep meat.
Sm	3.20E-05	3.20E-04	3.20E-03	Run 1 Biosphere Database (Watkins *et al*. [270]).
Sn	8.00E-03	8.00E-02	8.00E-01	US DOE [269, Tab.2.6] value for beef used as analogue.
Sr	3.00E-04	1.50E-03	4.00E-03	IAEA [240, Tab.31].
Tc	8.62E-03	8.62E-02	8.62E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Th	1.30E-03	1.30E-02	1.30E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Tl	4.00E-02	4.00E-01	4.00E+00	EA [241, Tab.D.8]. Sheep meat.
U	7.41E-04	7.41E-03	7.41E-02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Zr	2.00E-02	4.50E-02	1.40E-01	IAEA [240, Tab.31].

Table D.58: Uptake factors for goat meat. *Note that this page is set to print A3 size.*

Element	Uptake factor – goat meat (d kg^{-1})			
	Minimum	Most Likely	Maximum	Comment
Ac	5.00E-06	5.00E-05	5.00E-04	LLWR [239, Tab.E14]. Cattle meat value used.
Am	5.00E-05	5.00E-04	5.00E-03	IAEA [240, Tab.30]. Cattle meat value used.
Ba	1.30E-06	1.30E-05	1.30E-04	IAEA [240, Tab.32].
C	7.50E-03	7.50E-02	7.50E-01	LLWR [239, Tab.E14]. Cattle meat value used.
Ca	1.00E-03	1.30E-02	6.10E-01	IAEA [240, Tab.30]. Cattle meat value used.
Cd	1.50E-04	5.80E-03	6.00E-02	IAEA [240, Tab.30]. Cattle meat value used.
Cl	1.70E-03	1.70E-02	1.70E-01	IAEA [240, Tab.30]. Cattle meat value used.
Cm	5.00E-06	5.00E-05	5.00E-04	LLWR [239, Tab.E14]. Cattle meat value used.
Co	1.30E-04	4.30E-04	8.40E-04	IAEA [240, Tab.30]. Cattle meat value used.
Cs	1.20E-01	3.20E-01	1.9	IAEA [240, Tab.32].
Eu	4.71E-05	4.71E-04	4.71E-03	Run 1 Biosphere Database (Watkins *et al*. [270]). Cattle meat value used.
Fe	9.00E-03	1.40E-02	2.50E-02	IAEA [240, Tab.30]. Cattle meat value used.
H	1.00E-03	1.00E-02	1.00E-01	LLWR [239, Tab.E14]. Cattle meat value used.
Hf	1.00E-04	1.00E-03	1.00E-02	US DOE [269, Tab.2.6]. Cattle meat value used.
I	2.00E-03	6.70E-03	3.80E-02	IAEA [240, Tab.30]. Cattle meat value used.
Nb	6.00E-06	6.00E-05	6.00E-04	IAEA [240, Tab.32].
Ni	1.00E-03	1.00E-02	1.00E-01	LLWR [239, Tab.E14]. Cattle meat value used.
Np	1.00E-05	1.00E-04	1.00E-03	LLWR [239, Tab.E14]. Cattle meat value used.
Pa	1.00E-04	1.00E-03	1.00E-02	LLWR [239, Tab.E14]. Cattle meat value used.
Pb	2.00E-04	7.00E-04	1.60E-03	IAEA [240, Tab.30]. Cattle meat value used.
Pt	5.00E-04	5.00E-03	5.00E-02	EA [241, Tab.D.7]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold. Cattle meat value used.
Pu	8.80E-08	1.10E-06	3.00E-04	IAEA [240, Tab.30]. Cattle meat value used.
Ra	1.70E-04	1.70E-03	1.70E-02	IAEA [240, Tab.30]. Cattle meat value used.
Sb	1.10E-03	1.20E-03	1.30E-03	IAEA [240, Tab.30]. Young animals only. Cattle meat value used.
Sm	5.11E-05	5.11E-04	5.11E-03	Run 1 Biosphere Database (Watkins *et al*. [270]). Cattle meat value used.
Sn	8.00E-03	8.00E-02	8.00E-01	US DOE [269, Tab 2.6]. Cattle meat value used.
Sr	2.00E-03	2.90E-03	3.70E-03	IAEA [240, Tab.32].
Tc	7.50E-05	7.50E-04	7.50E-03	LLWR [239, Tab.E14]. Cattle meat value used.
Th	4.00E-05	2.30E-04	9.60E-04	IAEA [240, Tab.30]. Cattle meat value used.
Tl	1.20E-01	3.20E-01	1.9	IAEA [240, Tab.32]. Caesium as analogue as the most chemically similar element available from a limited dataset. Thallium commonly forms +1 oxidation states in environmental and aqueous systems and is said to resemble group I elements in behaviour. Caesium is also recommended as a thallium analogue in EA [241].
U	2.50E-04	3.90E-04	6.30E-04	IAEA [240, Tab.30]. Cattle meat value used.
Zr	2.00E-06	2.00E-05	2.00E-04	IAEA [240, Tab.32].

Table D.59: Uptake factors for poultry meat. *Note that this page is set to print A3 size.*

Element	Uptake factor – poultry meat (d kg^{-1})			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	6.00E-04	6.00E-03	6.00E-02	US DOE [269, Tab.2.7]. Americium as analogue as recommended by source.
Am	1.30E-03	1.30E-02	1.30E-01	Thorne [272, p.V].
Ba	9.20E-03	1.90E-02	2.90E-02	IAEA [240, Tab.34].
C	7.00E-01	7.00E+00	7.00E+01	Thorne [272, p.V].
Ca	4.40E-03	4.40E-02	4.40E-01	IAEA [240, Tab.34].
Cd	1.70E+00	1.70E+00	1.80E+00	IAEA [240, Tab.34]. Includes duck.
Cl	3.30E-01	3.30E+00	3.30E+01	Thorne [272, p.V].
Cm	1.30E-03	1.30E-02	1.30E-01	Thorne [272, p.V].
Co	3.00E-02	9.70E-01	1.90E+00	IAEA [240, Tab.34].
Cs	1.20E+00	2.70E+00	5.60E+00	IAEA [240, Tab.34].
Eu	3.80E-04	3.80E-03	3.80E-02	Maul and Egan [271, Tab.E11].
Fe	1.00E-01	1.00E+00	1.00E+01	US DOE [269, Tab.2.7].
H	1.70E-01	1.70E+00	1.70E+01	Thorne [272, p.V].
Hf	6.00E-06	6.00E-05	6.00E-04	US DOE [269, Tab.2.7]. Zirconium as analogue – both are group IV elements which typically exhibit similar chemical behaviour.
I	4.00E-03	8.70E-03	1.50E-02	IAEA [240, Tab.34].
Nb	3.00E-05	3.00E-04	3.00E-03	IAEA [240, Tab.34].
Ni	1.70E-01	1.70E+00	1.70E+01	Thorne [272, p.V].
Np	1.70E-03	1.70E-02	1.70E-01	Thorne [272, p.V].
Pa	6.00E-04	6.00E-03	6.00E-02	US DOE [269, Tab.2.7]. Americium chosen as analogue. Both are actinides and typically exhibit similar chemical behaviour.
Pb	1.70E-01	1.70E+00	1.70E+01	Thorne [272, p.V].
Pt	1.00E-01	1.00E+00	1.00E+01	US DOE [269, Tab.2.7]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	1.70E-04	1.70E-03	1.70E-02	Thorne [272, p.V].
Ra	7.00E-03	7.00E-02	7.00E-01	Thorne [272, p.V].
Sb	6.00E-04	6.00E-03	6.00E-02	US DOE [269, Tab.2.7].
Sm	3.90E-04	3.90E-03	3.90E-02	Maul and Egan [271, Tab.E11].
Sn	8.00E-02	8.00E-01	8.00E+00	US DOE [269, Tab.2.7]. Arsenic as analogue as recommended by source.
Sr	7.00E-03	2.00E-02	4.10E-02	IAEA [240, Tab.34].
Tc	1.30E-02	1.30E-01	1.30E+00	Thorne [272, p.V].
Th	1.70E-03	1.70E-02	1.70E-01	Thorne [272, p.V].
Tl	8.00E-02	8.00E-01	8.00E+00	US DOE [269, Tab.2.7]. Indium chosen as analogue. Both are in group XIII, possess similar ionic radii and form similar oxidation states, therefore are likely to behave similarly.
U	3.00E-01	7.50E-01	1.20E+00	IAEA [240, Tab.34].
Zr	6.00E-06	6.00E-05	6.00E-04	IAEA [240, Tab.34].

Table D.60: Uptake factors for eggs. *Note that this page is set to print A3 size.*

Element	Uptake factor – eggs (day kg^{-1})			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	5.00E-04	5.00E-03	5.00E-02	LLWR [239, Tab.E14].
Am	3.00E-04	3.00E-03	3.00E-02	IAEA [240, Tab.35].
Ba	8.70E-02	8.70E-01	8.70E+00	IAEA [240, Tab.35].
C	7.50E-01	7.50E+00	7.50E+01	LLWR [239, Tab.E14].
Ca	4.40E-02	4.40E-01	4.40E+00	IAEA [240, Tab.35].
Cd	1.00E-02	1.00E-01	1.00E+00	US DOE [269, Tab.2.9].
Cl	2.00E-01	2.00E+00	2.00E+01	LLWR [239, Tab.E14].
Cm	5.00E-04	5.00E-03	5.00E-02	LLWR [239, Tab.E14].
Co	2.60E-02	3.30E-02	4.00E-02	IAEA [240, Tab.35].
Cs	1.60E-01	4.00E-01	7.10E-01	IAEA [240, Tab.35].
Eu	3.80E-04	3.80E-03	3.80E-02	Maul and Egan [271, Tab.E11].
Fe	8.50E-01	1.80E+00	2.80E+00	IAEA [240, Tab.35].
H	1.00E-01	1.00E+00	1.00E+01	LLWR [239, Tab.E14].
Hf	2.00E-05	2.00E-04	2.00E-03	US DOE [269, Tab.2.9]. Zirconium as analogue – both are group IV elements which typically exhibit similar chemical behaviour.
I	1.90E+00	2.40E+00	3.20E+00	IAEA [240, Tab.35].
Nb	1.00E-04	1.00E-03	1.00E-02	IAEA [240, Tab.35].
Ni	1.00E-01	1.00E+00	1.00E+01	LLWR [239, Tab.E14].
Np	1.00E-03	1.00E-02	1.00E-01	LLWR [239, Tab.E14].
Pa	1.00E-02	1.00E-01	1.00E+00	LLWR [239, Tab.E14].
Pb	1.00E-01	1.00E+00	1.00E+01	LLWR [239, Tab.E14].
Pt	5.00E-02	5.00E-01	5.00E+00	US DOE [269, Tab.2.9]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	9.90E-06	1.20E-03	2.30E-03	IAEA [240, Tab.35].
Ra	4.00E-03	4.00E-02	4.00E-01	LLWR [239, Tab.E14].
Sb	7.00E-03	7.00E-02	7.00E-01	US DOE [269, Tab.2.9].
Sm	3.90E-04	3.90E-03	3.90E-02	Maul and Egan [271, Tab.E11].
Sn	1.00E-01	1.00E+00	1.00E+01	US DOE [269, Tab.2.9]. The source takes the value from phosphorous as an analogue.
Sr	2.50E-01	3.50E-01	6.40E-01	IAEA [240, Tab.35].
Tc	1.30E-02	1.30E-01	1.30E+00	LLWR [239, Tab.E14].
Th	3.00E-03	3.00E-02	3.00E-01	LLWR [239, Tab.E14].
Tl	1.00E-01	1.00E+00	1.00E+01	US DOE [269, Tab.2.9]. The source takes the value from phosphorous as an analogue.
U	9.20E-01	1.10E+00	1.20E+00	IAEA [240, Tab.35].
Zr	2.00E-05	2.00E-04	2.00E-03	IAEA [240, Tab.35].

Table D.61: Uptake factors for potatoes, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – potatoes, fresh weight (-)			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	1.50E-05	1.50E-04	1.50E-03	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_fauna table, Potato).
Am	2.31E-06	4.41E-05	7.14E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Ba	1.05E-04	1.05E-03	1.05E-02	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
C	1.25E-02	1.25E-01	2.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Ca	2.50E-02	2.50E-01	2.50E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cd	3.15E-02	3.15E-01	3.15E+00	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Cl	1.20E+00	1.20E+01	1.20E+02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cm	2.31E-06	3.15E-05	4.41E-04	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Co	2.10E-03	1.13E-02	1.41E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Cs	8.40E-04	1.18E-02	1.26E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Eu	2.50E-06	2.50E-05	2.50E-04	Run 1 Biosphere Database (Watkins *et al*. [270]).
Fe	1.05E-05	1.05E-04	1.05E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
H	1.00E-01	1.00E+00	1.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Hf	4.20E-05	4.20E-04	4.20E-03	IAEA [240, Tab.17 (Tubers)]. Zirconium as analogue – both are group IV elements which typically exhibit similar chemical behaviour. IAEA values are dry weight and thus have been converted.
I	9.80E-03	9.80E-02	9.80E-01	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Potato).
Nb	8.40E-05	8.40E-04	8.40E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Ni	2.50E-03	2.50E-02	2.50E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Np	1.49E-04	1.20E-03	5.67E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Pa	7.00E-05	7.00E-04	7.00E-03	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factors table, Potato).
Pb	3.15E-05	3.15E-04	5.46E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Pt	3.60E-04	3.60E-03	3.60E-02	EA [241, Tab.D.10 Root veg]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	7.98E-07	2.31E-05	1.05E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Ra	5.04E-05	2.31E-03	8.19E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Sb	4.20E-05	4.20E-04	4.20E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Sm	2.50E-06	2.50E-05	2.50E-04	Run 1 Biosphere Database (Watkins *et al*. [270]).
Sn	2.50E-02	2.50E-01	2.50E+00	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factors table, Potato).
Sr	1.55E-03	3.36E-02	3.36E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Tc	2.73E-03	4.83E-02	1.37E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Th	2.73E-06	4.20E-05	3.78E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Tl	8.40E-04	1.18E-02	1.26E-01	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted. Caesium as analogue as the most chemically similar element available from a limited dataset. Thallium commonly forms +1 oxidation states in environmental and aqueous systems and is said to resemble group I elements in behaviour. Caesium is also recommended as a thallium analogue in EA [241].
U	3.78E-05	1.05E-03	1.68E-02	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.
Zr	4.20E-05	4.20E-04	4.20E-03	IAEA [240, Tab.17 (Tubers)]. IAEA values are dry weight and thus have been converted.

Table D.62: Uptake factors for green vegetables, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – green vegetables, fresh weight (-)			
	Minimum	Most Likely	Maximum	Comment
Ac	1.00E-04	1.00E-03	1.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Green Veg).
Am	4.80E-06	3.24E-05	1.80E-04	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Ba	6.00E-05	6.00E-04	6.00E-03	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
C	1.00E-02	1.00E-01	2.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Ca	5.00E-02	5.00E-01	5.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cd	6.60E-03	6.60E-02	6.60E-01	US DOE [269, Tab.2.2]. Reported dry weight is multiplied by conversion factor.
Cl	1.68E+00	3.12E+00	5.76E+00	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Cm	2.40E-05	1.68E-04	9.72E-04	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Co	1.56E-03	2.04E-02	1.20E-01	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Cs	3.60E-05	7.20E-03	1.18E-01	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Eu	3.00E-04	3.00E-03	3.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Fe	1.20E-05	1.20E-04	1.20E-03	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
H	5.00E-01	5.00E+00	5.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Hf	4.80E-05	4.80E-04	4.80E-03	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted. Zr as analogue – both are group IV elements which typically exhibit similar chemical behaviour.
I	1.00E-02	1.00E-01	1.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Green Veg).
Nb	9.60E-04	2.04E-03	3.00E-03	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Ni	3.00E-03	3.00E-02	3.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Np	6.00E-04	3.24E-03	9.60E-03	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Pa	4.00E-03	4.00E-02	4.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Green Veg).
Pb	3.84E-04	9.60E-03	3.00E+00	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Pt	2.00E-04	2.00E-03	2.00E-02	EA [241, Tab.D.10]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	1.20E-06	9.96E-06	3.48E-05	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Ra	2.16E-04	1.09E-02	1.56E+01	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Sb	2.64E-06	1.13E-05	2.76E-05	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Sm	2.00E-04	2.00E-03	2.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Sn	1.00E-02	1.00E-01	1.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Green Veg).
Sr	4.68E-04	9.12E-02	9.36E-01	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Tc	5.40E-01	2.16E+01	4.08E+02	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Th	1.13E-05	1.44E-04	2.52E-02	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Tl	4.80E-05	4.80E-04	4.80E-03	US DOE [269, Tab.2.2]. Reported dry weight is multiplied by conversion factor. Indium chosen as analogue. Both are in group XIII, possess similar ionic radii and form similar oxidation states, therefore are likely to behave similarly.
U	9.36E-06	2.40E-03	1.06E+00	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Zr	4.80E-05	4.80E-04	4.80E-03	IAEA [240, Tab.17 (Leafy Vegetables)]. IAEA values are dry weight and thus have been converted.

Table D.63: Uptake factors for root vegetables, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – root vegetables, fresh weight (-)			
	Minimum	Most Likely	Maximum	Comment
Ac	1.00E-04	1.00E-03	1.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Root Veg).
Am	2.80E-05	9.38E-05	2.38E-04	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Ba	7.00E-05	7.00E-04	7.00E-03	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
C	1.00E-02	1.00E-01	2.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Ca	5.00E-02	5.00E-01	5.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cd	2.10E-03	2.10E-02	2.10E-01	US DOE [269, Tab.2.4]. Reported dry weight is multiplied by conversion factor.
Cl	6.72E-01	1.68E+00	5.04E+00	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Cm	2.80E-05	1.19E-04	5.46E-04	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Co	6.58E-03	1.54E-02	1.01E-01	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Cs	1.40E-04	5.88E-03	1.23E-01	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Eu	3.00E-04	3.00E-03	3.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Fe	1.40E-05	1.40E-04	1.40E-03	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
H	5.00E-01	5.00E+00	5.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Hf	5.60E-05	5.60E-04	5.60E-03	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted. Zirconium as analogue – both are group IV elements which typically exhibit similar chemical behaviour.
I	1.00E-02	1.00E-01	1.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factor table, Root Veg).
Nb	1.12E-03	2.38E-03	3.50E-03	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted. Two datapoints only.
Ni	3.00E-03	3.00E-02	3.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Np	7.00E-04	3.08E-03	5.04E-03	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Pa	4.00E-03	4.00E-02	4.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_fauna table, Root Veg).
Pb	3.36E-05	2.10E-03	4.62E-01	IAEA (2010) - Table 17 (Root Crops). IAEA values are dry weight and thus have been converted.
Pt	3.60E-04	3.60E-03	3.60E-02	EA [241, Tab D.10]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	9.80E-06	5.46E-05	8.12E-04	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Ra	2.80E-04	9.80E-03	7.84E+00	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Sb	5.60E-05	8.68E-05	1.54E-04	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Sm	2.00E-04	2.00E-03	2.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Sn	1.00E-02	1.00E-01	1.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_fauna table, Root Veg).
Sr	4.20E-03	1.01E-01	6.72E-01	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Tc	1.96E+00	6.44E+00	1.11E+01	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted. Two datapoints only.
Th	1.15E-06	1.12E-04	1.33E-02	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Tl	5.60E-06	5.60E-05	5.60E-04	US DOE [269, Tab.2.4]. Reported dry weight is multiplied by conversion factor. Indium used as analogue by source.
U	6.86E-05	1.18E-03	3.64E-02	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.
Zr	5.60E-05	5.60E-04	5.60E-03	IAEA [240, Tab.17 (Root Crops)]. IAEA values are dry weight and thus have been converted.

Table D.64: Uptake factors for fruit, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – fruit, fresh weight (-)			
	Minimum	Most Likely	Maximum	Comment
Ac	6.10E-06	6.10E-05	6.10E-04	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_plant_Transfer_Factors table, herbaceous fruit).
Am	1.30E-06	3.10E-05	6.20E-04	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)].
Ba	8.00E-05	8.00E-04	8.00E-03	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
C	1.25E-02	1.25E-01	2.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Ca	5.00E-02	5.00E-01	5.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cd	1.50E-02	1.50E-01	1.50E+00	US DOE [269, Tab.2.3].
Cl	5.00E-01	5.00E+00	5.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Cm	4.40E-04	5.30E-04	6.20E-04	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)].
Co	4.80E-04	4.80E-03	4.80E-02	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)].
Cs	8.60E-04	5.80E-03	8.00E-02	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)].
Eu	1.00E-06	1.00E-05	1.00E-04	Run 1 Biosphere Database (Watkins *et al*. [270]).
Fe	1.60E-05	1.60E-04	1.60E-03	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
H	1.00E-01	1.00E+00	1.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Hf	1.00E-04	1.00E-03	1.00E-02	US NRC [273].
I	4.10E-04	6.30E-03	3.10E-02	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)]. Fresh fruit weight used - no conversion factor.
Nb	1.28E-04	1.28E-03	1.28E-02	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Ni	1.00E-03	1.00E-02	1.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]).
Np	6.40E-04	2.88E-03	9.12E-03	IAEA (2010) - Table 17 (Non-leafy Vegetables). IAEA values are dry weight and thus have been converted.
Pa	2.80E-05	2.80E-04	2.80E-03	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_fauna table, herbaceous fruit).
Pb	2.40E-04	2.40E-03	6.24E-01	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Pt	2.80E-04	2.80E-03	2.80E-02	EA [241, Tab.D.10]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	1.30E-06	1.40E-04	2.10E-02	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)].
Ra	3.84E-05	2.72E-03	1.01E+00	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Sb	5.00E-04	5.00E-03	5.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_fauna table, herbaceous fruit).
Sm	1.00E-06	1.00E-05	1.00E-04	Run 1 Biosphere Database (Watkins *et al*. [270])
Sn	1.00E-02	1.00E-01	1.00E+00	Run 1 Biosphere Database (Watkins *et al*. [270]) (soil_to_fauna table, herbaceous fruit).
Sr	1.20E-03	1.70E-02	7.00E-02	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)].
Tc	1.80E+00	1.80E+01	1.80E+02	Run 1 Biosphere Database (Watkins *et al*. [270]).
Th	9.92E-06	1.25E-04	2.56E-03	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Tl	6.40E-06	6.40E-05	6.40E-04	US DOE [269, Tab.2.3]. Reported dry weight is multiplied by conversion factor. Indium used as analogue by source.
U	8.32E-05	2.40E-03	3.20E-02	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.
Zr	6.40E-05	6.40E-04	6.40E-03	IAEA [240, Tab.17 (Non-leafy Vegetables)]. IAEA values are dry weight and thus have been converted.

Table D.65: Uptake factors for mushrooms, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – mushrooms, fresh weight (-)			
	Minimum	Most Likely	Maximum	Comment
Ac	1.10E-05	3.20E-04	1.50E-02	SKB [274, Tab.6-25]. Lanthanum value taken from wild vegetation group (cR_Ter_pp) as analogue suggested by source. Dry weight is converted to fresh weight values.
Am	1.10E-05	3.20E-04	1.50E-02	SKB [274, Tab.6-25]. Lanthanum value taken from wild vegetation group (cR_Ter_pp) as analogue suggested by source. Dry weight is converted to fresh weight values.
Ba	5.80E-04	6.90E-03	0.15	SKB [274, Tab.6-25]. Strontium suggested by source as elemental analogue. Dry weight is converted to fresh weight values.
C	0.0125	0.125	20	Run 1 Biosphere Database (Watkins *et al*. [270]). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis. In the absence of fungi-specific data, this analogous approach represents a cautious estimate, since fungi do not photosynthesize.
Ca	2.50E-04	5.10E-03	6.30E-02	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Cd	2.30E-02	1.10E+00	2.20E+01	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Cl	7.10E-01	3.90E+01	9.60E+02	SKB [274, Tab.6-25]. Value taken from wild vegetation group (cR_Ter_pp). Dry weight is converted to fresh weight values.
Cm	1.10E-05	3.20E-04	1.50E-02	SKB [274, Tab.6-25]. Lanthanum value taken from wild vegetation group (cR_Ter_pp) as analogue suggested by source. Dry weight is converted to fresh weight values.
Co	5.90E-04	1.10E-02	0.7	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Cs	2.30E-02	3.3	120	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Eu	0.000026	0.00065	0.016	SKB [274, Tab.6-25]. Value taken from wild vegetation group (cR_Ter_pp). Dry weight is converted to fresh weight values.
Fe	0.0015	0.033	0.34	SKB [274, Tab.6-25]. Nickel (itself listed as an analogue for palladium) as analogue in absence of iron data. Dry weight is converted to fresh weight values. Choice of analogue is based upon similar properties of transition metals.
H	0.0125	0.125	20	Run 1 Biosphere Database (Watkins *et al*. [270]). C as analogue as per [241, Tab.A.3]. Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis. In the absence of fungi-specific data, this analogous approach represents a cautious estimate, since fungi do not photosynthesize.
Hf	0.00011	0.0028	0.068	SKB [274, Tab.6-25]. Zirconium as analogue – both are group IV elements which typically exhibit similar chemical behaviour. Dry weight is converted to fresh weight values.
I	0.0011	0.0065	0.016	SKB [274, Tab.6-25]. Value taken from wild vegetation group (cR_Ter_pp). Dry weight is converted to fresh weight values.
Nb	3.30E-05	8.10E-04	4.90E-02	SKB [274, Tab.6-25]. Value taken from wild vegetation group (cR_Ter_pp). Dry weight is converted to fresh weight values.
Ni	0.0015	0.033	0.34	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Np	0.000011	0.00032	0.015	SKB [274, Tab.6-25]. Lanthanum value taken from wild vegetation group (cR_Ter_pp) as analogue suggested by source. Dry weight is converted to fresh weight values.
Pa	0.000011	0.00032	0.015	SKB [274, Tab.6-25]. Lanthanum value taken from wild vegetation group (cR_Ter_pp) as analogue suggested by source. Dry weight is converted to fresh weight values.
Pb	0.00042	0.0032	0.034	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values. Nickel as analogue, both are in group X, no analogue suggested by source.
Pt	0.0015	0.033	0.34	SKB [274, Tab.6-25]. Ni as analogue due to same group membership. Dry weight is converted to fresh weight values.
Pu	0.000012	0.0009	1.5	SKB [274, Tab.6-25]. U as analogue. Dry weight is converted to fresh weight values.
Ra	0.00058	0.0069	0.15	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values. Strontium used by source as an analogue.
Sb	0.000027	0.00065	0.016	SKB [274, Tab.6-25]. Bismuth value taken from cereal group (cR_agri_cereal) as analogue, itself an analogue for Polonium in Table 6.25. No recommendation found for use of analogue for Sb. Given its tendency to form higher oxidation states (3+/5+), possible analogues from group I/II were discounted. Bi pertains to the same group as Sb and is found natively in similar oxidation states as Sb. Dry weight is converted to fresh weight values.
Sm	0.000014	0.00034	0.0098	SKB [274, Tab.6-25]. Value taken from wild vegetation group (cR_Ter_pp) as analogue. Dry weight is converted to fresh weight values.
Sn	0.000071	0.001	0.061	SKB [274, Tab.6-25]. Thorium value taken from wild vegetation group (cR_Ter_pp) suggested by source as analogue. Dry weight is converted to fresh weight values.
Sr	0.00058	0.0069	0.15	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Tc	0.00009	0.0064	0.45	SKB [274, Tab.6-25]. Rhenium chosen as analogue value taken from cereal group (cR_agri_cereal) in absence of Tc specific data. Both elements are group VII with similar ionic radii and similar chemical behaviour. Dry weight is converted to fresh weight values.
Th	0.000071	0.001	0.061	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Tl	0.023	3.3	120	SKB [274, Tab.6-25]. Caesium as analogue as per recommendation in EA [241, Tab.A.3]. Dry weight is converted to fresh weight values.
U	0.000012	0.0009	1.5	SKB [274, Tab.6-25]. Dry weight is converted to fresh weight values.
Zr	0.00011	0.0028	0.068	SKB [274, Tab.6-25]. Rhenium value taken from wild vegetation group (cR_Ter_pp) as analogue. Dry weight is converted to fresh weight values.

Table D.66: Uptake factors for berries, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – berries, fresh weight (-)			
	Minimum	**Most Likely**	**Maximum**	**Comment**
Ac	8.26E-04	8.40E-04	8.40E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Lanthanum as analogue - both in group III with similar chemical behaviour. Dry weight converted to fresh weight.
Am	3.22E-06	5.04E-05	2.66E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Ba	7.00E-05	7.00E-04	7.00E-03	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
C	1.25E-02	1.25E-01	2.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Ca	9.94E-04	5.04E-02	1.11E+00	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight. Strontium as analogue owing to same group membership and similar chemical behaviour.
Cd	3.50E-05	8.96E-05	2.80E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight. Silver as analogue owing to reasonably similar elemental properties and the unavailability of other analogue data.
Cl	5.00E-01	5.00E+00	5.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Fruit as analogue owing to a lack of suitable elemental analogue in berry uptake.
Cm	5.04E-06	4.48E-05	1.96E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Co	7.98E-03	1.96E-02	3.22E-02	IAEA [240, Tab.17 (non-leafy vegetables)]. Dry weight converted to fresh weight.
Cs	9.80E-05	2.94E-03	1.02E-01	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Eu	8.26E-04	8.40E-04	8.40E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Lanthanum as analogue since the Lanthanides are well known for possessing similar chemical properties. Dry weight converted to fresh weight.
Fe	1.40E-05	1.40E-04	1.40E-03	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
H	1.25E-02	1.25E-01	2.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]). Carbon as analogue as per EA [241, Tab.A.3]. Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Hf	1.00E-04	1.00E-03	1.00E-02	US NRC [273]. Value for fruit used, no suitable elemental analogue available for berry uptake.
I	4.10E-04	6.30E-03	3.10E-02	IAEA [240, Tab.19 (Temperate - Fruit - Woody Trees)]. Fresh fruit weight used - no conversion factor. Value for fruit used, no suitable elemental analogue available for berry uptake.
Nb	1.12E-04	1.12E-03	1.12E-02	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Ni	1.00E-03	1.00E-02	1.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]). No satisfactory analogue in IAEA [240, Tab.17 (Fruits, heads, berries, buds)]. Ni and Fe, although chemically similar, appear to exhibit lower transfer factors for other similar food groups therefore might give unrealistically low value as an analogue for berry. Cautiously uses the fruit value for Ni.
Np	5.60E-04	2.52E-03	7.98E-03	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Pa	8.26E-04	8.40E-04	8.40E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Lanthanum as analogue. Dry weight converted to fresh weight.
Pb	2.10E-04	2.10E-03	5.46E-01	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Pt	3.50E-05	8.96E-01	2.80E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Silver as analogue owing to reasonably similar elemental properties and unavailability of other elemental analogues. Dry weight converted to fresh weight.
Pu	8.40E-07	9.10E-06	2.80E-05	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Ra	3.36E-05	2.38E-03	8.82E-01	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Sb	2.10E-06	1.82E-05	2.24E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Sm	8.26E-04	8.40E-04	8.40E-04	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight. La as analogue.
Sn	2.10E-04	2.10E-03	5.46E-01	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight. Lead as analogue owning to same group membership conferring similar chemical properties.
Sr	9.94E-04	5.04E-02	1.11E+00	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Tc	1.80E+00	1.80E+01	1.80E+02	Run 1 Biosphere Database (Watkins *et al*. [270]). Value for fruit uptake used. No suitable elemental analogue available for berry uptake.
Th	8.68E-06	1.09E-04	2.24E-03	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Tl	9.80E-05	2.94E-03	1.02E-01	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight. Caesium as analogue as per recommendation in EA [241, Tab.A.3].
U	7.28E-05	2.10E-03	2.80E-02	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.
Zr	5.60E-05	5.60E-04	5.60E-03	IAEA [240, Tab.17 (non-leafy vegetables: fruits, heads, berries, buds)]. Dry weight converted to fresh weight.

Table D.67: Uptake factors for pasture, fresh weight. Dry-to-fresh conversion ratio as specified in Table D.52. *Note that this page is set to print A3 size.*

Element	Uptake factor – pasture, fresh weight (-)			
	Minimum	Most Likely	Maximum	Comment
Ac	1.00E-04	1.00E-03	1.00E-02	Run 1 Biosphere Database (Watkins *et al*. [270]) (grass).
Am	3.57E-03	3.41E-02	2.99E-01	Wildlife Transfer Parameter Database [265].
Ba	3.74E-03	2.30E-02	7.47E-02	Wildlife Transfer Parameter Database [265].
C	1.00E-02	1.00E-01	2.00E+01	Best estimate value from the Run 1 Biosphere Database (Watkins *et al*. [270]) (grass). Maximum value based on the plant/fodder value considered in LLWR [239; 275, App.A], which cautiously incorporated the potential impact from C-14 gas, emanating from the soil, being taken up during photosynthesis.
Ca	7.90E-02	2.71E-01	3.86E-01	Wildlife Transfer Parameter Database [265].
Cd	3.00E-03	1.36E+00	9.31E+00	Wildlife Transfer Parameter Database [265], grasses and herbs.
Cl	1.94E-02	1.54E+01	9.18E+01	Wildlife Transfer Parameter Database [265].
Cm	5.00E-05	5.00E-04	5.00E-03	Wildlife Transfer Parameter Database [265].
Co	3.00E-04	1.40E-02	6.20E-02	Wildlife Transfer Parameter Database [265].
Cs	9.54E-04	4.57E-01	3.65E+01	Wildlife Transfer Parameter Database [265].
Eu	2.44E-04	9.47E-03	6.33E-02	Wildlife Transfer Parameter Database [265].
Fe	1.80E-04	4.00E-04	1.00E-01	IAEA [240, Tab.17 (Pasture, all soil types)]. IAEA values are dry weight and thus have been converted.
H	5.00E-01	5.00E+00	5.00E+01	Run 1 Biosphere Database (Watkins *et al*. [270]) (grass).
Hf	6.80E-04	9.59E-03	7.85E-02	Wildlife Transfer Parameter Database [265], grasses and herbs.
I	5.33E-03	5.33E-02	5.33E-01	Wildlife Transfer Parameter Database [265], grasses and herbs.
Nb	4.46E-04	8.96E-04	3.63E-03	Wildlife Transfer Parameter Database [265].
Ni	3.29E-03	3.08E-02	1.88E-01	Wildlife Transfer Parameter Database [265].
Np	2.60E-03	1.22E-02	9.40E-02	IAEA [240, Tab.17 (Pasture, all soil types)]. IAEA values are dry weight and thus have been converted.
Pa	4.00E-03	4.00E-02	4.00E-01	Run 1 Biosphere Database (Watkins *et al*. [270]) (grass).
Pb	3.00E-04	4.50E-02	1.80E+00	Wildlife Transfer Parameter Database [265].
Pt	8.00E-03	8.00E-02	8.00E-01	EA [241, Tab.D.9]. Gold used as analogue due to unavailability of platinum data and chemical similarities between platinum and gold.
Pu	1.22E-02	9.42E-03	4.25E-02	Wildlife Transfer Parameter Database [265].
Ra	5.12E-05	7.28E-02	4.65E+00	Wildlife Transfer Parameter Database [265].
Sb	1.28E-03	2.78E-02	1.13E-01	Wildlife Transfer Parameter Database [265], grasses and herbs.
Sm	9.09E-05	6.88E-03	6.68E-02	Wildlife Transfer Parameter Database [265].
Sn	6.96E-04	9.98E-04	1.30E-03	Wildlife Transfer Parameter Database [265], grasses and herbs.
Sr	5.62E-03	3.41E-01	8.76E+00	Wildlife Transfer Parameter Database [265].
Tc	6.21E-03	9.96E+00	2.00E+01	Wildlife Transfer Parameter Database [265].
Th	9.46E-05	5.79E-02	2.67E+00	Wildlife Transfer Parameter Database [265].
Tl	4.06E-03	5.62E-03	6.20E-03	Wildlife Transfer Parameter Database [265], grasses and herbs.
U	7.68E-05	3.88E-02	5.54E+00	Wildlife Transfer Parameter Database [265].
Zr	2.00E-04	2.00E-03	2.00E-02	IAEA [240, Tab.17 (Pasture, all soil types)]. IAEA values are dry weight and thus have been converted.

Table D.68: Animal consumption rates of pasture, soil and water.

Animal	Consumption rate			Comment
	Pasture (kg y^{-1})	Soil (kg y^{-1})	Water (m^3 y^{-1})	
Beef Cattle	42000	220	11	Run 1 Biosphere Database [270]. These are total consumption rates. Contaminated consumption rates can be calculated in the GoldSim model by multiplication with the Fields to Farm Size ratio.
Milk Cattle	42000	220	27	Water consumption from the Run 1 Biosphere Database [270]. Grass and Soil consumption assumed based on Beef Cattle.
Sheep	2600	29	1.8	Run 1 Biosphere Database [270]. These are total consumption rates. Contaminated consumption rates are calculated in the GoldSim model by multiplication with the Fields to Farm Size ratio.
Poultry	180	7	0.073	Run 1 Biosphere Database [270].
Goat	3247	58	3.6	Pasture: Spencer [276, Tab.3] dry matter intake averaged for all goat weights listed in source, conservatively summed with additional nutritional requirements for late-stage pregnancy. Converted from pounds (lbs) dry matter consumed per day. Soil and water assumed to be double that of sheep.

Table D.69: Additional parameters required for the biosphere model.

Parameter	Value	Comment
Average English farm size (m^2)	8.80E+05	The average farm size in England in 2023 was 88 ha [277,Tab.1.1]. This value is used in the GoldSim model to calculate an adjustment factor to account for the assumption that livestock derive part of their annual intake from the potentially contaminated field/land but also from "clean" land on a farm. The derived value is an approximate scaling factor based on the fact that the Field or Land/Mire compartments are smaller than the average farm size. The same factor is also applied to exposure of the farmer (inhalation, external irradiation and skin contamination), who is assumed to spend part of their time tending the contaminated field/land. (Conservatively, the farmer's entire meat and root vegetable intake is assumed to derive from the contaminated area and the cattle are assumed to consume only contaminated river/supplied water.)
External contamination of pasture by soil (kg kg^{-1})	2.00E-03	A value of 2 x 10^{-3} kg dry soil kg^{-1} grass fresh weight is used, based on the IAEA BIOMASS project [278, Tab.C53].
Maximum dust load (kg m^{-3})	1.00E-06	Dust mass per unit volume of air, taken from the Run 1 Biosphere Database for Generic Dust in Air – temperate [270]. The range is based upon IAEA Generic Waste Acceptance Criteria. The maximum value is appropriate for soil that is mechanically disturbed (e.g. ploughing or digging or in dry, windy conditions). In all cases, dust is assumed to derive from the soil surface. Maximum value is used for farming/crop sewing activities relevant to the Farmer and Smallholder RPs. This value is also used for dust exposure to the Construction Worker RP. Best estimate and minimum values retained for future possible alternate runs.
Best estimate dust load (kg m^{-3})	1.00E-07	
Minimum dust load (kg m^{-3})	2.00E-08	

Parameter	Value	Comment
Small Particle Inhalation enhancement factor	4	Used for inhalation of dust. IAEA [279, p.30].
Small Particle Ingestion enhancement factor	2	Used for the ingestion of soil. IAEA [279, p.33].

D.4.4 Dose Coefficients

D12 Dose coefficients used to calculate the modelled dose to representative persons (adult, child and infant) are reported for external irradiation and ingestion pathways in Table D.70, for skin contamination from both dust and water immersion in Table D.71 and inhalation of particles in Table D.72.

D13 The skin contamination dose calculation considers only a single dose coefficient per radionuclide, aligning with the approach used for the ONDRAF/NIRAS Human Intrusion assessment for the Category A waste disposal facility at Dessel [280]. Skin dose coefficients are dependent on the exact location of the radiosensitive tissues of the skin - a depth of 4 mg cm^{-2} below the body surface would correspond to an average epidermal thickness for the head, trunk, upper arm and upper leg, whereas a depth of 8 mg cm^{-2} would apply to the lower arm, wrist, back of the hand, lower leg, ankle and upper foot. A 40 mg cm^{-2} depth applies to the palm of the hand and sole of the foot [280, §3.2.3]. The ICRP recommends a weight of material per unit area for adults of 7 mg cm^{-2}, which is the equivalent thickness of 70 µm of tissue [281, ¶64]. At this depth, the main component of the dose resulting from superficial contamination of the skin is due to beta irradiation from the radionuclide. Dose coefficients with values of 0.0 Sv h^{-1} Bq^{-1} m^2 indicate low energy beta emission not sufficient to penetrate the skin at the given depth of 70 µm [285]. The gamma contribution to the dose is generally just a few percent. Therefore, gamma – along with alpha contribution - are neglected, as recommended in [282, p.12]. Given the greater sensitivity of children and infants, a weight of material per unit area of 4 mg cm^{-2} has been assumed.

D14 Skin dose coefficients, $D_{skin,cont}$, used here are adopted from Kocher and Eckerman [285] assuming a uniform spread on the body surface. The assumption of radioactivity being deposited uniformly on the body surface is justifiable because the contamination deposited in the soil/sediment will generally be spread evenly, and the short range of electrons in soft tissue means that any hot spots of contamination have a limited influence.

Table D.70: Dose coefficients for external irradiation from the US Environmental Protection Agency (FGR15 – effective infinite depth) [283, Tab.4.5], and dose coefficients associated with ingestion of radionuclides from ICRP 119 [284, Tab.F.1]. Dose coefficients for implicitly modelled daughters are added to that of their explicitly modelled parent in proportion to the decay chain branching ratios (see Appendix B). Child and Infant coefficients are for a ten-year-old and a one-year-old, respectively. *Page set to A3 size.*

Radionuclide	External Irradiation (Sv m^3 Bq^{-1} s^{-1})			Ingestion (Sv Bq^{-1})			
	Adult	Child	Infant	Adult	Child	Infant	Comment
H3	3.41E-23	3.76E-23	4.19E-23	4.20E-11	5.70E-11	1.20E-10	
C14	3.14E-20	3.46E-20	3.86E-20	5.80E-10	8.00E-10	1.60E-09	
Cl36	4.21E-19	4.64E-19	5.17E-19	9.30E-10	1.90E-09	6.30E-09	
Ca41	0.00E+00	0.00E+00	0.00E+00	1.90E-10	4.80E-10	5.20E-10	
Fe55	3.36E-27	3.81E-27	4.33E-27	3.30E-10	1.10E-09	2.40E-09	
Co60	8.25E-17	9.08E-17	1.01E-16	3.40E-09	1.10E-08	2.70E-08	
Ni59	4.52E-22	5.02E-22	5.65E-22	6.30E-11	1.10E-10	3.40E-10	
Ni63	4.09E-21	4.51E-21	5.03E-21	1.50E-10	2.80E-10	8.40E-10	
Sr90	2.52E-18	2.76E-18	3.06E-18	3.07E-08	6.59E-08	9.30E-08	
Zr93	4.84E-21	5.34E-21	5.95E-21	1.10E-09	5.80E-10	7.60E-10	
Nb93m	3.04E-22	7.30E-22	9.33E-22	1.20E-10	2.70E-10	9.10E-10	
Nb94	4.82E-17	5.33E-17	5.97E-17	1.70E-09	3.40E-09	9.70E-09	
Tc99	1.01E-19	1.12E-19	1.24E-19	6.40E-10	1.30E-09	4.80E-09	
Cd113m	2.47E-19	2.72E-19	3.03E-19	2.30E-08	2.90E-08	5.60E-08	
Sn121m	1.34E-19	1.50E-19	1.69E-19	5.58E-10	1.21E-09	4.02E-09	
Sb125	1.23E-17	1.37E-17	1.54E-17	1.30E-09	2.54E-09	7.56E-09	
I129	7.88E-20	9.88E-20	1.29E-19	1.10E-07	1.90E-07	2.20E-07	
Cs134	4.75E-17	5.26E-17	5.90E-17	1.90E-08	1.40E-08	1.60E-08	
Cs137	1.72E-17	1.90E-17	2.14E-17	1.30E-08	1.00E-08	1.20E-08	No dose coefficient values for Ba-137 presented in ICRP 119.
Ba133	9.63E-18	1.08E-17	1.22E-17	1.50E-09	4.60E-09	6.20E-09	
Sm151	5.53E-21	6.10E-21	6.80E-21	9.80E-11	2.00E-10	6.40E-10	
Eu152	3.61E-17	3.99E-17	4.44E-17	1.40E-09	2.60E-09	7.40E-09	
Eu154	3.93E-17	4.34E-17	4.83E-17	2.00E-09	4.10E-09	1.20E-08	
Eu155	9.46E-19	1.09E-18	1.26E-18	3.20E-10	6.80E-10	2.20E-09	
***Hf178n**	6.09E-17	6.79E-17	7.64E-17	4.70E-09	7.80E-09	1.90E-08	
Pt193	2.23E-23	7.03E-23	1.20E-22	3.10E-11	6.90E-11	2.40E-10	
Tl204	3.71E-19	4.10E-19	4.58E-19	1.20E-09	2.50E-09	8.50E-09	
Pb210	7.01E-19	7.73E-19	8.62E-19	1.89E-06	4.50E-06	1.24E-05	
Ra226	5.74E-17	6.32E-17	7.00E-17	2.80E-07	8.01E-07	9.62E-07	Rn-222, Po-218, At, 218, Rn-218, Tl-210, Po-214 - no dose coefficient values are presented in ICRP 119.
Ra228	2.76E-17	3.04E-17	3.39E-17	6.90E-07	3.90E-06	5.70E-06	
Ac227	1.27E-17	1.42E-17	1.60E-17	1.21E-06	1.97E-06	4.27E-06	No data presented in ICRP 119 for At-219, Rn-219, Bi-215, Bi-211, Tl-207 and Po-211.
Th228	5.06E-17	5.55E-17	6.08E-17	1.43E-07	4.21E-07	1.09E-06	No data presented in ICRP 119 for Rn-220, Po-216, Po-212 and Tl-208.
Th229	8.86E-18	9.89E-18	1.11E-17	6.13E-07	1.17E-06	2.38E-06	No data presented in ICRP 119 for Fr-221, At-217, Rn-217, Po-213 and Tl-209.
Th230	6.21E-21	7.37E-21	8.53E-21	2.10E-07	2.40E-07	4.10E-07	
Th232	2.74E-21	3.37E-21	3.99E-21	2.30E-07	2.90E-07	4.50E-07	
Pa231	8.50E-19	9.53E-19	1.07E-18	7.10E-07	9.20E-07	1.30E-06	
U233	4.93E-21	5.73E-21	6.57E-21	5.10E-08	7.80E-08	1.40E-07	
U234	1.88E-21	2.44E-21	2.93E-21	4.90E-08	7.40E-08	1.30E-07	
U235	4.03E-18	4.55E-18	5.13E-18	4.73E-08	7.17E-08	1.33E-07	
U236	9.32E-22	1.32E-21	1.62E-21	4.70E-08	7.00E-08	1.30E-07	
U238	2.62E-18	2.88E-18	3.21E-18	4.84E-08	7.54E-08	1.45E-07	No data presented in ICRP 119 for Pa-234m.
Np237	5.83E-18	6.54E-18	7.36E-18	1.11E-07	1.12E-07	2.16E-07	
Pu238	5.29E-22	9.27E-22	1.18E-21	2.30E-07	2.40E-07	4.00E-07	
Pu239	1.47E-21	1.80E-21	2.10E-21	2.50E-07	2.70E-07	4.20E-07	No data presented in ICRP 119 for U-235m.
Pu240	5.46E-22	9.29E-22	1.18E-21	2.50E-07	2.70E-07	4.20E-07	
Pu241	1.40E-22	1.58E-22	1.78E-22	4.80E-09	5.10E-09	5.70E-09	
Pu242	3.08E-21	3.66E-21	4.16E-21	2.40E-07	2.60E-07	4.00E-07	
Am241	2.20E-19	2.65E-19	3.19E-19	2.00E-07	2.20E-07	3.70E-07	
Am243	4.77E-18	5.41E-18	6.13E-18	2.01E-07	2.22E-07	3.76E-07	
Cm243	2.88E-18	3.24E-18	3.65E-18	1.50E-07	1.60E-07	3.30E-07	
Cm244	1.00E-21	1.42E-21	1.71E-21	1.20E-07	1.40E-07	2.90E-07	

* Note that the cited sources provide a dose coefficient for what is labelled 'Hf-178m', but this is in fact for the 31-year half-live Hf-178n excited state.

Table D.71: Dose coefficients for skin contamination from dust/particulates are from Kocker and Eckerman [285, Tab.1] and skin contamination coefficients from immersion in contaminated water are from ICRP 144 [286]. Adult dose coefficients assume an average skin thickness of 7 mg cm^{-2} as recommended in ICRP 77 [287, ¶64]. Child and infant coefficients assume an average skin thickness of 4 mg cm^{-2}. Several coefficients have zero values since they are either alpha emitters or low energy beta emitters that are not expected to penetrate the skin [288]. Dose coefficients for implicitly modelled daughters are added to that of their explicitly modelled parent in proportion to the decay chain branching ratios (see Appendix B). *Page set to A3 size.*

Radionuclide	Skin Contamination (Sv m^2 s^{-1} Bq^{-1})				Water Immersion (Sv Bq^{-1} m^3 s^{-1})		
	Adult	Child	Infant	Comment	Adult	Child	Infant
H3	0.00E+00	0.00E+00	0.00E+00		2.53E-25	9.31E-26	4.00E-26
C14	9.19E-15	2.50E-14	2.50E-14		2.64E-21	2.62E-21	2.74E-21
Cl36	5.39E-14	6.97E-14	6.97E-14		2.01E-19	2.01E-19	2.08E-19
Ca41	0.00E+00	0.00E+00	0.00E+00	No data presented in Kocker & Eckerman [285]. Assume zero skin penetration due to low energy EC decay - as with external irradiation and water immersion.	0.00E+00	0.00E+00	0.00E+00
Fe55	0.00E+00	0.00E+00	0.00E+00		1.26E-26	1.45E-26	1.79E-26
Co60	3.14E-14	5.07E-14	5.07E-14		2.60E-16	2.81E-16	3.14E-16
Ni59	0.00E+00	0.00E+00	0.00E+00		1.43E-21	1.58E-21	1.84E-21
Ni63	0.00E+00	5.07E-16	5.07E-16		1.87E-23	1.66E-23	1.98E-23
Sr90	1.17E-13	1.43E-13	1.43E-13		1.57E-18	1.87E-18	2.95E-18
Zr93	0.00E+00	6.65E-16	6.65E-16		2.26E-23	2.00E-23	2.38E-23
Nb93m	0.00E+00	0.00E+00	0.00E+00		8.00E-21	1.33E-20	1.59E-20
Nb94	4.44E-14	6.02E-14	6.02E-14		1.49E-16	1.63E-16	1.86E-16
Tc99	2.73E-14	4.44E-14	4.44E-14		2.97E-20	2.97E-20	3.03E-20
Cd113m	4.75E-14	6.34E-14	6.34E-14		1.06E-19	1.07E-19	1.10E-19
Sn121m	4.75E-14	6.34E-14	6.34E-14	No data presented in Kocker & Eckerman [285] for Sn-121 or Sn-121m. Cd113m is used as analogue for An121m from Kocker and Eckerman. Although Cd109 is reported in ICRP107 [288] as having bounding beta and gamma decay emission of Sn121m, it is reported in Kocker and Eckerman [285] as having a dose coefficient of zero. Therefore, Cd113m which has a non-zero coefficient is taken as bounding, despite a lower reported gamma emission (0.0265 MeV compared with <E-04 MeV). Dose of the short-lived daughter is not included.	1.28E-19	1.50E-19	2.01E-19
Sb125	3.08E-14	5.71E-14	5.71E-14		3.90E-17	4.32E-17	5.06E-17
I129	6.02E-15	1.81E-14	1.81E-14		5.56E-19	7.14E-19	1.03E-18
Cs134	3.80E-14	5.07E-14	5.07E-14		1.47E-16	1.61E-16	1.85E-16
Cs137	5.06E-14	7.06E-14	7.06E-14		5.26E-17	5.78E-17	6.67E-17
Ba133	5.39E-14	6.97E-14	6.97E-14	No data presented in Kocker & Eckerman [285]. Ba140 is used for Ba133 from Kocker and Eckerman [285] as a bounding analogue in decay energy; it has similar atomic size and the half-lives are of similar magnitude.	3.22E-17	3.64E-17	4.36E-17
Sm151	1.65E-17	7.92E-16	7.92E-16		8.83E-23	1.08E-22	1.40E-22
Eu152	2.50E-14	4.44E-14	4.44E-14		1.15E-16	1.25E-16	1.43E-16
Eu154	5.70E-14	9.51E-14	9.51E-14		1.23E-16	1.34E-16	1.53E-16
Eu155	9.19E-15	2.41E-14	2.41E-14		4.00E-18	4.78E-18	6.11E-18
*Hf178n	6.34E-14	7.61E-14	7.61E-14	No data presented in Kocker & Eckerman [285]. I134 is used as an analogue for Nf178n since I134 decay emissions are bounding. No analogue data are available in Kocker & Eckerman [285] for radionuclides with bounding energy emission, similar half-life and nuclear size. The dose of the short-lived daughter is not included.	1.97E-16	2.20E-16	2.60E-16
Pt193	0.00E+00	5.70E-17	5.70E-17	No data presented in Kocker & Eckerman [285]. Pb210 is used as an analogue since Pb210 decay emissions are bounding of Pt193 and it has a similar half-life.	1.41E-21	2.13E-21	2.36E-21
Tl204	5.39E-14	6.65E-14	6.65E-14		2.33E-19	2.48E-19	2.78E-19
Pb210	6.02E-14	7.29E-14	7.29E-14		4.22E-19	4.50E-19	5.14E-19
Ra226	1.34E-13	1.63E-13	1.63E-13	No data presented in Kocker & Eckerman [285] for Rn-222, At-218, Rn-218 and Tl-210, and are not included.	1.76E-16	1.90E-16	2.16E-16
Ra228	6.34E-14	8.56E-14	8.56E-14		8.50E-17	9.25E-17	1.05E-16
Ac227	1.46E-13	1.83E-13	1.83E-13	No data presented in Kocker & Eckerman [285] for At-219, Rn-219 and Bi-215, and are not included.	3.76E-17	4.22E-17	5.05E-17
Th228	1.27E-13	1.76E-13	1.76E-13	No data presented in Kocker & Eckerman [285] for Rn-220 and is not included.	1.53E-16	1.65E-16	1.85E-16
Th229	1.63E-13	2.38E-13	2.38E-13	No data presented in Kocker & Eckerman [285] for Rn-217 and is not included.	2.68E-17	3.01E-17	3.59E-17
Th230	0.00E+00	2.88E-15	2.88E-15		2.94E-20	3.69E-20	4.64E-20
Th232	5.70E-17	8.56E-16	8.56E-16		1.58E-20	2.07E-20	2.61E-20
Pa231	2.09E-15	4.12E-15	4.12E-15		2.86E-18	3.25E-18	3.89E-18
U233	2.15E-17	1.46E-16	1.46E-16		2.11E-20	2.59E-20	3.19E-20
U234	6.65E-17	2.06E-16	2.06E-16		1.33E-20	1.84E-20	2.29E-20
U235	2.95E-14	7.00E-14	7.00E-14		1.40E-17	1.60E-17	1.95E-17
U236	6.02E-17	1.27E-16	1.27E-16		8.72E-21	1.28E-20	1.58E-20

Radionuclide	Skin Contamination (Sv m^2 s^{-1} Bq^{-1})				Water Immersion (Sv Bq^{-1} m^3 s^{-1})		
	Adult	Child	Infant	Comment	Adult	Child	Infant
U238	7.67E-14	1.07E-13	1.07E-13		3.58E-18	4.05E-18	5.25E-18
Np237	5.29E-14	9.60E-14	9.60E-14		1.98E-17	2.24E-17	2.70E-17
Pu238	0.00E+00	0.00E+00	0.00E+00		8.31E-21	1.29E-20	1.58E-20
Pu239	0.00E+00	1.20E-17	1.20E-17	No data presented in Kocker & Eckerman [285] for U-235m and is not included.	8.08E-21	1.06E-20	1.31E-20
Pu240	0.00E+00	0.00E+00	0.00E+00		8.08E-21	1.24E-20	1.53E-20
Pu241	0.00E+00	0.00E+00	0.00E+00	No data presented in Kocker & Eckerman [285] for U-237 and is not included.	3.59E-22	4.19E-22	5.19E-22
Pu242	0.00E+00	0.00E+00	0.00E+00		1.47E-20	1.90E-20	2.25E-20
Am241	6.97E-17	1.52E-15	1.52E-15		1.23E-18	1.54E-18	2.02E-18
Am243	7.30E-14	1.18E-13	1.18E-13		1.75E-17	2.03E-17	2.51E-17
Cm243	3.49E-14	5.39E-14	5.39E-14		1.02E-17	1.17E-17	1.42E-17
Cm244	0.00E+00	0.00E+00	0.00E+00		9.36E-21	1.36E-20	1.66E-20

* Note that the cited sources provided a dose coefficient for what is labelled 'Hf-178m', but this is in fact for the 31-year half-live Hf-178n excited state.

Table D.72: Dose coefficients associated with inhalation of radionuclides. Dose coefficient values for members of the public are taken from ICRP 119 [284, Tab.G.1] using the inhalation lung clearance type for absorption into the blood (S – slow, M – medium or F – fast) as recommended by the IAEA [289]. Where no lung clearance type recommendation is made by the IAEA [289, Tab.III.2F] or by the EA [241, Tab.B.1], the highest of the available dose coefficients for the relevant radionuclide is assumed. Dose coefficients for implicitly modelled daughters are added to that of their explicitly modelled parent in proportion to the decay chain branching ratios (see Appendix B). The table lists the lung clearance type assumed for the parent radionuclide, but those assumed for the daughters are recorded in the comment column. *Page set to A3 size.*

Radionuclide	Inhalation (Sv Bq^{-1})				
	Adult	Child	Infant	Lung Clearance Type	Comment
H3	4.50E-11	8.20E-11	2.70E-10	M	
C14	2.00E-09	2.80E-09	6.60E-09	M	
Cl36	7.30E-09	1.00E-08	2.60E-08	M	IAEA [289, Tab.III.2F] does not recommend a lung clearance type, so value of M taken from EA [241, Tab.B.1].
Ca41	9.50E-11	1.70E-10	2.60E-10	M	IAEA [289, Tab.III.2F] does not recommend a lung clearance type, so value of M taken from EA [241, Tab.B.1].
Fe55	3.80E-10	6.20E-10	1.40E-09	M	
Co60	1.00E-08	1.50E-08	3.40E-08	M	
Ni59	1.30E-10	2.10E-10	6.20E-10	M	
Ni63	4.80E-10	7.00E-10	1.90E-09	M	
Sr90	3.75E-08	5.37E-08	1.19E-07	M	Y-90 - IAEA [289, Tab.III.2F] does not recommend a lung clearance type, so value of S taken from EA [241, Tab.B.1].
Zr93	1.00E-08	4.10E-09	3.10E-09	M	
Nb93m	5.10E-10	8.20E-10	2.40E-09	M	
Nb94	1.10E-08	1.60E-08	3.70E-08	M	
Tc99	4.00E-09	5.70E-09	1.30E-08	M	
Cd113m	1.10E-07	1.30E-07	2.70E-07	F	IAEA [289, Tab.III.2F] does not recommend a lung clearance type and no value given in EA [241, Tab.B.1]. Highest adult dose coefficient value reported in ICRP 119 [284, Tab.G.1] assumed.
Sn121m	4.68E-09	6.68E-09	1.59E-08	M	Sn121m and Sn121 - IAEA [289, Tab.III.2F] does not recommend a lung clearance type and no value given in EA [241, Tab.B.1]. Highest adult dose coefficient value reported in ICRP 119 [284, Tab.G.1] assumed.
Sb125	5.59E-09	7.91E-09	1.85E-08	M	Lung clearance type of M recommend in IAEA [289, Tab.III.2F] for Te.
I129	3.60E-08	6.70E-08	8.60E-08	F	
Cs134	6.60E-09	5.30E-09	7.30E-09	F	
Cs137	4.60E-09	3.70E-09	5.40E-09	F	No dose coefficient values for Ba-137 presented in ICRP 119 [284, Tab.G.1].
Ba133	3.10E-09	5.10E-09	1.00E-08	M	
Sm151	4.00E-09	4.50E-09	1.00E-08	M	Only dose coefficients for lung clearance type M are presented in ICRP 119 [284, Tab.G.1].
Eu152	4.20E-08	4.90E-08	1.00E-07	M	Only dose coefficients for lung clearance type M are presented in ICRP 119 [284, Tab.G.1].
Eu154	5.30E-08	6.50E-08	1.50E-07	M	Only dose coefficients for lung clearance type M are presented in ICRP 119 [284, Tab.G.1].
Eu155	6.90E-09	9.20E-09	2.30E-08	M	Only dose coefficients for lung clearance type M are presented in ICRP 119 [284, Tab.G.1].
Hf178n	2.60E-07	3.10E-07	5.80E-07	F	Hf178n - IAEA [289, Tab.III.2F] does not recommend a lung clearance type and no value given in EA [241, Tab.B.1]. Highest adult dose coefficient value reported in ICRP 119 [284, Tab.G.1] assumed (only F and M data are presented). No data presented for Hf178m.
Pt193	2.10E-11	4.30E-11	1.60E-10	F	Only dose coefficients for lung clearance type F are presented in ICRP 119 [284, Tab.G.1].
Tl204	3.90E-10	8.80E-10	3.30E-09	F	Only dose coefficients for lung clearance type F are presented in ICRP 119 [284, Tab.G.1].
Pb210	9.99E-06	1.32E-05	3.23E-05	S	
Ra226	3.53E-06	4.94E-06	1.11E-05	M	M lung clearance type recommended for Ra-226; S for Pb-214. No recommendation in IAEA [289, Tab.III.2F] or EA [241, Tab.B.1] for Bi-214, so highest dose coefficient value assumed (M type). Rn-222, Po-218, At, 218, Rn-218, Tl-210, Po-214 - no dose coefficient values presented in ICRP 119 [284, Tab.G.1].
Ra228	2.63E-06	4.66E-06	1.02E-05	M	M lung clearance type recommended for Ra-228. No lung clearance type recommended in IAEA [289, Tab.III.2F] or EA [241, Tab.B.1] for Ac-228, so highest dose coefficient value assumed (F type).
Ac227	5.67E-04	7.44E-04	1.65E-03	F	Ac-227 - no lung clearance type recommended in IAEA (2014, Table III.2F) or EA [241, Tab.B.1]; highest dose coefficient value assumed (F-type). Lung clearance type S recommended in IAEA [289, Tab.III.2F] (Th-227); type M for Ra-223 and Pb-211. Fr-223 - only F-type data

Radionuclide	Inhalation (Sv Bq^{-1})				
	Adult	**Child**	**Infant**	**Lung Clearance Type**	**Comment**
					presented in ICRP 119 [284, Tab.G.1]. No data presented in ICRP 119 [284, Tab.G.1] for At-219, Rn-219, Bi-215, Bi-211, Tl-207 and Po-211.
Th228	4.32E-05	5.92E-05	1.39E-04	S	Bi-212 - no lung clearance type recommended in IAEA [289, Tab.III.2F] or EA [241, Tab.B.1]; highest dose coefficient value assumed (M type). Lung clearance type S recommended in IAEA [289, Tab.III.2F] (Th-228); type M for Ra-224 and Pb-212. No data presented in ICRP 119 [284, Tab.G.1] for Rn-220, Po-216, Po-212 and Tl-208.
Th229	8.58E-05	1.10E-04	2.31E-04	S	Lung clearance type S recommended in IAEA [289, Tab.III.2F] (Th-229); type M for Ra-225 and Pb-209. EA [241, Tab.B.1] recommends S-type for Ac-225 and M-type for Bi-213. No data presented in ICRP 119 [284, Tab.G.1] for Fr-221, At-217, Rn-217, Po-213 and Tl-209.
Th230	1.40E-05	1.60E-05	3.50E-05	S	
Th232	2.50E-05	2.60E-05	5.00E-05	S	
Pa231	1.40E-04	1.50E-04	2.30E-04	M	IAEA [289, Tab.III.2F] does not recommend a lung clearance type and no value given in EA [241, Tab.B.1]. Highest adult dose coefficient value reported in ICRP 119 [284, Tab.G.1] assumed (M-type).
U233	3.60E-06	4.90E-06	1.10E-05	M	
U234	3.50E-06	4.80E-06	1.10E-05	M	
U235	3.10E-06	4.30E-06	1.00E-05	M	Th-231 - IAEA [289, Tab.III.2F] recommends S-type.
U236	3.20E-06	4.50E-06	1.00E-05	M	
U238	7.72E-09	1.10E-08	3.11E-08	M	IAEA [289, Tab.III.2F] recommends S-type for Th-234 and M-type for U-238. Pa-234 - IAEA [289, Tab.III.2F] does not recommend a lung clearance type and no value given in EA [241, Tab.B.1], so highest adult dose coefficient value reported in ICRP 119 assumed (S-type). No data presented in ICRP 119 [284, Tab.G.1] for Pa-234m.
Np237	2.30E-05	2.20E-05	4.00E-05	M	IAEA [289, Tab.III.2F] recommends M-type for Np-237. Pa-233 - IAEA [289, Tab.III.2F] does not recommend a lung clearance type and no value given in EA [241, Tab.B.1], so highest adult dose coefficient value reported in ICRP 119 [284, Tab.G.1] assumed (S-type).
Pu238	4.60E-05	4.40E-05	7.40E-05	M	
Pu239	5.00E-05	4.80E-05	7.70E-05	M	IAEA [289, Tab.III.2F] recommends M-type for Pu-239. No data presented in ICRP 119 [284, Tab.G.1] for U-235m.
Pu240	5.00E-05	4.80E-05	7.70E-05	M	
Pu241	9.00E-07	8.30E-07	9.70E-07	M	IAEA [289, Tab.III.2F] recommends M-type for Pu-241 and U-237.
Pu242	4.80E-05	4.50E-05	7.30E-05	M	
Am241	4.20E-05	4.00E-05	6.90E-05	M	
Am243	4.10E-05	4.00E-05	6.80E-05	M	IAEA [289, Tab.III.2F] recommends M-type for Am-243 and Np-239.
Cm243	3.10E-05	3.10E-05	6.10E-05	M	
Cm244	2.70E-05	2.70E-05	5.70E-05	M	

D.5 Human Intrusion Parameters

D.5.1 SGHWR Region 1

D15 The GIM parameterisation for human intrusion cases 1 – 6 (as defined in Section 7.1) is presented in Table D.73 to Table D.77. Figure D.6 illustrates the layers in GIM that are intruded into by the large, deep ("deep_top" in GIM), pile and borehole intrusions. Table D.78 presents the calculated intersection areas for each intrusion type, and Table D.79 presented the underpinning calculations required to derive these areas (with reference to Figure D.7 and Figure D.8).

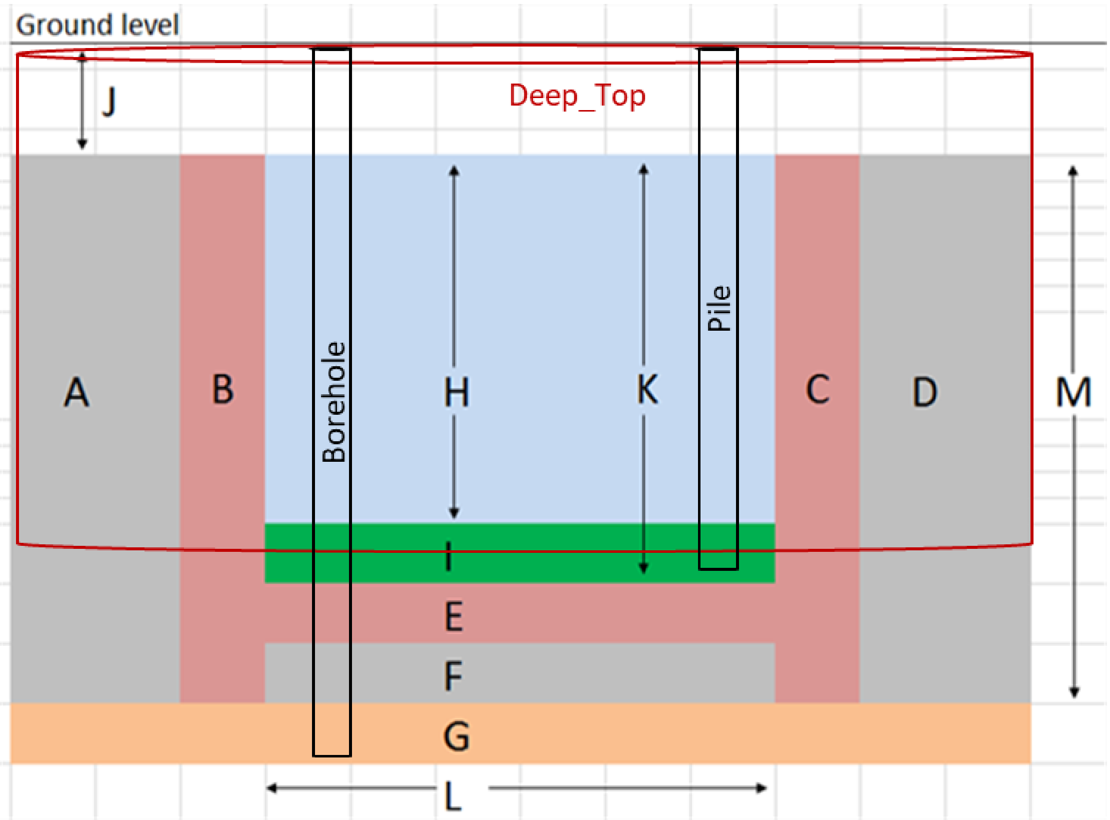

Figure D.6: Cross-section showing the layers intruded into by the large, deep ("deep_top" in GIM), borehole and pile intrusions in intrusion Cases 1, 2, 4 and the first boreholes in Cases 5 and 6.

Table D.73: GIM parameterisation for Cases 1, 2, 4, as described in Table 7.4, and the first borehole (**bold** denotes layers containing inventory). Note this page is set to A3 size.

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**1.55**	**Total thickness of bioshield wall concrete (in Case 2 this includes the mortuary tubes). This thickness varies from 1.22 m to 2.82 m [206, Tab.2.7]. For the PA a thickness of 1.549 m is assumed. As this is also the thickness of activation penetration the activity concentration is assumed to be in this layer and the "lining" layer is not used.**
C+D	**Wall 2**	**1.20**	**Thickness of containment walls (Wall 2 used to represent both primary and secondary containment). For the primary containment this thickness varies from 1.2 m to 1.5 m [210, §4.1.3]. The smallest thickness of this range is conservatively assumed. The secondary containment wall thickness is assumed to also be 1.2 m (as assumed in the Phase 2 PA). This is documented on the NF-Geometry tab.**
B	Wall 1 lining	0.00	Not needed.
C	**Wall 2 lining**	**0.15**	**Depth of penetration of contamination into the containment walls. This comprises 150 mm of concrete and 1 mm of paint [206, §2.12.2].**
I	**Infill**	**11.81**	**Backfill depth. Value here is the depth of the primary containment excluding the floor slab.**
E	**Base lining**	**0.15**	**Contaminated part of the primary containment floor. This comprises 150 mm of concrete and 1 mm of paint [206, §2.12.2]. Note this is only reached by the borehole.**
F	Base concrete	2.59	Uncontaminated part of the primary containment floor. This assumes a total floor depth of 2.74 m [210, §2.3.1].
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	11.81	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	30.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of Region 1 (length calculated to give the R1 plan area in the CSM [210, Tab.606/4] of 1,265 m^2)
L	Base width	42.00	
Total length of wall 1		144.24	This value will not impact the dose calculation in GIM provided it is sufficiently large. The value here is the outer perimeter of Region 1, calculated from the length and width (it is not related to the length of the bioshield wall concrete).
Total length of wall 2		144.24	This value will not impact the dose calculation in GIM provided it is sufficiently large. The value here is the outer perimeter of Region 1, calculated from the length and width (it is not related to the length of the containment wall concrete).

Table D.74: GIM parameterisation for Case 3, as described in Table 7.4, and the second borehole (**bold** denotes layers containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**1.20**	**Total thickness of the secondary containment wall concrete (assumed to be the same as the primary containment walls).**
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	**Wall 1 lining**	**0.20**	**Depth of contamination penetration into secondary containment walls. This varies dependent on the room (between 0.05 and 0.55 m into concrete, 0.02 m into paint, 0.1 to 0.2 m into brick and 0.03 m into fibreglass [210, §4.1]. Assumed 0.2 m (as assumed in [290]).**
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**11.81**	**Backfill depth. This is the depth of the secondary containment, assumed to be from the top of the floor slab (28.8 m AOD) to the ground surface (41.6 m AOD) [210].**
E	**Base lining**	**0.20**	**Contaminated part of the secondary containment floor. This varies dependent on the room (between 0.05 and 0.55 m into concrete, 0.02 m into paint, 0.1 to 0.2 m into brick and 0.03 m into fibreglass [210, §4.1]. Assumed 0.2 m (as assumed in [290]). Note the large, deep intrusion does not reach this, only the borehole.**
F	Base concrete	2.54	Uncontaminated part of the secondary containment floor.
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	11.81	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	30.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of Region 1 (length calculated to give the R1 plan area in the CSM [210, Tab.606/4] of 1,265 m^2).
L	Base width	42.00	
Total length of wall 1		144.24	This value won't impact the dose calculation in GIM provided it is sufficiently large. The value here is the outer perimeter of Region 1, calculated from the length and width.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.75: GIM parameterisation for Case 5/6, as described in Table 7.4, borehole 3 (and Case 5, borehole 4) (bold = layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**6.99**	**Bioshield wall. The depth of contamination penetration into the bioshield walls is large enough that a borehole could go through it without intersecting any clean material. Therefore, no dilution/averaging of the activity concentration is done here. The "infill" layer is used to represent the bioshield wall to ensure the borehole intersects it (the default assumption in GIM is for boreholes not to intrude into walls). Value here is the height of the bioshield [210, §4.1.1].**
E	**Base lining**	**0.15**	**Contaminated part of the primary containment floor. This comprises 150 mm of concrete and 1 mm of paint [206, §2.12.2].**
F	Base concrete	2.59	Uncontaminated part of the primary containment floor. This assumes a total floor depth of 2.74 m [210, §2.3.1].
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	6.99	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	30.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of Region 1 (width from [210, Tab.606/4], length calculated to give the R1 plan area in the CSM [210, Tab.606/4] of 1,265 m^2).
L	Base width	42.00	
Total length of wall 1		0.01	Not needed, but cannot be set to 0 in GIM.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.76: GIM parameterisation for Case 5, as described in Table 7.4, borehole 5/Case 6, borehole 4 (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**9.69**	**Height of the mortuary tubes. These run down the height of the bioshield and extend a further 2.7 m vertically [206, §2.11].**
E	**Base lining**	**0.15**	**Contaminated part of the primary containment floor. This comprises 150 mm of concrete and 1 mm of paint [206, §2.12.2].**
F	Base concrete	2.59	Uncontaminated part of the primary containment floor. This assumes a total floor depth of 2.74 m [210, §2.3.1].
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	9.69	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	30.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of Region 1 (width from [210, Tab.606/4], length calculated to give the R1 plan area [210, Tab.606/4] of 1,265 m^2).
L	Base width	42.00	
Total length of wall 1		0.01	Not needed, but cannot be set to 0 in GIM.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.77: GIM parameterisation for Case 6, as described in Table 7.4, borehole 5 (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**9.69**	**Height of the mortuary tubes. These run down the height of the bioshield and extend a further 2.7 m vertically [206, Section 2.11].**
E	**Base lining**	**0.15**	**Contaminated part of the primary containment floor. This comprises 150 mm of concrete and 1 mm of paint [206, Section 2.12.2].**
F	Base concrete	2.59	Uncontaminated part of the primary containment floor. This assumes a total floor depth of 2.74 m [210, Section 2.3.1].
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	9.69	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg/m3).
G	Bottom layer	0.00	Not needed.
N	Base length	30.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of Region 1 (width from PA input spreadsheet, 'NF - Geometry' tab, cell AI11, length calculated to give the R1 plan area in the CSM [Ref 5, Tab 606/4] of 1,265 m2).
L	Base width	42.00	
Total length of wall 1		0.01	Not needed, but cannot be set to 0 in GIM.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.78: Intersection areas for the scenarios considered – for specification on the 'DiagramsInput' tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Base, overlapping area (m^2)	Wall 1, overlapping area (m^2)	Wall 2, overlapping area (m^2)	Comment
Deep_top (Case 1)	5	314	158.44	31.64	123.92	Wall 1 and wall 2 overlapping areas derived in the calculations below.
Deep_top (Case 2)	5	314	158.44	31.64	123.92	The overlapping areas are the same for the Case 1 intrusion, as the area of the mortuary tubes is assumed to be included in the bioshield area.
Deep_top (Case 3)	5	314	176.19	137.81	0	Wall 1 overlapping area derived below. This assumes the ratio of secondary containment walls:floor is the same as the primary containment.

Table D.79: Calculations to derive the intersection areas.

Parameter	Value	Units	Comment
Primary containment width	18.6	m	[206, Fig.2.17 and 2.18].
Length shown by red arrow in Figure D.7	5.1	m	Calculated values
θ (Figure D.7)	0.54	radians	
2θ	1.07	radians	
Area of circle segment outside of rectangle (intercepting secondary containment)	9.67	m^2	
Area of Case 1 intrusion intersecting primary containment	272.69	m^2	
Primary containment length	23.8	m	[206, Fig.2.17].
Total area of primary containment	442.68	m^2	Calculated
Length of below-ground primary containment walls at 94’ 6” – 109’.	90.1	m	[206, Tab.2.17].
Length of below-ground primary containment walls at 109’ – 132’ 10”.	71.8		[206, Tab.2.17].
Total length of below-ground primary containment walls	161.9	m	The sum of the two lengths above.
Length of primary containment walls intersected by the Case 1 intrusion	99.73	m	Calculated based on the assumption that the fraction of primary containment wall intersected is equivalent to the area fraction of the primary containment that is intersected.
Area of primary containment walls intersected by the Case 1 intrusion	119.68	m^2	Calculated from the length and the wall thickness.
Area of secondary containment walls intersected by the Case 1 intrusion	4.24	m^2	Calculated assuming the same ratio of walls:floor as the primary containment.
Internal diameter of the bioshield	4.95	m	[210, §4.1.1].
Average wall thickness of the bioshield	1.55	m	This thickness varies from 1.22 m to 2.82 m [206, Tab.2.7]. For the PA a thickness of 1.549 m is assumed.
External diameter of the bioshield	8.05	m	Consistent with the internal diameter and the average wall thickness.
Area of the bioshield intersected by the Case 1 intrusion	31.64	m^2	Calculated. This is the total area of the bioshield as the Case 1 intrusion intersects the whole bioshield.
Region 1 total area	1265	m^2	[210, Tab.606/4].
Area of secondary containment walls intersected by Case 5 intrusion	137.81	m^2	Calculated assuming the same ratio of walls:floor as the primary containment.
Fraction of primary containment walls out of total containment walls intersected by Case 1 'Deep top' scenario by area	0.97	-	Fractions required to derive the inventory.
Fraction of secondary containment walls out of total containment walls intersected by Case 1 'Deep top' scenario by area	0.03	-	

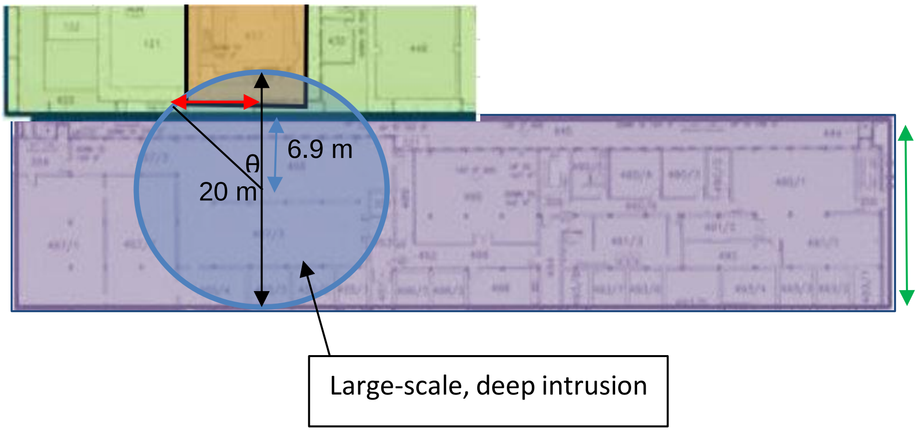

Figure D.7: Representation of the calculation used to derive intersection areas of boreholes into the SGHWR Region 1.

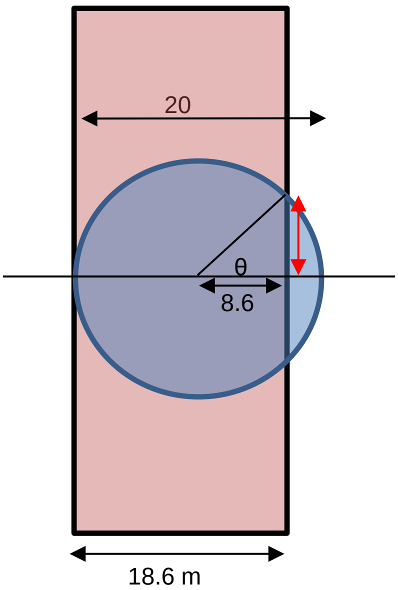

Figure D.8: Representation of the calculation used to derive intersection area for Case 7 (Deep, large-scale intrusion into part of the North Annexe walls and floor, part of the primary containment walls of Region 1, and backfill.

D.5.2 SGHWR North Annexe

D16 The GIM parameterisation for human intrusion cases 7 – 10 (as defined in Table 7.5) is presented in Table D.80 and Table D.81. Figure D.9 and Figure D.10 illustrate the layers in GIM that are intruded into by the large, deep (“deep_top” in GIM), pile and borehole intrusions.

D17 Table D.82 presents the calculated intersection areas for each intrusion type, and Table D.83 presents the underpinning calculations required to derive these areas.

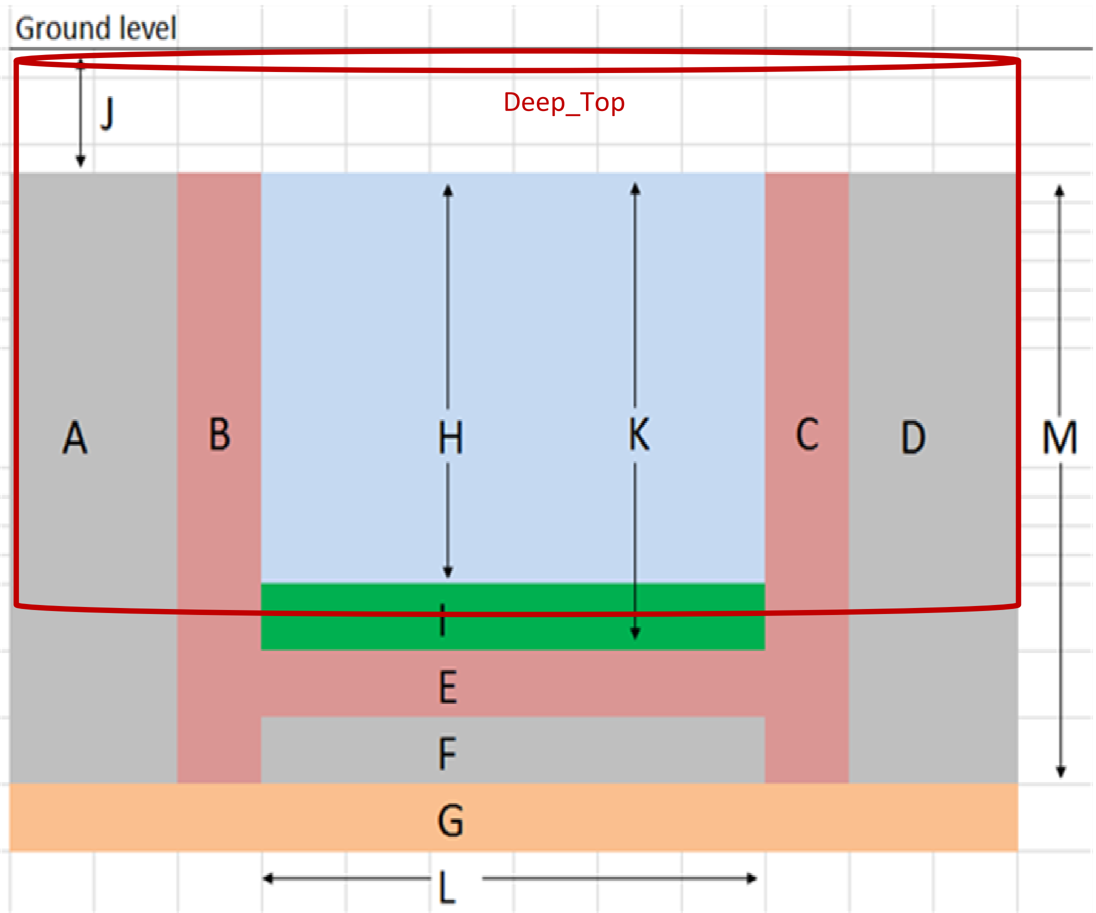

Figure D.9: Cross-section showing the layers intruded into by the deep, large-scale intrusion into the secondary containment (walls and floor) and the backfill (Case 7).

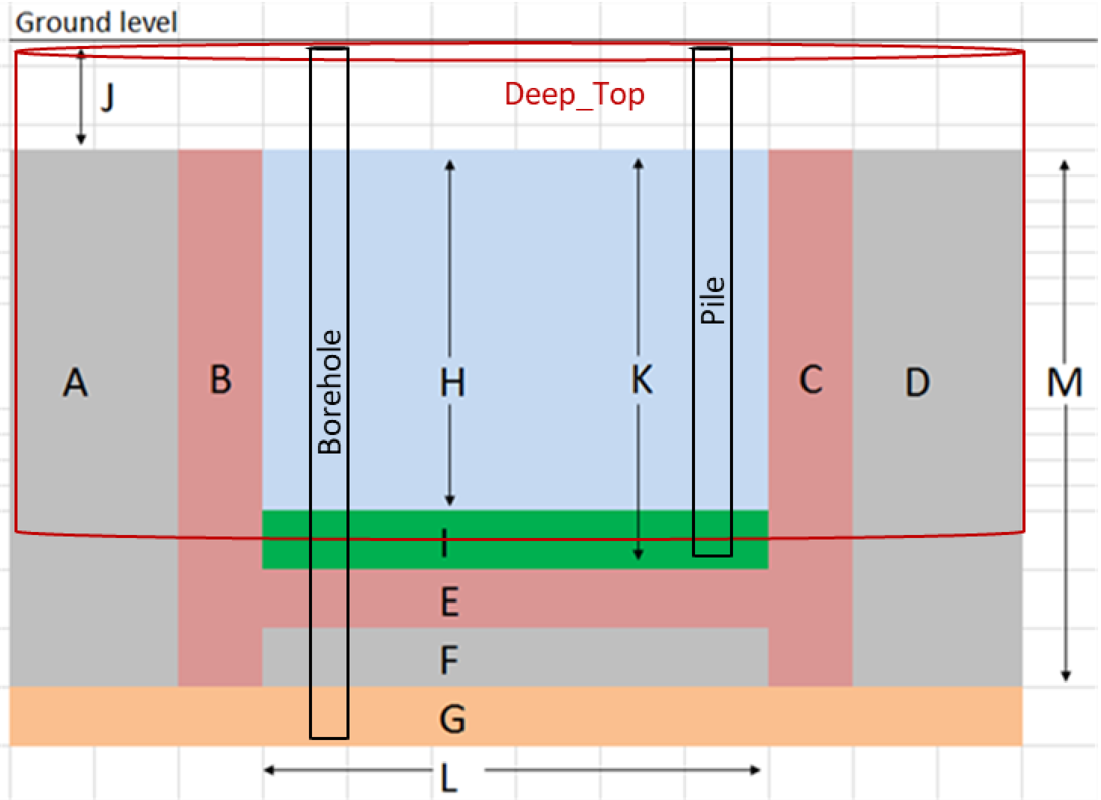

Figure D.10: Cross-section showing the layers intruded into by the deep, large-scale intrusion into part of the North Annexe walls and floor, part of the primary containment walls of Region 1, and backfill. (Cases 8 ,9 and 10).

Table D.80: GIM parameterisation for Case 7, as described in Table 7.5, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**1.20**	**Total thickness of the secondary containment wall concrete. This is assumed to be equal to the thickness of the primary containment wall concrete (as assumed in [290]). The primary containment wall thickness varies from 1.2 m to 1.5 m [210, §4.1.3]. The smallest thickness of this range is conservatively assumed.**
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	**Wall 1 lining**	**0.20**	**Depth of contamination penetration into secondary containment walls. This varies dependent on the room (between 0.05 and 0.55 m into concrete, 0.02 m into paint, 0.1 to 0.2 m into brick and 0.03 m into fibreglass [210, §4.1.4]. Assumed 0.2 m (as assumed in [290]).**
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**2.81**	**Backfill depth. Assumed height of North Annexe.**
E	**Base lining**	**0.20**	**Contaminated part of the secondary containment floor. This varies dependent on the room (between 0.05 and 0.55 m into concrete, 0.02 m into paint, 0.1 to 0.2 m into brick and 0.03 m into fibreglass [210, §4.1.4]. Assumed 0.2 m (as assumed in [290]). Note the large, deep intrusion does not reach this, only the borehole.**
F	Base concrete	0.13	Uncontaminated part of the secondary containment floor. Assumed total floor depth is the depth of the North Annexe floor.
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	2.81	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	19.62	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of the North Annexe (length calculated to give the north annexe plan area in the CSM [210, Tab.606/4] of 1593 m^2).
L	Base width	81.20	
Total length of wall 1		500.00	This value has no impact on the dose calculation in GIM provided it is sufficiently large. Here it is arbitrarily set to 500 to ensure it is sufficiently large to accommodate the intersection area.
Total length of wall 2		201.64	This value has no impact on the dose calculation in GIM provided it is sufficiently large. The value here is approximately the outer perimeter of North Annexe, calculated from the length and width.

Table D.81: GIM parameterisation for Cases 8, 9 and 10, as described in Table 7.5, (**bold** denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**0.30**	**Total thickness of the north annexe walls.**
C+D	**Wall 2**	**1.20**	**Total thickness of the primary containment walls. This varies from 1.2 m to 1.5 m [210, §4.1.3]. The smallest thickness of this range is conservatively assumed.**
B	**Wall 1 lining**	**0.05**	**Depth of contamination penetration into north annexe walls. This varies dependent on the room. Assumed 0.05.**
C	**Wall 2 lining**	**0.15**	**Depth of penetration of contamination into the primary containment walls. This comprises 150 mm of concrete and 1 mm of paint [206, §2.12.2].**
I	**Infill**	**2.81**	**Backfill depth. Calculated assuming a basal floor elevation of 37.8 m AOD for the North Annexe [210, Tab.606/4] and a cutline elevation for SGHWR of 40.61 m AOD.**
E	**Base lining**	**0.05**	**Contaminated part of the north annexe floor. This varies dependent on the room. Assumed 0.05 m.**
F	Base concrete	0.28	Uncontaminated part of the north annexe floor. Assumed a total floor depth of 0.33 m [210, §2.3.3].
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	2.81	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	19.62	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of the North Annexe (length calculated to give the north annexe plan area in the CSM [210, Tab .606/4] of 1593 m^2).
L	Base width	81.20	
Total length of wall 1		500.00	This value will not impact the dose calculation in GIM provided it is sufficiently large. Here it is arbitrarily set to 500 to ensure it is sufficiently large to accommodate the intersection area.
Total length of wall 2		201.64	This value will not impact the dose calculation in GIM provided it is sufficiently large. The value here is approximately the outer perimeter of North Annexe, calculated from the length and width.

Table D.82: Intersection areas for the large, deep scenario – for specification on the 'DiagramsInput' tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Base, overlapping area (m^2)	wall 1, overlapping area (m^2)	wall 2, overlapping area (m^2)	Comment
Deep_Top (Case 7)	5	314	176.19	137.81	0	Calculated assuming the same ratio of secondary containment walls:floor is intersected as for the primary containment in Region 1.
Deep_Top (Case 8)	5	314	168.56	131.84	13.60	Wall 1 and wall 2 overlapping areas derived in the calculations below; remaining area assigned to the base.

Table D.83: Calculations to derive the intersection areas of human intrusion into the North Annexe.

Parameter	Value	Units	Comment
Length of purple arrow in diagram above	10.00	m	The full diameter of the deep_top intrusion is 20 m (GIM assumption). The purple arrow is the radius.
Length of part of north annexe shown in figure (green arrow in diagram)	16.90	m	Length as assumed [290, Fig.7 & 8]. The length calculated in Table D.81 - dimension N, is assumed to be for the longer part of the North Annexe (not shown in the Figure above, but extends 'upwards' in the figure, alongside Region 1).
Length of blue arrow in diagram above	6.90	m	Calculated from lengths above
Length of red arrow in diagram above	7.24	m	Calculated from lengths above
θ	0.81	radians	Calculated from lengths above
2θ	1.62	radians	Calculated from lengths above
Area of Case 8 intrusion outside the north annexe (inside the primary containment)	30.99	m^2	Calculated from lengths above. Note this is a large difference to that calculated in [290] due to the different width of the north annexe.
Total area of primary containment	442.68	m^2	Values taken from calculations for the region 1 intrusions.
Total length of below-ground primary containment walls	161.90	m	
Area of primary containment walls intersected by the Case 8 deep top intrusion	13.60	m^2	Calculated using the above and the assumed primary containment wall thickness.
Total area of north annexe	1593.00	m^2	[210, Tab.606/4].
Fraction of north annexe area that is walls	0.44	-	Assumed to be in the same ratio as the primary containment (this is also the same as assumed for the secondary containment in the region 1 intrusions).
Area of north annexe intersected by the Case 8 deep top intrusion	300.40	m^2	Calculated from the total area of the deep top intrusion and the calculated area intersecting the primary containment.
Area of north annexe walls intersected by the Case 8 deep top intrusion	131.84	m^2	Calculated from the area and fraction above.

D.5.3 SGHWR Region 2 and South Annexe

D18 The GIM parameterisation for human intrusion cases 11 – 15 (as defined in Table 7.5) is presented in Table D.84, Table D.85 and Table D.86. Figure D.11 and Figure D.12 illustrate the layers in GIM that are intruded into by the large, deep (“deep_top” in GIM), pile and borehole intrusions.

D19 Table D.87 presents the calculated intersection areas for each intrusion type, and Table D.88 presents the underpinning calculations required to derive these areas.

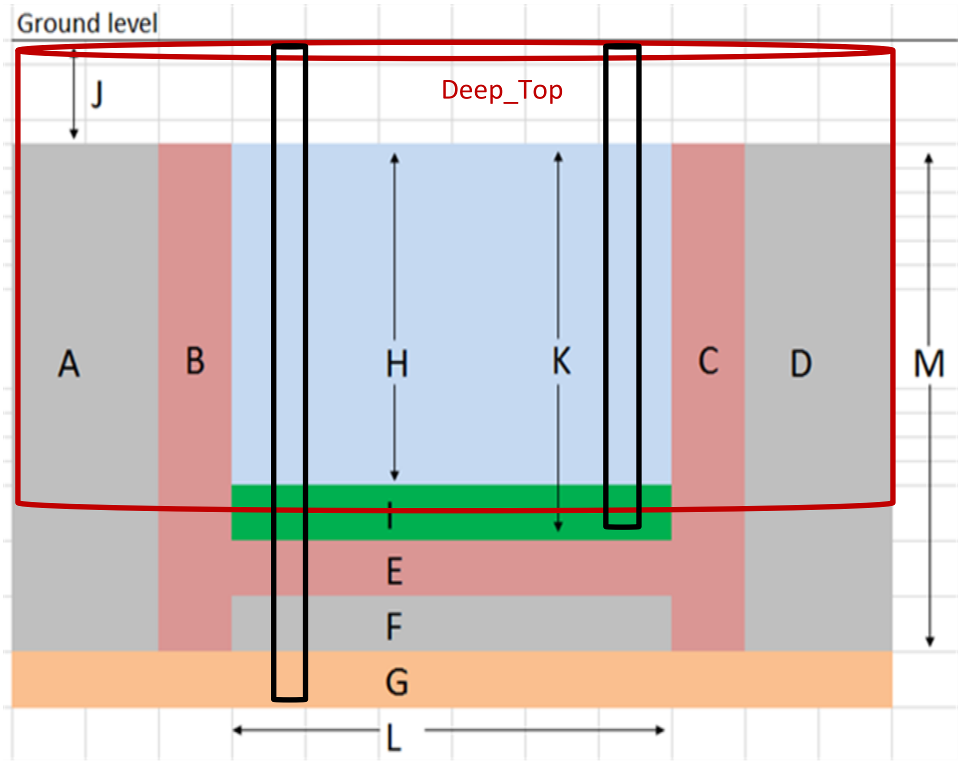

Figure D.11: Cross-section showing the layers intruded into by the deep, large-scale intrusion into the South Annexe (walls and floor) and the backfill (Cases 11, 12 and 13).

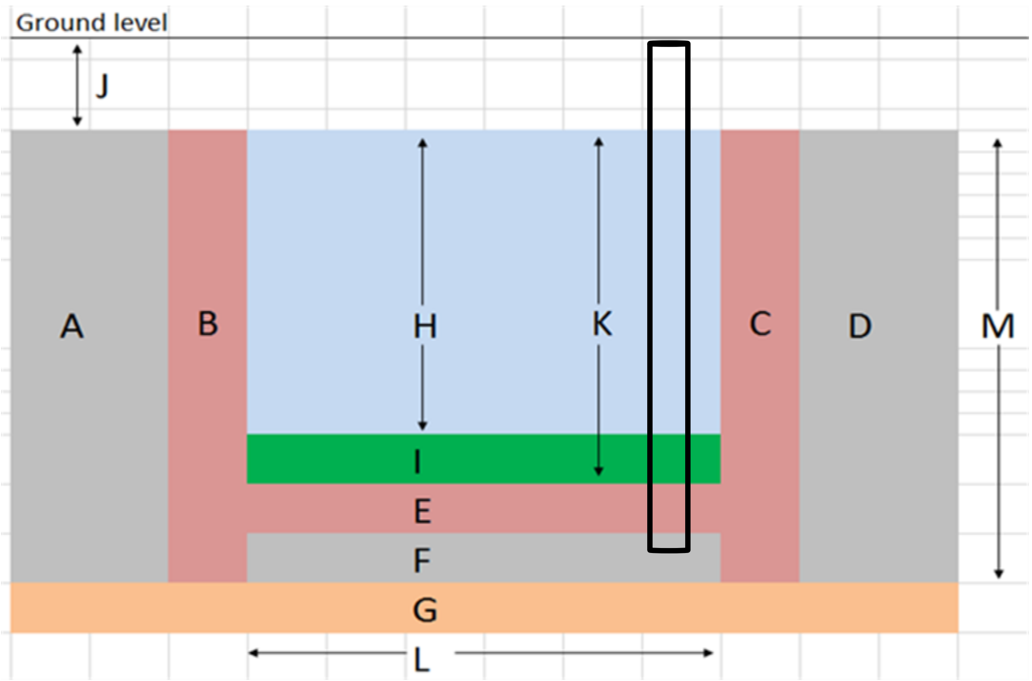

Figure D.12: Cross-section showing the layers intruded into piles into the secondary containment (Case 14).

Table D.84: GIM parameterisation for Cases 11, 12 and 13 as described in Table 7.6, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**0.30**	**Total thickness of the south annexe walls.**
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	**Wall 1 lining**	**0.05**	**Depth of contamination penetration into south annexe walls. This varies dependent on the room. Assumed 0.05.**
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**5.21**	**Backfill depth. Calculated assuming a basal floor elevation of 35.4 m AOD for the South Annexe [210, Tab.606/4] and a cutline elevation for SGHWR of 40.61 m AOD. Assumed the floor elevation of the majority of the south annexe; the pump pit has an elevation of 36.6 m AOD but is a very small portion of the total area of the south annexe. This is conservative for the borehole intrusions and does not make a difference for the large, deep and pile intrusions.**
E	**Base lining**	**0.05**	**Contaminated part of the south annexe floor. This varies dependent on the room. Assumed 0.05 m.**
F	Base concrete	0.18	Uncontaminated part of the south annexe floor. The total base slab thickness varies from 0.23 m to 0.53 m [210, §2.3.4); the minimum thickness is assumed here.
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	5.21	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	27.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of the South Annexe (length calculated to give the north annexe plan area in the CSM [210, Tab.606/4] of 2202 m^2).
L	Base width	81.20	
Total length of wall 1		500.00	This value won't impact the dose calculation in GIM provided it is sufficiently large. Here it is arbitrarily set to 500 to ensure it is sufficiently large to accommodate the intersection area.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.85: GIM parameterisation for Case 14, which is described in Table 7.6 (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**5.21**	**Backfill depth. Calculated assuming a basal floor elevation of 35.4 m AOD for the South Annexe [210 Tab.606/4] and a cutline elevation for SGHWR of 40.61 m AOD.**
E	**Base lining**	**0.20**	**Contaminated part of the secondary containment floor. This varies dependent on the room (between 0.05 and 0.55 m into concrete, 0.02 m into paint, 0.1 to 0.2 m into brick and 0.03 m into fibreglass [210, §4.1.4]. Assumed 0.2 m (as assumed in [290]). Note the large, deep intrusion does not reach this, only the borehole.**
F	Base concrete	1.48	Uncontaminated part of the secondary containment floor. Total floor depth assumed to be the Region 2 floor depth.
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	5.21	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	27.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of the South Annexe (length calculated to give the South Annexe plan area in the CSM [210, Tab.606/4] of 2,202 m^2).
L	Base width	81.20	
Total length of wall 1		0.01	Not needed, but cannot be set to 0 in GIM.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.86: GIM parameterisation for Case 15, Table 7.6, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**10.01**	**Backfill depth. Calculated assuming a basal floor elevation of 30.6 m AOD for the Delay Tank Room in Region 2 [210, Fig.606/4] and a cutline elevation for SGHWR of 40.61 m AOD.**
E	**Base lining**	**0.20**	**Contaminated part of the secondary containment floor. This varies dependent on the room (between 0.05 and 0.55 m into concrete, 0.02 m into paint, 0.1 to 0.2 m into brick and 0.03 m into fibreglass [210, §4.1.4]. Assumed 0.2 m (as assumed in [290]). Note the large, deep intrusion does not reach this, only the borehole.**
F	Base concrete	1.48	Uncontaminated part of the secondary containment floor. Total floor depth assumed to be the Region 2 floor depth.
H	Clean backfill	0.00	There is no clean backfill.
K	Cavity	10.01	The sum of layers H and I.
J	Burial depth	2.25	This layer is used to represent the cap (there is no additional clean cover other than the cap). SGHWR cap thickness to be considered in the PA are 2.25 m, 3.0 m and 4.0 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	27.12	These values have no impact on the dose calculated in GIM provided they are sufficiently large. Here they are set equal to the length and width of the perimeter of the South Annexe (length calculated to give the north annexe plan area in the CSM [210, Tab.606/4] of 2202 m^2).
L	Base width	81.20	
Total length of wall 1		0.01	Not needed, but cannot be set to 0 in GIM.
Total length of wall 2		0.01	Not needed, but cannot be set to 0 in GIM.

Table D.87: Intersection areas for the large, deep scenario – Region 2 and South Annexe – for specification on the ‘DiagramsInput’ tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Base, overlapping area (m^2)	wall 1, overlapping area (m^2)	wall 2, overlapping area (m^2)	Comment
Deep_Top (Case 11)	5	314	176.19	137.81	0	Wall 2 is unused. Wall 1 overlapping area is derived below; the remaining area is assumed to be the base.

Table D.88: Calculations to derive the intersection areas of Region 2 and South Annexe.

Parameter	Value	Units	Comment
South Annexe total area	2202	m^2	[210, Tab.606/4].
Fraction of south annexe intersected by the Case 10 ‘Deep top’ intrusion	0.14	-	Calculated
Fraction of south annexe area that is walls	0.44	-	Assumed to be in the same ratio as the north annexe (which is also the same as is assumed for the primary and secondary containment).
Area of north annexe walls intersected by Case 10 deep top intrusion	137.81	m^2	Calculated from the total area and the two fractions above.

D.5.4 Dragon Reactor

D20 The GIM parameterisation for human intrusion cases 16 – 23 (as defined in Section 7.1) is presented in Table D.89, Table D.90, Table D.91 and Table D.92. Figure D.13 illustrates the pile, borehole, deep top and small top intrusions modelled into the Dragon reactor. Figure D.15 illustrates a plan view of the small intrusion into the Dragon reactor. Table D.93 presents the calculated intersection areas for each intrusion type, and Table D.94 presents the underpinning calculations required to derive these areas.

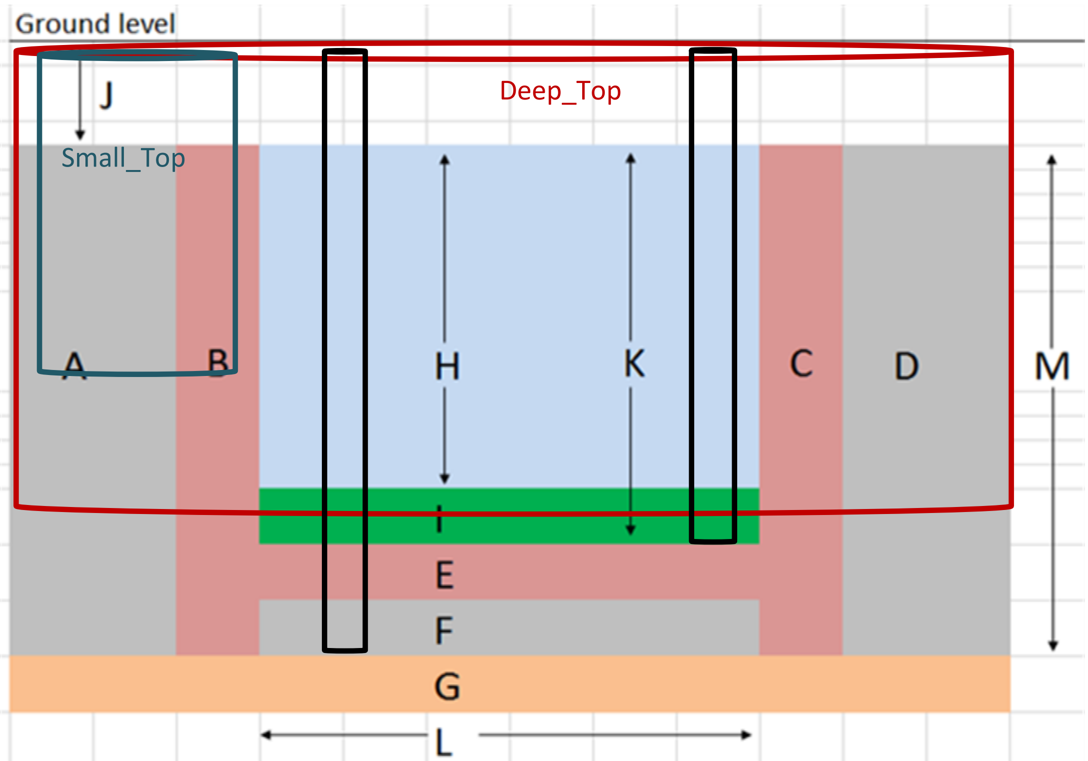

Figure D.13: Cross-section showing the layers intruded into, both piles and boreholes, into the Dragon reactor (Cases 16 – 23).

Table D.89: GIM parameterisation for Cases 16, 17, 18, 19 and 20 as described in Table 7.7, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**1.75**	**Total thickness of the bioshield wall concrete [206, Tab 3.1].**
C+D	**Wall 2**	**0.39**	**This layer is used to model the general building contamination. See calculations for derivation of thickness assumed to give an appropriate ratio of contaminated:uncontaminated concrete.**
B	**Wall 1 lining**	**0.50**	**Depth of penetration of bioshield inventory [206, §3.4.3].**
C	**Wall 2 lining**	**0.0021**	**Depth of penetration into the general B70 building contamination [224, DragonBuilding-GeneralArea tab cell AK326].**
I	**Infill**	**7.71**	**Backfill depth. Difference between the top elevation and floor slab elevation.**
E	**Base lining**	**0.0021**	**General building contamination in the floor slab – only the borehole scenario will intersect this.**
F	Base concrete	3.70	Total thickness of the floor slab [210, §2.2.2].
H	Clean backfill	0.00	No clean backfill present.
K	Cavity	7.71	The sum of layers H and I.
J	Burial depth	1.50	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	20.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are set equal to the diameter of the circular large, deep intrusion.
L	Base width	20.00	
Total length of wall 1		300.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300.
Total length of wall 2		300.00	

Table D.90: GIM parameterisation for Case 21, as described in Table 7.7 (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**7.71**	**Backfill depth. Difference between the top elevation and floor slab elevation.**
E	**Base lining**	**0.01**	**Depth of contamination penetration of the purge gas pre-cooler contaminated water leak [206, §3.6.3].**
F	Base concrete	3.69	Uncontaminated part of the floor slab (total thickness of the floor slab is 3.7 m [210, §2.2.2]).
H	Clean backfill	0.00	No clean backfill present.
K	Cavity	7.71	The sum of layers H and I.
J	Burial depth	1.50	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	20.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are set equal to the diameter of the circular large, deep intrusion.
L	Base width	20.00	
Total length of wall 1		300.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300.
Total length of wall 2		300.00	

Table D.91: GIM parameterisation for Case 22, as described in Table 7.7, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**7.71**	**Backfill depth. Difference between the top elevation and floor slab elevation (calculated in [290]).**
E	**Base lining**	**0.01037**	**Depth of contamination penetration of the Betalite store [224, DragonBuilding-GeneralArea tab, cell AM326].**
F	Base concrete	3.04	Total thickness of the Betalite store is 3.048 m [224, DragonBuilding-GeneralArea tab, cell C268]. Value here is the total thickness minus the contaminated depth.
H	Clean backfill	0.00	No clean backfill present.
K	Cavity	7.71	The sum of layers H and I.
J	Burial depth	1.50	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	20.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are set equal to the diameter of the circular large, deep intrusion.
L	Base width	20.00	
Total length of wall 1		300.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300.
Total length of wall 2		300.00	

Table D.92: GIM parameterisation for Case 23, borehole 1 as described in Table 7.7, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	**Infill**	**7.17**	**Bioshield wall.**
E	**Base lining**	**0.00210**	**General building contamination in the floor slab.**
F	Base concrete	3.70	Uncontaminated part of the floor slab (total thickness of the floor slab is 1.5 m [210, §2.2.2]).
H	Clean backfill	0.00	No clean backfill present.
K	Cavity	7.17	The sum of layers H and I.
J	Burial depth	1.50	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	20.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are set equal to the diameter of the circular large, deep intrusion.
L	Base width	20.00	
Total length of wall 1		300.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300 m.
Total length of wall 2		300.00	

Table D.93: Intersection areas for the large, deep scenario – for specification on the 'DiagramsInput' tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Base, overlapping area (m^2)	wall 1, overlapping area (m^2)	wall 2, overlapping area (m^2)	Comment
Deep_top (Case 16)	5	314	219.53	35.66	58.80	Calculated assuming the whole bioshield is excavated and the ratios of general building contamination to infill derived below.
Large_top (Case 17)	2	300	208.49	35.66	55.85	
Small_top (Case 18)	2	5	0	5	0	The small, shallow intrusion solely excavates the bioshield wall.

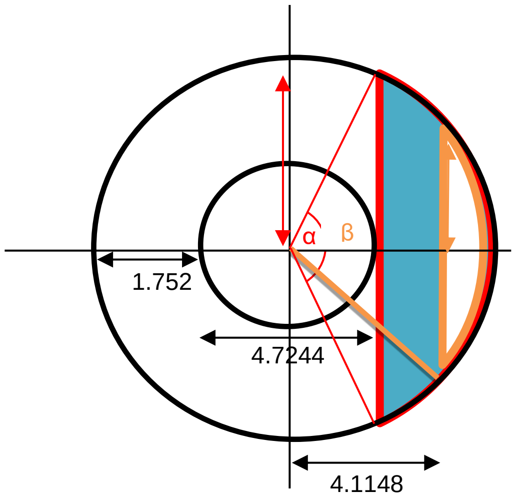

Figure D.14: A plan schematic of the Dragon bioshield. The blue shaded area illustrates the small intrusion (Case 18). Note the calculations show that the small intrusion fits fully within the bioshield wall (assuming the intrusion is a 5 m^2 area that is not necessarily rectangular).

Table D.94: Calculations to derive the intersection areas of human intrusion into the B70 building. *Note this page is set to A3 size.*

Parameter	Value	Units	Comment
Depth of penetration of general B70 building contamination into surfaces	0.00	m	GSL [224, DragonBuilding-GeneralArea tab cell AK326]. Note for tritium this is 0.3 m; however, to model it in GIM it is also assumed to be 0.0021 m.
Surface area of general B70 building surface contamination below the cutline	6458.26	m^2	GSL [224, DragonBuilding-GeneralArea tab cell E261]
Total surface area of B70 building surface contamination	16883.44	m^2	GSL [224, DragonBuilding-GeneralArea tab cell E256]
Surface area of general B70 building surface contamination above the cutline	10425.18	m^2	Calculated
Volume of general B70 building surface contamination below the cutline	13.56	m^3	Calculated
Total volume of general B70 building surface contamination.	35.46	m^3	Calculated
Volume of demolition arisings generated in-situ within and outside of Wall C	4891.00	m^3	[210, Tab.606/7]. This assumes the volume of arisings generated using conventional demolition techniques is 40% greater than the volume of in-situ material and that the volume is reduced on placement by 13% by compaction [206, Tab.2.6].
Volume of demolition arisings generated in-situ within and outside of Wall C prior to placement	5621.84	m^3	Calculated, assuming placement results in 13% volume reduction.
Volume of demolition arisings to be generated in-situ within and outside of Wall C (i.e. prior to being generated).	4015.60	m^3	Calculated, assuming generation results in 40% volume increase.
Proportion of concrete below cutline	0.29	-	GSL [224, DragonBuilding-GeneralArea tab cell N259]
Proportion of concrete above cutline	0.71	-	Calculated.
Ratio of contaminated B70 building concrete to uncontaminated B70 building concrete above cutline.	0.01	-	
Thickness of "Wall 2" to assume to give realistic ratio of contaminated/uncontaminated concrete	0.39	m	
Plan area of the bioshield	35.66	m^2	As calculated in Table D.25.
Total volume of blocks and rubble infill	6544.00	m^3	[210, Tab 606/7].
Approximate volume of in-situ below cutline general building concrete	1645.74	m^3	Calculated from the above cutline volume used to generate demolition arisings and the proportions of concrete above and below the cutline.
Proportion of below cutline general building concrete and infill concrete that is general building concrete.	0.21	-	Calculated in order to assign reasonable intersection fractions for the infill and the general building concrete.
Proportion of below cutline general building concrete and infill concrete that is infill concrete.	0.79	-	
Inner diameter of bioshield	4.72	m	As defined in [224].
Outer diameter of bioshield	8.23	m	
Width of 'small top' intrusion	1.00	m	Assumed.
Length of green arrow in diagram 1.	2.37	m	Calculated as represented in Figure D.14.
Length of red arrow in diagram 1.	3.37	m	
Angle α	1.92	radians	
Angle β	1.23	radians	
Area of red segment	8.28	m^2	
Area of green segment	2.43	m^2	
Area of 'small top' intrusion intersecting bioshield wall	5.00	m^2	
Area of 'small top' intrusion intersecting backfill	0.00	m^2	

D.5.5 Dragon B78

D21 Table D.95 presents the calculated intersection areas for each intrusion type into the Dragon B78 area. The GIM parameterisation for human intrusion cases 24 – 26 (as defined in Section 7.1) is presented in Table D.96.

Table D.95: Intersection area for the scenarios considered in Dragon B78 human intrusion cases - for specification on the 'DiagramsInput' tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Base, overlapping area (m^2)	wall 1, overlapping area (m^2)	wall 2, overlapping area (m^2)	Comment
Deep_top (Case 24)	5	314	314	0	0	The walls are not needed to model the B78 floor slab; the total excavation area is into the base.
Large_top (Case 25)	2	300	300	0	0	
Small_top (Case 26)	2	5	5	0	0	

Table D.96: GIM parameterisation for all Dragon B78 human intrusion cases, as described in Table 7.8 (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.01	Not needed, but cannot be set to 0 in GIM.
C+D	Wall 2	0.01	Not needed, but cannot be set to 0 in GIM.
B	Wall 1 lining	0.00	Layer not needed.
C	Wall 2 lining	0.00	Layer not needed.
I	Infill	0.00	Layer not needed.
E	**Base lining**	**0.0021**	**Thickness of contamination penetration into the B78 floor slab [224, 'B78-Building' tab, cell AB142]. Note for tritium this value is 0.15 m, however to model it in GIM it is also assumed to be 0.0021 m.**
F	**Base concrete**	**0.2979**	**Total thickness of the B78 floor slab. This is assumed to be the same as the penetration depth into the walls (0.3 m [206, §3.7.2]), which is largely consistent with diagrams showing the floor slab thickness to vary, but is around 10" [291].**
H	Clean backfill	0.00	No clean backfill present.
K	Cavity	0.00	The sum of layers H and I.
J	Burial depth	1.50	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg/m^{-3}).
G	Bottom layer	0.00	Not needed.
N	Base length	31.53	These values have no impact on the dose calculations provided they are sufficiently large. Here they are defined to give the correct surface area of the floor slab (709.49 m^2 [224, "B78-Building" tab]) assuming the floor slab were rectangular, with the width being the widths of areas E+F [224, "B78-Building" tab].
L	Base width	22.50	
Total length of wall 1		300.00	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300.
Total length of wall 2		300.00	

D.5.6 Dragon Mortuary Holes

D22 The GIM parameterisation for human intrusion cases 33 – 43 (as defined in Section 7.1) is presented in Table D.97 and Table D.98. Figure D.15 illustrates the deep top and small top intrusions modelled into the Dragon mortuary holes, while

D23 Figure D.16 illustrates an example borehole into the mortuary holes. Table D.99 presents the calculated intersection areas for each intrusion type, and Table D.100 presents the parameters required to derive input dimension and intersection areas.

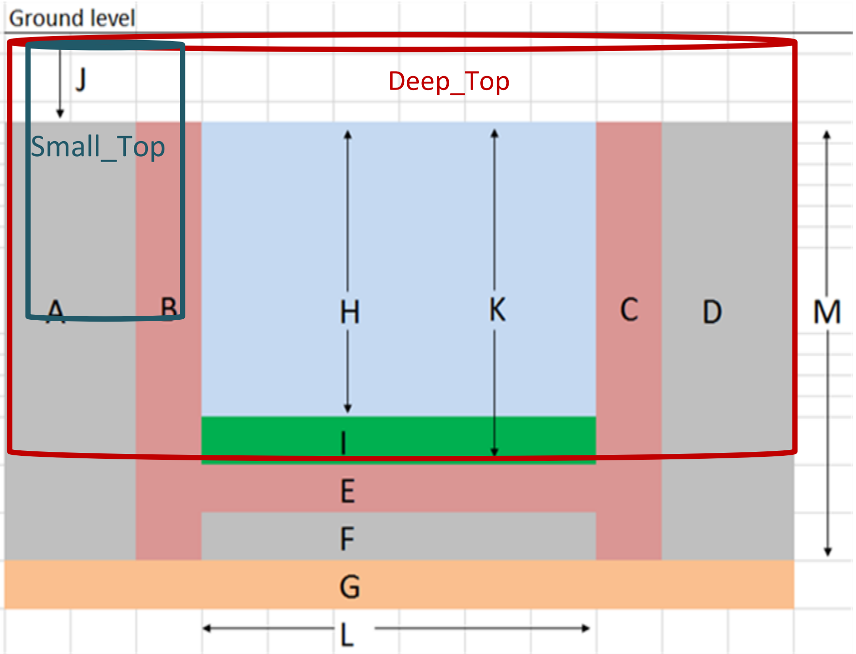

Figure D.15: Cross-section showing the layers intruded into by the deep, large-scale intrusion into the whole mortuary holes structure (Cases 29 – 32).

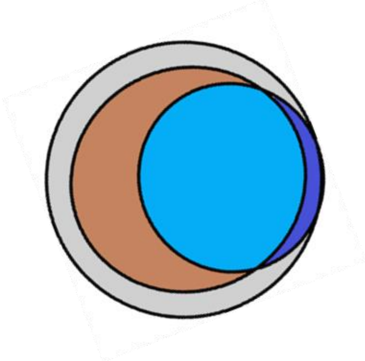

Figure D.16: An example borehole into the mortuary holes: the light blue is intersecting the grout and the dark blue the contaminated steel. This is one of five considered, each intruding into a single mortuary hole and intersection the maximum amount of contaminated metal.

Table D.97: GIM parameterisation for Cases 29, 30 and 31, as described in Table 7.9, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	**Wall 1**	**0.00635**	**Wall thickness of the steel primary mortuary holes.**
C+D	Wall 2	6.401	Concrete structure. There is no logical width - value here is the width of the concrete base; ensured the correct area of concrete is intersected through the specified intersecting area fractions.
B	**Wall 1 lining**	**0.001**	**Depth of contamination penetration into the steel primary mortuary holes [206, §3.9.3].**
C	Wall 2 lining	0.000	Layer not needed.
I	Infill	4.191	Clean grout infill. Value here is the height of the primary mortuary holes [206, Table 3.38].
E	Base lining	0.000	Layer not needed.
F	Base concrete	0.010	Layer not needed but cannot be set to 0 in GIM.
H	Clean backfill	0.000	No clean backfill present (clean grout accounted for in 'infill' layer).
K	Cavity	4.191	The sum of layers H and I.
J	Burial depth	1.500	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.000	Layer not needed.
N	Base length	11.278	Set to the length and width of the concrete base.
L	Base width	7.772	
Total length of wall 1		300.000	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300.
Total length of wall 2		300.000	

Table D.98: GIM parameterisation for Case 32, as described in Table 7.9, (bold denotes the layer containing inventory).

Dimensions in GIM	GIM layer name	Value (m)	Comment
A+B	Wall 1	0.010	Layer not needed but cannot be set to 0 in GIM.
C+D	Wall 2	0.010	Layer not needed but cannot be set to 0 in GIM.
B	Wall 1 lining	0.000	Layer not needed.
C	Wall 2 lining	0.000	Layer not needed.
I	Infill	0.000	Layer not needed.
E	**Base lining**	**0.052**	**Depth of contaminated steel. Thickness calculated to give the maximum possible volume of metal excavated, which is 0.0016 m^3 (Derivation of these two values given in [13, App.A]).**
F	Base concrete	4.139	Total height of the primary mortuary holes is 4.191 m [206, Tab.3.35]. This is the total height minus the contaminated depth.
H	Clean backfill	0.000	No clean backfill present.
K	Cavity	0.000	The sum of layers H and I.
J	Burial depth	1.500	This layer is used to represent the cap (there is no additional clean cover other than the cap). Dragon cap thickness to be considered in the PA are 1.5 m, 2.5 m and 3.8 m. The density of the cap is assumed to be that of soil (1500 kg m^{-3}).
G	Bottom layer	0.000	Layer not needed.
N	Base length	11.278	Set to the length and width of the concrete base.
L	Base width	7.772	
Total length of wall 1		300.000	These values have no impact on the dose calculations provided they are sufficiently large. Here they are arbitrarily set equal to 300.
Total length of wall 2		300.000	

Table D.99: Intersection area for the scenarios considered in Dragon mortuary holes human intrusion cases - for specification on the 'DiagramsInput' tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Base, overlapping area (m^2)	wall 1, overlapping area (m^2)	wall 2, overlapping area (m^2)	Comment
Deep_top (Case 29)	5	314	6.46	0.48	80.71	Derived from the input dimensions and calculations below.
Small_top (Case 30)	2	5	0.37	0.03	4.60	Assumed to intersect some of the steel, grout, and concrete based on the ratio in which they are present.
Large_top (Case 31)	2	300	6.46	0.48	80.71	Derived from the input dimensions and calculations below.

Table D.100: Calculations to derive the intersection areas of Dragon mortuary holes.

Parameter	Value	Units	Comment
Width of primary mortuary hole structure including walls	7.77	m	[224, MortuaryHoles-Inventory tab, cell D153].
Length of primary mortuary hole structure including walls	11.28	m	[224, MortuaryHoles-Inventory tab, cell D154].
Total plan area of mortuary hole structure	87.65	m^2	Calculated from the length and width of the structure.
Total volume of contaminated steel	0.32	m^3	[224, MortuaryHoles-Inventory tab, cell D160].
External diameter of a single primary mortuary hole	0.27	m	[224, MortuaryHoles-Inventory tab, cell D102].
Internal diameter of a single primary mortuary hole	0.26	m	[224, MortuaryHoles-Inventory tab, cell D103].
Total volume of steel	2.03	m^3	Calculated based on the ratio of contaminated:total steel.
Horizontal cross-sectional area of total steel	0.48	m^2	Calculated from the total volume of steel and the height of the mortuary holes.
Total void volume to be filled with grout	27.08	m^3	[224, MortuaryHoles-Inventory tab, cell D148].

D.5.7 A59

D24 The GIM parameterisation for human intrusion cases 33 – 43 (as defined in Section 7.1) is presented in Table D.101, Table D.102, Table D.103 and Table D.104.

D25 Figure D.17 illustrates the orientation and geometry parameters used in pile and borehole intrusions into the A59 area. Table D.105 presents the calculated intersection areas for each intrusion type, and Table D.106 presents the parameters required for averaging the radionuclide inventory.

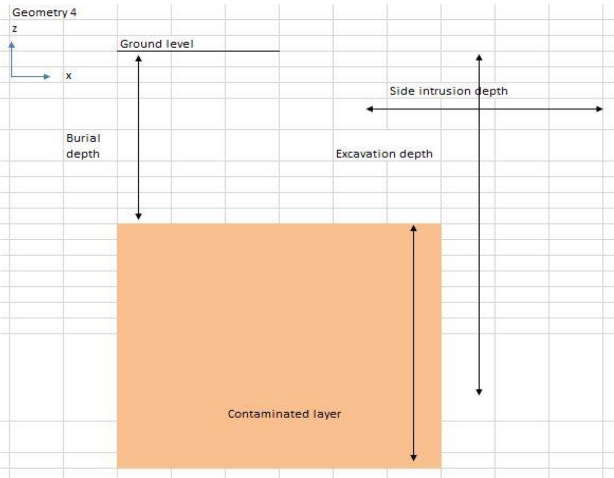

Figure D.17: Cross-section showing the layout of intrusions into the A59 area (Cases 33 – 43).

Table D.101: GIM parameterisation for cases 33-37, and part of case 40, as described in Table 7.10 (29 piles into the other A59 areas). Bold denotes the layer containing inventory.

GIM layer name / required parameter	Value (m)	Comment
Contaminated layer	**2.50**	**Contamination thickness for the "other A59 areas" [225, Tab.4.11].**
Burial depth	0.00	Depth of clean cover material.
Attenuation depth	0.00	Set equal to the burial depth.
Land length	44.35	Calculated from the width of the A59 'other' area and the total plan area [225,Tab 4.11]
Land width	72.80	Width of the A59 'other' area [225, Fig.2.9]

Table D.102: GIM parameterisation for cases 38 and 39, as described in Table 7.11. Bold denotes the layer containing inventory.

GIM layer name / required parameter	Value (m)	Comment
Contaminated layer	**2.96**	**Contamination thickness for case 37 calculated from the volumes of excavated A591/HVA and other A59 areas excavated and the plan area of the deep top intrusion. For case 38 this depth does not matter provided it is larger than 2 m, and so the same value is used as for case 37.**
Burial depth	0.00	Depth of clean cover material.
Attenuation depth	0.00	Set equal to the burial depth.
Land length	44.35	Set equal to the width of the A59 'other' area (calculated from the width of the A59 'other' area and the total plan area [225,Tab.4.11]). The A591/HVA area is smaller, however the length and width of the 'other' area are used to ensure sufficient area is available for the excavation; averaging of the activity concentrations is used to ensure the correct activity is excavated.
Land width	72.80	Set equal to the width of the A59 'other' area [225, Fig.2.9]. The A591/HVA area is smaller, however the length and width of the 'other' area are used to ensure sufficient area is available for the excavation; averaging of the activity concentrations is used to ensure the correct activity is excavated.

Table D.103: GIM parameterisation for cases 41, 42, and part of case 40, as described in Table 7.12 (11 piles into the A591/HVA area).

GIM layer name / required parameter	Value (m)	Comment
Contaminated layer	**4.25**	**Contamination thickness for the A591/HVA area.**
Burial depth	0.00	Depth of clean cover material.
Attenuation depth	0.00	Set equal to the burial depth.
Land length	5.14	Calculated from the width of the A591/HVA area [225, Fig.2.9] and the total plan area.
Land width	15.90	Width of the A591/HVA area [225, Fig.2.9].

Table D.104: GIM parameterisation for case 43 as described in Table 7.12.

GIM layer name / required parameter	Value (m)	Comment
Contaminated layer	**2.50**	**Contamination thickness for the Pit 3-PSA area.**
Burial depth	0.00	Depth of clean cover material.
Attenuation depth	0.00	Set equal to the burial depth.
Land length	31.88	Calculated from the width of the A591/HVA area [225, Fig.2.9] and the total plan area.
Land width	13.80	Width of the A591/HVA area [225, Fig.2.9].

Table D.105: Intersection areas for the scenarios considered - for specification on the 'DiagramsInput' tab in GIM.

Excavation Scenario	Excavation Depth (m)	Excavation area (m^2)	Bottom, overlapping area (m^2)	Comment
Deep_top (Case 33)	5	314	314	The intrusions go solely into the contaminated layer (the 'bottom' layer in GIM for the nuclide input).
Large_top (Case 34)	2	300	300	
Small_top (Case 35)	2	5	5	
Deep_top (Case 38)	5	314	314	
Large_top (Case 39)	2	300	300	
Small_top (Case 41)	2	5	5	
Small_top (Case 43)	2	5	5	

Table D.106: Intersection areas for the scenarios considered - for specification on the 'DiagramsInput' tab in GIM.

Parameter	**Value**	Units	Comment
Volume of A591/HVA area excavated in case 38	347.35	m^3	The whole A591/HVA area is excavated in case 38; calculated from the depth and plan area [225, Tab.4.11].
Volume of other A59 areas excavated in case 38	580.68	m^3	Calculated from the depth of the other A59 areas, and the area of the excavation that is from the other A59 areas (total excavation area minus the total A591/HVA area) [225, Tab.4.11].
Fraction of excavated contaminated material in case 38 that is from the A591/HVA area	0.37	-	Calculated from excavated volumes above.
Fraction of excavated contaminated material in case 38 that is from the other A59 areas	0.63	-	
Volume of A591/HVA area excavated in case 39	347.35	m^3	The whole A591/HVA area is excavated in case 39; calculated from the depth and plan area [225, Tab.4.11].
Volume of other A59 areas excavated in case 39	545.68	m^3	Calculated from the depth of the other A59 areas, and the area of the excavation that is from the other A59 areas (this is the total excavation area minus the total A591/HVA area) [225, Tab.4.11].
Fraction of excavated material in case 39 that is from the A591/HVA area	0.39	-	Calculated from excavated volumes above.
Fraction of excavated material in case 39 that is from the other A59 areas	0.61	-	

D.6 Site Occupancy Parameters

D26 The following figures and tables identify the assumed location of the individual modelled in the site occupancy calculations relative to the feature components.

D.6.2 SGHWR Region 1

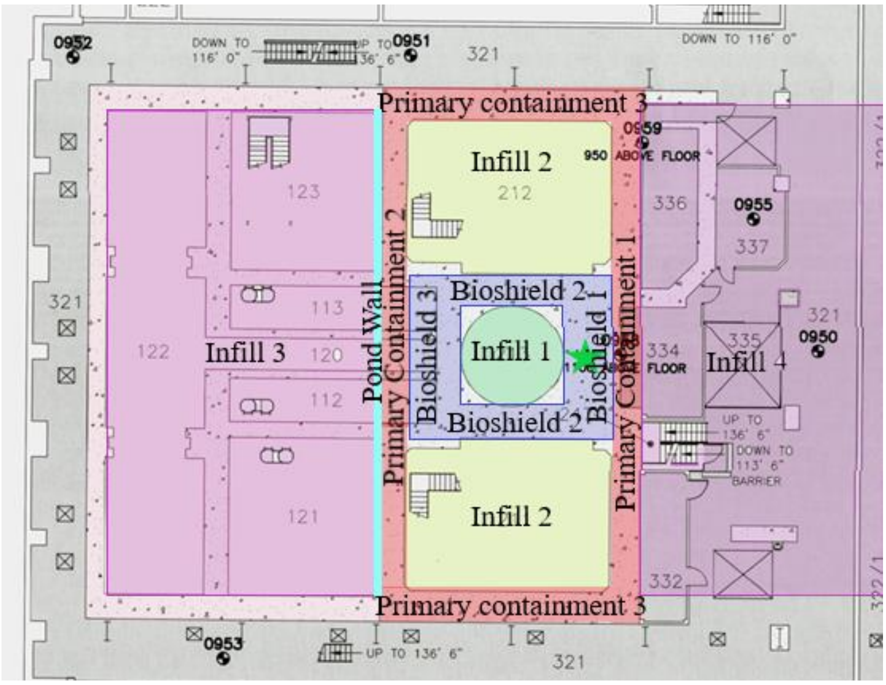

Figure D.18: Assumed location of the individual (green star) relative to Region 1 components**.**

Table D.107: Dimensions of the components comprising Region 1 and the location of the individual relative to Region 1 components[64].

Parameter - Rectangular volume	Length X direction (m)	Height Y direction (m)	Width Z direction (m)	X	Y	Z
Bioshield wall (where individual is located)	6.99	1.55	8.05	7.99	0.77	4.03
Bioshield wall (opposite where individual is located)	6.99	1.55	8.05	7.99	5.73	4.03
Bioshield wall (adjacent where individual is located)	6.99	1.55	4.95	7.99	4.03	0.77

64 Note the X value varies with cover material thickness, X=length + cover material thickness + 1 m (1 m dose point) or 0.02 m (surface dose point). Values presented here are for no cover material and dose point at 1 m.

Parameter - Rectangular volume	Length X direction (m)	Height Y direction (m)	Width Z direction (m)	X	Y	Z
Primary containment (right)	11.81	0.10	23.80	12.81	0.77	11.90
Primary containment (left)	11.81	0.10	23.80	12.81	7.28	11.90
Pond wall	11.81	0.10	23.80	12.81	8.38	11.90
Short primary walls	11.81	0.10	10.36	12.81	11.90	0.77
Bioshield infill	6.99	4.95	4.95	7.99	5.73	2.48
Infill in primary containment	11.81	10.36	7.87	12.81	0.77	11.90
Right infill	11.81	9.75	23.80	12.81	11.73	11.90
Left infill	11.81	13.26	23.80	12.81	21.74	11.90

D.6.3 SGHWR North Annexe

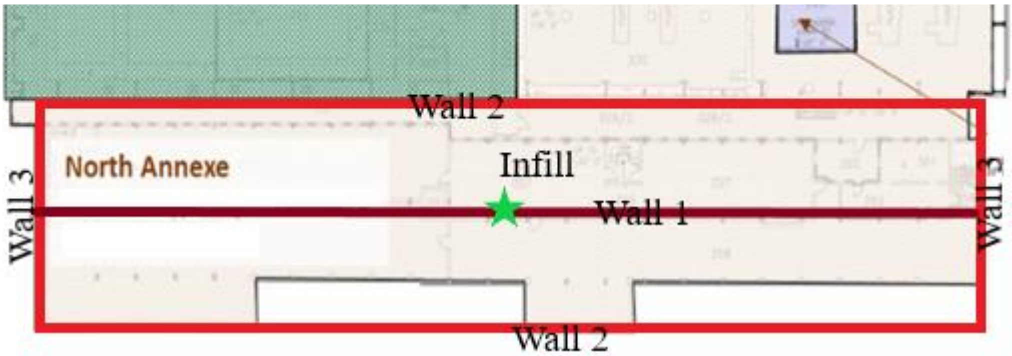

Figure 13.1: Assumed location of the individual (green star) relative to the North Annexe components.

Table D.108: Dimensions of the North Annexe components modelled and location of the modelled individual relative to North Annexe components[64].

Parameter - Rectangular volume	Height X direction (m)	Width Y direction (m)	Length Z direction (m)	X	Y	Z
Infill	2.81	81.20	18.25	3.81	40.60	9.12
Long Ancillary Walls	2.81	0.01	81.20	3.81	9.12	40.60
Middle Ancillary Wall	2.81	0.02	81.20	3.81	0.01	40.60
Short Ancillary Walls	2.81	0.01	18.25	3.81	40.60	9.12

D.6.4 SGHWR South Annexe

Table D.109: Dimensions of the South Annexe modelled components and location of modelled individual relative to South Annexe components. This assumed location of the individual is in the centre of the annexe and assumes a rectangular area for the annexe[64].

Parameter - Rectangular volume	Length X direction (m)	Height Y direction (m)	Width Z direction (m)	X	Y	Z
South Annexe	5.21	81.2	24.82	6.21	40.6	12.41

D.6.5 Dragon Reactor Complex

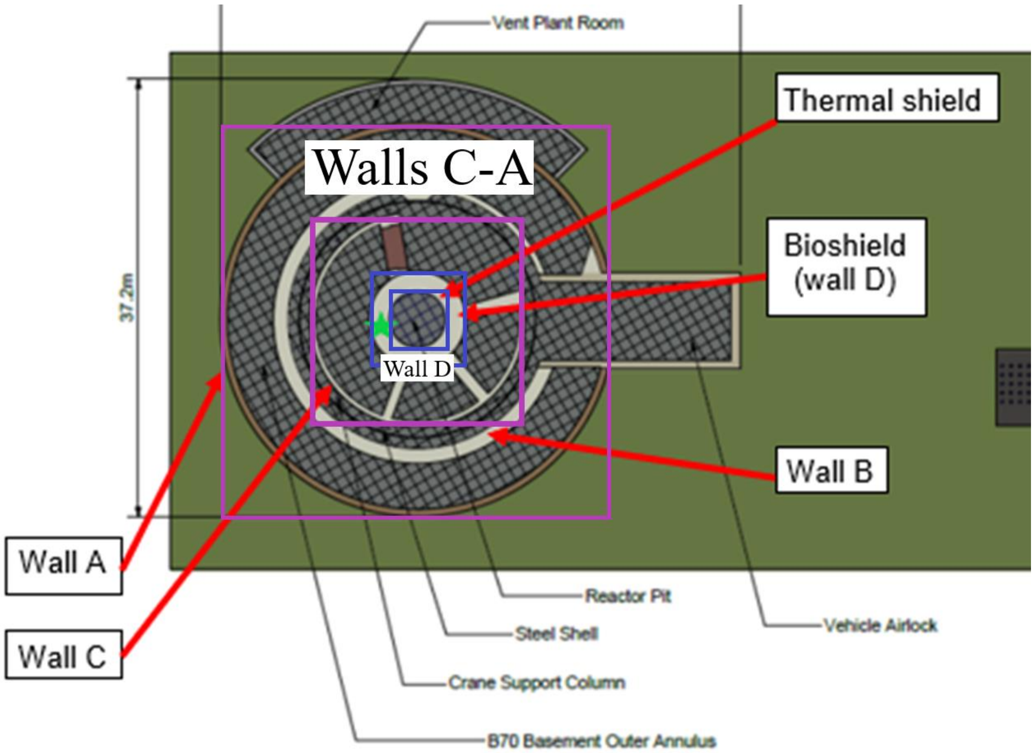

Figure D.19: Assumed location of the individual (green star) relative to the Dragon reactor components.

Table D.110: Dimensions of the modelled components comprising the Dragon reactor (m) and location of the individual relative to Dragon reactor components assuming cover material is present[64].

Parameter - Rectangular volume	Wall D			Infill between Wall D and C			Wall C-A and backfill in void space			Parameter - Cylinder volume	Infill within Wall D
	where individual is located	opposite where individual is located	adjacent to where individual is located	Long wall 1	Long wall 2	Short wall	Long wall 1	Long wall 2	Short wall		
Height (Y direction)	0.5	0.5	0.5	4.57	4.57	4.57	7.01	7.01	7.01	**Height**	7.17
Width (Z direction)	5.72	5.72	4.72	17.37	17.37	8.23	33.53	33.53	19.51	**Radius**	2.36
Length (X direction)	7.17	7.17	7.17	7.17	7.17	7.17	7.17	7.17	7.17	**Wall clad**	0
X	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17	8.17	**Top clad**	1.5, 2.5, 3.8
Y	0.25	4.97	2.86	6.07	11.30	7.43	13.09	18.31	14.44	**X**	8.17
Z	2.86	2.86	4.97	8.69	8.69	1.50	16.76	16.76	6.07	**Y**	2.61
Comment	Cover material cannot be applied to hollow cylindrical volume									**Z**	0

Table D.111: Dimensions of the components comprising the Dragon B78 building and Dragon mortuary holes, and location of the individual relative to each feature. The individual is assumed to be located in the centre of the "pit", assuming a rectangular area[64].

Parameter - Rectangular volume	Length X direction (m)	Height Y direction (m)	Width Z direction (m)	X	Y	Z
B78	0.002	31.53	22.50	1.00	15.77	11.25
Mortuary holes "pit"	4.72	7.77	6.40	5.72	3.89	3.20

D.6.6 A59 Area

Table D.112: Dimensions of the components comprising the OoS A59 area sub-regions, and location of the individual relative to each feature. The individual is assumed to be located in the centre of each area, assuming a rectangular area[64].

Parameter - Rectangular volume	Length X direction (m)	Height Y direction (m)	Width Z direction (m)	X	Y	Z
A591/HVA	4.25	13.8	5.92	5.25	6.9	2.96
A59 Other Areas	2.50	72.8	44.35	3.5	36.4	22.18
PSA/Pit 3	2.50	15.9	27.67	3.5	7.95	13.84

D.7 ERICA Parameters

Table D.113: List of ERICA reference organisms in terrestrial and freshwater ecosystems [292].

Terrestrial	Freshwater
Amphibian	Amphibian
Annelid	Benthic fish
Arthropod – detritivorous	Bird
Bird	Crustacean
Flying insects	Insect larvae
Grasses and Herbs	Mammal
Lichen and Bryophytes	Mollusc – bivalve
Mammal – large	Mollusc – gastropod
Mammal – small, burrowing	Pelagic fish
Mollusc – gastropod	Phytoplankton
Reptile	Reptile
Shrub	Vascular plant
Tree	Zooplankton

Table D.114: Peak environmental activity concentrations and time of peak in the modelled compartments, using the reference inventory, as exported from the natural evolution GoldSim model. The radionuclides are listed in the order they appear in ERICA.

Radio-nuclide	River Water		River Sediment		Field Soil		Mire Water		Mire Soil/Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{227}Ac	3.69E-08	52429	1.77E-03	52644	1.49E-05	53842	1.83E-06	51976	3.10E-03	51976
^{241}Am	1.97E-07	409	1.56E-02	547	2.11E-05	677	1.92E-05	408	5.00E-02	408
^{243}Am	8.09E-17	3370	1.01E-11	3600	3.93E-14	8940	7.38E-15	3355	1.92E-11	3355
^{133}Ba	6.64E-09	7.116	4.31E-07	19	1.99E-09	7.591	9.69E-11	118	3.88E-11	118
^{14}C	3.13E-06	1012	3.50E-03	1210	2.04E-05	1024	2.49E-04	1008	4.14E-03	1008
^{41}Ca	4.99E-06	843	3.85E-03	1145	1.66E-05	847	7.01E-04	830	5.61E-03	830
^{113m}Cd	9.79E-22	164.5	2.40E-22	253	9.42E-21	250	1.76E-19	164	2.64E-17	164
^{36}Cl	1.18E-06	476	1.45E-06	638	3.22E-07	476	9.32E-05	474	2.79E-05	474
^{243}Cm	2.39E-18	232	1.91E-15	265	6.69E-17	270	1.02E-18	291	9.45E-15	291
^{244}Cm	3.00E-12	128	1.59E-09	150.5	5.25E-11	153	4.68E-10	128	4.35E-06	128
^{60}Co	2.65E-13	45	3.47E-10	52	1.21E-12	52	3.72E-11	45	1.79E-08	45
^{134}Cs	1.35E-26	31	1.76E-24	33.5	2.80E-26	34	2.08E-24	31	2.50E-21	31
^{137}Cs	9.66E-11	213	1.50E-07	249	2.65E-09	253	1.31E-08	202	1.57E-05	202
^{152}Eu	3.81E-17	90	5.19E-20	196.5	1.67E-20	197.5	4.09E-21	152	1.23E-17	152
^{154}Eu	1.03E-19	90	1.76E-23	117.5	5.52E-24	119	6.91E-23	90	2.07E-19	90
^{155}Eu	7.69E-28	90.5	0.00E+00	0	1.57E-27	97	1.31E-25	90	3.93E-22	90
^{55}Fe	0.00E+00	0	0.00E+00	0	0.00E+00	0	3.99E-28	102.5	3.51E-25	102.5
^{3}H	1.35E-03	8.717	0.00E+00	0	2.55E-04	9.08	1.91E-01	8.179	1.91E-02	8.179
^{129}I	1.37E-06	514	4.69E-03	631	3.92E-06	518	1.09E-04	485	7.49E-04	485
^{93m}Nb	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0

Radio-nuclide	River Water		River Sediment		Field Soil		Mire Water		Mire Soil/Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{94}Nb	5.69E-10	13700	2.82E-07	13900	3.28E-07	14525	8.98E-08	13700	1.35E-04	13700
^{59}Ni	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
^{63}Ni	1.37E-05	96.5	6.46E-02	153	4.49E-04	149	2.04E-03	96.5	5.72E-01	96.5
^{237}Np	3.34E-10	1051	8.57E-07	741	4.76E-09	1069	4.29E-08	1046	1.50E-06	1046
^{231}Pa	2.26E-08	52581	9.77E-04	52824	1.50E-05	53845	1.87E-06	51968	3.75E-03	51968
^{210}Pb	3.62E-07	58384	1.98E-03	60626	1.37E-04	59878	3.95E-05	57063	7.91E-02	57063
^{238}Pu	4.63E-09	213	9.30E-05	281	2.04E-07	292	5.94E-07	213	4.39E-04	213
^{239}Pu	2.26E-07	335	1.03E-02	507	2.87E-05	606	2.90E-05	334	2.15E-02	334
^{240}Pu	2.44E-07	334	1.10E-02	505	3.05E-05	601	3.13E-05	334	2.32E-02	334
^{241}Pu	4.78E-10	90	2.61E-06	107.5	5.14E-09	108.5	6.14E-08	90	4.55E-05	90
^{242}Pu	1.68E-09	52577	1.06E-04	52791	3.88E-07	53000	1.71E-07	52484	1.26E-04	52484
^{226}Ra	2.05E-07	58366	1.74E-03	61098	1.33E-04	59931	2.43E-05	57398	6.08E-02	57398
^{228}Ra	3.24E-11	56430	5.74E-07	56721	2.45E-09	57697	1.02E-12	61249	2.54E-09	61249
^{125}Sb	2.54E-16	22	2.27E-14	26	6.25E-16	25.5	3.96E-14	22	2.45E-12	22
^{151}Sm	9.98E-18	137	7.00E-14	1031	1.48E-16	1055	3.81E-19	1675	3.54E-16	1675
^{90}Sr	9.03E-06	32.5	1.69E-04	56.5	8.59E-05	47.5	1.43E-03	32.5	7.42E-02	32.5
^{99}Tc	4.84E-07	474	2.19E-06	608	1.18E-07	474	3.83E-05	469	8.82E-06	469
^{228}Th	4.87E-12	56438	5.74E-07	56720	2.45E-09	57697	1.29E-12	61251	2.45E-09	61251
^{229}Th	1.42E-08	58635	1.69E-03	58829	6.18E-06	59558	1.34E-06	58776	2.55E-03	58776
^{230}Th	4.88E-08	63604	5.89E-03	63802	2.31E-05	64649	4.68E-06	63552	8.90E-03	63552
^{232}Th	4.86E-12	56509	5.88E-07	56718	2.27E-09	57771	5.28E-13	61321	1.00E-09	61321
^{204}Tl	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0

Radio-nuclide	River Water		River Sediment		Field Soil		Mire Water		Mire Soil/Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{233}U	1.11E-06	50550	3.55E-05	50650	6.97E-05	50600	1.68E-04	50550	3.35E-02	50550
^{234}U	9.82E-06	57.5	1.54E-04	161	3.55E-04	124.5	1.55E-03	57.5	3.11E-01	57.5
^{235}U	1.01E-06	51167	4.55E-05	51267	7.51E-05	51237	1.49E-04	50600	2.98E-02	50600
^{236}U	4.52E-08	50550	1.45E-06	50650	2.84E-06	50600	6.82E-06	50550	1.36E-03	50550
^{238}U	1.01E-05	57.5	1.58E-04	161	3.64E-04	124.5	1.59E-03	57.5	3.19E-01	57.5
^{93}Zr	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0

Table D.115: Peak environmental activity concentrations and time of peak in the modelled compartments, using the alternative inventory, as exported from the natural evolution GoldSim model. The radionuclides appear in the order they appear in ERCIA, with the default radionuclides listed alphabetically first, followed by the additional radionuclides included at Tier 2.

Radio-nuclide	Field Soil		Mire Water		Mire Soil		River Water		River Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{227}Ac	2.82E-07	52342	1.35E-02	52611	1.15E-04	53896	1.41E-05	51738	2.40E-02	51738
^{241}Am	5.67E-07	422	4.53E-02	560	6.15E-05	693	5.53E-05	421	1.44E-01	421
^{243}Am	2.98E-16	3265	3.72E-11	3480	1.28E-13	4505	2.83E-14	3250	7.36E-11	3250
^{133}Ba	2.07E-08	7.116	1.35E-06	19	6.21E-09	7.591	1.42E-09	118	5.69E-10	118
^{14}C	1.09E-05	1012	1.23E-02	1210	7.13E-05	1024	8.69E-04	1008	1.44E-02	1008
^{41}Ca	7.30E-05	844	5.66E-02	1250	2.43E-04	848	1.04E-02	830	8.33E-02	830
^{113m}Cd	1.08E-21	238	3.26E-22	257	1.28E-20	255	1.76E-19	162.5	2.64E-17	162.5
^{36}Cl	1.28E-06	476	1.57E-06	638	3.49E-07	476	1.00E-04	474	3.01E-05	474
^{243}Cm	3.20E-18	232	2.56E-15	265	8.96E-17	270	2.01E-18	295	1.87E-14	295

Radio-nuclide	Field Soil		Mire Water		Mire Soil		River Water		River Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{244}Cm	9.05E-12	129.5	4.80E-09	152	1.59E-10	154.5	1.41E-09	129.5	1.31E-05	129.5
^{60}Co	3.56E-13	45	4.66E-10	52.5	1.63E-12	52.5	5.01E-11	45	2.40E-08	45
^{134}Cs	3.64E-26	31	4.75E-24	33.5	7.55E-26	34	5.61E-24	31	6.73E-21	31
^{137}Cs	1.82E-10	211	2.82E-07	246	4.97E-09	250	2.59E-08	204	3.11E-05	204
^{152}Eu	3.20E-17	76	1.60E-19	196.5	5.16E-20	197.5	1.39E-20	155	4.17E-17	155
^{154}Eu	1.08E-19	76	4.67E-23	127	1.46E-23	128	1.09E-22	76	3.27E-19	76
^{155}Eu	9.17E-28	76.5	0.00E+00	0	1.97E-27	83.5	1.55E-25	76	4.66E-22	76
^{55}Fe	0.00E+00	0	0.00E+00	0	0.00E+00	0	8.35E-28	105.5	7.34E-25	105.5
^{3}H	2.95E-03	8.298	0.00E+00	0	5.56E-04	8.619	3.79E-01	8.156	3.79E-02	8.156
^{129}I	1.66E-06	507	5.70E-03	626	4.75E-06	511	1.32E-04	478	9.09E-04	478
^{93m}Nb	6.35E-09	62630	8.45E-06	62325	1.55E-06	62352	5.56E-07	61440	8.33E-04	61440
^{94}Nb	5.41E-09	59471	2.69E-06	59666	3.12E-06	60234	7.66E-07	59409	1.15E-03	59409
^{59}Ni	1.27E-08	1595	2.10E-04	1810	1.23E-06	1760	1.89E-06	1590	5.30E-04	1590
^{63}Ni	3.08E-05	106	1.54E-01	166	1.06E-03	161.5	4.60E-03	106	1.29E+00	106
^{237}Np	6.30E-10	1049	2.50E-06	755	9.09E-09	1066	6.80E-08	1046	2.38E-06	1046
^{231}Pa	1.73E-07	52584	7.49E-03	52849	1.16E-04	53894	1.45E-05	51727	2.90E-02	51727
^{210}Pb	2.07E-06	58068	1.13E-02	60262	7.81E-04	59543	2.28E-04	1765	4.56E-01	1765
^{238}Pu	1.34E-08	221	2.71E-04	289	5.95E-07	300	1.71E-06	221	1.27E-03	221
^{239}Pu	9.28E-07	340	4.24E-02	515	1.19E-04	616	1.19E-04	340	8.80E-02	340
^{240}Pu	1.08E-06	340	4.91E-02	512	1.37E-04	609	1.39E-04	339	1.03E-01	339
^{241}Pu	1.07E-09	92	5.85E-06	110	1.15E-08	110.5	1.37E-07	92	1.01E-04	92
^{242}Pu	1.98E-09	52577	1.26E-04	52791	4.59E-07	53001	1.99E-07	52477	1.47E-04	52477

Radio-nuclide	Field Soil		Mire Water		Mire Soil		River Water		River Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{226}Ra	1.17E-06	58032	9.94E-03	60719	7.56E-04	59595	1.38E-04	57025	3.44E-01	57025
^{228}Ra	6.44E-10	56437	1.14E-05	56727	4.87E-08	57702	1.53E-12	61224	3.82E-09	61224
^{125}Sb	1.31E-15	22	1.17E-13	26	3.23E-15	25.5	2.05E-13	22	1.27E-11	22
^{151}Sm	1.00E-17	123	2.19E-13	1031	4.64E-16	1055	5.66E-18	1675	5.26E-15	1675
^{90}Sr	1.75E-05	34	3.36E-04	58	1.69E-04	49	2.76E-03	34	1.44E-01	34
^{99}Tc	6.83E-07	467	3.09E-06	603	1.67E-07	467	5.40E-05	462	1.24E-05	462
^{228}Th	9.67E-11	56441	1.14E-05	56726	4.87E-08	57702	1.94E-12	61226	3.68E-09	61226
^{229}Th	1.54E-08	58614	1.83E-03	58809	6.71E-06	59537	1.45E-06	58775	2.76E-03	58775
^{230}Th	2.75E-07	63190	3.32E-02	63388	1.30E-04	64239	2.63E-05	63123	5.00E-02	63123
^{232}Th	9.67E-11	56514	1.17E-05	56723	4.51E-08	57777	7.94E-13	61296	1.51E-09	61296
^{204}Tl	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
^{233}U	1.20E-06	50550	3.83E-05	50650	7.53E-05	50600	1.81E-04	50550	3.62E-02	50550
^{234}U	1.59E-05	51179	5.66E-04	51286	1.04E-03	51253	1.98E-03	51183	3.96E-01	51183
^{235}U	1.24E-05	50600	5.15E-04	51247	8.60E-04	50700	1.91E-03	50600	3.82E-01	50600
^{236}U	6.80E-08	50550	2.19E-06	50650	4.28E-06	50600	1.03E-05	50550	2.05E-03	50550
^{238}U	1.68E-05	51175	6.04E-04	51281	1.11E-03	51249	2.06E-03	51182	4.12E-01	51182
^{93}Zr	9.09E-09	62096	9.07E-06	62293	1.48E-06	62312	9.90E-07	61433	4.06E-04	61433

Table D.116: Peak environmental activity concentrations and time of peak in the modelled compartments, using the Pu fingerprint alternative inventory for Dragon general building contamination, as exported from the natural evolution GoldSim model. The radionuclides appear in the order they appear in ERCIA, with the default radionuclides listed alphabetically first, followed by the additional radionuclides included at Tier 2.

Radio-nuclide	Field Soil		Mire Water		Mire Soil		River Water		River Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{227}Ac	2.80E-07	52348	1.35E-02	52619	1.14E-04	53915	1.41E-05	51738	2.40E-02	51738
^{241}Am	5.67E-07	421	4.53E-02	560	6.15E-05	693	5.53E-05	421	1.44E-01	421
^{243}Am	2.98E-16	3265	3.72E-11	3480	1.28E-13	4505	2.83E-14	3250	7.36E-11	3250
^{133}Ba	2.07E-08	7.116	1.35E-06	19	6.21E-09	7.591	1.42E-09	118	5.69E-10	118
^{14}C	1.09E-05	1012	1.23E-02	1210	7.13E-05	1024	8.69E-04	1008	1.44E-02	1008
^{41}Ca	7.30E-05	844	5.66E-02	1250	2.43E-04	848	1.04E-02	830	8.33E-02	830
^{113m}Cd	1.08E-21	238	3.26E-22	257	1.28E-20	255	1.76E-19	162.5	2.64E-17	162.5
^{36}Cl	1.88E-06	5.445	2.14E-06	631	5.10E-07	5.849	1.00E-04	474	3.01E-05	474
^{243}Cm	3.20E-18	232	2.56E-15	265	8.96E-17	270	2.01E-18	295	1.87E-14	295
^{244}Cm	9.05E-12	129.5	4.80E-09	152	1.59E-10	154.5	1.41E-09	129.5	1.31E-05	129.5
^{60}Co	3.56E-13	45	4.66E-10	52.5	1.63E-12	52.5	5.01E-11	45	2.40E-08	45
^{134}Cs	3.64E-26	31	4.75E-24	33.5	7.55E-26	34	5.61E-24	31	6.73E-21	31
^{137}Cs	1.83E-10	211	2.84E-07	247	5.01E-09	251	2.59E-08	204	3.11E-05	204
^{152}Eu	3.45E-17	75	1.92E-19	196.5	6.19E-20	198	1.39E-20	155	4.17E-17	155
^{154}Eu	1.76E-19	75	7.27E-23	129.5	2.28E-23	130	1.03E-22	75	3.10E-19	75
^{155}Eu	8.98E-28	75.5	0.00E+00	0	1.94E-27	82.5	1.52E-25	75	4.56E-22	75
^{55}Fe	3.69E-27	89.5	0.00E+00	0	0.00E+00	0	8.35E-28	105.5	7.34E-25	105.5
^{3}H	2.94E-03	8.299	0.00E+00	0	5.56E-04	8.621	3.79E-01	8.156	3.79E-02	8.156

Radio-nuclide	Field Soil		Mire Water		Mire Soil		River Water		River Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{129}I	1.66E-06	507	5.70E-03	626	4.75E-06	511	1.32E-04	478	9.09E-04	478
^{93m}Nb	6.35E-09	62630	8.45E-06	62325	1.55E-06	62352	5.56E-07	61440	8.33E-04	61440
^{94}Nb	5.41E-09	59471	2.69E-06	59666	3.12E-06	60234	7.66E-07	59409	1.15E-03	59409
^{59}Ni	1.27E-08	1595	2.10E-04	1810	1.23E-06	1760	1.89E-06	1590	5.30E-04	1590
^{63}Ni	3.08E-05	106	1.54E-01	166	1.06E-03	161.5	4.60E-03	106	1.29E+00	106
^{237}Np	3.10E-09	1079	2.51E-06	756	4.38E-08	1099	6.80E-08	1046	2.38E-06	1046
^{231}Pa	1.72E-07	52596	7.44E-03	52861	1.15E-04	53914	1.45E-05	51727	2.90E-02	51727
^{210}Pb	2.05E-06	58138	1.12E-02	60324	7.75E-04	59602	2.28E-04	1765	4.56E-01	1765
^{238}Pu	1.34E-08	221	2.71E-04	289	5.95E-07	300	1.71E-06	221	1.27E-03	221
^{239}Pu	9.28E-07	340	4.24E-02	515	1.19E-04	616	1.19E-04	340	8.80E-02	340
^{240}Pu	1.08E-06	340	4.91E-02	512	1.37E-04	609	1.39E-04	339	1.03E-01	339
^{241}Pu	1.07E-09	92	5.85E-06	110	1.15E-08	110.5	1.37E-07	92	1.01E-04	92
^{242}Pu	1.98E-09	52577	1.26E-04	52791	4.59E-07	53001	1.99E-07	52477	1.47E-04	52477
^{226}Ra	1.16E-06	58087	9.86E-03	60776	7.50E-04	59653	1.38E-04	57025	3.44E-01	57025
^{228}Ra	1.08E-08	56508	1.92E-04	56797	8.19E-07	57771	1.53E-12	61224	3.82E-09	61224
^{125}Sb	1.31E-15	22	1.17E-13	26	3.23E-15	25.5	2.05E-13	22	1.27E-11	22
^{151}Sm	1.00E-17	123	2.19E-13	1031	4.64E-16	1055	5.66E-18	1675	5.26E-15	1675
^{90}Sr	1.75E-05	34	3.35E-04	58	1.69E-04	49	2.76E-03	34	1.44E-01	34
^{99}Tc	6.83E-07	467	3.09E-06	603	1.67E-07	467	5.40E-05	462	1.24E-05	462
^{228}Th	1.63E-09	56511	1.92E-04	56796	8.19E-07	57771	1.94E-12	61226	3.68E-09	61226
^{229}Th	1.54E-08	58613	1.83E-03	58807	6.71E-06	59536	1.45E-06	58775	2.76E-03	58775
^{230}Th	2.72E-07	63234	3.29E-02	63432	1.29E-04	64283	2.63E-05	63123	5.00E-02	63123

Radio-nuclide	Field Soil		Mire Water		Mire Soil		River Water		River Sediment	
	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq kg^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)	Peak Conc. (Bq L^{-1})	Time of peak (y)
^{232}Th	1.63E-09	56585	1.97E-04	56794	7.59E-07	57845	7.94E-13	61296	1.51E-09	61296
^{204}Tl	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0	0.00E+00	0
^{233}U	1.20E-06	50550	3.83E-05	50650	7.53E-05	50600	1.81E-04	50550	3.62E-02	50550
^{234}U	1.57E-05	51181	5.54E-04	51289	1.02E-03	51256	1.98E-03	51183	3.96E-01	51183
^{235}U	1.24E-05	50600	5.12E-04	51252	8.59E-04	50700	1.91E-03	50600	3.82E-01	50600
^{236}U	6.80E-08	50550	2.19E-06	50650	4.29E-06	50600	1.03E-05	50550	2.05E-03	50550
^{238}U	1.66E-05	51178	5.90E-04	51285	1.09E-03	51252	2.06E-03	51182	4.12E-01	51182
^{93}Zr	9.09E-09	62096	9.07E-06	62293	1.48E-06	62312	9.90E-07	61433	4.06E-04	61433

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289 IAEA, *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*, IAEA General Safety Requirements Part 3, No. GSR Part 3, July 2014.

290 GSL, *Decommissioning: Site Restoration End State Radiological Performance Assessment – Approach, Scenarios and Modelling Basis*, Galson Sciences Ltd and National Nuclear Laboratory, GSL Report 1624-12, Version 1, Magnox Ltd Report ES(18)P197 Issue 1, March 2019.

291 UKAEA, *Sections - ground floor slab storage building*, Winfrith Dragon project, Drawing No. AE189734, Modification G, 19 June 1962.

292 ERICA Consortium (led by Norwegian Radiation and Nuclear Safety Authority), *ERICA Assessment Tool Version 2.0*, 2021 (updated 2023).

Appendix E Dose Rates Over Time for Alternative Assessment Cases and Variant/"What-if" Scenarios

E.1 Alternative Assessment Cases

E1 Figure E.1 to Figure E.18 present dose rates over time for the alternative assessment cases considered in the Winfrith NE assessment. See Section 10.1.3 for discussion of these results and Table 10.4 for the peak dose rates for each RP in each case.

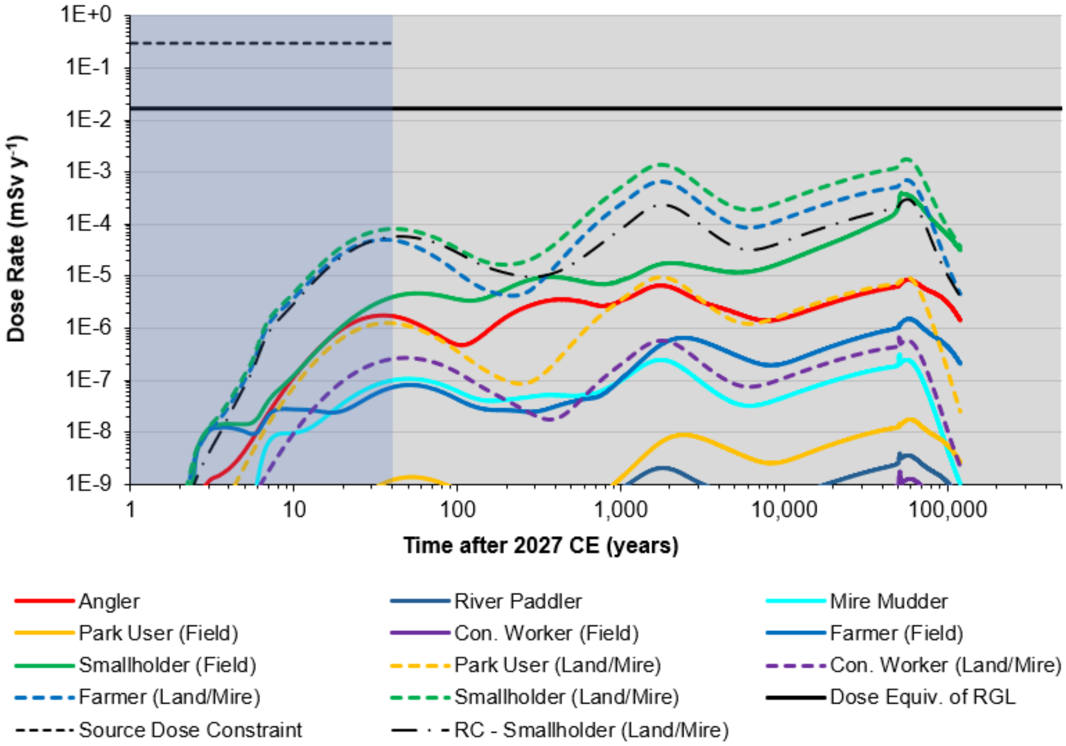

Figure E.1: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.1 (alternative inventory).

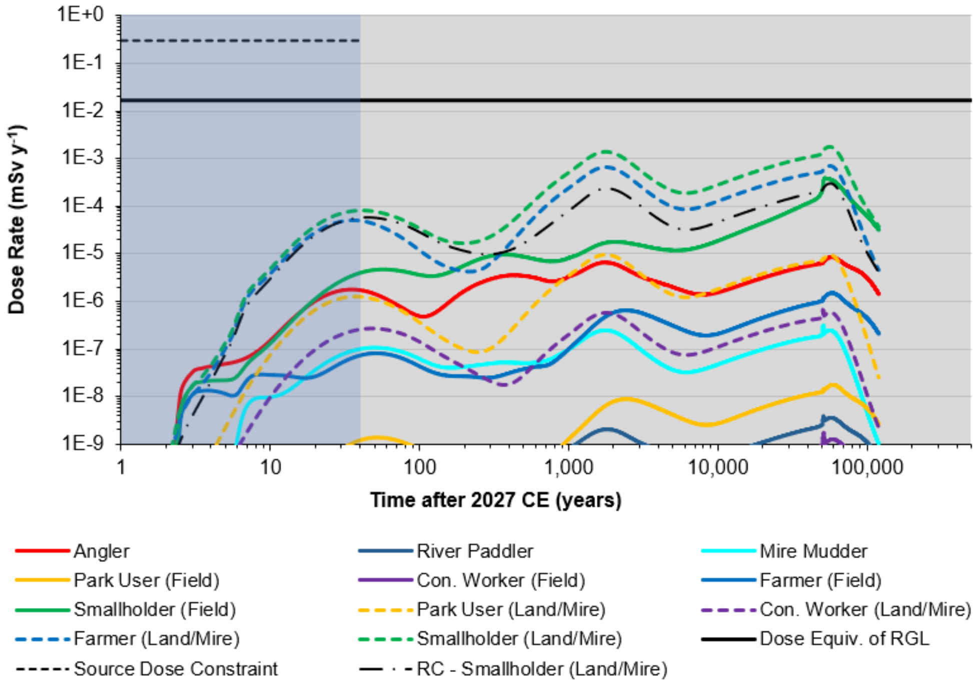

Figure E.2: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.2 (alternative (Pu) Dragon inventory).

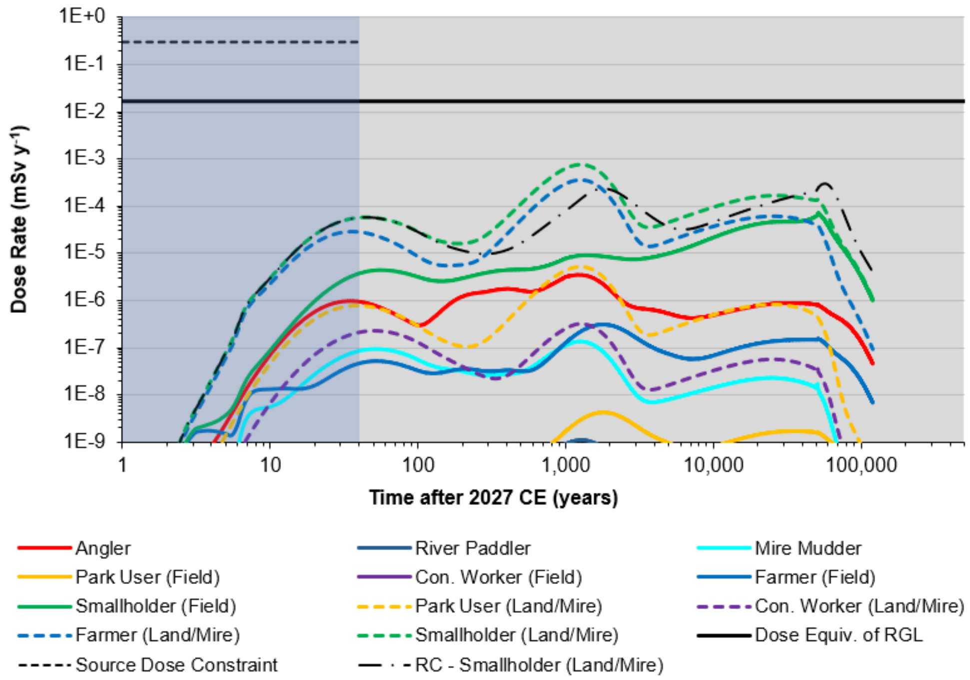

Figure E.3: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.3 (minimum near-field sorption).

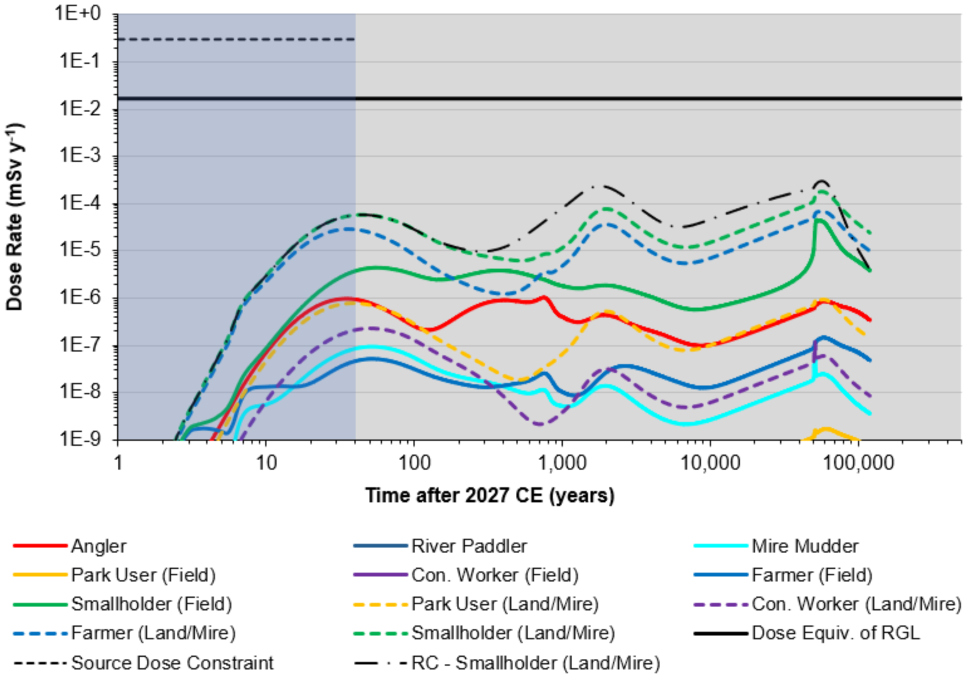

Figure E.4: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.4 (maximum near-field sorption).

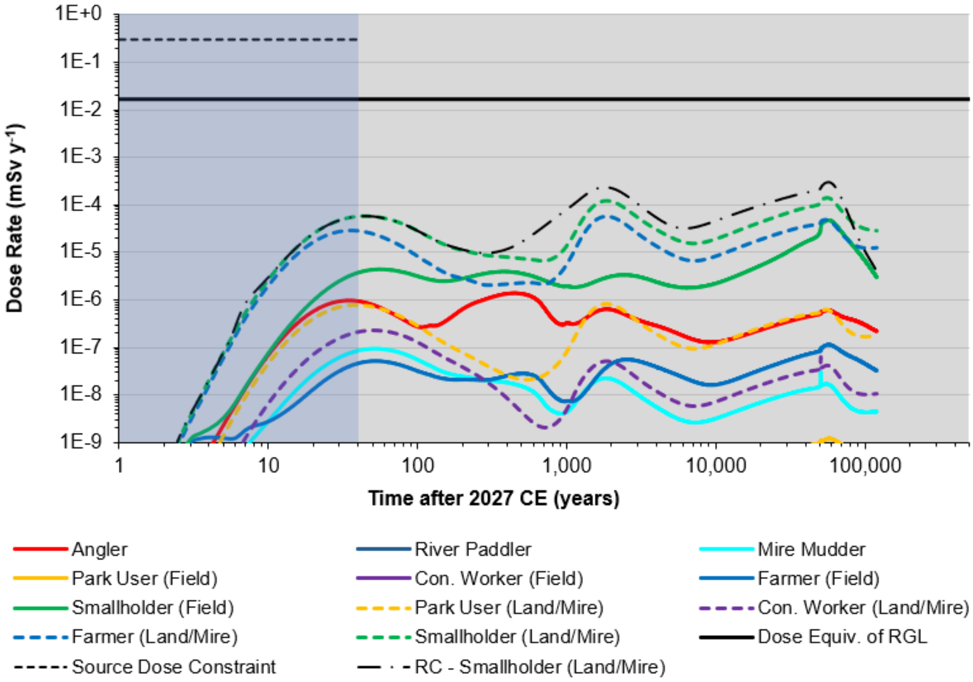

Figure E.5: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.5 (minimum concrete and rubble porosity).

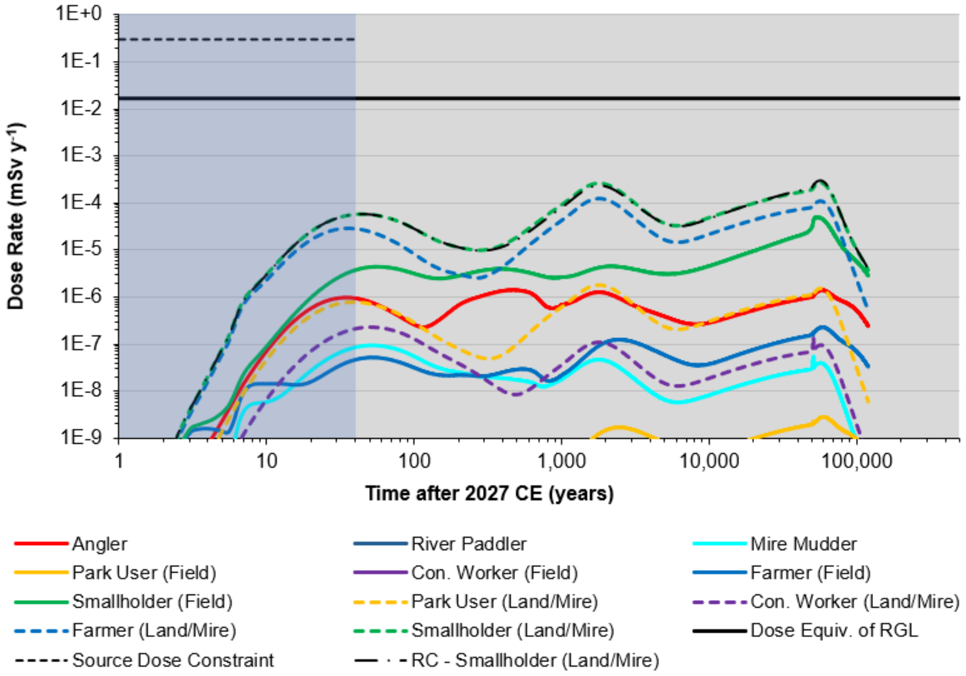

Figure E.6: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.6 (maximum concrete and rubble porosity).

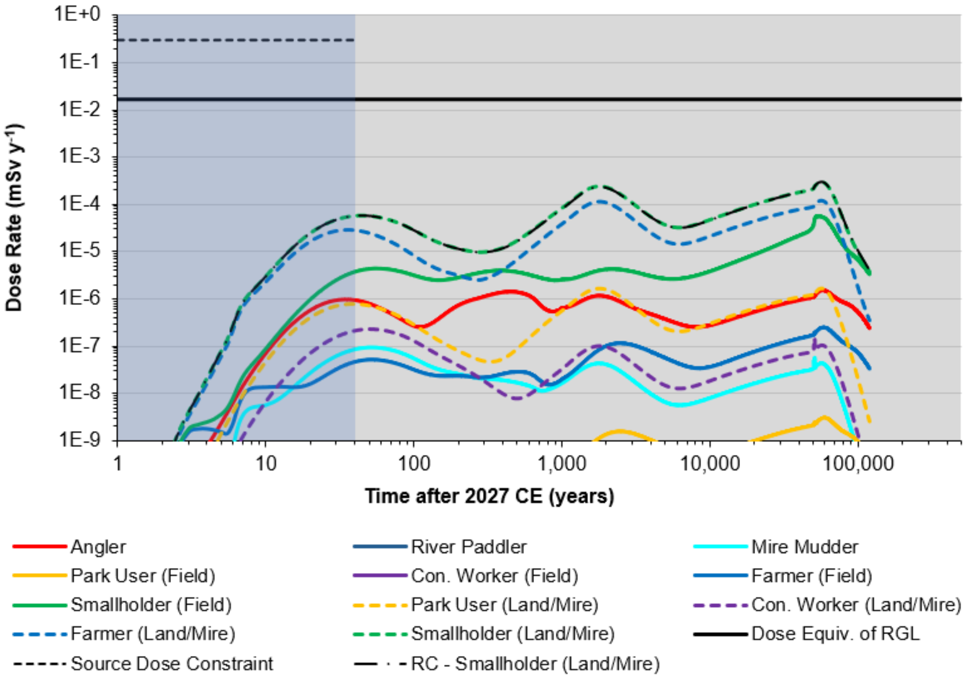

Figure E.7: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.7 (minimum dry bulk concrete density).

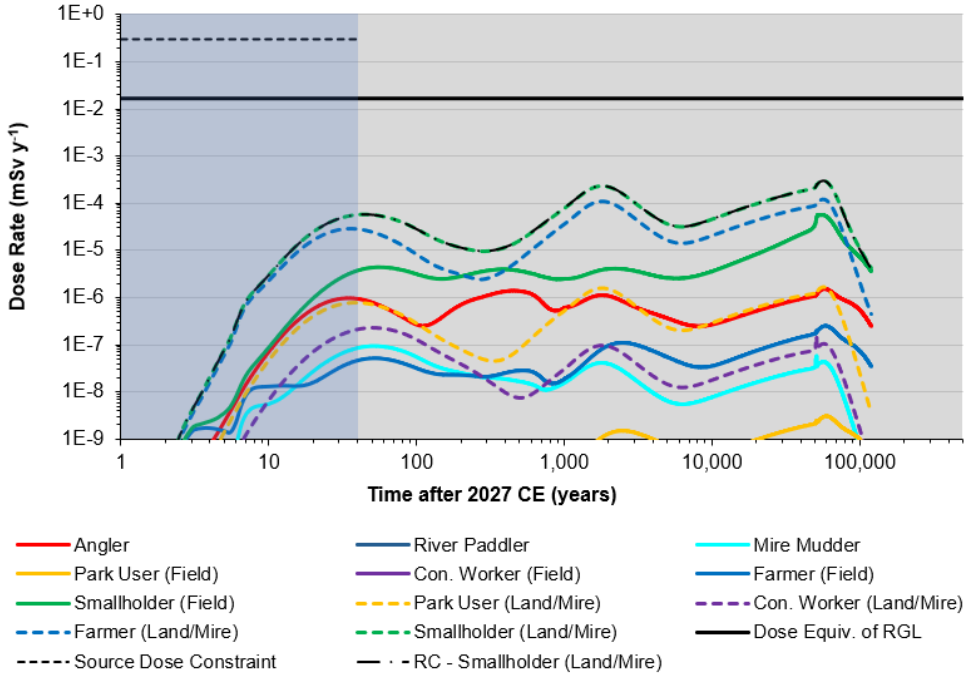

Figure E.8: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.8 (maximum dry bulk concrete density).

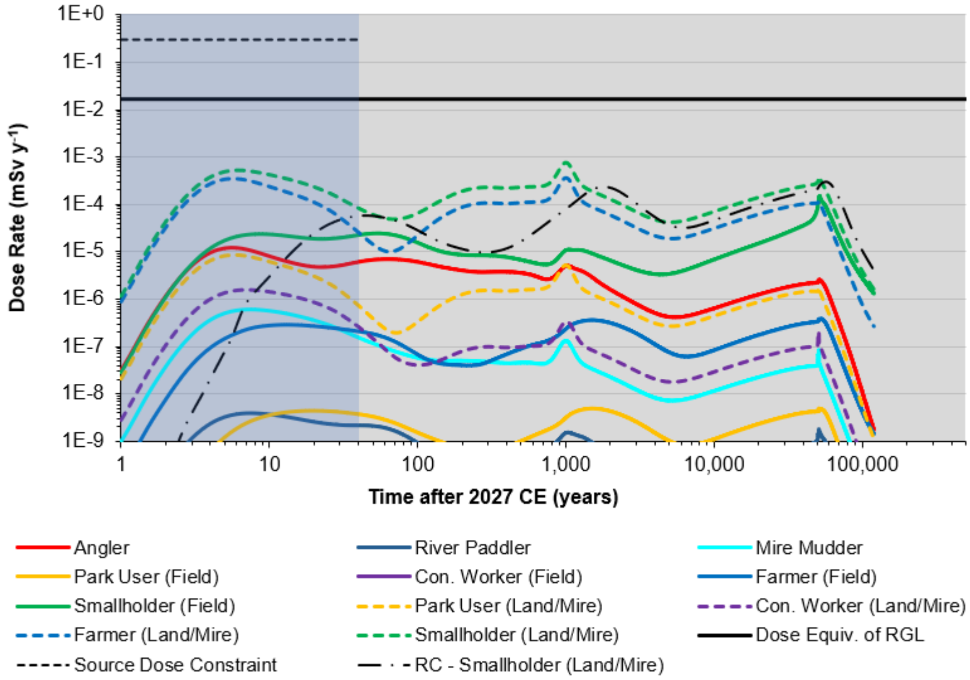

Figure E.9: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.9 (minimum geosphere sorption).

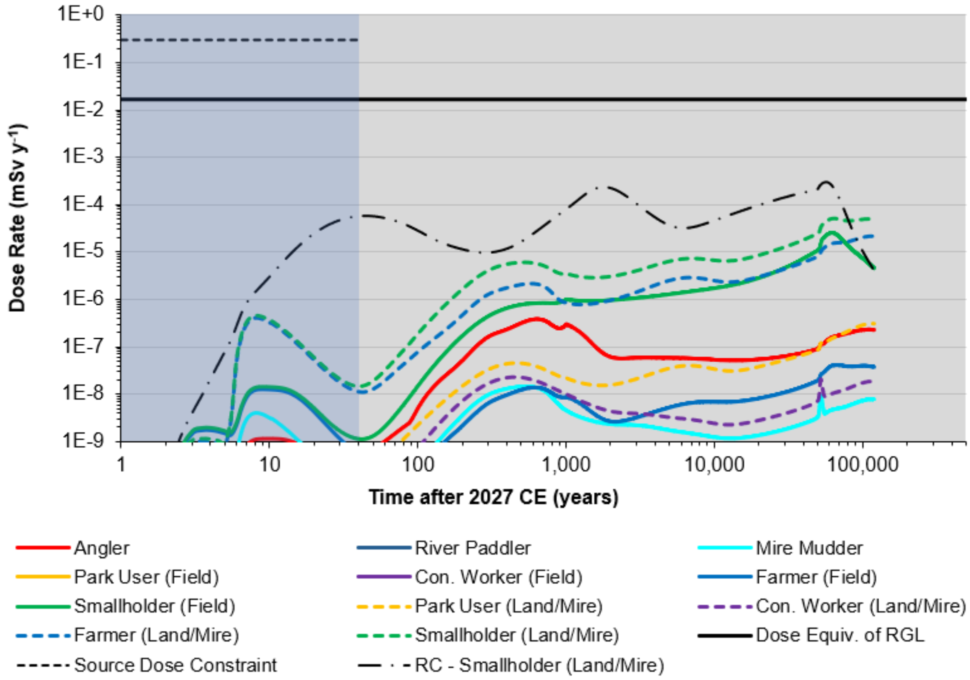

Figure E.10: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.10 (maximum geosphere sorption).

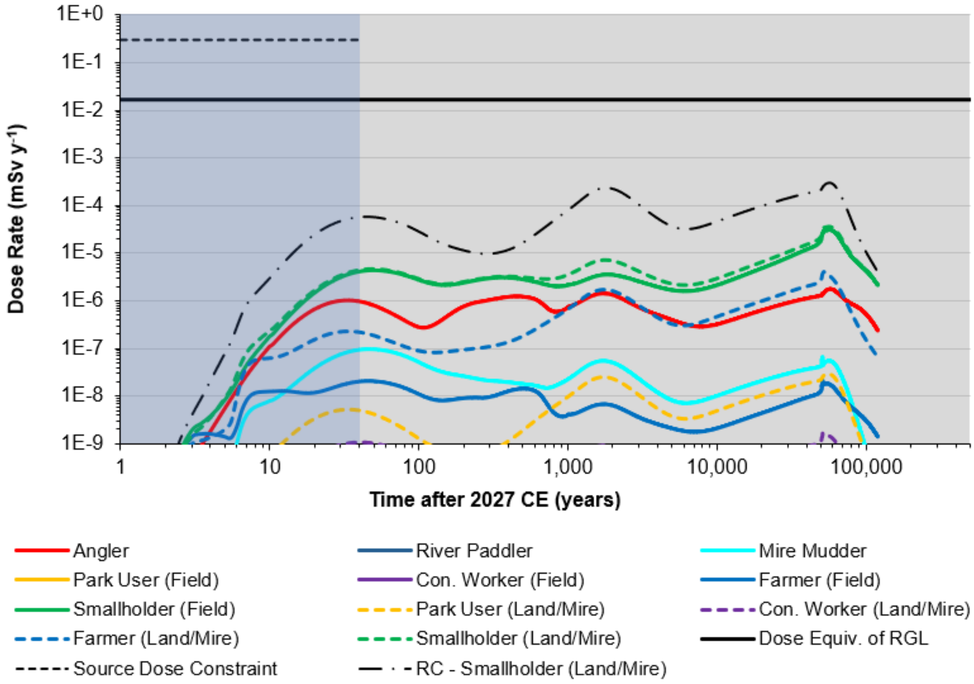

Figure E.11: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.11 (minimum biosphere sorption).

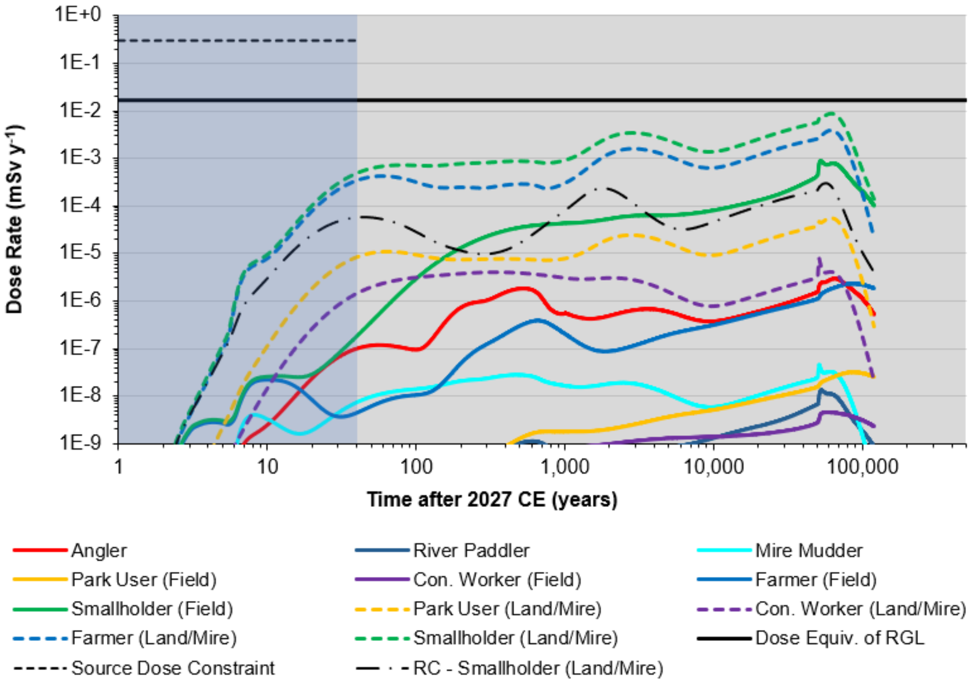

Figure E.12: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.12 (maximum biosphere sorption).

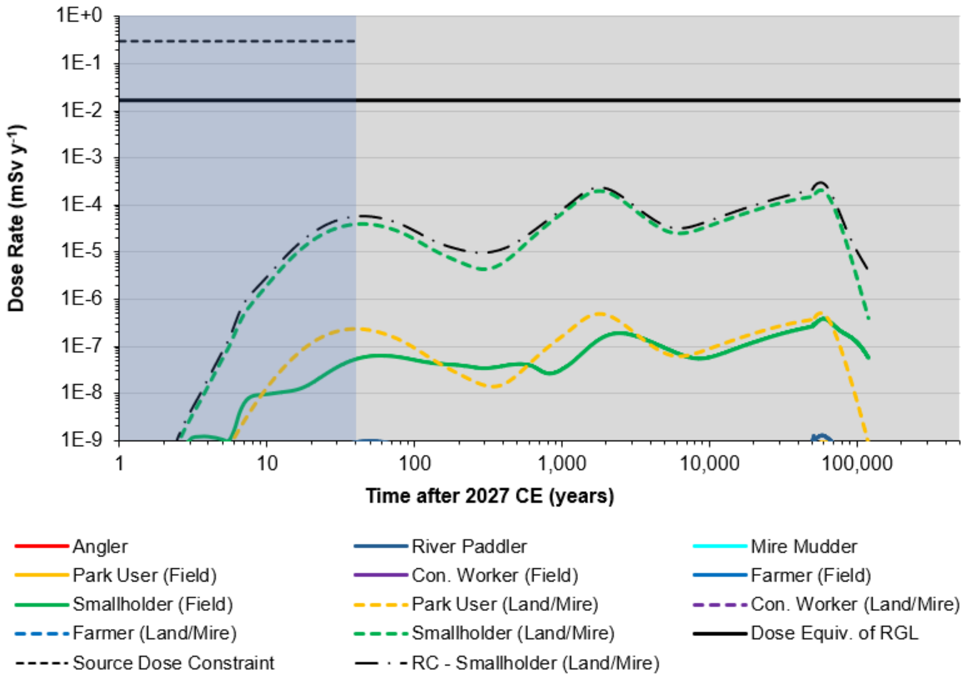

Figure E.13: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.13 (Child RP). Note: Angler, Construction Worker, Mire Mudder and Farmer are not possible activities for a child receptor.

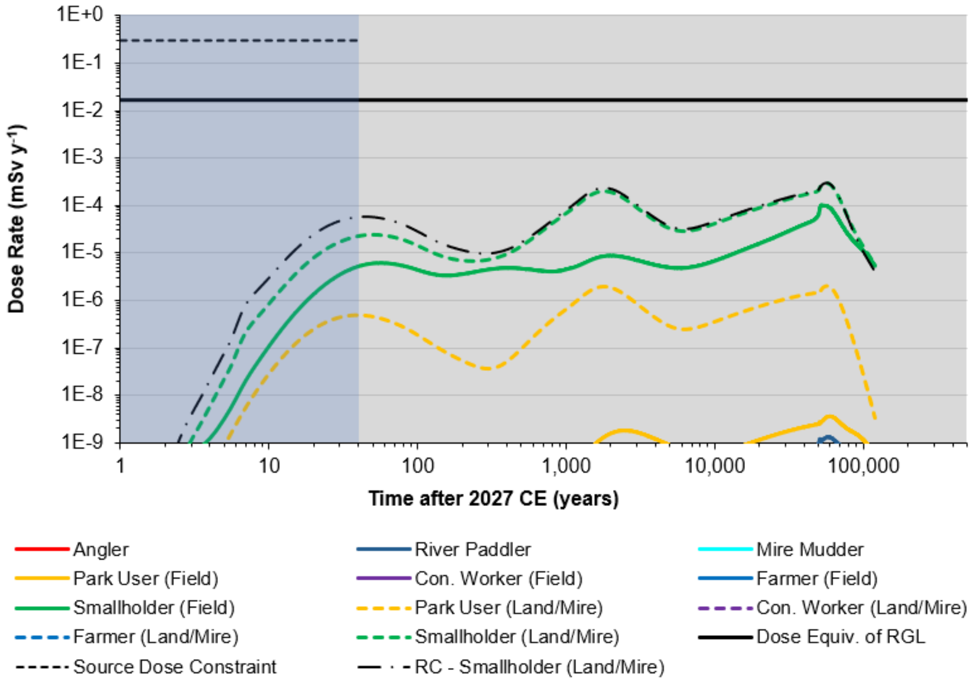

Figure E.14: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.14 (Infant RP). Note: Angler, Construction Worker, Mire Mudder and Farmer are not possible activities for a child receptor.

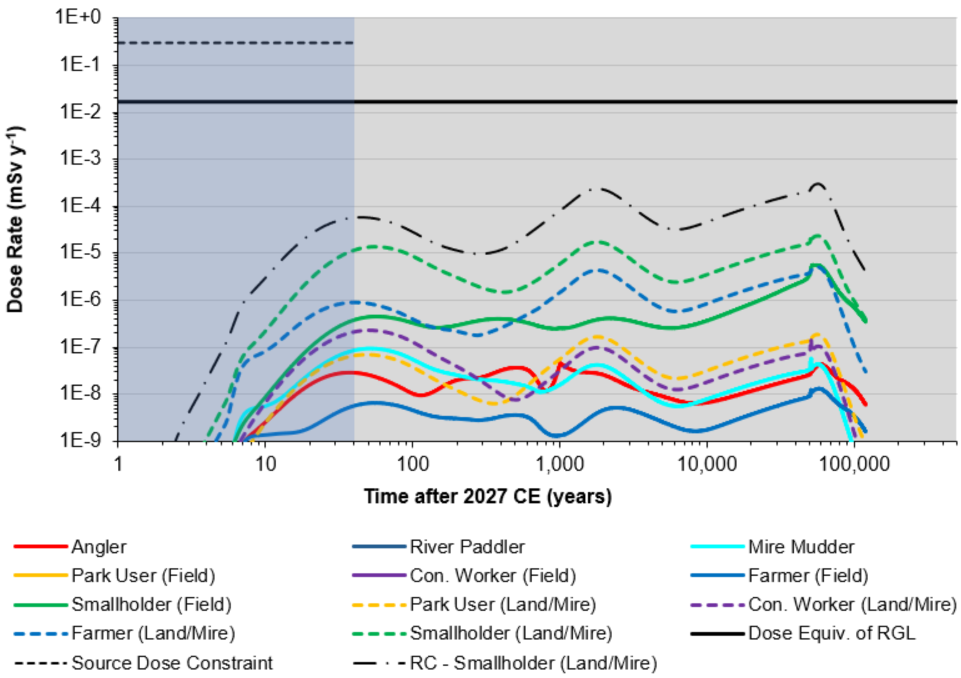

Figure E.15: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.15 (minimum uptake factors).

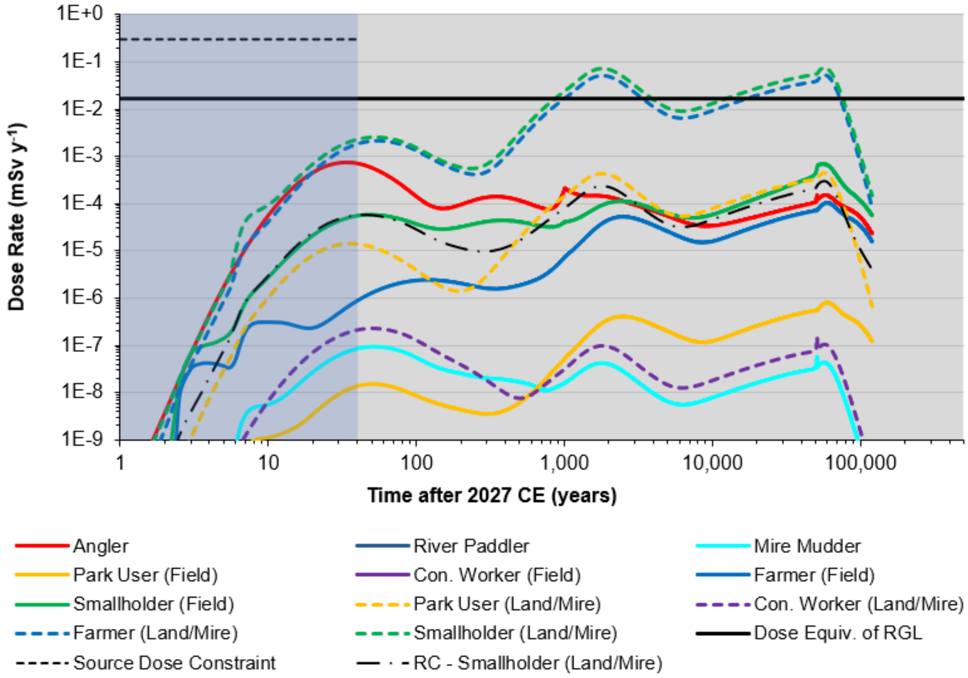

Figure E.16: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.16 (maximum uptake factors).

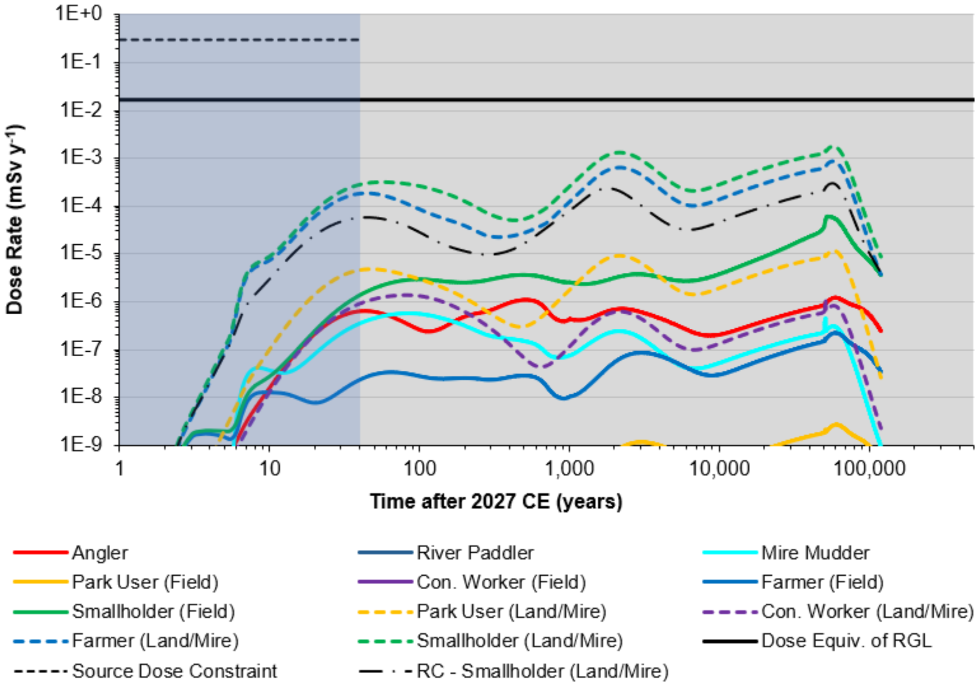

Figure E.17: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.17 (minimum mire outflow rate).

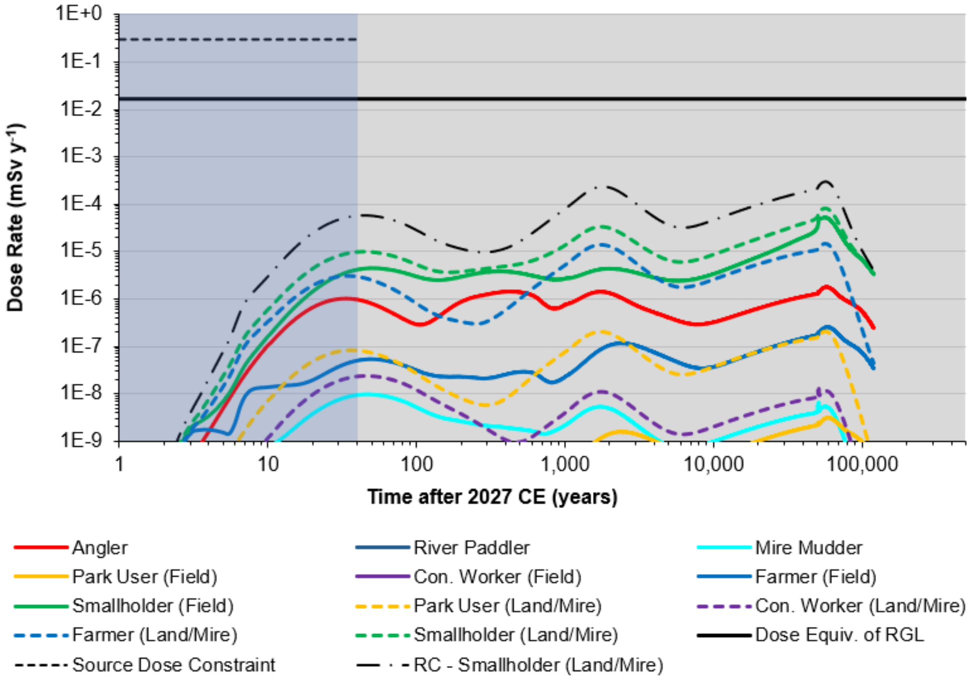

Figure E.18: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.18 (maximum mire outflow rate).

E.2 Variant Concept Scenarios

E2 Figure E.19 to Figure E.28 present dose rates over time for the variant concept scenarios considered in the Winfrith NE assessment. See Section 10.2.1 for discussion of these results and Table 10.5 for the peak dose rates for each RP in each case.

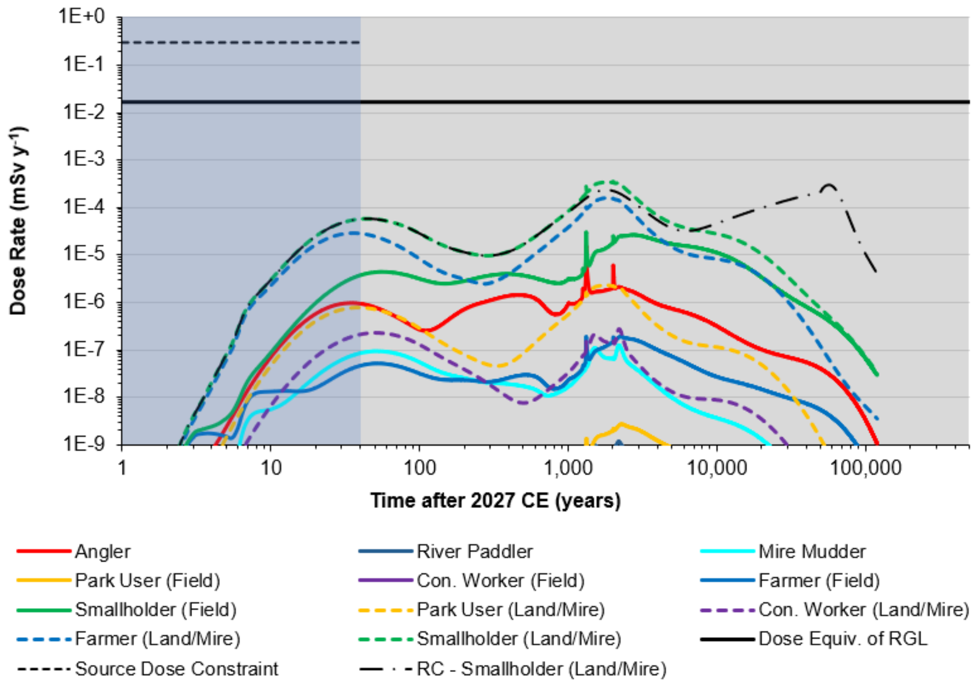

Figure E.19: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.1 (shorter chemical degradation duration).

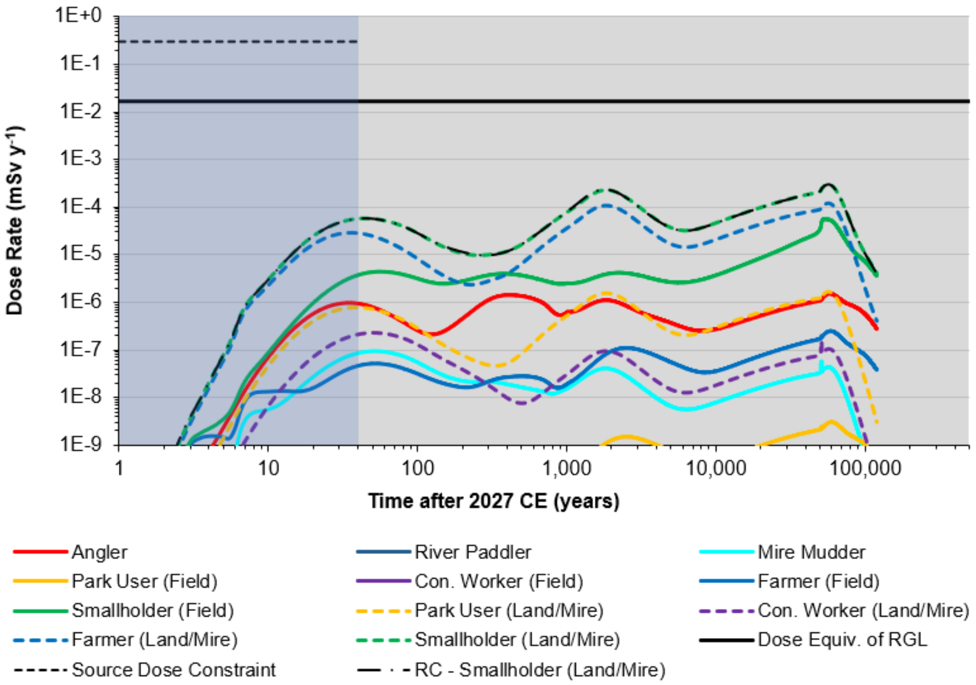

Figure E.20: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.2 (minimum initial hydraulic conductivity for SGHWR and Dragon structures).

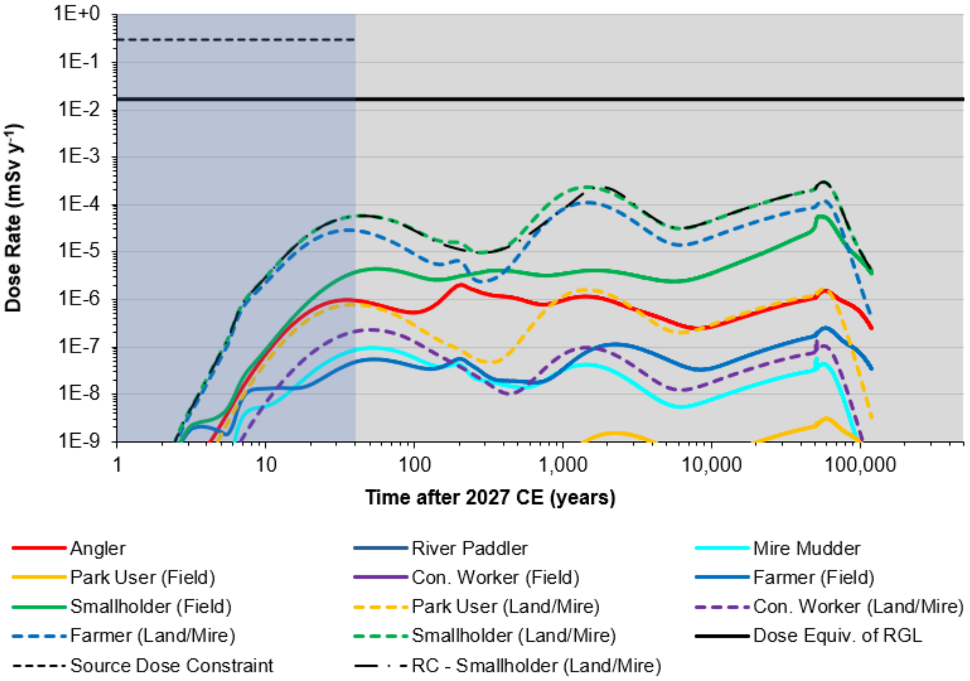

Figure E.21: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.3 (maximum initial hydraulic conductivity and shorter degradation period).

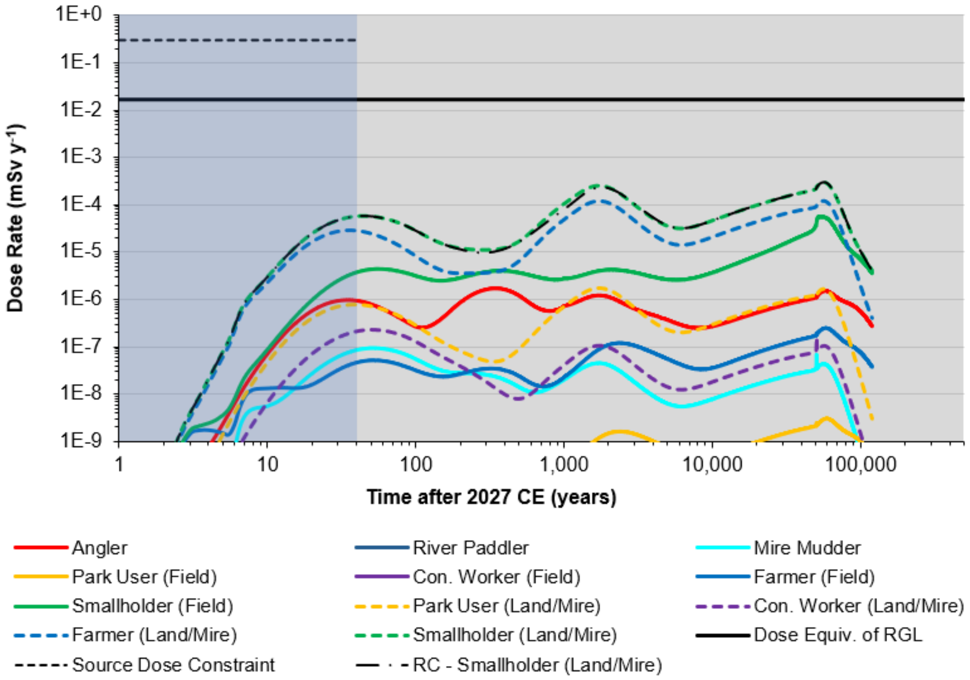

Figure E.22: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.4 (shorter cap degradation time).

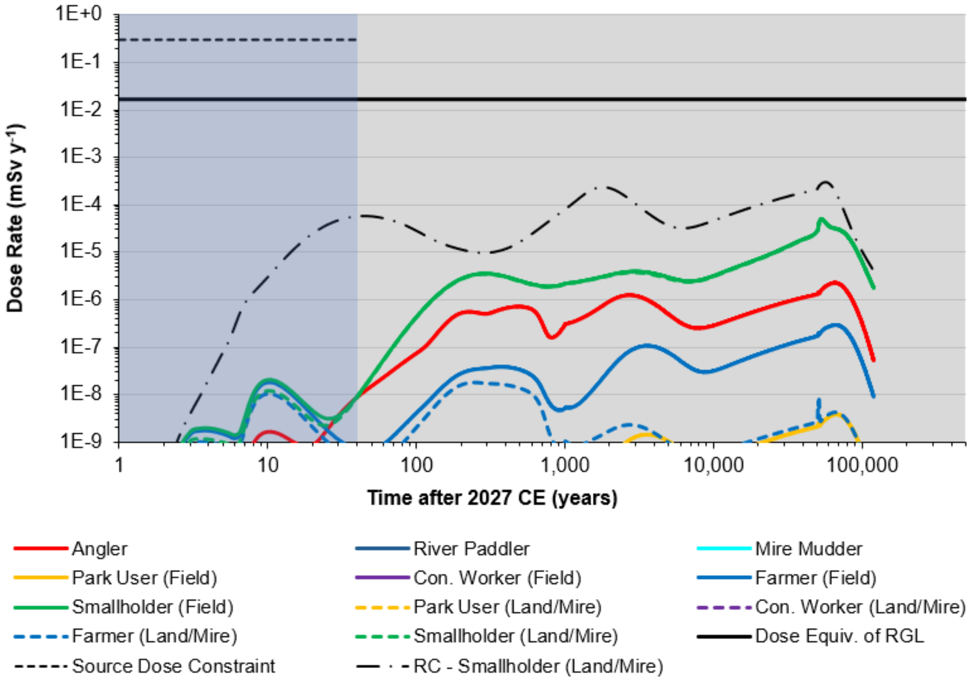

Figure E.23: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.5 (100% SGHWR and A59 groundwater release to the River).

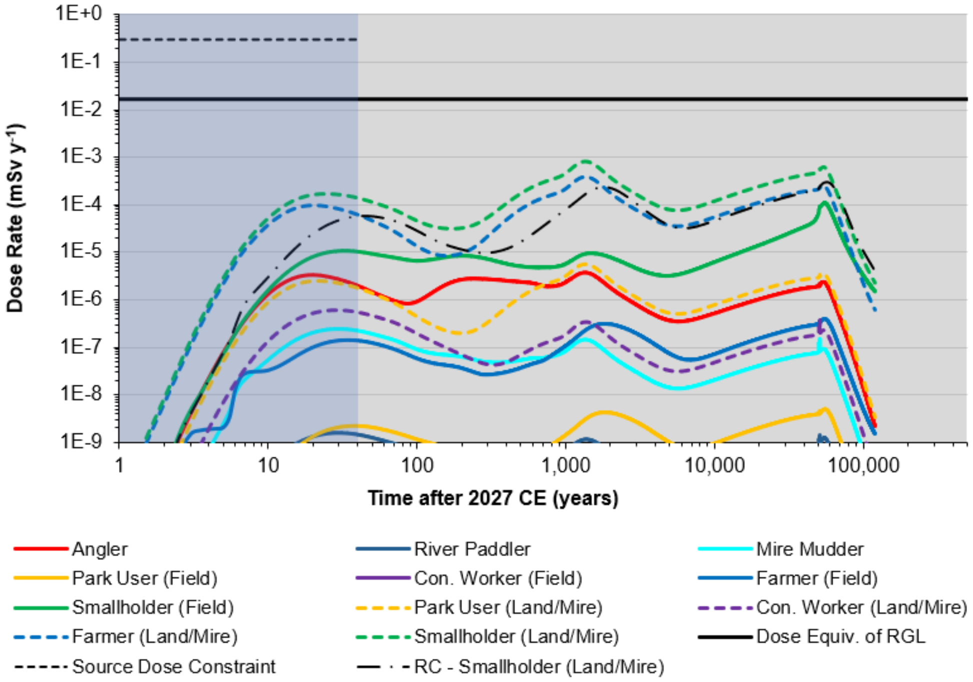

Figure E.24: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.6 (100% SGHWR and A59 groundwater release to the Land/Mire).

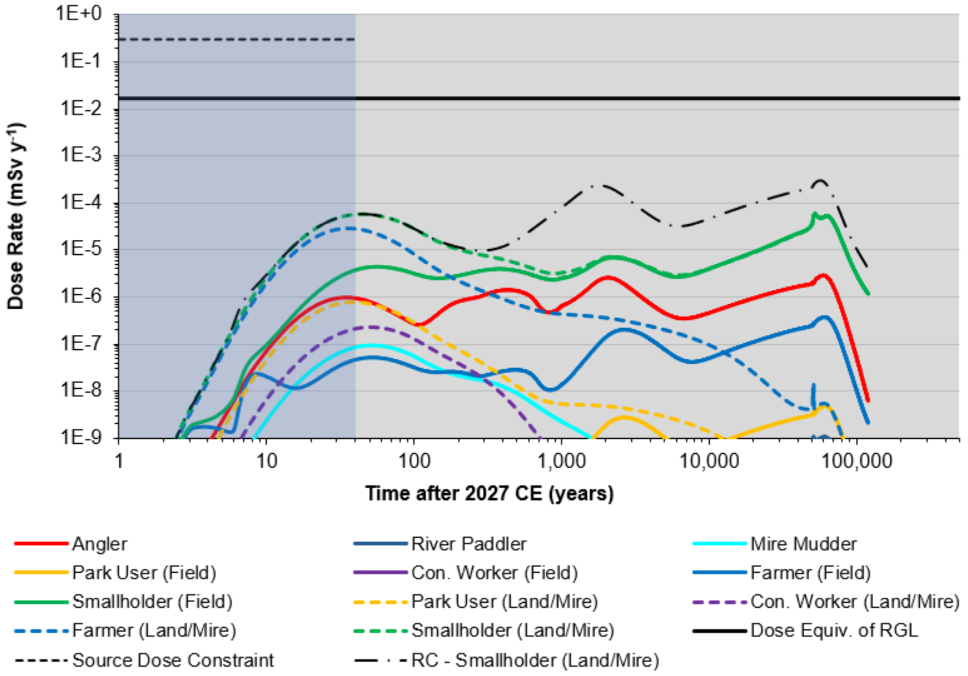

Figure E.25: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.7 (100% SGHWR groundwater release to Dragon).

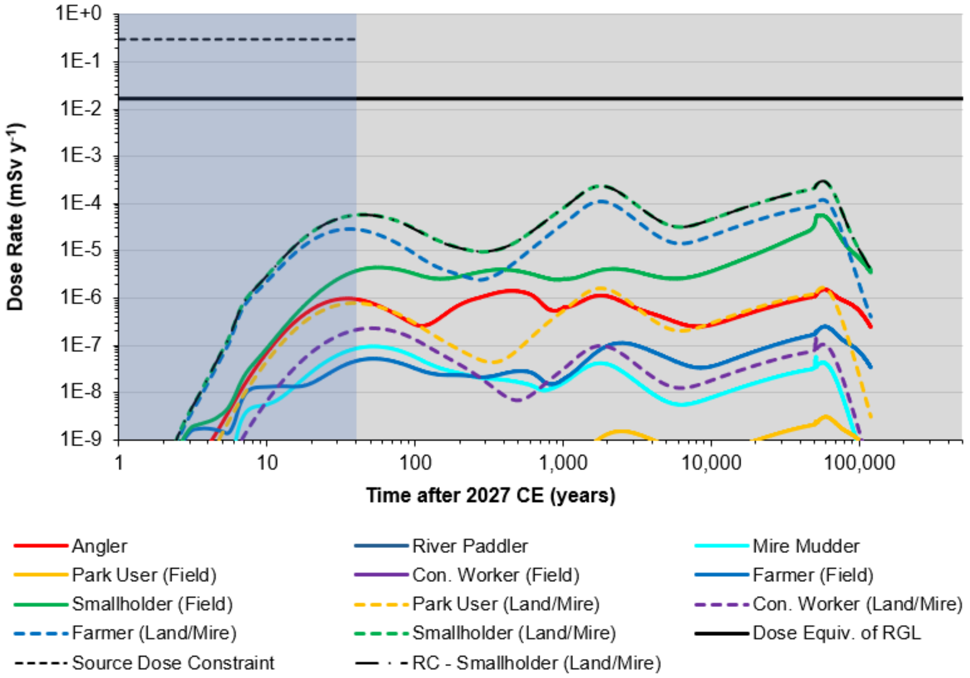

Figure E.26: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.8 (increased rate of rainfall infiltration through soil).

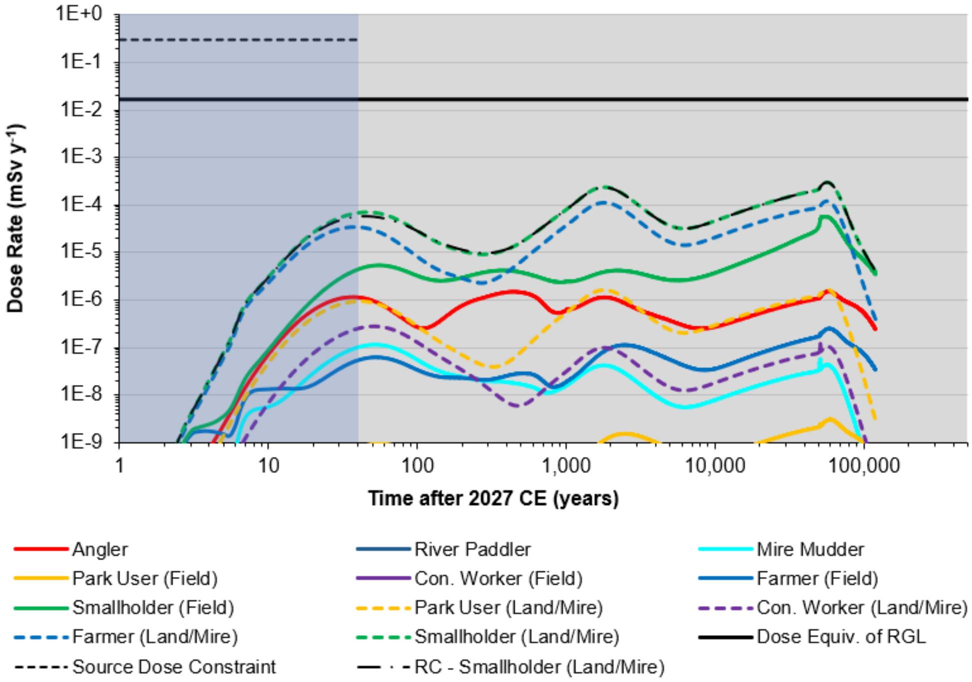

Figure E.27: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.9 (Reasonable Worst Case groundwater levels).

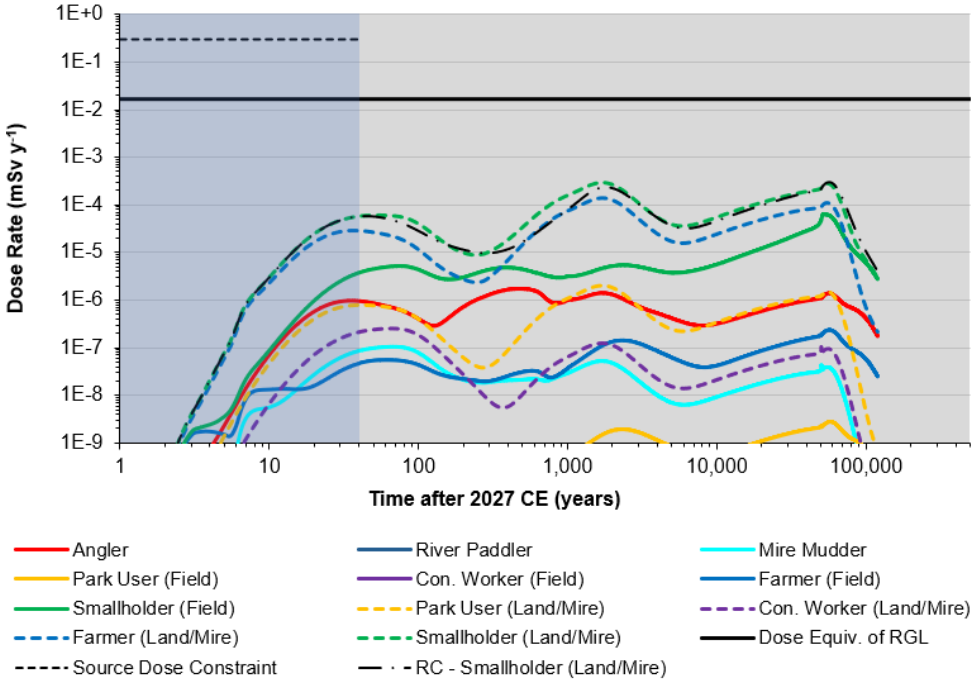

Figure E.28: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Concept Scenario VA.10 (Reasonable Worst Case groundwater levels with seasonal fluctuation).

E.3 Variant Configuration Scenarios

E3 Figure E.29 to Figure E.33 present dose rates over time for the variant configuration scenarios considered in the Winfrith NE assessment. See Section 10.2.2 for discussion of these results and Table 10.6 for the peak dose rates for each RP in each case.

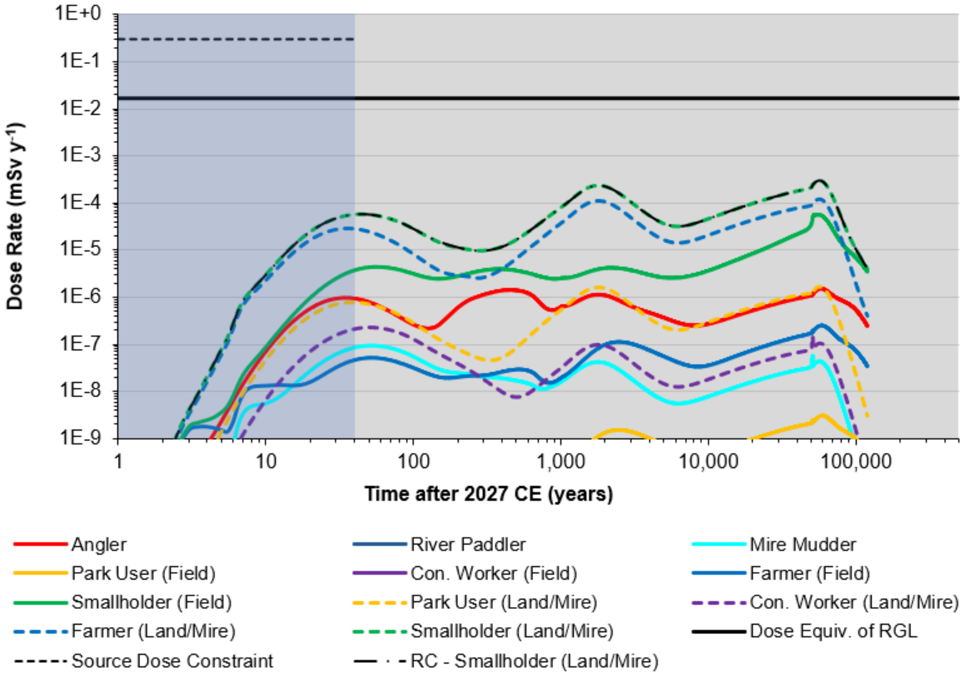

Figure E.29: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Configuration Scenario VB.1 (greater void spacing between blocks).

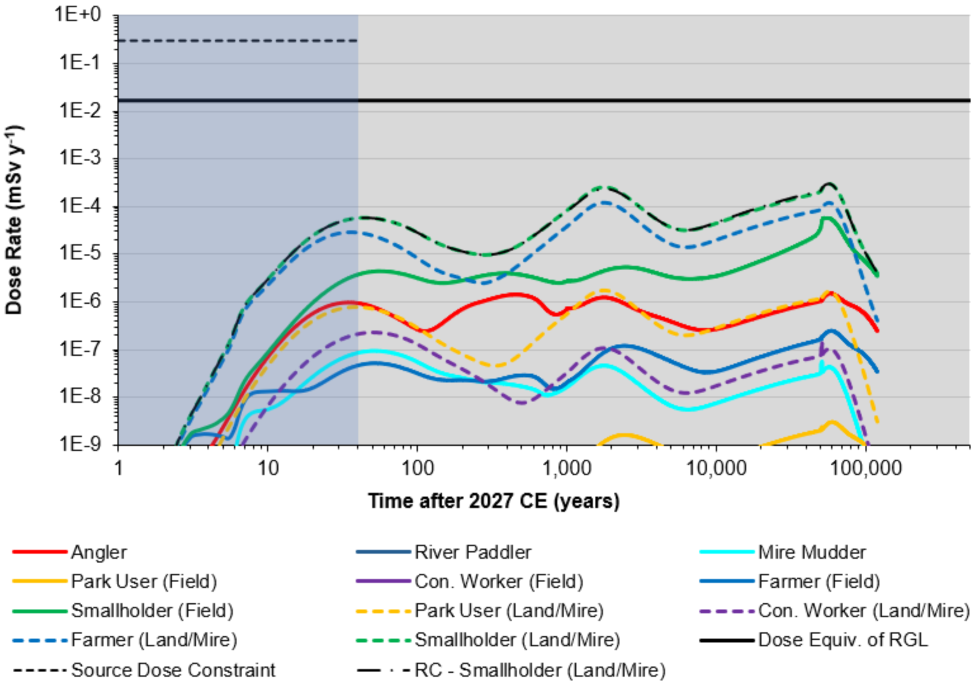

Figure E.30: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Configuration Scenario VB.2 (entirely rubble infill).

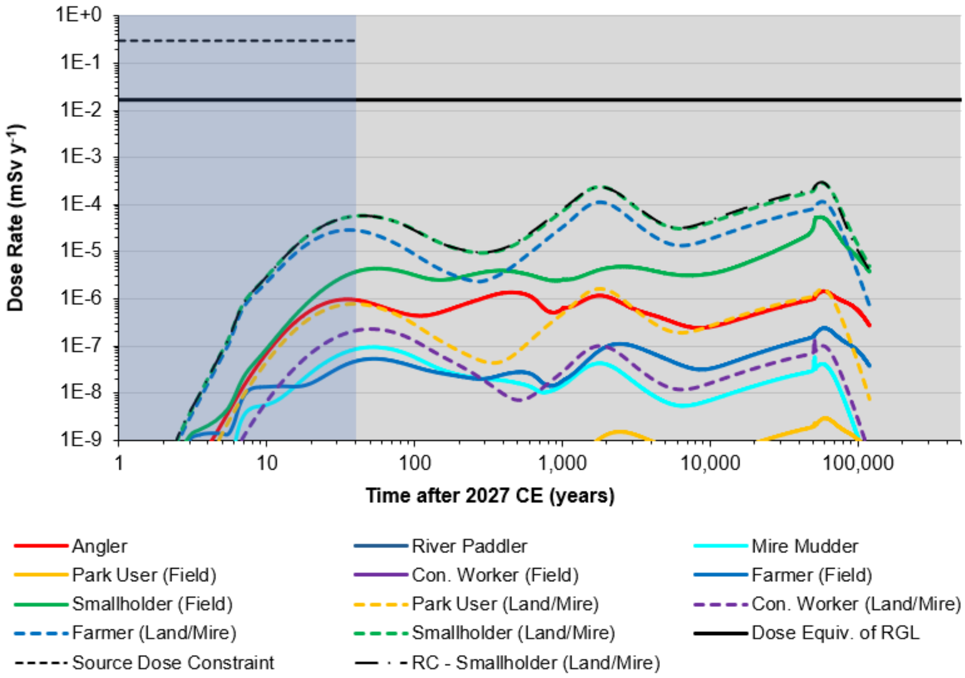

Figure E.31: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Configuration Scenario VB.3 (grouting of entire void volume).

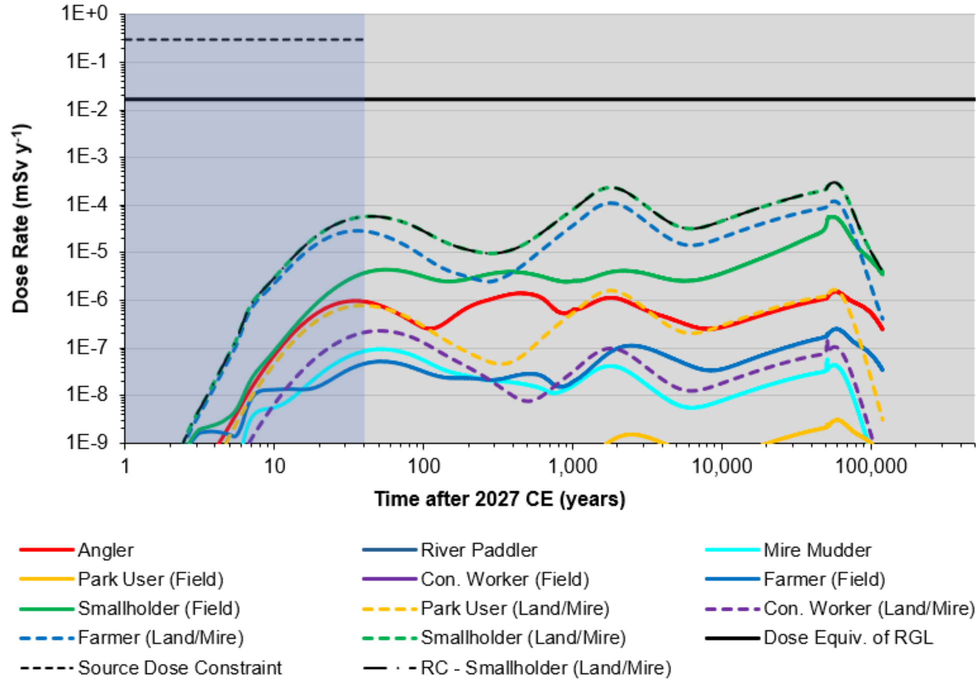

Figure E.32: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Configuration Scenario VB.4 (minimum block size).

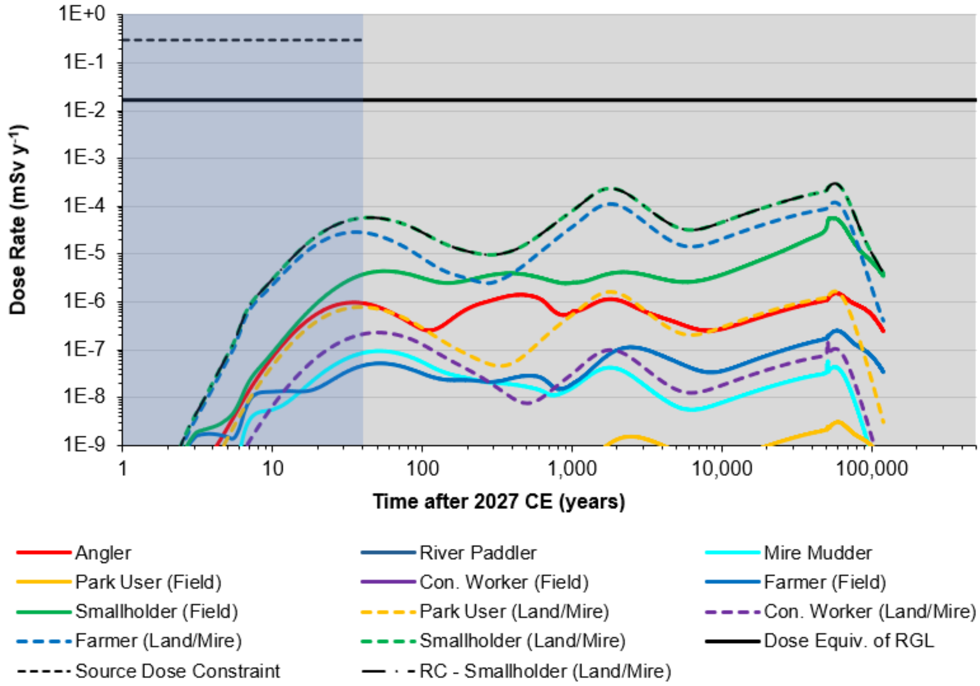

Figure E.33: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Variant Configuration Scenario VB.5 (maximum block size).

E.4 "What-If" Scenarios

E4 Figure E.34 to Figure E.35 present dose rates over time for the "what-if" scenarios considered in the Winfrith NE assessment. See Section 10.3 for discussion of these results and Table 10.7 for the peak dose rates for each RP in each case.

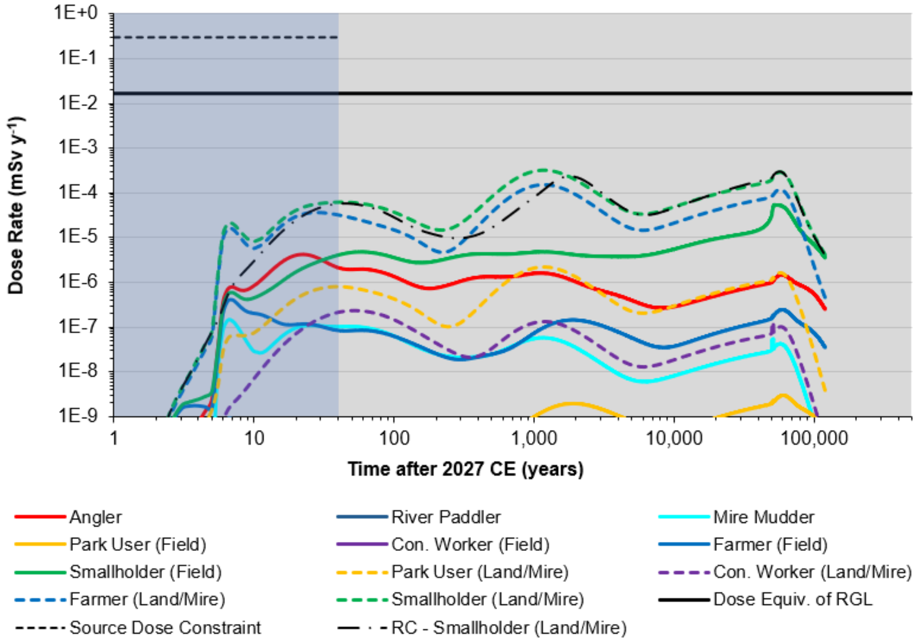

Figure E.34: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in "What-if" Scenario WI.1 (instantaneous hydraulic degradation).

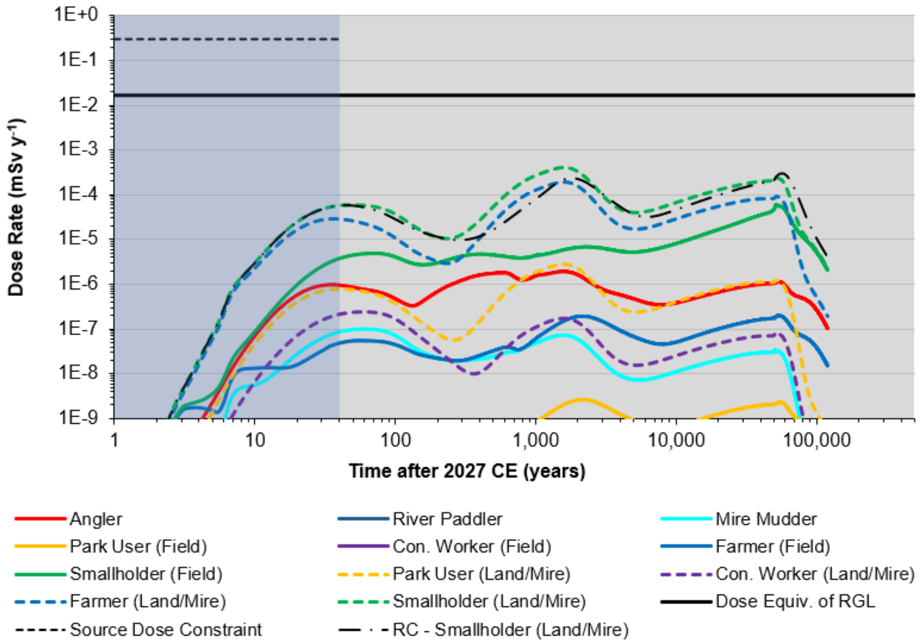

Figure E.35: Dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in "What-if" Scenario WI.2 (extreme climate change/groundwater 1 m bgl).

Appendix F Site Occupancy Alternative and Variant Case Results

F1 Table F.1 and Table F.2 present dose rates above buried in-situ features for the alternative assessment cases and variant scenarios considered in the site occupancy assessment. See Sections 10.4.2 and 10.4.3 for discussion of these results.

Table F.1: Dose rates (mSv h^{-1}) above buried in-situ features for site occupancy scenarios considering alternative inventories.

Year		**Location of dose point**	**2036**	**2066**
Structure			**mSv h^{-1}**	
SGHWR Region 1	Alternative inventory	Surface	2.17E-15	4.10E-16
		1 m	1.87E-15	3.61E-16
North Annexe	Alternative inventory	Surface	1.06E-17	1.04E-17
		1 m	9.63E-18	9.47E-18
South Annexe	Alternative inventory	Surface	1.75E-17	1.72E-17
		1 m	1.74E-17	1.71E-17
Dragon Reactor	Alternative inventory	Surface	2.79E-17	2.55E-17
		1 m	1.20E-16	1.31E-16
	Pu-FP inventory	Surface	2.55E-16	3.01E-16
		1 m	1.29E-15	1.55E-15
Dragon B78	Alternative inventory	Surface	9.52E-18	9.62E-17
		1 m	9.48E-18	9.57E-17
	Pu-FP inventory	Surface	1.06E-17	1.16E-16
		1 m	1.05E-17	1.16E-16
Dragon Mortuary Holes	Alternative inventory	Surface	1.29E-21	3.52E-22
		1 m	1.28E-21	3.47E-22
A591/HVA	Alternative inventory	Surface	2.45E-08	1.30E-08
		1 m	2.43E-08	1.29E-08
PSA/Pit 3	Alternative inventory	Surface	3.30E-08	1.68E-08
		1 m	3.27E-08	1.67E-08
A59 Other Areas	Alternative inventory	Surface	1.31E-08	7.21E-09
		1 m	1.31E-08	7.24E-09

Table F.2: Dose rates (mSv h^{-1}) above buried in-situ features for site occupancy scenarios considering variant cap/cover thicknesses.

Year		**Location of dose point**	**2036**	**2066**
Structure			**mSv h^{-1}**	
SGHWR Region 1	3 m	Surface	3.46E-13	6.40E-14
		1 m	2.88E-13	5.41E-14
	2.25 m	Surface	1.19E-10	2.19E-11

Year		Location of dose point	2036	2066
Structure			mSv h^{-1}	
		1 m	9.66E-11	1.78E-11
North Annexe	3 m	Surface	1.13E-15	1.11E-15
		1 m	1.11E-15	1.08E-15
	2.25 m	Surface	1.54E-13	1.48E-13
		1 m	1.50E-13	1.44E-13
South Annexe	3 m	Surface	1.69E-15	1.86E-15
		1 m	1.69E-15	1.66E-15
	2.25 m	Surface	2.66E-13	2.57E-13
		1 m	2.35E-13	2.26E-13
Dragon Reactor	2.5 m	Surface	8.21E-14	3.82E-14
		1 m	3.19E-13	2.98E-13
	1.5 m	Surface	1.79E-10	4.52E-11
		1 m	3.01E-10	2.06E-10
Dragon B78	2.5 m	Surface	2.42E-14	2.48E-14
		1 m	2.41E-14	2.47E-14
	1.5 m	Surface	1.66E-11	1.53E-11
		1 m	1.65E-11	1.52E-11
Dragon Mortuary Holes	2.5 m	Surface	4.45E-17	9.30E-19
		1 m	4.42E-17	9.23E-19
	1.5 m	Surface	1.33E-13	5.45E-14
		1 m	1.32E-13	5.40E-14
A591/HVA	0.3 m	Surface	1.77E-07	9.87E-08
		1 m	1.74E-07	9.73E-08
	0.1 m	Surface	1.64E-06	9.13E-07
		1 m	1.57E-06	8.74E-07
	No cover	Surface	6.53E-06	3.73E-06
		1 m	4.80E-06	2.74E-06
PSA/Pit 3	0.3 m	Surface	7.08E-08	3.78E-08
		1 m	7.02E-08	3.75E-08
	0.1 m	Surface	6.57E-07	3.50E-07
		1 m	6.52E-07	3.47E-07
	No cover	Surface	2.61E-06	1.42E-06
		1 m	2.31E-06	1.25E-06
A59 Other Areas	0.3 m	Surface	5.89E-08	3.31E-08
		1 m	5.93E-08	3.32E-08
	0.1 m	Surface	5.78E-07	3.20E-07
		1 m	5.44E-07	3.00E-07
	No cover	Surface	2.17E-06	1.22E-06
		1 m	2.06E-06	1.16E-06

Appendix G Human Intrusion Additional Results

G.1 Reference Case SGHWR Region 1

Table G.1: Calculated doses to receptors from borehole intrusions into SGHWR Region 1 in 2066 assuming the reference inventory and a cap thickness of 4.0 m. Case numbers in the left-most column refer to the list of intrusion cases in Table 7.4. Highlighting in pink indicates where the GRR dose guidance level for prolonged exposures (3 mSv y^{-1}) has been exceeded. None of the calculated doses to excavators exceed the GRR dose guidance level for transitory exposures (20 mSv y^{-1}).

Case	Receptor	Intrusion	Dose (mSv)
5	Excavator	Borehole 1 (Backfill, primary containment floor)	1.75E-03
	Infant, play area user	Borehole 1 (Backfill, primary containment floor)	1.70E-03
	Infant, land use	Borehole 1 (Backfill, primary containment floor)	2.32E-03
	Excavator	Borehole 2 (Backfill and secondary containment floor)	1.76E-03
	Infant, play area user	Borehole 2 (Backfill and secondary containment floor)	1.71E-03
	Infant, land use	Borehole 2 (Backfill and secondary containment floor)	2.32E-03
	Excavator	Borehole 3 (Bioshield wall and primary containment floor)	2.64E-03
	Infant, play area user	Borehole 3 (Bioshield wall and primary containment floor)	8.98E-03
	Infant, land use	Borehole 3 (Bioshield wall and primary containment floor)	2.27E-03
	Excavator	Borehole 4 & 5 (Pond wall and pond floor)	5.07E-03
	Infant, play area user	Borehole 4 & 5 (Pond wall and pond floor)	2.11E-03
	Infant, land use	Borehole 4 & 5 (Pond wall and pond floor)	1.14E-02
	Excavator	Total Boreholes (5)	1.63E-02
	Infant, play area user	Total Boreholes (5)	1.66E-02
	Infant, land use	Total Boreholes (5)	2.97E-02
6[65]	Excavator	Borehole 5 (Mortuary tubes and primary containment floor)	2.32E+00
	Infant, play area user	Borehole 5 (Mortuary tubes and primary containment floor)	5.94E-01
	Infant, land use	Borehole 5 (Mortuary tubes and primary containment floor)	3.56E+00
	Excavator	Total Boreholes (5)	2.33E+00

[65] Boreholes 1-4 in Case 6 are the same as those assessed in Case 5, hence the doses are not repeated.

Case	Receptor	Intrusion	Dose (mSv)
	Infant, play area user	Total Boreholes (5)	6.09E-01
	Infant, land use	Total Boreholes (5)	3.58E+00

G.2 Variant and Alternative Case Results Tables

G.2.1 SGHWR

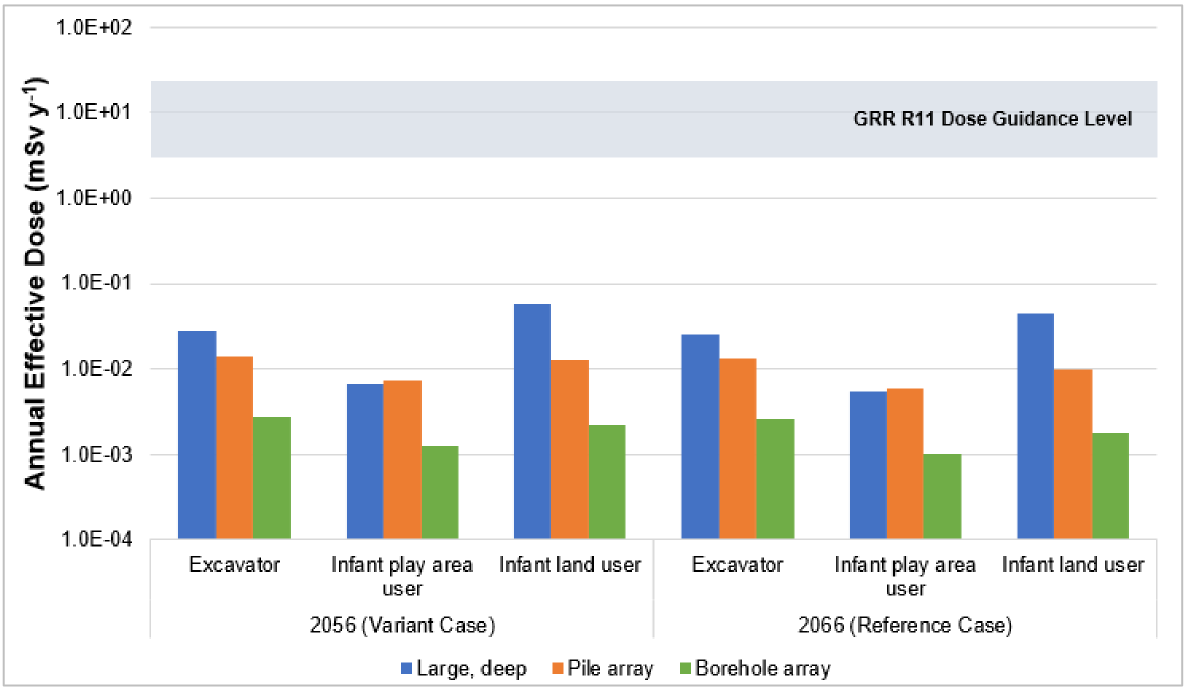

Figure G.1: Doses to receptors from intrusions into SGHWR North Annexe in 2056. Results shown assume the reference inventory and a cap thickness of 4.0 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

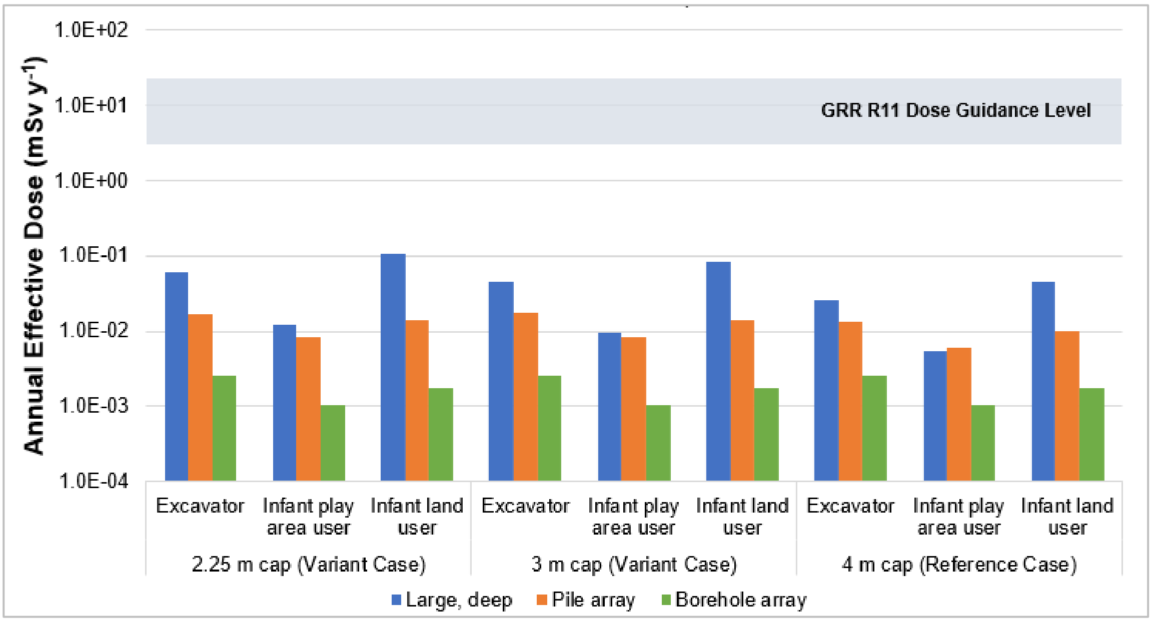

Figure G.2: Doses to receptors from intrusions into the SGHWR North Annexe in 2066 assuming the reference inventory. Results are shown for the two alternative cap thicknesses (2.25 m and 3.0 m) together with the reference cap thickness (4.0 m) for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

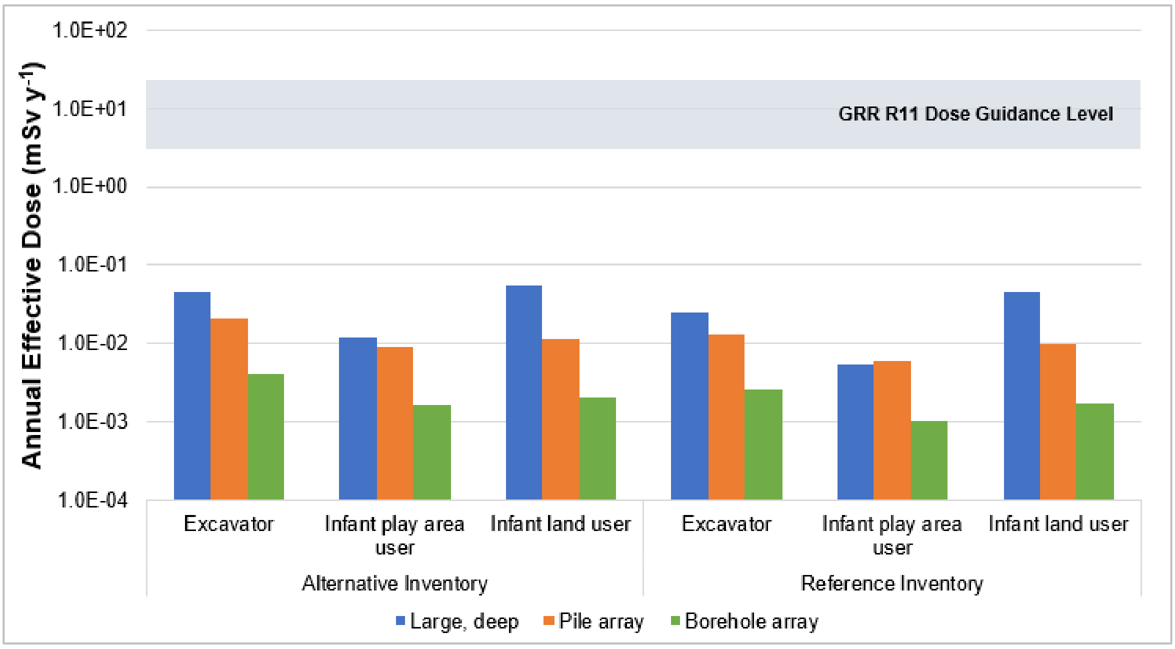

Figure G.3: Doses to receptors from intrusions into the SGHWR North Annexe in 2066 assuming the alternative inventory and reference cap thickness (4.0 m). Results are also shown assuming the reference inventory for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

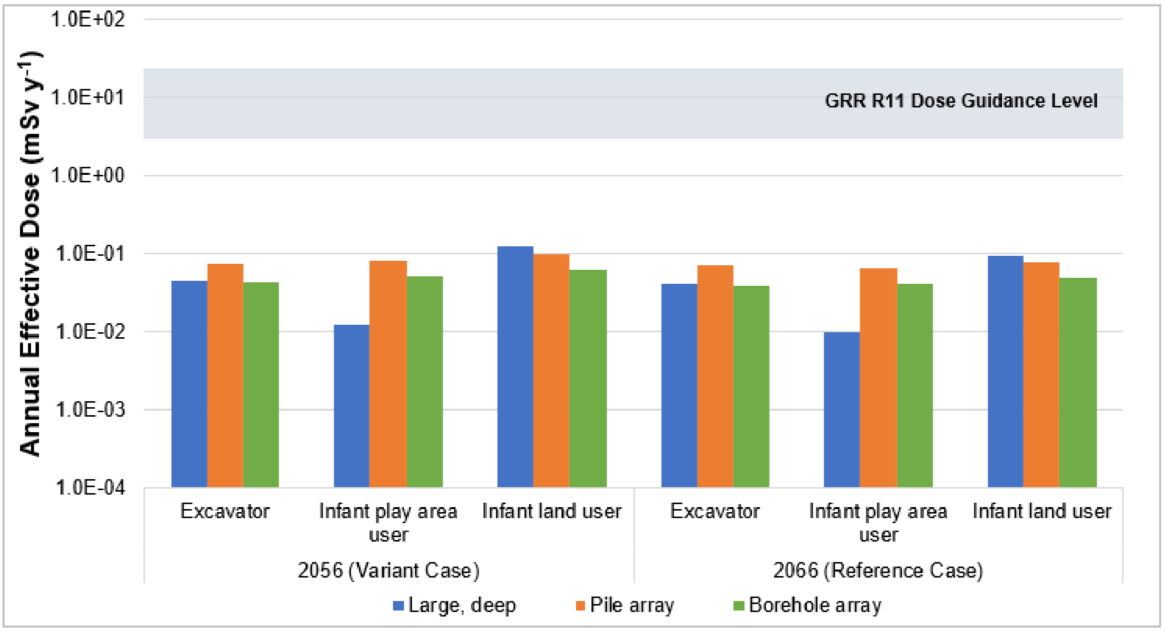

Figure G.4: Doses to receptors from intrusions into the SGHWR Region 2 and the South Annexe in 2056. Results shown assume the reference inventory and a cap thickness of 4.0 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

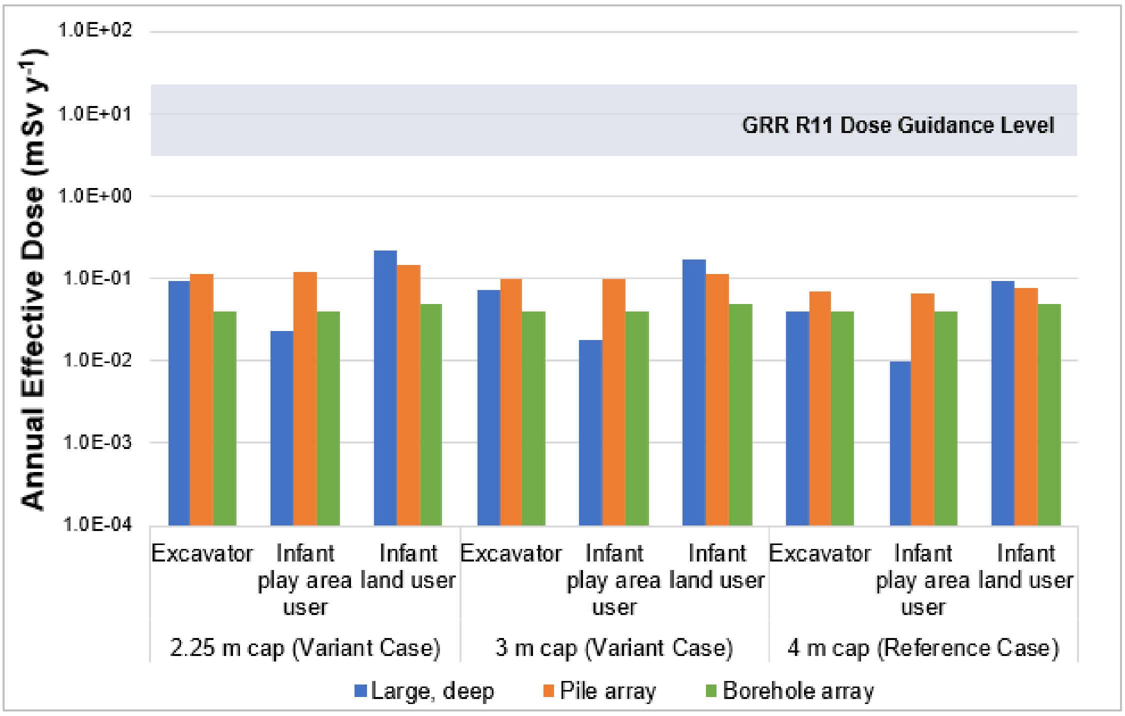

Figure G.5: Doses to receptors from intrusions into SGHWR Region 2 and the South Annexe in 2066 assuming the reference inventory. Results are shown for the two alternative cap thicknesses (2.25 m and 3.0 m) together with the reference cap thickness (4.0 m) for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

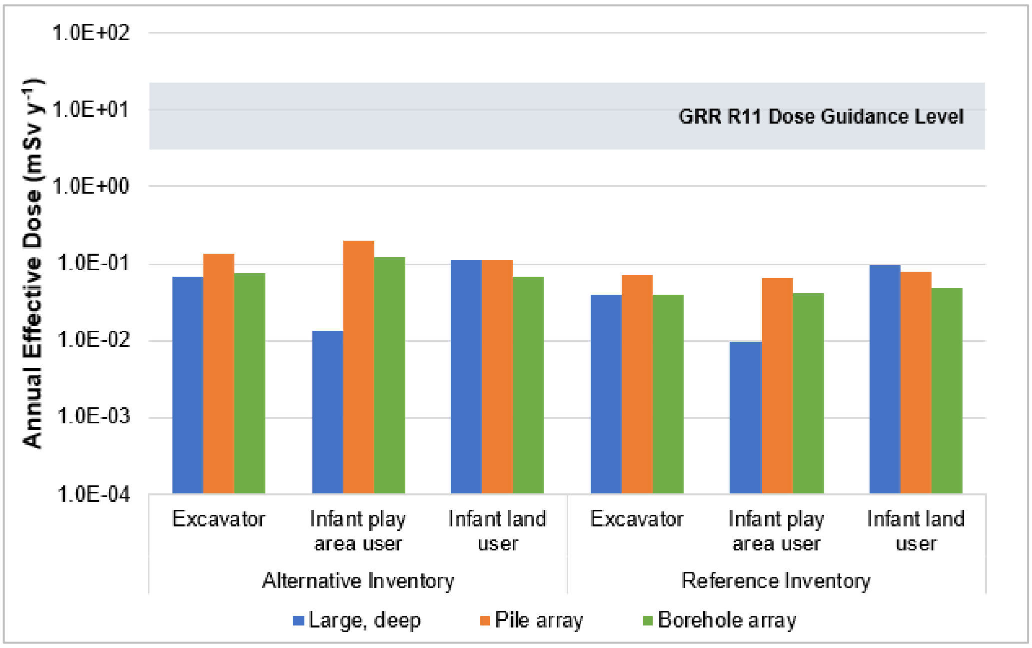

Figure G.6: Doses to receptors from intrusions into SGHWR Region 2 and the South Annexe in 2066 assuming the alternative inventory and reference cap thickness (4.0 m). Results are also shown assuming the reference inventory for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

G.2.2 Dragon Reactor Complex

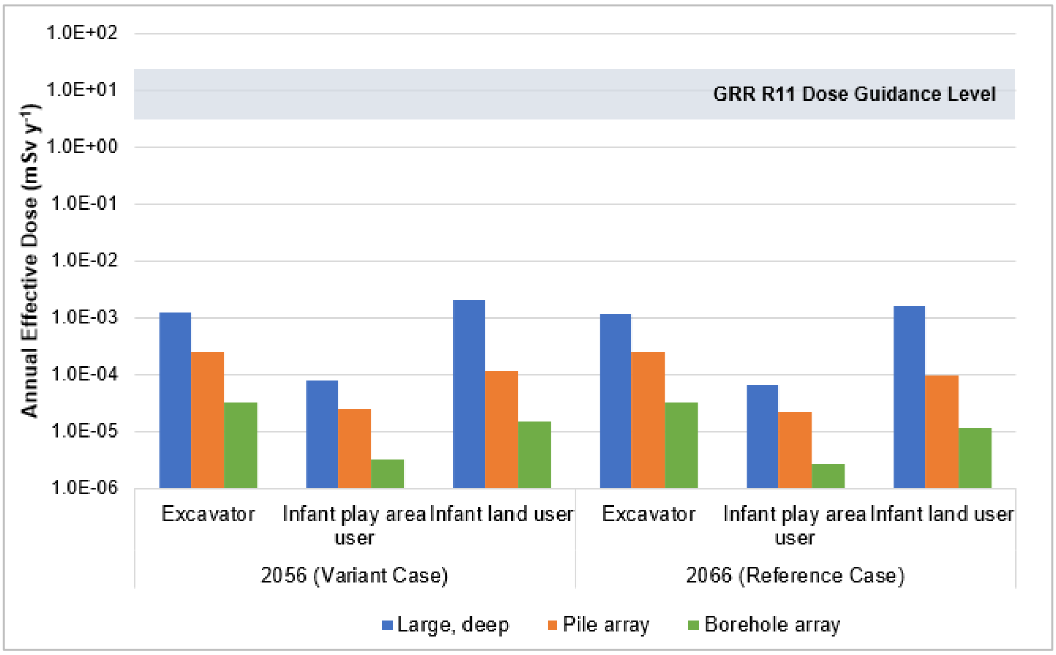

Figure G.7: Doses to receptors from intrusions into the B78 building floor slab in 2056. Results shown assume the reference inventory and a cap thickness of 3.8 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

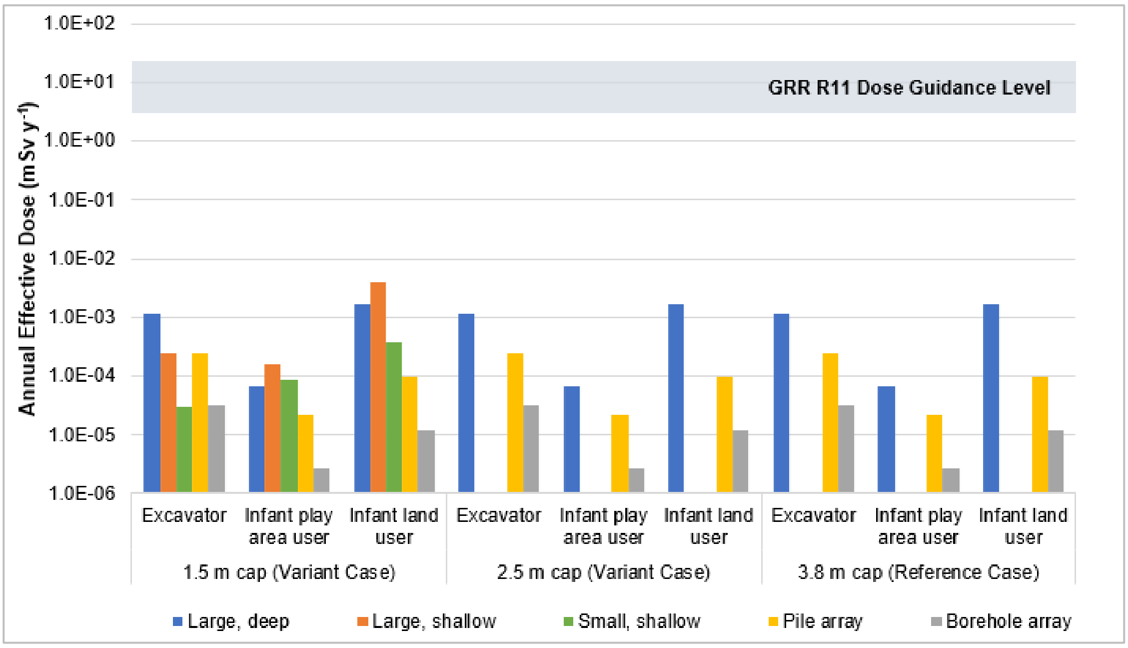

Figure G.8: Doses to receptors from intrusions into the B78 building floor slab in 2066 assuming the reference inventory. Results are shown for the two alternative cap thicknesses (1.5 m and 2.5 m) together with the reference cap thickness (3.8 m). Doses from the shallow intrusions only occur when assuming the thinnest cap (1.5 m) due to the depth of the shallow intrusions (2 m). The R11 dose guidance level range is indicated by the grey shaded band.

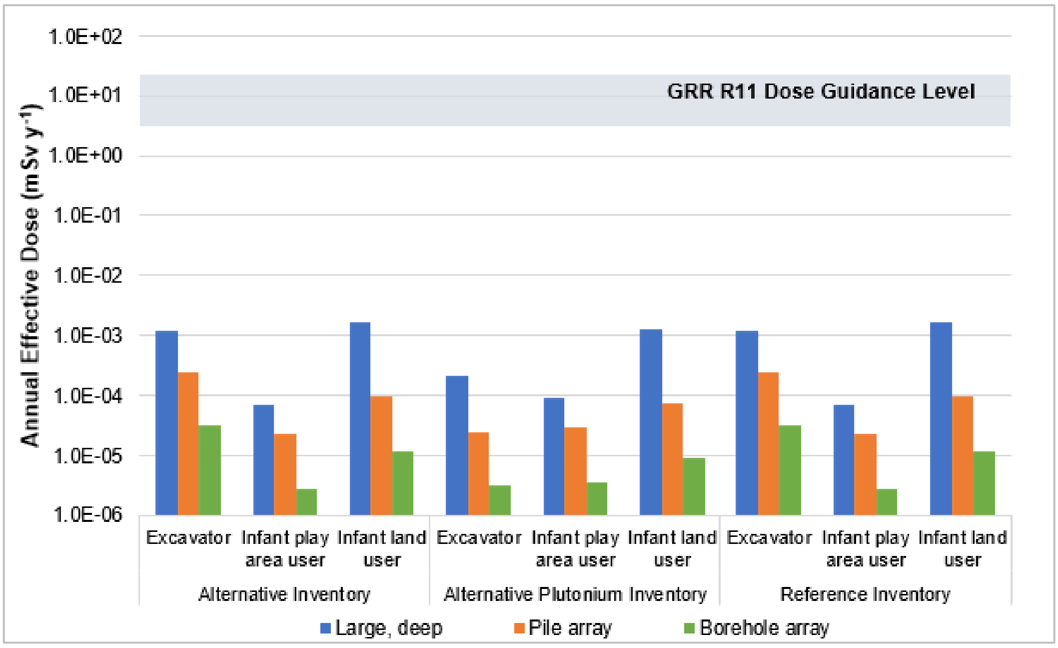

Figure G.9: Doses to receptors from intrusions into the B78 building floor slab in 2066 assuming the alternative inventory and the alternative plutonium inventory, compared to the reference inventory. All cases shown assume the reference cap thickness (3.8 m). The R11 dose guidance level range is indicated by the grey shaded band.

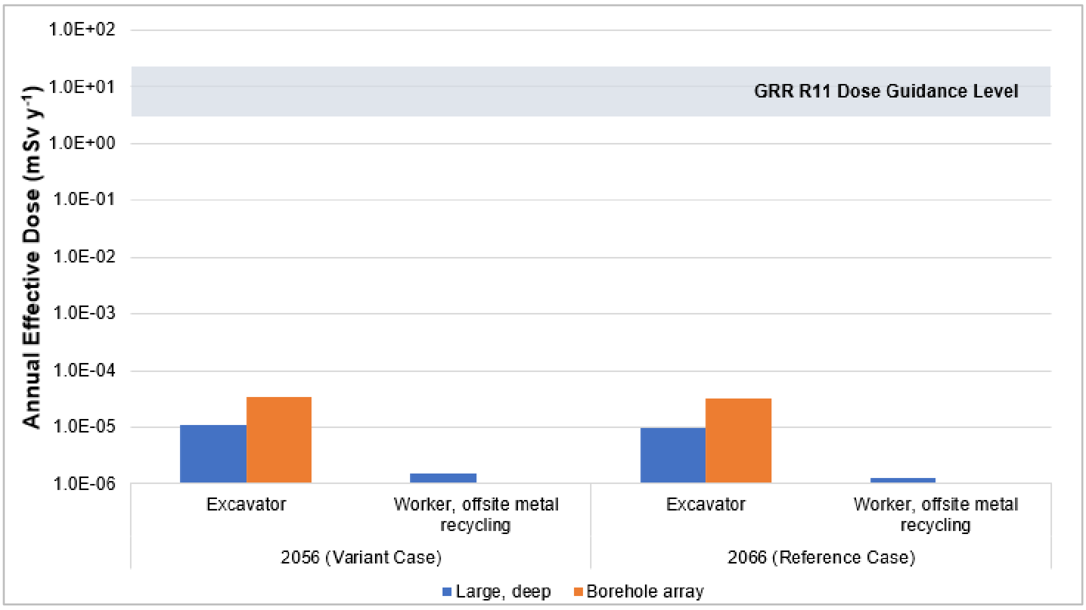

Figure G.10: Doses to receptors from intrusions into the Dragon mortuary hole structure in 2056. Results shown assume the reference inventory and cap thickness (3.8 m). Results are also shown for the Reference Case date of 2066. No doses are calculated to workers from boreholes as GIM does not assess this. The R11 dose guidance level range is indicated by the grey shaded band.

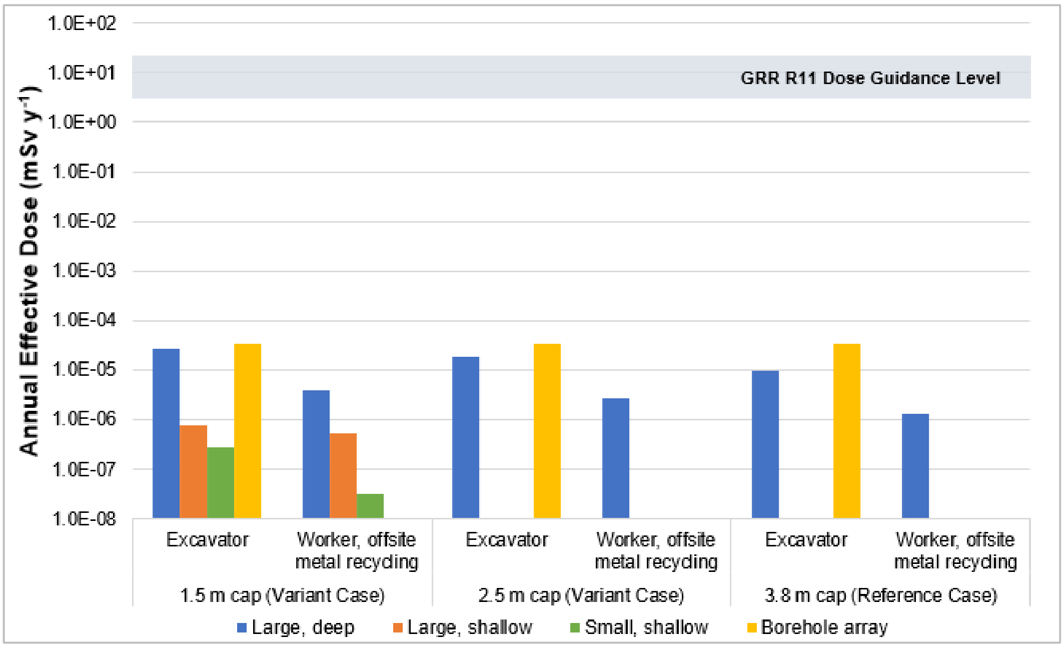

Figure G.11: Doses to receptors from intrusions into the Dragon mortuary hole structure in 2066 assuming the reference inventory and alternative cap thicknesses (1.5 m and 2.5 m). Doses from the shallow intrusions only occur when assuming the thinnest cap (1.5 m) due to the depth of the shallow intrusions (2.0 m), and no doses are calculated to workers from boreholes as GIM does not assess this. The R11 dose guidance level range is indicated by the grey shaded band.

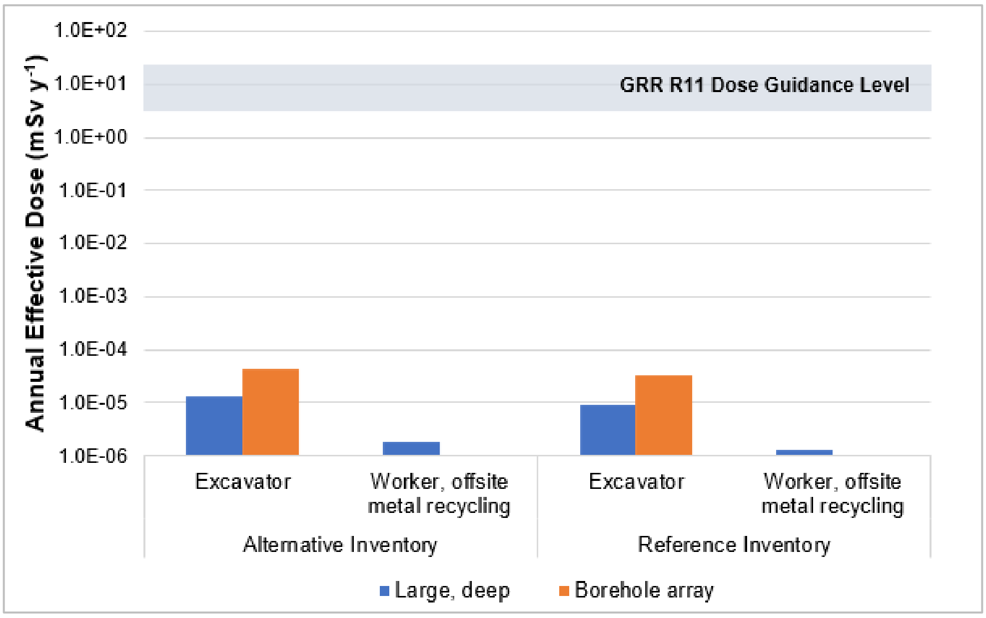

Figure G.12: Doses to receptors from intrusions into the Dragon mortuary hole structure in 2066 assuming the alternative inventory and reference cap thickness (3.8 m). Results are also shown assuming the reference inventory for comparison. Note that no doses are calculated to workers from boreholes as GIM does not assess this. The R11 dose guidance level range is indicated by the grey shaded band.

G.2.3 A59 Area

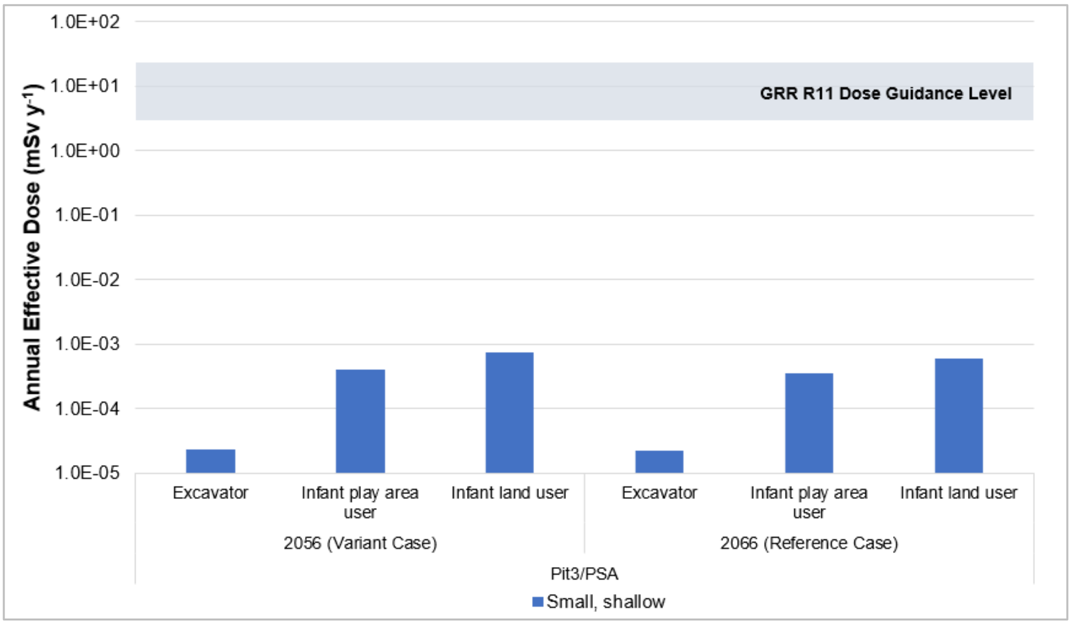

Figure G.13: Doses to receptors from intrusions into the remediated PSA/Pit 3 area in 2056. Results shown assume the reference inventory and reference cover material thickness of 0.5 m. Results are also shown for the Reference Case date of 2066 for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

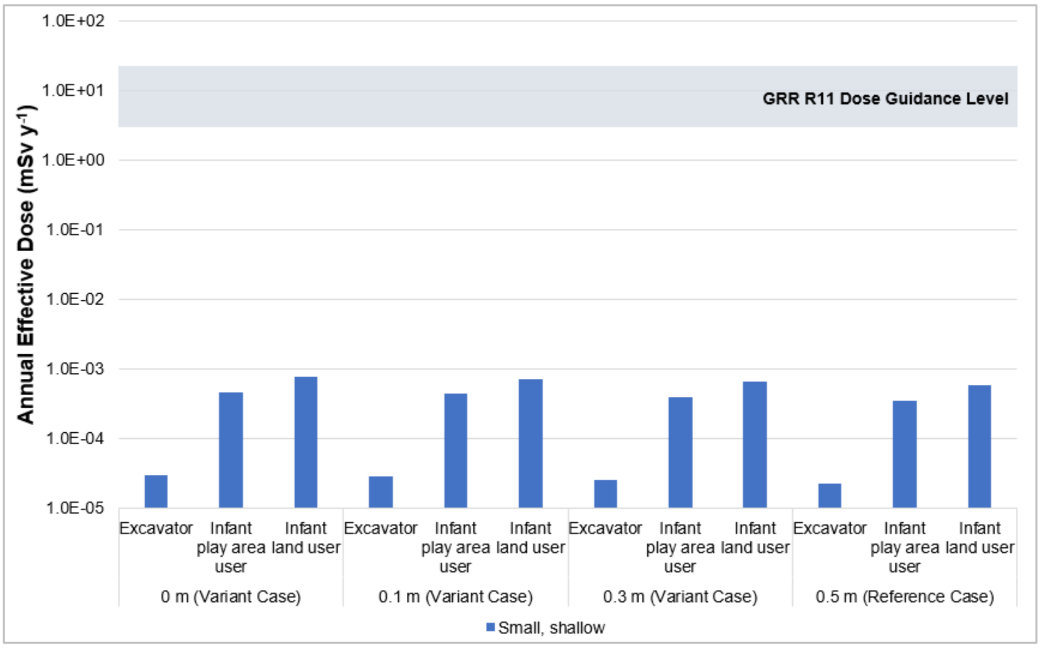

Figure G.14: Doses to receptors from intrusions into the remediated PSA/Pit 3 area in 2066 assuming the reference inventory. Results are shown for the three alternative cover material thicknesses (0 m, 0.1 m and 0.3 m) together with the reference cover material thickness (0.5 m) for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

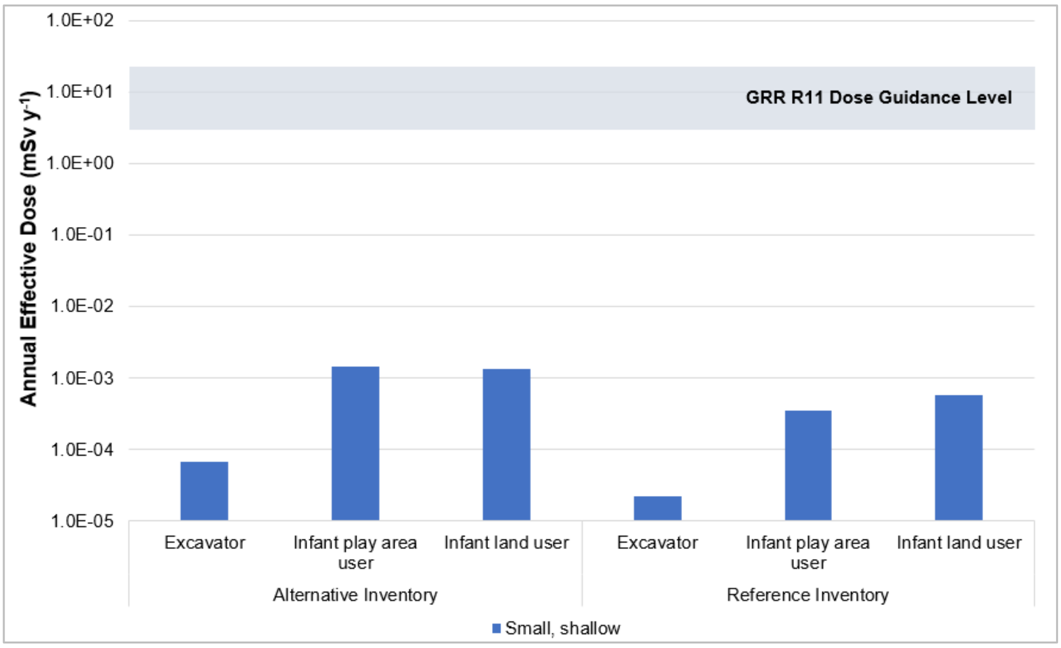

Figure G.15: Doses to receptors from intrusions into the remediated PSA/Pit 3 area in 2066 assuming the alternative inventory and reference cover material thickness (0.5 m). Results are also shown assuming the reference inventory for comparison. The R11 dose guidance level range is indicated by the grey shaded band.

Appendix H Model Run Management

H1 Table H.1 summarises the GSL run management system that records the details of each calculation or run that has been used to support the presentation and interpretation of the Winfrith NE assessment in this report. This enables each run to be repeated and the results to be reproduced. The information recorded is:

- Run ID – A unique integer that can be used to identify the run from which particular results have been derived.
- Address – The file address associated with a particular model run. This is where files (model input spreadsheet, GoldSim model file, model export spreadsheet) associated with a run are located.
- Assessment ID – ID number and Case/Scenario Name as detailed in Section 8.2.
- Adjusted Input Data Parameters – Identifies which parameters have been changed from their Reference Case state and identifies where the relevant controls in the PA input file are located.
- Number of calculations – The number of individual calculations in the run – used for the calculation of feature-specific impacts.
- Uses – Where the results of the run have been used, for example, in deriving a figure in this report, or in the presentation of results in a table.
- Comments – Any other relevant information, such as run times, unexpected results, confirmation of results.

H2 Note that all runs undertaken for this assessment were conducted using Version 1.02 of the Winfrith NE assessment model and PA input data file v1.02. The model was run for 120,000 years with the timesteps as specified in Section 5.1 (Time Stepping sub-section).

Table H.1: Run details for the Winfrith NE assessment cases considered in this report.

Run ID	Address	Assessment ID	Adjusted Input Data Parameters (Changes from the Reference Case)	No. of Calc.	Uses	Comment
1	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\01-Ref	Reference Case	N/A	18	Sections 10.1.1, 10.1.2, and 10.2.1	Also provides data for groundwater abstraction Variant Concept Cases VA.11, VA.12 and VA.13.
2	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\02-Alt_Inv	EE.1 Alternative inventory	"Model Controls" Inventory dataset = Alternative	1	Section 10.1.3 and E.1	
3	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\03-Path_Mire	VA.6 SGHWR and A59 groundwater discharge to mire	"Model Controls": SGHWR Release Proportion to the River Frome = 0% SGHWR Release Proportion to the mire = 100% A59 Release Proportion to the River Frome = 0% A59 Release Proportion to the mire = 100%	1	Section 10.2.1 and E.2	
4	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\04-Path_River	VA.5 SGHWR and A59 groundwater discharge to River Frome	"Model Controls": SGHWR Release Proportion to the River Frome = 100% SGHWR Release Proportion to the mire = 0% A59 Release Proportion to the River Frome = 100% A59 Release Proportion to the mire = 0%	1	Section 10.2.1 and E.2	
5	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\05-Child	EE.1.13 Child RP	"Model Controls" Receptor age = Child	1	Section 10.1.3 and E.1	
6	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\06-Infant	EE.1.14 Infant RP	"Model Controls" Receptor age = Infant	1	Section 10.1.3 and E.1	

Run ID	Address	Assessment ID	Adjusted Input Data Parameters (Changes from the Reference Case)	No. of Calc.	Uses	Comment
7	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\07-RWC	VA.9 Reasonable worst-case future groundwater levels	"Model Controls" Groundwater Level Dataset = Reasonable Worst Case	1	Section 10.2.1 and E.2	
8	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\08-Arbitrary_37m	VA.10 Reasonable worst-case future groundwater levels with seasonal fluctuation	"Model Controls" Groundwater Level Dataset = Arbitrary "NF - Flows" arbitrary case set to 37.0m SGHWR, 29.24m Dragon and 24.2m A59.	18	Section 10.2.1 and E.2	Arbitrary water levels - at maximum of seasonal fluctuation (37.0m for SGHWR)
9	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\09-Arbitrary_1mbgl	WI.2 Extreme climate change	"Model Controls" Groundwater Level Dataset = Arbitrary "NF - Flows" arbitrary case set to 39.61m SGHWR, 34.05m Dragon and 24.0m A59.	1	Sections 10.3 and E.4	Arbitrary water levels - to 1m bgl of each feature.
10	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\10-NF_Kd_min	EE.1.3 Minimum near-field sorption	"Model Controls" Near Field Partition Coefficients = Minimum	1	Section 10.1.3 and E.1	
11	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\11-NF_Kd_max	EE.1.4 Maximum near-field sorption	"Model Controls" Near Field Partition Coefficients = Maximum	1	Section 10.1.3 and E.1	
12	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\12-ChemDeg_1000y	VA.1 Shorter chemical degradation duration	"Model Controls" Chemical Degradation Time = 1000 y	1	Section 10.2.1 and E.2	
13	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\13-HydDeg_300y_1e-9	VA.3 Maximum initial hydraulic conductivity and shorter degradation period	"Model Controls": Hydraulic Degradation Time (y) = 300 Intact Concrete Hydraulic Conductivity (m/s) = 1e-9	1	Section 10.2.1 and E.2	
14	MXL WinfrithEndState\09.PA\11.PA_	VA.2 Minimum initial hydraulic	"Model Controls" Intact Concrete Hydraulic Conductivity (m/s) = 1e-12	1	Section 10.2.1 and E.2	

Run ID	Address	Assessment ID	Adjusted Input Data Parameters (Changes from the Reference Case)	No. of Calc.	Uses	Comment
	2023\03.NE_Model\03.Winfrith\ v1.02\14-HydDeg_1000y_1e-12	conductivity for SGHWR and Dragon structures				
15	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\ v1.02\15-Alt_Inv_Pu	EE.2 Alternative (Pu) Dragon inventory	"Model Controls" Inventory dataset = Alternative Pu (Dragon)	1	Section 10.1.3 and E.1	
16	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\ v1.02\16_Rubble_Infill	VB.2 Entirely rubble infill	"NF - Configuration" infill material column changed to Granular Concrete.	1	Sections 0 and E.3	
17	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\ v1.02\17_Grout_Infill	VB.3 Grouting of entire volume	"NF - Configuration" infill material column changed to Intact Concrete (Grouted).	1	Sections 0 and E.3	
18	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\ v1.02\18-Path_SGH_2_Dragon	VA.7 SGHWR groundwater discharge to Dragon	"Model Controls": SGHWR Release Proportion to the River Frome = 0% SGHWR Release Proportion to the mire = 0% SGHWR Release Proportion to Dragon = 100%	1	Section 10.2.1 and E.2	No change to A59 release paths.
19	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\ v1.02\19-Geo_Kd_min	EE.1.9 Minimum geosphere sorption	"Model Controls" Geosphere Partition Coefficients = Minimum	1	Section 10.1.3 and E.1	
20	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\ v1.02\20-Geo_Kd_max	EE.1.10 Maximum geosphere sorption	"Model Controls" Geosphere Partition Coefficients = Maximum	1	Section 10.1.3 and E.1	
21	MXL WinfrithEndState\09.PA\11.PA_ 2023\03.NE_Model\03.Winfrith\	EE.1.11 Minimum biosphere sorption	"Model Controls": Soil Partition Coefficients = Minimum Sediment Partition Coefficients = Minimum	1	Section 10.1.3 and E.1	

Run ID	Address	Assessment ID	Adjusted Input Data Parameters (Changes from the Reference Case)	No. of Calc.	Uses	Comment
	v1.02\21-Soil_Sediment_Kd_min					
22	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\22-Soil_Sediment_Kd_max	EE.1.12 Maximum biosphere sorption	"Model Controls": Soil Partition Coefficients = Maximum Sediment Partition Coefficients = Maximum	1	Section 10.1.3 and E.1	
23	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\23-Uptake_Factors_min	EE.1.15 Minimum uptake factors	"Model Controls" Uptake Factors = Minimum	1	Section 10.1.3 and E.1	
24	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\24-Uptake_Factors_max	EE.1.16 Maximum uptake factors	"Model Controls" Uptake Factors = Maximum	1	Section 10.1.3 and E.1	
25	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\25-Alt_Cap_Infil_Time	VA.4 Shorter cap degradation time	"Model Controls" Cap rainfall infiltration rate = Variant	1	Section 10.2.1 and E.2	
26	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\26-Variant_Soil_Recharge	VA.8 Increased rate of rainfall infiltration through soil	"Model Controls" Soil rainfall infiltration rate (recharge) = Variant	1	Section 10.2.1 and E.2	
27	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\27-Instant_HydDegrad	WI.1 Instantaneous hydraulic degradation	"NF - Configuration" Initial Intact Concrete Hydraulic Status column changed to Hydraulically Degraded (except for bioshields).	1	Sections 10.3 and E.4	Majority starts hydraulically degraded; this only impacts SGHWR now.
28	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\28-Void_Block_Space	VB.1 Greater void spacing between blocks	"NF - Geometry" cell AB28 void space between blocks (v/v) = 0.2	1	Sections 0 and E.3	

Run ID	Address	Assessment ID	Adjusted Input Data Parameters (Changes from the Reference Case)	No. of Calc.	Uses	Comment
29	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\29-Block_Size_min	VB.4 Minimum block size	"NF - Geometry" cell AB29 blocks size (m3) = 0.5	1	Sections 0 and E.3	
30	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\30-Block_Size_max	VB.5 Maximum block size	"NF - Geometry" cell AB29 blocks size (m3) = 2.4	1	Sections 0 and E.3	
31	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\31-Conc_Porosity_min	EE.1.5 Minimum concrete and rubble porosity	"NF - Materials" cell E54 porosity (intact concrete) = 0.1 "NF - Materials" cell E64 porosity (rubble) = 0.2	1	Section 10.1.3 and E.1	
32	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\32-Conc_Porosity_max	EE.1.6 Maximum concrete and rubble porosity	"NF - Materials" cell E54 porosity (intact concrete) = 0.26 "NF - Materials" cell E64 porosity (rubble) = 0.4	1	Section 10.1.3 and E.1	
33	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\33-Conc_Density_min	EE.1.7 Minimum dry bulk concrete density	"Model Controls" Intact Concrete Bulk Density (kg/m3) = 2250	1	Section 10.1.3 and E.1	
34	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\34-Conc_Density_max	EE.1.8 Maximum dry bulk concrete density	"Model Controls" Intact Concrete Bulk Density (kg/m3) = 2500	1	Section 10.1.3 and E.1	
38	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\38-Mire_Outflow_min	EE.1.17 Minimum mire outflow rate	"Bio - Materials" Land/Mire outflow rate, cell D65 - default value is 1.34E06 m^3/y - reduce by factor of 10	1	Section 10.1.3 and E.1	
39	MXL WinfrithEndState\09.PA\11.PA_2023\03.NE_Model\03.Winfrith\v1.02\39-Mire_Outflow_max	EE.1.18 Maximum mire outflow rate	"Bio - Materials" Land/Mire outflow rate, cell D65 - default value is 1.34E06 m^3/y - increase by factor of 10	1	Section 10.1.3 and E.1	

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