9. Long-Term Radiological and Non-Radiological Impacts of the Proposed Disposals

9.1 INTRODUCTION

Summary Boxes

9.1.1 Throughout this chapter, summary boxes are used. The colour of the boxes indicates the purpose of the summary box as follows:

Explainer	These boxes give introductory text to help understanding of the text that follows. They are also used to help explain some technical terms.
Regulatory requirements / regulatory expectations	These boxes are used to summarise either legal requirements, or expectations in regulatory guidance. These boxes are not a substitute for the full legislation or guidance that they aim to summarise.
Conclusions	These boxes give short summaries of the key points from the Applicant's assessments.

Scope of this Chapter

Explainer: Scope of This Chapter

To deliver the proposed development there are existing controls under other regulatory regimes that will have to be satisfied. This chapter explains other regulatory requirements that are relevant to the Long-Term Radiological and Non-Radiological Impacts and how it is considered that these will be complied with. This chapter summarises the findings of assessments of long-term impacts resulting from the "disposal" aspects of the Proposed Development. These impacts arise from:

"natural evolution" (meaning the gradual migration of pollutants from the disposals into groundwater and onward transport in the environment), and

future site occupancy (meaning people residing or working above the disposals).

This includes radiological and, where relevant, non-radiological aspects. It includes impacts on people, plants and animals, groundwater and streams.

This chapter also summarises assessments of the potential radiation doses to people arising from human intrusion into the disposals, if such intrusion were to occur[1].

This chapter includes a summary of the main assessments of the long-term impacts carried out to support the environmental permit application (made in

[1] For the assessments of intrusion impacts, after the site's environmental permit and nuclear site licence have both been surrendered, it is pessimistically assumed that no controls on land-use, access or development will apply to the site or its surroundings.

December 2023) for the Proposed Disposals[2]. These assessments relate to those aspects that are regulated by Natural Resources Wales (NRW) under environmental permitting legislation[3].

9.1.2 The current site aqueous discharges include the pumped discharge to Llyn Trawsfynydd of treated radioactive effluent and, separately via the 'diversion culvert' sump, of much of the site's drainage water (including slightly radioactive land drains water). When the Trawsfynydd site ceases to be subject to environmental permitting, these discharge arrangements will also have ceased. Most of the long-term impacts with which this chapter of the Environmental Statement is concerned could only occur after that time. It is not part of the scope of the Proposed Development to take the current site discharge arrangements out of service, but there is a requirement to assess the long-term impacts of the disposals after these permitted discharges have ceased.

Terminology

9.1.3 As explained in the Planning Statement submitted with the planning application and elsewhere within this Environmental Statement, whilst the radioactive materials being retained permanently either in situ (i.e. left where they are) or being used as infill in voids are, in environmental permitting terms, "waste", that is not necessarily the case within the Town and Country Planning regime for all the materials concerned. For comparison, non-radioactive redundant sub-surface structures left in the ground on former industrial sites are not usually regarded as "waste" in planning terms, even if contaminated by non-radioactive substances.

9.1.4 Similarly, whilst the word "disposal" is used throughout this Environmental Statement and in this chapter, this is mainly because that is how the permanent retention of the redundant radioactive structures and radioactive void infill is considered within the environmental permitting regime. Use of the word "**disposal**" is also a convenient shorthand means of describing the aspects of the Proposed Development most relevant to this chapter. The use of the word "disposal" in this

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[2] Main references:

- Trawsfynydd Site: Radiological Assessment of Natural Evolution for the Envisaged Dispo sal Area Structures – Reference (Base) Case and Variant Cases/Scenarios, DD/REP/0009/23, Issue 2, October 2023.
- Trawsfynydd Site: Radiological Assessment of Doses to a Site Occupier from the Envisa ged Disposal Area Structures - Base and Variant Cases, DD/REP/0008/23, Issue 2, October 2023.
- Trawsfynydd Site: Radiological Assessment of Human Intrusion for the Envisaged Disposal Area Structures - Base Case and Variant Cases/Scenarios, DD/REP/0007/23, Issue 2, October 2023.
- Trawsfynydd Ponds Complex Demolition and Disposal Project: Tiered Assessment of Ris ks to Groundwater from Non-Radiological Pollutants, DD/REP/0021/23, Issue 1, October 2023.

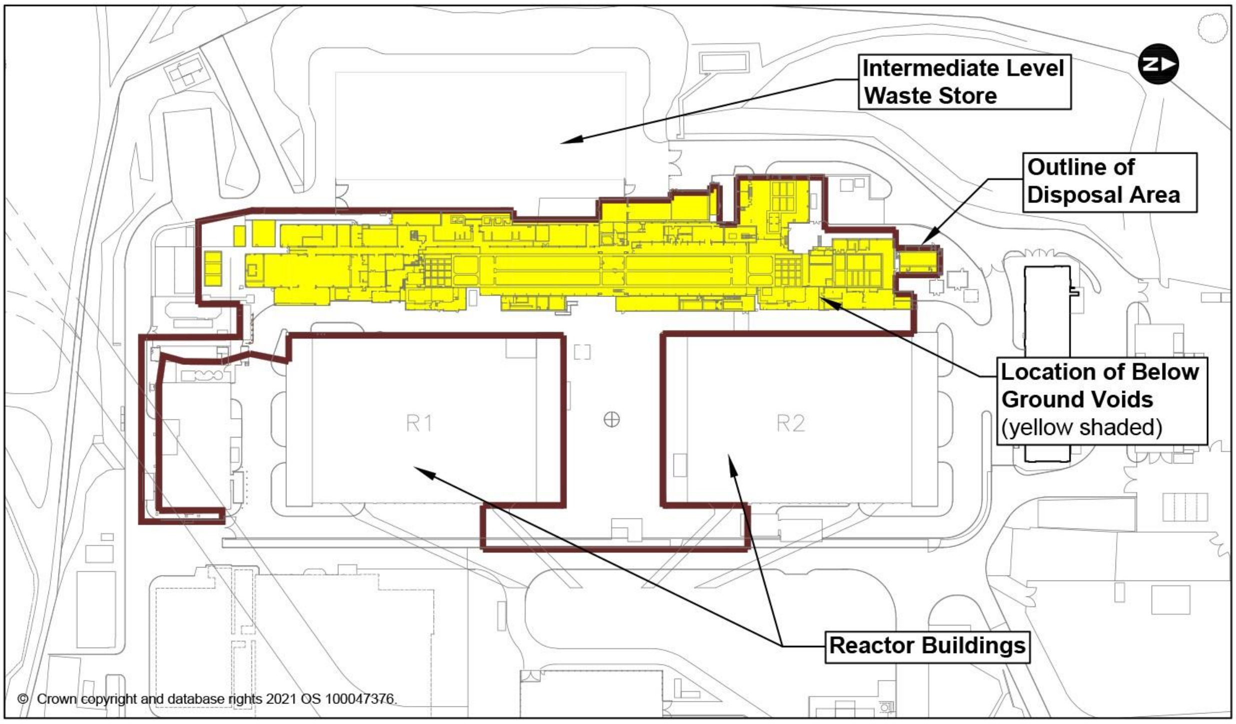
[3] Impacts deriving from potential changes to groundwater levels and flows have also been included in this chapter. These changes may occur because of works on under-ponds drains to be undertaken in advance of the Proposed Development. These works do not require planning permission. Nevertheless, they are discussed here because of their potential lasting (long-term) effects.

chapter (or in any of the other documentation supporting this planning application) should not be taken to have specific meaning in Town and Country Planning terms.

9.1.5 In this chapter, rather than using the term "Proposed Development", the term "**Proposed Disposals**" is sometimes used. This is because a significant part of the Proposed Development, namely the demolition works, is not in itself relevant to this chapter. However, when using the term "Proposed Disposals" this may include associated engineered features, such as the concrete cap, depending on the context in which the term is used.

9.1.6 As introduced in the Project Description (Chapter 3) and as shown on the planning application drawings, the term "**Disposal Area**" is also used. The Disposal Area, shown in Figure 9.1, includes several radioactively contaminated redundant underground features which require no further physical work but which are proposed to be permanently retained in place. This is the reason for the inverted T-shape towards the centre of the figure between the reactor buildings, and for the C-shape on the left of the figure.

Figure 9.1: Disposal Area - indicated by brown line. Structures highlighted in yellow are those with substantial below-ground voids.



9.1.7 Within this environmental statement, "**pollutant**" has the same meaning as that given in the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (based on the Water Framework Directive). There the term is defined as "*any substance liable to cause pollution*", though it identifies certain substances in particular. In these Regulations "**pollution**" means "*the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of* *aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment*".

9.1.8 Within this environmental statement, "**hazardous substance"** is also meant as defined in the same Regulations. The term refers to "*substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances which give rise to an equivalent level of concern*".

9.1.9 **"Radionuclides"** are unstable forms of chemical elements that release energy as they break down into a more stable configuration. In some contexts, radionuclides are referred to by the UK's environment agencies as "hazardous substances" because they release energy in the form of ionising radiation. In this chapter, when radioactivity is the primary property of interest, then the term "hazardous substance" is not used, but rather other terms such as "radionuclide" or "radioactive contamination" are used. [Note that a hazardous substances consent is not required from the local planning authority for the presence of a hazardous substance which creates a hazard from ionising radiation if present on, over or under land in respect of which a nuclear site licence has been granted][4].

EXPLAINER: ISOTOPES, RADIONUCLIDES, HALF-LIVES, AND TYPES OF RADIATION

Many people will be familiar with the term "isotopes". Isotopes are distinct "versions" of the same chemical element. In general terms, they have the same atomic number (number of protons in their nucleus, which dictates chemical behaviour) but different numbers of neutrons (which makes some isotopes of the same element radioactive and others not). The term "radionuclide" is sometimes used to refer to radioactive isotopes.

Radionuclides emit ionising radiation, which is a form of radiation that can harm living tissue and living organisms. Exposure to ionising radiation may occur through internal or external pathways. External exposure occurs when radionuclides are outside the body, in the surrounding environment or deposited on the skin. Internal exposure occurs when radionuclides are inhaled, ingested, or otherwise enters into the bloodstream (e.g. absorb through skin or injected in a wound).

The term "half-life" refers to the time it takes for radioactive decay to reduce the number of atoms of a particular isotope by a factor of two. In some cases, though, the isotope atoms have changed through radioactive decay into other radioactive forms with different half-lives and emitting different types of radiation.

There are three main types of ionising radiation:

Alpha particles – energetic helium nucleus that are highly ionising. Alpha particles are easily stopped (few centimetres in air, less than a tenth of a millimetre in biological tissue) and only cause harm through internal pathways.

Beta particles – high speed electrons or positrons that do less damage than alpha particles. Beta particles can travel tens of centimetres in air and a few

[4] In land use planning there is a regime related to gaining consent for the storage and use of defined hazardous substances from the planning authority. In Wales this is legislated via the Planning (Hazardous Substances) (Wales) Regulations 2015.

millimetres through material, meaning it can cause harm when deposited n the skin.
Gamma radiation – highly energetic photon (the most energetic photons in the electromagnetic spectrum). Gamma rays are similar to visible light but have much more energy and can penetrate material.
The type of ionising radiation emitted is unique for each radionuclide. The main radionuclides of interest for radiological protection at the disposal area are:
Caesium is a chemical element. Caesium-137 (Cs137) results from nuclear fission and is a radioactive isotope of Caesium. Cs137 has a half-life of about 30 years. When it decays, Cs137 itself emits beta particles, which are small, fast-moving particles with a negative electrical charge. Beta particles are easily stopped by relatively thin amounts of materials.
Cs137 has a very short-lived decay product, which is the radionuclide Barium-137m (Ba137m). Ba137m emits gamma rays when it decays, gamma rays being a form of electromagnetic radiation (just like X-rays or light). It is this short-lived daughter product that means Cs137 can be detected using gamma detectors, and which means that ionising gamma radiation deriving from Cs137 can have an effect even through concrete shielding, depending on the thickness of that shielding.
Strontium is another chemical element. Sr-90 (Sr90) is a radioactive isotope of Strontium. It is also a product of nuclear fission and is often present where Cs137 is present, at least initially. Sr90 also has a half-life of about 30 years. Sr90 is a pure beta particle emitter; it does not emit any gamma radiation.
Some isotopes of Plutonium, Americium and so on are also radioactive and therefore fall within the term "radionuclides". As a group, these heavier isotopes are sometimes referred to as "actinides". Actinides at Trawsfynydd were used in or derived from nuclear reactor fuel. (This does not mean that any actinides remaining at Trawsfynydd are capable of the sort of reactions that were occurring within reactors during operation). Different actinides variously emit alpha particles (which consist of two protons and two neutrons bound together into a particle identical to a helium-4 nucleus), beta particles, or gamma irradiation. Alpha particles are also easily stopped by relatively thin amounts of materials. Many actinides have very long half-lives and longer decay-chains than lighter radionuclides.

9.1.10 The term **"non-human biota"** in this chapter refers to non-human living organisms that may utilise the area around the Trawsfynydd site as habitat. These biota may therefore, eventually, receive a radiation dose deriving from the Proposed Disposals. This includes plants and animals using local watercourses downgradient of the Proposed Disposals.

9.1.11 If people or non-human biota are exposed to radionuclides, the radiation arising from those radionuclides results in the deposition of energy in the tissues of those people or biota. For people, this is measured in units of **Sieverts (Sv)**. For non-human biota, this is measured in **Grays (Gy)**. These terms are further explained later in this chapter.

9.1.12 The term "**representative persons**" means individuals who would be exposed to the greatest radiological dose for a given release of radioactivity into the environment from the Disposal Area.

9.1.13 Finally, “**natural evolution**” involves the gradual degradation of the concrete of the structures of the Proposed Disposals including the concrete cap, with a gradual increase in water passing through the disposals, resulting in contaminated leachate migrating away[5]. By definition, “natural evolution” excludes the consequences of unlikely, intrusive events, such as inadvertent excavations or drilling into the Proposed Disposals.

Appendices

9.1.14 The chapter appendices, which contain more detailed information on specific aspects relevant to this chapter, are:

- Appendix 9A: Environmental Permitting Regulations (EPR16)
- Appendix 9B: Guidance on Requirements for Release from Radioactive Substances
- Regulation
- Appendix 9C: Radioactive Inventory
- Appendix 9D: Radiological Impact Modelling Input Data
- Appendix 9E: Overview of Site Hydrogeology
- Appendix 9F: Baseline Environmental Radionuclide Data
- Appendix 9G: Predicted Environmental Concentrations of Radionuclides
- Appendix 9H: Intrusion Radiological Assessment Results
- Appendix 9I: Radiological Assessment of Impacts on Non-Human Biota
- Appendix 9J: Non-Radiological Assessment of Impacts on Controlled Waters
- Appendix 9K: Impacts on Groundwater Flows and Levels
- Appendix 9L: Radiological Assessment Uncertainties

Assessment Team

9.1.15 The assessments of radiation exposures to members of the public have been undertaken by Galson Sciences Ltd (GSL)[6]. GSL provide consultancy services to nuclear sector clients worldwide[7] including undertaking radiological and non-

[5] In the permit application the assessment of natural evolution also includes consideration of the long-term consequences of natural processes that might disrupt the disposals, such as earthquakes. For example, increased mobilisation of radionuclides if the concrete cap is severely damaged.

[6] The GSL natural evolution radiological assessment work has been peer reviewed by relevant specialists from the Nucleus Alliance of companies, led by Quintessa Ltd. Quintessa Ltd consultancy services cover geosciences, modelling, risk assessment and software development.

[7] GSL has performed work in most European Commission countries, Eastern Europe and Russia, the US, Japan, Australia and New Zealand, and directly for the European

radiological impact assessment and modelling. This includes environmental simulation, and modelling of different exposure pathways and mechanisms. GSL was involved in the successful application for the licensing of the world's only deep geologic repository for long-lived transuranic waste (in the USA). GSL has also led the development of environmental safety cases for authorisation of waste disposal facilities in the UK.

9.1.16 The assessments of radiation exposures to non-human biota have been undertaken by suitably qualified and experienced persons within the Applicant's organisation, using modelling data provided by GSL, with GSL reviewing the methodology and checking the correct application of the method.

9.1.17 The assessment of long-term non-radiological impacts has been undertaken by David Drury of WSP (formerly Golder Associates). This includes both non-radiological pollutant impacts on groundwater, and potential changes to groundwater levels and flows. David Drury is a hydrogeologist who has been involved in site investigation, hydrogeological conceptual model development and assessment of contaminated ground and groundwater at Trawsfynydd for around 25 years.

Guidance from the UK Environment Agencies

9.1.18 Extracts from relevant guidance and legislation are provided in Appendix 9A and Appendix 9B.

9.1.19 The principal guidance followed for the radiological assessment work presented in this chapter is set out in: Scottish Environment Protection Agency, Environment Agency and Natural Resources Wales. Management of Radioactive Waste from Decommissioning of Nuclear Sites: Guidance on Requirements for Release from Radioactive Substances Regulation, Version 1.0, July 2018 (informally known as the GRR). The main aspects of this guidance are summarised in Appendix 9B.

9.1.20 For non-radiological aspects, standard tiered risk assessment guidance been followed, including Environment Agency, 2018. Groundwater Risk Assessment for Your Environmental Permit. 3 April 2018.

9.2 CONSULTATION AND ENGAGEMENT

Overview

9.2.1 A summary of stakeholder engagement, though not including all regulatory engagement, is provided in the Statement of Community Involvement (Avison Young Reference: AY/17C1000085/SCI/02, Magnox Reference: TRAWS-23-043 Issue 02) submitted with the planning application. Some of these engagement activities are discussed below.

9.2.2 Stakeholder engagement activities have included:

- Pre-application discussions with Eryri National Park Authority (ENPA);

Commission, the OECD/Nuclear Energy Agency, the International Atomic Energy Agency (IAEA), and the World Health Organisation (WHO).

- Requests for an EIA screening and scoping opinions from ENPA;
- Presentations and discussions as part of the Site Stakeholder Group (SSG) meetings;
- Presentations and discussions as part of the Trawsfynydd End State Group (TESG) meetings;
- Discussion in a stakeholder workshop in November 2016 involving representatives of the Applicant, the Nuclear Decommissioning Authority (NDA), regulatory organisations covering England, Wales and Scotland, and representatives of the SSG;
- Request for feedback from elected Councillors (December 2022);
- Three staffed public engagement events and four further unstaffed exhibitions (summer 2023);
- Health Impact Assessment workshop (October 2023).

Health Impact Workshop

9.2.3 On 4th October 2023, a workshop was held at the Trawsfynydd site with members of the local community. The main points raised by members of the local community, pertinent to this chapter, were:

- A large number of assumptions have had to be made about the future in the assessments, is this a concern?;
- What if the ponds complex contains features or contamination levels that are presently unknown?;
- What are the potential radiological impacts from malicious intrusion?;
- What about long-term record keeping?

9.2.4 In response to each of these points:

- This chapter discusses uncertainties later. In general, cautious assumptions (likely to result in over-estimating consequences) have been made in the assessments, including in relation to the assumed radioactive inventory of the disposals.
- The ponds complex will be thoroughly characterised (meaning subject to a range of measurements) prior to demolition. There will be “acceptance” criteria for disposal pre-determined and agreed with NRW. Dose and risk assessments will be updated with new information as and when required. It is thought unlikely that there will be any significant shifts in understanding and unlikely that significantly more adverse radiological assessment results will arise. The Trawsfynydd ponds complex is not fundamentally different to ponds facilities throughout the Applicant’s fleet of reactor sites, meaning they are well understood, and there has been a cautious approach to the assessments

summarised in this chapter. The option of removing problematic features / radioactivity “hotspots”[8] is also available.

- It is considered that malicious intrusion is unlikely given the difficulty of breaking through the concrete cap. In any case, the hypothetical impacts from such an event should be no greater than already estimated in the inadvertent (uncontrolled) intrusion assessments summarised in the permit application and later in this chapter of the Environmental Statement. Those assessments assume intrusion into the most radioactive parts of the disposals, at the earliest potential time.
- Long-term record keeping is addressed through environmental permitting controls. All records can be made available to ENPA on request, and essential records will be retained in the NDA’s national nuclear archive.

Trawsfynydd End State Group (TESG)

9.2.5 NRW, supported by the Environment Agency (EA) in relation to radioactive substances regulation, have been members of the Trawsfynydd End State Group (TESG) since its inception in 2016. The TESG also includes representatives from ENPA and the Office for Nuclear Regulation (ONR) and has been meeting three or four times a year (including remotely through the period of COVID-19 restrictions).

9.2.6 The TESG has received numerous presentations from the Applicant concerning its developing approach to defining the end state of the Trawsfynydd site as a whole and of the ponds complex in particular. Following the formal adoption by the NDA of an overall site end state strategy involving the on-site disposal of radioactive waste (in the form of redundant structures and some demolition arisings), there have been more focused technical engagements between the Applicant and its regulators on specific aspects of the developing proposals.

Other Technical Engagement

9.2.7 During 2022 and 2023, a series of meetings was established between the Applicant, its technical consultants for topics relevant to this chapter, NRW and the EA. The topics discussed included:

- Characterisation (past and proposed), which concerns knowledge about the radioactive content of the ponds complex and associated features;
- the modelling of the release of radioactivity from the disposals, the transport of radionuclides in groundwater and surface water, the behaviour of radionuclides in the accessible environment, and consequent doses to people;
- the modelling of inadvertent (uncontrolled) human intrusion scenarios;
- non-radiological controlled waters risk assessment, including alkalinity / pH effects; and
- long-term monitoring (boreholes, drainage systems, surface waters).
-

[8] “Hotspot” is an industry term used for a discrete area of radioactivity due to having a much higher radioactivity concentration than the surrounding area.

Eryri National Park Authority EIA Scoping Opinion

9.2.8 The Proposed Development was subject to an EIA scoping request to ENPA and a final scoping opinion was received 23rd March 2023. In relation to this chapter, it stated:

"The information within the scoping report relating to the radiological impacts… have been reviewed.... the receptors identified appear to be appropriate and we concur with the need for the further assessments proposed. The approach to the long-term radiological assessments is in line with what NRW would expect to support the permit application under GRR (Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation) and NRW have indicated that they are in technical discussions with Magnox [now NRS] *on the validity of the models being used."*

9.2.9 The environmental permit variation application associated with the Proposed Disposals was submitted to NRW in December 2023. Concerning this, the ENPA scoping opinion stated:

"It is anticipated that further discussions will ensue as to the timing of both planning and permitting applications and if both planning and environmental permit applications (GRR) are to be staggered or twin tracked…As the ES [Environmental Statement] *sets out the results of the EIA process, for consistency of decision, the avoidance of doubt and possible legal challenge, it is trusted that the planning application submission including the ES where there are both permitting and planning considerations…will be consistent in contents".*[9]

9.2.10 This chapter summarises all the radiological and non-radiological long-term impacts considered as part of the permit variation application made to NRW in December 2023, including "natural evolution" of the disposals and the potential consequences of future inadvertent (uncontrolled) intrusion events after release of the site from regulation, with these assessments variously considering impacts to people, non-human biota and the environment. However, there are some small differences between this chapter and the environmental permitting submissions made in December 2023. These are discussed later in this chapter at **Section 9.3**.

9.2.11 This chapter is not intended as a full demonstration of compliance with all environment agencies' GRR requirements, though some discussion is provided. The comparisons with GRR requirements are made more fully in the environmental permit submissions.

9.2.12 This is the one topic in this Environmental Statement where the effects of somewhat distant anticipated future changes to the site, which have not yet been applied for, are considered. This chapter addresses impacts of the Proposed Disposals after the site has ceased to be a permitted and licensed site, taking account of likely site changes prior to that point being reached, as well as taking account of possible future land uses for the site and its immediate surroundings. This has been necessary in view of the long-term aspects of the proposals. This is not to say that such future changes to the site have yet been made, applied for or even designed, or that permission is being sought for them now or any time soon.

[9] Quote edited for clarity in the context of this chapter.

9.2.13 There may be localised changes to groundwater level and flow (as discussed with NRW during the EIA scoping exercise) occurring because of pre-development works on under-ponds sampling drains. Any such changes could, in principle, affect some of the long-term assessments presented in this chapter. These issues are therefore discussed herein.

9.3 COMPARISON WITH THE PERMIT APPLICATION

9.3.1 There are some minor differences between the assessments presented in this chapter of the Environmental Statement and the assessments for the December 2023 environmental permit application. For transparency, these are:

- The permitting assessments require a site-wide (cumulative) assessment that includes possible additional on-site disposals in the future (specifically, in this case, of the concrete of the reactor bioshields). However, it is EIA practice not to include in cumulative assessments future developments that have not been applied for and for which application(s) may not be made for quite some time (if ever). Instead, EIA practice is that later developments must take account of earlier consented or implemented developments as and when the later developments are proposed. Nevertheless, this chapter does provide some information on this issue.
- Sometimes, assessments undertaken for environmental permitting purposes may address radiation from past permitted discharges in a different manner to how an EIA is required to address background or baseline environmental conditions. Within this EIA, the background off-site radioactivity due to past permitted discharges to the lake is treated simply as an additional source of radiation exposure to people and to non-human biota (though actually it has little impact on the assessment findings for the time after achievement of the site final end state). Within this chapter, any additional contribution to the radiation exposure of people or of non-human biota from existing on-site radioactively contaminated ground is similarly addressed.
- The natural evolution radiological assessments for the environmental permitting submission pessimistically assume that rainwater and groundwater will start to pass through the infilled voids immediately after the concrete cap and drainage works are complete, leading to a new and increasing component in the radioactive discharges to the lake[10]. This EIA chapter assumes that significant/detectable and sustained increases in *total* radioactive discharges via the diversion culvert are not likely, because those discharges to the lake are dominated by the radioactivity associated with the contaminated ground on site that has been present for decades and is not part of the Proposed Disposals[11]. In fact, some reduction from present day radioactive discharges

[10] Because groundwater originating near the ponds complex is captured by drains that lead to the diversion culvert sump from where water is pumped to the lake.

[11] This assumption is supported by the outcomes of assessment modelling undertaken to support the associated permit application. The "site-wide" natural evolution assessment, which considered both the Proposed Disposals and the radioactively contaminated ground, found that the latter dominated in terms of radiological impacts up to the assumed site end state date, even when considering pessimistic flow rates through the disposals.

via the diversion culvert can be expected in the post-works period due to various factors including radioactive decay. The radioactive discharges via the diversion culvert are permitted and as such are subject to monitoring and notification levels specified in the permit (and subject to a requirement that the radioactivity in the discharges is minimised). Any unexpected increase would be investigated and, if required, remedied. This chapter focuses on the impacts after achievement of the site's physical final end state, when these pumped discharges to the lake will have ceased.

- The assessed dose rates to hypothetical future occupants of the Disposal Area used in the permit application in the main assumed that the concrete cap would be 0.15 m thick. However, for the planning application (and this Environmental Statement) a more realistic figure of 0.225 m (50% thicker) is used, reflecting evolution of the cap design in parallel with the development of the radiological assessments for the permit application.
- The non-human biota radiological assessment for the permit application was carried out with the ERICA tool (see Table 9.3 below) using its "Tier 1" screening methodology (which amongst other things combines the highest organism dose rate for each radionuclide independently, even if they are different organisms whose dose rates are being summed). That assessment also used peaks in radionuclide concentrations that do not actually occur at the same time in the radionuclide migration modelling results. Here, a more realistic approach based on Tier 2 of ERICA has been followed (as discussed in Appendix 9I) which considers all radionuclides for each organism in turn. The calculated numerical organism dose rate results for the Proposed Disposals are similar whether Tier 1 or Tier 2 are used and their implications in respect of potential harm to non-human biota are the same. In addition, for this chapter of the Environmental Statement the same modelled time profile of the environmental radionuclide concentrations that underpin the radiological assessments of impacts on people have been used for the assessment of impacts on non-human biota; this makes the non-human biota dose assessment methodology analogous to that used for the assessment of impacts on people.

9.4 BASELINE CONDITIONS

REGULATORY REQUIREMENTS Schedule 4 of The Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017 requires, insofar as it is relevant to the Proposed Development and the assessment of its impacts: *"A description of the relevant aspects of the current state of the environment (baseline scenario) and an outline of the likely evolution thereof without implementation of the development as far as natural changes from the baseline scenario can be assessed with reasonable effort on the basis of the availability of environmental information and scientific knowledge."* This information is summarised in this section, with the detail provided in appendices to this chapter.

Hydrogeology Overview (Appendix 9E)

9.4.1 The sub-surface comprises glacial drift and made ground overlying bedrock. The made ground comprises a range of material from large boulders to clay and includes excavated drift and bedrock that was excavated during site construction. The in-situ bedrock has a low permeability and allows groundwater flow only where fractures are present, mainly near its surface. The made ground predominates on the site, including the Disposal Area, and has high permeability.

9.4.2 Groundwater flows quickly across the site in an approximate west to east direction, mainly through the made ground, as well as through the site's engineered groundwater and surface water drains. To a lesser extent, groundwater also flows through fractures in the near surface bedrock. The shallowest groundwater within the Trawsfynydd site typically exists in discontinuous sub-surface pools overlying the very uneven bedrock surface.

9.4.3 Unless captured by the site's engineered drainage systems, groundwater that flows through the ground ultimately flows into the Nant Gwylan or the Afon Tafarn-helyg. Currently groundwater captured by the drains system around the reactor buildings is discharged via the "diversion culvert sump" pumps into Llyn Trawsfynydd. By the time the assessments presented here become relevant, these engineered drainage arrangements will have ceased, and all groundwater from the reactor buildings area would flow down gradient more directly into the Nant Gwylan or the Afon Tafarn-helyg.

9.4.4 Climate change is not expected to substantially alter the site hydrogeology. This is due to the controls on the site hydrogeology imposed by the bedrock topography and sub-surface engineered structures.

Radioactivity in the Environment at and Around Trawsfynydd (Appendix 9F)

9.4.5 The ponds complex footprint is the location of most of the Proposed Disposals. As a result of historic leakages from the cooling ponds, along a substantial portion of its length, the east side of the ponds complex sub-surface structure is in contact with radioactively contaminated ground. The radioactively contaminated ground is not itself waste unless excavated.

9.4.6 The estimated radiological inventory of this contaminated ground is included in Appendix 9C. Radionuclide concentrations in the contaminated ground east of the ponds (averaged over zones of the order of a few hundred m^3 each) are up to 20 Bq/g, with Caesium-137 (Cs137) being the dominant radionuclide (see Appendix 9F). At a much smaller scale, close to the inferred main ponds leakage point, Cs137 concentrations are an order of magnitude higher than this average value.

9.4.7 Radioactive contamination in the form of Cs137 and Strontium-90 (Sr90) is present in groundwater between the ponds complex and western Goliath track wall (a large sub-surface concrete structure used for site construction), east beyond the wall and to a lesser extent through the rock head trough feature beneath the northern part of the Reactor 1 building and in groundwater intercepted at Manhole 6. Groundwater beneath the southern part of the ponds complex also has some relatively low-level radioactive contamination.

9.4.8 Radioactivity is also present in the wider environment around the Trawsfynydd site because of historical and current site operations (due to permitted discharges), radioactive fall-out due to the Chernobyl nuclear reactor accident, and historical atmospheric weapons testing.

9.4.9 Cs137 and Sr90 have not been detected by the Applicant in water sampled from the Nant Gwylan, which receives water from the lake via the valved flow from Gyfynys Dam. During a monitoring period between 2019 and 2023 only one lake water concentration above the limit of detection has been recorded by the Applicant for Cs137 (the finding has not been repeated).

9.4.10 Stream sediments were characterised by the Applicant in 2021 for those radionuclides expected to be present in the suspended sediments derived from the valved flow from Gyfynys Dam. As expected, sediment samples from the Nant Gwylan contained higher concentrations of Cs137, Sr90 and Americium-241 (Am241) (which is also a marker for various other radionuclides) than in stream sediment sampled elsewhere. Comparison to lake sediment samples shows that the same radionuclides are found in the sediment of Llyn Trawsfynydd. The presence of the radionuclides in the Nant Gwylan is therefore likely due to the movement from Llyn Trawsfynydd of sediment that is contaminated because of past permitted discharges of radioactivity to the lake.

Public Radiological Exposure

9.4.11 The radiological impacts on the public from the Trawsfynydd site under the current baseline conditions arise from radioactivity remaining from past permitted discharges of radioactive aqueous and gaseous effluents during the period of electricity generation and from subsequent permitted discharges generated from (on-going) decommissioning operations.

9.4.12 Reports documenting assessments of radioactivity in food and the environment, and of the public's exposure to radiation, are issued annually by the Environment Agency, NRW, Northern Ireland Environment Agency, the Scottish Environment Protection Agency, the Food Standards Agency and the Centre for Environment Fisheries and Aquaculture Science. The latest of these is “RiFE 28”[12,13].

9.4.13 According to RiFE 28 the potential doses received by people in the area because of the past and current operation of Trawsfynydd site are a very small fraction of (addition to) the typical radiation exposure experienced by people in the UK arising from natural sources as well as from medical procedures, air travel and so on. In the RiFE reports, the estimated doses are expressed in units of milli-Sievert (mSv), where 1 mSv is one thousandth of a Sievert.

9.4.14 The dose to an angler who is assumed to consume lake fish and to spend relatively long periods of time in the location being assessed on the lake shore

[12] Environment Agency, Food Standards Agency, Natural Resources Wales, Centre for Environment Fisheries and Aquaculture Science, RIFE 28 Summary, Radioactivity in Food and the Environment, 2022. [online] Available at: RIFE 28 Summary, Radioactivity in Food and the Environment, 2022 - GOV.UK (www.gov.uk) [Accessed December 2023].

[13] Environment Agency et al. Radioactivity in Food and the Environment, 2022. [online] Available at: RIFE 28, Radioactivity in Food and the Environment, 2022 - GOV.UK (www.gov.uk) [Accessed December 2023].

was reported in RiFE 28 as 0.008 mSv for 2022. The dose to an infant who is assumed to consume terrestrial foods produced in the area and be subject to external and inhalation exposure near the Trawsfynydd site was reported in RiFE 28 as 0.038 mSv for 2022. It should be noted that those radionuclide concentrations in and around the lake which derive from historical discharges to Llyn Trawsfynydd are unlikely to be measurably affected by the Proposed Disposals.

9.4.15 The average UK individual annual public exposure to radiation is about 2.7 mSv (including all radiation sources), of which most on average is from natural sources. For Gwynedd, average annual exposure from natural sources is 2.8 mSv. These “background” dose rates should be kept in mind when considering the estimated doses arising from the proposed on-site disposals.

9.5 EMBEDDED MITIGATION MEASURES

9.5.1 As explained above, there are existing controls under other regulatory regimes that will have to be complied with. The requirements/expectations from these regulatory regimes have informed the development of the project description as an integral part of the design process such that there are embedded measures that are an integral part of the proposed development to ensure compliance.

Environmental Permitting Acceptance Criteria

9.5.2 “Disposal acceptance criteria”, including for emplacement of demolition arisings, will be produced for approval by NRW as part of the environmental permit variation process. This means that only suitable materials will be used for void infill (or retained in situ) as agreed with NRW. This is important to bear in mind as a mitigation against unsuitable materials being placed in below-ground voids or retained in below-ground structures. The acceptance criteria will have associated internal management arrangements and compliance checks.

Proposed Physical Mitigation Measures

9.5.3 As part of the design process, several embedded environmental measures are proposed:

- The provision of “overflow” routes for leachate that might build up within the infilled below-ground voids to escape before it reaches the ground surface, this leachate then entering the unsaturated zone below ground level. This is primarily to eliminate any possibility of leachate emerging or being present at or near the ground surface, as might occur if there was water ingress through the cap but the below-ground walls and floors of infilled voids were water-tight (or at least were rather less permeable than the cap).
- The targeted use of freshly poured concrete or grouted infill, such that there is no loose infill material below the water table level. The primary objective of this is to minimise the rate of discharges to groundwater of pollutants arising from wetted infill.
- The cap over the main disposals will comprise a reinforced concrete layer, with slight falls on its upper surface to shed water into the surrounding drainage,

thereby leading to negligible infiltration into the infilled voids while the cap is maintained[14].

- The cap extent is defined in part to simplify its geometry, which will increase its longevity.
- All radioactively contaminated pipe trenches beyond the cap extent will be filled with fresh concrete so that they cannot become a conduit for rain or groundwater[15].
- The concrete cap is to have water-bars to minimise water ingress through construction and expansion joints.

9.5.4 Several under-ponds sampling drains will also have had their radioactively contaminated "loose" contents removed or grouted in situ, in advance of the Proposed Development. However, other under-ponds sampling drains will be left in their current condition because they will remain above groundwater level and protected against water ingress from above.

Other Measures That Have Been Considered

9.5.5 Various other measures have been considered as part of the design process but are not proposed:

- There will be no specific layering of infill, e.g. emplacing the most radioactive infill at the top or at the bottom of the below-ground voids, since assessments have indicated there is no significant radiological benefit in such approaches.
- There may or may not be a need for localised radioactive inventory reduction, depending on the results of future characterisation. This could be undertaken to reduce some of the estimated intrusion and site occupancy doses to below the figures given later in this chapter (and of course reduce the actual doses, if these scenarios were to occur).

9.5.6 Prior to final site landscaping and release of the site from environmental permitting, it will be a decision for the future site owner / operator and the regulating authorities at the time as to whether to implement further barriers to rainwater infiltration or to intrusion, or whether to provide visual warnings to deter intrusion. No credit for such actions has been taken in the assessments and results summarised in this chapter.

9.5.7 It will also be a decision for the future site owner / operator and regulators as to when the site should be released from environmental permitting controls. Deferring release from environmental permitting would allow more radioactive decay before site occupancy or human intrusion events could take place, and thus reduce the maximum doses that could be incurred if they did take place.

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[14] There will be no use of High-Density Polyethylene (HDPE) or clay liners, and no overlaying of soils, on completion of the Proposed Development. The use of liners and overlaying with soils will be a consideration at the time of permit surrender some decades from now.

[15] This infill may also improve ground load-bearing capacity above the pipe trenches.

Corrective Measures (if required)

9.5.8 Though not strictly an embedded mitigation measure, the long-term monitoring and possible responses to unexpected adverse findings are summarised in the Project Description and at the end of this chapter. For example, should monitoring at the key Manhole 6 location detect unacceptable groundwater pH, chemical treatment of the water entering the manhole could be implemented quickly using standard technologies to reduce the pH of the water flowing off-site. Measures that do not require ongoing management, such as augmenting the cap and further permeation grouting of the demolition arisings within the below-ground voids of the ponds complex, could also be taken to remedy such a situation.

9.6 SCOPE OF THE ASSESSMENTS

Overview

9.6.1 Receptors of relevance to this assessment are summarised in Table 9.1. The various aspects of the assessment can be grouped into five main topics:

- radiological impacts on "representative persons" under conditions of "natural evolution";
- radiological impacts on non-human biota under conditions of "natural evolution";
- radiological impacts on future site occupants;
- radiological impacts on hypothetical persons affected by inadvertent (uncontrolled) intrusion into the Proposed Disposals; and
- non-radiological (water quality) impacts on controlled waters.

9.6.2 Doses from exposure to specific high dose rate items following intrusion events, should such items be inadvertently left present within the disposals, have not been presented here. Assessments of these doses have been included in the information submitted to NRW with the associated environmental permit application made in December 2023. Pre-demolition surveys will be conducted to identify any such items and enable their removal as appropriate.

Study Area

9.6.3 For the long-term radiological and non-radiological impacts, the concept of a study area is not strictly applicable. This is because the potential impacts are not necessarily limited to a specific area but may occur wherever relevant receptors exist, or may exist, in the long term. This was explained as part of the at the EIA scoping process and acknowledged by the ENPA. However, Figures 9.2 and 9.4 below indicate the geographical areas within which the potential receptors discussed could be located.

Direct radiological impacts via site occupancy by people can only be incurred by people using the land above the Proposed Disposals. Similarly, inadvertent radiation exposure could only be incurred by human "intruders" (people carrying out uncontrolled excavations) within the Disposal Area. However, indirect radiological impacts on people deriving from such intrusion (i.e. deriving from use of site-won materials taken away) could be incurred elsewhere.

9.6.4 “Down gradient” human receptors of radiological impacts include users of land that may become contaminated in the long term due to the migration of radionuclides in groundwater.

9.6.5 Other relevant environmental receptors for both radiological and non-radiological impacts may also be present at locations “down gradient” of the proposed on-site disposals: within groundwater; within surface water courses fed by groundwater; within any downstream surface water bodies; and within downstream ecosystems.

9.6.6 For the most part, the impacts on Llyn Trawsfynydd and users of Llyn Trawsfynydd are not included as “receptors” in this chapter. Pumped discharges to Llyn Trawsfynydd of water (including groundwater from the Disposal Area that has been intercepted by drainage systems) will have ceased by the time the long-term impact assessments described in this chapter become relevant. Prior to then, the radiological impacts associated with use of the lake will be dominated by radioactivity remaining from historical discharges from the site and by ongoing permitted discharges via the site diversion culvert (the latter being mainly associated with the existing radioactively contaminated ground).

Table 9.1 Summary of Proposed Scope of Assessment by Type of Impact and Potential Receptor

Type of Impact	Potential Receptor(s)	Supporting assessment
Radiological: impacts on people	• People, specifically users of the land around the Trawsfynydd site in the distant future, when controls on land use are assumed to have ceased. This includes hypothetical residents, farmers and anglers. • People who in the future might inadvertently intrude into the disposals, or who are exposed through uncontrolled use of excavated radioactive materials taken away from site. • People who in the future might occupy the land above the Proposed Disposals. • Hypothetical people using groundwater as a drinking water supply.	Appendix 9H
Radiological: impacts on non-human biota	• Non-human biota supported by ground or surface water down-gradient of the disposals.	Appendix 9I
Non-radiological (water quality)	• Groundwater and spring lines. • Surface water courses (and by implication, the flora and fauna that are supported by them).	Appendix 9J

9.6.7 In respect of non-radiological impacts, a qualitative risk assessment for the proposed on-site disposals was initially carried out (Appendix 9J). On this basis, the risks to groundwater and surface water from the non-radiological aspects of the following components of the disposals were identified as needing no further assessment:

- Active drains system and the original active effluent discharge pipe (metals and grout);
- Structural concrete including reinforcing steel, bitumen in expansion joints, PVC water bars;
- Residual hydrocarbon compounds, asbestos and inorganic chemicals;
- Wall and floor finishes; and
- Structural steel (if left in-situ).

9.6.8 However, quantitative assessment has been required in respect of:

- non-radioactive Chromium (VI) (which is a hazardous constituent of concrete) in leachate from concrete demolition arisings used as void infill; and
- alkalinity in leachate from concrete demolition arisings used as void infill.

9.6.9 The flows and levels of groundwater around the ponds complex may slightly change because of pre-development works. Indirectly, those pre-development works may therefore affect the radiological and non-radiological impacts discussed in this chapter. This is addressed in the main text of this chapter and in Appendix 9K. No non-local groundwater effects are expected from the pre-development works, no impacts on flooding, and no impacts on groundwater availability.

Temporal Scope

9.6.10 As noted earlier, Llyn Trawsfynydd and users of Llyn Trawsfynydd are not included as receptors since pumped discharges to Llyn Trawsfynydd of water (including intercepted groundwater from the Disposal Area) will have ceased by the time the long-term impact assessments summarised in this chapter become relevant (Table 9.2). This includes the non-radiological impacts on groundwater, given the expected longevity of the concrete cap.

9.6.11 All the assessments of radioactive and of non-radioactive aspects also assume that the current groundwater management system on the south side of Reactor 1 (which prevents groundwater entry into some Reactor 1 basement areas) will have been switched off before pollutants migrate away from the Proposed Disposals.

Table 9.2 Summary of Temporal Aspects

Issue	Relevant time period	Comments
Radiological impacts on people (natural evolution)	After the diversion culvert and drains leading to it are taken	The assessment considers changed land uses for the site and adjacent down-gradient land which may not take place for hundreds of

Issue	Relevant time period	Comments
	out of service[16] and after the end of the period of radioactive substances regulation for the Trawsfynydd site (and therefore alternative land uses are possible).	years into the future or not at all, but for assessment purposes the changed land uses are assumed to be from around 2080.
Radiological impacts on biota (natural evolution)	After the diversion culvert is taken out of service[17].	Assumed to be from about 2080.
Radiological impacts on people (human intrusion)	After the end of the period of radioactive substances regulation for the Trawsfynydd site.	Assumed to be from about 2080.
Radiological impacts on people (site occupancy)	After the end of the period of radioactive substances regulation for the Trawsfynydd site.	Assumed to be from about 2080.
Non-radiological impacts on groundwater and surface water quality (and, therefore, impacts on potential resources and non-human biota)	The time after water starts to enter and leave the ponds complex voids where it will have been in contact with concrete demolition arisings. This could be rainwater infiltrating from above, and/or groundwater infiltrating through the deepest parts of the structures enclosing the voids.	Given the robust nature of the structures, and the design life of the cap, this process is not expected to commence for some decades. However, there is no change over time in the non-radiological properties of disposals.

Potential Receptors of Radiological Impacts - People

9.6.12 A cautious approach to assessment of radiological impacts in the distant future involves assumed changes to land uses directly down-gradient of the Trawsfynydd site. It is assumed that the land currently occupied by the electrical switching compounds directly adjoining the Trawsfynydd site reverts to residential or

[16] Were any radioactive substances to migrate from the disposals whilst the current diversion culvert pumping arrangements remain in place (a situation not expected to arise to any significant degree), then in principle the diversion culvert monitoring would detect any significant change. In any event public exposure would be via public use of the lake and be indistinguishable from the public exposure due to other sources of radioactivity in that environment (mainly historical permitted discharges to the lake and current discharges mainly associated with site contaminated ground).

[17] Were any radioactive substances to migrate from the disposals whilst the current diversion culvert pumping arrangements remain in place, then exposure of non-human biota would be via their use of the lake and likewise be indistinguishable from biota exposure due to other sources of radioactivity in that environment.

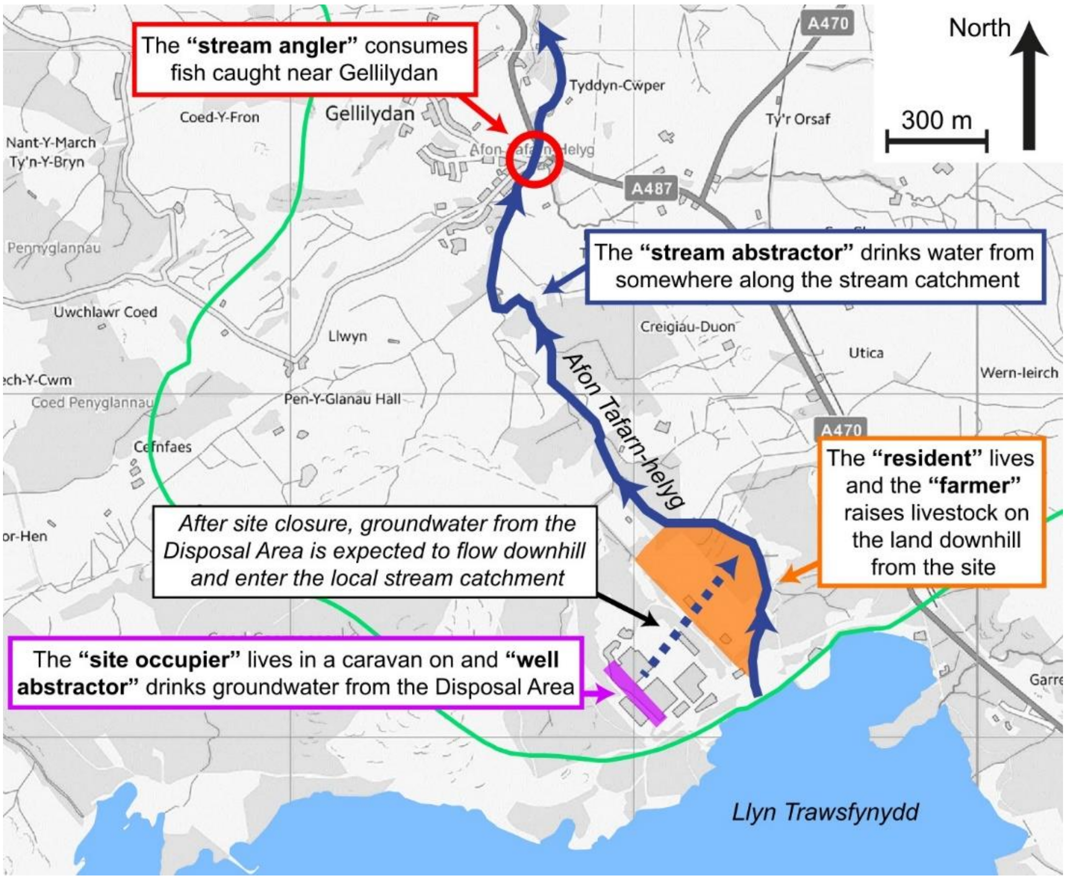
agricultural uses. The most important “representative persons” would then be (Figure 9.2):

- adult members of a farming family or a resident family using the land adjacent to the Trawsfynydd site, amongst other things consuming their own meat and vegetable produce; and
- an individual angler with a regular habit of catching and eating fish from the headwaters of the Afon Tafarn-helyg, downstream of the Trawsfynydd site.

9.6.13 Also assessed are doses to hypothetical persons abstracting water from the Afon Tafarn-helyg or from the ground (including within the current site boundary) for drinking purposes, notwithstanding the low likelihood of the latter type of abstraction given the abundance of fresh water in the vicinity of the Trawsfynydd site.

9.6.14 Also assessed are doses to hypothetical persons who might live or work on the land directly above the Proposed Disposals. Additionally, doses to hypothetical persons who in the future might inadvertently intrude into the disposed wastes (for example through drilling boreholes in the Disposal Area, or through excavations into the area for whatever purpose) and doing so without any radiological protection precautions, have been assessed. Likewise, assessments have been made of the potential radiation doses to persons exposed because of subsequent uses of any excavated radioactively contaminated concrete and masonry, deriving from its use as aggregate for construction purposes or its use as a constituent of soil used for food production.

Figure 9.2: Model of the biosphere and representative persons associated with natural evolution and site occupancy.



Potential Receptors of Radiological Impacts – Non-Human Biota (Flora and Fauna)

9.6.15 For species of non-human biota, the assessment considers adverse consequences for populations (in contrast to the assessment of radiological impacts on people where the focus is protecting individual persons). The assessment is described in Appendix 9I. Non-human receptors in or using the Nant Gwylan, Afon Tafarn-helyg and a hypothetical field down-gradient of the Proposed Disposals are assessed. These receptors cover all the default ERICA organisms.

Potential Receptors of Non-Radiological (Water Quality) Impacts

9.6.16 In the long term, along with radioactive contaminants, non-radioactive contaminants may be leached from the infilled ponds complex voids and enter groundwater. The receptors of non-radioactive contaminants in such leachate are the actual, or potential future, recipients of groundwaters that derive their flow, at least in part, from the Disposal Area, as well as the groundwater itself. The main actual or potential receptors are:

- groundwater in made ground within a distinct trough in the bedrock surface beneath part of the Disposal Area, which has cautiously been assumed to be a potential future resource[18]; and
- discharges from groundwater, such as springs and base flow to rivers. These may include the spring at Roadway 5 (on the licensed site) and the base flow to the Nant Gwylan, the Afon Tafarn-helyg and the unnamed stream flowing from Craig Gyfynys.

9.6.17 The assessment of the impact of non-radiological pollutants on these receptors is described in Appendix 9J. Provided that the impacts on groundwater within the made ground of the trough referred to above are acceptable, then the impacts at downgradient springs and in streams or rivers should also be acceptable.

9.7 MODELLING METHODOLOGIES

Introduction

REGULATORY REQUIREMENTS Schedule 4 of The Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017 requires, insofar as it is relevant to the Proposed Development and the assessment of its impacts: "*A description of the forecasting methods or evidence used to identify and assess the effects on the environment, including details of difficulties (for example technical deficiencies or lack of knowledge) encountered compiling the required information and the main uncertainties involved".* The forecasting methods are described in this section. Uncertainties and how they have been addressed are discussed later in this chapter.

9.7.1 Five types of assessment are required in relation to long-term radiological and non-radiological impacts as summarised in Table 9.3. The long-term consequences of any changes to groundwater flows and levels due to pre-development works on under-ponds sampling drains have been assessed using expert judgement and alternative scenario assessments (mainly described in appendices to this chapter).

[18] The shallowest groundwater within the Trawsfynydd site typically exists in discontinuous sub-surface pools overlying bedrock. Such pools are generally not considered to represent groundwater receptors but could form parts of contaminant transport pathways through the ground to surface water receptors. However, a relatively large pool of groundwater that extends beneath the southern part of the cooling ponds and the northern half of the Reactor 1 building within the made ground is considered to represent a potential receptor. This is because this pool of water is large enough and is recharged rapidly enough that it could be regarded as a "resource", for example being capable of sustaining water abstraction for more than 50 individuals (more than $10m^3$ per day).

Modelling Input Data

9.7.2 The data (or approaches adopted in the absence of specific data) are summarised in the appendices to this chapter, particularly Appendix 9C and Appendix 9D.

Modelling Tools

9.7.3 A number of different but commonly used modelling tools have been used for the assessments presented in this chapter. These are summarised in Table 9.3.

Table 9.3 Modelling Tools Used in the Assessments

Aspect	Model	Description
Radiological Impacts to Representative Persons Under Conditions of Natural Evolution	**GoldSim** GoldSim allows the modelling of complex environmental systems. This commercially available computer package is commonly used for safety assessments of proposed and existing radioactive waste management sites.	The Trawsfynydd natural evolution assessments all use the GoldSim radionuclide transport module, which includes features to facilitate simulation of radionuclide transport through concrete barriers and through the environment. GoldSim models processes such as decay and the ingrowth of decay products, sorption onto porous media, contaminant release from sources, advective and diffusive transport, and transport of contaminants sorbed to particulates.
Radiological Impacts to Non-Human Biota Under Conditions of Natural Evolution	**ERICA** Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) model and software, developed for the assessment of the radiological risk to terrestrial, freshwater and marine biota. The ERICA model and software are maintained by a consortium comprising the Norwegian Radiation Protection Authority, Environment Agency (England and Wales), UK Centre for Ecology & Hydrology (UK), IRSN (France) the Swedish	ERICA has been applied using modelled environmental radionuclide concentrations output by GoldSim. The assessments have used the most recent update of the ERICA software tool[19].

[19] The ERICA Tool 2.0 includes a new dosimetric methodology to reflect the changes presented in International Commission on Radiological Protection (ICRP) Publication 136 (ICRP 2017) and revised wildlife concentration factors and associated updated Environmental Media Concentration Limits (EMCL) values.

Aspect	Model	Description
	Radiation Safety Authority and CIEMAT (Spain).	
Doses to a future Site Occupier for the Envisaged Disposal Area Structures	**MicroShield®** MicroShield® is a commercially available comprehensive photon/gamma ray shielding and dose assessment program that is widely used for designing radiation shielding for given radiation sources and for estimating source strength from radiation measurements.	Calculation of site occupier doses requires assumptions about cap thickness, and occupancy times (hours per year). No shielding other than that provided by the cap was taken into account.
Radiological Impacts to Representative Persons Affected by Inadvertent Human Intrusion (After Release of the Site from Regulatory Control)	**Generic Intrusion Methodology (GIM)** spreadsheet tool. This spreadsheet tool was developed for the Applicant by Eden Nuclear and Environment Ltd. This tool has been developed and refined over the past six years.	GIM includes dose assessment models both for the "intruders" (persons carrying out excavations of one sort or another) themselves and for persons exposed as a result of radioactive materials removed from the site. The models have been applied to a range of shallow, deep, large area and small area intrusion events.
Non-radiological (water quality) impacts	N/A	The approach used has been the tiered hydrogeological risk assessment approach expected by NRW. See Appendix 9J: Non-Radiological Assessment of Impacts on Controlled Waters.

Radiological Impacts Under Conditions of Natural Evolution

9.7.4 This part of the assessment has focused on the release into groundwater of radionuclides from the Proposed Disposals. There are no credible processes by which significant releases of radionuclides could occur via emissions of ground gases, and the geomorphology of the site and surroundings is judged to be sufficiently stable that erosion will not lead to exposure and physical dispersal of the disposed wastes over relevant timescales.

9.7.5 The main elements of the natural evolution assessment model (created using GoldSim) represent:

- the "sources" of contamination (including the processes of eventual release of radionuclides into water infiltrating through in situ structures and emplaced demolition arisings);

- the “geosphere” pathways (by which the released radionuclides can migrate from the sources via groundwater, Figure 9.3); and
- the “biosphere” pathways (within which radionuclides emerging from the geosphere pathways can accumulate within various environmental media such as soil and water, Figure 9.4, and lead to the exposure to radionuclides, see Figure 9.2).

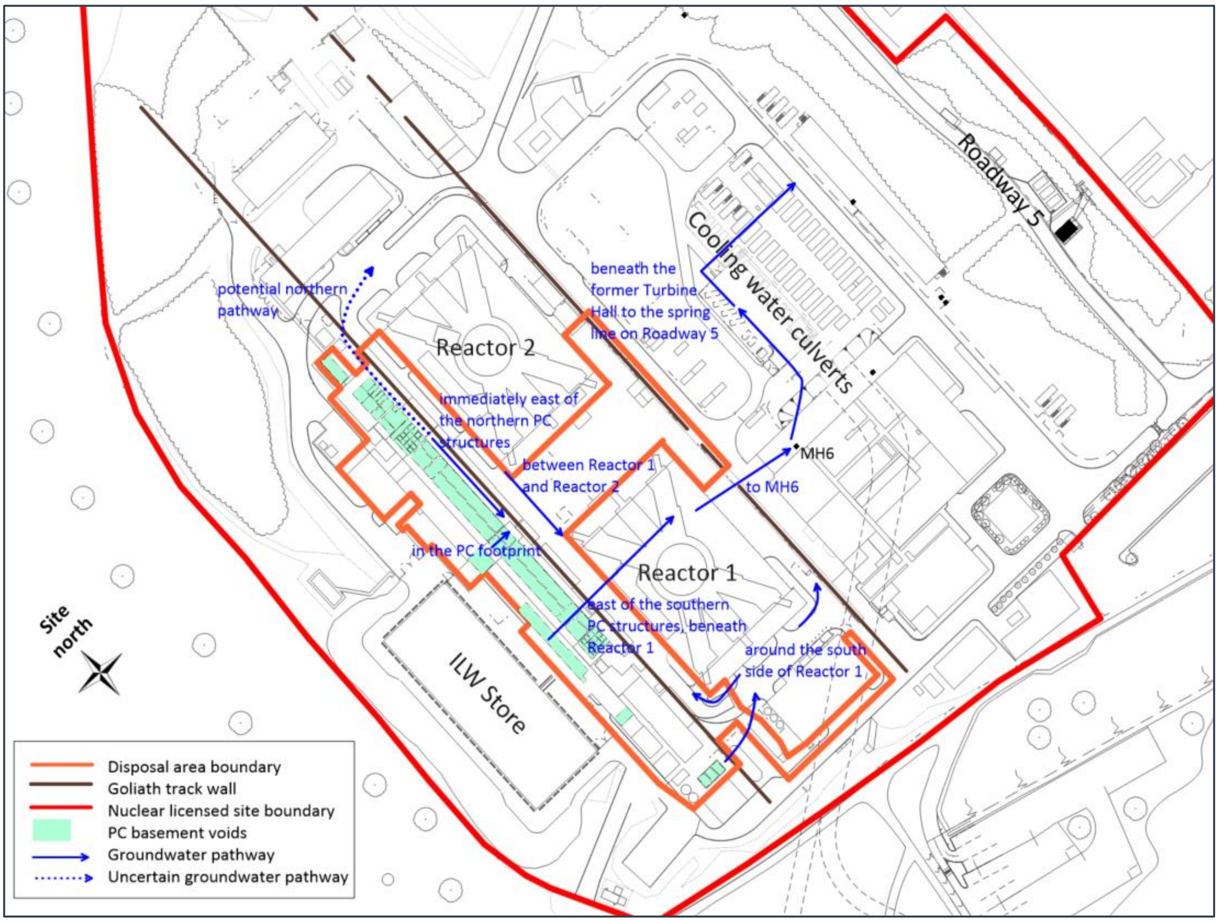
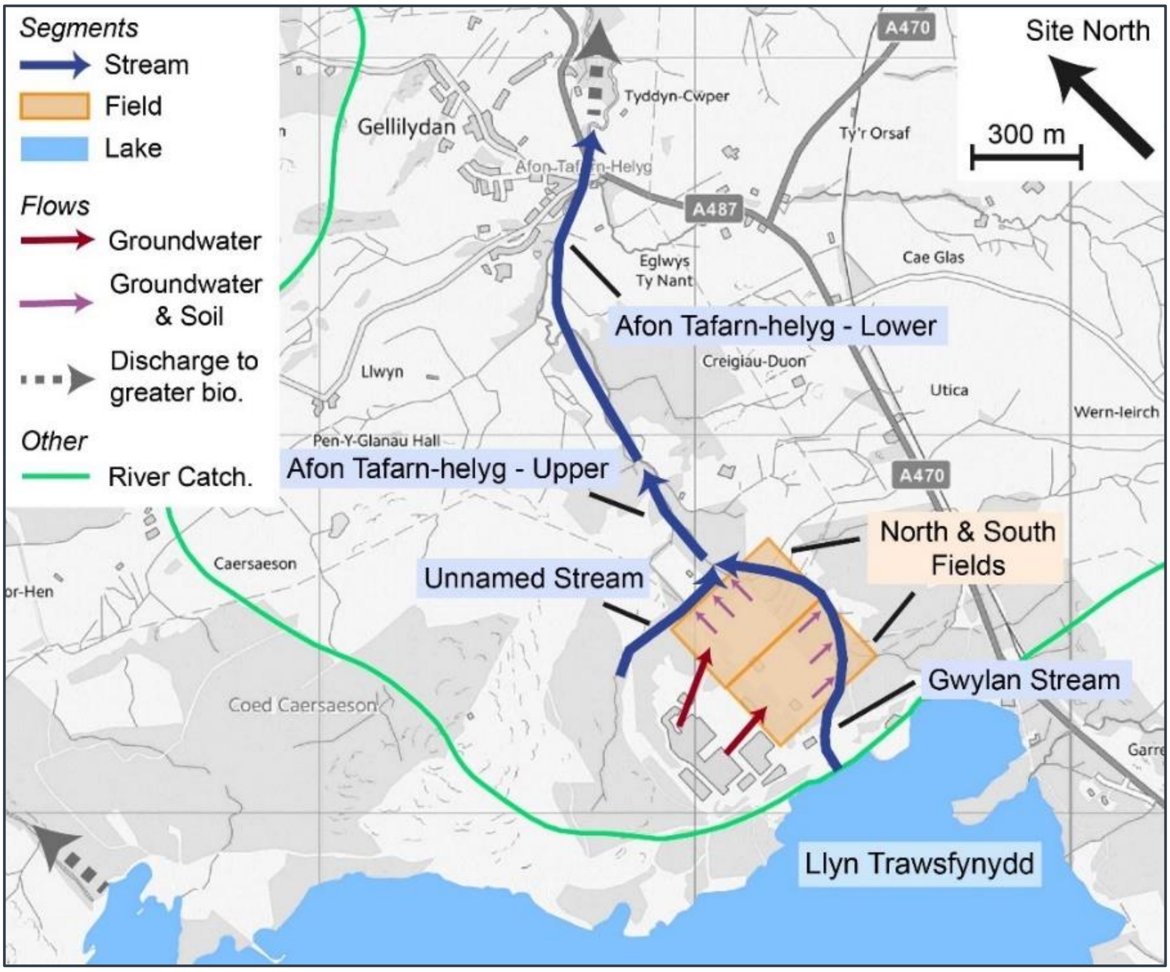


Figure 9.3: Principal Groundwater Flows (future site conditions)

9.7.6 The model considers how radioactivity released is transported in flowing groundwater to the biosphere. Two distinct groundwater discharge points to the biosphere (spring-lines) at relative topographical low points within the current Trawsfynydd site are considered. These discharges from the geosphere are assumed to directly enter land (soil) that forms part of the modelled biosphere.

9.7.7 The natural evolution assessments consider a stylised biosphere model element in which living organisms that occupy the biosphere, humans and non-human biota, may receive radiological doses. The parts of the biosphere modelled reflect the major hydrological features in the region, including the streams in the Afon Tafarn-helyg catchment, and the land directly downgradient of the site. For each of the modelled parts of the biosphere, the natural evolution assessment model calculates environmental concentration values; Bq/l for the freshwater bodies and Bq/kg for the soil.

Figure 9.4. Map showing the modelled parts of the biosphere in the natural evolution assessment model (termed "segments" in the figure) after reaching the site end state.



9.7.8 Within the biosphere model, the land directly downgradient of the site is modelled as two fields, referred to as the southern and northern fields. The locations of these fields with respect to the Trawsfynydd site are shown in Figure 9.4. They are positioned largely within the area that is currently occupied by the electrical switching compounds[20]. As predicting the exact location and extent of the groundwater discharges is difficult, the radionuclide concentration in each field is averaged. There is assumed to be negligible throughflow between the two fields. Groundwater flows in the soil travel downgradient, towards the Nant Gwylan and the unnamed stream for the southern and northern fields respectively.

9.7.9 The final step of the assessment involves the estimation of doses to representative persons via food consumption, external exposure etc., making use of habits data

[20] Though the future use of this area of land is not dependent on the continuation (or not) of the Trawsfynydd site environmental permit, these fields are cautiously assumed to be available for unrestricted use immediately after the site end state has been reached (assumed to be about 2080) and the site permit surrendered.

(food consumption rates etc.) in much the same way as is done in RiFE reports, as described earlier. The main difference here from the RiFE report calculations is that the RiFE reports provide “retrospective” dose estimates based on environmental monitoring data, whereas here it has been necessary to estimate “prospective” doses entirely based on modelling.

Doses to a Site Occupier for the Envisaged Disposal Area Structures

9.7.10 Annual doses to a person spending approximately half of the time living above one of the most radioactive near surface features of the disposals (covered by the concrete cap) have been assessed using the radiological inventory and standard radiation shielding assessment software (MicroShield®). The modelling takes no account of potential shielding that may be provided by any building, cabin or caravan that a person spending time above the disposals might be within; in effect the model is a ‘worst case’ scenario.

Radiological Impacts to Representative Persons Affected by Inadvertent Human Intrusion

9.7.11 The “intrusion” assessments use the Generic Intrusion Methodology (GIM) spreadsheet tool developed by Eden Nuclear and Environment Ltd. This tool has been developed and refined over the past six years. A generic methodology is appropriate to assess the stylised human intrusion scenarios which are not dependent on site-specific factors other than the physical configurations of the Proposed Disposals, which can be represented by choice of appropriate subsurface geometries within the GIM tool (e.g. buried pipe, slab or vault), and their levels and type of radioactivity.

9.7.12 The assessed impacts are of two broad types, namely relatively short-term radiation exposures received by people intruding into the Proposed Disposals, and longer-term exposures received by people because of excavated materials being used for purposes such as construction or incorporation into soils.

Non-radiological (water quality) Impacts

9.7.13 For non-radiological aspects, standard tiered risk assessment guidance has been followed[21]. This includes qualitative assessment for most potential non-radioactive contaminants, and quantitative assessment in two cases (chromium (VI) and alkalinity). The quantitative assessment includes relatively simply use of rainfall rates and groundwater flow rates.

Long-term Consequences of Changes to Groundwater Flows and Levels Due to Pre-Development Works on Under-Ponds Sampling Drains

9.7.14 The physical impacts on groundwater of the pre-development blocking some under-ponds drains has been assessed by an experienced hydrogeologist using expert judgement. The knock-on consequences of any such effects on the natural evolution radiological assessments are bounded by alternative scenario

[21] Environment Agency, Groundwater Risk Assessment for Your Environmental Permit, 3 April 2018.

calculations (Appendix 9L), and likewise for non-radiological assessments of impacts on groundwater quality (Appendix 9J).

9.8 SIGNIFICANCE EVALUATION CRITERIA

Radiological Impacts on People

9.8.1 EIA commonly uses a significance framework that seeks to assign sensitivity to receptors, to assign a magnitude of change to derive the level of effect, and then to state if the effect is significant. In the field of radiological protection, the term “significant” is not generally used. In part this is because, under all but the most extreme of circumstances, the effect of radiation exposure is to increase the probability of fatality or of certain hereditary effects occurring in the future, with the assumption of there being no radiation exposure threshold between “no risk” and “some risk”. The development proposed, will have to comply with all the relevant regulatory requirements regarding radiological exposure and doses to people. Whilst potential receptors could be considered to be high sensitivity receptors as long as the stringent regulatory requirements are met it is considered that the magnitude of the impact would be negligible, such that the impact would not be significant in EIA terms.

9.8.2 Appendix 9A refers to the general required standards in respect of radiation dose (or annual dose rate) to individual members of the public that may arise because of permitted disposals of radioactive waste. Doses are expressed in units of Sieverts (Sv), as explained in the box below.

EXPLAINER: RADIATION DOSES TO PEOPLE
The Sievert (Sv) is the standard unit of radiation exposure (dose) to people, relating to the energy absorbed per unit mass, the type of radiation involved, and the sensitivity of different parts of the body to the effects of radiation. From the magnitude of the dose, the risks associated with the dose can be evaluated by the application of a multiplication factor. Doses are often expressed in terms of thousandths of a Sv (milli-Sv or mSv) or millionths of a Sv (micro-Sv or µSv).

9.8.3 Appendix 9B refers to the specific dose and risk guidance levels in the environment agencies’ document “Guidance on Requirements for Release of Nuclear Sites from Radioactive Substances Regulation” (GRR).

REGULATORY REQUIREMENTS
GRR requirement R10 (risk guidance level after release from radioactive substances regulation) states:
“Operators should demonstrate…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)”.

9.8.4 As explained in the box above, one of the main radiological protection criteria for the time after the environmental permit is surrendered, against which the proposals for on-site disposals of radioactive waste will be judged by NRW, is a risk guidance level of 1 in a million per year (that is, risk of death or heritable defect). This criterion applies to the “natural evolution” and “site occupancy” scenarios (GRR requirement R10).

9.8.5 This risk level corresponds to a radiation dose rate of about 17 µSv/year (0.017 mSv/year) if it is assumed that the dose occurs. If the dose is unlikely to occur, a dose rate of 17 µSv/year would be equivalent to a risk less than 1 in a million per year, because in that case the risk includes the probability (likelihood) of the dose occurring. Similarly, if the dose is unlikely to occur, a dose rate above 17 µSv/year could still be equivalent to a risk of 1 in a million per year (or less), if the probability (likelihood) of the dose occurring is taken into account.

9.8.6 For inadvertent (uncontrolled) human intrusion, dose guidance levels apply (GRR requirement R11). The effective dose to hypothetical members of the public during and after an inadvertent and uncontrolled intrusion into the disposed radioactive waste (e.g. an excavation) should be consistent with the dose guidance levels, meaning a dose in the range of around 3 mSv/yr (if there would be prolonged radiation exposure to any one person as a result of the intrusion) to around 20 mSv in total to any one person (if there would only be a short, time-limited exposure as a result). For human intrusion, the GRR criteria do not allow for consideration of likelihood of these doses occurring (though clearly some of the scenarios considered are particularly unlikely).

9.8.7 For comparison, the radiation doses to individuals arising from natural processes and from various human activities are provided in Table 9.4. The average total dose from radiation to an individual in the UK is about 2.7 mSv per year (including all radiation sources), though there is considerable variation between individuals depending on the location of their main residence and any medical procedures undertaken. For a resident of Gwynedd, the average is about 2.8 mSv per year for natural background radiation.

Table 9.4a Average Exposure of Individuals in the UK in 2010 (mSv)22

Ubiquitous radiation in the environment	
Radon and thoron	1.3
Intake of natural radionuclides (excluding radon)	0.27
Terrestrial gamma radiation	0.35
Cosmic radiation	0.33
Weapons fallout	0.005
Exposure from the use of radiation	
Patient exposure from the medical use of radiation	0.44
Occupational exposure from the use of radiation	0.0004
Total dose from the use of radiation	0.44

[22] Public Health England (2016) Ionising Radiation Exposure of the UK Population: 2010 Review [online] Available at: PHE-CRCE-026 (publishing.service.gov.uk) [Accessed August 2022].

Table 9.4b Average Exposure of Individuals from Air Travel (mSv)

Estimated Doses due to Cosmic Radiation from taking a Return Flight from the UK to Various Destinations Worldwide (mSv)[22]	
Paris (France)	0.01
Madrid (Spain)	0.02
Delhi (India)	0.07
Tokyo (Japan)	0.1
Sydney (Australia)	0.2

Radiological Impacts on Non-Human Biota

9.8.8 With respect to non-human biota, there are no statutory criteria for determining radiological protection of the environment. The unit for radiation exposure of non-human biota is the Gray (Gy), as explained in the box below.

EXPLAINER: RADIATION DOSES TO PLANTS AND ANIMALS
The Gray (Gy) is the energy absorbed per unit mass from exposure to radiation. In practice, the energy absorbed is often referred to in thousandths of a Gray (milli-Gy or mGy) or millionths of a Gray (micro-Gy or µGy).

9.8.9 A generic cautious non-human biota dose rate criterion of 10 µGy/hr is sometimes applied. However, alternative IAEA[23] dose rate screening values of 40 µGy/hr for terrestrial animals, birds, amphibians and reptiles and 400 µGy/hr for plants and other aquatic organisms are also considered benchmarks below which populations are unlikely to be significantly harmed. See also Appendix 9I regarding the NRW position on the 40 uGy/hr criterion. It is considered that, as long as the dose rates can be achieved the magnitude of any impact on any receptors (even those of high sensitivity) would be negligible, such that the impact would not be significant in EIA terms.

Non-Radiological Impacts on Controlled Waters (Groundwater and Surface Waters)

9.8.10 In the field of non-radiological impacts on groundwater and the resultant potential effects on people and biota, a “threshold” approach is often adopted. An impact is not regarded as “significant” if the concentration of pollutants in groundwater, and in surface waters dependent upon groundwater, would not exceed appropriate water quality standards (principally freshwater Environmental Quality Standards) at key locations. Specifically, the relevant criteria used in the assessments reported here are:

- For non-radioactive chromium (VI): less than 1 micro-gram per litre (1 µg/l), which is the freshwater annual average Environmental Quality Standard; and
- For groundwater alkalinity effects, pH to be between 6 and 9.

9.8.11 It is considered that, as long as the appropriate water quality standards are met the magnitude of any impact on any receptors (even those of high sensitivity) would be negligible, such that the impact would not be significant in EIA terms.

[23] Derived from the IAEA (Technical Report Series No 332, 1992.) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Sources and effects of ionising radiation, Report to the General Assembly, 1996.

9.9 ASSESSMENT RESULTS

9.9.1 Modelling results for the following scenarios are presented:

- Figure 9.5: impacts for “representative persons” for the “natural evolution” of the Proposed Disposals – for this figure, calculated dose rates have been scaled against the average annual individual dose for persons in the UK (2.7 mSv per year); and
- Figure 9.6: annual dose rates for a hypothetical “caravan resident” who spends 4,500 hours per year (approximately 50% of their time) located on top of the concrete cap, directly over the four most radioactive near-surface components of the Proposed Disposals, shown as a function of time. These results have been similarly scaled.

Figure 9.5: Impacts on “Representative Persons” for “Natural Evolution”

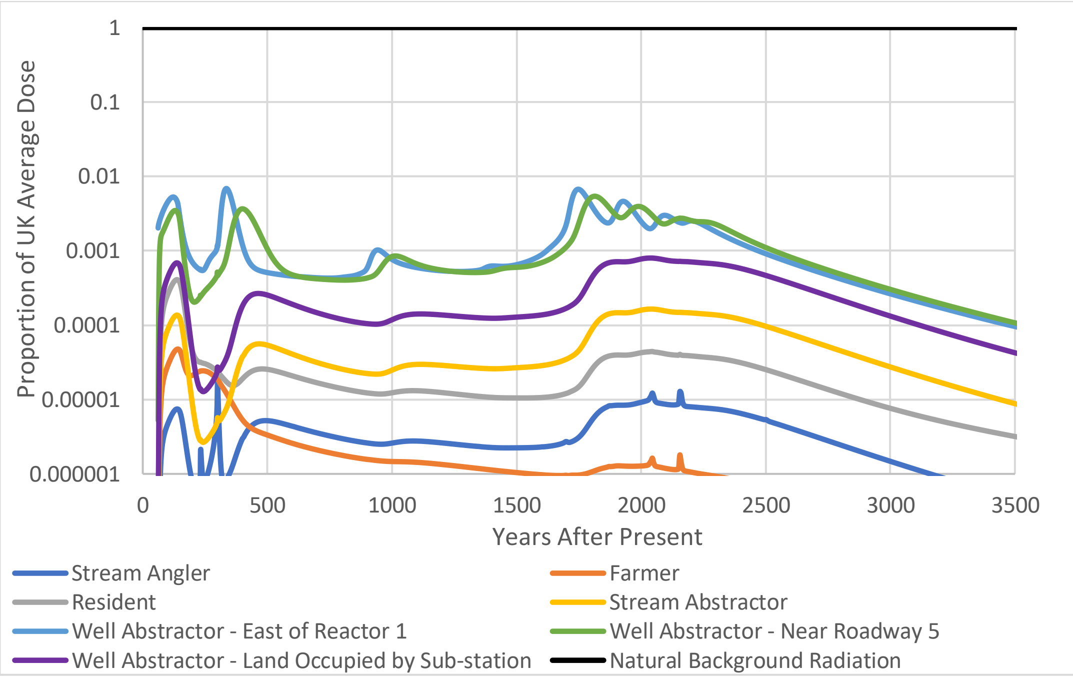
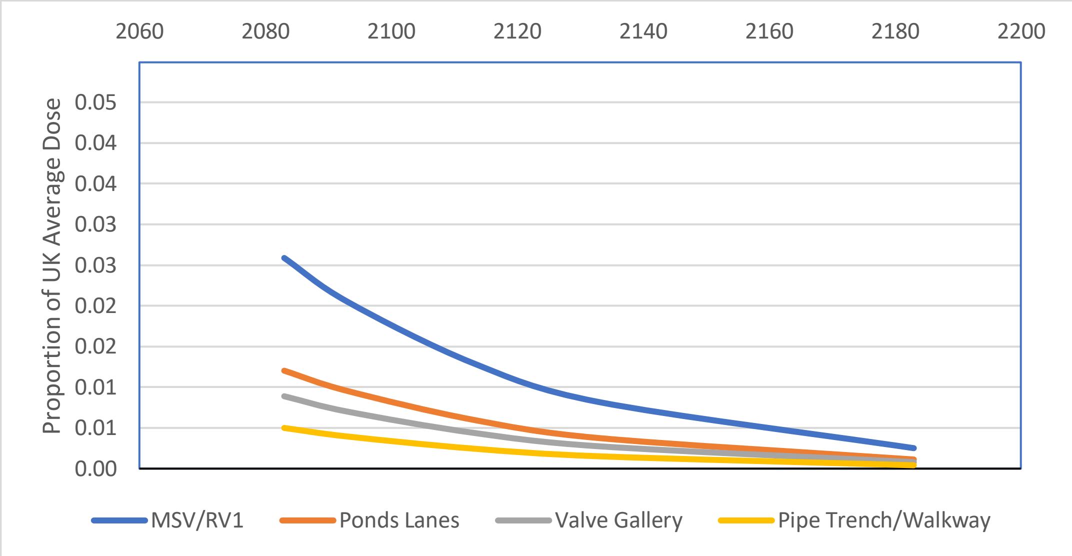


Figure 9.6 Site Occupancy Dose Rates Over Time



Note that the calculation of the reduction over time shown from 2083 is based on Cs137 being the dominant contributor.

9.9.2 As can be seen, the calculated impacts on "representative persons" for "natural evolution" of the site are very small, with the peak additional radiation exposure being less than 1% of the average annual individual dose in the UK.

9.9.3 For most of the representative persons (resident, farmer etc), the risk (of death or heritable defect), if the calculated peak dose rate were incurred, is well below the risk guidance level of 1 in a million per year.

9.9.4 The peak dose rate case to a drinking well abstractor, where the well is just east of Reactor 1, has also been estimated. In that specific case, the calculated peak dose rate is 18.5 µSv/year, only slightly above the 17 µSv/year dose rate equivalent of the risk guidance level of 1 in a million per year. However, the risk is much lower than 1 in a million per year if the likelihood of there being a drinking well in that location at the time of the peak is taken into account.

9.9.5 Based on the current assumed radioactive inventory and a concrete cap that is 0.225m thick, the calculated annual dose to a site occupier spending about half of their time directly above the most radioactive parts of the near-surface components of the Proposed Disposals will also be well below the annual average dose for an occupant of the UK, even if the occupancy arises as soon as 2080.

9.9.6 If site occupancy is assumed to occur in about 2080, the calculated dose rate to the occupant exceeds the 17 µSv/year dose rate equivalent of the risk guidance level of 1 in a million per year by a factor of about four; this is for the worst-case occupancy location above the Proposed Disposals. This worst case is very unlikely to occur (which reduces the actual risk, see paragraph 9.8.5), and the radioactivity levels leading to this finding may be over-estimated at the current time. If required, the estimated and actual dose rate could be addressed by various physical means such as reducing the radioactivity levels in the relevant relatively near-surface locations. Other possible measures, if required, include delaying release of the site from environmental permitting beyond 2080.

CONCLUSIONS: DOSES TO PEOPLE FROM FUTURE LAND USES

All the estimated future doses to "representative persons" using the land over or in the vicinity of the Proposed Disposals in the long term after release of the site are a small fraction of the background radiation experienced by all people. This includes the doses to any future site occupants.

The highest calculated doses to a site occupier (which are based on a person spending about half of their time above the most radioactive near-surface features within the disposals) are likely to be consequences of cautious assumptions for certain parts of the radioactive inventory, resulting in over-estimates of the consequences. These parts of the ponds complex have yet to be fully characterised. It is, of course, also unlikely that the location with the highest dose rates at the ground surface above the Proposed Disposals would be occupied at the first opportunity (assumed to be ~2080).

9.9.7 Key results relating to intrusion scenarios are provided in Appendix 9H. These address the potential impacts on hypothetical persons intruding upon the disposals without specific personal protective equipment or radiological controls, and the potential impacts on hypothetical users of land affected by deposited excavated materials.

9.9.8 For the current radionuclide inventory estimates, one of the highest calculated impacts relating to intrusion scenarios is the annual dose to a hypothetical infant land user. In this scenario, the representative person (infant) is assumed to play in a garden/smallholding where excavated contaminated material has been spread, and is assumed to eat produce that has been grown in that garden/smallholding, and is assumed to eat products from animals reared there. With the generally cautious radioactive inventory and with other assumptions that have been made for the purposes of the intrusion assessments, this hypothetical infant land user would get an annual dose not dissimilar to the UK's average individual annual dose from all sources, though it would of course be additional.

9.9.9 The annual dose to the hypothetical infant land user in this scenario is, like for other intrusion scenarios, dependent on the time of the intrusion event. The results presented in Appendix 9H are for intrusion events around 2080, with an illustration given in Appendix 9H of how the infant land user dose would reduce as a function of the time at which the intrusion event is assumed to occur.

CONCLUSIONS: HUMAN INTRUSION

The assessed human intrusion doses, both the doses to the persons undertaking the intrusion (the excavator or driller etc.) and to any persons subsequently affected by the use of any materials taken away, are considered to be acceptable.

The worst-case dose is to a hypothetical infant land user following an intrusion event. This infant land user would get an annual dose not dissimilar to the UK's average individual annual dose. This is acceptable not least because of the unlikely sequence of events required to give this assessed dose, including intrusion into the most contaminated parts of the ponds complex at the earliest opportunity after release of the site from controls (assumed to be ~2080), and the removal of contaminated materials for incorporation into land used for food production.

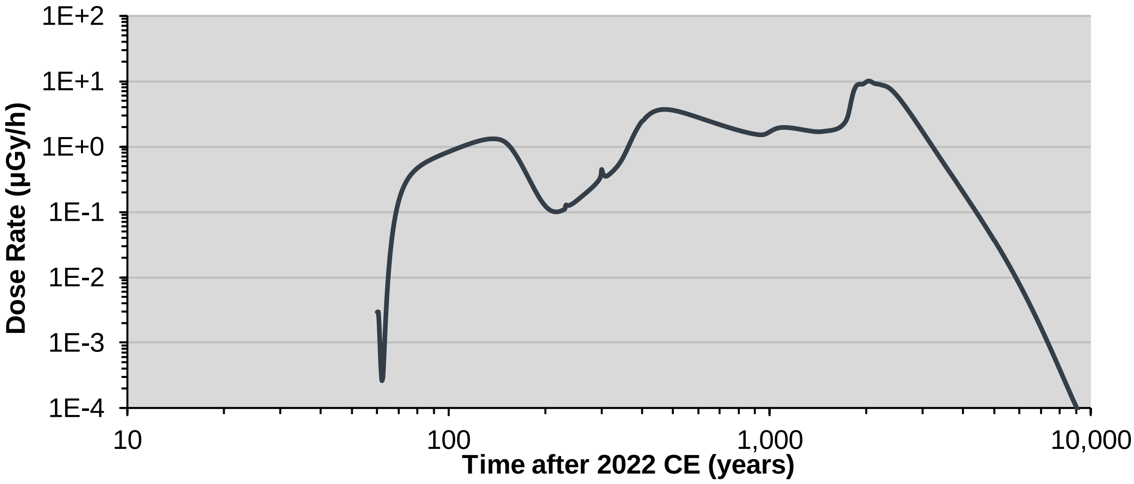
The calculated highest doses to those exposed because of inadvertent (uncontrolled) intrusion are also likely to be consequences of cautious assumptions for certain parts of the radioactive inventory, likely resulting in over-estimates of the consequences. These parts have yet to be fully characterised. If necessary, the estimated intrusion doses could be reduced through reducing or removing the radioactivity in relevant locations.

Impacts on non-human biota

9.9.10 The radiological risk assessment for non-human biota is described in Appendix 9I. This addresses non-human biota in a hypothetical field located approximately where the electrical switching compounds are currently located, as well as non-human biota in the Nant Gwylan / Afon Tafarn-helyg streams system. In all cases, even the lowest dose rate thresholds for potential radiological harm to non-human biota at a population level are not exceeded. An example plot of the non-human biota dose rate as a function of time is shown in Figure 9.7 below.

CONCLUSIONS: NON-HUMAN BIOTA
The peak dose rates to non-human biota are below all the commonly used dose rate thresholds for harm.

Figure 9.7: Impacts on Nant Gwlan Non-Human Biota for "Natural Evolution" (insect larvae)



Impacts on non-radioactive groundwater and surface water quality

9.9.11 The non-radiological risk assessment for controlled waters is described in Appendix 9J. Most potential non-radioactive pollutants are shown there, based on qualitative arguments, to present little risk of unacceptable impacts. Two potential pollutants required more detailed assessment: chromium (VI), which is a hazardous substance found in older concrete; and hydroxyl ions (a form of alkalinity), which is non-hazardous but nonetheless subject to environmental standards.

9.9.12 Quantitative calculations have shown that chromium (VI) from concrete demolition arisings poses little likelihood of unacceptable inputs to groundwater or down gradient surface water receptors under all the various scenarios considered.

9.9.13 In the case of pH, which is a measure of hydroxyl ions/alkalinity, the calculations show that the pH might exceed the upper pH level and hence result in an unacceptable impact on groundwater some years after cap degradation. However, it is important to note that the assessment is conservative in that it does not include carbonation of the concrete infill material. Carbonation, which is a natural chemical process expected to significantly reduce the alkalinity impact of the infill on the groundwater downgradient of the ponds complex, has not been included in the calculations. This is because there is insufficient information in the literature on carbonation rates to assess its mitigating effects quantitatively.

9.9.14 However, it is known that carbonation processes take place, because pH levels in the diversion culvert, receiving groundwater from the turbine hall area, only exceeded the upper pH value for a few years after similar concrete demolition material was placed in the turbine hall below-ground voids. The assumption is that in that case the pH declined after a few years because carbonation of the fill material had taken effect. Therefore, in the case of the infill of the ponds complex, the effects of carbonation are expected to take effect well before the time at which cap degradation has reached the point that allows sufficient flow of water through the concrete infill to cause the high pH levels that would theoretically occur in the absence of carbonation.

CONCLUSIONS: NON-RADIOLOGICAL IMPACTS ON CONTROLLED WATERS Two potential “pollutants” were identified as requiring quantitative assessment. These were chromium (VI) and groundwater alkalinity. Both are common issues with demolition arisings used to infill below-ground voids. Calculations have shown that chromium (VI) from concrete demolition arisings poses little likelihood of unacceptable inputs to groundwater or down gradient surface waters. It is not possible to show by calculation that groundwater alkalinity will be always acceptable in the future, because it is not possible at the present time to numerically model certain beneficial, naturally occurring chemical effects on concrete demolition materials. However, experience elsewhere on the site indicates that the alkalinity impacts will be acceptable.

Long-term consequences of changes to groundwater flows and levels due to pre-development works on under-ponds sampling drains

9.9.15 In Appendix 9K, potential impacts on groundwater flows and levels due to pre-development blocking of some of the hypothetical groundwater flow paths from the west to east sides of the ponds complex (ponds lanes) are considered. It is concluded that there will be no significant effects on groundwater flows or levels arising from the pre-development works on under-ponds sampling drains.

9.9.16 The results of radiological assessments will not materially adversely change because of the pre-development works from those presented:

- the modelling did not take into account the planned removal of some of the radioactive inventory in under-ponds drains in the pre-development works, and therefore the under-ponds drains inventory in the modelling is already cautious in that respect;

- the modelling assumed that most of the under-ponds drains that are or could be below the water-table are below water-table level anyway; and
- the possible outcomes are bounded by the alternative scenarios considered as part of the uncertainty assessments (Section 9.11, Appendix 9L). This is also true for the non-radiological, tiered risk assessment (Appendix 9J).

9.9.17 As a result of the pre-development works on under-ponds sampling drains, the groundwater level is unlikely to rise above the level of those under-ponds drains currently anticipated to remain well above groundwater level and for which no intervention such as removal or grouting of their contents is proposed (drains 12-16).

9.9.18 Whilst not expected, if groundwater were to rise around the ponds complex, such that the level was above some voids or parts of voids planned to contain "loose" infill, then the use of monolithic infill[24] (see Project Description (Chapter 3)) could be slightly increased to maintain the objective of having no "loose" infill below the highest expected groundwater level.

CONCLUSIONS: GROUNDWATER FLOWS AND LEVELS
The pre-development blocking of some drains under the ponds complex buildings could, in theory, have some local impacts on groundwater flows and levels. Locally, the groundwater levels may rise slightly (though remain well below ground level), and some groundwater may flow in different directions (again, only locally). However, it is concluded that there will be no significant changes to the assessed radiological or non-radiological consequences of the Proposed Disposals. There would also be no impact on water resources.

9.10 CUMULATIVE RADIOLOGICAL IMPACTS

REGULATORY REQUIREMENTS
Schedule 4 of The Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017 requires, insofar as it is relevant to the Proposed Development and the assessment of its impacts:
"A description of the likely significant effects of the development on the environment resulting from…
(e) the cumulation of effects with other existing and/or approved projects, taking into account any existing environmental problems relating to areas of particular environmental importance likely to be affected..."
This information is summarised in this section, with further information provided in various appendices to this chapter.

9.10.1 The calculated potential radiological impacts presented in previous sections of this chapter do not account for existing environmental radioactivity. The existing environmental radioactivity includes:

[24] This may be achieved using clean concrete before emplacement of demolition arisings, and/or with permeation grouting of pre-emplaced demolition arisings.

- Sub-surface radioactively contaminated ground in proximity to the ponds complex; and
- Radioactivity deriving from past and current permitted radioactive discharges to Llyn Trawsfynydd which is known to enter Nant Gwylan and the Afon Tafarn-helyg via the compensation flow from the lake.

9.10.2 These above two additional sources of radioactivity are discussed below. The potential radiological impacts of possible further on-site disposals in the future are also briefly discussed.

9.10.3 The doses to users of Llyn Trawsfynydd, as reported in RiFE reports (see paragraph 9.4.14), will not be altered by the Proposed Disposals. In effect, this is a separate group of people to those considered in the long-term radiological assessments (resident, farmer, stream angler etc).

9.10.4 The doses and dose rates presented throughout this chapter would be in addition to the natural background radiation exposure experienced by everyone, and in addition to the radiation exposure people might incur through medical procedures[25], air travel and so on (see paragraph 9.4.15). This annual dose rate has not been added to the figures given, but the fact that these various other sources of radiation exposure would or may be additional to the dose rates presented is acknowledged.

Natural Evolution – Cumulative Doses to People and Non-Human Biota

9.10.5 In terms of natural evolution, releases from the on-site radioactively contaminated ground and/or radionuclides migrating to the Nant Gwylan from the lake via the Gyfynys dam sluice will, to some extent, add to the estimated future doses to all the representative persons (groups) from the Proposed Disposals. However, as can be seen from the environmental concentration plots in Appendix 9G, releases from the Proposed Disposals dominate over the impacts from the contaminated ground and the lake in the long term. Thus, peak dose rates to human users of local streams or fields are not expected to increase significantly from those presented above in Figure 9.5. For the same reasons, releases from the Proposed Disposals tend to dominate the peak dose rate to non-human biota.

9.10.6 For a hypothetical well (groundwater) abstractor representative person (Figure 9.5), the lake radioactivity will not have any impact on the dose rates associated with the well locations considered, whilst the contaminated ground radioactivity is not expected to alter the peak dose rates (which are too far into the future to be affected by the contaminated ground).

Human Intrusion

9.10.7 In respect of human intrusion doses, the radioactivity in the lake is not relevant. The contaminated ground is too deep to have any additive impact for shallow intrusions. However, for large deep intrusions it is possible that an excavation

[25] In general, radiation exposure because of medical exposure is regarded as having a diagnostic or treatment benefit for the patient to off-set the risks associated with that radiation exposure.

could overlap both contaminated ground and the Proposed Disposals. This scenario has not been explicitly assessed; however, large deep intrusions into both contaminated ground and another feature would result in the excavation of large volumes of uncontaminated ground, in addition to the contaminated material, and therefore would be expected to yield lower doses than intrusion into the concrete features alone (for the higher activity features assessed).

Site Occupancy

9.10.8 In respect of site occupancy, i.e. persons spending significant periods of time located above the Proposed Disposals and the concrete cap, the radioactively contaminated ground around the ponds is too deep to have any discernible effect and the lake radioactivity is not relevant. There is no cumulative impact to consider for this group.

Future On-Site Disposals

9.10.9 In the future the concrete bioshields and (now emptied) Miscellaneous Activated Components (MAC) vaults (both within the reactor buildings) may be proposed to remain on site indefinitely as (in environmental permitting terms) on-site disposals of radioactive waste. However, under EIA regulations, it is not a requirement, and it is not practice, to include the cumulative impacts of future developments which have not yet been granted permission or which not yet even been formally proposed. However, the cumulative environmental impact assessment of any such future developments will, at the time they are proposed, need to consider all previously permissioned, relevant developments.

9.10.10 For the environmental permit application submitted to NRW in December 2023, the results of the site-wide natural evolution radiological assessments of impacts on people were presented that included the present Proposed Disposals, the existing radioactively contaminated ground, and bioshields and MAC vaults if also disposed of in a similar manner to the ponds complex. These assessments of impacts on people show that for these sources, there is unlikely to be any significant cumulation of effects. This is because peak dose rates from the Proposed Disposals either occur at different times to peaks from the two other sources considered, or are of a significantly different magnitude, leading to a single source dominating the dose.

9.11 UNCERTAINTIES

REGULATORY REQUIREMENTS
Schedule 4 of The Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017 requires, insofar as it is relevant to the Proposed Development and the assessment of its impacts:
"*A description of the forecasting methods or evidence used to identify and assess the effects on the environment, including details of difficulties (for example technical deficiencies or lack of knowledge) encountered compiling the required information and the main uncertainties involved*".

The forecasting methods have been described earlier in this chapter. This section now summarises uncertainties and how they have been addressed, with details provided in Appendix 9L.

9.11.1 The principal uncertainties in relation to the radiological impacts of the proposals and how they have been addressed are set out in Appendix 9L. All significant uncertainties have been addressed as described there. Other than for the groundwater well abstractor, the results presented above relate to cautious / best estimate calculations and not to variant (alternative) scenario calculations which explore more bounding circumstances.

9.11.2 In relation to the natural evolution assessments of radiological impacts on people, the general approach to uncertainties has been:

- to use cautious or best estimate parameter choices in the first instance (cautious parameter choices being likely to result in over-estimates of the radiological consequences);
- to ignore some potentially mitigating factors;
- where best estimate parameter choices are used in the first instance, to consider alternative parameter choices in alternative calculations; and
- for most representative persons, to consider alternative natural evolutions and disposal configurations in variant and "what if" scenarios e.g. what if there is effectively no concrete cap to limit rainwater ingress from above.

9.11.3 All alternative calculations are considered to give acceptable predicted radiological consequences (Appendix 9L).

9.11.4 In relation to the natural evolution assessments of radiological impacts on non-human biota, some of the points in paragraph 9.11.2 also apply to this aspect. In addition, the impacts have been explored using the ERICA code in several different ways, as explained in Appendix 9I.

9.11.5 All the radiological assessments of impacts on people and on non-human biota have as their starting point the radioactive inventory of the Proposed Disposals. To date there has been only limited direct radiological characterisation, with use of assumptions and inferences, though overall the assumed inventory for the assessments is believed to be conservative (i.e. a larger inventory than there is in reality). The relative paucity of direct radiological characterisation data will be addressed in the coming years through further planned characterisation prior to the demolitions. As new information becomes available, the radiological assessments will be reviewed. The option to undertake localised decontamination to reduce the radioactive inventory in areas of relatively high activity and/ or near the ground surface will remain under review.

9.11.6 With regards to the uncertainties relating to non-radiological impacts on the environment, these are discussed in Appendix 9J. The principal uncertainty is the rate of carbonation of the demolition arisings placed in the sub-surface ponds complex voids. Carbonation is a natural chemical process expected to significantly reduce the alkalinity impact of the infill on the groundwater downgradient of the ponds complex (this alkalinity impact being likely to occur once water starts to enter and exit the infilled voids). The use of such demolition materials for the infill of sub-surface structures in the UK is common practice and is not known to result in wide-spread unacceptable consequences.

9.11.7 There will be “acceptance criteria” for what wastes can be used to infill voids and for what can be left in-situ, these acceptance criteria being related to both the standards set out in the GRR and the results of the assessments undertaken by the Applicant and its consultants as summarised in this chapter. Any findings of concrete, masonry or other materials that do not comply with the acceptance criteria can, if required (i.e. if an exception case cannot be made), be removed prior to demolition or prior to emplacement of demolition arisings. This will provide a further safeguard in terms of potential impacts on people and on the environment.

9.11.8 As discussed in the next section, after completion of the works, i.e. after completion of the concrete cap and the associated drainage system, there will be a long period of concrete cap inspection and maintenance, and a long period of environmental monitoring involving the monitoring of groundwater, surface water and site discharge points. In the event of unexpected adverse findings during the monitoring period, various responses to reduce the impacts are available. Potential responses include repairs to the concrete cap or grouting the infilled materials.

9.12 POST-WORKS PHASE MONITORING

9.12.1 A preliminary post-works phase water environment monitoring plan has been produced to support the environmental permit application to allow the Proposed Disposals within the Disposal Area, including the monitoring of boreholes and drainage systems that include collected groundwater (see Project Description (Chapter 3)).

9.12.2 The monitoring has been designed to detect any adverse trends or occurrences over the years and decades following completion of the works, i.e. after completion of demolition, void infilling, construction of the concrete cap, and installation of associated storm water run-off drainage. Such monitoring is expected to continue in some form until the site environmental permit is surrendered.

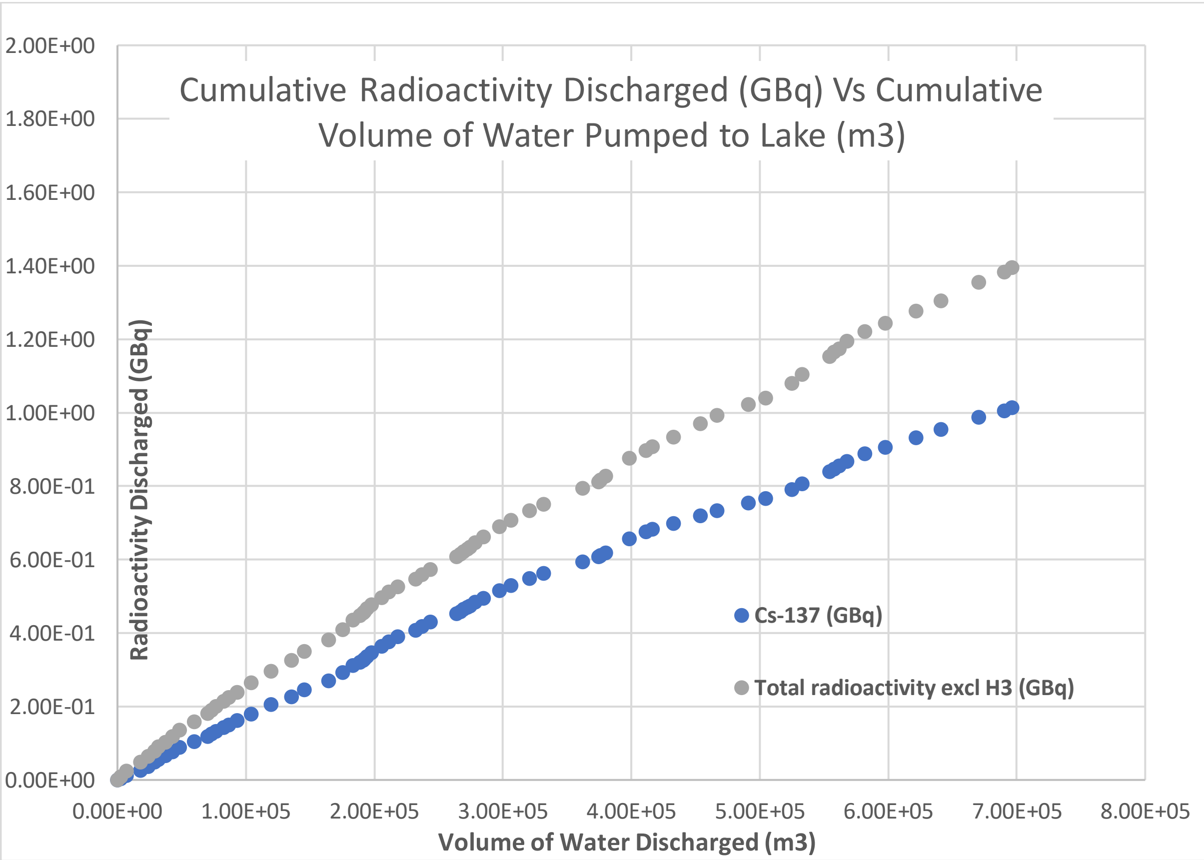
9.12.3 The long-term groundwater and surface water monitoring plan is subject to approval by NRW through the environmental permitting regime and will likely require revision (with NRW agreement) to take account of matters such as the continued collection of baseline water level and quality information. It may also be adapted over time (again with NRW agreement) in response to the post works phase monitoring results, or in response to physical changes on the site as a result of decommissioning works.

9.12.4 Part of the post-works monitoring regime is the monitoring of the discharges to Llyn Trawsfynydd via the diversion culvert system. Should there be an increase in radioactivity migrating away from the ponds complex area after the works are complete, this will be detectable in the diversion culvert monitoring[26], as explained below.

9.12.5 Because the diversion culvert system receives radioactively contaminated groundwater from the area of existing contaminated ground around the ponds complex, the system forms a permitted discharge route to Llyn Trawsfynydd, and it is subject to monitoring through the site's environmental permit. These arrangements will not fundamentally change for some decades to come. The radioactivity in the diversion culvert water is monitored on a weekly basis (using bulked samples taken daily). The volume of water discharged from the diversion culvert to the lake is also monitored. This allows the data to be analysed in various ways to determine whether there are any unusual discharge events or adverse long-term trends occurring.

9.12.6 Figure 9.8 shows an example of how the diversion culvert data can be presented in a manner that would show adverse long-term trends. The figure shows that the cumulative Cs137 discharge and the cumulative total radioactivity discharged (excluding tritium) are both approximately linear (a straight line) when plotted against the cumulative water volume discharged. An adverse upwards trend would be shown by an upwards bend or kink in that line.

Figure 9.8 Plots of Cumulative Cs137 Discharges Against Cumulative Water Volume Discharges for the Diversion Culvert from April 2016 to March 2022



[26] There is a possible northern groundwater pathway from parts of the ponds complex which, if shown to be present, will also be monitored via boreholes in the post-works period. The existence of this northern groundwater pathway is currently under investigation.

9.12.7 Monitoring data will be subject to expert review of concentrations of contaminants against baseline concentrations, including time-series trend analysis. Actions that may be taken in response to adverse results include:

- Should the pH of the water become unacceptably high, treatment of water at Manhole 6 (an accessible location slightly east of the reactor buildings through which water intercepted by the groundwater drainage system passes);
- Concrete cap inspection and repair or enhanced maintenance;
- Additional capping of the disposals; or
- In situ grouting of the material deposited in the voids.

9.13 CONCLUSIONS

9.13.1 This chapter of the Environmental Statement has summarised assessments of the effects of the Proposed Disposals with respect to long-term radiological and non-radiological impacts via “natural evolution” and future site occupancy. This has included radiological and non-radiological aspects as appropriate, and included impacts on people, non-human biota and controlled waters.

9.13.2 It is expected that the period during which the Trawsfynydd site remains subject to environmental permitting will last into the latter half of this century. For some decades the site will remain subject to environmental permitting and subject to a nuclear site licence, and land-use controls will apply. When the site has ceased to be subject to environmental permitting or the site licence, it is pessimistically assumed that no land-use, access or development controls apply to the site. This chapter has therefore summarised potential doses to people from human intrusion events that could hypothetically occur at that time.

9.13.3 The following table summarises the assessment findings:

Aspect	Impacts from the Proposed Disposals
Radiation doses to people from gradual migration of radionuclides from the Proposed Disposals.	Estimated annual doses peak at a level which is significantly (orders of magnitude) less than the average individual radiation exposure in the UK (which is about 2.7mSv per year).
Site occupancy, e.g. person using a caravan as a residence above the Proposed Disposals.	Estimated annual doses are significantly less than the average individual radiation exposure in the UK (which is about 2.7mSv per year). Both the estimated and actual annual dose in this scenario will depend on factors such as the concrete cap thickness, final site landscaping and the final radioactivity levels in the structures and infill just below the cap.
Radiation doses to plants and animals from	Estimated doses in the local stream network and in a hypothetical field in the location of the current switching

Aspect	Impacts from the Proposed Disposals
gradual migration of radionuclides from the Proposed Disposals.	compound are well below any recognised threshold for harm to non-human biota.
Intrusion doses: intruders (excavators), if this were to occur.	The estimated doses to persons carrying out (uncontrolled) excavations are all far below the regulatory guidance levels for this type of event (20mSv), for all intrusion events considered.
Intrusion doses: use of radioactive materials removed from the site, if this were to occur.	Some of the estimated doses to persons exposed to radiation because of materials taken away from the site for other (uncontrolled) uses are around the regulatory guidance levels for this type of event (3mSv per year). The finding is likely due to the pessimistic radioactive inventory data and assumptions used in the calculations that exaggerate the assessed level of dose received, but if the radioactive inventory in the relevant key locations is found to be broadly correct or under-estimated, then radioactivity levels can be reduced by localised decontamination prior to demolition to address this issue.
Non-radioactive pollutant effects on groundwater.	Previous experience of infilling large voids on the site with concrete demolition arisings indicates that the alkalinity will be within acceptable limits. However, it is not possible to numerically prove this. For the only hazardous pollutant of interest (a form of chromium that is a constituent of older concrete), calculations show that groundwater concentrations will be acceptable.
Impact of pre-development blocking some under-ponds drains.	Any effects of the pre-development work on under-ponds drains are likely to be very localised. The radiological and non-radiological impacts of the Proposed Disposals via groundwater pathways will not be significantly increased from the assessment findings presented in this chapter.

9.13.4 “Disposal acceptance criteria”, including for emplacement of demolition arisings, will be produced for approval by NRW as part of the environmental permit variation process. This means that only suitable materials will be used for void infill (or retained in situ) as agreed with NRW. This is important to bear in mind as a mitigation against unsuitable materials being placed in below-ground voids or retained in below-ground structures. These disposal acceptance criteria will be derived in such a way as to prevent non-compliance with GRR dose and risk guidance levels.

9.13.5 It is concluded that, with use of localised decontamination prior to demolition and other design measures if found to be necessary, all the relevant regularity requirements, standards and guidelines identified relating to long-term radiological and non-radiological impacts will be complied with. There are therefore no significant long-term effects of the proposals.

Appendix 9A: Environmental Permitting Regulations (EPR16)

Schedule 23 (Radioactive Substances Activities)

The Proposed Disposals will require an amendment to the Trawsfynydd site's environmental permit granted under Schedule 23 of EPR16. The required variation to the site's environmental permit will only be granted by NRW if, amongst other things, the Applicant has demonstrated that the limits set out in law regarding radiological exposure of the public would continue to be met and that the radiation doses to members of the public arising from the proposals would be minimised. NRW will also have to be satisfied that the proposed strategy of on-site disposal of suitable radioactive wastes and the proposed means of implementing that strategy represent the best available techniques (BAT) for the management of those radioactive wastes.

Dose Limit and Other Criteria

With respect to the limits set out in law regarding radiological exposure of the public, the dose limit (deriving from the EU Basic Safety Standards Directive) is 1 mSv/yr. As stated in EPR16, in exercising its functions the regulator must also have regard to doses from individual sources and/or sites, sometimes known as "dose constraints".

Application of BAT

Via permits issued to operators such as the Applicant under EPR16, all forms of disposal of radioactive waste must be shown to use the Best Available Techniques (BAT) and be optimised, such that radiological impacts to members of the public are As Low As Reasonably Achievable (ALARA), all relevant economic and social factors being taken into account.

BAT and ALARA are linked regulatory concepts widely used and understood within the nuclear and radioactive waste management industries. Neither concept means the unlimited application of resources to increase the containment of radioactive waste to the maximum degree possible or to reduce the radiological consequences of radioactive waste management activities to the minimum technically achievable.

Current Permitted Discharges

The permitted routine aqueous discharges routes from the Trawsfynydd site are[27]:

- the system provided for the discharge of radioactive waste from the site's active effluent treatment plant to Llyn Trawsfynydd;

[27] Discharges *via* routes identified in 4th and 5th bullet points listed are not relevant to the Proposed Disposals.

- drainage water collected in the diversion culvert pumping station, which is situated at a low point on the eastern side of the Trawsfynydd site, discharged to Llyn Trawsfynydd via pipelines;
- high-level overflow discharge of water collected in the diversion culvert pumping station to Afon Tafarn-helyg via the adjacent stream (Nant Gwylan), used only in extreme weather conditions and not in normal operational use;
- the system provided for discharging treated sewage effluent from the sewage treatment plant to Llyn Trawsfynydd; and
- the high-level overflow discharge of water collected in the sewage system to the stream adjacent to the Northern Outlet Point (NOP), feeding Afon Tafarn-helyg, or to the Trawsfynydd site surface water drains, used only in extreme weather conditions and not in normal operational use.

The second and third of the permitted aqueous effluent discharges listed above include water collected by the Trawsfynydd site's storm (road drains) system. They also include intercepted groundwater that has been radioactively contaminated because of groundwater passing through radioactively contaminated ground[28]. There will continue to be discharges of radioactive aqueous effluent via the diversion culvert pumping station deriving from the contaminated ground around the ponds complex until the diversion culvert pumping station is taken out of service and ceases to be a permitted discharge route. This change will require NRW to grant a further variation to the site's EPR16 permit.

Schedule 22 of EPR16 (Groundwater Activities)

The proposed deposition of demolition arisings as infill material within below ground voids of the ponds complex means that the Proposed Disposals will be considered by the environmental regulator to represent a "groundwater activity" under Schedule 22 of EPR16. In Wales such activities are regulated by NRW, and so NRW will need to be satisfied that all relevant requirements of Schedule 22 of EPR16 will be met.

Schedule 22 of EPR16 imposes an obligation on the environmental regulator to "prevent" inputs of hazardous substances (including radionuclides) to groundwater. Demonstration that inputs of radioactive substances to groundwater have been "prevented" is expected to use the established international approach[29] to radiological protection based on minimisation and ALARA. In respect of potential non-hazardous pollutants, Schedule 22 of EPR16 imposes obligations to take necessary measures to "limit" inputs of non-hazardous substances.

In determining whether the present proposals for Trawsfynydd should be permitted under EPR16, NRW will additionally have to be satisfied that the Water Environment

[28] The contaminated ground largely originated because of historical leaks from the irradiated fuel cooling ponds and is mainly present between the ponds complex and the reactor buildings, as shown by borehole investigations.
[29] As established by the International Atomic Energy Agency (IAEA) and within European Union Basic Safety Standards Directive.

(Water Framework Directive) (England and Wales) Regulations 2017 will be complied with, including the prohibition of “direct discharges” of pollutants into groundwater.

Appendix 9B: Guidance on Requirements for Release from Radioactive Substances Regulation

The principal regulatory guidance relevant to the long-term radiological aspects of the Proposed Disposals is the document published in 2018 by the environment agencies (including NRW) called "Management of Radioactive Waste from Decommissioning of Nuclear Sites: Guidance on Requirements for Release from Radioactive Substances Regulation", commonly known as the GRR. In Wales, "Radioactive Substances Regulation" (RSR) means regulation under Schedule 23 of Environmental Permitting Regulations 2016 (EPR16).

The GRR sets out five principles (Box 9B1) and fifteen requirements (Figure 9B1) that must be met for a site such as Trawsfynydd to be released from environmental permitting following on-site disposal of radioactive waste.

Box 9B1: GRR Principles

Principle	Meaning
Principle 1: Level of protection against radiological hazards	The site shall be brought to a condition at which it can be released from radioactive substances regulation, through a process that will provide protection against the radiological hazards to people and the environment, to the national standards applicable at the time when relevant actions are taken.
Principle 2: Optimisation (as low as reasonably achievable)	The site shall be brought to a condition at which it can be released from radioactive substances regulation, through a process that will keep the radiological risks to individual members of the public and the population as a whole As Low As Reasonably Achievable (ALARA) throughout the period of regulation and afterwards, as far as can be judged at the time when relevant actions are taken.
Principle 3: Level of protection against non-radiological hazards	The site shall be brought to a condition at which it can be released from radioactive substances regulation, through a process that will provide protection to people and the environment against any non-radiological hazards associated with the radioactive substances, to a level consistent with that provided by the national standards applicable at the time when relevant actions are taken.
Principle 4: Reliance on human action	When the site is ready to be released from regulation there shall be no requirement for human action in order to protect people and the environment. The site should be brought to a condition at which it can eventually be released from radioactive substances regulation, in a manner which places a progressively reducing reliance on human action to protect

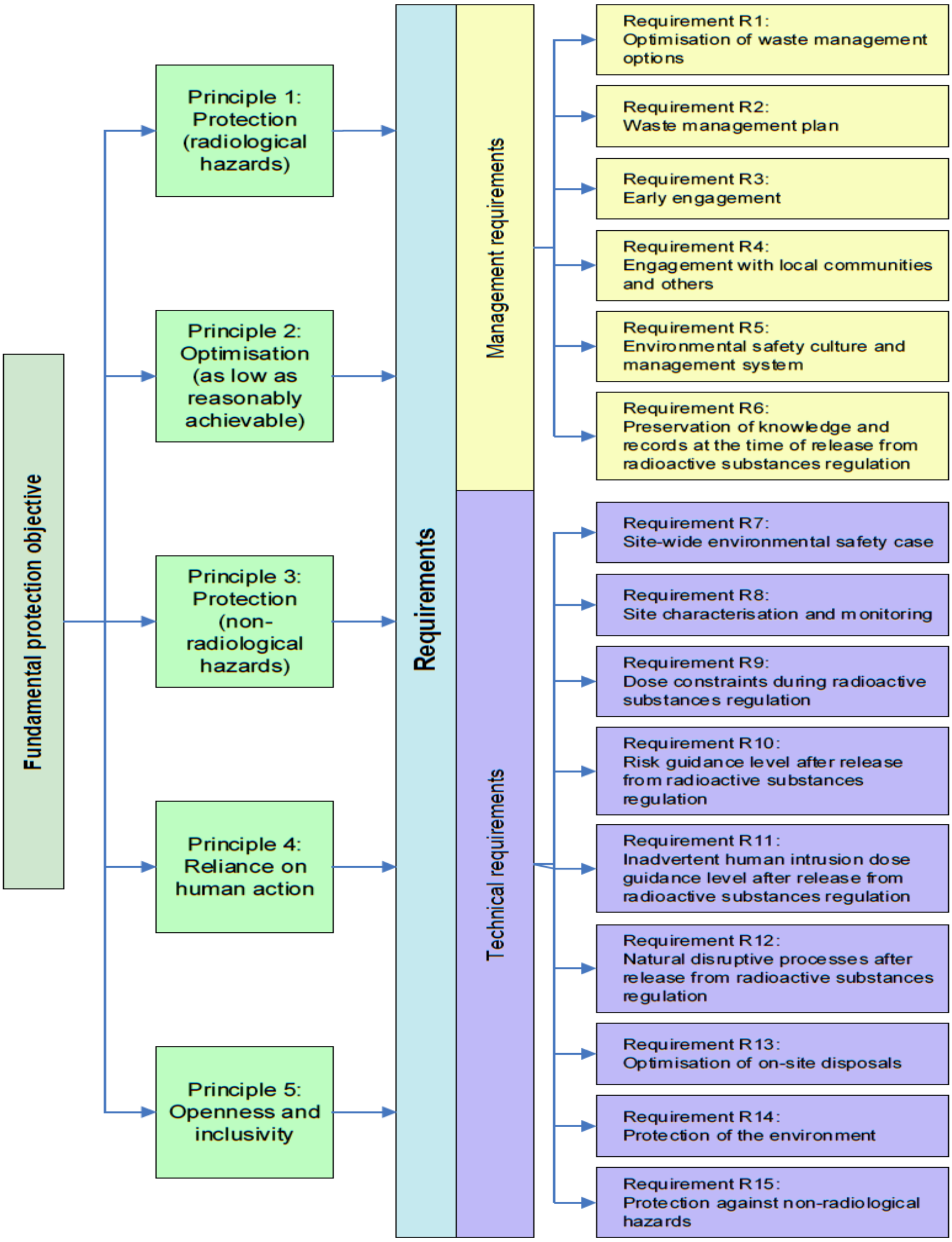
Box 9B1: GRR Principles	
Principle	**Meaning**
	people and the environment against radiological and any associated non-radiological hazards.
Principle 5: Openness and inclusivity	A process that is open and inclusive shall be used to bring the site to a condition at which it can be released from radioactive substances regulation.

One of the requirements (R7) is to develop a Site Wide Environmental Safety Case, defined in the GRR as *"A documented set of claims, made by the operator of a nuclear site, to demonstrate achievement by the site as a whole of the required standard of environmental safety." In this context, "environmental safety*" is defined as "the safety of people and the environment both during the period of RSR [Radioactive Substances Regulation] and afterwards into the indefinite future".

Another requirement (R2) is to develop a Waste Management Plan, defined in the GRR as "*A documented plan, prepared by the operator of a nuclear site, which provides a comprehensive description of the current intent for dealing with all radioactive substances on or adjacent to the site and demonstrates how waste management has been optimised*."

These two requirements are incorporated within the site's current EPR16 environmental permit. Taken together, the Site Wide Environmental Safety Case and the Waste Management Plan, and their supporting assessments, will be the primary means of demonstrating that the proposed on-site disposals will comply with all legal obligations regulated by NRW through EPR16. This includes both radiological and non-radiological aspects.

Figure 9B1: Relationship between GRR Fundamental Protection Objective, Principles and Requirements



Dose and Risk Guidance Levels

When the site ceases to have an EPR16 permit (which the Applicant expects to be some decades into the future), the GRR requirements R10 and R11 include the following:

- Aside from uncontrolled human intrusion scenarios, the radiological risk to a member of the public deriving from the remaining radioactivity should be consistent with a risk guidance level of one in a million per year (10^{-6} per year)[30]. This risk level corresponds with a radiation dose to an individual member of the public of about 17 µSv/yr (0.017 mSv/yr), assuming that the dose occurs. If the dose is unlikely to occur, a dose rate of 17 µSv/year would be equivalent to a risk less than 1 in a million per year, because in that case the risk includes the probability (likelihood) of the dose occurring. Similarly, if the dose is unlikely to occur, a dose rate above 17 µSv/year could still be equivalent to a risk of 1 in a million per year (or less), if the probability (likelihood) of the dose occurring is taken into account.
- The effective dose to hypothetical members of the public during and after an inadvertent and uncontrolled intrusion into the disposed radioactive waste should be consistent with the dose guidance levels, meaning a dose in the range of around 3 mSv/yr (if there would be prolonged radiation exposure to any one person as a result of the intrusion) to around 20 mSv in total to any one person (if there would only be a short, time-limited exposure as a result). For human intrusion, the GRR criteria do not allow for consideration of likelihood of these doses occurring.

[30] The risk here refers to risk of death, or of certain hereditary effects being caused, as a result of radiation exposure.

Appendix 9C: Radioactive Inventory

Radioactive features of the ponds complex and associated redundant infrastructure that are credible candidates for leaving on-site at Trawsfynydd have been identified and radioactive inventory estimates developed[31]. The inventory estimates for these features have uncertainties which have been addressed by making credible but cautious assumptions.

There is also some radioactive inventory associated with the radioactively contaminated ground located within and around the Disposal Area. Based on past intrusive investigations, this amounts to just under 40 GBq, with Cs137 being the principal single radionuclide present[32]. The radioactively contaminated ground will likely remain on site indefinitely but because it is not a radioactive waste (unless excavated), this ground does not require a permit variation or planning permission for its indefinite retention[33]. Where indicated, the radiological assessments summarised in this Environmental Statement have taken the presence of this radioactivity into account.

Although they may be proposed for on-site disposal in the future, this appendix does not include the radioactive inventory for the reactor primary bioshields (concrete barriers that surround the reactor pressure vessels) or for the reactor Miscellaneous Activated Component (MAC) vaults (that are adjacent to but deeper than the bioshields). This inventory information is available on request.

Sources of Radioactivity

Some of the Trawsfynydd site structures have become contaminated through normal operations as well as a result of specific incidents and leaks. Characterisation information suggests contaminated concrete features are mainly contaminated in a near-surface layer (generally expected to be less than one centimetre thick) through past direct contact with solid or liquid radioactive waste.

Contamination of structures across the Disposal Area has mostly derived from five sources of radioactivity:

[31] Detailed in a report (Galson Sciences Ltd, Trawsfynydd Site: Bounding Radioactive Inventory for Ponds Complex Structures and Associated Infrastructure, 1631-26REP Version 2, Magnox Ltd ref. DD/REP/0029/22 Issue 2, October 2023), which is available on request.

[32] The radioactively contaminated ground is associated with leaks from the cooling ponds that happened in the 1970s and early 1980s. The inventory is within the “made ground” (a superficial deposit overlying the bedrock and up to 10m thick), mainly below the water table and typically more than 3m below ground level. This ground has been characterised through the drilling of boreholes and the taking of samples for analysis.

[33] The radioactively contaminated ground is a consideration in the Site Wide Environmental Safety Case and will be a considered at the time of permit surrender.

- Radioactive liquids Key sources include:
    - Ponds water – Water containing dissolved radioactivity and suspended radioactive solids derived from spent fuel elements stored in the ponds during operations.
    - Effluents from effluent-generating facilities and effluent-treatment facilities across the site.
- Resin

Within the Active Effluent Treatment Plant, radioactive effluent was passed through ion exchange resin mainly to remove dissolved radioactivity, such as Cs137 and Sr90. Significant quantities of radioactive spent resin were stored within the ponds complex resin vaults.

- Fuel Element Debris (FED)
- During station operation, spent fuel elements were transferred from the reactor buildings to the ponds complex acceptance bays. Some magnox (magnesium alloy) external features on the fuel elements were removed along with nimonic springs and housing clips. The fuel elements were then transferred to the ponds lanes for cooling and storage, whilst the removed material, known as FED, was transferred to the North and South FED vaults for storage, and latterly to the Magnox Debris Handling and Storage Facility (MDHSF).
- Sludge
- This arose from the corrosion and degradation of magnox fuel element cladding in pond storage. This sludge accumulated in the ponds lanes and elsewhere within the conditioning and filtration plant involved in the recycling of pond water or treatment of radioactive effluent.
- Other active waste
- Parts of the ponds complex stored other types of mainly dry, potentially dusty miscellaneous radioactive waste.

Fingerprints

To derive inventory estimates needed to support the various assessments, information on the “radionuclide fingerprints” of radioactivity that could be left on-site at the end state is required. Radionuclide fingerprints refer to the specific radionuclide composition of the total radioactivity level on or in a feature. Several fingerprints have been used. The origins of the various fingerprints include analyses of:

- pond walls concrete;
- spent ion exchange resin;
- sludge samples and concrete cores taken from the Ponds North Void (where sludge was previously stored);
- loose particulate from the FED vaults;

- samples taken from active drains systems;
- samples taken from under-ponds drains; and
- samples taken earlier in the decommissioning programme intended to encompass solid LLW that was expected to be generated during deplanting of the ponds complex.

Summary of Radiological Inventory Estimates

The cautiously estimated (meaning likely to be over-estimated) radioactive inventory of the Proposed Disposals is summarised in Table 9C.1. In the estimated inventory, only a relatively small number of features contain most of the radioactivity. These are the: north and south FED vaults; the ponds lanes (mostly associated with the construction and expansion joints); under-ponds drains; Resin Vault 1; and the Main Sludge Vault.

Table 9C.1 –Radioactive Inventory of the Proposed Disposals (in the Disposal Area).

Note: Values given in this table are for 2022; the actual radioactive inventory will decrease over time due to radioactive decay.

Area ID	Feature	Total Activity (MBq) Below cut line	Above cut line	Basis of inventory
D01	Final Delay Tanks	1.58E+03	1.73E+00	Characterisation data
D02	Final Effluent Delay Tank structures	6.65E-01	4.25E-02	
D04	Active workshop	6.43E+01	1.00E+02	Assumption
	Chemistry laboratory	1.25E+01	2.54E+01	
	Other minor features	4.38E+00	1.23E+01	
D05	Laundry (ground)	2.35E+01	6.53E+01	Assumption
	Laundry (lower and basement)	4.02E+02	-	
	Active Effluent Treatment Plant / Pond Water Treatment Plant basement	1.80E+03	-	
	South filter room	-	5.88E+02	
	North filter room	-	6.29E+03	
	Pond Water Treatment Plant Bay	2.57E+02	3.19E+02	
	Other minor features	8.70E+00	2.03E+01	
D06	North FED vaults	3.89E+03	-	Assumption
	South FED vaults	3.89E+03	-	
	FED overbuilding (over vaults) - South	-	2.67E+01	
	FED overbuilding (over acceptance bay & pond void) - South	-	2.56E+01	
	FED overbuilding (over vaults) - North	-	2.67E+01	
	FED overbuilding (over acceptance bay & pond void) - North	-	2.56E+01	
	Ponds Lanes including estimated residual dust after vacuuming (including joints). The inventory for the joints is given separately (second number).	1.74E+01 + 1.63E+04	3.36E+02 + 5.79E+03	Inference & characterisation data
	South Acceptance Bay	1.40E+02	8.52E+01	Inference
	Pond South Void	4.08E+02	2.72E+02	
	North Acceptance Bay	1.40E+02	8.52E+01	

Area ID	Feature	Total Activity (MBq) Below cut line	Above cut line	Basis of inventory
	Pond North Void	5.32E+02	2.65E+02	Inference & characterisation data
	Blocks cut from dividing walls	-	1.15E+04	Inference & characterisation data
	Under-ponds Drains 1 & 2 residual channel radioactivity	1.86E+00	-	Characterisation data
	Under-ponds Drains 3 to 6	6.36E+03	-	
	Under-ponds Drain 7 residual channel radioactivity	1.38E+03	-	
	Under-ponds Drains 8 & 9 residual channel radioactivity	4.04E+00	-	
	Under-ponds Drains 10 & 11	3.75E+03	-	
	Under-ponds Drains 12 to 15	1.97E+03	-	
	Under-ponds drain 16	2.11E+02	-	
	Blinding concrete	1.73E+03	-	Characterisation data
	Sleeper walls	1.49E+01	-	Assumption
	Other minor features	-	2.25E+00	Assumption
D08	Ponds walkways & outer walls	6.88E+02	8.63E+02	Characterisation data
D09	Valve gallery & caesium units	2.00E+02	1.03E+03	Assumption
	Other minor features	2.15E+00	4.84E+00	
D10	Despatch bay	1.30E+02	1.78E+03	Assumption
	Flask Washdown Basement Area	4.07E+02	-	Characterisation data
D11 / D12	D11 & D12	1.14E+01	2.67E+01	Assumption
D13[34]	R4 store	2.23E+00	1.15E+01	Assumption
	Other minor features	3.99E+00	8.18E+00	
D14	Waste sorting building	4.37E+00	7.50E+00	Assumption
D15	Resin Vault 2	4.20E+01	-	Inference
	Resin Vault 3	4.20E+01	-	
	Resin Vault 2/3 over vault (west)	1.14E+02	1.74E+02	
	Resin Vault 2/3 over vault (east)	-	8.28E+02	

[34] Note that building D13 excludes the Active Waste Vaults themselves, which are included within D28.

Area ID	Feature	Total Activity (MBq)		Basis of inventory
		Below cut line	Above cut line	
	Resin Vault 2/3 pipe trench	1.68E+02	-	Characterisation data
D18	Main Sludge Vault residuals control room	3.10E-01	-	Assumption
D20	Low Level Waste (LLW) building	2.30E+00	-	Assumption
D21	North FED ventilation plant	1.76E+00	1.32E+00	Assumption
D22	North FED retrievals	8.06E+01	1.89E+02	Assumption
	Minor features	2.79E+01	4.02E+01	
D23	South FED retrievals	8.28E+01	1.86E+02	Assumption
	Other minor features	3.22E+01	5.12E+01	
D24	Transportable ILW Solidification Plant process (ground & upper)	1.46E+01	1.88E+01	Assumption
	Minor features	3.84E+00	3.60E+00	
D25	DWTP (ground)	7.13E+01	2.51E+02	Assumption
	DWTP (lower)	2.16E+01	-	
	Resin lines	2.08E-02	-	
	Other minor features	-	4.68E+00	
D26	Ponds corridor	3.66E+00	5.62E-01	Assumption
D27	Ponds sub-change room	4.93E+01	1.19E+02	Assumption
D28	Resin Vault 1	1.60E+04	4.64E+03	Inference
	Resin Vault 1 corridor & plant room	1.83E+01	2.54E+01	Assumption
	Resin Vault 1 over vault	-	1.29E+02	
	Main Sludge Vault	1.06E+04	3.71E+03	Inference
	Main Sludge Vault over vault	-	5.66E+01	Assumption
	Active Waste Vaults. The inventory for the porous concrete layers on the floor of the Active Waste Vaults is given separately (second number).	2.05E+03 + 2.52E+03	-	Assumption
	Other minor features	-	2.24E+01	Assumption
D29	Ponds scabbling export building	6.80E+00	5.67E+00	Assumption
D30	South FED centre courtyard building	1.44E+01	5.79E+01	Assumption
D33	South FED material handling building	9.72E+00	-	Assumption
D34	South FED Glasdon Hut	1.01E-01	-	Assumption
D35	South FED support building	1.68E-01	-	Assumption

Area ID	Feature	Total Activity (MBq) Below cut line	Above cut line	Basis of inventory
D36	MDHSF process cell & drum vault	5.09E+01	4.02E+02	Assumption
D37	Ponds lanes pipe trench	1.62E+03	-	Assumption & characterisation data
D38	Ponds scabbling control room	6.96E-01	-	Assumption
D39	Resin vault 2/3 Electrical Panel	8.40E-02	-	Assumption
Redundant infrastructure outside of the ponds complex	Active drains - System 1	6.12E-02	-	Characterisation data
	Active drains - System 2	2.42E-02	-	
	Active drains - System 3	2.65E+01	-	
	Active drains - System 6	2.28E+00	-	
	Active drains - System 8	7.68E-01	-	
	ADT Vault/Chamber	6.31E+01	-	
	Oil separator – Active Drain Tank	4.83E-01	-	Inference
	Oil separator - System 6	1.22E+00	-	
	Oil separator - System 8	3.65E-01	-	
	Gaseous effluent filter vaults	3.09E+01	-	Assumption
	Western goliath track wall	9.12E+00	-	Assumption
All	Total Inventory (MBq) excluding inventory components expected to be removed	8.0E+04	4.0E+04	Summation of the above. Note that the radiological assessments considered a slightly larger total inventory that included loose infill from drains 1, 2, 8 and 9 (now proposed to be removed prior to this development).
	Total Inventory (GBq) excluding inventory components expected to be removed	80	40	

Appendix 9D: Radiological Impact Modelling input Data

Tables of key parameters and data sources are provided at the end of this appendix. These are taken from the following documents and the references therein:

- Trawsfynydd Site: Radiological Assessment of Natural Evolution for the E nvisaged Disposal Area Structures — Reference (Base) Case and Varian t Cases/Scenarios, DD/REP/0009/23, Issue 2, October 2023.
- Trawsfynydd Site: Radiological Assessment of Human Intrusion for the Envisaged Disposal Area Structures — Base Case and Variant Cases/Scenarios, DD/REP/0007/23, Issue 2, October 2023.
- Trawsfynydd Site: Radiological Assessment of Doses to a Site Occupier f rom the Envisaged Disposal Area Structures — Base and Variant Cases, DD/REP/0008/23, Issue 2, October 2023.

Key Parameters Common to All Assessments

For some input parameters, all assessments use the same source data. This applies to:

- Radiological inventory data. A radiological inventory has been developed providing estimated activity concentrations and total activities for 90 separate features located within the Disposal Area (Appendix 9C).
- Feature geometries. Within the radiological inventory, dimensional data for each feature are collated and utilised to allow for the derivation of total activities. These geometric data are sourced from a three-dimensional building information model of the ponds complex (developed in the Autodesk Revit software) and construction-era drawings.

Key Parameters – Natural Evolution Assessments

The natural evolution assessment model consists of a connected network of “compartments” that are used to model aqueous radionuclide transport through and out from the disposals, the site geosphere and the local surrounding biosphere.

Material Parameters

Several different solid materials are considered in the modelling, including:

- To represent materials within the disposals (concrete). Various sub-types of concrete are modelled including:
- “intact” concrete – concrete that primarily represents the intact walls and floor of the ponds complex located below the ground surface and the proposed concrete cap. This concrete is mechanically competent and of low permeability at the start of a model run.

- “granular” concrete – concrete that represents broken concrete/masonry demolition arisings emplaced in below-ground voids.
- To represent the geosphere material surrounding the disposals (made ground) – this is the dominant superficial deposit found on the Trawsfynydd site.
- To represent the biosphere materials located around the site:
- soil – present in modelled fields.
- freshwater sediment – present at the base of Llyn Trawsfynydd and carried in suspension within the streams of the Afon Tafarn-helyg catchment.

For each of these solid materials, porosity, bulk density and sorption (partition) coefficients need to be defined; the values used are summarised below in Table 9D.1.

For concrete, some of these parameters are modelled as varying over time. This is to represent chemical degradation of the concrete, which is primarily associated with leaching. As water infiltrates into the disposals, it slowly leaches certain mineralogical constituents from the concrete. This increases its porosity, lowers its density and alters how certain radionuclides will sorb to the concrete (tending to reduce radionuclide sorption).

Modelled Compartments

For the disposals themselves, releases are calculated through the definition of multiple compartments for each modelled feature. Aqueous releases out of the disposals flow directly into one of the geosphere compartments.

The geosphere compartments are defined based on the principal groundwater flow path present on the site (see Figure 9.3), which flows eastwards via the infilled rockhead (bedrock surface) trough located under the southern part of the ponds complex and the northern part of Reactor 1 building. The main function of these compartments is to convey releases from the disposals to the biosphere. The geometry of the geosphere compartments is derived from a review of constraints associated with concrete sub-surface structures (e.g., western goliath track wall), the rockhead topography and the potential for flows to utilise the groundwater drainage system associated with the reactor buildings.

The biosphere compartments represent areas of the local surrounding region where flows from the geosphere discharge and where receptors may be exposed to the accumulation of any radionuclides released from the disposals. The modelled biosphere compartments are near the site, as any radionuclides released will be rapidly diluted and dispersed as they are transported through the biosphere. The geometries of the biosphere compartments are primarily based on values used in an earlier Trawsfynydd biosphere model[35].

[35] Westlakes Scientific Consulting, Specification of a biosphere model for the Trawsfynydd site, Document Number 980340/01, January 1999,

Hydrological and Hydrogeological Parameters

Flow rates between the compartments of the natural evolution model are parameterised using three approaches:

- For the disposals, Darcy's Law is used as the basis to estimate flow rates into and out of features driven by rainfall infiltration and groundwater flow. In addition to the chemical degradation of concrete (discussed above), hydraulic degradation of intact concrete is also considered. This results in the initially very low flow rates through the intact concrete of the cap and below-ground structures changing over time to much higher rates[36]. Upon complete hydraulic degradation, it is assumed in the model that concrete structures have the same hydraulic properties as the surrounding ground and thus do not act as a barrier to water flow.
- For the geosphere, flow rates are based on measurements collected at Manhole 6 ('MH6' in Figure 9.3). The water that flows into Manhole 6 is from the interception of groundwater by the porous pipe groundwater drainage system associated with the reactor buildings, which is inferred to intercept most if not all of the groundwater flowing through the Disposal Area.
- For the biosphere (Figure 9.4), flows are estimated through water balance calculations that consider the outflow from the geosphere, compensation flows out of Llyn Trawsfynydd and rainfall in the Afon Tafarn-helyg catchment.

Further details on specific hydrological and hydrogeological parameters utilised in the model are presented in Table 9D.2.

Concentration Factors

As radionuclides enter the biosphere, they contaminate biosphere materials (e.g., soil, water). Radionuclides associated with these materials can be taken up by plants (pasture, vegetables, fruit), primarily through root uptake. Radionuclides are also taken up by animals (fish, cattle, sheep, poultry), primarily through consumption of contaminated soil or contaminated plants. Radionuclides can subsequently transfer to people through their consumption of plant- and animal-derived foodstuffs. Within the natural evolution model, radionuclide concentration (uptake) factors are used to calculate such transfers. These factors have been primarily compiled from either the IAEA 2010 Terrestrial and Freshwater Environments Parameter Value Handbook[37] or

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[36] Hydraulic degradation is modelled to occur exponentially, with complete degradation occurring 300 years after completion of the disposals. This duration is cautiously selected based on values considered in other natural evolution assessments developed for near-surface disposal facilities in the UK and other countries.

[37] IAEA, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, January 2010.

the Wildlife Transfer Parameter Database[38] (for transfer to pasture and fish). Any gaps in the data have been filled through use of values from other natural evolution assessments developed for near-surface disposal facilities, primarily in the UK[39].

Habits of Representative Persons

Dose rates to human receptors are considered through definition of a set of "representative persons", defined in the GRR as "an individual receiving a dose that is representative of the more highly exposed individuals in the population". The representative persons implemented in the natural evolution model encompass a range of exposure modes aligned with observed local habits (Figure 9.2). For the assessments, the representative persons have been cautiously parameterised mainly through use of averages of the "high-rate" occupancy and consumption values reported in the 2005 and 2018 habits surveys for the Trawsfynydd area (Table 9D.3).

Dose Coefficents

Dose coefficients are used to convert radionuclide activity exposures (to representative persons) to effective dose rates. In the natural evolution assessments, three types of exposure are considered: ingestion, inhalation and external irradiation. The dose coefficients used all derive from a 2010 ONDRAF/NIRAS dose coefficient compendium[40]:

- For inhalation and ingestion, the underlying source is the International Commission on Radiological Protection (ICRP) Publication 72[41].

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[38] Wildlife Transfer Parameter Database, IAEA Summary Tables – April 2015 Snapshot. https://www.wildlifetransferdatabase.org/downloadsummary.asp. Retrieved 01/02/2023.

[39] The main reports being:
Watkins, B., Walke, R., Walden-Bevan, R., Venter, A., Stone, D. and Tang, A., Run 1 Biosphere Database, Biosphere Parameters and Associated Data for the Dounreay Area, UKAEA Dounreay Report GNGL(02)TR24, March 2002.
Thorne, M., Derivation of Biosphere Factors for use in the Drigg Post-Closure Radiological Safety Assessment. Mike Thorne and Associated Ltd., Report MTA/P0012/2002-1, Issue 2 - referenced in Drigg Safety Case as DTP/123, 2003.
LLWR, LLWR Environmental Safety Case, Radiological Assessment Calculation for the Groundwater Pathway for the LLWR 2011 ESC, SERCO/TCS/E003796/011, Issue 6, April 2011.

[40] ONDRAF/NIRAS, Compendium of Dose Coefficients and Related Quantities for Assessing Human Exposure, NIROND-TR 2008-27E, Version 2, November 2010.

[41] International Commission on Radiological Protection, *Age-dependent doses to members of the public from intake of radionuclides: Part 5 – Compilation of ingestion and inhalation dose coefficients*, ICRP Publication 72, Annals of the ICRP 26(1), 1996. Values more recently reproduced in ICRP Publication 119.

- For external irradiation over contaminated sediments or ground, the underlying source is the US Environmental Protection Agency Federal Guidance Report No. 12[42].

The ONDRAF/NIRAS compendium was utilised rather than direct use of the underlying sources as the compendium has cautiously adjusted the dose coefficient values to include the dose associated with any short-lived daughter radionuclides.

Key Parameters – Human Intrusion Assessments

It is not possible to specify in detail the nature of any future intrusion into the Proposed Disposals, but the Generic Intrusion Methodology (GIM) developed for the Applicant provides a range of generic excavation types of different magnitudes (various depths and areas) for assessment purposes[43]. In general terms, these are shallow intrusions that might result in exposure to near-surface material, deeper intrusions that might result in the exposure to large quantities of deeper material, piles that may intersect features over a wide area, and boreholes. Table 9D.4 presents these generic excavation scenarios. 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.

People undertaking excavation and these post-excavation activities may be exposed to radioactivity through a number of exposure pathways: external exposure; inhalation and ingestion of dust; ingestion of contaminated food; and skin contamination.

GIM includes a set of default assumptions and parameter values for each exposure scenario based on current working practices and existing studies. Table 9D.5 presents a description of the parameter inputs for and the most significant exposure pathway for the excavator (initial intruder) and for the representative persons that would receive the highest doses from subsequent use/handling of excavated material[44].

Key Parameters – Site Occupancy Assessments

Site occupancy calculations have been undertaken using MicroShield®. For these calculations the default parameter values built into the modelling software[45] have been used.

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[42] K. F. Eckerman & J. C. Ryman, *Federal Guidance Report No. 12 – External exposure to radionuclides in air, water and soil*, EPA-402-R-93-081, U.S. Environmental Protection Agency, Washington, DC, September 1993.

[43] As detailed in the GIM handbook (Eden Nuclear and Environment, Generic Intrusion Methodology (GIM) for Radiological Assessment of Nuclear Site End States: GIMv2.1.3, ENE-0174/B15/2022/D1, Issue 1.4, Magnox Reference DD/REP/0026/22, Issue 1, March 2022) and Excel spreadsheet tool (Eden Nuclear and Environment, Generic Intrusion Methodology (GIM), Excel Workbook Version 2.1.3, Magnox Reference DD/MISC/0293, Issue 1, March 2022).

[44] As presented in Galson Sciences Ltd, Trawsfynydd Site: Radiological Assessment of Human Intrusion for the Envisaged Disposal Area Structures — Base Case and Variant Cases/Scenarios, 1637 Version 2, DD/REP/0007/23 Issue 2, October 2023.

[45] Grove Software, MicroShield User's Manual, Version 11, 2017.

TABLES

Table 9D.1 Summary of Solid Material Properties

Material	Parameter	Value	References / Comments
Concrete	**Porosity**	Ranges from 0.1 to 0.42, depending on type and degradation state.	The 0.1 value is representative of intact undegraded concrete and is derived based on an ONDRAF/NIRAS review of concrete porosity values[46].
	Bulk Density	Ranges from 2400 kg/m^3 to 1548 kg/m^3 depending on type and degradation state.	The 2400 kg/m^3 value represents a typical density of normal concrete[47]. For concrete where the porosity is higher than 0.1, the density is estimated based on the porosity difference relative to intact undegraded concrete.
	Partition coefficients	Varies between modelled elements and concrete chemical degradation state.	Undegraded values are based on sorption to Stage 2 cement paste, with values reduced to account for cement paste only being a minor proportion (15%) of concrete. Degraded values are based on sorption to granite (representing the aggregate in the concrete). Both sets of partition coefficients are from an SKB data compilation report[48].
Made ground	**Porosity**	0.3	Average porosity value of made ground at the Trawsfynydd site[49].
	Bulk density	1700 kg/m^3	Based on the density considered for the contaminated ground on site[50].

46 Section 7.5 of ONDRAF/NIRAS, Selection of near field parameters for the Dessel near surface repository, NIROND-TR 2010-07 E, Version 1, Revision 9, December 2011.

47 References include McGraw-Hill Encyclopaedia of Science and Technology and Dorf, Richard. *Engineering Handbook.* New York: CRC Press, 1996.

48 Tables 7-8 and 8-7 of SKB, Data report for the safety assessment SR-PSU. Swedish Nuclear Fuel and Waste Management Company (SKB), Report R-14-10, 2014.

49 Golder Associates (UK) Ltd, Trawsfynydd site: 2018 Hydrogeological Interpretation, Contractor Document Number 1780044.620, Version A.2, November 2019.

50 Golder Associates (UK) Ltd, Interpretation of Radioactive Contamination of Ground and Groundwater: 2019 Update, Contractor Document Number 1780044.623, Version A.1, February 2021.

Material	Parameter	Value	References / Comments
	Partition coefficients	Varies between modelled elements.	Values for caesium, nickel and strontium based on site radioelement sorption information for the made ground[51]. For other elements, values are primarily estimated through analogy to drift deposits (unit B2 – Clay rich tills, sands and gravels) located around the Low Level Waste Repository[52].
Soil	**Porosity**	0.3	Values aligned with those used in the 1999 Trawsfynydd biosphere model[53].
	Bulk density	1500 kg/m^3	
	Partition coefficients	Varies between modelled elements.	Primarily sourced from the IAEA 2010 Terrestrial and Freshwater Environments Parameter Value Handbook[54].
Freshwater sediment	**Porosity**	0.75	Values aligned with those used in the 1999 Trawsfynydd biosphere model[55].
	Bulk density	650 kg/m^3	
	Partition coefficients	Varies between modelled elements.	Primary sourced from the IAEA 2010 Terrestrial and Freshwater Environments Parameter Value Handbook[56].

Table 9D.2 Summary of key hydrological and hydrogeological parameters.

Parameter	Value	References / Comments
Hydrologically effective rainfall	1,393 mm/yr	Effective rainfall value for north-west Wales, as used in local site water balance calculations[57].

[51] Golder Associates (UK) Ltd, Groundwater flow and contamination investigation, Trawsfynydd Power Station: Factual report on programme of site characterisation, February - July 1997, 96544047.351, Version A.1, 1998.

[52] LLWR Environmental Safety Case, Radiological Assessment Calculation for the Groundwater Pathway for the LLWR 2011 ESC, SERCO/TCS/E003796/011, Issue 6, April 2011

[53] Westlakes Scientific Consulting, Specification of a biosphere model for the Trawsfynydd site, Document Number 980340/01, January 1999.

[54] IAEA, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, January 2010.

[55] Westlakes Scientific Consulting, Specification of a biosphere model for the Trawsfynydd site, Document Number 980340/01, January 1999.

[56] IAEA, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, January 2010.

[57] Golder Associates (UK) Ltd, Trawsfynydd site: 2018 Hydrogeological Interpretation, Contractor Document Number 1780044.620, Version A.2, November 2019.

Parameter	Value	References / Comments
Hydraulic gradient in the made ground located around the disposals	0.1	Best estimate value based on the monitoring of groundwater along the western edge of the Trawsfynydd site[58].
Hydraulic conductivity of "intact" concrete	1.00E-10 m/s (undegraded) to 1.14E-04 m/s (degraded)	Undegraded value chosen based on a review of concrete hydraulic conductivity values used in near-surface disposal facility safety assessments[59]. The degraded value is assumed to equal the average hydraulic conductivity of made ground at the Trawsfynydd site.
Yearly volumetric flow along the eastern geosphere path	41,000 m^3	Based on the measured value at Manhole 6[60].
Yearly volumetric flow into the Afon Tafarn-helyg catchment from Llyn Trawsfynydd	79,000 m^3	Typical flow rate in the Nant Gwylan[61].
Yearly volumetric flow into the Afon Tafarn-helyg catchment from rainfall	5,126,000 m^3	Calculated based on the effective rainfall rate and a catchment area of ~370 ha (based on catchment area values[62]). Note that in the model, this overall flow rate is apportioned, entering at multiple points along the modelled stream network.

[58] Golder Associates (UK) Ltd, Trawsfynydd site: 2018 Hydrogeological Interpretation, Contractor Document Number 1780044.620, Version A.2, November 2019.
[59] Galson Sciences Ltd, Methodology for Magnox Reactor Sites End States: Aqueous Release and Transport Modelling, 1631-TN5, Version 1.2, Magnox Reference DD/EAN/0032/19 Issue 1, June 2019.
[60] Golder Associates (UK) Ltd, Trawsfynydd site: 2018 Hydrogeological Interpretation, Contractor Document Number 1780044.620, Version A.2, November 2019.
[61] Golder Associates (UK) Ltd, Trawsfynydd site: 2018 Hydrogeological Interpretation, Contractor Document Number 1780044.620, Version A.2, November 2019 & Table 4 of Westlakes Scientific Consulting, Specification of a biosphere model for the Trawsfynydd site, Document Number 980340/01, January 1999.
[62] Westlakes Scientific Consulting, Specification of a biosphere model for the Trawsfynydd site, Document Number 980340/01, January 1999.

Table 9D.3 Representative persons (RP) habits data for the natural evolution assessments.

RP Group	Assumed Habits Data Primarily based on the CEFAS habits surveys for the Trawsfynydd area CEFAS: Centre for Environment, Fisheries and Aquaculture Science
Resident	External occupancy: 730 hours per year Total occupancy: 6,800 hours per year (shielding factor = 0.1 when indoors) Poultry consumption: 17 kgs per year Eggs consumption: 18 kgs per year Green vegetables consumption: 37 kgs per year Root vegetables consumption: 56 kgs per year Potato consumption: 30 kgs per year Other vegetables consumption: 20 kgs per year Inadvertent soil consumption rate: ~0.01 kgs per year Domestic fruit consumption: 26 kgs per year
Farmer	External occupancy: 840 hours per year Beef consumption: 24 kgs per year Lamb consumption: 29 kgs per year Milk consumption: 105 litres per year
Stream angler	Occupancy on the banks of streams: 310 hours per year (external exposure based on modified semi-infinite mass source geometry). Fish consumption: 1.5 kgs per year Fish were assumed to be taken from the Afon Tafarn-helyg.
Stream abstractor	Stream consumption: 600 litres per year. This value based on generalised habit data[63]. For the stream abstractor, dose rates were calculated based on a volumetric-weighted streamwater concentration, calculated based on the water concentrations in the Nant Gwylan, the unnamed stream from Craig Gyfynys and the Afon Tafarn-helyg.
Well abstractor	Groundwater consumption: 600 litres per year. This value based on generalised habit data[64]. For the well abstractor, dose rates were calculated separately for a well constructed at three alternative positions downgradient of the disposals.

[63] Smith, K.R., and Jones, A.L., Generalised habit data for radiological assessments. NRPB W41. National Radiological Protection Board, Chilton, Oxfordshire, 2003.
[64] Smith, K.R., and Jones, A.L., Generalised habit data for radiological assessments. NRPB W41. National Radiological Protection Board, Chilton, Oxfordshire, 2003.

Table 9D.4: Human Intrusion Excavation Scenarios in GIM

Scenario	Description	Dimensions	Volume Assumed to be Removed for Use Elsewhere
Small shallow	Excavations representing typical exploratory excavations.	5 m^2 to a depth of 2 m.	10 m^3
Large shallow	Excavations representing extensive excavations for building foundations.	300 m^2 to a depth of 2 m.	600 m^3
Large deep	Excavations representing the excavation needed to construct a wind turbine.	314 m^2 to a depth of 5 m.	1570 m^3
Boreholes	A single borehole is considered for each feature within the disposals.	20 m deep but 0.03 m^2 areal extent.	0.6 m^3 (per borehole)
Piles	A single pile is considered for each feature within the disposals.	6 m deep but 0.03 m^2 areal extent.	0.18 m^3 (per pile)
Pile array	An array of piles is used in the foundations for a further development on the site of the disposals.	There is assumed to be 2 m between each excavated pile and piles are located around the perimeter of the feature of interest.	0.18 m^3 x no. of piles (case specific)

Table 9D.5: Human Intrusion Scenarios: Exposed Persons Data. For the assessments, default input data, as proposed in GIM, have been used.

Exposed Persons	Description	Primary Exposure pathway	Exposure time	Other input data
Intruder (Excavator)	A worker undertaking an excavation	Inhalation	Hours of exposure dependent on excavation type: Small intrusion: 10 hrs Large shallow: 80 hrs	Suspended dust loading Breathing rate Inadvertent ingestion rate Dilution factor[65] Density per unit area on exposed skin

[65] The intrusion event results in excavation of some material from the feature (some of which may be contaminated and some of which may not be contaminated). It may also result in excavation of uncontaminated material from outside the feature. The exposure equations take account of the mixing of these different materials during the excavation event and this is represented by a dilution factor.

Exposed Persons	Description	Primary Exposure pathway	Exposure time	Other input data
			Large deep: 900 hrs Borehole: 20 hrs Pile: 6 hours	
Worker in a portacabin	Represents the situation where the excavated material is used as aggregate (hardcore) for a car park in which a portacabin is located	External	1800 hours of exposure per year	Dilution factor
Infant play area user	Represents the situation where the excavated material is used as aggregate (hardcore) for a play area	External	400 hours of exposure per year	Suspended dust loading Breathing rate Dilution factor Inadvertent ingestion rate Density per unit area on exposed skin
Infant land user	"Using" covers all infant activities including direct contact with, or ingestion/inhalation of, soil, as well as eating produce (crops and animal produce).	Ingestion	1461 hours of exposure per year	Inadvertent ingestion rate Concentration factors for food stuffs Foodstuffs consumption rate for infant Suspended dust loading Breathing rate Soil/grass consumption rate by animal Dilution factor Density per unit area on exposed skin

Appendix 9E:
Overview of Site Hydrogeology

The information in this appendix is based on the knowledge of the Trawsfynydd site geology and hydrogeology accumulated over several decades66.

The text below refers to Goliath track walls. These are substantial, sub-surface structures used for the original construction of the power station. The western wall runs just east of the ponds complex, and the eastern wall runs east of the reactor buildings. Both are aligned with “site north”. Both may have some influence on groundwater flows.

Overview

The site’s sub-surface comprises drift deposits and made ground overlying bedrock. The made ground includes drift and excavated bedrock and is composed of material ranging from large boulders to clay.

The main flows of water into ground on the Trawsfynydd site are:

- infiltration into unpaved ground; and
- near surface flow (in drift) from Craig Gyfynys to the west of the site.

Of secondary importance are:

- the upward flow from deep bedrock of water that has recharged on Craig Gyfynys; and
- leakage from surface water drains.

Across the developed part of the site, water beneath the ground is mainly water that flows quickly across the site through groundwater drains and surface water drains as well as through connecting zones of transmissive made ground above rock-head and through any transmissive features in the near surface bedrock. Sub-surface water flows broadly from west to east following the fall in topography.

Groundwater Levels

Groundwater levels in the near surface bedrock near Llyn Trawsfynydd (in the southern, less developed part of the site) are determined by the lake level, except downgradient of the dams where the dams are almost completely successful in preventing the lake level being transmitted to the ground.

Groundwater levels near the groundwater drains that are below the water table (such as near those drains leading to MH6) and in drained made ground (e.g., in the rock-

[66] WSP, Trawsfynydd Ponds Complex: Hydrogeological Conceptual Model to Support the Demolition and Disposal Project, DD/REP/0020/23, Issue 1, June 2023.

head trough below Reactor 1) are nearly constant over time. Variations in groundwater level are likewise prevented close to the springs on Roadway 5.

Elsewhere, groundwater levels in the made ground respond clearly and quickly to rainfall.

Ground Permeability

British Geological Survey (BGS) information[67] shows that the bedrock beneath the site (Rhinog Grits) is classed as a secondary A aquifer. The bedrock is typically low permeability and allows groundwater flow only where fractures are present[68]. Fractures are typically more frequent closer to the bedrock surface and less frequent at depth. The made ground can be generally described as permeable.

Groundwater Flows

Shallow groundwater flow is influenced by sub-surface structures including the reactor building foundations and cooling water culverts.

Most groundwater flowing through the Disposal Area is intercepted by groundwater drains, although the magnitude of this flow is uncertain since the only currently available estimate is based on a short campaign of flow measurements in Manhole 6 (MH6) in 1997 (before it became subject to confined space work controls).

The ponds complex and reactors are located on a platform constructed by excavation into the lower slopes of Craig Gyfynys. In such a setting, groundwater flow can, in general, be expected to be from the bedrock into the overlying or adjacent made ground. This will occur where the water table in the made ground is lower than the head of groundwater in the underlying or adjacent bedrock. However, given the relative transmissivities of the bedrock and made ground, the upward flow of groundwater can be expected to be small compared with the flow in the made ground recharged by infiltrating water from the surface.

Table 9E.1 gives more detail of the groundwater flows.

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[67] British Geological Survey (BGS), (n.d.). Aquifer Designation Date. [online] Available at: https://www.bgs.ac.uk/datasets/aquifer-designation-data/ [Accessed 10 November 2023].

[68] A series of packer tests has shown that the bedrock at the Trawsfynydd site decreases in permeability with depth, that the hydrogeological unit is controlled by fractures, and that the hydraulic conductivity is typically low but highly variable and heterogeneous. For example, a hydraulic conductivity range was recorded in borehole BH104 of 1.2×10^{-6} to 9.9×10^{-7} between 12.9 to 20.3m bgl followed by results too low to analyse at the base of the borehole at 30.4m. BH104 is located south-west of the ponds complex.

Table 9E.1 Groundwater flows by zone across the site.

Zone	Description
East of the northern ponds complex structures	• Mobile groundwater occurs in made ground in pools on the rock-head topography in an approximately 3m wide zone between the east side of the ponds complex and the western Goliath track wall. Where rock-head in this zone is high, the water table is in bedrock. • The western Goliath track wall has the potential to be a barrier to easterly groundwater flow in made ground but apertures in it, perhaps including purpose-built drainage pipes above the rock-head, may explain how groundwater is able to pass through it. • The water table falls from north to south along the west side of the Goliath track wall south of the north FED vaults. It is interpreted that groundwater pools on the rock-head sawtooth topography (Figure 9E.1) and, following rainfall, water is inferred to fill the pools and cascade from one small topographic depression in the rock-head to another through the transmissive made ground. • There is currently no groundwater level information immediately east of the ponds complex structures from the north FED vaults to the Active Waste Vaults, but groundwater flow is expected to follow the fall of the rock-head which is inferred to be to the north.
Between Reactor 2 and Reactor 1	• Groundwater that passes through the parts of the western Goliath track wall north of the south ponds lanes flows in made ground close to rock-head into a groundwater drain flowing north to south between

Zone	Description
	Reactor 2 and Reactor 1, into the groundwater drains around Reactor 1.
Reactor 2	• Reactor 2 is founded on bedrock and its external walls are expected to be a barrier to groundwater flow in the made ground. • The low transmissivity of the bedrock means that little lateral flow of groundwater is expected in the footprint of Reactor 2. • Bedrock groundwater discharges into the unlined Reactor 2 west sub-floor void when bedrock groundwater levels are higher than the local rock-head
South side of Reactor 1	• Groundwater around the Final Delay Tanks and south of Reactor 1 flows over rock-head and in the absence of the current dewatering system would pool against the south wall of Reactor 1 . • When not pumped, the groundwater probably flows out of this pooled area along the southern part of the groundwater drain along the west side of Reactor 1 and thence into made ground in the rock-head trough beneath the northern part of the reactor building and/or to made ground to the north and east, possibly being diverted by the solid part of the eastern Goliath track wall and/or the cooling water culverts towards the drain leading to MH6.
East of the southern ponds complex structures and beneath Reactor 1	• Flow is interpreted to take place through undocumented purpose-built drainage holes in the western Goliath track wall and, at least locally, within fractures beneath it in bedrock. • Groundwater on the west side of Reactor 1, and north of a rock-head high close to the southwest corner of

Zone	Description
	Reactor 1, is expected to flow northwards in made ground into the made ground filled rock-head trough that extends beneath the Active Effluent Treatment Plant basement, south ponds lanes and northern part of the Reactor 1 building. • Groundwater flow in the trough is from west to east in made ground and drains.
East of Reactor 1	• Most of the groundwater passing through the made ground filled rock-head trough and around the east side of Reactor 1 is captured by the pipe leading from the groundwater drain on the east side of Reactor 1 into the main storm drain at MH6 (Figure 9E.2). • From MH6, the intercepted groundwater currently drains by gravity through solid pipes to MH7 and on into MH103. • The storm drain (solid pipes) then runs from MH103 to the diversion culvert via the main drains oil interceptor and the diversion culvert pump sumps. • From there, water is currently pumped via diversion culverts No. 3 and No. 4 and is discharged to Llyn Trawsfynydd. • Ultimately, this pumping arrangement will have to be replaced with a passive drainage system (that takes into account flood risks), and the solid pipe system downstream of MH6 may be blocked (either deliberately or through degradation).
Beneath the former turbine hall to roadway 5	• Groundwater not intercepted by groundwater drains feeding into MH6 is inferred to flow eastwards via a ‘saddle’ in the rock-head topography under the west side of the turbine hall. • Beyond the ‘saddle’ in rock-head, groundwater flow is inferred to follow

Zone	Description
	the rock-head topography until it reaches the cooling water culverts. • Here, it is probably collected by a drainage pipe that runs along the west side of the cooling water culverts within the former turbine hall footprint before passing through a west-east pipe beneath the northern part of the culverts. • It then flows over the falling rock-head towards a spring line located at the foot of the bank on the west side of Roadway 5. • The groundwater seepage is currently captured by road gulley drains and a French drain installed at the spring line and flows in surface water drains to the Northern Outlet Pipe (NOP in Figure 9E.2) where it discharges to the unnamed stream running off Craig Gyfynys.

Figure 9E.1 Groundwater interaction with rock-head adjoining the Goliath track wall

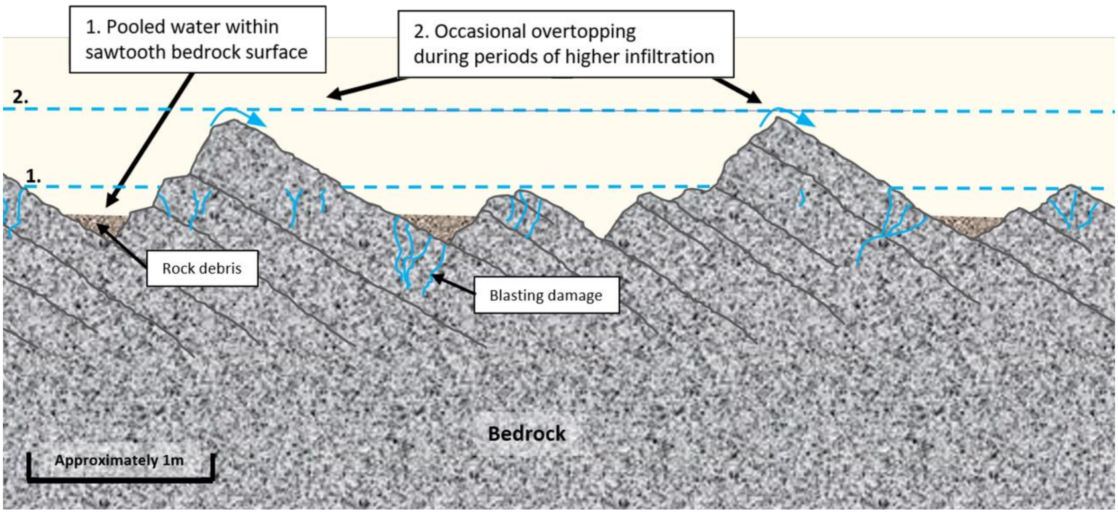
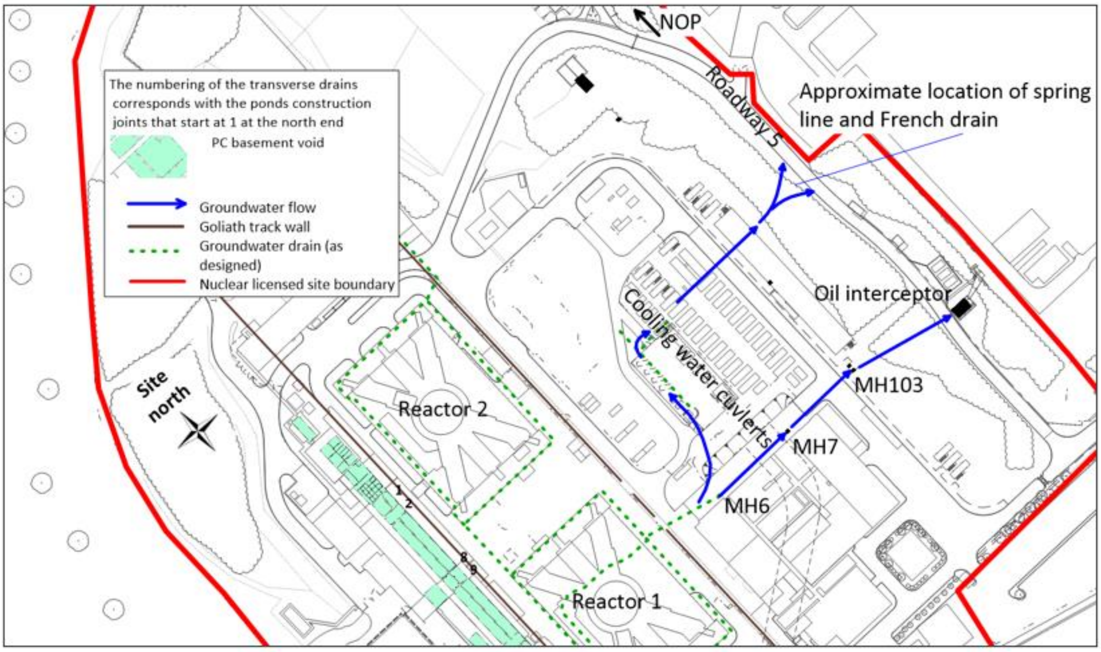


Figure 9E.2 Flow of Groundwater from MH6 (current site conditions)



Appendix 9F: Baseline Environmental Radionuclide Data

9F1: Baseline Environmental Radionuclide Data: EXISTING GROUND CONTAMINATION AROUND THE PONDS COMPLEX

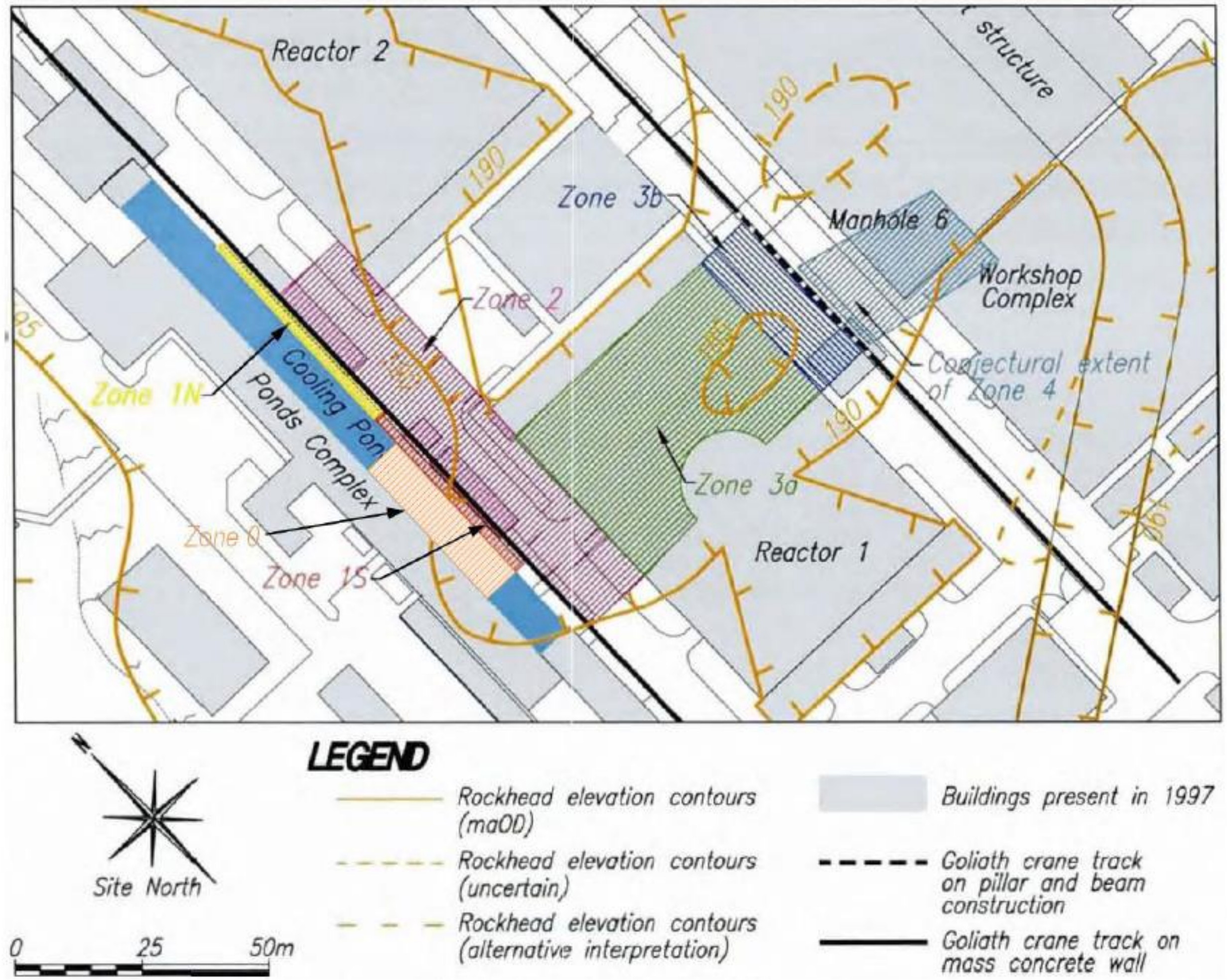
A summary of radionuclide concentration data in soils (solid samples) relating to historic ponds water leaks is provided here. These data are based on intrusive investigations largely undertaken in the late 1990s.

Table 9F1.1 Estimated radionuclide concentrations of contaminated ground (values decay-corrected to 2022) – zones shown in Figure 9F1.1

Radio-nuclide	Specific Activity (Bq/g)															
	Zone 0	Zone 1 North			Zone 1 South			Zone 2			Zone 3			Zone 4		
	Best Estimate	Mini-mum	Best Estimate	Maxi-mum	Mini-mum	Best Estimate	Maxi-mum	Mini-mum	Best Estimate	Maxi-mum	Mini-mum	Best Estimate	Maxi-mum	Mini-mum	Best Estimate	Maxi-mum
Co60	4.0E-04	1.5E-05	1.6E-03	7.9E-02	8.6E-06	1.5E-03	7.8E-02	8.6E-07	1.5E-04	1.1E-02	2.5E-07	3.2E-05	2.2E-03	2.6E-07	3.1E-05	2.2E-03
Sr90	4.2E-01	2.4E-01	1.7E+00	5.6E+00	1.4E-01	1.6E+00	5.5E+00	1.4E-02	1.6E-01	8.0E-01	4.0E-03	3.4E-02	1.5E-01	4.1E-03	3.3E-02	1.6E-01
Cs134	8.9E-06	4.3E-06	3.5E-05	8.9E-05	2.4E-06	3.3E-05	8.7E-05	2.4E-07	3.3E-06	1.3E-05	7.0E-08	7.1E-07	2.4E-06	7.3E-08	7.0E-07	2.5E-06
Cs137	4.6E+00	5.4E+00	1.9E+01	3.2E+01	3.0E+00	1.7E+01	3.1E+01	3.0E-01	1.7E+00	4.5E+00	8.8E-02	3.7E-01	8.6E-01	9.2E-02	3.7E-01	8.7E-01

Radionuclide	Specific Activity (Bq/g)															
	Zone 0	Zone 1 North			Zone 1 South			Zone 2			Zone 3			Zone 4		
	Best Estimate	Minimum	Best Estimate	Maximum	Minimum	Best Estimate	Maximum	Minimum	Best Estimate	Maximum	Minimum	Best Estimate	Maximum	Minimum	Best Estimate	Maximum
Pu238	1.2E-03	3.5E-04	4.8E-03	3.2E-02	2.6E-04	6.1E-03	6.06E-03	2.6E-05	4.5E-04	4.5E-03	5.7E-06	9.6E-05	8.8E-04	5.9E-06	9.5E-05	8.8E-04
Pu239 + Pu240	5.7E-03	1.4E-03	2.3E-02	1.4E-01	1.2E-03	2.7E-02	2.7E-02	1.2E-04	2.1E-03	2.0E-02	2.3E-05	4.6E-04	3.9E-03	2.3E-05	4.5E-04	3.9E-03
Pu241	2.5E-02	4.74-03	9.9E-02	8.2E-01	5.3E-03	1.5E-01	1.5E-01	5.3E-04	9.2E-03	1.2E-01	7.8E-05	1.98E-03	2.3E-02	8.1E-05	1.9E-03	2.3E-02
Am241	6.9E-03	2.7E-03	2.8E-02	1.4E-01	1.5E-03	2.6E-02	1.4E-01	1.5E-04	2.6E-03	2.0E-02	4.4E-05	5.5E-04	3.8E-03	4.5E-05	5.4E-04	3.8E-03
Cm243 + Cm244	6.1E-05	2.4E-05	2.5E-04	1.2E-03	1.3E-05	2.3E-04	1.2E-03	1.3E-06	2.3E-05	1.7E-04	3.9E-07	4.9E-06	3.4E-05	4.0E-07	4.8E-06	3.4E-05
Total	5.1E+00	5.6E+00	2.0E+01	3.9E+01	3.2E+00	1.9E+01	3.7E+01	3.2E-01	1.9E+00	5.4E+00	9.2E-02	4.1E+00	1.1E+01	9.6E-02	4.0E-01	1.1E+00

Figure 9F1.1 – Extent of the radioactively contaminated ground (shown on the map as Zones 0 to 4) associated with the leakage from the Cooling Ponds in the 1970s and 1980s.



9F2: Baseline Environmental Radionuclide Data: GROUNDWATER, SURFACE WATER AND STREAM SEDIMENTS

All the data presented here are based on sampling and analysis commissioned by the Applicant.

EXPLAINER: ENVIRONMENTAL MONITORING DATA

The groundwater and surface water sampled at and around the Trawsfynydd site is not used as drinking water but for context, radiological concentrations have been compared to drinking water guideline values defined in the World Health Organisation (WHO) Guidelines for Drinking Water Quality (2022, Fourth edition incorporating the first and second addenda). Unless otherwise stated, concentrations are below the radionuclide drinking water standards or gross beta / gross alpha drinking water screening values as appropriate.

Since 2018 gross alpha has generally been reported as ‘gross alpha as Pu242’. Prior to 2018 the laboratory reports didn’t specify a calibration nuclide i.e. it was reported simply as ‘gross alpha’. Only where other analyses enable identification of the specific alpha-emitting radionuclides is it possible to accurately determine whether the total alpha is wholly natural in origin, anthropogenic (man-made), or a mix of both.

Gross beta analysis detects energetic beta radiation. The beta emitting radionuclides dissolved in water at Trawsfynydd are the naturally occurring isotope of potassium, K40, and the fission products, Cs137 and Sr90. The response of a beta activity detector depends on the energy of the beta emission and is therefore nuclide specific. Gross beta activity is reported by laboratories in two ways: as though it is all due to K40 (referred to as ‘gross beta as K40’) and/or as though it is all due to Cs137 (referred to as ‘gross beta as Cs137’). Since 2017 each sample that has been analysed for gross beta has been reported as both gross beta as K40 and gross beta as Cs137.

The radionuclides of most relevance to the Proposed Disposals are Cs137 and Sr90 as these are the largest in total activity terms of the radionuclides present in the ponds complex. Cs137 and Sr90 are radioactive fission products, both with half-lives of around 30 years. Transuranic radionuclides such as isotopes of plutonium and americium (also present in the ponds complex but in lower amounts than Cs137 and Sr90) tend to be longer lived but are less mobile in the water environment (unless adhered to suspended sediments).

All sediment concentrations relate to dried samples.

Note that the abbreviation “LOD” means “limit of detection”. The abbreviation BH means “borehole”, and the abbreviation MH means “manhole”. Manholes are locations that allow access to the below-ground site drainage systems.

Statistics have been used to describe the range of activity concentrations of the relevant nuclides in the following sections. The dataset includes results which were below the LOD of the analytical equipment. The LODs differ by radionuclide / determinand

and can vary between individual measurements or sets of measurements. A range of limit of detection values has been provided in data summary tables capturing the minimum and maximum LOD for each radionuclide / determinand across the dataset. Some results for water have been included at the LOD in the calculation of the mean (average) values for a particular radionuclide / determinand. Sampling locations are provided in figures at the end of this appendix.

GROUNDWATER QUALITY: BOREHOLES

The groundwater sampling is from a borehole network that has been largely developed to investigate radioactive contamination of the ground and groundwater, including boreholes targeted at areas of known contamination. Therefore, the data will tend to over-estimate the typical levels of contamination across the whole site.

Historical leaks from the ponds complex have occurred, and the leakage from the cooling ponds construction joint No. 7 (close to which BH213 is located) is the main contributor of radioactivity in groundwater immediately east of the ponds and in groundwater down-gradient from this point. The locations of boreholes are shown on figures at the end of this appendix.

Summary statistics from the radiological analysis (gross alpha, gross beta, Sr90 and Cs137) of groundwater samples obtained from the borehole network are shown in Table 9F2.2.

Table 9F2.2 Summary Statistics for Borehole Groundwater Samples

	No. of Samples	No of Detections	LOD (Bq/l)	% Below LoD	Mean (Bq/l)	WHO Screening Level (Bq/l)
Gross Alpha	143	28	0.016 to 0.13	80.4	0.2	0.5
Gross Alpha Pu242	367	91	0.00189 to 0.44	75	0.08	0.5
Gross Beta Cs137	458	452	0.031 to 0.066	1.3	15.63	1.0
Gross Beta K40	458	452	0.023 to 0.053	1.3	12.38	1.0
Sr90	86	55	0.014 to 0.14	36	15.65	10
Cs137	449	66	0.2 to 1.8	85.3	6.6	10

Gross alpha

Only 1.4% of results (seven of the 510 samples) are above the WHO screening level for drinking water of 0.5 Bq/l. These were recorded at five locations: BH213 (east of the ponds complex, close to the historical leak), BH242A (located east of the ponds complex), BH254A (located east of Reactor 1), BH502 on the south side of the ponds complex and BH403 (east of the turbine hall). The highest activity concentration reported was in BH213 (19.7 Bq/l) in March 2018.

Gross Beta

Of the gross beta results above the LOD, 25% of those reported as K40 and 30% of those reported as Cs137 were above the WHO screening level of 1.0 Bq/l. The highest concentrations were in boreholes BH213 and BH242A.

The spatial distribution of gross beta activity is shown in Figure 9F2.1. Values on average above the WHO screening level are in the majority clustered east of the ponds complex in boreholes BH213, BH234, BH235, BH242A and BH251. BH213, BH234 and BH235 are located between the ponds complex and the western Goliath track wall. BH242A is located east of the Goliath track wall and BH251 is located within the made ground trough feature which follows an east to west trending route beneath the ponds complex and the Reactor 1 building.

In addition, boreholes BH206, BH254A, BH412, BH501, BH502, BH507 and BH508 have average concentrations above the WHO screening level. BH501 and BH502 are south of the ponds complex, and all other of these locations are east of the reactors and adjacent to the former turbine hall.

BH251 monitors made ground groundwater in the rockhead trough which extends beneath the south end of the ponds complex to beneath Reactor 1. Concentrations in the rockhead trough are much lower than immediately east of the historical leak at the cooling ponds construction joint No. 7.

Strontium-90

Where the gross beta (minus naturally occurring K40) concentration exceeds a borehole specific trigger level (usually the WHO screening level of 1Bq/l) then Sr90 (the primary pure beta emitter associated with contamination from the ponds complex) is analysed. This dataset is therefore skewed to areas of radiological contamination.

The assessment level used for Sr90 (used here for context) is 10 Bq/l (WHO, 2022). The distribution of average concentrations of Strontium-90 is shown in Figure 9F2.2. Though the majority of samples were above LOD, only two locations, BH213 and BH242A, had values over WHO guidelines for all samples obtained. The maximum values in these two boreholes were 40 Bq/l (February 2018) and 240 Bq/l (February 2019) respectively. The maximum results for Sr90 correspond to the peaks in gross beta.

In general, average concentrations for Sr90 recorded at each groundwater location are below the WHO guidance level of 10 Bq/l. Only the two locations discussed above (BH213 and BH242A) are on average above this level. Both boreholes are located to the east of the ponds complex, near the gap between Reactors 1 and 2. BH213 is approximately 3m from the east wall of the ponds complex, with BH242A approximately 8m east of BH213 and the other side (down gradient) of the western Goliath track wall.

Caesium-137

The guidance level used for Cs137 (stated here for context) is 10 Bq/l (WHO, 2022). The distribution of concentration of caesium-137 is shown in Figure 9F2.3. Some 3.5% of the sample results were above the guidance level and they occurred at four locations: BH213, BH234, BH235 and BH251. Values at BH213, BH234, and BH235 were above the guidance level on every occasion, whilst BH251 was only above the guidance level on one occasion at 11 Bq/l.

The spatial distribution of Cs137 is similar to that of Sr90, with the exception that the guidance level was not exceeded for Cs137 at BH242A approximately 8m east of BH213. The highest concentrations were within the 3m wide zone between the east side of the ponds complex and the western Goliath track wall. The values were generally highest in BH213.

Borehole BH251 lies in the rockhead trough feature. Values were below the drinking water guidance level in this borehole except for a value of 11 Bq/l in August 2019.

Other Gamma Emitting Radionuclides

Americium-241 (Am241), which is a gamma emitting indicator for the presence of Pu241 and other plutonium isotopes, has been analysed in BH213 on nine occasions between 2016 and 2020. Results were below the detection limit of ~0.8 Bq/l except in February 2018 and May 2019. The result reported for May 2019 has been recognised as erroneous due to an accidentally acidified unfiltered sample. The February 2018 result has also been flagged as anomalous given the concentrations observed as data peaks in both gross beta and Cs137 datasets. There have therefore been no confirmed Am241 results above the LOD between 2016 and 2020. Plutonium nuclide analysis has not been included in groundwater suites of analysis in the timeframe under evaluation (2016 onwards).

Tritium

A total of 177 samples were analysed for tritium between 2016 and 2018. Of these, only one sample (recorded as 3.9Bq/l in BH405 in February 2018) was above the LOD; this result is within the range of the LOD which has varied between 3.5 and 9.0 Bq/l. Tritium has a WHO guidance level of 10,000 Bq/l. BH405 is in the north of the site, approximately 30m north of Reactor 2.

GROUNDWATER QUALITY: MANHOLE 6

Most of the groundwater passing through the made ground filled rock-head trough as far as the east side of Reactor 1 is captured by the pipe leading from the groundwater drain on the east side of Reactor 1 into the main storm drain at MH6. Manhole 6 (MH6) radiological statistics data is contained in Table 9F2.3 and have been reviewed separately to the groundwater statistics.

Table 9F2.3 Manhole 6 (MH6) Radiological Statistics

	No. of Samples	No of Detections	LOD (Bq/l)	% Below LoD	Mean (Bq/l) Summary statistics only included with 3 or more detections	Screening/ guidance levels (Bq/l)
Gross alpha as Pu242	7	0	0.019 to 0.069	100	N/A	0.5
Gross beta as Cs137	7	7	-	0	5.85	1
Gross beta as K40	7	7	-	0	4.73	1
Tritium	6	0	4.3 to 5.4	100	N/A	10,000
Sr90	4	4	-	0	0.79	10
Cs137	7	7	-	0	3.94	10

To date, MH6 was sampled six times during 2018 and once in July 2022. Key points are:

- Gross beta results at MH6 were above LOD and the WHO screening level.
- Gross beta levels follow the variation in Cs137 concentrations at MH6.
- Although there are fewer data points for Sr90, the gross beta variation over time may also be reflected by Sr90, albeit at lower concentrations.
- All radionuclide specific results were below LOD except Sr90 and Cs137.
- All radionuclide specific results were below WHO guidance levels.

SURFACE WATER QUALITY: STREAMS

There are three streams within the vicinity of the site, the Nant Gwylan, the “un-named stream” and the Afon Tafarn-helyg. Each of these is discussed in-turn below.

There are two sampling points on the Nant Gwylan as follows (Figure 9F2.4):

- SW2 Nant Gwylan upstream of the Diversion Culvert pump sumps; and
- SW3 Nant Gwylan downstream of the Diversion Culvert pump sumps.

SW3 represents the water quality in the stream down-gradient of the site’s Diversion Culvert storm overflow and SW2 represents the up-gradient condition, fed from the Gyfynys Dam. There is very little difference between the water quality at the two locations (as expected given the general absence of diversion culvert sump overflows). As such both are kept together for a statistical summary of gross alpha and gross beta activity representative of the Nant Gwylan. This is shown in Table 9F2.4.

Table 9F2.4 Gross Alpha & Gross Beta Statistics for Nant Gwylan Water Samples

Nant Gwylan (SW2 & SW3)	No. of Samples	No of Detections	LOD (Bq/l)	% Below LoD	Mean (Bq/l)	Screening Level (Bq/l)
Gross Alpha as Pu242	25	4 (3 at SW2 and 1 at SW3	0.011 to 0.064	84	0.03	0.5
Gross Beta Activity (as Cs137)	28	26 (12 SW2 and 14 SW3)	0.057 and 0.062	7.14	0.05	1
Gross Beta Activity (as K40)	28	26 (12 SW2 and 14 SW3)	0.046 and 0.049	7.14	0.04	1

A total of 28 samples were collected from 2017 to 2022 in both SW2 and SW3. Key points are:

- The maximum value of gross alpha (reported as Pu242) was 0.025 Bq/l at SW2 in August 2018.
- SW3 recorded gross alpha above the LOD on one occasion in August 2019 at 0.02 Bq/l.
- 93% were above LOD for gross beta.
- The maximum gross beta value was at SW3 in July 2022 with very little difference between SW2 and SW3.
- Only one sample of Sr90 was analysed. This was from SW3 in Q4 2016 and was reported as below the LOD (<0.011 Bq/l).
- A total of 28 samples were analysed for Cs137 in both SW2 and SW3 and all results were below the LOD (0.23 - 0.43 Bq/l). No other gamma emitting radionuclides were above LOD.

There is also a sampling point on the northern outlet pipe (NOP) (SW5) in the northeast corner of the Site which feeds into the un-named stream. A second sampling point (SW6) is located on the un-named stream downstream of SW5 and downstream of a discharge from the Scottish Power Compound. Radiological data were obtained between November 2016 to July 2022. Gross alpha and gross beta summary statistics are presented for SW5 in Table 9F2.5 and for SW6 in Table 9F2.6.

Table 9F2.5 Gross Alpha & Gross Beta Statistics for Northern Outlet Pipe Water Samples

Northern outlet pipe (SW5)	No. of Samples	No of Detections	LOD (Bq/l)	% Below LoD	Mean (Bq/l) Summary statistics only included with 3 or more detections	Screening Level (Bq/l)
Gross Alpha	4	1	0.016 to 0.03	75	N/A	0.5
Gross Alpha Pu242	18	3	0.013 to 0.045	83.3	0.023	0.5
Gross Beta Activity (as Cs137)	21	20	0.04	4.76	0.21	1
Gross Beta Activity (as K40)	21	20	0.033	4.76	0.17	1

Table 9F2.6 Gross Alpha & Gross Beta Statistics for SW6 Water Samples

SW6 (un-named stream down-stream of SW5)	No. of Samples	No of Detections	LOD (Bq/l)	% Below LoD	Mean (Bq/l) Summary statistics only included with 3 or more detections	Screening Level (Bq/l)
Gross Alpha	4	0	0.019 to 0.024	100	N/A	0.5
Gross Alpha Pu242	12	1	0.017 to 0.064	91.7	N/A	0.5
Gross Beta Activity (as Cs137)	15	15	-	0	0.162	1
Gross Beta Activity (as K40)	15	15	-	0	0.128	1

Key points are:

- Gross alpha has been measured as 'Gross Alpha' and 'Gross Alpha as Pu242'. For 'Gross Alpha', eight samples were tested in total from SW5 and SW6 with one recorded above the LOD in February 2018. For 'Gross Alpha as Pu242' 30 samples were tested in total with 87% recorded below the LOD. The maximum value at SW5 was 0.025 Bq/l in August 2021 and the maximum value at SW6 was 0.021 Bq/l in August 2019.
- For gross beta 95% of results were above LOD in SW5 and 100% in SW6. The maximum value at SW5 was 0.457 Bq/l in August 2019 compared to a maximum in SW6 of 0.267 Bq/l in November 2017.
- No Sr90 analysis has been undertaken in SW5 or SW6.
- A total of 39 samples were analysed for Cs137 across SW5 and SW6 and there were no results above LOD. No other gamma emitting radionuclides were above LOD during the periods of monitoring. Seven samples of tritium were sampled in SW5 with no concentrations over LOD.

The Afon Tafarn-helyg runs south to north, to the east of the National Grid and Scottish Power Compounds east of the Site. It has a confluence with the Nant Gwylan east of the National Grid Compound and a confluence with the un-named stream north of the Scottish Power Compound. There are two surface water sampling points on the river immediately upstream (SW9) and downstream (SW8) of the confluence with the un-named stream. Samples were obtained from SW8 and SW9 during two rounds, one in May 2021 and one in February 2022. Strontium-90 was to be conducted if gross beta concentrations exceeded a specified threshold. The results were as follows:

- Gross alpha was detected in only one of the four samples. The result, (expressed as "Gross alpha as Pu242") was 0.01 Bq/L at SW8 in May 2021. The LOD ranged between 0.01 and 0.03 Bq/l.
- Gross beta was detected in all four samples. The results (expressed as "Gross beta as Cs137") were as follows: SW8 - 0.086 and 0.092 Bq/l; and SW9 - 0.088 and 0.095 Bq/l.
- No gamma emitting radionuclides, including Cs137 were detected.
- Strontium-90 analysis was not conducted as the relevant gross beta thresholds were not exceeded.

SEDIMENT QUALITY: STREAMS

A series of stream sediment samples were collected in August 2021. Of these, three were on the Nant Gwylan (SED2, SED3 and SED11), four were on the un-named stream which drains Craig Gyfynys (SED1, SED1B, SED10 and SED6), and two were on Afon Tafarn-helyg which flows east of the site (SED8 and SED9 located downstream and upstream respectively of the confluence with the un-named stream). The locations of these sediment samples are shown in Figure 9F2.5 and the average radionuclide concentrations in Table 9F2.7. Only those radionuclides that were recorded above the limit of detection are shown in the table.

Nant Gwylan results show a pattern of slightly higher concentrations than the un-named stream and Afon Tafarn-helyg, notably for Am241, Cs137, and Sr90. Samples from the lake are on average higher than the stream samples, again notably for Am241, Cs137, and Sr90. Nant Gwylan is sourced from the lake via a sluice gate in Gyfynys Dam. The presence of the radionuclides in Nant Gwylan is likely because of the migration of sediment from Llyn Trawsfynydd that contains radionuclides due to permitted radioactive discharges to the lake.

Table 9F2.7 Sediment Samples Radionuclide Concentrations (averages)

	Nant Gwylan (Bq/g)	Un-named Stream (Bq/g)	Afon Tafarn-helyg (Bq/g)
Am241	0.008	0.003	0.002
Cs137	0.537	0.021	0.012
Pu239/240	0.002	<LOD	0.002
Sr90	0.008	0.002	0.002

SUMMARY OF CURRENT RADIOLOGICAL GROUNDWATER, SURFACE WATER AND SEDIMENT QUALITY

Cs137 and Sr90 were not detected in water sampled from the Nant Gwylan, from the Northern Outlet Pipe or from the un-named stream flowing off Craig Gyfynys. During a monitoring period between 2019 and 2023 only one above LOD lake water concentration has been recorded for Cs137; the finding has not been repeated.

The quality of stream sediment was characterised in 2021 for those radiological substances expected to be present in suspended sediments derived from the valved flow from Gyfynys Dam. Sediment samples from the Nant Gwylan contained higher concentrations of Cs137, Sr90, and Am241 than in stream sediment sampled elsewhere. The presence of the radionuclides in the Nant Gwylan is likely due to the migration of sediment from Llyn Trawsfynydd that is contaminated because of permitted radioactive discharges to the lake.

FIGURES

Figure 9F2.1 Average Gross Beta as K40 Spatial Distribution in Groundwater

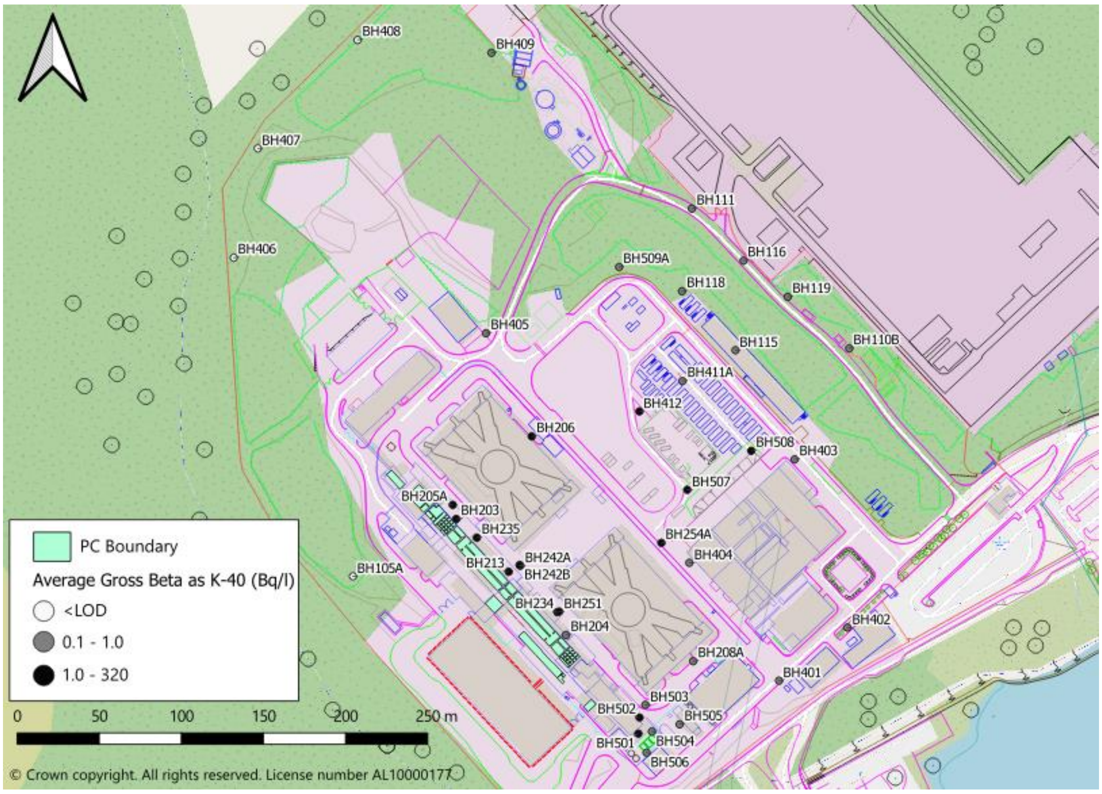


Figure 9F2.2 Distribution of Average Concentrations of Strontium-90 in Groundwater

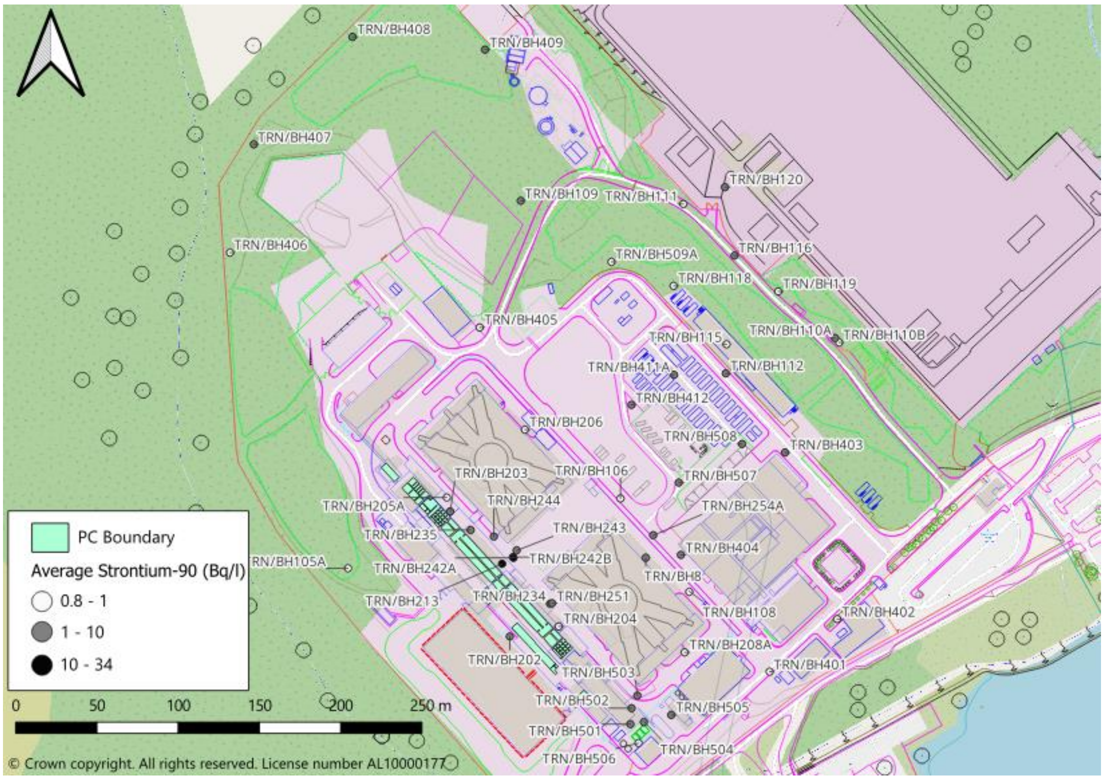


Figure 9F2.3 Distribution of Concentrations of Caesium-137 in Groundwater

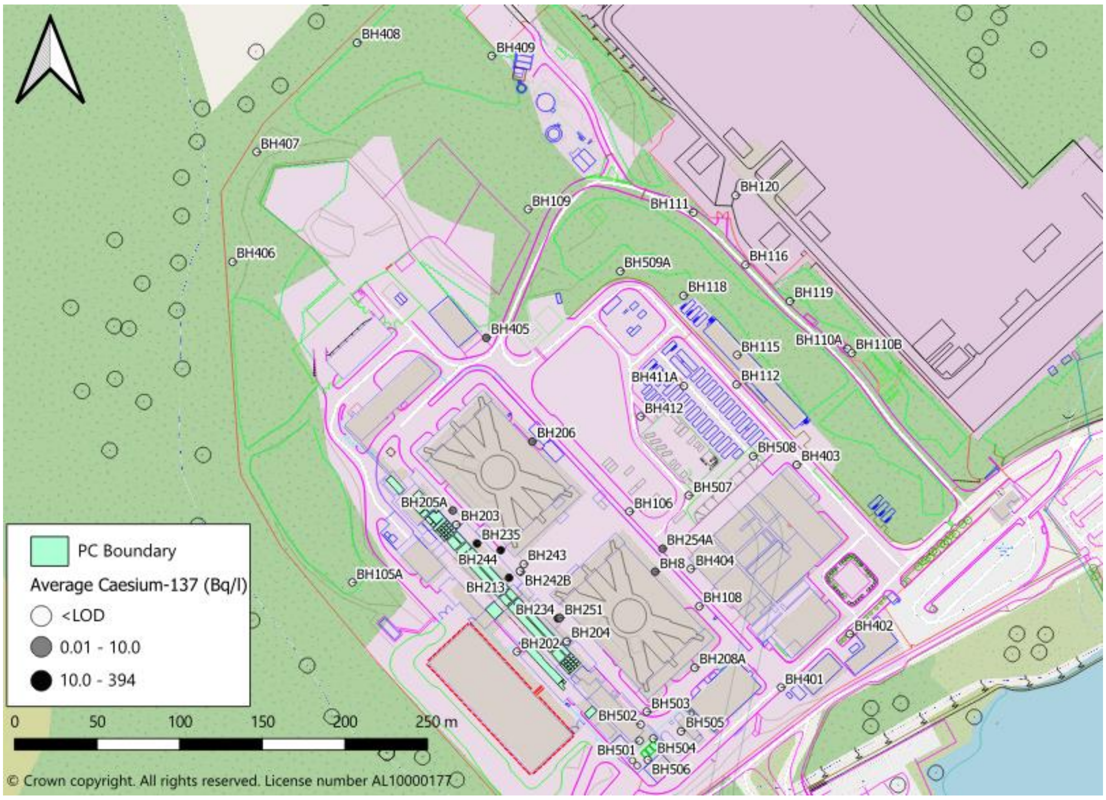


Figure 9F2.4 Surface Water Monitoring Locations

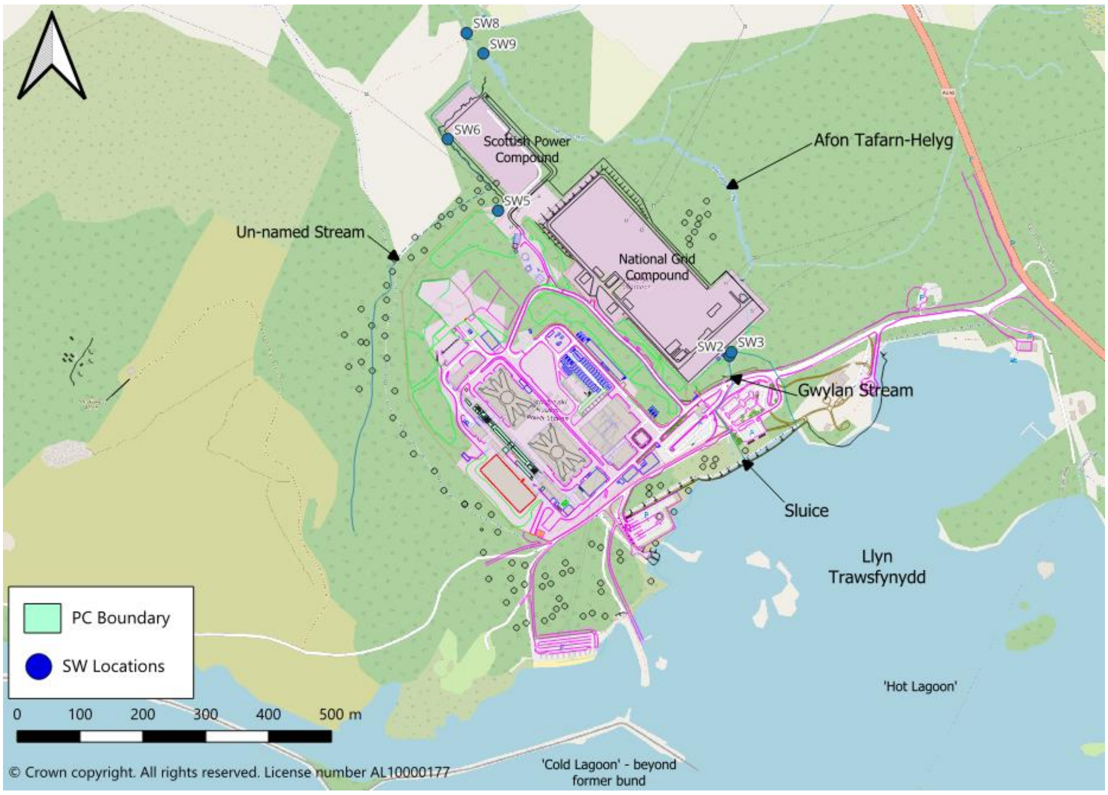
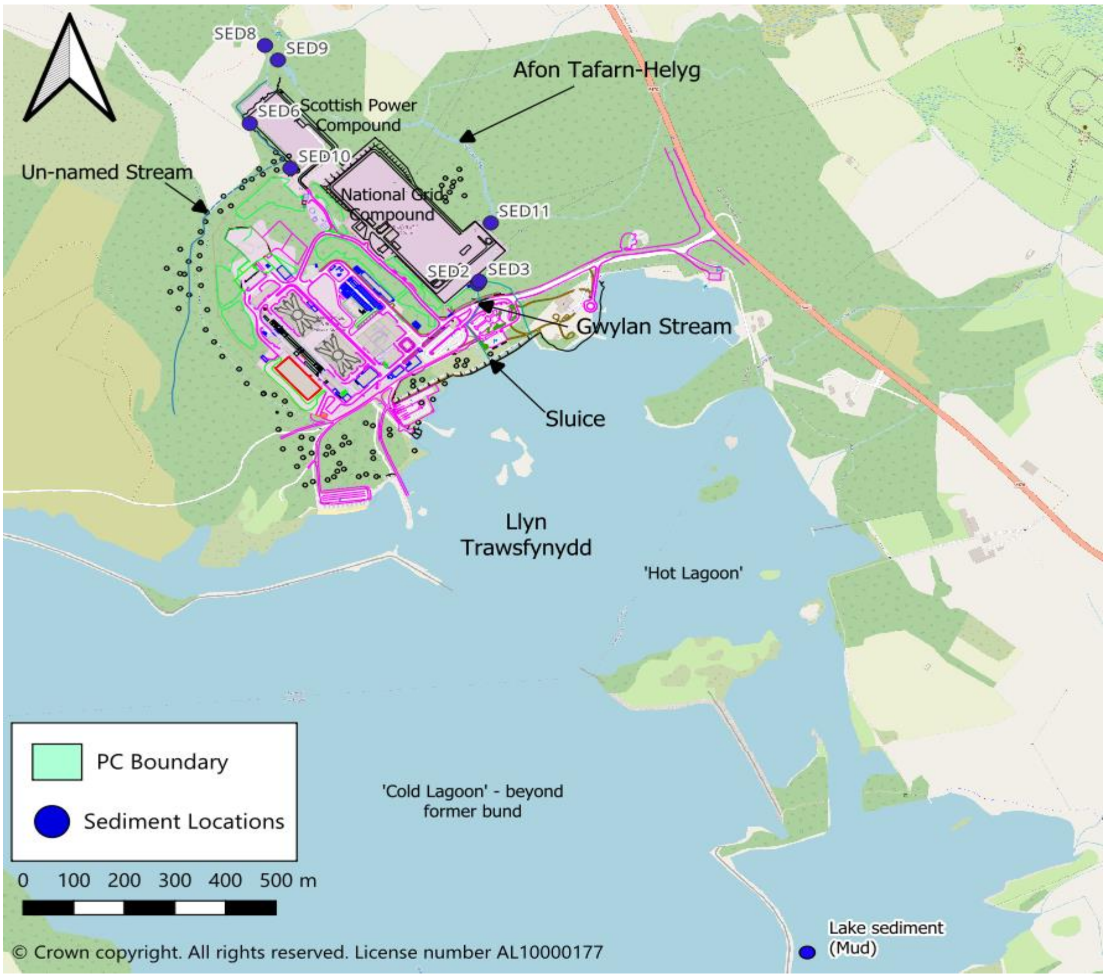


Figure 9F2.5 Sediment Sampling Locations August 2021



Appendix 9G: Predicted Environmental Concentrations of Radionuclides

The plots in this appendix provide the predicted environmental concentrations of the selected[69] radionuclides arising from the Proposed Disposals, with and without inputs from pre-existing radioactive contamination on site and in the lake.

Radioactivity input from the lake is based on the following parameters and data:

- flow rate through dam into the Nant Gwylan: 2.5 litres per second;
- suspended sediment in lake water: 0.003 grams per litre; and
- the radionuclide concentrations given in Table 9G.1 and Table 9G.2[70].

Table 9G.1 Radionuclides dissolved in lake water (2022)

Radionuclide	Activity Concentration (Bq/litre)	Comments
Sr90	4.00E-02	Cautiously estimated based on the approximate average of the total beta measurements recorded in the "hot lagoon".
Cs137	2.70E-02	Value set at half the limit of detection (almost all results are below the limit of detection)

Table 9G.2 Radionuclides sorbed to lake sediments (based on average 2022 concentrations)

Radionuclide	Activity Concentration (Bq/g)
Sr90	1.13E-02
Cs137	1.09E+00
Pu238	7.35E-03
Pu239	2.91E-02
Am241	5.71E-02

EXPLAINER: ENVIRONMENTAL CONCENTRATION PLOTS
In the left-hand set of plots below, only the radioactivity contributions from the Proposed Disposals are shown. In the right-hand set of plots below, the total

[69] The selected radionuclides tend to be the most important dose contributors to humans and non-human biota and they are they include the main radionuclides measured in lake sediments.

[70] WSP, Trawsfynydd Site: Current Quality of Groundwater, Surface Waters and Associated Sediments, 62282528_A01, Revision 2, Magnox Reference DD/REP/0040/23 Issue 2, November 2023.

radioactivity including contributions from existing environmental radioactivity are shown:

Migration of radioactivity from the existing on-site radioactively contaminated ground and from the lake via the compensation flow to Nant Gwylan will add radioactivity to the streams.

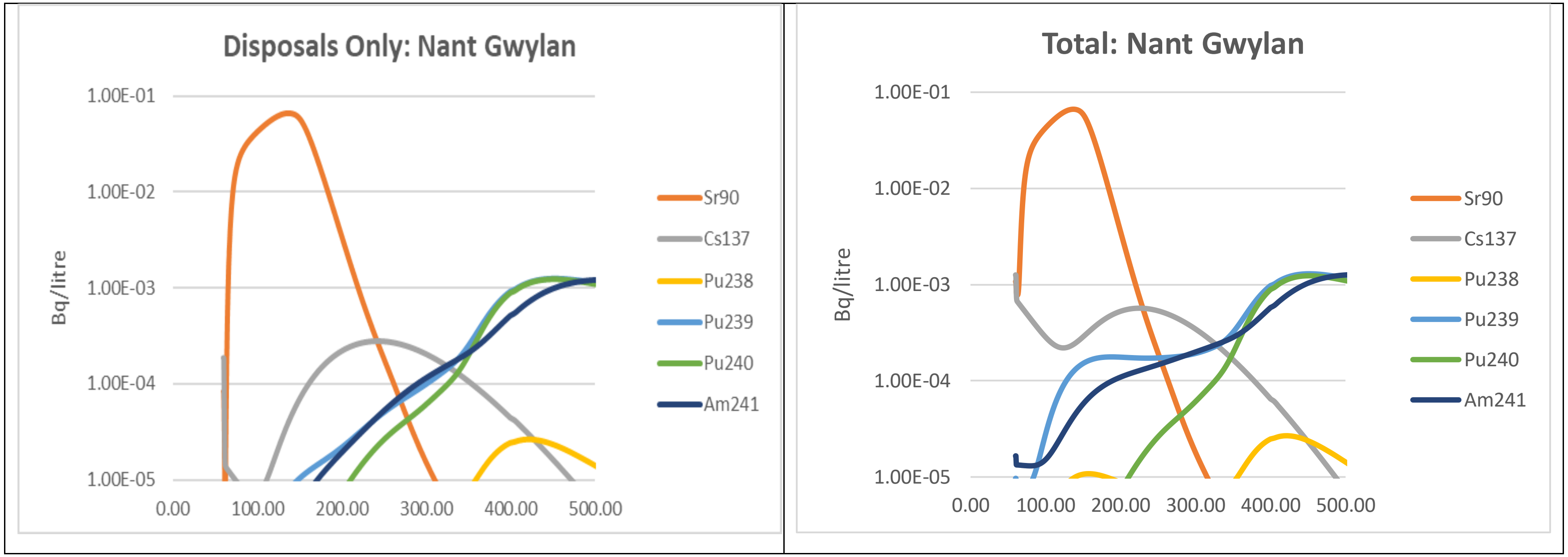
For the southern field and for groundwater in the rock-head trough east of Reactor 1, only the existing on-site radioactively contaminated ground will additionally contribute.

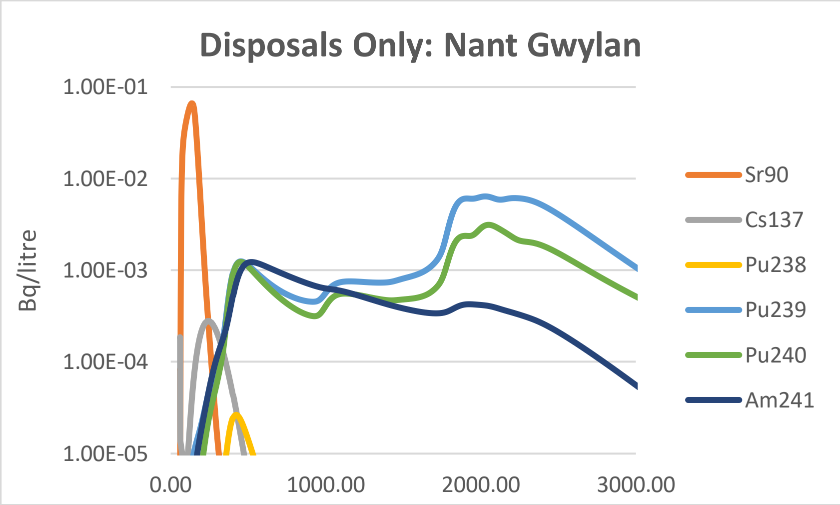
The modelling output data indicate that by about 150 years from now, the Proposed Disposals will dominate groundwater radioactivity in the rock-head trough east of Reactor 1.

The upper plots are for the first 500 years, whilst the lower plots extend to 3,000 years to show the very long-term impacts (as modelled).

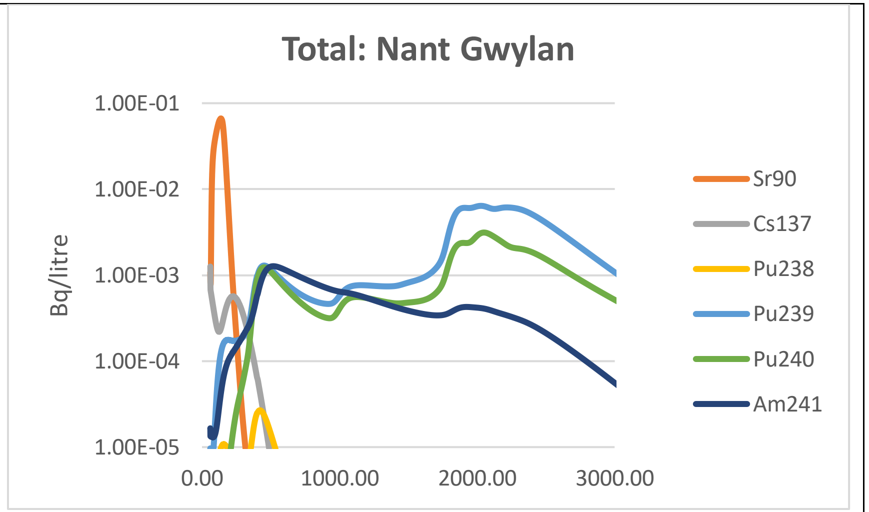
In the plots, year 0 is 2022, and the results shown are for the time after about 2080, i.e. after the site end state has been reached.

Figure 9G.1 Radionuclide Concentrations in Nant Gwylan (including activity associated with suspended sediment)



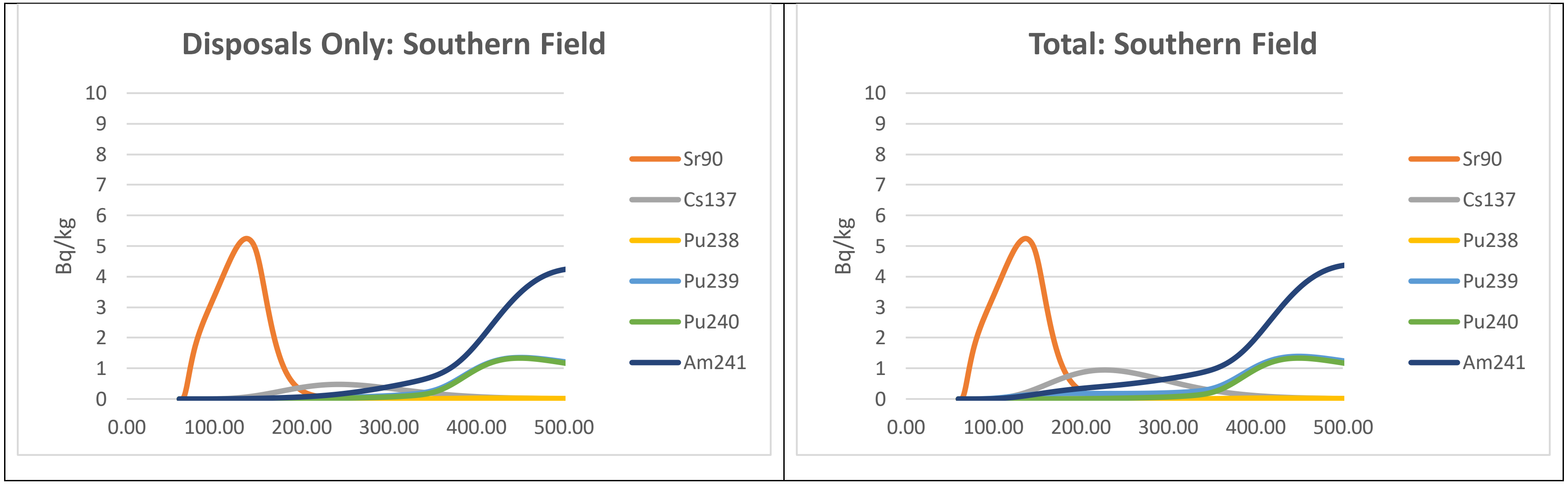


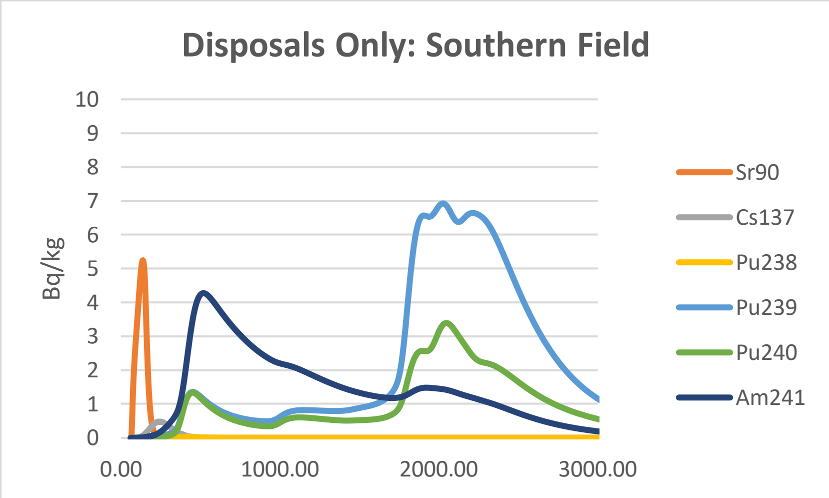
Disposals Only: Nant Gwylan
Bq/litre
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
0.00
1000.00
2000.00
3000.00
Sr90
Cs137
Pu238
Pu239
Pu240
Am241



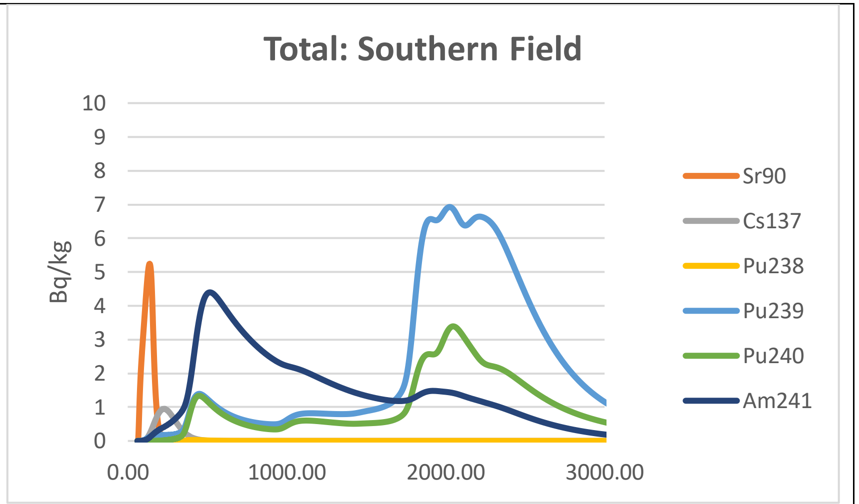
Total: Nant Gwylan
Bq/litre
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
0.00
1000.00
2000.00
3000.00
Sr90
Cs137
Pu238
Pu239
Pu240
Am241

Figure 9G.2 Radionuclide Concentrations in Soil in the Southern Field



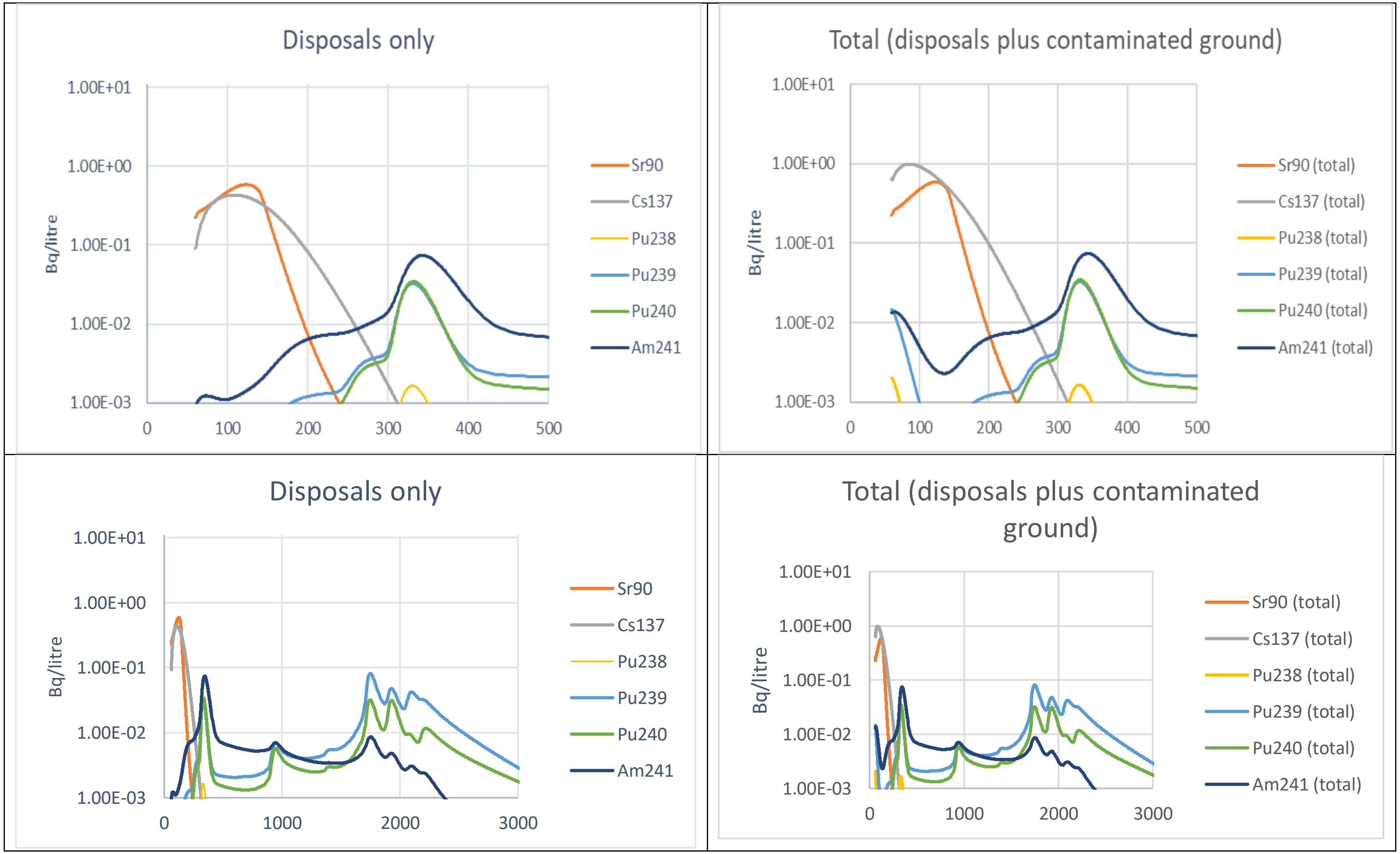


Disposals Only: Southern Field
Bq/kg
10
9
8
7
6
5
4
3
2
1
0
0.00
1000.00
2000.00
3000.00
Sr90
Cs137
Pu238
Pu239
Pu240
Am241



Total: Southern Field
Bq/kg
10
9
8
7
6
5
4
3
2
1
0
0.00
1000.00
2000.00
3000.00
Sr90
Cs137
Pu238
Pu239
Pu240
Am241

Figure 9G.3 Radionuclide Concentrations in Groundwater in the Eastern End of the Rockhead Trough



Appendix 9H: Intrusion Radiological Assessment Results

REGULATORY REQUIREMENTS
GRR requirement R11 (inadvertent human intrusion dose guidance level after release from radioactive substances regulation) applies to human intrusion scenarios as follows:
"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."

Table 9H.1 presents the potential doses to an "excavator" (the "intruder" undertaking the excavations or constructing boreholes, piles etc.) for a variety of intrusion scenarios. Gaps in the table indicate where intrusion scenarios have not been assessed because the doses from such intrusions would be lower than other calculated doses. The maximum assessed dose to the intruder is about 630 µSv, which is 0.63 mSv, which compares to the GRR guidance level of 3 mSv.

Table 9H.1: Potential Dose Impacts to an Excavator (µSv)

Feature	Small intrusion	Large shallow intrusion	Large deep intrusion	Pile array intrusion	Borehole intrusion
D01 Final Delay Tanks	1.07E+00	-	-	8.03E+00	1.35E-01
D04 Active Workshop	4.49E-02	3.32E-01	-	3.35E-01	8.45E-03
D05 Laundry	8.04E+00	-	-	3.27E+00	3.27E+00
D05 Active Effluent Treatment Plant / Ponds Water Treatment Plant	1.46E+01	7.02E+01	-	1.95E+02	5.68E+00
D06 South FED Vault	6.82E+00	-	-	6.02E+01	3.84E+00
D06 Ponds South Vault / South	1.47E+01	-	-	1.62E+01	8.59E+00

Feature	Small intrusion	Large shallow intrusion	Large deep intrusion	Pile array intrusion	Borehole intrusion
Acceptance Bay					
D06 Ponds Lanes	4.01E+01	4.30E+01	3.46E+01	9.20E+01	6.63E+00
D06 North FED Vault	6.80E+00	-	-	5.98E+01	3.84E+00
D06 Ponds North Vault / North Acceptance Bay	1.05E+01	-	-	3.36E+01	1.31E+01
D10 Flask Washdown Basement Area	6.78E-01	-	-	2.66E+00	2.30E-01
D15 Resin Vault 2&3	1.27E+00	-	-	1.11E+01	9.34E-01
D28 Resin Vault 1	1.87E+01	3.96E+01	6.29E+02	5.28E+01	5.59E+00
D28 Main Sludge Vault	6.12E+01			7.29E+01	1.16E+01
D28 Main Sludge Vault/Resin Vault 1	6.44E+01			-	-
D28 Active Waste Vaults	1.47E+00			2.03E+01	1.13E+00
D37 Ponds lanes pipe trench	6.16E+00	-	-	7.43E+00	2.53E+00
Active Drains Network	6.02E-02	4.11E-02	-	1.10E-01	5.55E-02

The plots below provide the highest potential doses from subsequent processing or use of excavated material. Only the key (most significant) events are shown.

Figure 9H.1: Small Shallow Intrusion (in ~2080)

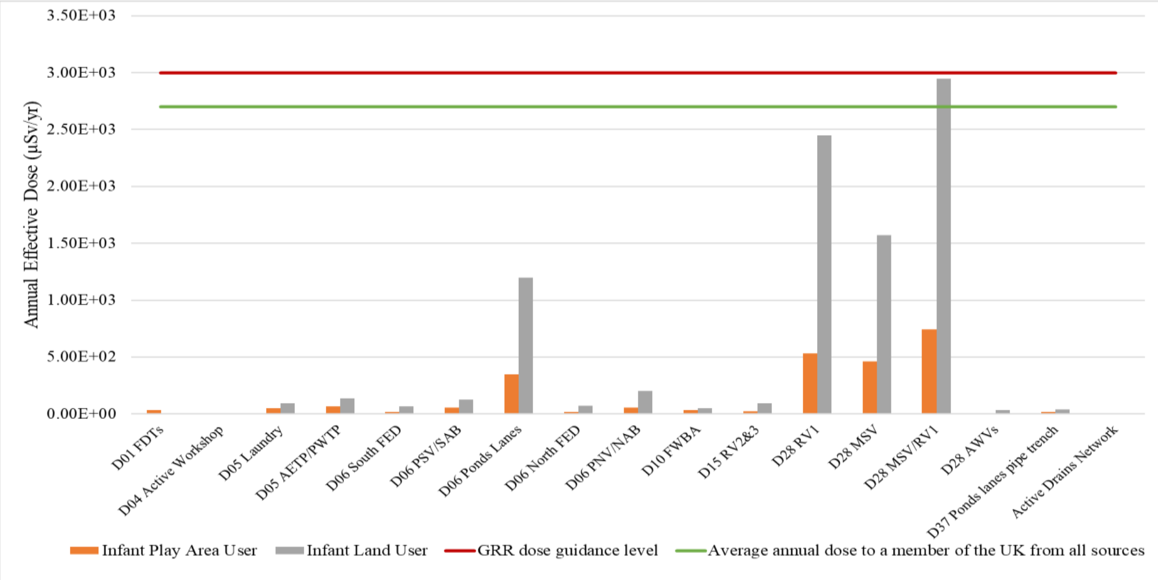


Figure 9H.2: Large Shallow Intrusion (in ~2080)

Note: Northern voids refers to Main Sludge Vault, Resin Vault 1 and Active Waste Vaults.

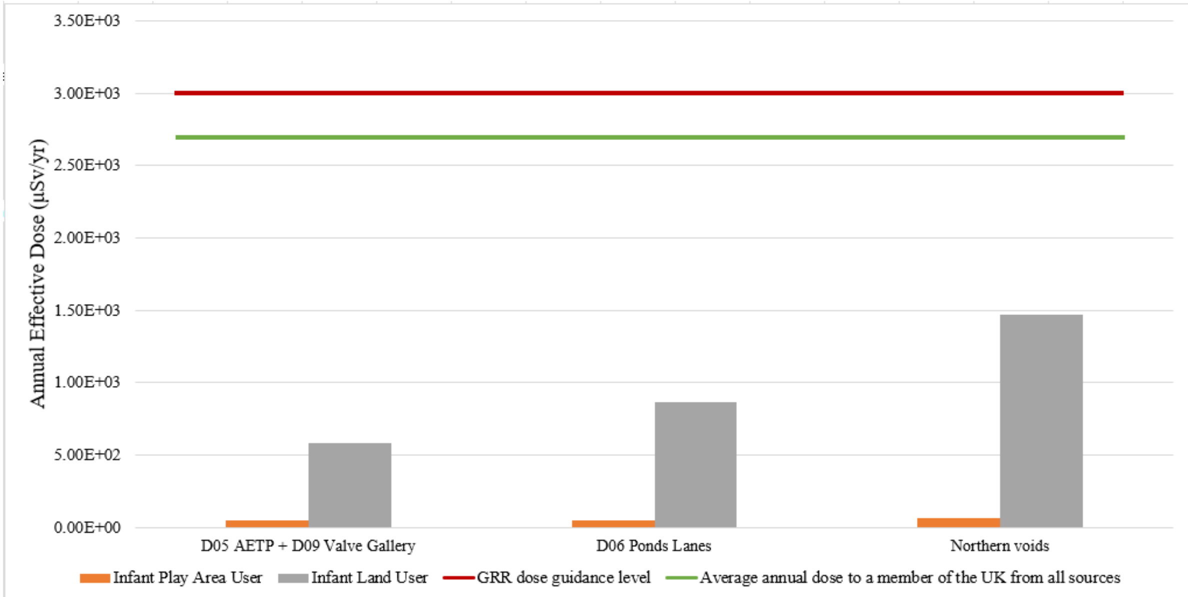
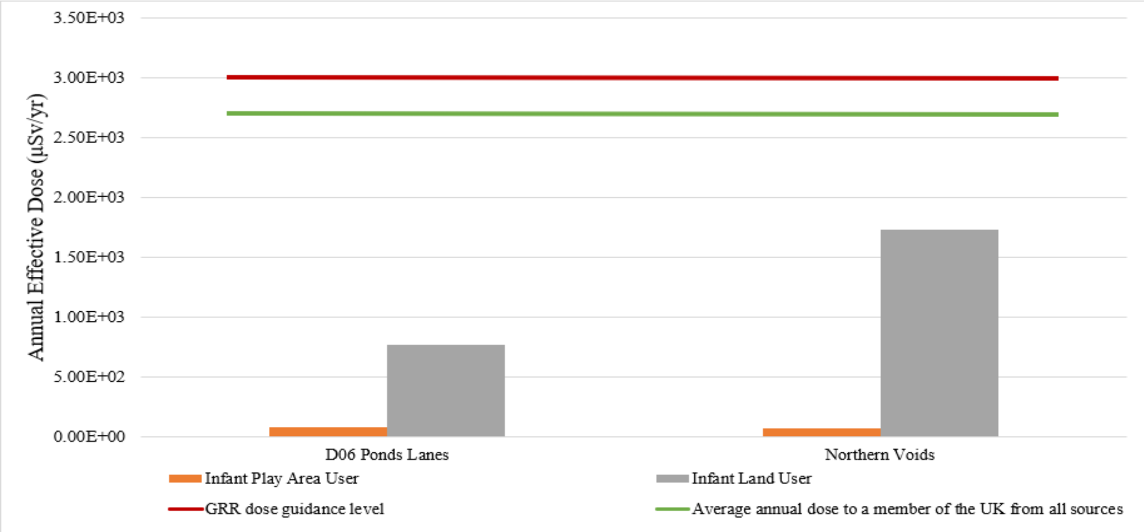


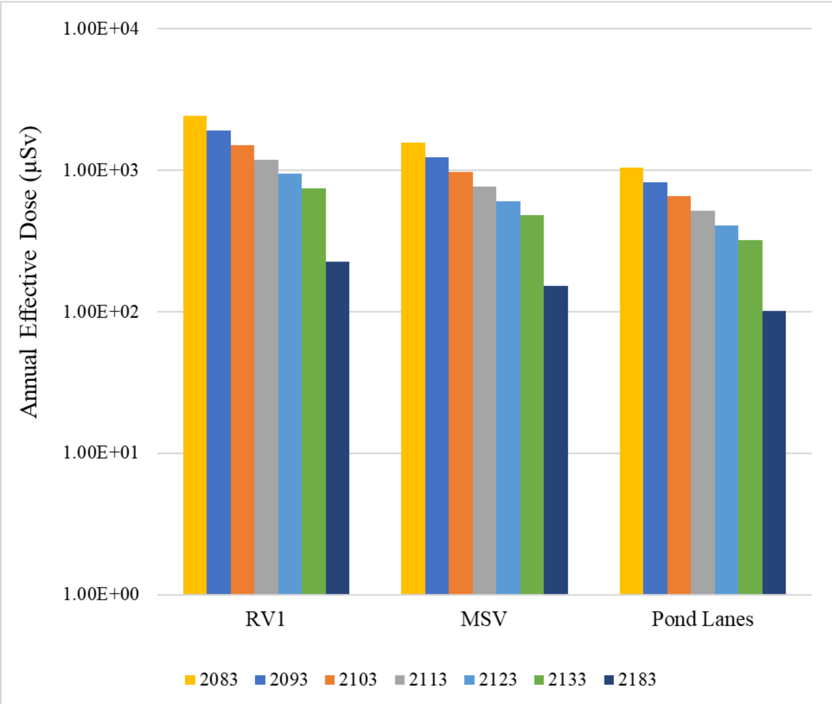
Figure 9H.3: Large Deep Intrusion (in ~2080)

Note: Northern voids refers to Main Sludge Vault, Resin Vault 1 and Active Waste Vaults.



In Figure 9H.4 below, the annual dose following a small shallow intrusion into the most radioactive near-surface features to an infant land user as a function of time after 2080 is shown; as can be seen, the dose rate from this intrusion scenario is much lower if the initial intrusion event takes place later.

Figure 9H.4: Calculated doses to an infant land user from small shallow intrusions into Resin Vault 1, the Main Sludge Vault and the ponds lanes at different points in time. Note the logarithmic scale.



Appendix 9I: Radiological Assessment of Impacts on Non-Human Biota

REGULATORY REQUIREMENTS
GRR requirement R14 (protection of the environment) requires operators to "*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, RSR.*"
In line with Requirement R14, "*operators are expected to carry out an assessment and to draw conclusions about the effects of the site on the environment using the best information available at the time. Particular consideration should be given to the effects on designated conservation areas on or near the site.*"

Designated Sites

There are several statutory biodiversity sites of international importance (European Sites/Natura 2000[71]) within 10km of Trawsfynydd site. There are also several statutory biodiversity sites of national or local importance within 5km. However, the locations that would be impacted by the Proposed Disposals, as discussed in this appendix, are not presently part of any ecologically designated sites.

Methodology

The ERICA computer code[72] has been used for the non-human biota assessment. The ERICA code and associated methodology involves the calculation of dose rates, in micro-Grays (μGy) per hour, to reference organisms given user-provided radionuclide concentration values in the relevant environmental media.

The calculations presented here are for the times after the site end state has been reached (and pumped discharges to the lake have ceased). The calculations include radionuclide contributions from the existing radioactively contaminated ground on site and inputs to the streams from the lake (both radionuclides in solution and adhered to suspended sediment coming from the lake in the controlled compensation flow), though it is the radioactivity from the Proposed Disposals that dominates the dose rates at the time of the biota dose rate peak.

[71] Natura 2000 is the name of the European Union wide network of nature conservation sites. The network was established under Directive 92/43/EEC on the Conservation of Natural Habitats and Wild Fauna and Flora (the 'Habitats Directive). This network comprises of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs).

[72] Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA). The ERICA model and software are being maintained by a consortium comprising the Norwegian Radiation Protection Authority, Environment Agency (England and Wales), UK Centre for Ecology & Hydrology (UK), IRSN (France) the Swedish Radiation Safety Authority and CIEMAT (Spain).

After consultation with the ERICA developers, the code has been used for this assessment in “Tier 2” mode to provide organism dose rates per unit environmental activity (water or soil). Using Tier 2 of ERICA, with the “uncertainty factor” parameter set to 1, the dose rate factors in Table 9I.1 and Table 9I.2 have been extracted. The dose rate factors in the tables have then been combined with the modelled time profile of the environmental concentrations (see Appendix 9G) in the Nant Gwylan and Afon Tafarn-helyg stream network as well as in a hypothetical field (the “southern field”) where the National Grid 400 kV switching compound is currently located. This results in a time profile for the dose rate to each organism that ERICA considers, both for the streams environment and for the southern field environment.

Table 9I.1 ERICA Tier 2 Freshwater Environment Dose Rates Per Unit Activity Concentration (µGy per hour / Bq per litre in water):

	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc – bivalve	Mollusc – gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
C-14	5.24E+00	5.25E+00	5.25E+00	5.09E+00	5.11E+00	5.25E+00	5.24E+00	5.23E+00	5.25E+00	1.10E-01	5.25E+00	2.43E-01	5.02E+00
Sr90	5.85E-02	9.36E+00	1.74E+00	2.12E-01	1.96E+01	1.76E+00	5.68E+01	3.10E-01	9.33E+00	9.08E-02	1.06E+01	8.60E-02	4.79E-01
Cs137	3.87E-01	3.06E+00	3.58E-01	3.32E+00	6.44E+00	8.55E-01	3.00E+00	2.77E+00	6.74E-01	1.14E-02	3.13E+00	3.16E+00	6.96E-03
Pu238	1.54E+02	3.64E+01	9.37E+01	1.94E+01	1.08E+03	1.54E+02	2.29E+02	1.02E+02	2.89E+01	6.59E+01	1.54E+02	4.68E+01	1.56E+01
Pu239	1.45E+02	3.42E+01	8.80E+01	1.82E+01	1.01E+03	1.45E+02	2.15E+02	9.60E+01	2.71E+01	6.18E+01	1.45E+02	4.39E+01	1.46E+01
Pu240	1.45E+02	3.43E+01	8.82E+01	1.83E+01	1.01E+03	1.45E+02	2.15E+02	9.62E+01	2.71E+01	6.19E+01	1.45E+02	4.40E+01	1.47E+01
Am241	1.54E+02	5.06E+01	9.37E+01	1.08E+03	1.09E+03	1.54E+02	1.08E+03	5.39E+02	4.78E+01	6.58E+01	1.06E+02	7.01E+01	1.08E+03

Note: with the given environmental concentrations, the peak dose rate is greatest for insect larvae (in bold in the table above).

Table 9I.2 ERICA Tier 2 Terrestrial Environment Dose Rates Per Unit Activity Concentration (µGy per hour / Bq per kg in soil):

	Amphibian	Bird	Mollusc - gastropod	Reptile	Annelid	Arthropod - detritivorous	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Shrub	Tree
C-14	3.90E-02	3.90E-02	1.24E-02	3.90E-02	1.25E-02	1.24E-02	1.24E-02	2.58E-02	2.56E-02	3.90E-02	3.90E-02	2.58E-02	3.79E-02
Sr90	5.66E-04	6.80E-04	5.26E-05	6.89E-04	3.23E-05	1.03E-04	9.26E-05	3.34E-04	1.48E-03	9.70E-04	9.29E-04	1.04E-04	4.61E-04
Cs137	3.68E-04	2.36E-04	1.43E-04	3.76E-04	3.08E-04	3.20E-04	1.52E-04	2.72E-04	5.97E-04	1.05E-03	7.73E-04	3.63E-04	1.42E-04
Pu238	8.27E-04	7.62E-05	3.86E-03	3.31E-04	1.56E-03	1.20E-03	5.99E-04	3.83E-04	4.18E-03	4.42E-04	4.42E-04	1.02E-03	3.20E-05
Pu239	7.76E-04	7.15E-05	3.62E-03	3.11E-04	1.47E-03	1.13E-03	5.63E-04	3.60E-04	3.93E-03	4.15E-04	4.15E-04	9.56E-04	3.00E-05
Pu240	7.78E-04	7.16E-05	3.63E-03	3.11E-04	1.47E-03	1.13E-03	5.64E-04	3.60E-04	3.93E-03	4.15E-04	4.15E-04	9.58E-04	3.01E-05
Am241	3.16E-03	9.12E-04	5.07E-03	2.13E-03	3.96E-03	3.08E-03	3.66E-03	2.91E-03	3.87E-02	8.81E-04	8.85E-04	7.70E-04	1.38E-05

Note: with the given environmental concentrations, the peak dose rate is greatest for lichen & bryophytes (in bold in the table above).

Table 9I.3 ERICA Tier 1 Freshwater Environment Dose Rates Per Unit Activity Concentration (µGy per hour / Bq per litre in water):

	Freshwater (µGy per hour / Bq per litre in water)	Limiting Reference Organism
C-14	2.02E1	Benthic Fish
Sr90	1.11E2	Mollusc Bivalve
Cs137	2.32E1	Insect Larvae
Pu238	2.22E3	Insect Larvae
Pu239	2.09E3	Insect Larvae
Pu240	2.09E3	Insect Larvae
Am241	2.25E3	Insect Larvae

Table 9I.4 ERICA Tier 1 Terrestrial Environment Dose Rates Per Unit Activity Concentration (µGy per hour / Bq per kg in soil):

	Terrestrial (µGy per hour / Bq per kg in soil)	Limiting Reference Organism
C-14	1.20E-1	Tree
Sr90	4.88E-3	Lichen and Bryophytes
Cs137	3.62E-3	Mammal Large
Pu238	1.36 E-2	Lichen and Bryophytes
Pu239	1.28 E-2	Lichen and Bryophytes
Pu240	1.28E-2	Lichen and Bryophytes
Am241	1.34 E-1	Lichen and Bryophytes

Results

It is found, using the methodology described above, that:

- the highest modelled impact is on insect larvae in the Nant Gwylan, for which the peak organism dose rate is about 10 μGy per hour, occurring in the model after about 2,000 years (Figure 9I.1);
- using average environmental radionuclide concentrations at any point in time for the Nant Gwylan, lower Afon Tafarn-helyg and the upper Afon Tafarn-helyg (all upstream of Gellilydan), the peak organism dose rate is about 3 μGy per hour, also occurring in the model after about 2,000 years; and
- for the hypothetical southern field, the highest impact is on lichen and bryophytes, and the peak dose rate is 0.18 μGy per hour, occurring in the model after about 500 years (Figure 9I.2).

A 40 μGy per hour dose rate value for anthropogenic radioactivity is recognised by the environment agencies for England and Wales as an appropriate limit in terms of preventing harmful effects on the integrity of Natura 2000 sites[73,74]. This threshold of 40 μGy per hour is the same as the lower 1992 guideline level for terrestrial animals published by the International Atomic Energy Agency[75]. All of the modelled peak organism dose rates are well below this level.

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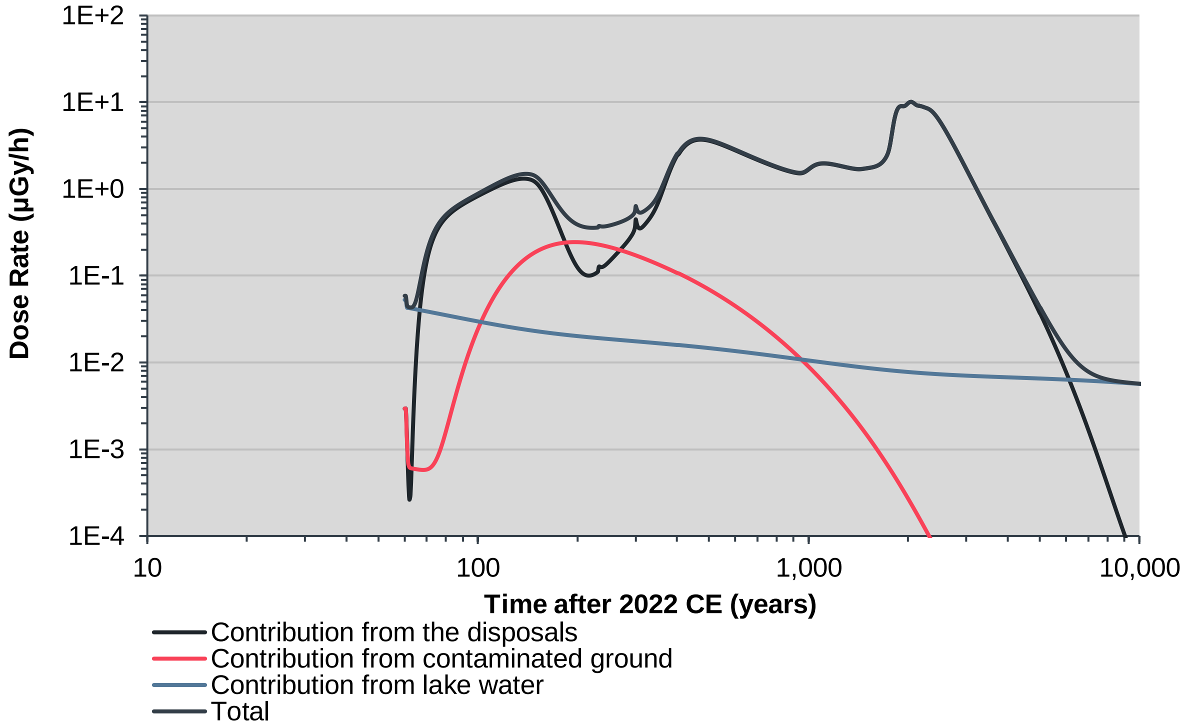
[73] Published by Environment Agency, Habitats Assessment for Radioactive Substances, Better Regulation Science Programme, Science Report: SC060083/SR1, May 2009. Note that the dose rate threshold is determined in this Environment Agency document in cognisance that there will be additional background natural radiation exposure for non-human biota.

[74] 'How to apply' guidance supporting NRW form RSR-C5 for making applications for on-site disposals states "*The Environment Agency, Natural England and Natural Resources Wales have agreed a threshold of 40 μGy h^{-1} below which there would be no adverse effect to the integrity of a Natura 2000 site. The 40 μGy h^{-1} criterion is an action level relating to total impacts from all permitted discharges (aerial and liquid discharges) that may affect a Natura 2000 site*".

[75] IAEA 1992. Effects of Ionising Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards. Technical Report Series No. 332, International Atomic Energy Agency, Vienna.

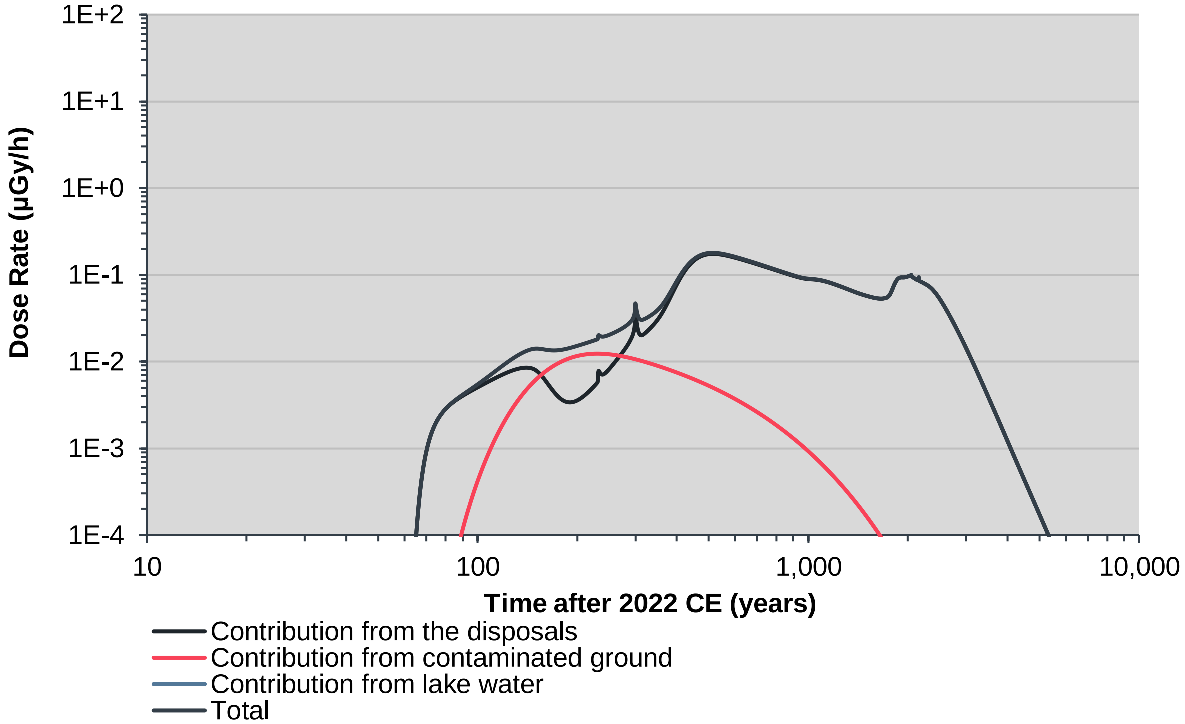
Figure 9I.1 Modelled Post End-State Dose Rate to Insect Larvae in the Nant Gwylan[76,77]



[76] About 60 years after 2022 is when it is assumed that the current site drainage arrangements (that include pumping intercepted radioactively contaminated groundwater to the lake via the diversion culvert) will cease.

[77] Using more pessimistic assumptions, whereby the Cs137 in water input to the streams from the lake is increased to the maximum observed, and the suspended sediment radioactivity concentrations in lake water are increased by a factor of ten, does not alter the peak dose rates.

Figure 9I.2 Modelled Post End-State Dose Rate to Lichen and Bryophytes in the Southern Field



ERICA Tier 1 vs Tier 2

For the associated environmental permit application made to NRW in December 2023, a screening assessment largely based on Tier 1 of ERICA was undertaken. Tier 1 includes slightly more pessimisms than Tier 2, including that the dose rate given for each radionuclide is for the organism that is most affected by that radionuclide, meaning that the dose rate summed over all radionuclides is not necessarily a dose rate that applies to any one type of organism. The calculations undertaken for the permit application also, unlike here, assumed that all peaks in radionuclide concentrations occur simultaneously.

Using ERICA, the Tier 1 dose rate factors in Table 9I.3 and Table 9I.4 can be compared with the Tier 2 dose rate factors in Table 9I.1 and Table 9I.2. When combined with the time-profile of the environmental radionuclide concentrations, the overall assessment conclusion of no harm to populations of organisms or to ecosystems is the same with both the permit application approach and the Tier 2 approach set out here. For example, for the Nant Gwylan, the Tier 1 peak non-human biota dose rate is about 20 µGy per hour compared with 10 µGy per hour (insect larvae) using Tier 2. Undertaking the assessment using the radionuclide concentration peaks together (as if they occur at the same time) in conjunction with Tier 1 gives 30 µGy per hour for Nant Gwylan.

Appendix 9J: Non-Radiological Assessment of Impacts on Controlled Waters, including Groundwater and Surface Waters

REGULATORY REQUIREMENTS

GRR requirement R15 (protection against non-radiological hazards) states: "*Operators shall bring their site to a condition at which it can be released from radioactive substances regulation, through a process that will protect people and the environment against any non-radiological hazards associated with the radiological hazards both during the period of, and after release from, radioactive substances regulation. The level of protection should be consistent with that provided by the national standard applicable at the time when relevant actions are taken.*"

EXPLAINER: CONTROLLED WATERS / GROUNDWATER RISK ASSESSMENT

A non-radiological groundwater risk assessment has been undertaken[78] in accordance with relevant regulatory guidance[79]. The guidance encourages a tiered approach to groundwater risk assessment, depending on the level of risk. The three tiers are:

Tier 1 – qualitative risk screening;
Tier 2 – generic quantitative risk assessment; and
Tier 3 – detailed quantitative risk assessment.

Central to groundwater risk assessment is the "conceptual site model" which identifies source-pathway-receptor linkages. Here: "source" means the origin of the contamination; "pathway" refers to the means by which the contamination can come into contact with the receptor(s); and the "receptors" are the entities which are vulnerable to harm from the contamination source.

As for other parts of this chapter, it is assumed that the current pumping arrangements (the groundwater abstraction system on the south side of Reactor 1 and the diversion culvert system) will have been decommissioned by the time any of the processes discussed here come into effect. This chapter therefore refers to the period after achievement of the site end state.

[78] Trawsfynydd Ponds Complex Demolition and Disposal Project: Tiered Assessment of Risks to Groundwater from Non-Radiological Pollutants, DD/REP/0021/23, Issue 1, October 2023.

[79] Environment Agency, 2018. Groundwater Risk Assessment for Your Environmental Permit. 3 April 2018. https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit.

Outline of the Conceptual Site Model

Potential Sources

The potential sources of non-radioactive contamination associated with the Proposed Development were identified by site-based personnel. The following have been identified:

- The non-radioactive aspects of the decommissioned active drains systems and original active effluent discharge pipe;
- In situ structural concrete including rebar, bitumen in expansion joints and PVC water bars;
- Cement that may be used with the demolition arisings and from concrete (see Table 9J.1) that may be introduced to some voids;
- Residual hydrocarbon compounds within the ponds complex;
- Residual asbestos;
- Wall and floor finishes;
- Structural steel;
- Residual inorganic chemicals; and
- Concrete and masonry demolition arisings used for bulk infill to voids.

Routine groundwater monitoring data show elevated concentrations of chlorinated hydrocarbons within the Disposal Area. The chlorinated hydrocarbons are inferred to be released to groundwater from made ground contaminated with chlorinated solvents from former activities on the site. This contaminated ground is not associated with, nor will it be affected by, the long-term presence of the Proposed Development. This issue is therefore not considered further here.

Pathways

Groundwater flow is generally from “site west” to “site east” (where “site north” aligns with the two reactor buildings - see Figure 9J.1), following the fall in topography across the site[80]. Groundwater flows primarily in the made ground, with flow through the bedrock being of secondary importance. Note that Figure 9J.1 shows a potential groundwater flow pathway to the north of Reactor 2. At time of writing, further hydrogeological characterisation work is planned to investigate whether this potential northern pathway is actually present.

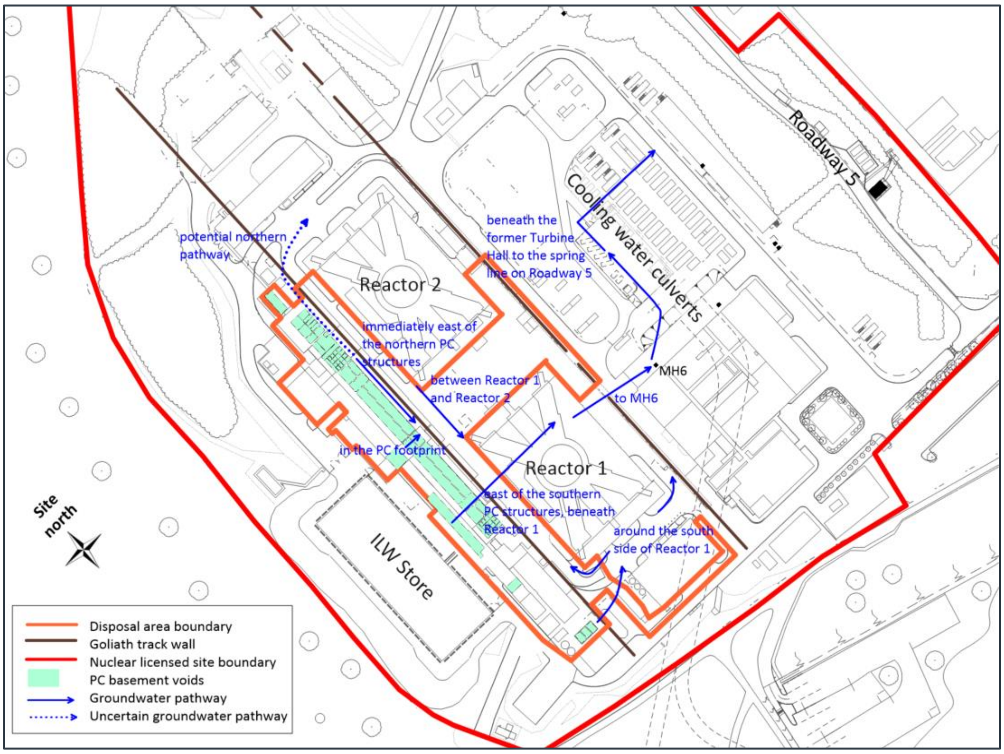
[80] The site’s hydrogeological setting and a detailed description of the groundwater flow pathways from the Proposed Development are provided in an appendix to Chapter 7 Geo-environmental Impacts and Surface Water Quality. This is summarised in Appendix 9E of this chapter. Figure 9J.1 illustrates the pathways for the hydrogeological conditions at the site after the end state is achieved.

Receptors

The EIA scoping process identified potential receptors of relevance to this part of the EIA as:

- Groundwater in the Rhinog Formation (bedrock);
- Groundwater in the made ground within a distinct trough in the bedrock surface beneath the Reactor 1 building;
- Discharges from groundwater, such as springs and base flow to streams and rivers. These include the spring at Roadway 5 (on the current licensed site) and the base flow to the Nant Gwylan, the Afon Tafarn-helyg and the unnamed stream flowing from Craig Gyfynys.

Figure 9J.2 – Illustration of the Groundwater Pathways from the Proposed Development After the Site End State is Achieved



Tier 1 – Qualitative Risk Screening

Qualitative risk screening has been undertaken to assess whether potential discharges from the contaminant sources listed above are acceptable or whether further assessment is required. For most potential pollutants, Tier 1 screening can eliminate the need for more detailed risk assessment, as summarised in Table 9J.1. In two cases, those of chromium (VI) and hydroxyl ions, quantitative assessment is required.

Table 9J.1 Tier 1 Groundwater Risk Assessment

Potential Pollutant	Discussion
The non-radioactive aspects of the decommissioned active drains system and original active effluent discharge pipe	Most of the residual secondary containment (pipework and manholes) of the decommissioned active drains system and original active effluent discharge pipe is not contaminated with non-radioactive substances. Any mild non-radioactive (most likely hydrocarbon) contamination on the internal surfaces of the manholes and oil interceptors is unlikely to be mobile as these structures were jet washed when the primary pipework was removed. Any mild contamination of the internal surfaces of such structures is now trapped under the fresh concrete infill. Similarly, should non-radioactive contaminants be left on the internal surfaces of the iron or stainless-steel secondary pipework it will now be immobilised and isolated by cement grout. Infiltrating rainwater will flow past the decommissioned active drains system and original active effluent discharge pipe as it migrates in the unsaturated zone to the water table. Concentrations of hazardous substances in that water because of this interaction can be expected to be negligible and the concentrations of non-hazardous pollutants well within relevant environmental standards. Further, only minimal dilution in underlying groundwater would be needed to avoid pollution by non-hazardous pollutants were they to be present.
In situ structural concrete including rebar, bitumen in joints and PVC water bars	Structural concrete is commonplace in the UK below the water table in the form of building foundations for example. Such features are routinely left in situ in perpetuity and are not commonly known to have a detrimental effect on groundwater quality. Therefore, structural concrete left in situ below the water table is rarely, if ever, subject to groundwater risk assessment. In this case, the below ground structural concrete in the Disposal Area has almost all been present for over fifty years and its disposition with respect to the water table will not change because of the Proposed Development. Routine monitoring of groundwater and surface water quality in the past twenty years has not shown a detrimental effect on water quality from structural concrete and no detrimental effect is expected in the future. Non-concrete components of the structures (rebar, “flexcell” filler in expansion joints and PVC) will become more available to water over the long term as the encasing concrete degrades. Corrosion will release constituents of rebar to water, but the rate of corrosion is expected to be low. The main contaminant released will be iron and this can be expected to precipitate either in the unsaturated zone and/or in the oxygenated groundwater beneath and down gradient of the disposals. Bitumen (in flexcell) is comprised of mostly heavier weight polycyclic aromatic hydrocarbon compounds and is unlikely to contain hydrocarbon compounds with appreciable aqueous solubility, consistent with its use as a sealant. PVC is essentially insoluble, as required from its use as a water bar material. Therefore, the discharges from the structural concrete, rebar, bitumen in expansion joints and PVC in water bars are

Potential Pollutant	Discussion
	expected to result in non-discernible concentrations of hazardous substances and concentrations of non-hazardous pollutants are expected to be well within relevant environmental standards.
Cement to be used in the voids	Cement may be used to condition demolition arisings and fresh concrete may be introduced to some below ground voids. The cement and concrete have not yet been specified but they are expected to be of standard composition and therefore not polluting.
Residual hydrocarbon compounds within the ponds complex	Residual hydrocarbon compounds may remain in only nine spaces / rooms within the ponds complex and the extent of stained concrete is expected to be a few square metres in each. The relevant hydrocarbon mixtures consist of relatively large molecule hydrocarbon compounds that have low or very low solubility and mobility in groundwater. The planned surface cleaning will remove the more water mobile compounds. The concentrations of hydrocarbon compounds in the potential discharge from the low mass of relatively immobile compounds are unlikely to be discernible and minimal (or no) dilution in underlying groundwater will be needed to avoid pollution.
Residual asbestos	Asbestos fibres do not dissolve or migrate in groundwater. A measure of its low risk to groundwater is the absence of an asbestos drinking water standard in the UK. Likewise, the World Health Organisation (WHO) has not set a guideline value for asbestos in drinking water. Asbestos is not a groundwater contaminant of concern and the small amounts of asbestos that will be present in the disposals are not expected to give rise to asbestos in groundwater.
Wall and floor finishes	All wall and floor finishes have a negligible solubility in water as they were used to seal surfaces from ingress of water or were specifically chosen to be used in potentially damp or wet environments. The discharges from the wall and floor finishes that will remain in the ponds complex are expected to have acceptably low concentrations of hazardous substances and concentrations of non-hazardous pollutants are expected to be within relevant environmental standards.
Structural steel left in situ	The mass of structural steel left in situ is expected to be relatively low. It will be progressively exposed to water as paint protection deteriorates but the anticipated rate of corrosion is low. The main contaminant released will be iron and this can be expected to precipitate either in the unsaturated zone and/or in the oxygenated groundwater beneath and down gradient of the voids. As such the discharge from the structural steel is expected to have acceptably low concentrations of hazardous substances and concentrations of non-hazardous pollutants are expected to be within relevant environmental standards.

Potential Pollutant	Discussion
Residual inorganic chemicals	The mass of residual inorganic chemicals that may be left in the ponds complex will be very small. They will be present mainly in the concrete floors of the acid and caustic tank room, and in the surface of the concrete tanks in the laundry basement (surfactants). Of the chemicals that may have been spilled only sodium hydroxide will remain. Spilled acid will have reacted with the concrete, leaving predominantly calcium salts. Given the intended jet washing of these surfaces, any residual chemical remaining will be relatively immobile in water. Hazardous substances are unlikely to be associated with any of the chemicals used. Only minimal dilution, if any, in underlying groundwater will be needed to avoid pollution.
Inorganic substances (excluding chromium (VI) and alkaline ions)	The leachability of some inorganic substances including Al, Ca, Cu, Fe, Mg and Zn, silicon and sulphate may increase in the presence of the high pH leachate that may be generated from the concrete-based demolition material used to infill the below-ground voids. However, published literature does not identify examples of pollution of groundwater by inorganic substances (except by alkaline anions) leached from concrete-based demolition arisings. In addition, laboratory testing of stockpiled demolition arisings of concrete and masonry (of similar age to those associated with the Proposed Development) from another site managed by the Applicant demonstrated low leachability of inorganic substances.

Tier 2 Quantitative Risk Assessment

Potential pollutants that require Tier 2 Risk Assessment (chromium (VI) and hydroxyl ions)

The demolition arisings associated with the Proposed Development that are to be deposited as infill to below-ground voids comprise concrete (aggregate bound together with cement) and brick. The cement used was normal or rapid hardening Ordinary Portland Cement (OPC) supplemented by pulverised fly ash in some structures. Bricks used in the UK are made by firing clay and are chemically inert.

Cements (such as OPC) containing greater amounts of clinker and cements that were produced prior to the implementation of the Chromium (VI) Directive (2003/53/EC) in 2005 contain greater amounts of soluble chromium (VI)[81]. Concretes made before 2005, such as the demolition arisings associated with the Proposed Development, can therefore be expected to contain greater amounts of chromium (VI)[82]. Chromium (VI), a groundwater hazardous substance, may therefore leach to groundwater. More detailed assessment in respect of chromium (VI) has therefore been required.

The leaching of concrete involves a gradual change of interstitial porewater composition from a typical young concrete interstitial porewater with a pH >13 to a more evolved interstitial porewater with a pH <10. The pH of water in contact with emplaced demolition arisings can therefore be expected to be higher than the freshwater environmental quality standard (i.e., pH between 6 and 9 for 95% of the time). More detailed assessment of pH has therefore been required.

These further assessments have been done by reference to “compliance limits” in accordance with regulatory guidance. The compliance limit is generally a literature value that represents the contaminant concentration below which harm to the receptor will not occur. Compliance limits should be met at appropriate locations between the contaminant source and the receptors.

Compliance Limits

Manhole 6 (MH6) is approximately 100 m downgradient of the Disposal Area within the groundwater pathway, within the rockhead trough that underlies the northern part of the Reactor 1 building. By establishing groundwater concentrations at or upgradient of MH6, explicit consideration is not required of what happens if it is assumed that MH6, or the drain downstream of it, becomes blocked after the site end state is achieved. The findings of assessment of compliance at or upgradient of MH6 are protective of the groundwater in the rockhead trough that underlies Reactor 1 (Figure 9J.1), and of receptors downstream of MH6 including the spring line on Roadway 5 to which groundwater would flow in these circumstances[83].

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[81] Chromium is a trace element of raw materials used in cement production. It is present in raw materials in the form of chromium (III) but is oxidized to form hexavalent chromium (VI) in cement kilns.

[82] Studies indicate that chromium (VI) is about 50-80% of the total chromium content in OPC.

[83] MH6 is upgradient of where groundwater currently mixes with site-derived surface water runoff and the discharge to the surface water environment (currently via the diversion culvert pump sumps). By establishing that pollutant concentrations (that are protective of surface

For chromium (VI) the relevant limit is taken to be the higher of the laboratory limit of quantification and the natural background concentration. Here, the selected compliance limit is taken to be 1 µg/l.

The hydroxyl ion that gives rise to the alkaline leachate is a non-hazardous pollutant. The compliance limit for protecting surface waters from non-hazardous pollutants are by default Environmental Quality Standards (EQSs). A compliance limit for pH has been set at the freshwater annual average EQS applied by NRW, which requires pH to be between 6 and 9 for 95% of the time. This pH compliance limit is the same as the permitted pH (*"between 6 and 9"*) of site drainage discharged to Llyn Trawsfynydd via diversion culverts No. 3 and No. 4. It is also consistent with the permitted diversion culvert storm overflow into the Nant Gwylan.

General Approach to the Generic Quantitative Risk Assessment

The assessment described here was conducted based on the expected "natural evolution" of the disposals, referred to in this appendix as the "reference case". Alternative calculations to address uncertainty in the values of some parameters were also undertaken. A "variant case" calculation in which there is a groundwater pathway from the north of the Proposed Development was also assessed.

Reference Case Calculations

The rate of infiltration to the deposited demolition arisings (voids infill) within the ponds complex footprint is quantified in the same way as it is in the radiological assessment conducted to support the permit variation application. Infiltration to the voids infill is assumed to be controlled by the vertical hydraulic conductivity of the concrete cap. The hydraulic conductivity of the concrete cap is assumed to be $1x10^{-10}$ m/s initially, but concrete degradation is assumed to cause it to increase over time. The onset of cap degradation is expected to be many decades after construction, and after the site end state is achieved[84]. However, the date of onset of cap degradation does not affect the results of the calculations presented here.

The rate of infiltration through the cap cannot exceed the hydrologically effective rainfall, assumed to be 1,393 mm/year. The effect of the assumptions is that the infiltration through the concrete cap starts at 3.2 mm/year and rises to 1,393 mm/year after about 130 years and is steady at this rate thereafter. The area of the ponds complex basement voids is approximately 1,535 m^2. The infiltration to, and therefore leakage from, the infilled voids is therefore calculated to start at approximately 5 m^3/year and rise to 2,139 m^3/year[85] about 130 years after cap degradation starts.

The rate of leakage of water from the below-ground voids filled with demolition arisings is assumed to be the same as the rate of infiltration through the cap. The risk assessment assumes that cap degradation starts as soon as the cap is constructed, therefore leakage also commences as soon as the cap is constructed.

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water quality) are sufficiently low at MH6, or prior to groundwater reaching MH6, then the risk to all surface water bodies is cautiously addressed.

[84] However, in the radiological assessments of natural evolution, the onset of cap degradation in the reference case is cautiously assumed to be immediately after cap construction, decades before achievement of the site end state.

[85] 3.2 mm/year * 1,535 m^2 = 5 m^3/year.

1,393 mm/year * 1,535 m^2 = 2,139 m^3/year.

The flow of groundwater at MH6 is assumed to be the lowest flow rate measured in MH6 (1.3 l/s, equivalent to around 41,000 m^3/year) even though the flow of water in MH6 at other times of year, and especially following rainfall, will be higher. Higher flows will correspond to lower environmental concentrations of potential pollutants.

Climate Change Calculation

Climate change to 2100 might change the hydrologically effective rainfall to values between a reduction of 15% (i.e. to 1,185 mm/year) and an increase of 23% (i.e. to 1,713 mm/year). This potential variation has very limited effect on the outcome of the assessments presented here. For example, any change in the hydrologically effective rainfall will likely change groundwater flow by the same proportion as it changes the rate of leakage from the voids infill once degradation means the cap no longer limits infiltration of rainwater. The concentration of chromium (VI) in groundwater downgradient is therefore insensitive to hydrologically effective rainfall being different to that assumed by the reference case.

Northern Pathway Calculation

It is possible that groundwater that passes beneath the northern part of the ponds complex does not flow south into the rockhead trough beneath Reactor 1 to MH6 but instead flows north of Reactor 2. The groundwater flow in the northern pathway has been estimated to be 15,700 m^3/year, based on assuming that the 41,000 m^3/year seen at MH6 takes groundwater flow from about 170m length of the ponds complex whereas the northern pathway takes groundwater flow from about 65m length of the ponds complex, with an assumption of the same volumetric flow per metre length in both cases. Leakage from the infilled voids into groundwater in the northern pathway is calculated to start at approximately 1 m^3/year and rise to 423 m^3/year, based on a plan area for the voids involved in the northern pathway of 303 m^2 and the same effective rainfall rate as stated above.

Tier 2 – Generic Quantitative Risk Assessment of Chromium (VI) From Concrete Demolition Arisings

Inorganic contaminants are progressively released by water from a granular material by the process of leaching. The greater the volume of water that has passed through a given mass of material, the greater is the mass of material leached.

Leaching tests were conducted on ten samples of concrete and masonry demolition arisings from buildings on another site managed by the Applicant with a similar construction history to the Trawsfynydd ponds complex[86]. The assessment of these tests cautiously assumed that the chromium analysed in the leachate was all chromium (VI).

Using the average leachable concentration of chromium of the samples described above, the initial chromium (VI) concentration in water in the demolition arisings is calculated to be as high as 21 µg/l. On this basis, the concentration of chromium (VI) in the discharge to groundwater appears to exceed the compliance limit (1 µg/l). However, leakage from the infilled voids is calculated to be initially diluted by a factor of well over 8000 in groundwater immediately downgradient (41,000 m^3/year groundwater flow divided by 5 m^3/year leakage). For many years the concentration of chromium (VI) in water in the demolition arisings can therefore be expected to be reduced by dilution in groundwater to a concentration much

[86] Note that even if fly-ash containing concrete is present in the Trawsfynydd ponds complex demolition arisings, available data indicate that the chromium content is unlikely to be much different to the composition of the concrete used to assess leachability.

lower than the compliance limit below the water table in the trough in rockhead immediately downgradient of the infilled voids.

The calculated amount of dilution will reduce as the cap degrades and leakage increases, and it is calculated to reduce to a factor of approximately 20 if the cap fully degrades (41,000 m^3/year groundwater flow divided by 2,139 m^3/year leakage). In later years, however, the concentration of chromium (VI) in demolition arisings themselves will have been reduced by chromium depletion such that lower amounts of dilution are sufficient to reduce the concentration in groundwater in the trough in rockhead immediately downgradient of the infilled voids to lower than the compliance limit.

Leakage from the infilled voids to the northern pathway is calculated to be initially diluted by a factor of about 16,000 in groundwater immediately downgradient of the infilled voids (15,700 m^3/year groundwater flow divided by ~1 m^3/year leakage). The calculated amount of dilution will reduce as leakage increases and it is calculated to reduce to a factor of approximately 40 if the cap fully degrades (15,700 m^3/year groundwater flow divided by 423 m^3/year leakage). This dilution is enough to reduce the chromium (VI) in the northern pathway groundwater to below the compliance limit, even ignoring chromium depletion over time.

Tier 2 – Generic Quantitative Risk Assessment Of Alkaline Leachate from Concrete Demolition Arisings

Approach

The calculations on which the results set out below are based conservatively ignore processes that will attenuate hydroxyl ions in the subsurface. Specifically, the calculations do not reduce the concentration of hydroxyl ions due to:

- Carbonation of the deposited concrete demolition arisings (expected to inhibit the generation of alkaline leachate by infiltrating rainwater);
- Neutralisation of alkaline leachate by groundwater;
- Carbon dioxide dissolution into groundwater;
- Reaction of alkalinity with aluminosilicate minerals in the geosphere pathways (made ground); and
- Surface adsorption of carbonates on iron oxyhydroxide minerals in the geosphere pathways.

For context, the monitoring in boreholes located upgradient of the ponds complex shows the pH of groundwater is typically less than 7, i.e. slightly acidic. Groundwater that has moved onto the developed part of the site has a higher pH, i.e. is slightly alkaline.

Reference Case Calculation

The pH of groundwater in the rockhead trough at the location of MH6 has been calculated. The calculation first determines a concentration of hydroxyl ions in water in contact with the demolition arisings that is assumed saturated with dissolved portlandite (calcium hydroxide), and then derives the concentration in water at MH6 following dilution of the contact water in groundwater. The pH of water at MH6 was calculated to be 8.6, which is within the acceptable range, at the onset of cap degradation. However, cap degradation increases the rate of infiltration to the demolition arisings and thereby the rate of leakage, and based on the assumed increase in hydraulic conductivity of the cap over time, it takes 18 years after the onset of cap degradation for the calculated pH of water at MH6 to rise to the upper compliance limit (pH 9)[87]. However, empirical observations from the existing uncapped deposits of concrete demolition arisings on the Trawsfynydd site presented below show alkalinity effects on water quality subside over timescales much shorter than this. Given the time it is calculated for the pH of groundwater at MH6 to rise to the compliance limit and the conservative assumptions underlying the calculation (particularly the absence of carbonation), it is concluded that release of hydroxyl ion alkalinity associated with the Proposed Development poses little likelihood of unacceptable inputs to groundwater.

Illustration of Potential Effect of Carbonation

Following carbonation (and/or leaching in the very long term) of the demolition arisings, the water (leachate) in contact with the concrete-based demolition arisings could be around pH 10. The pH of water at MH6 calculated for these circumstances is calculated to be 8.7 (below the upper compliance limit) due to dilution even once the cap has fully degraded.

Variant Case Calculation

Calculation of groundwater pH in the northern pathway was carried out in the same way as the calculation of the pH of groundwater flowing through MH6 with the following amendments to parameter values:

- The plan area of the ponds complex voids from which leakage is assumed to flow to the northern pathway is taken as 303 m^2; and
- The flow in the northern pathway is assumed to be 15,700 m^3/year.

The initial pH of groundwater in the northern pathway affected by leakage is calculated to be 8.1, comfortably below the compliance limit and, in the absence of carbonation of the demolition arisings, it is calculated to take 53 years after the onset of cap degradation for it to rise to the compliance limit as a consequence of the assumed degradation of the concrete cap. As noted below this is long after the timescales that empirical observations from the existing deposits of concrete demolition arisings on the Trawsfynydd site show alkalinity effects on water quality subside.

Empirical Observations

This section provides reassurance that the demolition arisings to be placed in the ponds complex voids can be expected to become carbonated before cap degradation makes the rate of leakage so high that leachate would raise the pH of groundwater at MH6 to exceed the compliance limit.

The turbine hall was located east of the reactors. The above ground structure of the turbine hall was demolished in 2003 and the concrete demolition arisings were placed in its below ground basements. The total volume (approximately 20,800 m^3) of demolition arisings infill was much larger than the estimated 5,200 m^3 that will be placed in the ponds complex. Whilst the 2003 demolition almost filled the voids, the final 2,547 m^3 was filled in late 2016 and the early part of 2017 with arisings from the demolition of the administration and workshops complex. On this second occasion the emplaced material was crushed first. As

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[87] The pH of groundwater flowing through the location of MH6 is calculated to reach the compliance limit well before infiltration through the cap is limited to the hydrologically effective rainfall. Uncertainty in the amount of hydrologically effective rainfall therefore has no effect on the calculated time it takes for the pH of groundwater flowing through MH6 to rise to the compliance limit in the absence of carbonation of the demolition arisings.

part of this second phase of works, the additional deposit of concrete-based demolition arisings was covered with a welded low permeability high density polyethylene membrane in June 2017.

The Northern Outlet Pipe, located at the north-eastern site boundary, is the outlet of a surface water drainage system which drains ‘Roadway 5’ which runs site south to site north close to the eastern boundary of the site and down topographic and hydraulic gradient of the former turbine hall basement. The surface water passes through a small oil interceptor before discharging via the Northern Outlet Pipe into the unnamed stream flowing from Craig Gyfynys. Following placement of demolition arisings in the turbine hall basement in 2003 the pH measurements were higher than recorded before the demolition and this continued until early 2005. The highest pH value in this period was 8.61. There is no indication in the monitoring results of an effect from the second phase of works to fill the remainder of the turbine hall basement.

Routine monitoring of groundwater in boreholes was not being undertaken around the time of the first phase of placement of demolition arisings in the turbine hall. Monitoring results following the 2016/2017 deposits showed a short-lived increase in groundwater pH immediately beneath the turbine hall basement but no discernible effect downgradient[88]. There is negligible diluting water that would be expected to lower the pH of groundwater as it flows from beneath the turbine hall basement to the down gradient boreholes and it is therefore interpreted that the alkalinity has been attenuated by other processes.

The 2003 pH measurement of highly alkaline water (11.87) in a redundant drain that led from the turbine hall basement into MH6 until it was blocked in around 2004 is close to, but lower than, that expected (12.5) if the intergranular porewater in the backfill is saturated with portlandite. The risk assessment undertaken for the reference case has taken a cautious approach and assumed that the pH of water in contact with the demolition arisings has reached pH 12.5.

Conclusions

For the majority of the potential sources of non-radioactive contaminants, it can be demonstrated through qualitative arguments that the Proposed Development poses negligible risk of unacceptable pollution of groundwater. However, for chromium (VI) that might leach from the demolition arisings used for voids infill, and likewise for hydroxyl ions leached from the voids infill materials that may raise the groundwater pH, quantitative assessment has been required.

By quantitative assessment, it has been shown that chromium (VI) from concrete demolition arisings poses little likelihood of unacceptable inputs to groundwater or down gradient

[88] Monitoring has been undertaken quarterly since late 2016, in a suite of boreholes that has evolved over time, to meet land characterisation needs and in response to findings. Beneath the footprint of the turbine hall basement the groundwater pH was higher than elsewhere in 2017 and throughout 2018. It was typically around 8 but, in some places, and on some occasions exceeded 9. Whilst fewer boreholes were monitored, the pH anomaly is not evident in the 2019, 2020, 2021 and 2022 monitoring data. The groundwater pH values at boreholes located downgradient of the turbine hall basement (BH112, BH114 and BH118) were lower than those within the turbine hall basement and typical of those upgradient of the turbine hall basement.

surface water receptors under reference case, alternative assessment or variant concept scenarios.

For alkaline leachate, because the quantitative risk assessment does not account for carbonation of the demolition arisings and other attenuating processes such as are empirically inferred to occur in groundwater flowing from beneath the turbine hall basement, the calculated pH values in groundwater at MH6 and in water downgradient of the ponds complex deposits are likely to be overestimates. When empirical observations following the turbine hall basement infill are considered, the risk assessment demonstrates that the pH of leachate released from the Disposal Area will pose little likelihood of unacceptable inputs to groundwater or the down gradient surface water receptors (including the groundwater in the rockhead trough, the spring at Roadway 5, Nant Gwlyan, and the Afon Tafarn-helyg).

Appendix 9K: Impacts on Groundwater Flows and Levels

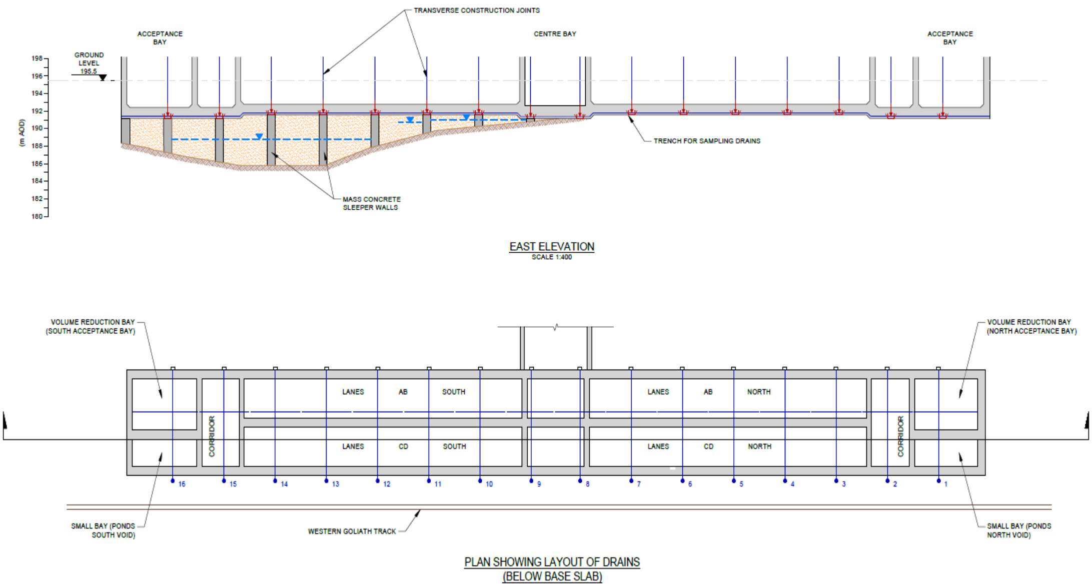
The information in this appendix is based on the knowledge of the Trawsfynydd cooling ponds complex and the localised hydrogeology accumulated over several decades[89].

Beneath the base slab of the cooling ponds are sixteen ‘sampling drains’ which were designed to intercept leakage of water from the cooling ponds during the site’s operational phase. Figure 9K.1 shows the layout of the sampling drains. Sampling drains are numbered from north (drain 1) to south (drain 16).

The sampling drains were designed to contain any ponds water entering them from above but not to be subject to the entry of groundwater. However, some of them are known to have leaked into the ground and/or been subject to the ingress of groundwater. They were not designed to act as groundwater drains and the extent to which they do remains uncertain. All of these sampling drains are known or inferred to have radioactive contamination of their fabric (i.e. of the porous pipes, surrounding gravel and enclosing concrete channels).

The northern sampling drains (1 to 9) are founded on bedrock. The southern sampling drains (10 to 16) are founded on concrete sleeper walls (transverse parts of the drains) and on made ground (longitudinal parts) due to a trough in the bedrock surface (rock-head). Figure 9K.1 shows that the invert levels of sampling drains 1, 2, 8, 9, 15 and 16 are slightly deeper than the other sampling drains. Drain 7 was “removed” in 2016, meaning that its contents were removed and the concrete channel that remained was backfilled with fresh clean concrete.

Figure 9K.1 Under-Ponds Sampling Drains



89 WSP, Trawsfynydd Ponds Complex: Hydrogeological Conceptual Model to Support the Demolition and Disposal Project, DD/REP/0020/23, First Issue (Revision 3), June 2023.

Groundwater level data and direct observation of water in them indicate that drains 1, 2, 8 and 9 are below the water table for much of the time. For this reason, these drains will be blocked prior to the Proposed Development commencing. This may be achieved by "removing" the drain (in the same manner as was undertaken for drain 7) or potentially by grouting them to immobilise the radioactive contamination in them and excluding groundwater.

The data also indicate that groundwater levels in the made ground and bedrock could be intermittently higher than the invert (base) levels of at least some of sampling drains 3-6, 10 and 11. At the present time, it is proposed not to "remove" these drains but rather to grout them, though for technical reasons both approaches remain an option. These works will also be undertaken prior to the Proposed Development commencing.

The invert levels of sampling drains 12-16 are about 2m above the water table in the made ground in the rock-head trough. These are referred to as the "dry" sampling drains and it is proposed to leave these drains in their current condition with no intervention.

The interventions described above would block any groundwater that had previously been passing through the affected sampling drains from west to east. If this happens, then that groundwater would be diverted elsewhere, and the average and typical maximum groundwater levels in the made ground on the west side of the ponds structure could rise to some extent:

- Groundwater flow would be diverted northwards in made ground adjacent to the west wall of the ponds complex and then eastward towards the north end of Reactor 2, and/or southward into the rock-head trough then eastward between the sleeper walls under the southern ponds structure[90]. Groundwater flow paths from the west to the east of the ponds complex would therefore be lengthened.

- However, assuming that the made ground to the west of the ponds complex is as transmissive (permeable) as elsewhere on the Trawsfynydd site (and there is no reason to believe otherwise) then the rise in typical maximum groundwater levels associated with the lengthened flow paths would be small and very unlikely to reach the internal floor levels of the ponds.

[90] The latter pathway would almost certainly receive any flow diverted from drains 8 and 9 (to be "removed" prior to the proposed disposals), while any flow diverted from drains 1 and 2 (also to be "removed" prior to the proposed disposals) might go either northward or southward.

Appendix 9L: Radiological Assessment Uncertainties

Uncertainties have been addressed in various ways for the radiological assessments. Common to these is the cautious approach of using generally conservative assumptions in the derivation of the radioactive inventory assumed to be present in the first place (Appendix 9C). The assessments will be revisited as better characterisation data become available, and if necessary specific parts of the radioactive inventory can be removed, reduced or relocated to limit certain doses or dose rates that could arise in the future.

Human intrusion assessments have been undertaken through the use of stylised scenarios (e.g. in relation to excavation geometries and depths). Uncertainties have been addressed through exploration of the effect of assuming different intrusion locations (in relation to specific radioactive below-ground structures), and through the selection of generally cautious parameters (likely to over-estimate the radiological consequences). An example of the latter is the suspended dust concentrations experienced by the intruders (those carrying out the uncontrolled excavation or drilling). A main source of uncertainty is the remaining radioactive inventory at the time of the hypothetical intrusions. This has been addressed by assuming that intrusion events could happen at the first possible time after release of the site from radioactive substances regulation (about 2080) – this ensures that the intrusion events are assessed assuming that they happen at the time when the least amount of radioactive decay has occurred.

A similar cautious approach has been taken with future site occupancy by:

- assessing the impact of this occupancy occurring from around 2080;
- considering occupancy over different parts of the sub-surface structures (including over the most radioactive ones); and
- ignoring any potential radiation shielding provided by the building, cabin or caravan used by a hypothetical future site occupant.

Table 9L.1 summarises the main uncertainties identified in the development of the natural evolution assessments of impacts on people. The general approach to uncertainties in the natural evolution assessment has been:

- to use cautious or best estimate parameter choices in the first instance;
- to ignore some potentially mitigating factors (such as solubility limits for radionuclides dissolved in water);
- where best estimate parameter choices are used in the first instance, to consider alternative parameter choices in variant assessment calculations (results available on request); and
- for most representative persons, to consider alternative natural evolutions and disposal configurations in variant and “what if” scenarios, e.g. what if there is effectively no concrete cap to limit rainwater ingress from above (again the results of these scenarios are available on request).

The people who will potentially receive doses from the features within the scope of the Proposed Disposals are not known. This uncertainty was explored by defining multiple “representative persons” (Appendix 9D). Two of the representative persons are assumed to occupy land immediately adjoining the site, which is currently occupied by the electrical switching compounds. It is assumed that the land is used either for grazing livestock or for residential occupancy, which allows for the consideration of external irradiation, ingestion and inhalation radiation exposures.

For variant (alternative) assessment calculations and scenarios considered in relation to the Proposed Disposals, exceedances of the dose rate equivalent of the risk guidance level (Appendix 9B) have been calculated only in a single scenario[91]. This scenario considers the unlikely situation of a representative person abstracting and consuming groundwater close to the east side of Reactor 1 (with the results for this receptor included in Figure 9.5). For other well positions considered, all further away from the Proposed Disposals, no exceedances were calculated. The exceedance of the dose rate equivalent of the risk guidance level at the peak dose rate for a person drinking water from an abstraction well in the rockhead trough by Reactor 1 is not large, would be a temporary exceedance, and the peak dose rate is only a small fraction of the average individual dose rate in the UK. It is also an improbable scenario, meaning that the risk would not necessarily exceed the risk guidance level.

The natural evolution model has also been used for the non-human biota radiological assessment, using dose per unit environmental concentration factors (e.g. µGrays / Bq per litre) taken from ERICA (see Appendix 9I). This has not been done for any of the variant or “what if” cases in the table below. ERICA is understood to be cautious in its assumptions, and the predicted dose rates to non-human biota are shown to be sufficiently below the level of potential concern. This is true whether Tier 1 or Tier 2 is used within ERICA.

[91] See Paragraph 9.8.5. which is relevant to applying an equivalent dose to the risk guidance levels in this appendix.

Table 9L.1: Main Uncertainties and their Treatment in the Natural Evolution Assessment (Note: this is not a complete list of the uncertainties and their impacts evaluated for the associated environmental permit application).

Uncertainty	Treatment of uncertainty in the natural evolution assessment
The radioactivity of the disposals.	Uncertainty is accounted for within the inventory through cautious estimates that are expected to result in an overestimate of the total true level of radioactivity for the features within the scope of the Proposed Disposals. In addition, an assessment of the impact of disposal of a greater radiological inventory in certain infilled voids was also undertaken.
Hydraulic properties (e.g. porosity, hydraulic conductivity) associated with the proposed concrete cap and the pre-existing in situ concrete (i.e. the ponds complex walls and floors).	The hydraulic parameter with the greatest uncertainty range is believed to be the hydraulic conductivity of intact concrete and its evolution over time. This parameter greatly influences the rate of rainfall-driven infiltration through the proposed concrete cap and the rate of groundwater-driven flow through pre-existing in-situ concrete structures. Porosity values for intact concrete are also uncertain, but to a lesser relative degree than hydraulic conductivity. Two alternative assessment cases were considered using minimum and maximum credible initial hydraulic conductivity values for the proposed concrete cap and pre-existing in situ concrete. Two alternative assessment cases were also undertaken considering the minimum and maximum credible hydraulic degradation times for intact concrete.
No site-specific radioelement sorption coefficients for concrete are available.	Within the literature there is significant variability in sorption coefficients for the cement (and to a lesser extent aggregate) associated with both undegraded and degraded concrete. Reviews that have considered sorption coefficient parameterisation have summarised this variation into minimum, maximum and best estimate values. To bound the impact of this uncertainty, two alternative cases were assessed that consider the impact of minimum and maximum credible concrete sorption coefficients.
The rates of radionuclide diffusion out from the concrete.	It was assumed that radionuclides associated with emplaced broken demolition arisings are instantly available for advective transport (that is, transport in a flowing medium) upon completion of the concrete cap. However, for the in-situ structures, radionuclides will need to diffuse out of the near-surface contaminated layer prior to the advective transport. This diffusive transport is cautiously modelled through only considering diffusion towards the advective flows in the voids and never the other way (i.e. never deeper into the in situ concrete structure).
The evolution of chemical properties associated with the in-situ disposals, emplaced concrete demolition arisings and the concrete cap.	As concrete chemically degrades, changes in porewater chemistry will impact radionuclide sorption. In general, and specifically for the key radionuclides of the inventory, sorption tends to decrease as the concrete degrades. The natural evolution assessment model accounted for this by explicitly modelling concrete chemical degradation. To bound the uncertainty associated with this, another assessment was undertaken assuming that concrete chemical degradation is simply linked directly to hydraulic degradation of intact concrete.
The degree and extent of saturation of concrete, both at present and in terms of their future evolution.	In terms of radionuclide transport, the degree and extent of saturation influences the radionuclide diffusion rate out of near-surface contaminated layers and the time of initial advective releases. To bound this latter aspect, which is affected by the rate at which the disposals saturate, all calculations cautiously assumed that the source compartments partially or fully saturate (dependent on their position relative to the local water table) instantaneously.
The flow of water entering and leaving the local groundwater system, both across the site and around the ponds complex.	The impact of uncertainty in the site water balance was explored in an alternative assessment case that considers a maximum geosphere flow rate incorporating the proportion of rainfall currently intercepted by the surface water drains across the Trawsfynydd site. No minimum value alternative assessment case was considered, as the flow rate used in the main calculations is assumed to be a good estimation of the minimum flow rate.
Future changes in climate leading to changes in flow rates and local water table elevation.	There is uncertainty in how the rainfall rate could alter due to climate change, and its associated impacts on flow rates and the elevation of the local water table. At the Trawsfynydd site, UKCP18 (UK climate predictions) data suggest it is more probable that rainfall will increase, potentially leading to increases in rainfall infiltration and thus groundwater flow rates. To assess the potential impact of this uncertainty, two reasonably credible assessment cases were undertaken considering the impacts of minimum and maximum rates of hydrologically effective rainfall on flow rates in the disposals, geosphere and biosphere, and associated potential changes to the elevation of the local water table. To ensure complete bounding of this uncertainty in relation to water table elevation, though it is physically unrealistic, a “what-if” scenario was assessed considering the impact of the local water table reaching the ground surface.
The impact of extreme external hazards on the disposals and the concrete cap.	A “what-if” scenario was undertaken that aimed to bound the worst-case impact of an external hazard (such as an earthquake) on the hydraulic properties of the disposal structures. This scenario assumed the hydraulic properties instantly changed to degraded values upon completion of the concrete cap (even though the site is still licensed and permitted at that time).
Groundwater from the northern end of the ponds	For features located in the north of the ponds complex, potential northward flows could discharge to parts of the modelled biosphere located close to the north-western boundary of the Trawsfynydd site. The radiological impacts resulting from potential northwards flowing groundwater, emanating from the northern part of the ponds complex, were considered in a variant scenario.

Uncertainty	Treatment of uncertainty in the natural evolution assessment
complex may travel along alternative flow paths.	
Whether the Trawsfynydd groundwater drainage system could continue to act as a preferential flow path for aqueous releases, bypassing much of the modelled geosphere and/or biosphere, after achievement of the site final end-state.	At present, the porous pipe drainage system around Reactor 1 intercepts groundwater that has entered the made ground within the rockhead trough located under the southern part of the ponds complex and the northern part of the Reactor 1 building. Intercepted groundwater is piped downgradient to the diversion culvert. In the main calculations, it is assumed that these drains will be inoperative at the site end state (~2080), with groundwater instead flowing through made ground east of Reactor 1 and discharging a few hundred metres downgradient at a spring line located near Roadway 5. Two variant scenarios were assessed considering the permanent effectiveness of parts of this drainage system. In the first scenario, the portion of the drainage system between Reactor 1 and Roadway 5 (~150m) was assumed to remain effective, thus bypassing much of the geosphere flow path. In the second scenario, the portion of the drainage system between Reactor 1 and the diversion culvert (~350m) was assumed to remain effective, with intercepted water outflowing directly into the Nant Gwylan and thus bypassing much of the geosphere flow path and parts of the modelled biosphere.
Radioelement sorption coefficients for made ground, soil and stream sediments.	Sorption of radioelements to made ground, soil and stream sediments will control how quickly radioelements enter or are dispersed into the wider biosphere. Site-specific radioelement sorption information for the made ground at the Trawsfynydd site is only available for caesium, nickel and strontium. The impact of the uncertainty in sorption, for these and other elements, was explored by undertaking alternative assessment cases that considered minimum and maximum credible sorption coefficients.