Winfrith End State Project:
Site-Wide Environmental Safety Case 2025

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Review/Revision Register

Version	Date	Amendments / Change
Version 1 Draft 1	31/05/2024	First working draft for NRS review.
Version 1 Draft 2	01/07/2024	Revised in response to NRS review.
Version 1 Draft 3	09/07/2024	Revised in response to additional NRS review comments on v1d1.
Version 1 Draft 4	18/11/2024	Revised in response to revisions in underpinning reports (e.g. radiological inventory, radiological and non-radiological risk assessments, restoration management plan, strategy decisions) and peer review.
Version 1 Draft 5	14/12/2024	Revised in response to additional NRS review, peer review close-out comments and revisions to underpinning reports.
Version 1 Draft 6	17/12/2024	Revised in response to additional NRS review.
Version 1	19/12/2024	Revised in response to final NRS review.
Version 2	01/05/2025	Minor corrections made to the human intrusion dose calculation results in Section 7.4.3; there are no changes to the conclusions, dominant radionuclides or dose pathways.

Overview of the Site-wide Environmental Safety Case

Why our work matters

At Nuclear Restoration Services (NRS), we are dedicated to the safe, secure, and sustainable decommissioning and restoration of nuclear sites. Our mission extends beyond merely dismantling reactors; we aim to create a positive legacy for future generations and bolster resilient local economies.

Transforming Winfrith for the future

The decommissioning and restoration of the Winfrith site is set to be the first of its kind in the UK. Our approach not only considers the technical challenges but also places a strong emphasis on the community and environment. By restoring the site to heathland, we're creating valuable habitats for local wildlife and providing amenity value for the local community. The decommissioning and restoration of the site will be a world leading example in sustainable decommissioning that is built on the views of the local community. Restoration of the site will support development of valuable and rare habitats that are unique to Dorset.

Overall Vision for the Winfrith Site

E1 The Winfrith nuclear site in Dorset is a former nuclear power research and development site owned by the Nuclear Decommissioning Authority (NDA) and operated by Nuclear Restoration Services (NRS). It is located approximately four miles from the south Dorset coast, two miles west of the village of Wool and ten miles east of Dorchester. The site has been extensively decommissioned over several decades and will be the first NRS site to reach its Interim End Point (IEP), the point at which physical decommissioning activities will be complete. It is one of the first sites in the UK to apply for permission to implement on-site disposal of some low-level radioactive waste, in accordance with the NDA's waste hierarchy and principles of sustainability and risk-based management.

E2 At the IEP, expected to be reached before 2040, the only radioactive features proposed to remain on site will be contaminated below-ground concrete structures (and rubble infill) associated with the Steam-Generating Heavy Water Reactor (SGHWR) and the Dragon reactor complex. These disposals will be safely isolated beneath the site surface, which will consist of heathland suitable for public access. For several decades beyond the IEP, NRS will provide stewardship of the site through passive management and environmental monitoring, until the site is judged to be suitable for release from regulatory controls.

Stakeholder Engagement, Next Land Use and Environment

E3 Extensive engagement with local stakeholders, including members of the public, landowners, local councils, regulatory bodies and other local stakeholder groups, has determined the next land use for the site to be a heathland of amenity value to the local community (Figure E.1). Return of the natural environment and protection of the site's sensitive flora and fauna are key stakeholder priorities. The site is located partially within the Winfrith Heath Site of Special Scientific Interest, a substantial and varied tract of heathland that encompasses a range of acidic heath and mire ecological communities. It is also adjacent to the Winfrith and Tadnoll Heath nature reserve, an internationally significant conservation area. The marshy valley of the River Frome, a major chalk stream of southern England, lies to the north-east of the site and the River Win, a tributary of the Frome, runs close to the southern boundary of the site.

Figure E.1: Habitats present within the location of the former Zebra reactor (November 2022) showing open mosaic/acid grassland/heathland mosaic habitat that has developed by natural regeneration within the last 10 years.

Decommissioning Activities

E4 Seven of the original nine reactors on the site have been decommissioned and fully removed, and the remaining reactors (SGHWR and Dragon) have been defueled and are in the process of being decommissioned. All higher-activity radioactive waste generated from decommissioning the remaining reactors is being removed from the site for storage and subsequent disposal in dedicated facilities elsewhere in the UK.

E5 Decommissioning is on-going across the site, including the decommissioning of the drains and demolition of ancillary facilities such as offices. Additionally, the Blacknoll Reservoir, Active Liquid Effluent System (ALES) and Sea Discharge Pipeline are being prepared for decommissioning.

Regulatory Regime

E6 The site currently operates under a nuclear site licence, issued under the Nuclear Installations Act 1965 by the Office for Nuclear Regulation. The land within the current site perimeter fence is 83 ha, although only 70 ha is within the area covered by the nuclear site licence. The site also has an Environmental Permit issued by the Environment Agency (EA) for activities involving radioactive substances. The land covered by the environmental permit extends beyond the perimeter fence and includes the route of the Sea Discharge Pipeline, which transfers effluent from the site to the sea discharge point.

E7 In England activities involving radioactive substances are regulated by the EA under the Environmental Permitting (England and Wales) Regulations 2016 (EPR16). Release from radioactive substances regulation (RSR) cannot take place until the EA is satisfied that all activities involving radioactive substances and any disposals of radioactive waste (solid, liquid or gaseous) on or from the site have ceased, and that the site is in a state that will ensure a satisfactory standard of protection for people and the environment. The environment agencies use the term Site Reference State (SRS) to refer to the condition of a nuclear site when it is fully compliant with the requirements for release of the site from RSR.

E8 Implementation of the proposed end state will require several regulatory permissions. These include a variation to the site's RSR (EPR16) permit to allow on-site disposal of radioactive wastes, a permit for a 'deposit for recovery' (DfR) operation to allow recovery of suitable non-radioactive waste from decommissioned facilities on site and its deposit in below-ground voids, and planning consent.

The GRR and Optimisation of Waste Management

E9 Following deplanting and removal of the reactor cores and any areas of higher-activity contamination from the SGHWR and Dragon reactor complex, large volumes of lightly contaminated concrete will remain. Historically, this would have been removed, broken up, emplaced in hundreds of waste containers, and transported from the site to permitted disposal facilities elsewhere in the UK. The extensive underground voids left on site would then have been filled with imported clean (non-radioactively contaminated) material to reprofile the land surface.

E10 In 2018 the environment agencies (the Scottish Environmental Protection Agency, Natural Resources Wales and the Environment Agency) jointly published guidance on the requirements for release of decommissioning nuclear sites from radioactive substances regulation (referred to here as the GRR). The GRR requires site operators to consider all options for management and disposal of radioactive waste from the site, including the potential for on-site disposal. The process for assessing options is carried out in a structured and iterative process referred to as optimisation. Subsequent strategic options assessments and stakeholder engagement undertaken by NRS indicated that on-site disposal of some radioactive wastes generated on the site is the preferred option as it minimises risks to site workers, reduces the number of lorry movements needed to transport material on and off site, has a smaller carbon footprint, uses fewer resources, costs less and minimises nuisance to local communities. NRS only considers on-site disposal of wastes that would meet safety requirements and where this is demonstrated to be the optimised approach.

E11 Since the strategic options assessment, the proposals for on-site management of radioactive wastes have been developed into conceptual designs that demonstrate regulatory compliance and safe long-term performance of the disposals. Further engagement with the local community, wildlife and habitat organisations, and Dorset Council has also influenced how the site surface will be restored, surface water managed, specific ecological habitat types encouraged, and public access enabled.

End State Conceptual Design

E12 The conceptual plan for the site end state, which will deliver the next land use, is illustrated in Figure E.2 and involves:

- On-site disposal of the SGHWR and Dragon reactor complex concrete structures.
  - Following reactor core removal and deplanting, all accessible non-structural materials (e.g. non-structural metal, wood, plasterboard, cables) will be removed for management off site, and penetrations through below-ground boundary structures sealed as necessary.

   - Above-ground structures will be demolished and the arisings emplaced in the voids formed by the in-situ below-ground structures. Demolition waste from existing rubble stockpiles will be used to fill any remaining void space and provide a level surface to support emplacement of engineered caps to cover the disposals. The caps will be covered with locally derived soil to encourage habitat development.
- Decommissioning and removal of other remaining structures to at least 1 m below ground level. Decommissioning and removal of the ALES facility and the Sea Discharge Pipeline, and appropriate off-site disposal of the waste generated. Voids will be profiled or backfilled to prevent subsidence hazards. Remaining sub-surface structures will be covered with local soil to encourage heathland development.
- Appropriate management of any radioactively-contaminated ground to ensure that the remaining land is out-of-scope (OoS) of RSR, including remediation of the former A59 area of the site.
- Appropriate management of non-radioactively contaminated land and groundwater based on an appropriate risk assessment and options appraisal.
- Suitable decommissioning of site drains to prevent flow paths developing and to restore the site's natural hydrological function.
- Creation of a valley mire to manage surface water, reduce flow from the site to the River Frome and associated downstream flood risk, and encourage development of sustainable habitats.
- Establishment of conditions that encourage development of heath, grassland and mire habitats. Removal of non-native trees.
- Removal of surface features including car parks, roads, most fences and certain footpaths.
- Stewardship of the site, including environmental monitoring and passive habitat management, for approximately 30 years after the IEP, with the site surveillance and monitoring data used to build confidence that the disposals behave as anticipated.

Figure E.2: Existing and proposed view of the SGHWR (left) and Dragon (right) disposals at the site end state, following demolition and installation of an engineered cap.

SWESC Objective and Scope

E13 This version of the Site-Wide Environmental Safety Case (SWESC) for the Winfrith site supports the permit variation application to the EA to allow on-site disposal of radioactive waste. It also provides a central reference for other permissions that are required in connection with on-site disposal, including the accompanying application to the EA for a DfR permit.

E14 A SWESC is 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"*. This SWESC presents claims with supporting arguments and evidence to demonstrate that the proposed site end state meets the five principles and fifteen management and technical requirements set out in the GRR, and shows how people and the environment will be protected from radiological and associated non-radiological hazards, both now and in the future.

E15 The SWESC scope considers the environmental safety (safety of people and the environment) of the entire Winfrith permitted site and takes account of the influence of the adjacent Tradebe Inutec nuclear licensed site. It assesses the safety at present and in all future states of the site, including after the IEP and for thousands of years after the SRS. It addresses management of both radiological and non-radiological hazards in the context of environmental protection in order to support all required regulatory applications. As well as the GRR, this SWESC supports demonstration of compliance with:

- Groundwater and surface water protection under Schedules 22 and 21 of EPR16.
- Management of non-radiological wastes and material (recovery and re-use) under EPR16.
- Nuclear site licence conditions relevant to environmental protection and land quality management.

Environmental Safety Claims, Arguments and Evidence

E16 Safety (that is, adequate and optimised protection of workers, the public and the environment from hazards) is central to all activities and operations on the Winfrith site, including development of the end state. This SWESC demonstrates that the Winfrith site, including the proposed on-site disposals, meets the regulatory requirements for protection of people and the environment from radiological and non-radiological hazards during the period of RSR and beyond. It is structured around a set of claims and arguments for delivery of a safe, optimised end state, followed by a summary of the evidence, with reference to more detail in supporting reports. The five claims made and underpinned in this SWESC are:

- **Sound Management:** All operations, including work contributing to this SWESC and implementation of the disposals, are and will continue to be undertaken within a sound management framework and positive environmental safety culture. These management arrangements will ensure a structured, transparent and traceable implementation of the proposed end state. This will be delivered in accordance with emplacement acceptance criteria, construction quality assurance plans and stewardship arrangements, and will systematically manage unexpected conditions. The management arrangements also ensure effective leadership, sufficient resources, a commitment to continuous learning, and enduring knowledge management.
- **Undertaking Dialogue:** There has been frequent engagement with regulators, local communities and other relevant stakeholders in an open and inclusive manner to define

the next land use and develop proposals for the end state, on-site disposals and the SWESC. Engagement with relevant stakeholders will continue throughout end state implementation and up to the SRS.

- **Disposal System Understanding:** The wastes and the end state conceptual design proposed for on-site disposal, their surroundings (geosphere and biosphere) and future evolution are sufficiently understood for the purpose of assessing and demonstrating environmental safety. Where uncertainty exists, a structured uncertainties management methodology has been used to develop a forward programme with the aim of improving the understanding of the disposal system as decommissioning proceeds.
- **Optimisation:** Strategic options assessments have demonstrated that the preferred approach of disposing of radioactive wastes on the Winfrith site as part of the site end state is optimised. This end state presents the best overall approach when assessing a range of safety, environmental and social factors relating to management of wastes generated on the site. Evaluation of specific waste management and design options for the on-site disposals to optimise their configuration is ongoing and will continue until their implementation.
- **Demonstration of Environmental Safety:** Methodologies have been developed to cautiously and proportionately assess the risks to humans and the environment from the proposed end state, both during and after release of the site from RSR. These assessments show that the potential risks are compliant with regulatory requirements, including quantitative criteria, and that the proposed on-site disposals will not result in appreciable impacts beyond those caused by background levels of radioactivity and contaminants in the environment.

E17 The SWESC will be maintained until the site is released from RSR, with updated versions being issued at key points in the site lifecycle and as needed to support further regulatory applications.

Contents

Glossary and Acronyms

Note that in the descriptions below, bold text upon first mention is used to identify terms or acronyms defined elsewhere in this glossary.

ADR	Alternative Discharge Route
ALARA	As Low As Reasonably Achievable
ALES	Active Liquid Effluent System
AOD	Above Ordnance Datum
APC	Area of Potential Concern
Assessment Case	A calculation undertaken to consider a specific evolution of the disposals. A **scenario** can encompass one or more assessment cases.
BAT	Best Available Technique
BEIS	Department for Business, Energy and Industrial Strategy (now superseded by DESNZ)
BGS	British Geological Survey
CCE	Cautious, central estimate
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CEMP	Construction Environmental Management Plan
Component	A part of a **feature** for which a separate inventory is derived, such as individual rooms, the tritium ingress component of general building contamination, etc.
CQAP	Construction Quality Assurance Plan
CSM	Conceptual Site Model
DC	Dorset Council
DCC	Dorset County Council: Former authority, now part of the DC unitary authority
DESNZ	Department for Energy Security and Net Zero
DfaP	Disposal for a Purpose: Infilling unwanted voids with radioactive waste. Defined in the **GRR** as “On-site disposal of solid radioactive waste by permanent deposit where, if radioactive waste were not available, other materials would have to be found to fulfil the purpose”.
DfR	Deposit for Recovery
DGL	(GRR) Dose Guidance Level
DIP	Dorset Innovation Park

Dose Pathway	A broad mechanism or process that could lead to RPs potentially receiving a radiation dose. For example, migration of radionuclides from a source or natural disruption of a source.
DPUR	Dose per Unit Release – factors used to convert radionuclide fluxes to the biosphere to dose to members of the public.
DQO	Data Quality Objective
DQRA	Detailed quantitative risk assessment (in the context of hydrogeological risk assessment)
DWS	Drinking Water Standard
EA	Environment Agency
EAC	Emplacement Acceptance Criteria
EAST	External Active Storage Tanks
EIA	Environmental Impact Assessment
EIADR	Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999
EQS	Environmental Quality Standard
EPA90	Environmental Protection Act 1990
EPR16	Environmental Permitting Regulations 2016 (as amended)
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
ES	Environmental Statement
ESC	Environmental Safety Case - The collection of arguments, provided by the developer or operator of a disposal facility that seeks to demonstrate that the required standard of environmental safety is achieved (also see SWESC).
Feature	Discrete contaminated structure or area, composed of one or more **components**. For the SGHWR, features include Region 1 (which includes the mortuary tubes, primary containment and the ponds components), the bioshield, Region 2 (including the secondary containment and ancillary areas components). For the Dragon **reactor complex**, features include the bioshield, reactor building and primary mortuary hole structure.
FEP	Features, Events and Processes
FML	Flexible Membrane Liner
FP	Forward Programme
GCL	Geosynthetic Clay Liner
GIM	Generic Intrusion Methodology
GIS	Geographical Information System
GPLC	Guiding Principles for Land Contamination

GQRA	Generic quantitative risk assessment (in the context of hydrogeological risk assessment)
GRR	A guidance document produced by the UK's environment agencies, with the full title "Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from **RSR**".
GWDD	Ground Water Daughter Directive
GWDTE	Groundwater Dependent Terrestrial Ecosystem
ha	hectare
HRA	Hydrogeological Risk Assessment (the non-radiological risk assessment)
HTR	High Temperature Reactor
Human intrusion	Any human action that accesses the waste or that damages a barrier providing an environmental safety function after the release from RSR. In the case of inadvertent human intrusion, such actions are unintentional.
HVA	(A59) Heavy Vehicle Airlock
IA	Independent Assessment
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEP	Interim End Point. The point in time at which the Winfrith IES is achieved.
IES	Interim End State. The condition of the Winfrith **site** following all physical decommissioning and clean-up activities required to make the land suitable for the next planned use of the site (but an environmental permit or other restrictions remain in force).
In-situ disposal(s)	(Of redundant below-ground radioactive structures) On-site disposal of solid radioactive waste, such as a buried structure, by leaving it permanently in position, together with any necessary preparatory works.
ISAM	Improvement of Safety Assessment Methodologies for Near-Surface Disposal Facilities
LLWR	Low Level Waste Repository
LOD	Limit of Detection
LQM	Land Quality Management
LQR	Land Quality Register
LTP	Lifetime plan
m agl / bgl	metres above / below ground level
MCM	Minimum Critical Mass

MoD	Ministry of Defence
MSS	Master Summary Schedule
National Landscapes	Replaced “Areas of Outstanding Natural Beauty” in England and Wales in 2023.
NDA	Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency
NIA65	Nuclear Installations Act 1965
NIGLQ	Nuclear Industry Group for Land Quality
NRS	Nuclear Restoration Services
NVC	National Vegetation Classification
NWAT	(EA) Nuclear Waste Assessment Team
OECD	Organisation of Economic Co-operation and Development
ONR	Office for Nuclear Regulation
On-site disposal	On-site disposal encompasses both **in-situ disposal** and disposal for a purpose (**DfaP**).
Out of Scope / OoS	Material or waste with a level of radioactivity such that it is deemed to be non-radioactive and not subject to regulation under **RSR**.
PA	Performance Assessment (the radiological risk assessment)
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PDC	Purbeck District Council: former local council, now part of the DC unitary authority
PGPC	Purge Gas Pre-Cooler
PIE	Post Irradiation Examination
PSA	(A59) Pressurised Suit Area
QA	Quality Assurance
Radioactive waste	Radioactive material that is no longer of use.
Radioactive material	Material in which the concentrations of radionuclides are greater than the values specified in RSR. Excludes material lawfully disposed of as waste or contaminated ground that remains where it was contaminated.
RCP	Representative Concentration Pathway
Reactor complex	The group of buildings and other structures associated with the Dragon reactor remaining on the Winfrith **site**.
Reference Case	The **assessment case** considering the expected evolution of the Winfrith site as based on current understanding of the

	proposed on-site disposals, site characteristics, and the surrounding region.
Restricted use	Controls over a site that contribute to radiological protection of people and the environment.
RGL	(GRR) Risk Guidance Level
RMP	Restoration Management Plan
RP	Representative Person. The **GRR** defines an RP as "an individual receiving a dose that is representative of the more highly exposed individuals in the population" and notes that it is "equivalent of, and replaces" the previously used terms "average member of the critical group" and "potentially exposed group".
RQ	Risk Quotient
RSR	Radioactive Substances Regulation. A generic term used by the environment agencies. In England, radioactive substances regulation is under the **EPR16**.
RSRL	Research Sites Restoration Limited
RT	Radionuclide Transport
RWC	Reasonable worst case
RWMC	(NEA) Radioactive Waste Management Committee
SAC	Special Area of Conservation
SCC	Site Closure Committee
Scenarios	Descriptions of alternative possible evolutions of the disposal system, representing structured combinations of **FEPs** relevant to the performance of the disposal system.
SES	Site end state - The condition of the entire site (including the land, structures and infrastructure) once decommissioning and clean-up activities have ceased.
SGHWR	Steam Generating Heavy Water Reactor
Site Reference State	State of the site marking the boundary between the period of restricted use of a site and a subsequent period of unrestricted use.
SIMP	Staged Inventory Management Plan
SOCI	Statement Of Community Involvement
SPA	Special Protection Area
SQEP	Suitably Qualified and Experienced Person
SRS	Site Reference State
SSE	Scottish & Southern Electricity
SSoW	Safe System of Work

SSSI	Site of Special Scientific Interest
SWESC	Site-Wide Environmental Safety Case. A documented set of claims to demonstrate achievement by the site as a whole of the required standard of environmental safety.
SWMMP	Site Wide Materials Management Plan
SWP	Safety Working Party
TCPA	Town and Country Planning Act 1990
TCE	Trichloroethylene
TPH	Total Petroleum Hydrocarbon
UKAEA	United Kingdom Atomic Energy Authority
UKCP	UK Climate Projections
UMD	Uncertainties Management Database
UMM	Uncertainties Management Methodology
UMP	Uncertainties Management Plan
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
Validation monitoring	Monitoring to confirm that the state and behaviour of the site is in accordance with the assumptions of the SWESC. Validation monitoring is carried out by the permit holder and may continue for a period after the end of all planned work on site involving radioactive substances.
WaFD	European Water Framework Directive
WER2017	Water Environment (Water Framework Directive) (England and Wales) Regulations 2017
WESTG	Winfrith End State Tactical Group
WFD	Waste Framework Directive
WHO	World Health Organisation
WMP	Waste Management Plan
WSSG	Winfrith Site Stakeholder Group

Winfrith Site: Site-Wide Environmental Safety Case

1 Introduction

1.1 Background

1 The Winfrith nuclear site, located in Dorset (Figure 1.1), is a former nuclear power research and development site. Nine experimental reactors, each with a unique design, and associated laboratories were developed and operated on the site between 1957 and 1995. The site, owned by the Nuclear Decommissioning Authority (NDA) and operated by Nuclear Restoration Services (NRS)[1], is currently being decommissioned.

Figure 1.1: Map of the region surrounding the Winfrith site (developed using OS OpenData January 2024 release © Crown copyright). The red star denotes the approximate location of the site.

2 The site is located partially within nationally and internationally important heathland habitat, which encompasses a range of acidic heath and mire ecological communities. The valley of the River Frome lies to the north-east of the site and the River Win, a tributary of the Frome, runs close to the southern boundary of the site.

3 NRS engagement with local stakeholders since 2006 has identified the preferred next planned land use of the site as heathland with public access of amenity value to the local community. In accord with stakeholder views, NRS intends to decommission the remaining facilities to provide a site end state suitable for heathland with public access.

4 The Winfrith site has been extensively decommissioned over a number of decades, with seven of the nine reactors and all of the active laboratories removed. The current aim is to reach the

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

Interim End Point (IEP) before 2040. The IEP is the point at which all physical decommissioning and waste management activities will be completed and public access to the site is planned. As part of this, all higher-activity radioactive waste is being removed from the site for storage and subsequent disposal in dedicated facilities elsewhere in the UK.

5 Key remaining site features include: the last two reactors, the Steam Generating Heavy Water Reactor (SGHWR) and the Dragon reactor complex (which both have substantial below-ground void spaces); the Active Liquid Effluent System (ALES) and associated Sea Discharge Pipeline; some areas of potentially radioactively-contaminated ground such as the former A59 area; and site infrastructure. Figure 1.2 highlights the on-site features and Figure 2.1 identifies the off-site route of the Sea Discharge Pipeline, which starts at ALES and travels underground to the south coast.

Figure 1.2: Aerial view of the Winfrith site with key features marked.

6 Activities involving radioactive substances in England are regulated by the Environment Agency (EA), under the Environmental Permitting (England and Wales) Regulations 2016 (EPR16) [1] and as amended [2; 3; 4; 5]. The environmental permit for the Winfrith site specifies what radioactive substances activities are allowed. Release from radioactive substances regulation (RSR)[2] cannot take place until the EA is satisfied that all activities involving radioactive substances and any disposals of radioactive waste (solid, liquid or gaseous) on or from the site have ceased, and that the site is in a state that will ensure a satisfactory standard of protection for people and the environment. Relevant regulatory guidance was published in July 2018 in the *Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from Radioactive Substances Regulation* (referred to here as the GRR) [6]. The environment agencies define the term Site Reference State (SRS) in the GRR

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

as the condition of a nuclear site when it is fully compliant with the requirements for release of the site from RSR.

7 As stipulated in the site's RSR Permit [7] and consistent with the GRR, the EA requires NRS to prepare and maintain throughout the lifecycle of the permitted site:

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

8 In broad terms, the SWESC demonstrates the environmental safety of the site, both before and after release from RSR, whilst the WMP [8] sets out a plan for waste management activities leading to release of the site from RSR and demonstrates that such activities have been optimised. As stated in the GRR [6, ¶1.6.3], the WMP and SWESC each provide the means by which the operator should demonstrate compliance with the environment agencies' requirements both during and after RSR of the site.

9 The Winfrith WMP and SWESC will be maintained through the remainder of the site lifecycle in accordance with management system requirements [9]. The documents will be updated at significant milestones, at routine intervals and prior to achieving the SRS. The activity to maintain these documents has been included in the Winfrith forward programme. Where further work is identified in this SWESC, the actions for the forward programme are indicated using a "FP.x" numbering system and bold text (as in the case below). The requirements are then summarised in Chapter 8.

FP.1 Maintain a WMP and SWESC for the lifetime of the Winfrith site RSR permit.

10 This version of the SWESC for the Winfrith site has been produced to support a permit variation application for on-site disposal of solid radioactive waste, as described in Section 1.2. The SWESC has also been developed to support regulatory applications for other permissions that are required in connection with on-site disposal.

1.2 Purpose and Scope of the Permit Application

11 This SWESC supports an application to vary the site RSR Permit under the terms of Schedule 23 of EPR16 to allow disposal in-situ and for a purpose of radioactive wastes on site (referred to here as a GRR variation). In addition, the SWESC will support applications for a Deposit for Recovery (DfR) Permit[3] and planning consent to implement the proposals.

12 The GRR [6] requires operators to assess different options for the disposal of radioactive waste arising from decommissioning, including on-site disposal options[4]. Following options analysis and stakeholder engagement, on-site disposal has been identified as the preferred option for

[3] This SWESC supports two permit applications under EPR16 to enable the proposed end state. Where reference is made to the "permit application", the text applies to both applications, but the prefixes RSR or DfR are stated where the text applies to only one of the permit applications.

[4] On-site disposal encompasses both in-situ disposal (on-site disposal of solid radioactive waste, such as a buried structure, by leaving it permanently in position, together with any necessary preparatory works) and disposal for a purpose (on-site disposal of solid radioactive waste by permanent deposit where, if radioactive waste were not available, other materials would have to be found to fulfil the purpose).

managing radioactive structures associated with the SGHWR and Dragon reactor complex (see Figure 1.3) [10]. It is proposed that:

- the below-ground portion of the SGHWR reactor building is disposed of in-situ, with the above-ground portion demolished and the resulting concrete demolition arisings used to fill the below-ground voids;
- the below-ground portion of the Dragon reactor building is disposed of in-situ, with the above-ground portion demolished and the resulting concrete demolition arisings used to fill the below-ground voids;
- the floor slab of the neighbouring Dragon fuel storage building (B78) is disposed of in-situ, with the remainder of the building structure demolished and the resulting concrete demolition arisings used to fill the Dragon reactor below-ground voids;
- the Dragon used fuel (primary) mortuary holes, set in the Dragon fuel storage building floor, remain in place and are backfilled with cementitious material;
- radioactive and non-radioactive demolition arisings from the existing rubble stockpile of historically decommissioned site facilities are used to infill any remaining below-ground voids in the SGHWR and Dragon reactor buildings; and
- engineered caps are installed above the in-situ disposals and covered with locally derived soil to encourage habitat development.

13 Figure 1.3 shows historical photos of the constructed SGHWR and Dragon reactor complex and Figure 1.4 shows the substantial excavations below-ground. The status of facility decommissioning is summarised in Section 2.2 whilst Section 5.1 describes the SGHWR and Dragon reactor complex features proposed to be disposed of on-site. Figure 1.5 shows the SGHWR and Dragon reactor complex in their present state and the proposed view following demolition, in-situ disposal of the existing below-ground structure and installation of an engineered cap.

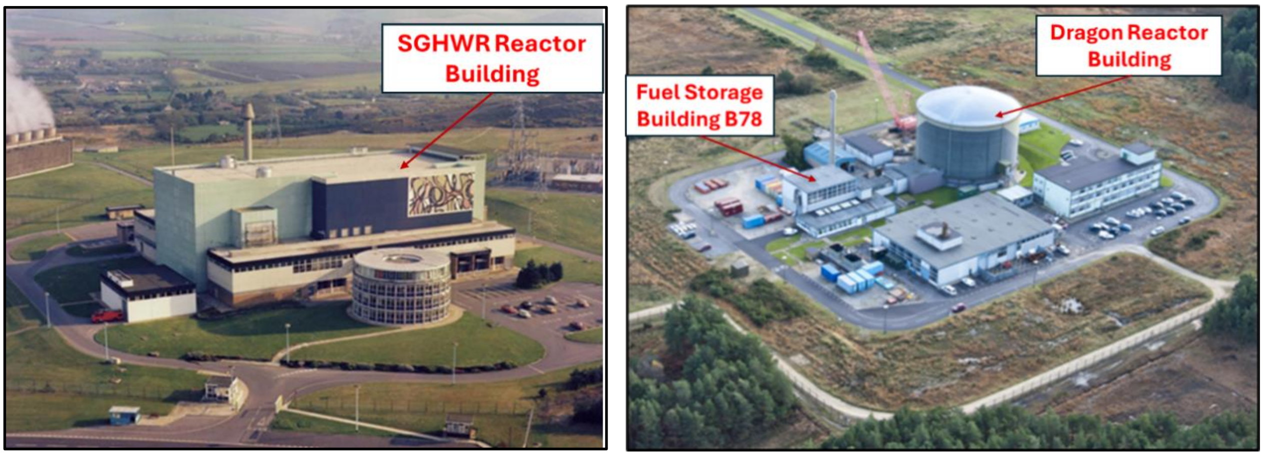

Figure 1.3: Historical photos of the SGHWR and Dragon reactor complex prior to any decommissioning.

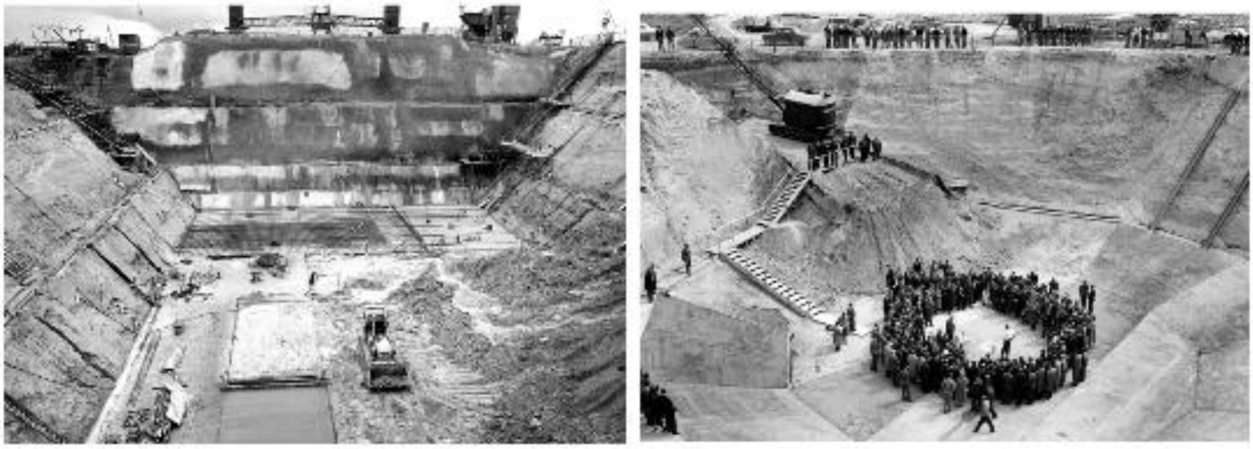

Figure 1.4: Substantial below-ground reactor excavations: SGHWR (left) in the 1960s and the Dragon (right) inauguration ceremony in 1960.

Figure 1.5: Existing and proposed view of the SGHWR (left) and Dragon reactor complex (right) at the site end state, following demolition and installation of an engineered cap.

14 Options assessments have been completed on all other remaining buildings, structures and contaminated land on the site. These assessments have demonstrated that the preferred management approach to all other buildings, structures and contamination is management off-site. A summary of the process, reasoning and output is provided in the WMP [8]. Therefore, the following materials and wastes do not form part of the permit application for on-site disposal because they will be removed for off-site management and disposal elsewhere:

- all higher-activity radioactive waste;
- plant, equipment and ancillary items including bulk asbestos, accessible non-structural metalwork, and other recoverable materials and wastes removed from the SGHWR and Dragon reactor complex buildings; and

- all other radioactive features, including radioactively contaminated structures, infrastructure and land – this includes contaminated land at A59, the ALES facility, contaminated on-site drains and the Sea Discharge Pipeline

15 To deliver the proposed site end state landscaping activities to remove non-native trees, manage surface water and encourage heathland habitat regeneration and biodiversity net gain will be undertaken, as defined in the Restoration Management Plan (RMP) [11]. The RMP has been developed to support the Environmental Permit applications and the associated planning application under the Town and Country Planning Act (TCPA) [12] and Environmental Impact Assessment (EIA) regulations [13], which will be submitted to Dorset Council.

16 Additional RSR permit variations will be sought in the future, as necessary to support waste management activities.

1.3 Purpose and Scope of this SWESC

17 The GRR defines a SWESC as [6, §C2]:

> *"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. Where relevant, the SWESC includes the environmental safety case for any on-site disposal facility. The SWESC also takes account of contributions to the combined impact on representative persons from adjacent nuclear sites, and from areas of contamination and previously permitted disposals outside the site."*

18 The GRR [6, §4.2] requires that the SWESC demonstrates consistency with the GRR principles and shows that the fifteen GRR management and technical requirements are met. The SWESC must be sufficiently comprehensive and robust to provide adequate confidence in the environmental safety of the site. In particular, the operator is expected to demonstrate through the SWESC how the site meets the regulatory requirements for protection of people and the environment from radiological and the associated non-radiological hazards, both now and in the future.

19 The scope of the SWESC outlined in the GRR [6, §4.3] includes:

- *"…the claims, arguments and evidence needed to support an application for release from RSR"* by demonstrating the environmental safety of:
  - *"the present condition of the site, and site conditions that might occur before eventual release from RSR"*, and
  - "*future conditions of the site after release from RSR"*.
- *"…take account of all radioactive substances (whether disposed waste or contaminated ground or groundwater) remaining on and adjacent to the site".*
- *"…describe all aspects of the site setting and conditions that may affect environmental safety".*
- *"…include quantitative environmental safety assessments for both the period of RSR and afterwards".*
- *"…take into account the potential consequences of climate and landscape change".*
- *"…consider the possibility and consequences of a criticality event".*

20 It is important to note that in addressing this scope, the GRR highlights that the "*operator should maintain a SWESC whose complexity is proportionate to the hazards involved"* [6, ¶4.3.8].

21 This SWESC presents or references claims, arguments and evidence to demonstrate that the Winfrith site meets the regulatory requirements regarding environmental protection. The SWESC considers the environmental safety of the entire Winfrith permitted site, including the associated infrastructure that is currently used for authorised gaseous and liquid effluent discharges. The SWESC also takes account of the influence of the adjacent Tradebe Inutec nuclear licensed site.

22 The SWESC covers the present and future states of the site, including after all physical decommissioning and remediation work is completed (i.e. the IEP). Thus, the SWESC considers the present-day radiological impacts of authorised discharges and features such as ALES and gaseous and liquid discharge points that will not be present in the future.

23 Although the SWESC is required by the GRR, which is concerned primarily with management of radioactively-contaminated material, this SWESC covers management of both radiological and non-radiological hazards in the context of environmental protection in order to support the GRR application and ensure a holistic assessment of risks. Requirements additional to the GRR that are considered in this SWESC include:

- surface water and groundwater protection under Schedules 21 and 22 of EPR16;
- management of non-radiological wastes and material (recovery and re-use) under EPR16; and
- nuclear site licence conditions relevant to environmental protection and land quality management.

24 As noted above, the SWESC will be maintained until the site is released from RSR, with updated versions issued at key points in the decommissioning programme and as needed to support regulatory applications. This SWESC supersedes previous versions produced in 2017 [14] and 2019 [15] and, along with the other supporting documents (Section 1.4), has been produced to support the application to the EA to vary the Winfrith RSR permit to allow on-site disposal of radioactive waste and DfR activities at SGWHR and the Dragon reactor complex.

25 The information presented in this issue of the SWESC is not intended to be the final position. As a live document, the SWESC will evolve as the site is decommissioned and disposals are implemented. Only the SWESC that informs the permit surrender decision at the SRS will contain the final position on all topics, with that version collating all engineering, characterisation and monitoring evidence to demonstrate the safety of the implemented on-site disposals at the SRS. Maintenance of the SWESC is discussed in Section 3.4.11. Areas of future development are highlighted in the description of the forward programme (see Chapter 8). This issue of the SWESC is considered fit for purpose, that is, it is at an appropriate stage of development to support an application to vary the extant RSR permit to enable on-site disposal.

1.4 Relationship to Other Documents

26 A suite of documents, headed by the SWESC and WMP and supported by a series of underpinning topic reports (Figure 1.6), have been produced to support the regulatory applications. The hierarchy of the documentation is as follows:

- Tier 0: A non-technical summary.
- Tier 1: The SWESC summarising the claims, arguments and supporting evidence (this document) and the WMP documenting the overall optimised approach to managing all radioactive substances on or adjacent to the site.

- Tier 2: Topic reports consolidating key information and key supporting reports with more detailed evidence to support the main arguments.
- Tier 3: Underpinning interpretative technical reports, reviews and management plans.
- Tier 4: Reports containing raw data, records for quality assurance purposes, third-party reports and scientific literature that are referenced in the SWESC.

27 The SWESC has been developed as a single overarching document encompassing the claims and arguments, with references to supporting documents at a more detailed level where necessary. It is written such that it is stand-alone with regard to all of the key claims, arguments and evidence required to demonstrate safety, but more detail can be found in the supporting references, which are clearly signposted.

28 The SWESC is supported by information provided within the WMP. The WMP [8], and accompanying WMP Appendix A spreadsheet [16], provide an overview of all existing waste, materials and land quality management arrangements for the site, and document the current plans for its management, for the remaining lifetime of the RSR permit. The WMP summarises or signposts to evidence that the preferred management approach for all radioactive wastes and contaminated ground is, or will be, optimised. The WMP presents information regarding the management of both non-radioactive and radioactive wastes, in order to present a holistic view of how wastes, materials and hazards present on the site are being and will be managed.

29 There is some overlap between the purposes of the WMP and SWESC, especially regarding demonstration of optimisation (GRR Requirements R1 and R13). The WMP is the primary source of evidence of optimisation of all types of waste over the lifecycle of the site, regardless of whether the waste is proposed to remain on site as part of the end state or not. The SWESC focusses on demonstration of an optimised end state and the safety of the proposed on-site disposals.

30 Key supporting reports for this issue of the SWESC include the following:

- **End State Radiological Inventory Report –** The Radiological Inventory Report [17] describes and quantifies the radiological inventory proposed to remain on the Winfrith site at the end state, together with the data and assumptions underpinning it.
- **Non-radiological Inventory Reports** – The inventory of non-radiological materials currently on-site is described in the site-wide Non-radiological Inventory Report [18]. An estimate of the water-available non-radiological inventory assumed to be present in the SGHWR and Dragon proposed disposals has also been produced [19, §3].
- **Site Description Reports** – The characteristics of the Winfrith site and local surrounding region, and the information necessary to support the development of the SWESC and the radiological and non-radiological risk assessments, are described in the Site Description Report [20] and the Hydrogeological Interpretation Report [21].
- **Staged Inventory Management Plan** – A staged radiological and non-radiological characterisation plan is set out in the Staged Inventory Management Plan (SIMP) [22], which describes the key gaps and uncertainties in inventory data and sets out future phases of characterisation.
- **Radiological Risk Assessment –** The radiological Performance Assessment (PA) [23] assesses the potential radiological risks to humans arising from the on-site disposals through natural evolution, direct radiation and inadvertent intrusion. Radiological risk to non-human organisms is also assessed.

- **Non-radiological Risk Assessment** – The potential impacts to groundwater from non-radiological hazards associated with the proposed on-site disposals are considered in a tiered Hydrogeological Risk Assessment (HRA) [24].
- **Design Substantiation Report** – The conceptual engineering designs for the proposed disposals at SGHWR and Dragon, including the functional requirements and how the designs support compliance, are described in the Design Substantiation Report [25].
- **Emplacement Acceptance Criteria** – The physical, chemical, radiological and biological limits for materials and wastes that can form part of the completed disposals are defined in the Emplacement Acceptance Criteria (EAC) [26].
- **Stewardship Plan** – The management and monitoring arrangements for the site through to the SRS to ensure the protection of people and the environment are detailed in the Stewardship Plan [27].

31 The supporting topic reports will be updated periodically as more information becomes available or is refined through the forward programme.

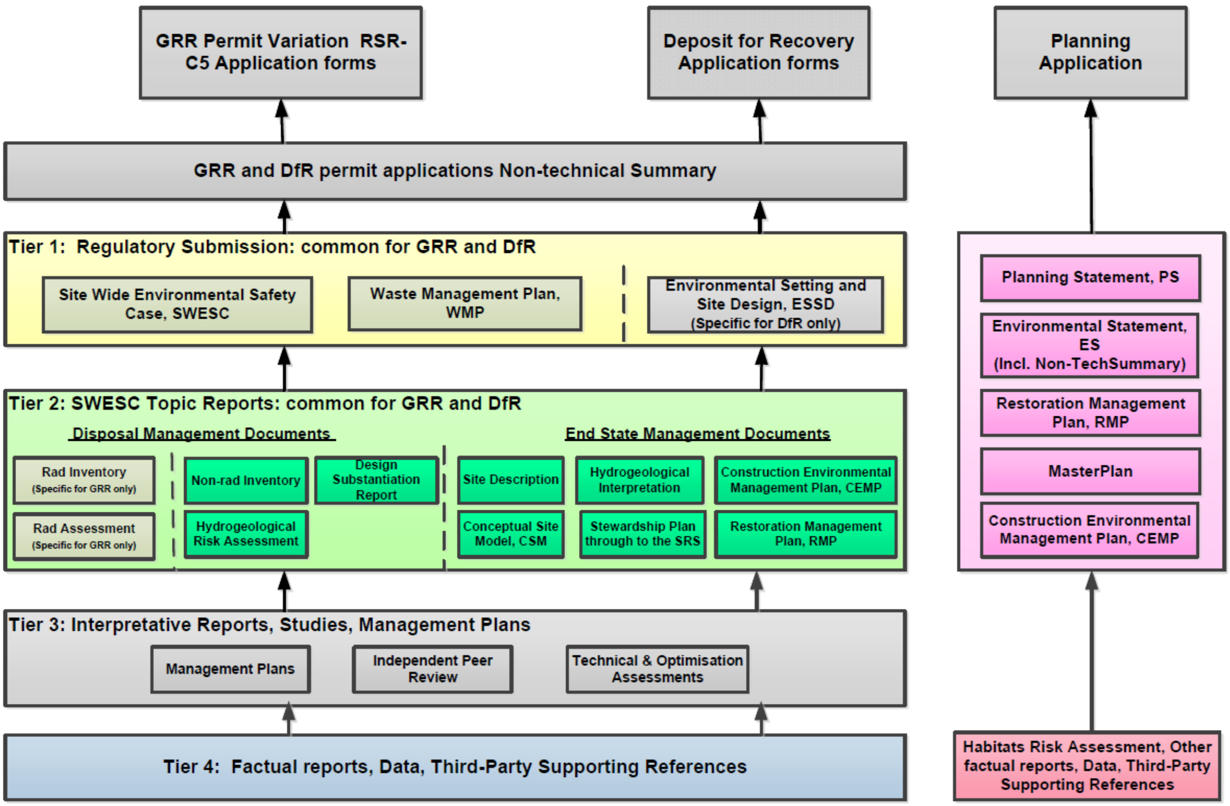

Figure 1.6: Winfrith end state RSR permit variation and DfR permit application document hierarchy.

1.5 Report Structure

32 The remainder of this document is structured as follows:

- Chapter 2 provides a description of the history and current status of the site (Section 2.1), summarises the remaining decommissioning plans (Section 2.2), and sets out the condition of the site at the IEP and at the SRS (Section 2.3).

- To aid traceability, the safety case claims are highlighted using purple boxes and their underpinning arguments are highlighted using numbered blue boxes. In Chapters 3 to 7 the arguments supporting each claim are numbered using the format M.x for management arguments, U.x for arguments related to undertaking dialogue, D.x for arguments related to disposal system understanding, O.x for arguments related to optimisation and S.x for arguments related to demonstrating environmental safety.
- Chapter 3 presents an overview of the safety strategy and management framework, and its underlying basis, that ensures **sound management (Claim 1)** and maintenance of a positive environmental safety culture.
- Chapter 4 discusses how an open and inclusive approach to engagement has been used in **undertaking dialogue (Claim 2)** with regulators, local communities and other relevant stakeholders.
- Chapter 5 demonstrates the **understanding of the disposal system (Claim 3)**, which is formed of the features for on-site disposal and their surroundings.
- Chapter 6 focusses on **optimisation (Claim 4)** of the strategic approach to decommissioning and waste management on the site, and optimisation of the concept designs to support the application for on-site disposal.
- The arguments and evidence in Chapter 7 **demonstrate that people and the environment are now, and will continue to be, adequately protected** from the radiological and non-radiological hazards remaining on or adjacent to the site **(Claim 5)**.
- Chapter 8 summarises the ongoing work to develop the material in this SWESC and address the regulatory requirements, collating the FP.x activities identified in Chapters 1 to 7.
- Chapter 9 concludes with collation of all the claims and associated arguments in this SWESC.
- Chapter 10 lists the references used in this report.
- Appendix A summarises the safety-related uncertainties with a significance rating of high identified in the development of the SWESC and included in the NRS Uncertainties Management Database (UMD).
- Appendix B sets out tables (“cross-walks”) mapping how the top-level regulatory requirements for environmental protection set out in key guidance and legislation are met by the material in this SWESC and underlying reports.

2 Description of the Winfrith Site

2.1 History and Present-day Description

33 The Winfrith site is located approximately four miles from the south Dorset coast, two miles west of the village of Wool, and ten miles east of Dorchester (Figure 2.1). Initially the site encompassed 129.4 ha; however, the eastern section of the site was delicensed and transferred to English Partnerships in 2004. This area has now been developed, along with additional adjacent land, as a science and technology park known as the Dorset Innovation Park (DIP). In addition, the Tradebe Inutec nuclear licensed site is adjacent to the eastern boundary of the Winfrith site [28; 29]. The remaining 83 ha Winfrith nuclear site is enclosed by a perimeter fence (Figure 2.2). However, only 70 ha of this falls under the nuclear site licence issued by the Office for Nuclear Regulation (ONR) under the Nuclear Installations Act 1965 [30]. Land covered by the RSR permit [7] extends beyond the perimeter fence as shown in Figure 2.3. The boundaries of the regulated areas for the RSR permit and the nuclear site licence, and the land owned by the NDA, are slightly different and the term “site” is used generically in this report to cover all three cases, unless otherwise specified. The definition of “site” in the definition of the SWESC (see the Glossary) refers to the site specified in the RSR permit.

34 In addition to the main site, there is a 14 km long Sea Discharge Pipeline that runs roughly south-southwest from the site into the English Channel at Arish Mell near Worbarrow Bay. The terrestrial section of the Sea Discharge Pipeline is 9.3 km long (Figure 2.1) and runs beneath farmland and a section of the Ministry of Defence (MoD) Lulworth and Bovington tank firing range, as well as Lulworth Estate Parks and Gardens. The RSR permit includes the route of the Sea Discharge Pipeline.

35 The mainline London Waterloo – Weymouth railway line runs along the northern edge of the site. The valley of the River Frome, a major chalk stream in southern England, lies to the north of the railway line, and the River Win, a tributary of the Frome, runs close to the southern boundary of the site (Figure 2.2).

36 The site is located partially within the Winfrith Heath Site of Special Scientific Interest (SSSI), and partially within the Tadnoll and Winfrith Heath nature reserve, an internationally significant conservation area which also encompasses the adjacent wetland Ramsar site [31]. The 185 ha Winfrith Heath SSSI is a substantial and varied tract of heathland near the western limit of the Dorset Heaths Special Area of Conservation (SAC) encompassing a range of heath and mire ecological communities. The area supports a diverse population of nationally rare plant, insects, animal and bird life, including nightjar, Dartford warbler, silver studded blue butterfly and all six species of native reptiles.

37 The route of the Sea Discharge Pipeline runs through the Dorset National Landscape, the Lulworth Park and Gardens and the South Dorset Coast SSSI [32]. Arish Mell is incorporated in the Isle of Portland to Studland Cliffs Special Area of Conservation (SAC). The coastline across Dorset and East Devon, including Worbarrow Bay, is part of the Jurassic Coast UNESCO World Heritage site.

38 There are a number of residential and commercial properties less than 1 km from the site [33, §6.1]. Five residential properties are located to the north of the site, the DIP is located to the east of the site, and to the south of the site in the village of East Knighton there are several farms, residences and businesses. The Tadnoll and Winfrith Heath Nature Reserve covers most of the area to the west of the site, where cattle graze all year round.

39 Constructed from 1957 and officially opened in 1961, the Winfrith nuclear site was a centre for reactor research, design and development, housing nine unique experimental and prototype reactors over its lifetime [34]. The Winfrith site also had facilities for nuclear fuel manufacture and examination and other experimental laboratories, as well as waste treatment and storage facilities. Decommissioning of the site started in the 1990s, and the last operational reactors, NESTOR (Neutron Source Thermal Reactor) and DIMPLE (Deuterium Moderated Pile of Low Energy), were shut down in 1995 [34, p.10]. The remaining reactor fuel was removed from the site in 1995.

40 The two most well-known reactors on the Winfrith site, Dragon and the SGHWR, became operational in the 1960s [34, p.8]. The Dragon reactor was a prototype 20 MW high-temperature helium-gas-cooled experimental reactor, built and managed as part of an Organisation of Economic Co-operation and Development (OECD) project to develop high temperature reactors (HTR) and to develop graphite-coated uranium-thorium fuel cycle technology. The SGHWR was a 100 MW light-water cooled and heavy-water moderated reactor that supplied electricity to the national grid from 1968 to 1990 and was the only Winfrith reactor to do so. The other seven research reactors, which have all now been decommissioned and removed from the site, were zero or very low power systems.

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

42 The locations of the major facilities on the site discussed in this SWESC are shown in Figure 2.2 along with neighbouring sites and the Rivers Frome and Win, located to the north and south-west of the site respectively. In addition to the SGHWR and Dragon reactor complex, key features to note in Figure 2.2 include the former A59 area, the ALES facility (which also marks the start of the Sea Discharge Pipeline), and Flume 1, which is the route of surface water discharge to the River Frome.

Figure 2.1: Ordnance Survey map showing the Winfrith nuclear licensed site (green outline) and the route of the Sea Discharge Pipeline (black line) [35]. The site and the route of the Pipeline form the area covered by the Winfrith RSR permit [7].

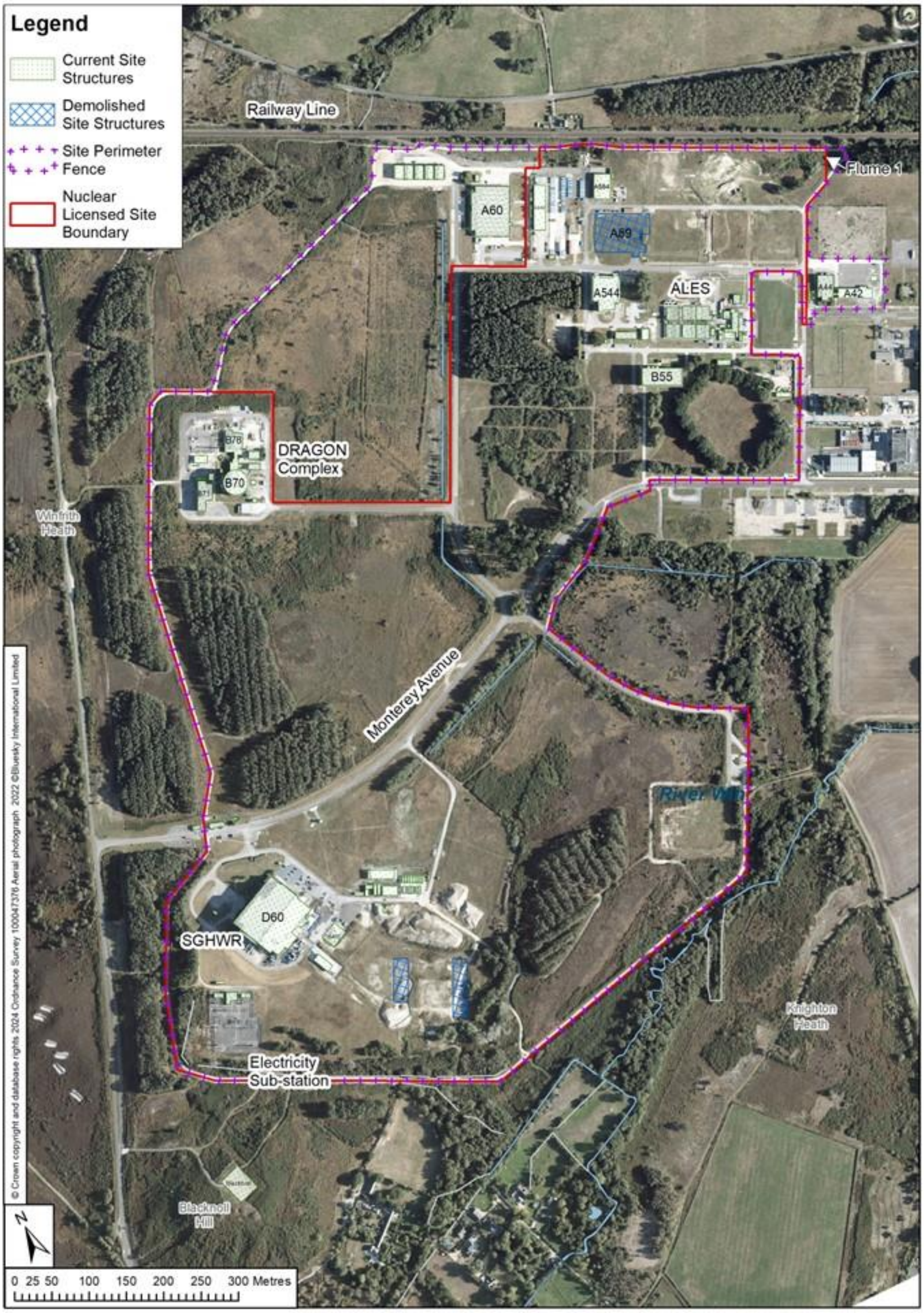

Figure 2.2: Aerial photograph (2022) with the principal features of the Winfrith site and its surroundings indicated, including current and demolished site structures [19, Fig.606/2]. The land and facilities labelled A50 and B4 correspond to the Tradebe Inutec nuclear licensed site.

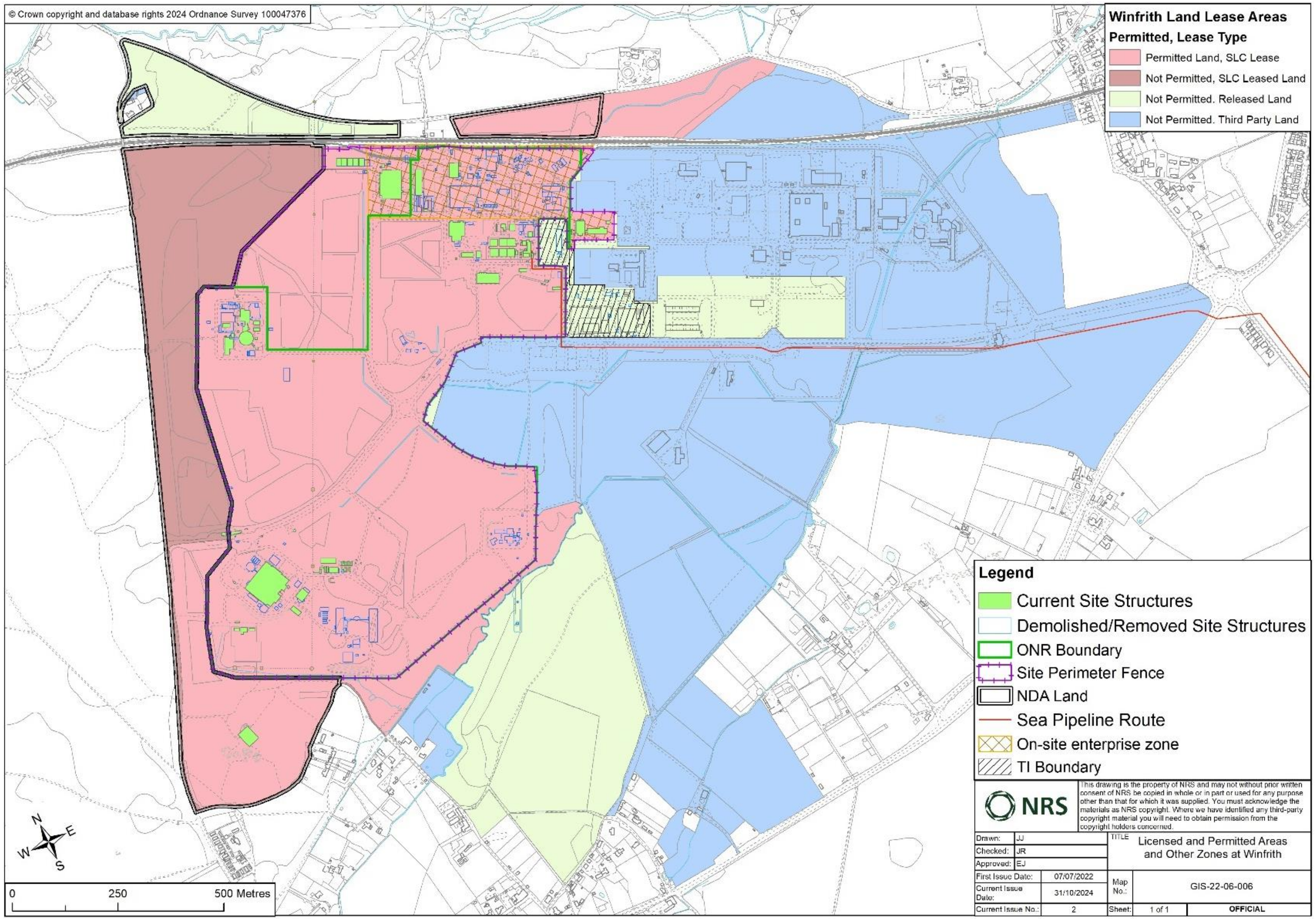

Figure 2.3: Licensed and permitted areas on the Winfrith site – the perimeter fence is denoted by the purple hashed line, the nuclear site licence by the green line (where it deviates from the purple line), and dusky pink shading denotes land covered by the RSR permit (including the Sea Discharge Pipeline, the route of which is shown in Figure **2.1**).

2.2 Decommissioning Plans

2.2.1 Overview

43 Decommissioning plans are required for nuclear sites under Condition 35 of the Nuclear Site Licence. The plan must be safe, deliverable and in accordance with policy, regulation and guidance. The NDA Strategy [36] sets the broad context for the approach to decommissioning. The NDA strategy prioritises hazard reduction to focus effort and resources on managing the highest hazard items and wastes as early as can be safely achieved, to progressively reduce the risk to operators and site security requirements. These requirements are reflected in the site-specific decommissioning plan. The original Winfrith site decommissioning plan was set out in 1990 as reactor and research operations ceased. More recently, this has become the LC35 decommissioning and waste management plan, reflected in the site Lifetime Plan (LTP). The LTP was issued in 2013 [37] with a forward strategy [38] provided in 2014. The LTP is maintained 'live' and progress is reported and updated monthly. Changes to the decommissioning plan must be carefully managed to ensure regulatory compliance, be optimised and be appropriately justified in a business case prior to being incorporated into the LTP.

44 Strategic options assessments have been completed to determine the decommissioning and waste management strategy for key features on the Winfrith site (e.g. SGHWR [39], Dragon reactor complex [40], A59 contaminated land [41], Sea Discharge Pipeline [42]) as well as the site as a whole (e.g. the End Point Specification [43]) (Section 6.2). Potential interactions between the individual features are considered in arriving at an optimised decommissioning plan for the entire site. The decommissioning plan and LTP have been updated to reflect the output of options assessments, as well as the evolving policy and regulatory framework.

45 The decommissioning strategy and programme prioritise hazard reduction to focus effort and resources on managing the highest hazard items and wastes as early as can be safely achieved, to progressively reduce the risk to operators and site security requirements.

46 This decommissioning plan has been successfully implemented at Winfrith for a number of decades with the successive removal from the site of nuclear fuel, seven former research reactors, all former experimental laboratory facilities, and the SGHWR pond water.

47 Decommissioning and waste management continue at present, with near-term works focused on removing the two remaining reactor cores (SGHWR and Dragon), packaging of the resultant wastes and transporting it off site. This will further reduce the hazard associated with the site.

48 Additionally, decommissioning, demolition and remediation operations continue across the site to manage ancillary facilities and services such as waste management facilities, the drainage network, contaminated land and the Sea Discharge Pipeline.

2.2.2 Enabling Activities

49 Enabling and construction activities are required across the site to allow safe delivery of the decommissioning plan and the end state. The key enabling activities include:

- Construction of a grout plant and curing facility to enable fabrication of suitable radioactive waste containers, and safe processing and packaging of wastes, on the site (with their subsequent disposal off-site at facilities elsewhere in the UK).
- Installation of portacabins and waste storage tents on the site as needed. As buildings are successively decommissioned and demolished, temporary additional and alternative accommodation is required for both work force and waste management activities.

- An Alternative Discharge Route (ADR) is required to manage radioactive effluent arisings from the remainder of the decommissioning activities, to allow decommissioning of the ALES and Sea Discharge Pipeline. Engineering alterations within SGHWR and the Dragon reactor complex have been completed to allow the on-site drainage network to be placed out of service; however, an alternative discharge route is still required.

2.2.3 SGHWR

50 The SGHWR commenced decommissioning after defueling was completed in 1992. Phase 1 decommissioning between 1992 and 2006 included:

- draining the cooling ponds and management of the associated effluent and sludge;
- decommissioning, removal and management of all secondary containment plant and equipment including the turbines and cooling-water infrastructure; and
- removal of all electricity generating infrastructure such as the turbine and alternator.

51 The sludges generated during operations which were stored in the External Active Storage Tanks (EAST) were grouted into 500 l drums and placed in storage. The final waste drums were removed for off-site disposal in March 2024 [44] and the EAST facility has now been decommissioned.

52 Phase 2 decommissioning commenced in 2012 with the aim of removing all remaining plant and equipment in the primary containment to allow retrieval of the core. Phase 2 is ongoing and work to date included:

- removal of the steam drums and heat exchangers;
- removal of the moderator (D_2O) system;
- licensing of the area as an asbestos enclosure to allow removal of the asbestos lagging boxes surrounding the core; and
- cutting of the primary circuit above and below the reactor core to isolate it and enable core retrieval.

53 Current and future SGHWR decommissioning works include:

- structural modifications to allow installation of core cutting equipment, including an under-core jack, and remote waste handling facilities; and
- cutting of the core, assay of the resultant wastes and packaging.

54 Once waste from the core removal has been packaged, grouted into containers and stored in the curing facility until the grout has set, it will be dispatched off-site for storage at the Harwell Interim Box Store, pending availability of the planned national Geological Disposal Facility.

55 Following completion of core retrieval and associated waste management, further characterisation and detailed design of the proposed SGHWR disposal can commence (see Section 5.1.1 for discussion of the SGHWR features proposed to remain in-situ). The detailed design and characterisation cannot start until core retrieval is complete as parts of the structure will be inaccessible prior to this point.

56 Once the detailed design, additional characterisation and any soft strip[5] is complete, implementation of the disposal can commence. Further information on the final stages of implementing the proposed SGHWR on-site disposal is provided in Section 5.1.3.

2.2.4 Dragon Reactor Complex

57 Phase 1 decommissioning of the Dragon reactor complex commenced after operations ceased in 1978. During Phase 1, significant plant and equipment from the reactor cathedral area (the area above the reactor core within the reactor primary containment) was decommissioned and disposed of off-site. Additionally, ancillary systems from the reactor were removed and disposed of off-site.

58 During the 1980s, several parts of the facility were re-purposed for waste processing or storage operations, including the storage of tritium dials (Betalites) pending onward management.

59 Several major items of plant and equipment were removed and managed off-site during the 1990s and 2000s, including the Fission Product Delay Beds.

60 Phase 2 decommissioning commenced in 2012 with the removal of the remaining equipment in the cathedral area and enabling works to allow core retrieval. All enabling works for core retrieval are now complete and core retrieval has commenced.

61 Following completion of core retrieval and waste management, further characterisation and detailed design in support of the proposed Dragon reactor complex disposal can commence. The proposed Dragon disposal includes the B70 Dragon reactor building below-ground structure and the connected B78 Dragon fuel storage building floor slab, which contains 50 primary mortuary holes within it (see Section 5.1.2 for further details). The detailed design and additional characterisation cannot start until core retrieval is complete as parts of the structure will be inaccessible prior to this point.

62 Once the detailed design, additional characterisation and any required soft strip are complete, implementation of the disposal can commence. Section 5.1.3 presents further information on the on the final stages of implementing the proposed Dragon reactor complex on-site disposal.

2.2.5 Minor Facilities and Structures

63 A number of minor buildings remain across the site, primarily associated with waste management operations, material storage areas or worker accommodation facilities. These buildings will be decommissioned once they are no longer required and suitable resource is available for demolition and waste management. Further details on the decommissioning plan for each zone of the site and the buildings contained therein can be found in the Winfrith End Point Specification [43].

64 Once decommissioning of each building is complete, these structures will be removed to at least 1 m below ground level and characterisation will be completed in accordance with the Winfrith Zone Close-out Process to demonstrate radioactive contamination levels are below out-of-scope (OoS) of RSR levels [43, App.A; 45, App.A] (see Section 5.3.2). Where necessary, remediation will be completed to ensure areas meet the End Point Specification [43].

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5 Soft-strip refers to the removal of non-structural items and materials from a building.

65 The minor facilities scope includes the ALES facility and the on-site drainage network. The ALES facility (Figure 2.4) will be decommissioned once the ADR is available (Section 2.2.2) and discharge operations via ALES cease. ALES decommissioning will entail removal of all plant and equipment, with suitable waste processing, followed by removal of any sub-surface contamination and demolition of above-ground structures. Below-ground structures will either be removed, if shallow, or suitably characterised and left in-situ with soil cover to at least 1 m depth.

66 The drainage network comprises both active and non-active drains. The active system includes drain lines, sump tanks and various pits across the site that feed into the ALES facility. The non-active drains include process drains, surface water drains and surface water soakaways. Most of the water from the on-site surface water drainage network flows to Flume 1, and then through a culvert beneath the railway into the Frome Ditch before reaching the River Frome (see Figure 2.2). The drains will be assessed and managed in accordance with the Drains Strategy [46]. Drains that are identified as contaminated will be excavated and managed off-site. Those drains satisfying the criteria as uncontaminated [46, §4] will be decommissioned and left in-situ. Decommissioning may include the blocking, or breakage, of drains to prevent water flow and enable a more natural hydrograph on-site.

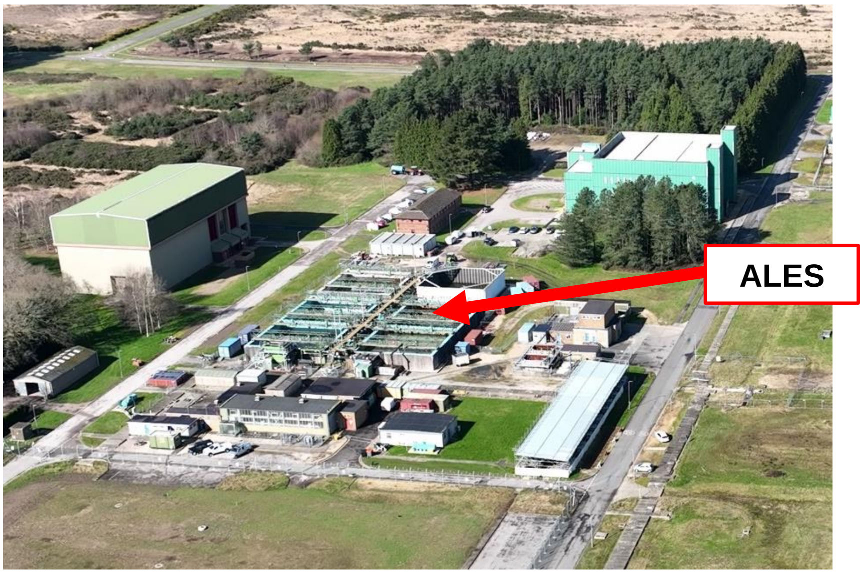

Figure 2.4: Aerial photograph of the ALES facility including the various delay tanks.

2.2.6 Land Quality Assessment and Remediation

67 A register of land and groundwater that is, or is suspected to be, radiologically and/or non-radiologically contaminated is maintained to record potential contamination through the lifecycle of the site [47]. Once decommissioning of minor facilities and structures is complete, the condition of the remaining land will be assessed in accordance with the End Point Specification [43]. All land areas identified as being potentially contaminated will be characterised, assessed against threshold values and site background values, and remediated as necessary to meet the End Point Specification. Any land that does not meet the End Point Specification will be removed and the waste generated managed off-site. The Land Quality Management (LQM) programme for the site is discussed in Section 5.3.2.

68 Options assessments completed to date have identified that all radioactively contaminated land will be remediated to OoS levels and so these areas are not considered in this SWESC. The

potentially radiologically-contaminated land in the A59 area (as indicated on Figure 1.2) will also be remediated sufficient to demonstrate that the remaining ground is OoS of RSR [48, §4; 49] and so does not form part of the permit application. However, as discussed later, there is the potential for combination of releases from the SGHWR disposal and A59 area. Therefore, the A59 area remains within the scope of the radiological risk assessment [23], albeit with a radiological inventory estimate that is OoS of RSR, in order to ensure a robust transparent assessment. In order to provide context to the risk assessment results, information about the A59 area and estimated remediated radiological inventory is included in this SWESC (Sections 5.2 and 5.4.3), but the A59 area is not part of the RSR permit application.

2.2.7 Blacknoll Reservoir

69 The Blacknoll Reservoir provided an emergency cooling water supply for the SGHWR during operations and is located outside the site perimeter fence (south-west corner of Figure 2.2). The Reservoir is a large concrete structure, with a one-million-gallon capacity, that is blended into the surrounding landscape (Figure 2.5); the immediate surrounding area has SSSI status and there are a number of bronze age tumuli in close proximity. The reservoir was emptied in the 1990s and is awaiting decommissioning. The decommissioning plan is to backfill the reservoir with suitable soil-based material to make the structure safe and leave in-situ [43, App.A]. There is no radiological inventory associated with the reservoir.

Figure 2.5: Photograph of the off-site Blacknoll Reservoir.

2.2.8 Sea Discharge Pipeline

70 The Sea Discharge Pipeline was installed in 1959/60 to provide a route for discharge of radioactive effluent arisings from site operations. The Pipeline is formed of four individual pipes (a pair of parallel carbon steel pipes each containing an inner pipe for more active effluent) that run 9.7 km from the site to Arish Mell on the English Channel and a further 3.7 km out to sea. Additionally, there are 12 valve pits and two ancillary structures, the Break Pressure Tank and Shore Valve House, along its length (Figure 2.1). The majority of the Pipeline is about 1.5 m deep, although some pipe sections are shallower and some are deeper [50] (Figure 2.6). For example, the sections beneath the MoD Lulworth and Bovington Firing Range had a minimum burial depth of 8 ft (at the time of construction) and some of the Pipeline in the firing range is

also encased in 2 ft-thick concrete. Above the Pipeline, current land use is a mixture of agricultural fields, roads and housing.

71 The decommissioning plan for the Sea Discharge Pipeline is to remove the entire Pipeline and ancillary structures [51], including the section beneath the Firing Range [52]. Further options assessments will be completed to determine how best to remove the Pipeline and the preferred management route.

Figure 2.6: Image showing the construction of the Sea Discharge Pipeline and its route through the gates of Lulworth Castle [50, Fig.2.2].

2.3 Site End State Vision and Specification

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

73 The NDA states that the site's end state is defined by *"the high-level remediation objectives of the site, considering the land's next planned use or probable futures"* [53]. The next planned use of a decommissioned nuclear site is influenced by the local environment and community views. The Winfrith site sits within an important and sensitive local environment, with nationally and internationally recognised heathland and wetland conservation areas. Engagement with local stakeholders identified the preferred next planned land use for the site as a heathland with public access, of amenity value to the community [54]. A consultation in 2006/2007 identified a 'Heathland Landscape' as the preferred option with the possibility of retaining some areas for commercial use in the north of the site. A further consultation in 2013 aimed at defining the end state in more detail [55] explored views around landscape and management options, finding a preference for restoration of the natural environment and protection of the site's flora

and fauna. Subsequent engagement (2018 - 2023) with the local community, local councils, the public, regulatory bodies and other site stakeholders further shaped the decommissioning strategy and the vision for the end state.

74 The Restoration Management Plan (RMP) [11] sets out the approach to creation and regeneration of a mosaic of acid grassland and heathland habitats on the Winfrith site. Following engagement with Natural England, Dorset Wildlife Trust, Dorset Council and the EA, the RMP sets an objective to restore the natural hydrological function of the site [11, §1.2]. The RMP describes the activities required to ensure that the site functions as required, once all active management systems have been removed. For example, the RMP provides information on the mitigations required to manage flood risk once the drainage network has been decommissioned (see Section 5.3.3). The RMP supports the planning application and has been developed with awareness of the risk assessments.

75 The planned status of structures, contamination and infrastructure at the IEP is set out in the End Point Specification [43]. The decommissioning plan and End Point Specification [43] support development of appropriate heath, grass and mire habitats to meet stakeholder expectations, and provide an end state suitable for heathland with public access. The End Point Specification describes, at a high level, the end state for each aspect of the site to ensure the next planned land use can be delivered. Table 2.1 summarises the currently intended interim end state for all site aspects, subject to detailed design development and future optimisation (as discussed in Chapter 6).

Table 2.1: Specification for the intended site end state. Adapted from [43, App.A].

Aspect	Description
Drains	Drains will be assessed for contamination in-situ and, where demonstrated as OoS, will be decommissioned and isolated to prevent flow paths developing and will remain in place. Drains that do not meet end state threshold values (radiological / non-radiological) will be removed and managed as waste.
Surface water	Isolate or remove artificial drainage to restore the natural hydrograph. Backfill land drains to encourage natural flood management, including decommissioning of the 48” main drain and Flume 1. Creation of a valley mire in the north-east of the site to mitigate surface water flood risk and prevent an increase in flood risk to neighbours (see Section 5.3.3 for more information on the proposed mire).
Structures	Remove all structures to at least 1 m below ground level, with the exception of the Dragon reactor complex which will be demolished in accordance with the optimised strategy to ground level. Demonstrate absence of contamination in any remaining below-ground structures (with the exception of the proposed disposals). Provide suitable cover over sub-surface structures to encourage heathland development.
Voids	Sufficiently backfill or re-profile voids to prevent subsidence hazards. Backfill material to be determined by suitable risk assessment and further optimisation. Demolition wastes are only to be used for backfilling the proposed disposals at SGHWR and the Dragon reactor complex. All other voids, should they need backfilling, will use soil.
Adopted services	The majority of the utilities and services on site are adopted and all activities need to be completed by the services owner. A programme of removal is required, although this may not align with site decommissioning plans.
Un-adopted services	Above-ground services to be removed. Below-ground services to be isolated and mapped.

Aspect	Description
Surface features	Remove surface features including car parks, roads, most fences and certain footpaths. The top surface for roads will be removed and sub-base will be broken up. Fences in proximity to the rail head are the responsibility of Network Rail who will determine the on-going requirements.
Landscaping	Undertake landscaping as required, including emplacing caps above in-situ disposals. Re-profiling to mitigate flood risk is also required.
Ecology and habitats	Provision of conditions suitable for heathland regeneration and management to maximise habitat values. Removal of non-native plantation trees.

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

77 Following a period of approximately three decades to allow for environmental monitoring in the stewardship phase (see Section 3.4.10), and subject to regulatory approval, the permit will be surrendered and the site will meet the SRS. Once the SRS has been reached the site will fall under normal planning and development controls managed in line with the Town and Country Planning Act (TCPA) [12].

3 Safety Strategy and Management Framework

Claim: Sound Management
All operations are, and will continue to be, undertaken within a sound management framework and a positive environmental safety culture. These management arrangements will ensure a structured, transparent and traceable implementation of the proposed end state. This will be delivered in accordance with emplacement acceptance criteria, construction quality assurance plans and stewardship arrangements, and will systematically manage unexpected conditions. The management arrangements also ensure effective leadership, sufficient resources, a commitment to continuous learning, and enduring knowledge management.

3.1 Definitions

78 The GRR Glossary [6, §C2] defines a "safety strategy" as *"an approach or course of action designed to achieve and demonstrate environmental safety"* and defines "environmental safety" as *"the safety of people and the environment both during the period of RSR and afterwards into the indefinite future".*

79 Note that in the safety strategy presented in this SWESC, the word "safety" refers to "environmental safety" as defined in the GRR (see above). Environmental safety is a broader concept than purely radiological or nuclear safety, which is limited to the safety of people.

80 The GRR [6, ¶2.3.3] envisages that the development of the WMP and SWESC should be coordinated and subject to an overall management strategy:

> *"The operator should have a clear strategy to support the development of their WMP and SWESC; a safety strategy (IAEA, 2012). The strategy is a high-level integrated approach comprising an overall management strategy for the various activities required to ensure that WMP and SWESC are properly coordinated and that they address all relevant considerations."*

81 In this context, the safety strategy to support an optimised end state is both the process of working towards an end state that is safe, and the demonstration that it is safe, now and in the future.

3.2 International and National Regulatory Framework and Guidance

M.1 There is an established framework of international and national principles, regulation and guidance that is integrated into the NRS management system. This ensures that the proposed on-site disposals will be implemented in a manner that protects the health and interests of people and the integrity of the environment, both during the period of regulation and afterwards.

82 Key relevant international and national principles, policies and guidance and their context are set out in this section. The international framework has informed development of UK legislation and guidance, such that compliance with the national framework ensures adherence to the internationally agreed principles. This section discusses how these have been addressed in the context of the Winfrith site end state proposals. Regulatory compliance cross-checks are presented as a series of tables in Appendix B detailing the applicable regulatory requirements and guidance, with references to sections of the SWESC or underlying reports containing material that addresses each requirement or guidance point. In addition, NRS process documents, standard procedures and manuals include tables or lists of compliance requirements (i.e. regulatory requirements, international safety standards and relevant

guidance) that are addressed by applying the process, procedure or operation described in the relevant document.

3.2.1 International Guidance and Principles for Radioactive Waste Management

International Atomic Energy Agency (IAEA)

83 The UK is a signatory to the IAEA Joint Convention on the Safety of Spent Nuclear Fuel Management and the Safety of Radioactive Waste Management [56]. The Joint Convention is the only international legally binding instrument to address, on a global scale, the safety of spent fuel and radioactive waste management. As a Contracting Party, the UK must demonstrate a commitment to apply stringent safety measures and prepare and submit a National Report on the applied measures, as well as to participate in the Review Meetings. NRS support the generation of the National Report through providing radioactive waste inventory data to the national inventory database (UKRWI) and reporting plans for site closure and for post-closure active and passive institutional control.

84 Under the Convention, the UK (and by extension NRS) must consider the wide variety of guidance documents and technical reports covering all aspects of radioactive waste management produced by the IAEA. Examples of how NRS takes account of IAEA documentation include:

- NRS has used these documents whilst carrying out the safety assessments supporting this SWESC. In particular, the performance assessment that supports this SWESC was developed using a structured approach consistent with IAEA guidance for best practice (e.g. [57; 58]) (see Section 7.2.1 and [23, §2]).
- The Winfrith End State Stewardship Plan [27] is in part based upon the IAEA and Joint Convention requirements and guidance on institutional control [56; 59; 60].
- The NRS management system documents consider and address the IAEA requirements *"for establishing, assessing, sustaining and continuously improving effective leadership and management for safety in organizations concerned with, and facilities and activities that give rise to, radiation risks"* [61]. For example, Clause 2.2(c) relating to ensuring the safe management and control of all radioactive material and radiation sources is addressed through implementation of the NRS *"Management of Waste"* process document [62] and supporting standard procedures and forms.

International Commission on Radiological Protection (ICRP)

85 The ICRP has defined a system of radiation protection through recommendations based on three principles [63, §5.6]:

- Justification – no practice shall be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes.
- Optimisation – the magnitude of the doses, the number of people exposed, and the likelihood that potential exposures will occur shall be kept as low as reasonably achievable (ALARA), taking into account economic and social factors.
- Limitation – limits are placed on the dose and risk to individuals so that they do not exceed a value that is considered acceptable.

86 Although these general principles have no direct legal force in the UK, they underlie all radiation protection activities and are reflected in other international principles and guidance, such as those set by the IAEA and the European Commission. The principles and guidance inform UK regulations and guidance, through which they are enforced.

87 The ICRP has also developed guidance on the application of its principles in specific areas, including radioactive waste disposal (e.g. [64; 65; 66; 67]). This ICRP guidance has been considered by the UK regulators in the setting of radiological protection targets in the GRR [6]. Compliance with the GRR ensures compliance with the ICRP principles.

European Commission

88 A number of European Commission Directives and Regulations have been made under the Euratom Treaty, of key importance being the Basic Safety Standards (BSS) Directives. Council Directive 96/29/EURATOM of 13 May 1996 [68] lays down BSS for the protection of the health of workers and the general public against the dangers arising from ionising radiation. The European Commission BSS are consistent with the BSS set by United Nations organisations (e.g. [69]) and are required to be implemented in the European Union Member States. The European Commission BSS were revised in 2014 [70], maintaining consistency with international consensus [71]. The 2014 European Commission BSS revisions have been implemented in UK legislation. The main provisions of the BSS are implemented in England via EPR16 [1], the Nuclear Installations Act 1965 [72], the Ionising Radiations Regulations 2017 [73], the Ionising Radiation (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018 [74], the Radiation (Emergency Preparedness and Public Information) Regulations 2019 [75], and the Justification of Practices Involving Ionising Radiation Regulations 2004 [76] and its 2018 amendment [77]. Compliance with UK legislation therefore ensures compliance with the BSS.

Nuclear Energy Agency (NEA)

89 The mission of the NEA's Radioactive Waste Management Committee (RWMC) is *"to assist Member Countries in developing safe management strategies and technologies for spent nuclear fuel, long-lived waste and waste from the decommissioning of nuclear facilities".* Although much of the programme of the RWMC is concerned with deep geological disposal of long-lived waste, many of the general principles, methodologies and problems addressed are also of relevance to near-surface and surface disposal. The conduct of the safety assessment and the development of this SWESC have taken account of recommendations from the NEA (e.g. [78]).

3.2.2 Relevant UK Regulations, Policy and Guidance

Environmental Permitting Regulations 2016 (as amended)

90 In England, disposals of radioactive waste (solid, liquid or gaseous) on or from the site are regulated by the EA under EPR16 [1], specifically Schedule 23. To support operators, the environment agencies have produced guidance associated with specific aspects of compliance with RSR. The sub-sections below summarise the GRR requirements, and guidance regarding the identification of radioactive substances that can be considered "out of scope" (OoS) of RSR.

91 Note that aspects of environmental permitting associated with groundwater protection and non-radiological hazards, which are deemed of relevance to this SWESC, are collectively discussed with other relevant directives and regulations (see Paragraphs 112 to 115).

Radioactive Waste and the GRR

92 The GRR [6, ¶1.3.1] sets out a fundamental protection objective as follows:

> "*Our fundamental protection objective is to ensure that a nuclear site is brought to a condition at which it can be released from RSR, through a process which protects the health and interests of people and the integrity of the environment, both during the period*

of regulation and afterwards, and which inspires public confidence and takes account of costs."

93 Note that the fundamental protection objective in the GRR builds on the IAEA fundamental protection objective [79].

94 The GRR requires operators to assess different options for the disposal of radioactive waste arising from decommissioning, including the potential for leaving radioactivity on site. In this regard, the GRR sets out [6, ¶1.2.1]:

- the requirement for optimised plans for the management of the radioactive wastes from decommissioning and clean-up of a nuclear site;
- the standards that must be met if those optimised plans identify that radioactive wastes are best managed by on-site disposal; and
- the standards that a nuclear site must meet to enable it to be released from RSR.

95 The GRR identifies three types of on-site disposal, of which the latter two are proposed for the Winfrith site [6, §2.6]:

- On-site disposal of radioactive waste in a dedicated disposal facility. A disposal facility is defined as *"an on-site engineered facility where solid radioactive waste is permanently emplaced solely for the purpose of disposing of that waste"*.
- On-site disposal of radioactive waste in-situ – here termed "in-situ disposal", and defined in the GRR [6, §C2] as *"on-site disposal of solid radioactive waste, such as a buried structure, by leaving it permanently in position, together with any necessary preparatory works"*.
- On-site disposal of radioactive waste for a purpose – also termed "disposal for a purpose" (DfaP) and defined in the GRR [6, §C2] as *"on-site disposal of solid radioactive waste by permanent deposit where, if suitable radioactive waste were not available, other materials would have to be found to fulfil the purpose"*. The GRR [6, ¶2.6.12] lists the following examples of such purposes:
  - *"Making land safe, for example by filling voids".*
  - *"Constructing roads, tracks and hard-standing".*
  - *"Constructing bunds, barriers or screens".*
  - *"Landscaping to comply with local planning authority requirements".*

96 The GRR shows how the environment agencies' Fundamental Protection Objective is to be fulfilled by meeting five principles and 15 requirements (Figure 3.1). The requirements of the GRR (presented in Table 3.1), which are referred to in this SWESC by their "R1" to "R15" nomenclature, are defined to enable the operator to provide evidence that the principles have been met.

97 This SWESC and associated WMP are the primary (Tier 1) documents that demonstrate that NRS has addressed and will continue to address the requirements of the GRR. Table 3.1 also signposts to the section in this SWESC where there is a description of how NRS is ensuring that the requirements are met. A full cross-check against GRR requirements is presented in Appendix B.1, showing where in this SWESC each requirement is addressed and provides the references for key supporting documents.

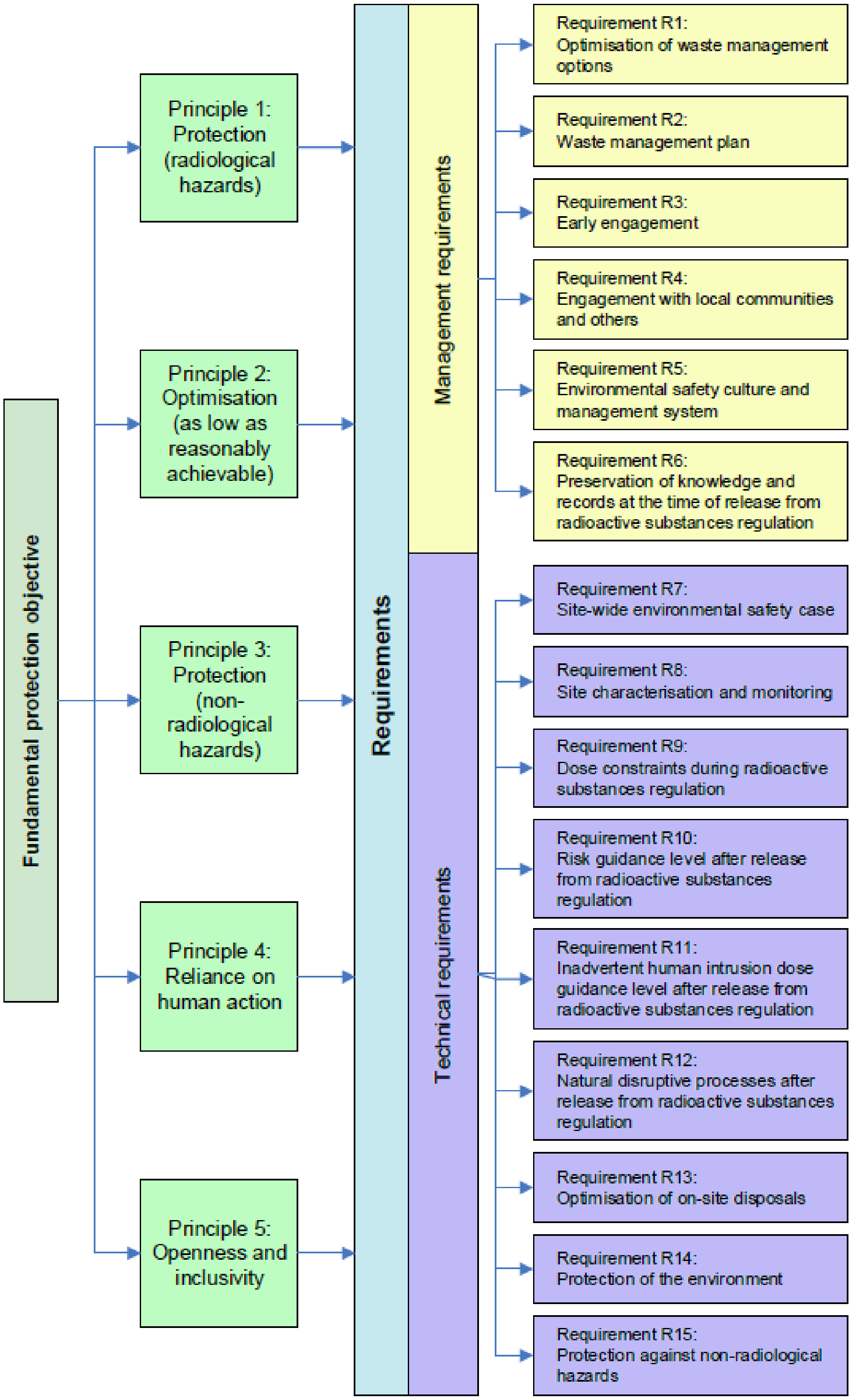

Figure 3.1: Relationships between the GRR's fundamental protection objective, principles and requirements (reproduced from the GRR [6, Fig.2]).

Table 3.1: GRR Requirements R1 to R15 with their associated introductory paragraph [6] and the sections of the SWESC in which they are addressed.

Requirement	SWESC Section
Requirement R1: Optimisation of waste management options	Section 6.2
"Operators should use a proportionate process to select options, for managing radioactive waste arising from decommissioning and clean-up, that are optimised. This process shall ensure that the radiological risks to individual members of the public and the population as a whole are kept as low as reasonably achievable (ALARA) taking account of economic and social factors. The process should also consider the need to manage radiological risks to other living organisms and to manage the non-radiological hazards associated with radioactive waste."	
Requirement R2: Waste Management Plan	The WMP accompanies the SWESC; its scope is discussed in Sections 1.1 and 1.4
"Operators should prepare a waste management plan (WMP) to manage the programme of disposals of radioactive waste from their nuclear site, and implement the plan to achieve the site reference state."	
Requirement R3: Early engagement	Section 4.1
"Operators should engage as early as possible with the relevant environment agency."	
Requirement R4: Engagement with local communities and others	Section 4.2
"Operators should engage with local communities, ONR, the planning authority, other interested parties and the public on their developing WMP and SWESC."	
Requirement R5: Environmental safety culture and management system	Section 3.4
"Operators should maintain a positive environmental safety culture appropriate to the activities being undertaken on-site and should have a management system, organisational structure and resources sufficient to provide the following functions: (a) planning and control of work; (b) the application of sound science and good engineering practice; (c) commissioning of appropriate research and development; (d) provision of information; (e) documentation and record-keeping (see also Requirement R6); and (f) quality management"	
Requirement R6: Preservation of knowledge and records at the time of release from radioactive substances regulation	Section 3.4.5
"Operators shall manage and retain adequate records of their site's journey to completion of all planned work involving radioactive substances and also, where necessary, provide adequate records of the controls applied up to the site reference state being achieved along with the required validation monitoring data. Operators should provide these records in a form suitable for long-term preservation and access, and should propose arrangements for the long-term safe-keeping and management of the records."	
Requirement R7: Site-Wide Environmental Safety Case	All sections
"Operators should maintain a site-wide environmental safety case (SWESC) to demonstrate that people and the environment will be adequately protected from ionising radiation and any associated non-radiological hazards, both before and after their site is released from radioactive substances regulation."	

Requirement	SWESC Section
Requirement R8: Site characterisation and monitoring *"Operators should carry out a programme of site characterisation and monitoring to provide information needed to support the WMP and SWESC. The programme shall include appropriate validation monitoring to provide technical confirmation that progress towards the site reference state is as expected or to validate that the site reference state has been achieved."*	Section 5
Requirement R9: Dose constraints during the period of radioactive substances regulation *"During the period of radioactive substances regulation the effective dose, from the authorised site, to a representative person shall not exceed a source-related dose constraint and a site-related dose constraint."* *… "0.3 mSv per year from any source from which radioactive discharges are made; and 0.5 mSv per year from the discharges from any single site".*	Section 7.3
Requirement R10: Risk guidance level after release from radioactive substances regulation *"Operators should demonstrate through the SWESC that, after release from radioactive substances regulation, the assessed risk from the remaining radiological hazards to a representative person should be consistent with a risk guidance level of 10^{-6} per year (that is, a risk of death or heritable defect of 1 in a million per year due to exposure to ionising radiation)."*	Sections 7.4.1 and 7.4.2
Requirement R11: Inadvertent human intrusion dose guidance level after release from radioactive substances regulation *"Operators should assess the potential consequences of inadvertent human intrusion into any local concentrations of radioactive substances on the site after release from radioactive substances regulation. The assessed effective dose to a representative person during and after the assumed intrusion should not exceed a dose guidance level in the range of around 3 millisieverts per year (3 mSv/y) to around 20 millisieverts in total (20 mSv). Values towards the lower end of this range are applicable to prolonged exposures, while values towards the upper end of the range are applicable only to transitory exposures."*	Section 7.4.3
Requirement R12: Natural disruptive processes after release from radioactive substances regulation: application of risk guidance level and dose guidance level *"Operators should show in the SWESC that people will be adequately protected in the case of natural disruptive processes which expose radioactive waste or contamination or impair protective barriers after the site is released from radioactive substances regulation."*	Sections 5.3.1 and 7.4.1
Requirement R13: Optimisation of on-site disposals *"Operators shall, through a process of optimisation, ensure that the radiological risks to individual members of the public and the population as a whole, from the on-site disposal of radioactive waste, are kept as low as reasonably achievable (ALARA) taking into account economic and social factors. Radiological risks shall be optimised throughout the period of radioactive substances regulation and afterwards, as far as can be judged at the time when relevant actions are taken. The process should also consider the need to manage radiological risks to other living organisms and to manage the non-radiological hazards associated with radioactive waste."*	Section 6.3

Requirement	SWESC Section
Requirement R14: Protection of the environment	Section 7.8
"Operators shall assess the radiological effects of the site on the environment with a view to showing that all aspects of the environment are adequately protected, both during the period of, and after release from, radioactive substances regulation."	
Requirement R15: Protection against non-radiological hazards	Section 7.9
"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."	

Out-of-Scope (OoS) Substances

98 Below certain activity concentrations, substances can be considered OoS of regulation and so are not subject to any requirement under Schedule 23 of EPR16. Concentration thresholds for individual radionuclides are presented in EPR16 and government guidance [1; 80]. For substances containing multiple radionuclides, a sum of fractions (or "sum of quotients") approach is used to determine if a substance is OoS [80, ¶2.24].

99 The GRR [6, ¶2.2.13] states that:

> *"For simplicity, we* [the EA] *presume that any site (or part of a site) in which levels of radionuclides do not exceed the RSR out-of-scope values, meets the standard for release from RSR. If the operator can demonstrate that this is the case, we consider our standard has been met without the need for further radiological assessment."*

100 Waste material that is OoS of RSR is required to be managed as "directive waste" under the requirements of the Waste Framework Directive and associated legislation.

101 NRS standard procedure S-051 [81] sets out the process for NRS sites for the radiological management, control and clearance of material and waste to ensure that the requirements of the EPR16 are met.

102 NRS standard procedure S-100 [82] sets out how NRS ensures that "directive waste" is managed in accordance with relevant legislation.

103 Note that land in-situ, where demonstrated to be OoS, including unexcavated contaminated soil and buildings permanently connected with land, is excluded from the scope of the Waste Framework Directive. If an in-situ below-ground structure or contaminated land is demonstrated to be OoS, it is not classified as directive waste unless it is excavated.

Deposit for Recovery (DfR)

104 Directive waste (e.g. OoS concrete arisings from building demolition) can be recovered to *"ensure that the waste serves a useful purpose by replacing other substances which would have had to be used for that purpose"* (e.g. infilling below-ground void space) [83, ¶3.10]. The recovery of directive waste by its permanent deposit requires a "deposit for recovery" (DfR) permit under EPR16 Schedule 9 (which enacts the "Waste Framework Directive" 2008/98/EC).

105 The EA defines DfR applications as either a Standard Rules Permit or a Bespoke Permit. The EA's requirements for a Standard Rules Permit [84] have been assessed in the Winfrith DfR

application. Given the location and local environment associated with Winfrith, a Standard Rules Permit is not available to the site. An application for a Bespoke Environmental Permit has been provided in parallel to this SWESC and application to vary the RSR permit in accordance with the terms of GRR. Appendix B.6 identifies the conditions for the DfR Permit addressed in the Winfrith DfR application and provides cross-references to where the condition is addressed in this SWESC and references to key supporting documents.

Nuclear Installations Act 1965 (as amended)

106 The ONR regulates nuclear site safety and security under the Nuclear Installations Act 1965 (as amended) [30] and is responsible for granting nuclear site licences to operators [72]. A set of 36 Conditions, covering design, construction, operation and decommissioning, is attached to each licence. The parts of these conditions that concern environmental protection, land quality management and implementation of the end state are set out in Appendix B.5 based on ONR guidance on land quality management [85] along with details of how these conditions are addressed within the permit variation application. The details provided in this SWESC are in addition to current management system arrangements and do not supersede existing processes. Additionally, Appendix B.3.2 sets out the expectations of the ONR and EA for Land Quality Management at nuclear licensed sites [86] and how they are addressed in the context of the site end state.

107 Regulatory changes are in progress to provide a more proportionate regulatory framework for nuclear sites in the final stages of decommissioning [87]. It is intended that a nuclear site licence can be ended once the ONR is satisfied that all nuclear safety issues have been addressed and once the site meets internationally agreed standards (specifically, the NEA's 2014 criteria for exclusion of decommissioning sites from the Paris Convention [88]). At this point, the site could be delicensed and regulation of the site transferred from the ONR to the relevant environment agency and the Health and Safety Executive. This will enable regulation proportionate to the risks present on former nuclear sites in the final stages of decommissioning. These proposals have been provided for in the Energy Act 2023 [89] but further regulatory changes are required to allow full enactment.

Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999 (as amended)

108 The potential impacts from decommissioning nuclear sites are assessed through the Environmental Impact Assessment for Decommissioning Regulations (EIADR) [90; 91] (1999). Regulation 13 of the EIADR requires the impact of changes or extensions to an on-going decommissioning project to be assessed. In these cases, the licensee must undertake an internal screening of the proposed changes to the decommissioning plan to determine whether they could potentially cause significant adverse effects on the environment. The screening assessment (termed a "Change Assessment") for the proposed SGHWR and Dragon end states has been completed in accordance with NRS's EIADR compliance process S-159 [92].

Town and Country Planning Act 1990 (as amended) and the Town and County Planning (Environmental Impact Assessment) Regulations 2017

109 Proposals for the on-site disposal of radioactive waste and the change of land use associated with site restoration requires planning permission under the Town and Country Planning Act (TCPA) [12]. The current intention is that a number of applications for planning permission will be made to Dorset Council. This includes an application for all the development required at the Winfrith site (excluding the Sea Discharge Pipeline and Blacknoll Reservoir) to achieve the agreed interim end state; this includes demolition activities, waste disposals, restoration and re-profiling, and a change of land use. A separate planning application for the development

associated with the terrestrial part of the Sea Discharge Pipeline will be made. The sections of the Sea Discharge Pipeline in the marine environment will be subject to planning development consent under both the TCPA and the Marine and Coastal Access Act.

110 The Environmental Impact Assessment (EIA) Scoping Opinion from Dorset Council, issued in April 2019 [93], confirmed that the proposed Winfrith end state requires an Environmental Statement, as a summary of the Environmental Impact Assessment, to support the full planning application.

111 The EIA for the main site considers the environmental context and the potential environmental impacts of the proposed development required at the site to achieve the agreed interim end state. Appendix B.4 details where the information to be covered by the EIA is addressed in this SWESC and supporting documents.

Other Environmental Legislation and Self-regulatory Processes

112 The European Union "Groundwater Daughter Directive" 2006/118/EC (GWDD), and its parent directive the "Water Framework Directive" 2000/60/EC, are both concerned with the protection of groundwater against pollution, the prevention and limitation of inputs of pollutants to groundwater, and the prevention of deterioration of the status of groundwater bodies. These directives are implemented by the groundwater provisions in Schedule 22 of EPR16 [1] and the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (WER2017) [94]. More specifically:

- Paragraph 20(2)(j) of WER2017 places a *"prohibition of direct discharges of pollutants into groundwater"*,
  - WER 2017 explains that "*"direct discharges of pollutants into groundwater" means the discharge of pollutants into groundwater without percolation through the soil or subsoil".*
  - EA internal guidance [95, p.32] states that an input (discharge) is direct if *"the discharge goes into an open, artificial structure like a shaft, borehole or well that extends down to or into the water table"* or *"the discharge uses a natural feature like a swallow hole with rapid flow to the water table – meaning a travel time of minutes".*
- Regulation 3(2) of WER2017 states that the Environment Agency *"must determine an authorisation so as, in particular-*
  - *a) to prevent deterioration of the surface water status or groundwater status of a body of water… and*
  - *b) otherwise support the achievement of the environmental objectives set for a body of water…"*
- Paragraph 6 of Schedule 22 of EPR16 [1] states that *"the regulator must, in exercising its relevant functions, take all necessary measures—*
  - *(a) to prevent the input of any hazardous substance to groundwater, and*
  - *(b) to limit the input of non-hazardous pollutants to groundwater so as to ensure that such inputs do not cause pollution of groundwater."*

113 With regard to surface water protection, Schedule 21 of EPR16 [1] contains requirements for the control of discharges of polluting substances to surface waters.

114 These regulations are collectively referred to as the "groundwater protection legislation". Appendix B.2 sets out where in this SWESC and supporting documents it is demonstrated that the proposed site end state meets the requirements of this legislation.

115 The following legislation is considered to be applicable in relation to the management of non-radiological hazards, in addition to the groundwater protection legislation discussed above:

- Control of Asbestos Regulations 2012 (CAR2012) [96] – NRS has a duty under Regulation 4 to locate, assess, record, manage and monitor the asbestos containing materials that are present on the site and communicate their presence to employees, contract staff, visitors and contractors. Management of asbestos at the Winfrith site is carried out in accordance with CAR2012 via the site Asbestos Management Plan [97].
- Environmental Protection Act 1990 (as amended) [98] – Part 2A of the act is the primary relevant regulatory regime associated with non-radioactive land contamination. The requirements of meeting Part 2A of EPA90 (relevant to this SWESC) and how these are addressed by NRS are discussed in Appendix B.3.1.

Policy for Notifying Neighbouring Countries

116 As the UK has left the Euratom Treaty, the requirement for the UK to submit information to the European Commission on plans for the disposal of radioactive waste (under Article 37 of the Treaty) no longer applies. The UK Government has issued the Transboundary Radioactive Contamination (England) Direction 2020, which requires the EA to consider *"whether plans to dispose of radioactive waste are liable to result in the radioactive contamination, significant from the point of view of health, of water, soil or airspace of notifiable countries"*. This is reflected in EA Form RSR-C5, the application form for proposed on-site disposals, which requires the applicant to "*provide a prospective dose assessment for the most exposed members of the public in Member States of the European Union and/or Norway",* but only if certain radiological criteria [99] are met. These radiological guidance criteria reference the radiological assessments completed in response to GRR Requirements R9 and R10 [6]. A transboundary assessment is only needed for proposed on-site disposals where the radiological assessments indicate that [99]:

- *"the effective dose from the facility to a local representative person during the period of radioactive substances regulation (GRR Requirement R9) is ≥10 microSv per year, or*
- *the assessed radiological risk to the local representative person after release from radioactive substances regulation (GRR Requirement R10) is ≥6 x 10^{-5} per year, or*
- *there are exceptional pathways of exposure to EU Member States and/or Norway either during or after the period of regulation, e.g., involving the export of foodstuffs."*

117 Section 7.6 assesses the need for a transboundary assessment for the proposed on-site disposals.

3.3 Approach to Ensuring Environmental Safety

M.2	There is a clear strategy for demonstrating compliance with the principles and regulatory requirements of radioactive waste management, key to which is the principle that safety is central to all processes and activities.

118 Commitment to environmental safety is built into all aspects of NRS's management system (see Section 3.4). A strategic approach for the site end state has been developed, as set out in this SWESC, based on the principle that safety is central to all processes and activities. This

approach supports the company's mission statement, in particular the objective to safely and securely deliver its sites to closure.

119 The strategic approach identifies the processes and activities needed to demonstrate how environmental safety will be ensured throughout the remaining decommissioning programme, implementation of the disposals and the stewardship phase, and after the SRS has been achieved. The strategic approach is based on the five main principles set out in the GRR (see Figure 3.1). These processes and activities which have been, and will continue to be, carried out to demonstrate environmental safety are detailed throughout the SWESC and are summarised and signposted below.

1. **Sound Management – Operate within a sound management framework and a positive environmental safety culture.**

120 Management arrangements are in place to ensure:

- a structured development of the proposed end state with a transparent and traceable approach to implementation;
- the proposed end state is in accordance with the emplacement acceptance criteria; and
- effective leadership, arrangements for policy and decision making, sufficient resources, a commitment to continuous learning, and arrangements for succession planning and knowledge management.

121 Application of the NRS management system is the primary approach to ensuring sound management and maintenance of a positive environmental safety culture. Relevant aspects of the NRS management system are described in Section 3.4.

2. **Undertaking Dialogue – Work in an open and inclusive manner.**

122 In accordance with GRR Principle 5, NRS endeavours to use *"a process that is open and inclusive… to bring the site to a condition at which it can be released from radioactive substances regulation"* [6, ¶A2.18]. This is largely achieved through engagement with relevant stakeholders, both in terms of the regulatory sphere and the local community. Open and inclusive engagement has been fundamental to developing the proposals for on-site disposal (see Section 4).

3. **Disposal System Understanding – Develop an adequate understanding of the disposal system (i.e. the wastes, the below-ground structures and their surroundings).**

123 GRR Requirement R8 requires operators to carry out a programme of site characterisation and monitoring to provide information needed to support the WMP and SWESC (Table 3.1). The broad topics highlighted in the GRR in regard to this [6, ¶A4.14 to ¶A4.22] include:

- *"The nature, magnitude and distribution of the radiological hazards remaining on or adjacent to a site"* – The approach to management and characterisation of the radiological inventory for the material proposed for on-site disposal is discussed in Sections 5.4.1 and 5.4.3.
- *"The nature, magnitude and distribution of any non-radiological hazards associated with, or potentially interacting with, the radiological hazards"* – The approach to management and characterisation of the non-radiological inventory for the material proposed for on-site disposal is discussed in Sections 5.4.1 and 5.4.4.
- The *"geological properties"*, *"dynamic geological processes"*, *"resource potential"*, *"background radioactivity"*, *"biosphere"*, and *"past and present rates of movement and*

diffusion of these [radiological and non-radiological] *hazards, if for example transported by groundwater"*, which herein are collectively considered as "site characteristics" – The current understanding of site characteristics and NRS's approach to further characterisation is discussed in Section 5.3.

- *"A proportionate approach to site characterisation and monitoring"* – A forward characterisation approach has been developed with the aim of furthering the understanding of the disposal systems (as discussed in Sections 5.3 and 5.4.1), supported by a structured uncertainties management methodology (Section 3.4.6).

124 Broadly, these topics can be split between work that has been completed previously and supports this application, and work to be completed prior to implementation. The former is focused on collating and summarising past and present characterisation and monitoring information to develop a current understanding of the site and its surroundings. The latter is focused on future work that will lead to an improvement in this understanding going forward, through reducing the number and/or magnitude of uncertainties.

4. Optimisation – Identify optimised configurations for the on-site disposals.

125 GRR Requirements R1 and R13 require NRS to undertake optimisation assessments to ensure that potential radiation exposures to people are ALARA, taking account of economic and social factors.

126 A standardised process is used to conduct robust Best Available Technique (BAT) assessments for managing radioactive waste at NRS sites to ensure a consistent and proportionate approach to optimisation. The options assessment process is described in Section 6.1. The proposed optimised end state configuration has been identified in an iterative manner using this approach[6], as discussed in Sections 6.2 and 6.3. The WMP [8] demonstrates that the management of all radioactive wastes is optimised, whether the waste is proposed for on-site or off-site management.

127 Optimisation is an iterative process extending into the future. As the design of the proposed disposals and wider end state develops and further information is gathered, options assessments will be completed, reviewed or updated as necessary (see Section 6.4)

128 While the main focus of optimisation in the GRR is on radiological protection, the NRS process reflects industry standards in assessing safety (including radiological and non-radiological hazards), technical and socio-economic factors to provide a balanced assessment of potential benefits and detriments.

5. Demonstrating Environmental Safety – Confirm that people and the environment are protected against radiological and non-radiological hazards.

129 Requirements R9 to R12, R14 and R15 of the GRR require operators to confirm that people and the environment are protected against radiological and non-radiological hazards. To address these requirements, multiple assessments have been developed to determine the potential radiological and non-radiological risks associated with decommissioning in general and with the wastes and materials that are proposed to remain on the site. Calculated impacts can then be compared with the relevant quantitative criteria to demonstrate protection of people and the environment.

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[6] As optimisation is an ongoing process, individual assessments have been undertaken in accordance with the management system requirements extant at the time.

130 The approaches and assessments undertaken to meet the GRR requirements and demonstrate environmental safety are introduced in Section 7 and detailed in the underlying reports:

- Radiological risk assessments have been completed to demonstrate that the potential radiological impacts of the proposed disposals comply with the quantitative dose and risk criteria set out in GRR Requirements R9, R10, R11 and R12 [6]. Assessments consider potential impacts during works to implement on-site disposals and in the long term, with no reliance on human action. The approach to radiological assessments is discussed in Section 7.2.1.
- Non-radiological risk assessments have been completed to demonstrate that a level of protection is in place for the non-radiological hazards associated with the proposed disposals that is consistent with that delivered by the relevant national standards/regulatory requirements for protection of people and the environment. The approach to non-radiological assessments is discussed in Section 7.2.2.

131 The assessment process is iterative, based on the outcomes of the optimisation process and new data becoming available.

132 The five strands of the strategic approach relate directly to the five environmental safety claims of this SWESC, for which the arguments and evidence are presented in Chapters 3 to 7.

3.4 Management System and Safety Culture

M.3	All operations are, and will continue to be, undertaken within a sound management framework, including work contributing to this SWESC.

133 At Winfrith, application of the management system is the primary approach to ensuring sound management and maintenance of a positive environmental safety culture. The management system is introduced below and the application of the management system to decommissioning projects at Winfrith is discussed, followed by a discussion of specific management methodologies of relevance to this SWESC.

3.4.1 Overview of the Management System

134 The NRS board and executives provide overall leadership and have defined policies to direct the company. The following policies govern the approaches to site operation and decommissioning[7]:

- PS01: Corporate Governance Policy.
- PS03: Knowledge Information and Records Policy.
- PS04: Enterprise Risk Management.
- PS05: Business Continuity.
- PS08: Environment, Health, Safety and Quality Policy.
- PS12: Sustainability Policy.
- PS14: Nuclear Safety Policy.

135 The management system ensures processes and procedures are in place to meet licence and permit conditions and allow work to be carried out in a manner that prioritises not only staff

[7] A full list of company policies and associated objectives can be found in S-111 [100].

safety but the safety of the public and the environment. All corporate policies, procedures and standards within the management framework emphasise the overriding importance of nuclear and environmental safety. The management arrangements are applied at Winfrith through the Harwell and Winfrith Site Manual (MAN 001) [101].

136 The management system promulgates agreed ways of working to implement these company policies and deliver the objectives of the company through both company Process Documents (denoted PD-XXX), Standards (denoted S-XXX) and Manuals (M-XXX). It encompasses all aspects of the company, including culture, training and experience required to undertake activities, and is binding on all personnel. The management system is defined at a corporate level and is applied through specific arrangements at local (site) levels.

137 The management system is defined within PD-010 ('Management System' [102]) and takes an integrated/process-based approach to defining how the legal, governance and contractual obligations are met. The management system also specifies how the requirements of ISO standards ISO9001 (quality assurance), ISO14001 (environmental management systems), ISO45001 (management systems of occupational health and safety) and ISO55001 (asset management) are delivered[8]. This is verified through external audit of the management system (ISO (re)accreditation process[9]). The management system takes the form of a document hierarchy that describes how corporate policies feed into fleet-wide processes and procedures and how these are implemented at a site-specific (local) level. This document hierarchy is represented in Figure 3.2.

138 Further details on the most relevant aspects of the management system can be found in the company manual M-023, "Introduction to the Safety, Security & Environment Management Prospectus" [104] and the "Management System" process document [102].

139 All activities at Winfrith are completed in accordance with the requirements of the management system. This system provides a comprehensive framework that ensures the health, safety and security of staff and the public, and protection of the environment. Within the remainder of this section, high-level details are provided on the application of the management system to activities at Winfrith, the checks and procedures associated with ensuring compliance, and activities that are currently ongoing to ensure alignment of the management system with the GRR.

140 The overarching methodology to initiate, develop, implement, maintain and close out all projects is detailed in Process Document PD-024 [105], "Portfolio Management", which creates a "Lifetime Plan" performance baseline. All projects at Winfrith exist on the company "Lifetime Plan" performance baseline, and once initiated they must proceed through defined processes to ensure they are effectively managed. Process Document PD-025 [106], "Programme & Project Management" sets out the generic stages to managing projects to ensure effective oversight and assurance in delivery.

141 To ensure effective project delivery, technical authorities (design authority, waste authority and project sanction reviews) review project development at defined stages in the project lifecycle to ensure conformance with management system requirements.

142 The Design Management Manual, MAN 004 [107], describes Harwell and Winfrith's arrangements for engineering design, its management and its application to ensure such

[8] Details on the requirements of these standards can be found on the International Organization for Standardization webpage: https://www.iso.org/standards.html

[9] The most recent re-accreditation audit was in April 2024 [103].

activities are properly executed and documented. This manual supports the Engineering Delivery process document, PD-018 [108].

143 Process document PD-026 [62] on management of waste defines the key processes followed to ensure that all activities involving waste are undertaken in compliance with site licence conditions and EPR16.

144 The current management system will be updated, in accordance with PD-010 [102], to address Condition 1.1.3 of the site RSR Permit [7], which is to maintain a WMP and SWESC. The actions needed to review existing processes and create new processes to fully embed the requirements of the GRR into the company management system were too extensive to complete in time for the Permit Improvement Condition introducing Condition 1.1.3. Therefore, instead, an interim process [9] has been created to specifically address Condition 1.1.3 whilst permanent changes to the management arrangements, which will cover the full extent of the GRR (not just the requirement for a SWESC and WMP), are developed and implemented.

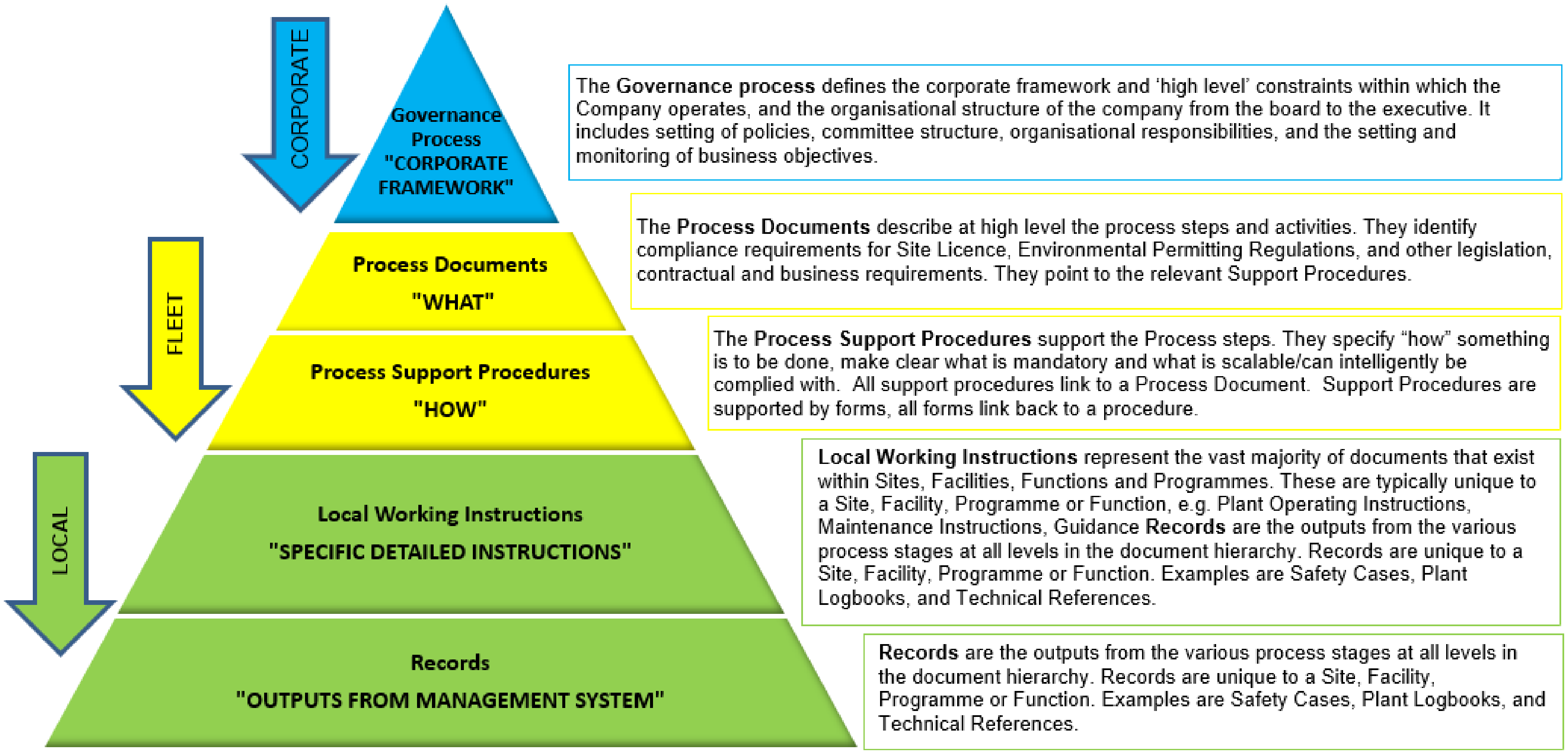

Figure 3.2: NRS management system document hierarchy [102].

3.4.2 Environmental Safety Culture

M.4 NRS is committed to high standards of environmental safety and quality, as formalised in the Winfrith Site Manual and the overarching Environment, Health, Safety, Security and Quality (EHSS&Q) management system. As a result, there is a positive environmental safety culture at Winfrith.

145 The Winfrith site is managed to comply with both its nuclear site licence and environmental permits (including the RSR permit), and the Health and Safety at Work Act [109]. Compliance with these legal requirements is a key component of the executive and site's leadership teams accountabilities. To ensure compliance with these requirements organisations must have a positive safety culture and embed learning and questioning attitudes into their organisation.

146 Under GRR Requirement R5 [6], the EA expects *"operators to maintain a positive environmental safety culture, such as appropriate individual and collective attitudes and behaviours, and require their suppliers to do the same"* and that the culture is *"reflected in and reinforced by the operators' management systems"* [6, ¶3.32]. This is also reflected in EA principles on management and leadership for the environment [110], which set out expectations on how an operator should manage its business and provide leadership to ensure that the business minimises its impact on people and the environment.

147 The GRR [6, §C2] defines environmental safety culture as:

> *"The characteristics and attitudes of organisations and individuals that ensure that the protection of people and the environment receives proper attention."*

148 The primary goal of NRS is to protect people and the environment, and the company works to minimise the environmental impact of its operations. NRS engages with its stakeholders to seek the widest possible approval of how to manage its environmental responsibilities.

149 All staff and site-based contractors are required to undertake mandatory training both upon starting within the company and on an annual 'refresher' basis. This includes training on specific environmental safety issues (e.g. environment, radiation and fire safety) as well as training on expected behaviours for fostering a respectful work environment (e.g. diversity, equality and discrimination).

150 As part of NRS training all staff are encouraged to adopt a questioning attitude to ensure that both physical and technical work is appropriate and safe and will not have adverse effects on people or environment. Psychological safety training is provided to all staff. This training emphasises the importance of creating the right environment for people to raise concerns by highlighting the importance of both raising and receiving these concerns in a constructive and non-confrontational manner. A significant component of the safety training relates to reducing the likelihood and consequence of human error by using human performance error avoidance tools. The training identifies the leading causes of errors (e.g. stress, time pressure, poor communication) and the tools and techniques that can successfully mitigate error-inducing scenarios.

151 The NRS Executive Board commissions an annual employee engagement survey which all staff are encouraged to participate in. This anonymous survey is devised by a specialist survey company that features a standard set of questions. These questions cover a wide range of topic areas which include 'management support', 'freedom of opinions' and 'safety'. The results of this survey are analysed at team and functional levels in order to identify and address areas that require improvement. Although this survey does not explicitly address environmental

safety, it considers the overarching management systems and working environment that is key to ensure protection of people and the environment.

152 The management system promotes a strong environmental safety culture through business improvement (continuous learning), problem identification (including creating an environment for raising concerns) and resolution.

Business Improvement (Continuous Learning)

153 Organisational learning is captured and applied through the "Business Improvement" Process Document (PD-016) [111]. This defines four strands to continuous improvement activities within the company:

- improvement programme;
- assurance programme;
- corrective and preventative actions; and
- management review.

154 Progress is monitored and reported to the appropriate governing body. For strategic initiatives, such the Company Safety Improvement Programme (CSIP), the company Executive monitor progress on improvements. Learning events are assessed and monitored by responsible managers, the Operating Experience, Feedback and Learn (OEFL) department and Lead Investigators, where appropriate.

155 The inputs to the business improvement programme include:

- strategic initiatives that originate from the Executive;
- improvements that are aimed at ensuring compliance, maintaining excellent safety performance and driving continual improvement (these initiatives are captured within the Company Safety Improvement Programme (S-188) [112]); and
- reporting and investigating events (S-190) [113].

Problem Identification and Resolution

156 Standard S-190, "Event reporting and investigation and operational experience feedback", defines how sites seek to effectively and efficiently use lessons learned to improve safety, security, reliability and to prevent loss. This company standard ensures that events are identified, reported and recorded, to enable the causes to be established, corrective and preventative actions implemented and learning opportunities shared to prevent reoccurrence. If an event is potentially significant (from a safety or compliance point of view) then a tiered approached to investigating the event's causes and to identify appropriate actions to prevent recurrence is applied.

157 Company Standard S-133, "'Blame Free' Reporting and Investigation of Events" [114] is used to promote reporting of events and near-misses. All staff and contractors are responsible for identifying and promptly reporting events, learning opportunities, good practices and near misses, and team leaders are responsible for encouraging team members to report events and near misses. An anonymous reporting system, 'Safe Call', is also available for all staff and contractors.

158 Any events, near misses or good practices are recorded on the Q-pulse database[10]. Q-pulse entries can be made either via an on-line or paper form with the more significant events, from both within and outside of the company, appearing on the Company Operational Organisational Learning (COOL) database. This database provides a key route for safety communication. It is accessible on the company intranet pages and personnel can elect to receive topic specific information via email alerts. This process supports the timely distribution of safety information throughout the company.

159 Findings in the form of improvement opportunities and non-conformances are communicated to enable correction of deficiencies, action to protect people and the environment, to prevent businesses losses, and to exploit identified opportunities to make improvements. The process of managing findings and feedback (internal and external) is outlined in MAN 0041 ('Findings (Improvement Opportunity and Non-Conformance) Management') [115].

3.4.3 Planning and Control of Work

M.5 There is an overarching process to appropriately control works and ensure that contractor processes are acceptable and compatible with those at Winfrith. Specific arrangements will be put in place to control works to demolish the reactors and implement on-site disposal safely.

160 The specific arrangements for control of the works to implement the demolition and on-site disposal proposals are being developed, including how emplacement acceptance criteria are, and will continue to be, applied (see Section 3.4.8), as well as construction quality assurance for all phases of work (CQAP [128]). Planned verification activities to demonstrate that the works have been successful, and that the SRS will be reached, are documented in the Stewardship Plan (see Section 3.4.10).

161 Control of the implementation of the proposed end state, including those for SGHWR and the Dragon reactor complex, will be partially based on other regulatory permissions. For example, the DfR Permit will specify the technically competent manager for oversight of the recovery activities. Similarly, the planning development consent will specify many of the mitigation measures to minimise impact on the environment through the implementation phase.

FP.2 Establish implementation and delivery plans for control of the works to demolish the reactors and safely implement the on-site disposals in line with NRS management system requirements and quality controls.

162 Specific demolition and emplacement plans for implementing the disposals will be developed at the appropriate time in the decommissioning process. Approval and control of the development and implementation works will follow the overarching processes in the management framework. Intrusive work at the Winfrith site is controlled by:

- MAN 0016 - Work Control Process Manual [116]; and
- MAN 0032 - Plant Management Manual [117].

163 All physical works are managed through the works control process. A Safe System of Work (SSoW) is required for all works and is reviewed and approved by appropriate authorities.

[10] Q-Pulse is an event action tracking system. Note that Q-Pulse has recently been rebranded as Ideagen.

164 Work carried out by contractors is controlled in accordance with procedure PRC 0245: Contractor Management [118] and the Winfrith Site Rules [119].

3.4.4 Integration of the SWESC and Other Site Decommissioning Activities

M.6 The programme of work for decommissioning at Winfrith is being carried out according to an ordered plan. The plan for defining and delivering the end state is integrated into the site decommissioning plan. The consistency of the SWESC (and supporting assessments) is validated through routine interfaces and ensuring ownership of documents by appropriate technical and project authorities.

165 Integration of decommissioning activities and the Winfrith end state is managed through the Site Closure Committee (SCC) [101]. The purpose of the SCC is to oversee the delivery of the site end state, considering and coordinating the interests of the site, programmes and other stakeholders. The committee is attended by representatives of the Winfrith Senior Leadership team, the Winfrith End State Manager as well as senior project managers who have responsibility for the site's significant decommissioning projects (e.g. SGHWR, Dragon and Plant and Structures (which covers the decommissioning of the rest of the site)). In addition, the Winfrith end state team have regular working level meetings with the Environment and Engineering teams as well as topic-specific forums to ensure that work programmes are performed in a complementary and integrated manner.

166 Examples of integrated cross-department work areas and topics that have benefited from this approach include:

- Defining the optimum engineering approach for how the reactors can achieve their end states, leading to a co-authored Design Substantiation Report [25].
- Agreeing emplacement acceptance criteria for the SGHWR and Dragon decommissioning teams work to.
- Agreeing with the Plant and Structures decommissioning team the end point specification and verification process for land areas and sub-surface structures on the site.
- Management of water ingress into SGHWR below-ground voids during the period of high groundwater levels experienced during the winter of 2023/24.
- Defining the optimum timing for decommissioning of the Active Liquid Effluent System.
- Defining the optimum end state for the A59 area and identifying the key interfaces that influenced the option description and scoring.

167 Additionally, the site programmes, including End State, Decommissioning, Waste Management and Asset Care have an integrated, site wide programme called the Master Summary Schedule (MSS). The MSS presents the complete programme of work for the site to meet its end state and allows for programme activities (LTP) to be integrated and interfaces between work areas to be managed.

3.4.5 Knowledge Management and Record-keeping

M.7	There are procedures to ensure effective knowledge management now and for the future. This includes managing information assets to ensure that the information recorded is fit for purpose, available to the appropriate information users, and is backed-up and archived appropriately. Records are kept in a form suitable for long-term preservation and access.

168 The GRR Requirement R6 states that *"operators shall manage and retain adequate records of their site's journey to completion of all planned work involving radioactive substances and also, where necessary, provide adequate records of the controls applied up to the SRS being achieved along with the required validation monitoring data"* [6, ¶A3.37]. The GRR emphasises the importance of records management, with the key need being to pass knowledge about the site to future generations in an effective manner.

169 Records of on-site disposals will include information generated prior to achieving the IEP (e.g. on the nature of the disposals, the inventory, the SWESC and the underpinning assessments and location details) and information generated between the IEP and the SRS (e.g. monitoring data). Records need to be comprehensive to ensure that there is sufficient knowledge to make a case that the SRS has been achieved and for future generations to understand the hazards present at the site. However, the information stored will also need to be selective to ensure retention of important items and allow information to be more easily found. This means that it is necessary to assess each record and decide whether or not it needs to be retained and for how long ('record appraisal').

170 Records will also be generated and maintained for the recovery of wastes and for implementation of the engineered caps, in line with normal arrangements for DfR activities. The records will include details of any engineering remedial works, characterisation, European waste catalogue codes, and details of emplacement.

171 Data collection, its assessment for storage, and subsequent storage will be the responsibility of Winfrith site management up to the site's IEP and of NRS (centrally) beyond the IEP and up to the SRS. Current record-keeping arrangements for cataloguing (digital and paper), storing and accessing records at Winfrith up to the site's IEP will continue. The arrangements beyond the IEP up to the SRS, and beyond the SRS, have yet to be defined; however, approaches will be compliant with regulatory requirements and good practice.

FP.3 Data storage arrangements beyond the IEP to be developed in accordance with regulatory and local authority requirements, as well as good practice in the nuclear industry.

172 Within the sub-sections below, details are provided on the knowledge management requirements in the management system and the specific tool that is being used for the storage of digital data.

Knowledge Management

173 The management system incorporates requirements for knowledge management, information assurance, intellectual property and records management. These topics are collectively summarised in PD-023 [120], with further details provided in underlying topic-specific Standard Procedures. The company standards are produced in-line with relevant British and International Standards and maintained in accordance with requirements on continuous improvement.

174 "Knowledge management" is defined in the management system as *"how we capture, share, act upon and embed things that we learn in order to help us do work safer, quicker and more economically"*. The relevant standard procedure, S-734 [121], lists the company activities undertaken in support knowledge management. Records generated in relation to on-site disposal will fall within the "capture and communicate" knowledge management activity, where explicit knowledge is recorded through "reports, advice notes, meeting minutes" which "capture evidence, statistics, and data".

175 The specifics of records management are detailed in standard procedure S-419 [122], the purpose of which is to *"ensure the effective management of records including meeting all legal and other records retention obligations".* The procedure recognises that there are uncertainties regarding the methods that will be used in the future to store and manage long-term records, but present-day management of such records should be governed by the procedure set for "vital records", which requires that records should be retained in multiple formats (digital, hard copy, microfilm) and in multiple suitable locations. Requirements on records management will be updated as good practice evolves.

176 Some records relating to the implementation of on-site disposals will also be designated "vital records"; the specification for these will be defined prior to commencement of the demolition works for both SGHWR and the Dragon reactor complex.

177 Paper records for long-term storage (typically greater than two years) that are not required for regular local inspection are transferred to Nucleus (The Nuclear and Caithness Archives), the NDA archive for storage and preservation. Records that will be required for regular access are stored digitally on the company records system.

Digital Storage of Information

178 Whilst the current indexing arrangements in Standard S-419 are robust and compliant with regulatory requirements and relevant standards, an enhanced means of managing digital information has been be adopted to support management of land quality and on-site disposals across NRS. The "Information Management and Geographical Evaluation System" (IMAGES) is used for collating and compiling technical information and data associated with decommissioning, site characterisation, land quality management and site end state programmes.

179 IMAGES is designed to hold all information associated with site end states and link this to a mapping interface, in the form of geographical information system (GIS) tools. This information can comprise both quantitative technical data as well as supporting documents, drawings and photographic evidence.

180 IMAGES is currently used to store data and information related to the following topics:

- land quality management;
- groundwater quality and water levels;
- survey, sampling and characterisation data;
- end state programmes and SWESC development;
- building histories for characterisation and decommissioning; and
- site delicensing.

181 All documents that relate to the on-site disposal permit or DfR applications are held on IMAGES. It is expected that records that are required to support maintenance of the permits and the eventual SRS permit revocation application will also be held in IMAGES.

182 IMAGES comprises a series of interlinked modules associated with specific types of records and technical data, as shown schematically in Figure 3.3. The system was designed specifically for long-term land quality management, characterisation and compliance monitoring to support site closure and the potential release of nuclear sites from regulatory control.

183 IMAGES manages large volumes of different types of inter-related data, avoids bespoke data formats and has the ability to link end state decisions to technical data and supporting evidence in reports, thereby providing a clear audit trail. IMAGES includes integrated quality assurance information, revision workflows and validation processes for the records and data held within the system across the various modules. IMAGES also standardises data capture between contractors, projects, sites and over long time periods. This in turn allows data assessments, trends and comparisons to be made.

184 The land assessment and site closure module of IMAGES records a chronological record of works undertaken over long time periods to support ongoing compliance and the case for site end states, thereby removing the reliance on personal knowledge about an area or issues on a site. The excavation (and materials transfer and deposition) module functionality of IMAGES is specifically suited for records relating to on-site disposals.

185 IMAGES is an existing, well developed and supported system based on industry standard software that is used across the NDA estate. It therefore has a high level of resilience from long-term IT platform support. As a critical business information asset, changes to IMAGES or with the underlying programming, are carefully managed across the NDA estate.

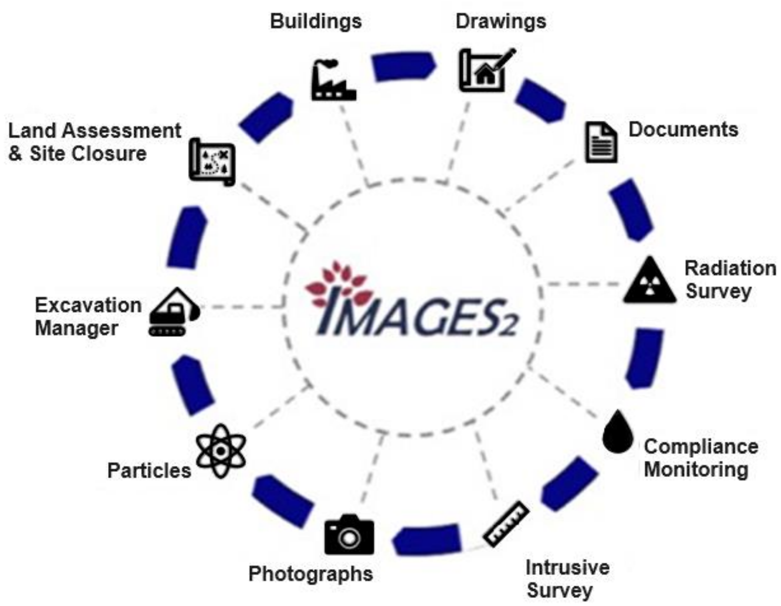

Figure 3.3: The main IMAGES modules.

3.4.6 Uncertainty Management

M.8	An uncertainties management methodology ensures that uncertainties in the knowledge base, decision-making and assessments are taken into account. The uncertainty management system is used to assess and monitor uncertainties, and to steer future work to address and better understand key uncertainties to support future decisions.

186 The management of technical uncertainties for GRR-related matters has been standardised across all NRS sites through the Uncertainties Management Methodology (UMM) [123]. The UMM's purpose is to ensure that uncertainties in the end state are demonstrably and transparently identified and managed appropriately and proportionally to the associated risks.

187 Application of the UMM is an iterative three-step process:

- Conduct "Uncertainties Assessments" (i.e. identify the uncertainties, assumptions and information gaps in a report).
- Enter the results of the assessments into the live Uncertainties Management Database (UMD), then undertake iterative further assessments leading to decisions (recorded in the UMD) as to how each uncertainty is to be managed.
- Produce Uncertainties Management Plans (UMP) as and when required.

188 For Winfrith, Uncertainties Assessments (UAs) have been undertaken for the key work streams supporting the SWESC, including the Radiological [17] and Non-radiological [18] Inventory estimates and performance assessments [23], the Site Description [20], the Conceptual Site Model [19] and the Design Substantiation report [25]. These are appended to the relevant reports and are also recorded in the Winfrith UMD. The uncertainties with a significance rating of "high" from these reports are reproduced in Appendix A.

189 The UMD (a single spreadsheet) is the master record of GRR uncertainties at the Winfrith site, documenting their assessment, sentencing, tracking and response. The information contained in the UMD is used to influence the direction of further work towards areas of significant uncertainty and to proactively prioritise that work. The UMD also documents the criteria and justification for uncertainties that are to be tolerated. Where areas of significant uncertainty are recorded, one or more actions aiming to reduce the uncertainty are defined and recorded in the UMD, along with plans for action completion and, once complete, a close-out statement.

3.4.7 Quality Management

M.9	Deliverables are produced within audited and accredited quality management systems and NRS has systems and tools in place to monitor the quality of deliverables. The quality system includes: (i) working arrangements for production, review and ownership of documents, data and models; (ii) processes to ensure use of suitably qualified and experienced personnel; (iii) a graded approach to quality assurance, with independent assessment and peer review; (iv) staged design development; (v) implementation quality assurance plans; and (vi) verification and validation monitoring arrangements.

190 The Winfrith end state quality arrangements are defined within the Quality Assurance Management Plan (QAMP [124]). The purpose of this management plan is to ensure that work is performed in an integrated manner using approaches and assumptions that are consistent with the aim of producing a coherent product across multiple work streams.

191 The scope of the QAMP includes:

- standard working arrangements for the production and management of documents, data recording, modelling, data and records;
- arrangements for review and verification of documents, data and assessments;
- clear ownership of data, spreadsheets, model production and review processes; and
- a records management process to ensure standardisation within the project.

192 The QAMP encompasses four procedures:

- document management;
- data management;
- spreadsheet management; and
- model management.

193 The QAMP defines the roles and responsibilities relevant to document and spreadsheet production and applies a graded approach to quality assurance that is based upon a grading system defined within 'Management of Business Models (including Spreadsheets)' S-396 [125] (for spreadsheets) and 'Verification and Review' S-325 [126] (for documents). Any proposed modification, experiment or decommissioning activity (including new build or modification to plant under construction), which may affect nuclear safety or the environment, is subject to the grading (categorisation) process to define the safety significance, approval and permissioning routes. Dependent on the potential significance, proposals can be subject to independent peer review.

194 The "Independent Assessment" manual (MAN 009) defines how assurance activities are undertaken by independent assessors or auditors [127]. The aim of the assurance programme is to ensure that the management arrangements work effectively so that work done at all sites is safe and compliant with the relevant legal and other requirements. The findings from internal assurance activities are recorded as actions within the NRS actions tracking system Q-Pulse and, when all actions are closed out, the independent assessment is also formally closed out.

195 Work carried out by contractors (on and off site) is controlled in accordance with procedure PRC 0245: Contractor management [118]. The competence of the contracting organisation is evaluated during the procurement process to ensure that they are suitably qualified and experienced in the appropriate skills areas.

196 Contractors employ their own quality assurance arrangements to complete their defined work scope. Technical review of the contractor's document and data outputs are completed in accordance with the processes outlined in the QAMP.

197 Independent peer review is applied for core documents, such as this SWESC. Peer review considers not only the scope and strength of the arguments presented but also the overall quality of the document. Peer review comments are managed and responses documented, with the close out of the review process recorded.

198 With respect to the proposed on-site disposals, the following checks and balances have been (and will continue to be) employed throughout the development of the GRR application:

- Permitting: This SWESC and supporting documents have all been developed by suitably qualified personnel using expert judgement as appropriate to manage uncertainty. The underpinning documents underwent extensive internal (contractor and NRS) review involving constructive discussions and critical technical appraisal. Core documents have been independently peer reviewed (see Section 7.11.6). The permit variation application is assessed by the appropriate NRS management including the Environment Manager, the Environment, Health, Safety and Quality (EHS&Q) Manager and the Site Closure Director.

- Detailed design development: The development of the detailed engineering design will be managed through the Design Management Process (MAN 004 [107]). This process will apply suitable controls to ensure that the design of the on-site disposals is both compliant with all legal requirements and fit for purpose. The phases of end state design development in relation to the design aims, safety assessments, information input and implementation are discussed in Section 5.1.
- Implementation: Delivery of the on-site disposals design will be controlled through application of the Construction Quality Assurance Plan (CQAP) [128]. The purpose of the CQAP is to set out how the construction and implementation of the feature end states will be carried out in a manner that is consistent with the claims, arguments and assumptions in the SWESC. In addition, the works will be controlled through application of the Construction Environmental Management Plan (CEMP) [129] and procedure 'PD-018 'Engineering Delivery' [108].
- Validation monitoring: Delivery of the validation monitoring programme will be controlled through the site's existing RSR compliance arrangements (see Winfrith Compliance Matrix [130] which lists the process and procedure documents which are in place to ensure compliance with current permit conditions). Monitoring results will be shared regularly with the EA (see Section 3.4.10).

199 Feedback and learning from ongoing project work is regularly reviewed to improve the quality and delivery of future work.

3.4.8 Management of Environmental Impacts During End State Implementation

M.10 All operations required to implement end state plans will be appropriately managed, controlled and monitored to minimise the environmental impacts in accordance with management system requirements. Appropriate systems will be put in place to minimise and control secondary waste generation, dust during cutting and demolition, water management for dust suppression and cutting, and noise and transport impacts on the local community.

200 Worker safety during activities to implement the reactor end states will be considered in developing detailed design and implementation plans, compliant with management system requirements, and will follow a systematic risk-based approach to identify and mitigate risks. Worker safety is outside the scope of the RSR permit application, but the necessary activities will be designed, planned and undertaken in compliance with the Construction (Design & Management) Regulations (CDM15) [131] and applying all appropriate practices such as hazard identification, risk management and mitigation, use of expert advice, appropriate tools and techniques, etc.

201 Environmental impacts during operations to implement the reactor and site end state have been assessed through the optimisation process and will be considered and managed as part of detailed design. This includes commitments to identify, mitigate and monitor the potential impacts. Mitigations and techniques to be followed during the decommissioning tasks to reach the end state are detailed in the CEMP [129]. Detailed plans will be developed in conjunction with the principal contractor and these will address:

- Appropriate management of water in the structures during end state implementation, whether introduced through cutting processes (cooling water), sprays for dust suppression, groundwater entry or extreme weather events.
- Minimisation of noise and dust during demolition. For example, optimum excavation techniques and water management can be utilised to minimise dust creation, and some activities could be undertaken within negative pressure tents. Noisy activities could be undertaken during a time window agreed with neighbours, although this is expected to be a short-term activity with minimal impact on residential or commercial neighbours.
- Transportation of materials and workers on and off-site will be minimised, so far as achievable. On-site disposal already reduces material and waste transport compared to off-site disposal of the reactor buildings (see Section 6.2.1), but opportunities to optimise movements of waste and recyclable materials off site will also be considered.
- Waste material generated during the demolition process will be appropriately stored and managed, if it cannot be deposited immediately.
- Measures will be taken to mitigate the impact on the surrounding ecology and protected species.
- Measures will be applied to minimise the impacts on soil quality through appropriate stripping and storage of topsoil and subsoil.

3.4.9 Application of Emplacement Acceptance Criteria

M.11 In the context of environmental safety of waste disposals, use of systematically derived acceptance criteria will ensure that disposals are undertaken in conformity with the SWESC. Physical, chemical, radiological and biological emplacement acceptance criteria (EAC) have been developed for the proposed on-site disposal of radioactive waste and deposit of recovered non-radioactive waste.

202 Emplacement Acceptance Criteria [26] (EAC) have been developed to provide guidance to the decommissioning projects on how to manage decommissioning, select new materials and produce wastes which are suitable for retention or emplacement in the voids.

203 The EAC are a concise set of criteria against which materials and wastes will be screened to determine if the waste/material can be considered for emplacement or retention. The criteria are divided into four components:

- physical characteristics (e.g. the physical form of the material);
- chemical characteristics (e.g. restrictions on disposal of hazardous materials);
- biological characteristics (e.g. restrictions on disposal of biological hazards); and
- radiological characteristics (e.g. activity concentration limits).

204 Radioactive and non-radioactive material proposed to be left in-situ, used for engineering or used for infill, will need to demonstrate conformity to the entirety of the EAC before being considered for retention or emplacement. If a specific material or type of material does not meet the entirety of the EAC, optimisation may be undertaken to determine whether any risk associated with the material is acceptable. Where an optimised and risk-based approach is justified, this will be recorded in the disposal records. Where optimisation or risk assessment identifies retention is not acceptable, the material would be removed and transferred for off-site management via an appropriate waste route in accordance with NRS arrangements. Records of all materials and wastes rejected for on-site management will also be generated and retained.

205 Supporting characterisation information will be of sufficient quality to confirm alignment with the EAC, and therefore the claims and arguments presented in this SWESC and the underpinning risk assessments. Records of assessment of wastes against the EAC will be generated and retained to demonstrate conformance with the criteria. Figure 3.4 shows the interface between characterisation and the EAC.

206 The EAC will be revised following determination of the RSR and DfR permit applications to be consistent with any conditions included in the permits.

FP.4 Revise the EAC following determination of the RSR and DfR permit applications to be consistent with the issued permits.

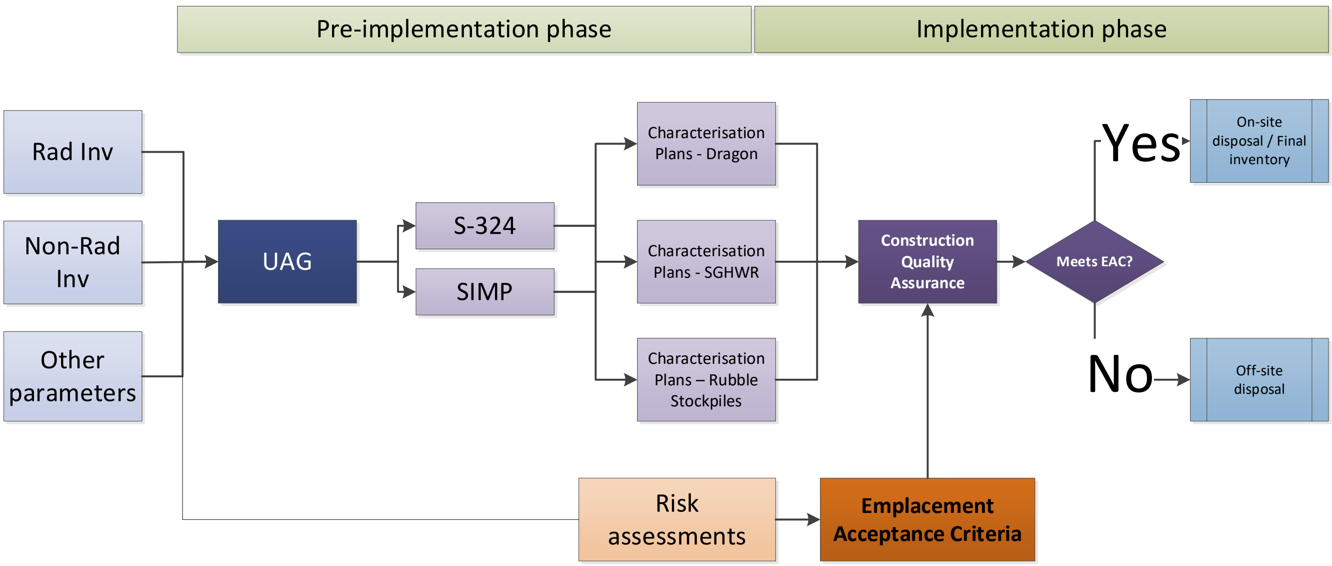

Figure 3.4: Interface between characterisation and emplacement acceptance criteria [22, Fig.3]. Previously undefined acronyms used in this figure are: UAG - uncertainties, assumptions and gaps, SIMP - Staged Inventory Management Plan, S-324 is the NRS standard procedure for characterisation management.

3.4.10 Site Stewardship to the SRS

M.12 Management control arrangements (termed stewardship arrangements) for the site have been developed to ensure effective assessment and monitoring of the site for the period between completion of active decommissioning and reaching the SRS. The arrangements control how the site will be maintained and the monitoring that will build confidence that the disposals behave as anticipated in this SWESC.

207 The existing site management arrangements and controls will remain in place until the site's IEP, supplemented with stewardship activities following implementation of each on-site disposal. There will be a period of stewardship continuing up to the SRS. Details of the arrangements that will be in place are given in the Stewardship Plan [27] and are summarised here.

208 Management of the site following active decommissioning through to the SRS will ensure that:

- public health and safety are safeguarded;

- the site is managed and maintained such that it allows for safe public access and provides the leisure amenity requested by stakeholders;
- environmental safety requirements are met with no overall adverse impact on the natural environment;
- regular monitoring of the site is undertaken; and
- records of the site and the disposals on it are preserved.

209 After the IEP public access to the site will be possible and physical deterrents (e.g. fencing) will be removed.

210 Between the IEP and the SRS the site will be managed centrally by NRS as there would not be a need for a permanent presence on the site. Attendance at the site would be limited to carrying out the following management and monitoring activities [27]:

- Site surveillance:
  - There will be occasional surveillance (e.g. walkovers and routine inspection of the engineered caps) associated with managing the landscape and identifying any unplanned activities on site after the IEP. Actions can then be undertaken to correct any issues needing attention.
- Habitat management arrangements, which include:
  - ground maintenance (e.g. heath cutting, pruning, maintenance of fire breaks, removing invasive species); and
  - surface water management activities (e.g. clearing and repairing watercourses).
- Environmental monitoring:
  - Engineered cap monitoring, which will primarily involve regular visual inspections to identify any intrusions into the cap, slumping or settling, erosion, drainage issues, etc. and periodic radiation dose monitoring for reassurance purposes.
  - Natural environment (habitats) monitoring to be undertaken to track restoration performance against the RMP target habitats [11].
  - Validation monitoring:
    - Some of the boreholes in the current groundwater monitoring programme will be used to validate the performance of the SGHWR and Dragon reactor complex end states through the decades between the site IEP and the SRS.
    - Groundwater samples will be analysed for radiological and non-radiological species and field parameters (e.g. pH, redox conditions).

211 The results of the various monitoring programmes will be interpreted on a regular basis to determine whether they are consistent with modelling expectations and whether there are any observable trends. Where a judgement has been reached that the disposals are performing in accordance with the SWESC, then no further action would be needed. If a change from the baseline is identified in one or more sets of monitoring results, then NRS and the NDA will determine if further action is appropriate.

212 Data and information arising from the monitoring programmes will be managed in accordance with the records management procedures described in Section 3.4.5. The monitoring programme outcomes will be communicated to the regulators and stakeholders as appropriate on a regular basis (see Chapter 4).

FP.5 Establish the management procedures necessary for site stewardship, including detailed monitoring, analysis and communications plans.

3.4.11 Development and Maintenance of the SWESC

M.13 Company management arrangements have been established to ensure that the SWESC and associated WMP are reviewed and updated on a regular basis, and that a clear audit trail is maintained.

213 The SWESC has been developed in accordance with the management arrangements described above (Sections 3.4.2, 3.4.5, 3.4.6 and 3.4.7) and will evolve through to a final assessment of the safety of the implemented on-site disposals at the SRS. Updates to the SWESC will reflect growing knowledge about the site and disposals, new characterisation data and feedback from regulators, together with, for example, developments in environmental safety measurement and assessment techniques, climate predictions and in technical understanding.

214 The environment agencies' guidance on the periodicity of SWESC production is set out in the GRR [6, ¶4.5.1]:

> *"The operator should maintain the SWESC in the light of factors such as developments at the site, new information, changes in legislation and government policy. They should update the SWESC at suitable intervals up to the release from RSR and should comprehensively review the SWESC at suitable intervals no less frequently than every 10 years. The SWESC, including any quantitative assessments within it, will need, at each stage, to be sufficiently detailed and comprehensive to inform and support the operators' decommissioning and clean-up programme in accordance with the WMP."*

215 This requirement is currently incorporated into the management arrangements via an interim process [9] pending implementation of new management system arrangements.

216 Comprehensive reviews (and updates where necessary) of the SWESC will be produced as required up to the SRS. As a minimum this will include an update once the disposals have been completed and a 10-yearly review as per the GRR.

217 The currently foreseen versions of the SWESC are as follows (Figure 3.5):

- The Permit Application SWESC (this document) has been prepared to support the permit variation application, building on the previous versions produced in 2017 [14] and 2019 [15]. Along with the SWESC, a WMP and other documents supporting the overall disposal case have been developed (see Section 1.4).
- The EA and other regulators will review the permit variation application and it is possible, though not definite, that when NRS responds to regulator comments, this may lead to an update of the SWESC.
- An updated SWESC will be prepared following the completion of all work involving radioactive substances. This version will demonstrate that the site's IEP has been achieved and will include updated information on the radioactive and non-radioactive inventories based on data acquired during decommissioning and demolition work. There may also be changes in the design of the disposals as a result of further

optimisation during the detailed design phase that needs to be incorporated into the SWESC (see Section 6.3). The revised SWESC will present the expected performance anticipated during the period after the IEP and beyond the SRS, and therefore will set the boundaries for environmental performance.

- The SWESC will then be reviewed at a minimum every 10 years in the period between the site IEP and the SRS. Where there are results from the environmental monitoring that would impact the claims, arguments and evidence set out in SWESC then this may lead to an updated SWESC. Note that a new version of the SWESC may not be required for each review cycle if there are no substantive changes that need to be included.
- The Final SWESC produced will demonstrate that people and the environment are and will continue to be adequately protected, that is, it will demonstrate that the SRS has been achieved and that the conditions for release of the site from RSR have been met. It will use the environmental monitoring data gathered over the preceding ~30 years to demonstrate that the disposals have performed within the agreed boundaries.

218 A document revision history and review register will be included in future versions of the SWESC. Arrangements for keeping the EA updated of changes to the SWESC will be agreed in due course.

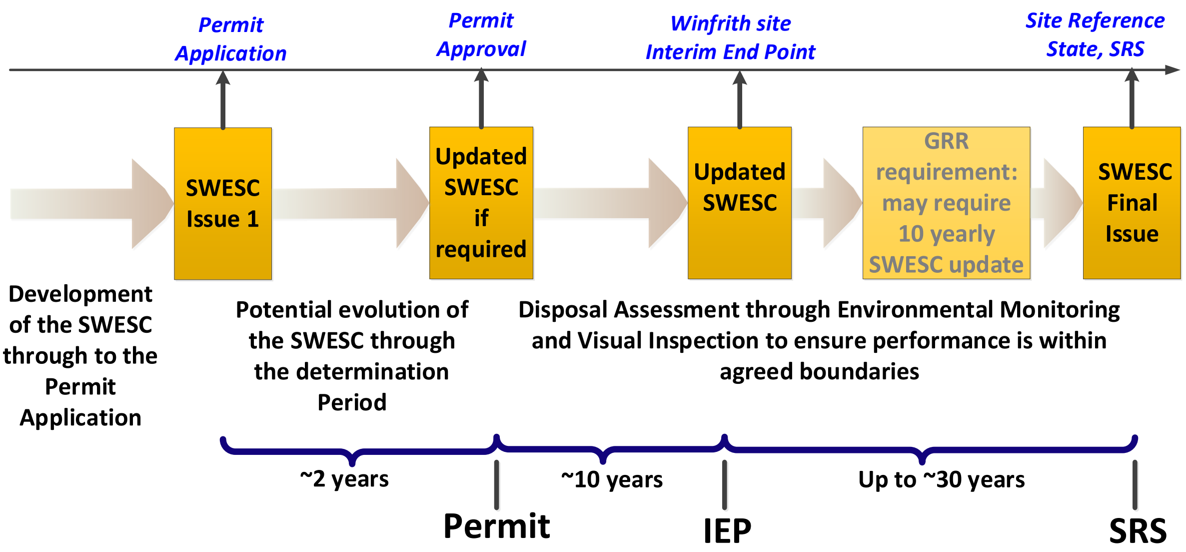

Figure 3.5: Winfrith end state SWESC development through to the SRS [27].

4 Undertaking Dialogue

Claim: Undertaking Dialogue
There has been frequent engagement with regulators, local communities and other relevant stakeholders in an open and inclusive manner to develop proposals for the end state, on-site disposals and the SWESC. Engagement with relevant stakeholders will continue throughout end state implementation and up to the SRS.

219 Management system arrangements for managing interactions with regulators and other stakeholders (including the local community) are defined within Process Document PD-002 'Stakeholder Engagement and Socioeconomics' [132]. This process identifies the major stakeholder interfaces and ensures formal communication arrangements are established, documented and understood.

220 Engagement to develop the proposals for the end state and on-site disposals has been on-going for over 10 years. Feedback from stakeholders and regulators has been gained through a variety of approaches suitable to gain the most effective input, including:

- On a one-to-one basis to address topic-specific issues.
- On a group basis to discuss tactical and strategic issues that concern more than one party. For example, regular meetings are held with the Winfrith Site Stakeholder Group (SSG), which is an independent, local community-based body, with administrative support provided by NRS as site operator (see below).
- Through public engagement events, the most recent of which was held in May and June 2023 [54].

221 All stakeholder interactions are recorded in the Winfrith End State 'Key Meetings Register'. Key engagement activities are summarised in Figure 4.1.

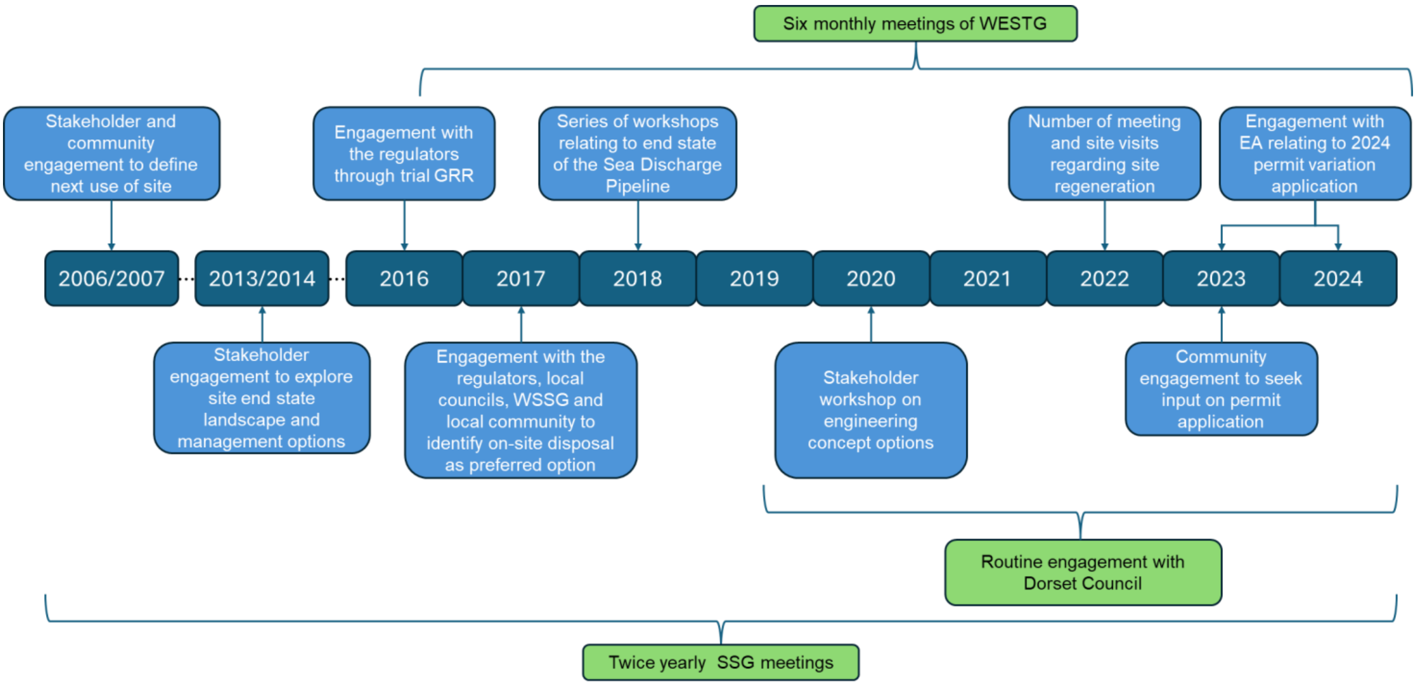

Figure 4.1: Summary timeline of key engagement activities.

4.1 Interaction with the Regulators

U.1 Relevant regulators have been engaged throughout the development of proposals for the site end state and on-site disposals since 2016 and will continue to be engaged as appropriate until the SRS is achieved. In addition to the EA, this includes engagement with other regulators and authorities whose responsibilities cover some aspects of the environmental impacts of decommissioning the site and on-site disposal, including the Office for Nuclear Regulation (ONR), Dorset Council and its planning authority, Natural England and the Marine Management Organisation (MMO).

4.1.1 Environment Agency

Engagement Through Trial Use of the 2016 Draft GRR

222 Winfrith was one of three sites that trialled the Draft GRR (the 2016 consultation document), as part of the "lead and learn" exercise. This included engaging with those in the environment agencies who were tasked with developing and planning the implementation of the GRR. Trial use of the Draft GRR included preparation of early versions of a WMP and SWESC for Winfrith, as well as supporting documents, which were subject to detailed review and feedback from the EA.

223 Contact with representatives of the environment agencies, as well as representatives of the NDA, ONR, Department for Business, Energy and Industrial Strategy (BEIS) and others proceeded in parallel during 2016-2017 through the UK-wide Site End States Strategic Steering Group. During and immediately after the period of trial use of the Draft GRR, the Site End States Strategic Steering Group interacted with tactical groups for each of the "lead and learn" sites, including the Winfrith End State Tactical Group (WESTG).

Winfrith End State Tactical Group

224 The WESTG has met approximately every six months in some form since February 2016, its primary purposes being to: identify and seek resolution of issues that are potential impediments to defining the end state for the site and/or effective delivery of work towards it; and ensure that there is early engagement on emerging issues prior to and during wider public engagement [133]. The WESTG members include representatives from the NDA, the EA, the ONR, Dorset Council planning team, and Natural England. The regulatory role within the WESTG is to provide advice and guidance in support of the development of the permit and planning applications, as well as escalating issues that cannot be resolved at a tactical level.

225 The primary outputs from the WESTG are agreed meeting minutes and updated versions of the issues / actions tracker (a record of identified issues along with the person / organisation responsible for addressing the issue).

Winfrith Site Stakeholder Group

226 The WSSG meet twice a year and it is a forum for open and transparent communication between the local community, the NDA, the site operator, local authorities (Dorset Council) and regulators, including the EA. It operates under the principles of openness and transparency, with the aim of being accessible to its communities. Meetings give stakeholders the opportunity to comment on and influence site strategies and plans. The WSSG is primarily site-focused but takes account of wider policy issues and developments. Meetings of the WSSG include discussions relevant to on-site disposal at Winfrith as well as updates on decommissioning activities. Meeting minutes are published on the SSG webpage: https://nrsssg.com/site/winfrith/.

Specific Meetings with the EA Relating to the 2024 Permit Variation Application

227 For the 2024 permit variation application, there has been regular engagement with the EA, outside of the WESTG, through in-person and online meetings that have focused on specific technical topics. Aspects of this SWESC and underpinning application document suite were developed in light of discussions at these meetings.

228 To ensure that these 'first of a kind' applications for on-site disposal are developed in accordance with regulator expectations, key documents and packages of work have been presented and submitted for advice and guidance ahead of submission. For example, first issues of the radiological and non-radiological inventories were provided and assessed by staff in the EA Nuclear Waste Assessment Team (NWAT) and the Geosciences Operations Team. Additionally, collaborative workstreams have been completed in relation to potential climate change impact on groundwater. Feedback received from the regulator through technical meetings has guided development and improvement of technical underpinning, including further modelling, and undertaking additional characterisation as appropriate.

229 Further meetings with the EA to discuss technical issues are envisaged to be needed throughout the permit application determination period, implementation of the end state and the validation monitoring period through to the SRS.

FP.6 Continue dialogue with the EA regarding determination of the permit application, implementation of the end state, and management of the environmental permits, SWESC and WMP.

4.1.2 Other Regulatory Bodies

Office for Nuclear Regulation

230 The ONR regulates nuclear site safety and security. It is intended that a nuclear site licence can be ended once the ONR is satisfied that all nuclear safety issues have been addressed and once the site meets internationally agreed standards.

231 Representatives of the ONR have been present at almost all meetings of the WSSG and WESTG. Engagement is on-going in relation to both the implementation of the end state and the process for exiting the nuclear site licence with on-site disposals in place.

Dorset Council

232 Dorset Council are the local planning authority responsible for review of the planning application associated with on-site disposal at Winfrith, as well as other site decommissioning activities requiring planning consent.

233 There has been extensive engagement with Dorset Council around the decommissioning schedule and plans for the IES:

- Dorset Council have been present at the WESTG meetings to share progress and request views and feedback, and have been included in all engagements regarding the site.
- Dorset Council[11] was present for the optimisation workshops to define the preferred

[11] Early rounds of engagement were with Purbeck District Council and Dorset County Council before they merged into a unitary authority.

approach to managing SGHWR and the Dragon reactor complex structures.

- The Waste Local Plan was updated to include a policy specific to Winfrith decommissioning that allows for applications in support of on-site disposal and recovery of wastes [134].
- There has been routine engagement with planning officers since the scoping opinion was issued (2019, [93]) to manage development the planning application, including the EIA and RMP.
- Pre-application support with Dorset Council planning officers is through a Memorandum of Understanding. For pre-application advice, a Planning Performance Agreement (PPA) covering a wide range of the council departments including ecology, highways and flood risk, has been agreed.

Natural England

234 Natural England is the government's advisory body for the natural environment in England. Its powers include defining ancient woodlands, awarding grants, designating National Landscapes and Sites of Special Scientific Interest, managing certain national nature reserves, overseeing access to open country and other recreation rights, and enforcing associated regulations.

235 There has been extensive engagement with Natural England throughout development of the proposals for Winfrith. Natural England attended optimisation workshops to define the preferred end state for the SGHWR and Dragon reactor complex structures. Representatives also attended the options assessment workshops for both the marine and terrestrial Sea Discharge Pipeline. Additionally, representatives have provided input into landscape and restoration designs as they have developed over the previous six years. Natural England routinely attends WESTG meetings and dedicated meetings have been held to discuss plans for the disposals and site restoration, as well as habitat surveys and restoration design.

236 Engagement increased in 2022 for the end state habitat designs, ecological survey requirements and RMP requirements, with monthly meetings now in place.

Marine Management Organisation

237 The MMO's purpose is to protect and enhance the marine environment, and support UK economic growth by enabling sustainable marine activities and development. Removal of the marine section of the Sea Discharge Pipeline will require permission from the MMO. MMO staff attended the options assessment workshop to define the preferred end state for the intertidal and marine structures. Further engagement will be undertaken in developing permissions to remove the Sea Discharge Pipeline.

FP.7 Continue dialogue with the other regulatory bodies regarding other necessary permissions and site restoration.

4.2 Interaction with Local Communities and Stakeholders

U.2 A high priority has been attached to stakeholder engagement and the views of the site's stakeholders are sought and taken into account when developing the decommissioning and restoration plans for the site. Engagement with local communities and stakeholder groups in an open and inclusive manner is a key priority.

238 There has been extensive engagement with the local community and other stakeholders in defining both the next planned land use and the end state, the outputs of which are described

in the ‘Statement of Community Involvement’ (SOCI) [54]). The end state engagement activities undertaken include:

- Meetings of the WSSG (as discussed above) including members of the local community.
- Formal consultation with the local community and stakeholders in 2006/2007 to define the site’s next planned land use. The output of this process defined the next planned land use of the Winfrith site as a heathland landscape of amenity value to the local community, with the potential for further economic development associated with the north end of site and rail siding, should a use be identified.
- A successful engagement programme through 2013/14 explored stakeholder views on possible site landscape and management options [38; 135]. The preferred options were:
  - Landscape: Hybrid between Option L1 - Habitat and Ecology and Option L2 – Amenity, with continued availability of the railway siding, and the necessary infrastructure to support it and the continued work of Tradebe Inutec, and with programmes in place for the management of the SSSIs and surface water arisings.
  - Management: Option M3 based upon a reduction in the nuclear licensed site area at 2021 (the assumed IEP at the time), with continued control of one or two ‘licensed islands’ up to the Final End Point. This approach would manage risks from residual contamination and to ensure that the entire site is safe for use as public access heathland. This option remained flexible to accommodate change or new data, such as a shorter decay period or early licence surrender.

  The output of the engagement informed further discussions on the IES for the Winfrith site, leading to its definition as:

  “Heathland with Public Access, suitable for amenity use and with the potential for employment opportunities in the northern area of the site.”
- In 2017 further engagement was undertaken with a range of stakeholders, including the representatives from the local community and WSSG, EA, ONR, councillors from Purbeck District Council (PDC) and Dorset County Council (DCC)[12]. This engagement identified on-site disposal of low-level radioactive and non-radioactive contaminated building materials as the preferred management option for the SGHWR and Dragon reactor buildings [136].
- In 2018, a number of workshops were undertaken to define the end state for the Winfrith Sea Discharge Pipeline. Workshops included attendees and input from the local community, landowners, tenants, EA, ONR, PDC, DCC, Natural England, Dorset Wildlife Trust, Historic England, the MMO and the Crown Estate [137]. Additional meetings with landowners were held specifically to understand their concerns and level of acceptance with regard to in-situ disposal options.
- In 2020, a stakeholder workshop was held to understand the views of the EA, the ONR, Dorset Council, Natural England and the Dorset Wildlife Trust on engineering concept options for the SGHWR and Dragon reactor complex end states [138].
- In 2022, a number of consultation meetings and site walkovers were held with Natural England, the EA, Dorset Council and Dorset Wildlife Trust to aid in the development of the site RMP.

[12] Purbeck District Council (PDC) and Dorset County Council (DCC) merged to create the Dorset Council (DC) unitary authority in 2020.

- In 2023 engagement with local communities was undertaken in the Winfrith area to seek input into end state plans and designs ahead of the application(s) being submitted in 2024. Community input was sought on three concept designs that were developed to balance providing inclusive access with optimal habitat regeneration. The engagement is described and analysed in detail in the SOCI [54]:
  - Flyers, postcards, local advertising (posters and local parish magazine) and social media (the local village Facebook pages, Twitter and LinkedIn) were used to promote the following engagement activities:
    - An exhibition supported by senior NRS staff within village halls local to Winfrith. This included information boards that presented the plans for on-site disposal of the SGHWR and Dragon reactor complex buildings.
    - An internet-based ‘virtual exhibition’ that mirrored the content of that presented within the local village halls (above).
  - Through both the physical and virtual exhibitions attendees were invited to respond to a questionnaire to enable views on the proposals to be registered. A total of 49 questionnaires were completed and of these 98% supported the proposals for on-site disposal and only one did not, favouring the use of the site for new nuclear reactors instead. In response to the proposals for restoration of the site to heathland with public access, 71% (35) of respondents agreed with the proposal to consider habitat to be the key priority in the site restoration and to restore the site to heathland with public access.
  - Copies of the promotional and engagement material can be found in the appendices of the SOCI [54].

239 Further engagement is planned prior to submission of the planning and permit applications to capture community views on the Environmental Statement and mitigation measures. Engagement will continue throughout the determination period and into delivery of the end state.

FP.8 Continue to engage with members of the local community and other stakeholders throughout the remaining permit period.

5 Disposal System Understanding

Claim: Disposal System Understanding
The wastes and the end state conceptual design proposed for on-site disposal, their surroundings (geosphere and biosphere) and future evolution are sufficiently understood for the purpose of assessing and demonstrating environmental safety. Where uncertainty exists, a structured uncertainties management methodology has been used to develop a forward programme with the aim of improving the understanding of the disposal system as decommissioning proceeds.

5.1 Understanding of the Features for On-site Disposal

D.1 The Winfrith site features proposed for on-site disposal are sufficiently well understood in terms of their operational history, engineering, geometry/extent and material properties. This has allowed relevant components (for inventory derivation and modelling of potential impacts) to be identified, and material volume calculations to be undertaken. Conceptual designs for the disposals have been developed consistent with the current system understanding and optimisation assessments undertaken to date, and by considering reasonably engineered and safely implementable options.

240 There is a detailed understanding of the operational history, geometry, engineering and material properties of present-day site features that are expected to form part of the end state. This has been developed through:

- Review of documentation, such as technical drawings produced prior to and during construction of the reactors and site facilities, and operational records.
- Interactions with subject matter experts who have been involved in the past and current decommissioning works at the Winfrith site.
- Data and reports from surveys conducted over many years for different purposes and using a variety of methods including visual inspection, laser analysis, engineering/structural surveying, and radiological/chemical characterisation.

241 The only structures intended for on-site disposal are the SGHWR and the Dragon reactor complex[13]. Each reactor is formed from multiple components. These components are described in the following sections, together with a discussion on how the components are considered in the risk assessments for the proposed on-site disposals (Chapter 7). More detailed information is contained within the Radiological Inventory Report [17], Conceptual Site Model [19] and the Design Substantiation Report [25].

242 The Design Substantiation Report sets out the design stages that apply to the proposed SGHWR and Dragon reactor complex on-site disposals [25, Fig.8 and Fig.9] (see Figure 5.1). The proposed disposals are currently at the conceptual design stage (as summarised in Section 5.1.3), in which key design aspects are “frozen” to support decision-making and this permit application. The detailed design stage will occur after determination of the permit application to ensure conditions specified in the planning permission and environmental permit can be incorporated.

[13] Other non-radioactive (OoS) sub-surface structures may remain on-site, but they are not wastes and are not in the scope of this SWESC and permit application.

243 The conceptual designs are underpinned by a set of engineering assessments and studies including:

- SGHWR structural assessment and demolition study [139].
- Consideration of concrete permeability [140].
- Evidence for groundwater ingress [141].
- Review of construction joints and water bars [142].
- Review of penetrations in the structures [25].
- SGHWR and Dragon reactor basement structural integrity assessment [143].

244 The engineering assessments have been developed, in parallel with the development of optimisation and risk assessments, to demonstrate that the below-ground concrete structures are sufficiently robust to maintain integrity and prevent direct discharge through implementation and up to achieving the SRS. The long-term performance of these structures in relation to protection of the environment is considered in Section 7.4.1.

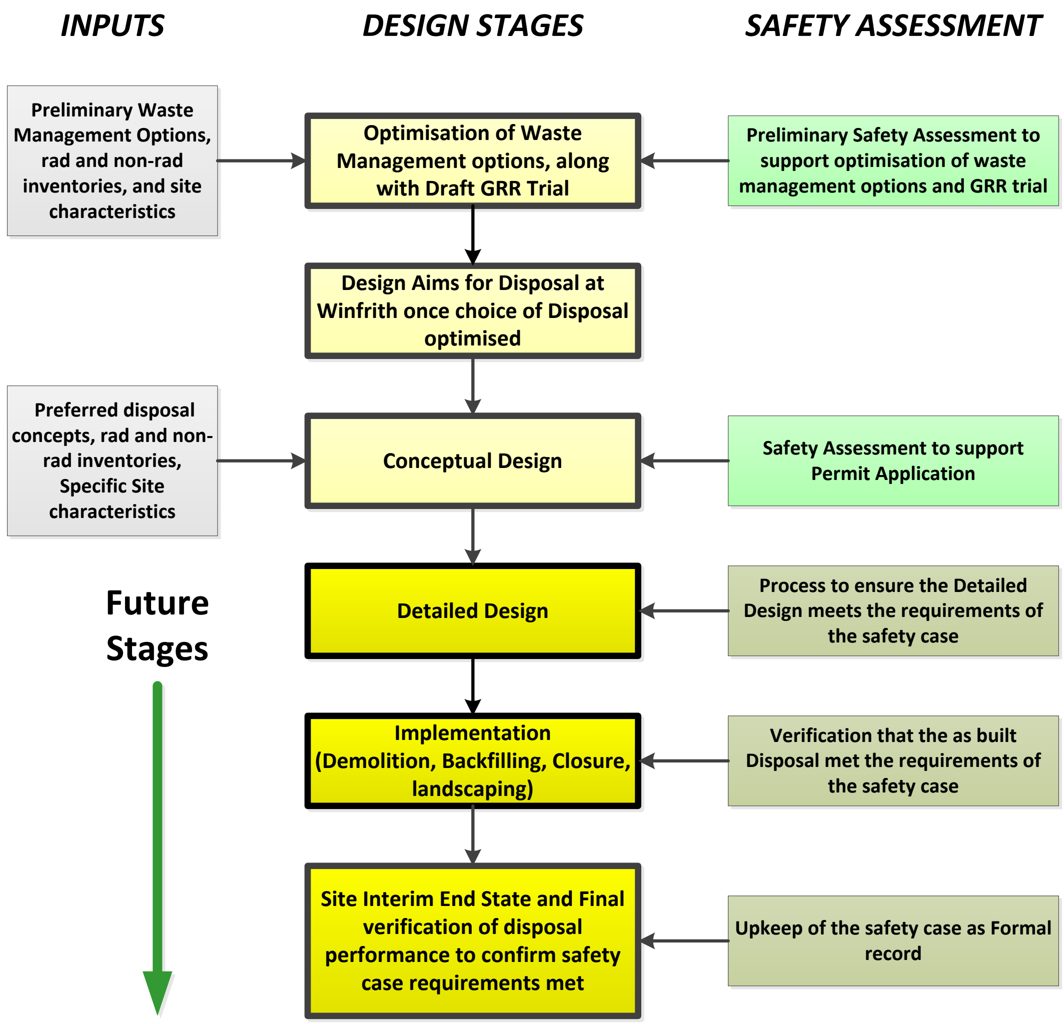

Figure 5.1: The design process showing the relationship between the design phases and the design aims, safety assessments, information input and implementation [25, Fig.8].

5.1.1 SGHWR

245 The SGHWR was the largest reactor on the Winfrith site and was the only light-water cooled and heavy-water moderated reactor ever to be built in the UK [144]. The reactor achieved first criticality in 1968 and operated for 23 years for research and electricity supply to the national grid (the only Winfrith reactor to do so), before it was switched off in 1990.

246 The SGHWR reactor building, D60, consists of ten levels, three of which are below ground and are constructed mainly of reinforced concrete. Above ground, the structure is a steel-clad metal frame with masonry (brick) and concrete internal structures. The SGHWR structure consists of the following features:

- **Bioshield** [17, §2.10]. A reinforced concrete structure located on levels 1-3 (below ground) at the centre of the primary containment that enclosed the reactor core during reactor operation. The bioshield is 7.0 m high and its walls vary from 1.2 m to 2.8 m thick.
- **Mortuary tubes** [17, §2.11]. The mortuary tubes consist of ten storage locations for irradiated items constructed as part of the bioshield. Each tube consists of a ‘cast-in’ steel liner approximately 0.2 m in diameter and runs from the top of the bioshield to 2.7 m below the bioshield, where a 90° bend exits from the east wall of the primary containment.
- **Primary containment** [17, §2.12]. A massive concrete structure with walls 1.2 m to 1.5 m thick extending from level 1 to level 6. It houses the reactor core and formerly held numerous support operations and processes, including steam drums, clean-up plant and electrical control. The bioshield and mortuary tubes lie within the primary containment. The external walls of the primary containment are strengthened by concrete buttresses. The areas between the buttresses are enclosed by brickwork, forming cofferdam voids that have been backfilled with gravel to provide structural support [25, §A.8; 17; §2.13.2]. The cofferdams were designed to help prevent water ingress into the facility [17; §2.13.2].
- **Secondary containment** [17, §2.13]. A concrete structure extending from level 1 to level 9 that housed the turbine / alternator, emergency water supplies, additional circuit supplies, plantrooms, ponds complex, effluent facilities, waste processing areas and workshop areas. The wall thickness varies depending on the area, with walls more than 1 m thick for the condenser cell in the turbine hall, to walls of relatively standard construction (e.g. 0.3 m thick).
- **Ponds** [17, §2.14]. There are three distinct types of pond within the SGHWR complex, all adjacent to the primary containment: fuel element ponds used for the storage of spent fuel prior to off-site transport; dump ponds; and suppression ponds. The ponds were emptied after fuel transfer ceased and were drained between 2003 and 2005. There are cofferdams surrounding the underground portion of the ponds as well as the primary containment [17; §2.13.2]. The concrete ponds are lined with fibreglass and are more than 11 m deep. The smallest (dump) ponds are 9.5 m by 2 m and the largest, the fuel element pond, is 22.9 m by 4.9 m.
- **Ancillary areas** [17, §2.15]. A considerable number of rooms in the SGHWR exist outside the secondary containment structure. Some of these rooms supported active process operations: the active workshops, the boiler house basement, the fuel oil tank room, the active cooling water pump house basement and the cable basement. There are also many rooms in the ancillary areas that did not support active process operations.

247 All operational plant and equipment from the primary and secondary containment, with the exception of the reactor core and ventilation system, has been decommissioned and removed (see Figure 5.2). Preparations are in process for removal of the SGHWR core. The resulting waste will be grouted in built-for-purpose containers and will be transported off-site for storage [8].

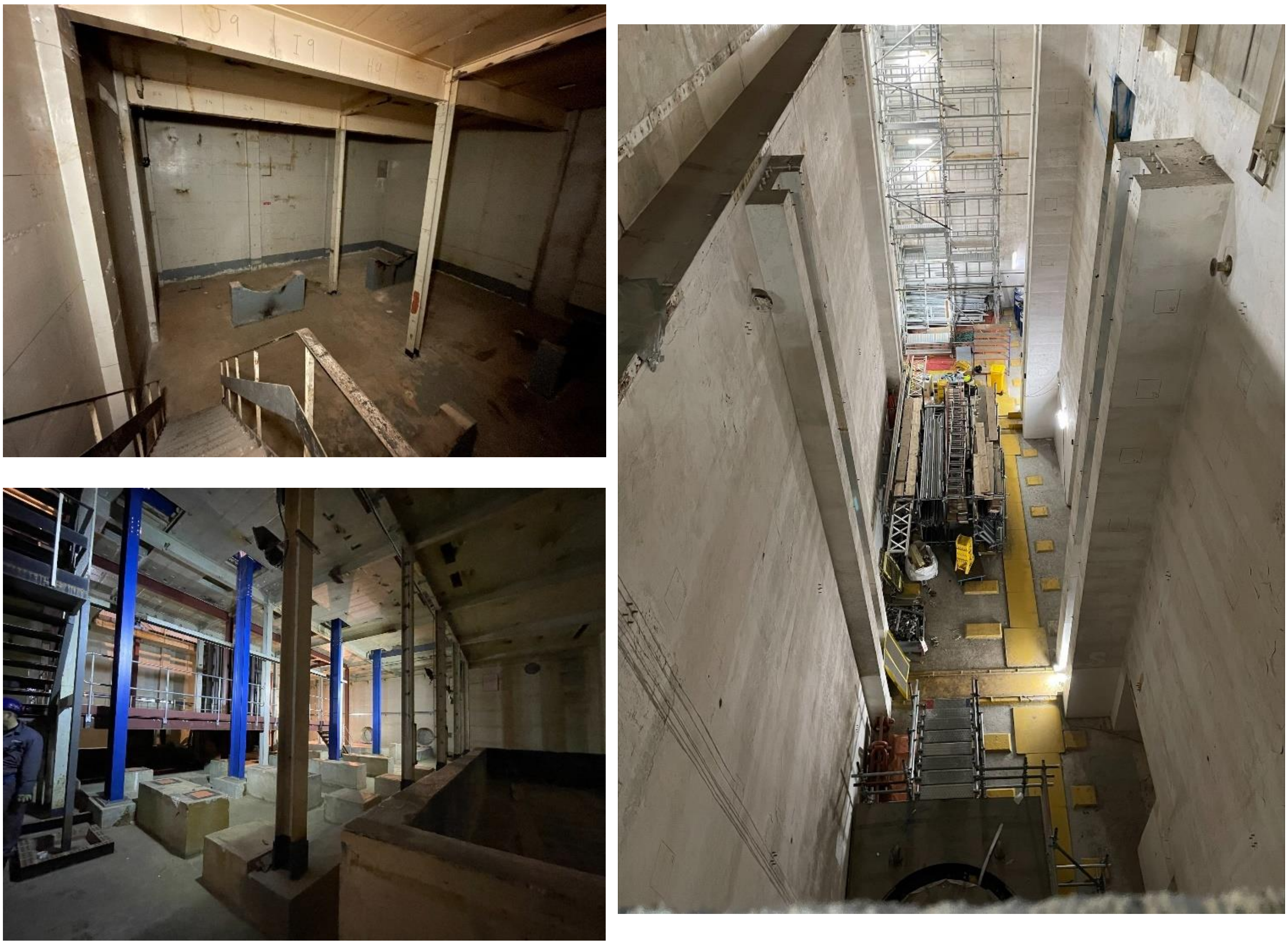

Figure 5.2: Photos showing SGHWR rooms in various stages of decommissioning, being completely stripped (top left), the use of temporary additional structural steels in some areas to support core removal (bottom left), and the cleaned ponds being used as a temporary laydown area (right).

248 The structural integrity assessment [143] concluded that the thick-walled below-ground structures of the SGHWR primary containment and turbine hall will retain their structural integrity through demolition and backfilling works to achieve the IES (as discussed in Section 6.3.1), potentially subject to some local propping and remedial works.

249 There are various penetrations in the below-ground structures of the primary containment and turbine hall, including large openings for the vent stack exhaust pipes and the redundant cooling water mains [25] (see Figure 5.3). Penetrations in boundary structures (i.e. structures that are, or may be through climate change, in contact with groundwater and could allow direct discharges to groundwater) will be sealed. The detailed design will address how these will be filled and appropriately sealed prior to backfilling [25; §4.2.6]. Additionally, the structural integrity report [143] recommended sealing the hatches to the cofferdams as an extra protection [25, §A.8]. The potential for groundwater ingress and egress has been considered [25, §4.2.4]

and a 2023 survey [141] found no evidence of groundwater ingress. In 2024 water ingress has been observed, which has occurred coincidently with very high levels of rainfall. The reasons for this increased water ingress and the routes that the ingress takes are currently being investigated. The detailed design will need to address the underlying cause of groundwater ingress/egress and, if this could become a direct discharge to groundwater, optimise the management approach.

FP.9 Investigate recent (2024) SGHWR water ingress and identify appropriate and optimised remediation options where this could become a direct discharge to groundwater.

Figure 5.3: Examples of penetrations in the SGHWR below-ground structures, ranging from relatively small pipe openings (left) to large emergency cooling water mains (right).

250 Although the SGHWR comprises many rooms, the below-ground level elements have been simplified, for the purposes of risk assessment modelling, into four regions based on the elevation of the basal floor slab in each region. Each region consists of structural elements (walls and floors) which will remain in-situ, and void spaces (rooms) between them, which will be filled with concrete blocks and/or demolition arisings. The SGHWR regions are summarised in Table **5.1** and illustrated in Figure 5.4 and Figure 5.5, and form the basis of the conceptual model of the proposed SGHWR on-site disposal considered in the risk assessments.

251 Following removal of all accessible non-structural materials where it is optimised to do so, the remaining above-ground structure will be demolished to 1 m below ground level (with reference to the south side ground level of 41.6 m; see Figure 5.5). The below-ground voids will be filled with concrete blocks (in Region 1) and demolition arisings from the above-ground SGHWR demolition and with demolition material from the existing site rubble mounds. The risk assessments consider a variety of scenarios including the emplacement of concrete blocks at the base of Region 1 and the remaining void space topped up with demolition arisings, and the use of demolition arisings throughout the structure.

Table 5.1: Summary of SGHWR regions considered in the risk assessments (based on [19, §2.2.1]). AOD = above Ordnance Datum. The current observed average groundwater elevation around SGHWR is 32.76 m AOD [180, Tab.616/1].

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

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

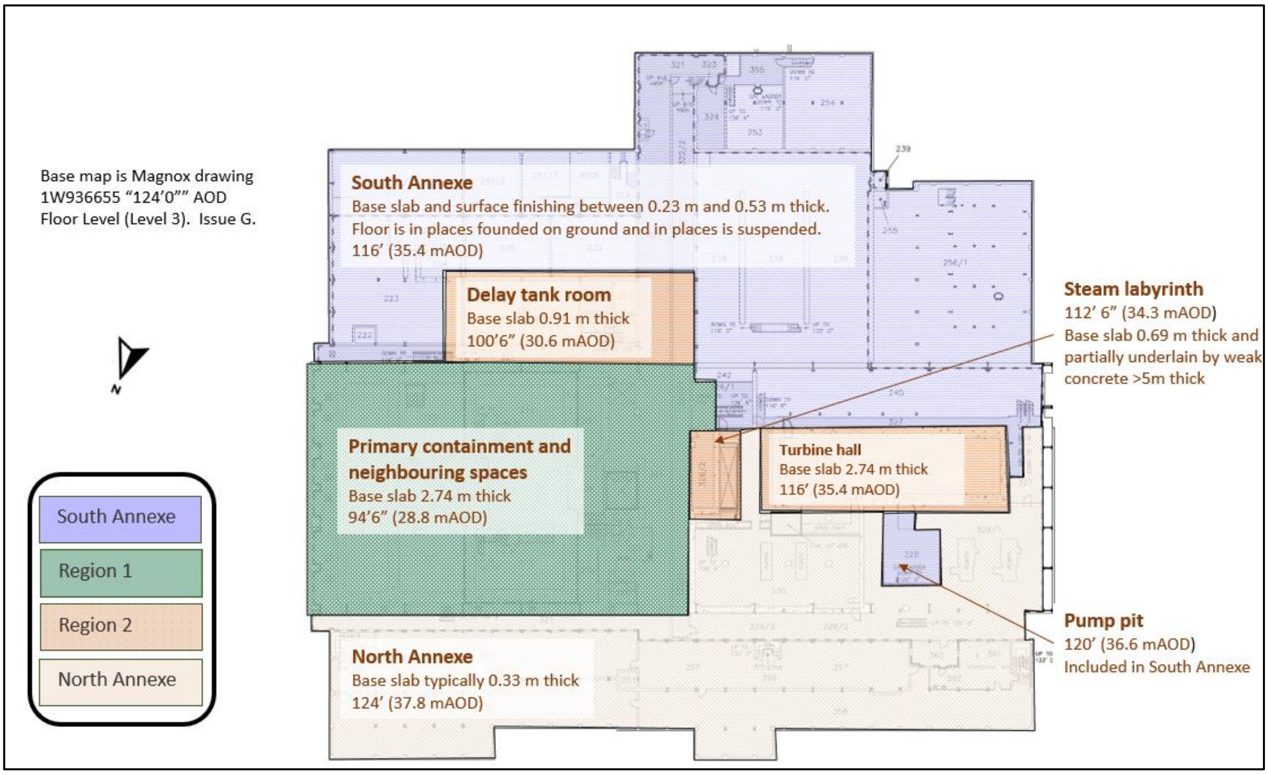

Figure 5.4: Plan showing the four below-ground regions of the SGHWR structure considered in the risk assessments [19, Fig.606/4].

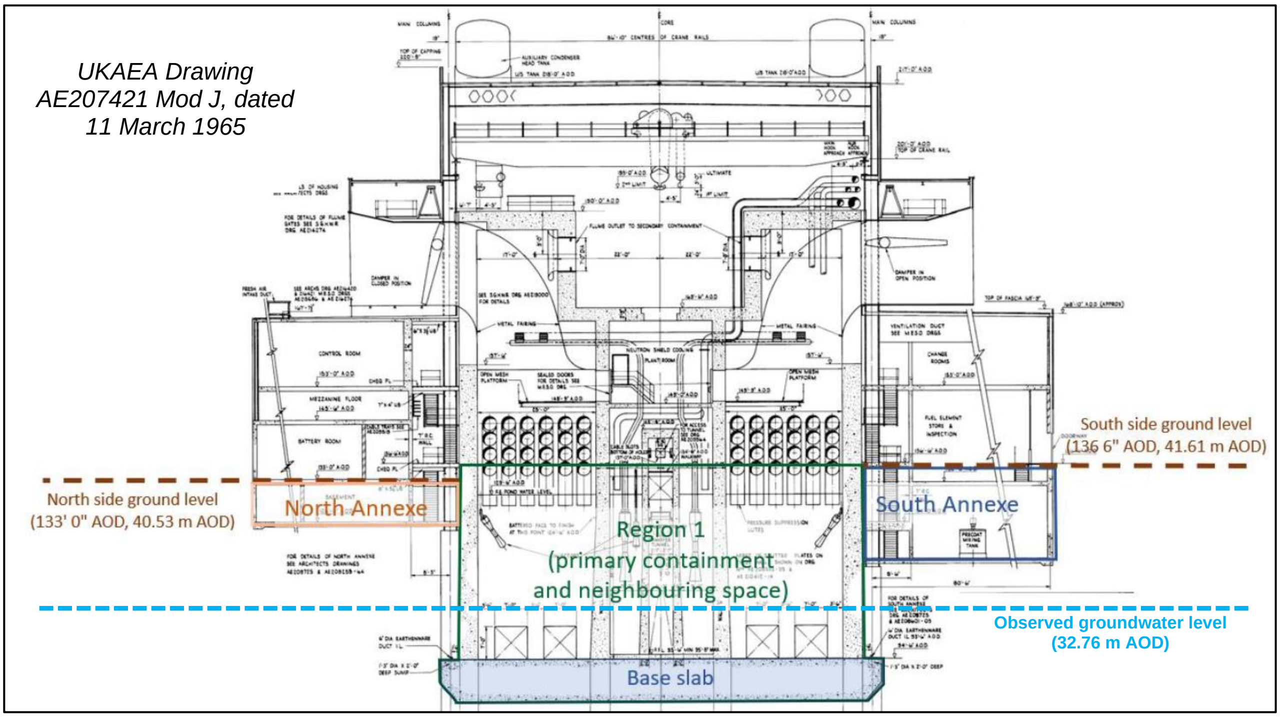

Figure 5.5: Cross-section through the SGHWR structure with ground level and current groundwater level indicated. Edited based on [19, Fig.606/5]. Note the diagram shows plant and equipment that has been decommissioned and removed.

5.1.2 Dragon Reactor Complex

252 The Dragon reactor was an experimental high-temperature reactor with a graphite-moderated, helium gas-cooled core. Operational between June 1965 and September 1975 [145], it was built and managed as part of an OECD project to develop high temperature reactors (HTR) and to develop graphite-coated uranium-thorium fuel cycle technology.

253 The Dragon reactor building, B70, is attached by a corridor to the fuel storage building, B78. The Dragon reactor building is founded on a 3.7-m-thick steel-reinforced concrete base slab, is circular in plan-view and has three concentric concrete walls referred to as Wall A, Wall B and Wall C from the outside in, as shown in Figure 5.6. There is a steel inner containment shell between Walls B and C, and Wall D forms the concrete bioshield around the reactor.

254 The Dragon reactor complex consists of the following key components:

- **Bioshield** [17, §3.4]. A cylindrical reinforced concrete structure extending from the steel base plate and surrounding the reactor pressure vessel and thermal shield tanks. Parts of the bioshield were constructed from barytes concrete. The bioshield is 1.8 m thick at its widest point, narrowing slightly (with a larger inner diameter) towards the top of the reactor chamber. The inner diameter is 4.7 m and the height in April 2024 (following removal down to the +18' level) was 12.6 m.
- **B70 reactor building** (excluding bioshield) [17, §3.5]. The remaining structure of the Dragon reactor building, primarily consisting of concentric concrete Walls A, B and C, and the steel containment shell, as well as the concrete walls, floors and ceilings of various internal rooms. These include a room used for the storage of tritium (^3H) dials, known as Betalites, at the -25' level in the outer annulus (between Walls A and B). Walls B and C are either side of the steel inner containment shell, the below-ground portion of which is proposed to remain in-situ.

- **B78 fuel storage building** (excluding the primary mortuary hole structure) [17, §3.7]. The floor slab of the B78 building is contiguous with that of the B70 building vehicle airlock and there are steel rail tracks embedded in the floor slab running all the way from B78 to the reactor core, which were used to transport fuel between the buildings. The B78 building has been used more generally for decommissioning activities and waste packaging and storage prior to dispatch off site.
- **Primary mortuary hole structure** [17, §3.9]. Built into the floor of building B78 is the mortuary hole structure, comprising 90 mortuary holes that were used to store Dragon fuel elements during its operational life and for the storage of other materials following defueling of the Dragon reactor. The mortuary hole structure includes a 50-hole used fuel ("primary") store and a 40-hole fresh fuel store, with the latter to be removed and disposed of off-site. Constructed in a concrete lined and filled pit roughly 5 m below ground level, the primary mortuary hole system comprises vertical galvanised mild steel tubes.

255 A recent assessment [143] concluded that, as for SGHWR, the thick-walled below-ground structures of the Dragon reactor will retain their structural integrity through demolition and backfilling works to achieve the IES (as discussed in Section 6.3.1). No water accumulation or ingress has been observed in the Dragon reactor building either historically or currently. As for SGHWR, there are some penetrations in the below-ground structures of the Dragon reactor. Where penetrations pose a risk of direct discharge to groundwater, the optimised approach to sealing will be assessed and repairs completed prior to backfilling [25, §A.8].

256 The below-ground level elements of the Dragon reactor complex are relatively simple and the regions forming the conceptual model for radiological risk assessment broadly correspond to the components listed above. In addition to the below-ground parts of the structures, there are below-ground void spaces in the middle of the bioshield (where the reactor was), between Walls C and D, and between Walls A and B[14]. Other than the mortuary holes, the floor slab is the only below-ground structure associated with building B78, and it has no significant below-ground void spaces.

257 The Dragon reactor and fuel storage building structures are illustrated in Figure 5.6 and Figure 5.7 respectively.

258 The plant and equipment required for operations has been decommissioned and removed, with the exception of the core and the ventilation system.

259 Following removal of all accessible non-structural materials, the remaining above-ground Dragon reactor complex structures will be demolished to ground level and the surrounding land reprofiled. The below-ground voids will be filled with concrete blocks (within Wall C) and broken concrete from the above-ground demolition and with demolition arisings from the existing site rubble mound. The risk assessments assume that concrete blocks will be placed in the void within Wall A and topped up with demolition arisings, and the other Dragon voids would be filled with demolition arisings.

[14] There are also below-ground void spaces outside of Wall A (such as the service duct). However, based on discussions with facility staff, these are assumed to be uncontaminated and will be filled with clean material. Therefore, they do not form part of the proposal for on-site disposal and are not modelled in the risk assessments. As a potential route for direct discharges, the service duct penetrations will be sealed where optimal to do so prior to backfilling.

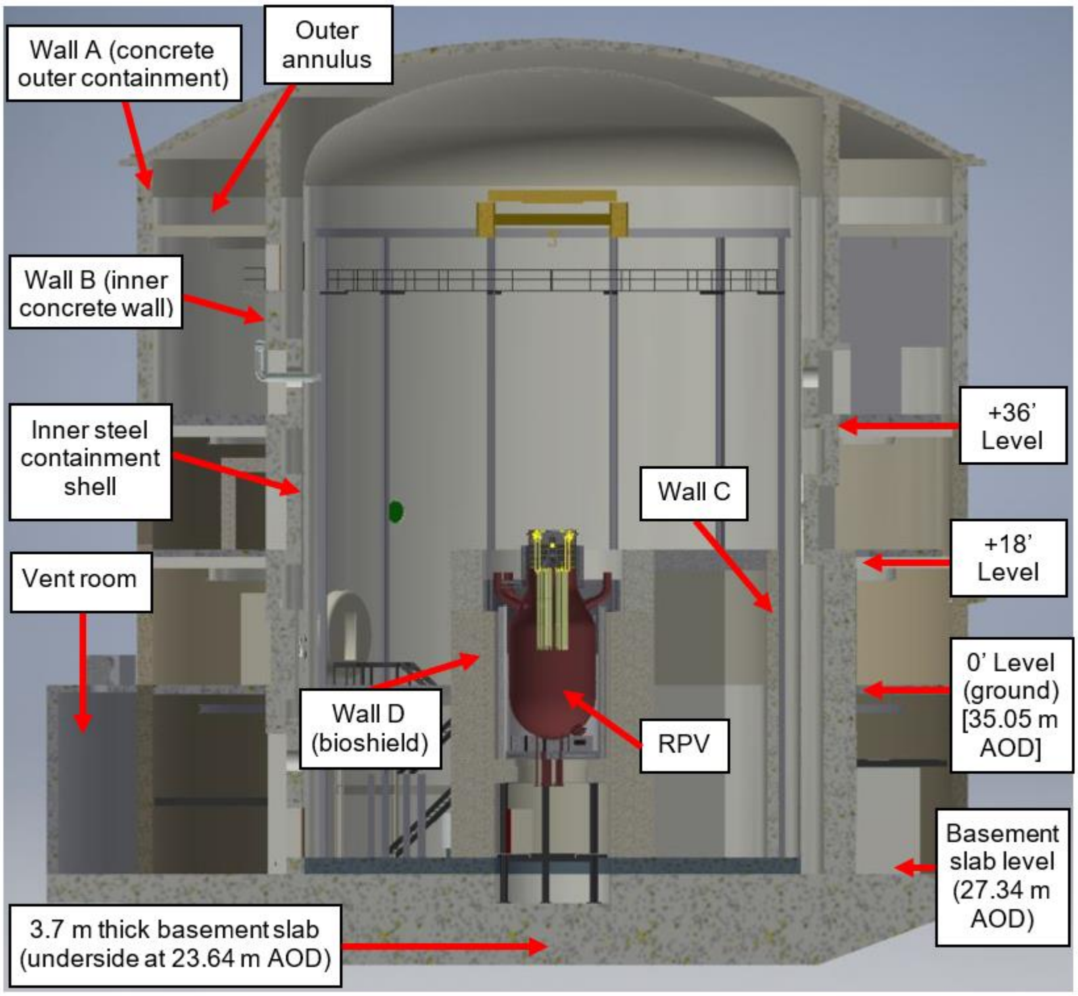

Figure 5.6: Split-view graphical model of the status in 2018 of the Dragon reactor building (edited from [146, Fig.1]).

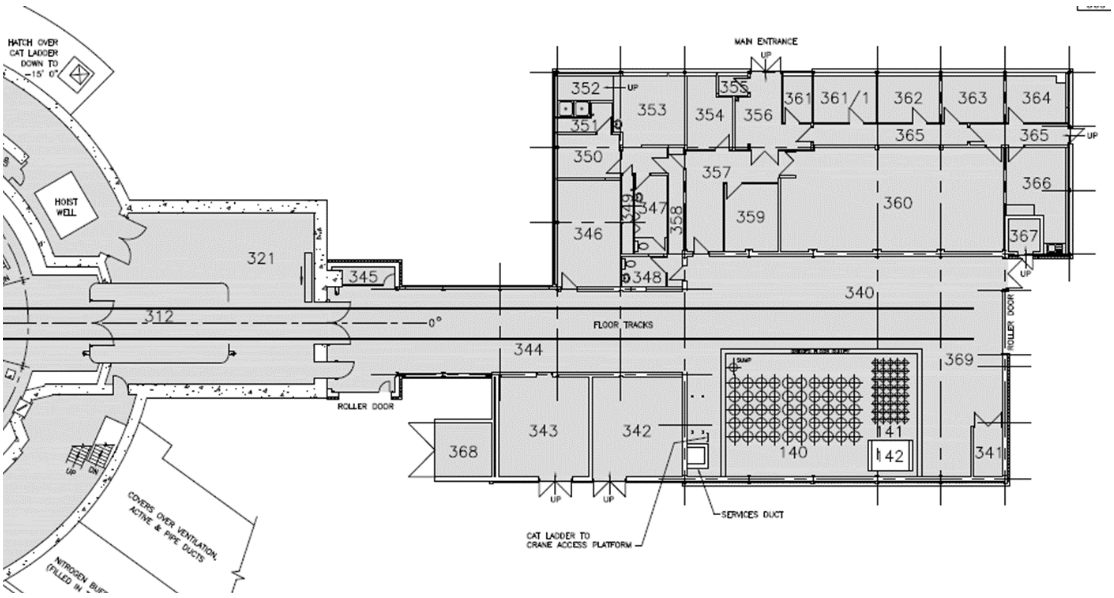

Figure 5.7: Plan view of the B78 building and its connection to the Dragon reactor building (B70) (extract from [147]). The used and fresh fuel mortuary hole structures are shown within B78, labelled 140 and 141 respectively.

5.1.3 Summary of the Conceptual Design for On-site Disposals

260 Optimisation of the proposed on-site disposals and their end state configuration is discussed in Chapter 6. The conceptual design for the proposed disposals is summarised as:

- Removal of accessible metals and other non-concrete/masonry materials where it is practicable to do so.
- Demolition of Dragon reactor complex structures to ground level and the SGHWR structure to 1 m below ground level (relative to the elevation of the south side of the building) using conventional demolition techniques for the bulk of the buildings, along with block cutting for robust concrete walls.
- Filling and sealing of penetrations in the below-ground boundary structures, as needed to prevent direct discharges to groundwater.
- Remaining SGHWR and Dragon reactor voids filled with large concrete 'blocks' at the base of the voids (in the SGHWR Region 1 and within Dragon reactor Wall C) and demolition rubble from the above ground level structures or existing rubble mounds (Figure 5.8 and Figure 5.9).
- Filling of the Dragon primary mortuary holes with cementitious grout.
- Implementation of engineered caps over the SGHWR and Dragon reactor complex disposals (see Figure 5.10 and Section 6.3.4).
- Appropriate landscaping and planting above the cap, including surface water drainage to remove water and limit infiltration, in accordance with the Functional Requirements [25]. Additional requirements for the cap and landscaping cover are specified in the RMP [11].

261 The frozen conceptual designs form the basis of the risk assessments presented in Chapter 7. Detailed designs will be developed after determination of the permit application.

FP.10 Ensure that the detailed design of the proposed on-site disposals is optimised, is consistent with the SWESC and underpinning assessments, and is in accordance with the functional requirements.

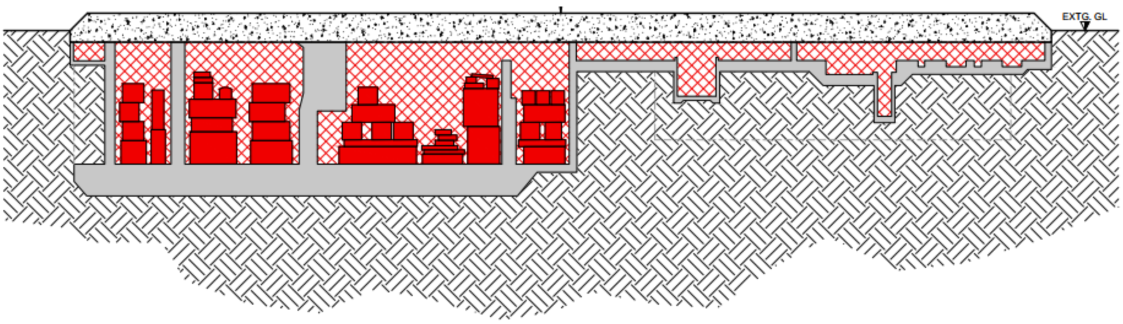

Figure 5.8: Schematic showing the conceptual design for the SGHWR end state. Large concrete blocks (solid red) placed in below-ground voids and demolition rubble and stockpile material (red hatched area) placed around and above these blocks and in the annexe areas at higher level.

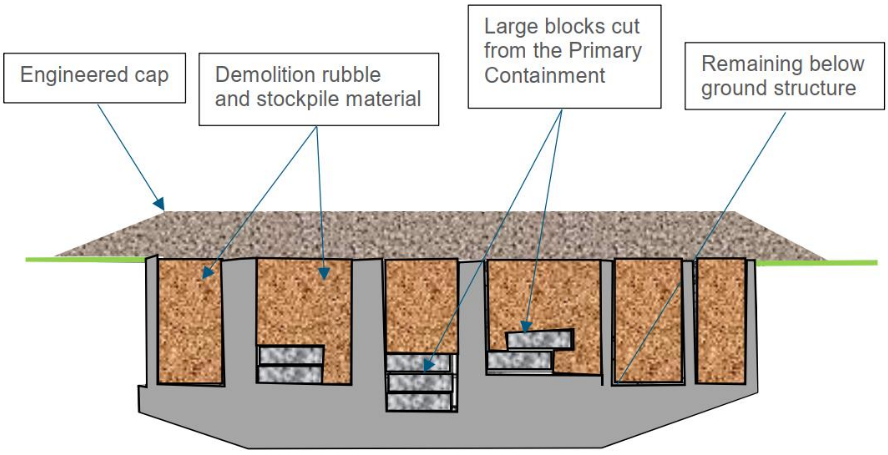

Figure 5.9: Schematic showing the conceptual design for the Dragon reactor end state. The cap will extend over the B78 floor slab and the mortuary holes (not shown).

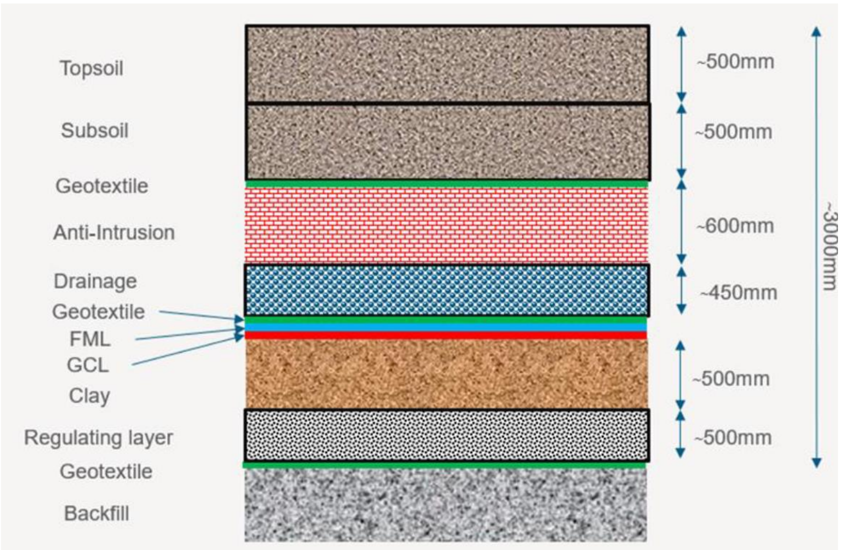

Figure 5.10: Illustration of the ten capping layers in the conceptual design for the engineered cap over the on-site disposals [148, Fig.615/1]. Acronyms: FML = Flexible Membrane Liner; GCL = Geosynthetic Clay Liner. The geomembrane, geosynthetic clay and mineral layers act together to vertical movement of infiltrating water. The overlying drainage layer is intended to shed infiltrating water to the edge of the cap.

5.2 Understanding of Additional Risk Assessment Features

262 All other areas of site, including land and sub-surface slabs, will be remediated to OoS levels. There are known areas of contamination on the site that will be remediated prior to the IEP. The remaining areas of site will be assessed in accordance with the Zone Close-out Process [45] and suitable evidence will be generated and retained.

263 The management strategy for the potentially radiologically-contaminated land in the former A59 area is now to remediate (if necessary) and remove off-site discrete areas of contamination such that the remaining ground is OoS of RSR (Section 6.2.2). Thus, the A59 area does not form part of the GRR permit application. However, there is the potential for combination of

releases from the SGHWR disposal and OoS land in the A59 area. Thus, the A59 area remains within the scope of the radiological risk assessment [23], albeit with a radiological inventory estimate that is OoS of RSR, in order to ensure a robust transparent. Nonetheless, although the risks from the remediated OoS A59 area are presented in Chapter 7 and the supporting risk assessments, this area does not form part of the GRR permit application.

264 A full description of the A59 area, its history, incidents with potential for ground contamination, building demolition and the remediation programme is presented in Chapter 2 of the A59 Inventory Report [149]. Following demolition of the A59 active handling and decontamination building, the remaining contamination is expected to lie at the base of the historical excavations. For the purposes of the radiological risk assessments, the remediated OoS A59 area is modelled as three sub-areas: the A591 / Heavy Vehicle Airlock (HVA) area; the Pit 3 / Pressurised Suit Area (PSA) area; and the remaining A59 Other area.

5.3 Site Understanding and Characterisation

5.3.1 Understanding of the Site at the Present Day

D.2 A detailed description of the current characteristics of the site and the local surrounding region has been developed to support both the demonstration of environmental safety and optimisation. Development of this understanding has involved desk studies, site investigations and detailed quantitative modelling.

265 The current characteristics of the Winfrith site, and the information necessary to support the development of the SWESC, and the radiological and non-radiological risk assessments, are fully described in the Winfrith Site Description Report [20] and the Hydrogeological Interpretation Report [21]. The salient features of the site are summarised here.

Topography and Physiography

266 The site is located within the valley of the River Frome. The site is bordered by two distinct river systems (see Figure 2.2 on page 33): to the north, the River Frome and, skirting the south-east of the site, the smaller River Win (a tributary of the Frome). The site itself is relatively low-lying, with ground elevations ranging from 20 m AOD to 50 m AOD, and with the ground sloping downwards towards the Rivers Win and Frome from the summit of Blacknoll Hill at 62 m AOD just south of the south-west corner of the site [20, §2.2; 21, §3.1] (Figure 5.11). The topography on the north side of the railway falls to about 17 m AOD adjacent to the River Frome.

267 Around 85% of the Winfrith site is classed as permeable ground. This consists of heathland, tree plantations and grassland, and includes a protected woodland (Coltsclose Corner). Made ground includes buildings, associated hard-standing areas, a network of roads and car-parking areas [23, §3.3.1].

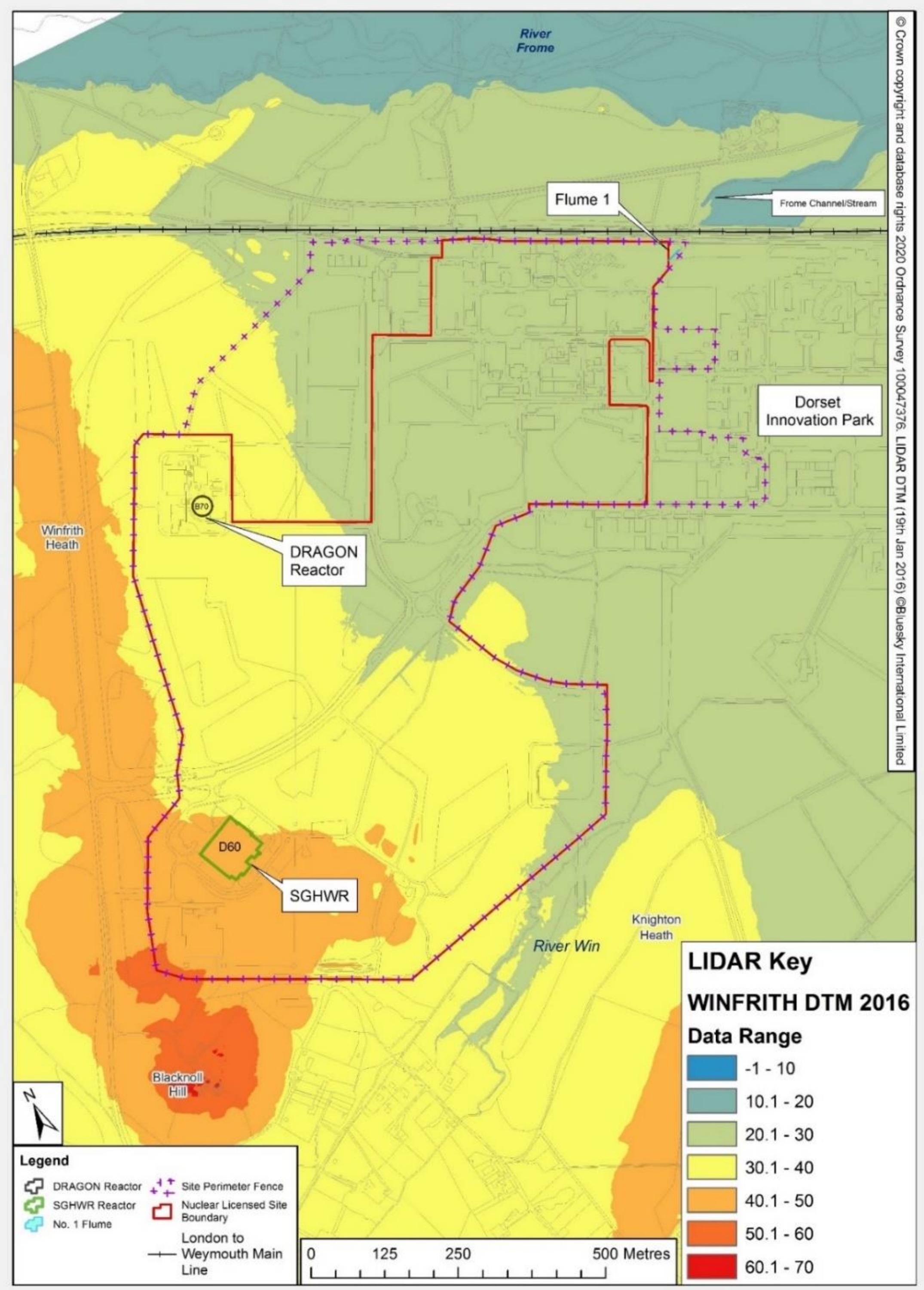

Figure 5.11: Winfrith site topography; the colour scale corresponds to m AOD [21, Fig.604/5].

Soils and Geology

268 The soils underlying the site are defined as the "Shirrell Heath 1 Formation", comprising well-drained, acid, sandy soils, with a bleached sub-surface horizon [150]. In general terms, this formation is a podzol (Figure 5.12), which are typified by a leached sandy layer and are often associated with heathlands.

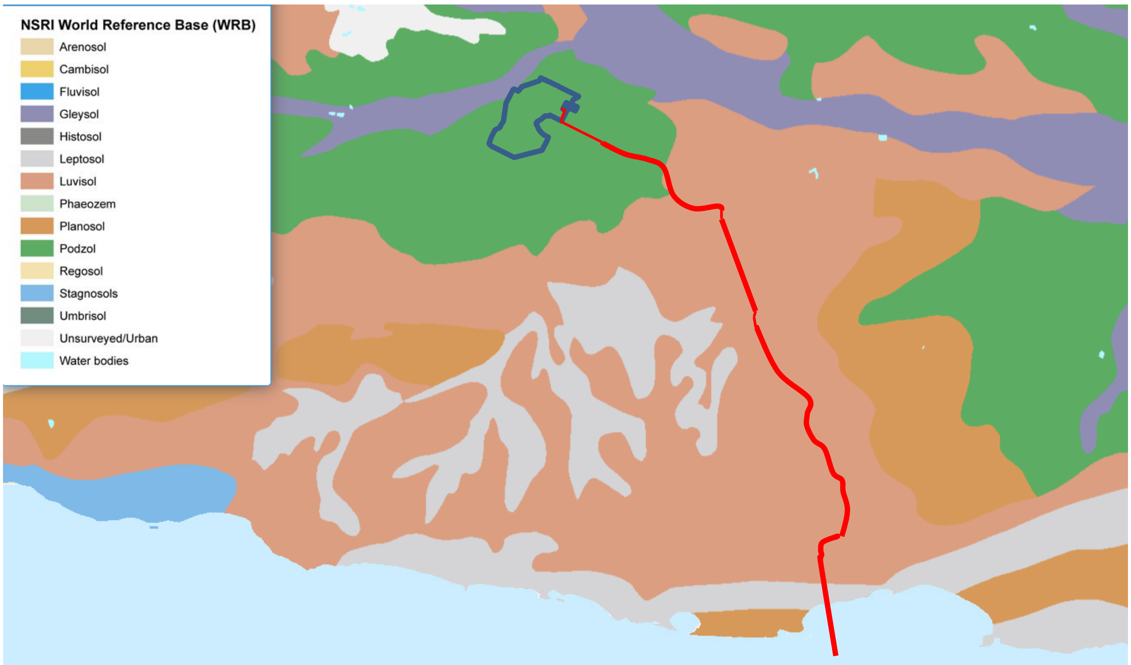

Figure 5.12: Map showing the soil types in the Dorset region [150], with an indicative outline of the site location and route of the Sea Discharge Pipeline.

269 The bedrock geology of Dorset is dominated by Cenozoic and Mesozoic formations that are folded in a broad synclinal basin, termed the Wareham Basin. The main Cenozoic Groups underlying the Winfrith site are the Bracklesham and Thames Groups, of which the Poole and London Clay Formations are the main units, and these are underlain by the Mesozoic age White Chalk, of which the local formation is termed the Portsdown Chalk Formation. The superficial and bedrock geology in the region of the Winfrith site, in order of increasing depth, is listed in Table 5.2 and shown in Figure **5.13**. The units are described as follows [20, §4.2; 21, §5]:

- Made Ground – This includes asphalt, paving, the remains of demolished buildings and reworked natural material. The site was heavily modified during the 1950s/1960s construction phase, so very little of the pre-construction surface levels remain. In areas that have been further developed there is typically around 1 m of Made Ground. Greater thicknesses of made ground also exist locally where excavations have been backfilled.
- Quaternary Deposits – Head and River Terrace Deposits are present across much of the site (although patchy to the west) and are up to 4 m thick. Head deposits comprise clay, silt, sand and gravel, and on the site tend to be associated with the slopes of higher ground and run northwards through the central part of the site. The River Terrace Deposits comprise sand and gravel and are associated with the trace of the Rivers Frome and Win, being particularly dominant on the east of the site. The boundary between the Quaternary deposits and underlying Poole Formation cannot be defined with confidence across parts of the site.
- Poole Formation – This is the bedrock formation beneath the site and much of the immediate surrounding area to the north and west. The Poole Formation consists of a sequence of alternating clays and fine to coarse sands, but is highly variable. The thickness of the Formation to the north-east of the site is reported to be around 25-30 m. The thickness to the south of the site (in the vicinity of the SGHWR) is not clear due to uncertainty in the depth of its boundary with the London Clay.

- London Clay Formation – The London Clay Formation includes sand and clay rich zones. The variable nature of the London Clay means that there are alternative interpretations of its thickness beneath the Winfrith site.
- Portsdown Chalk Formation – The Chalk underlies the London Clay Formation and is present some 60 m below ground surface. Regionally up to 130 m thick, the thickness of the Chalk beneath site has not been proven.

270 Determining the precise boundary between the Poole Formation and London Clay is challenging as they can appear very similar in samples. The clay below some parts of the site, including SGHWR (Figure 5.14), can therefore be interpreted as part of the London Clay or could be a significant clay lens in the Poole Formation [21, §5.2.5]. However, regardless of which interpretation is correct, the presence of a thick clay layer beneath the SGHWR and immediate surrounds would act locally as an aquitard, preventing migration down from the SGHWR and acting as an effective barrier for possible contaminant migration.

Table 5.2: The superficial and bedrock geology in the region of the Winfrith site in order of increasing depth [21, Tab.604/5].

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

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

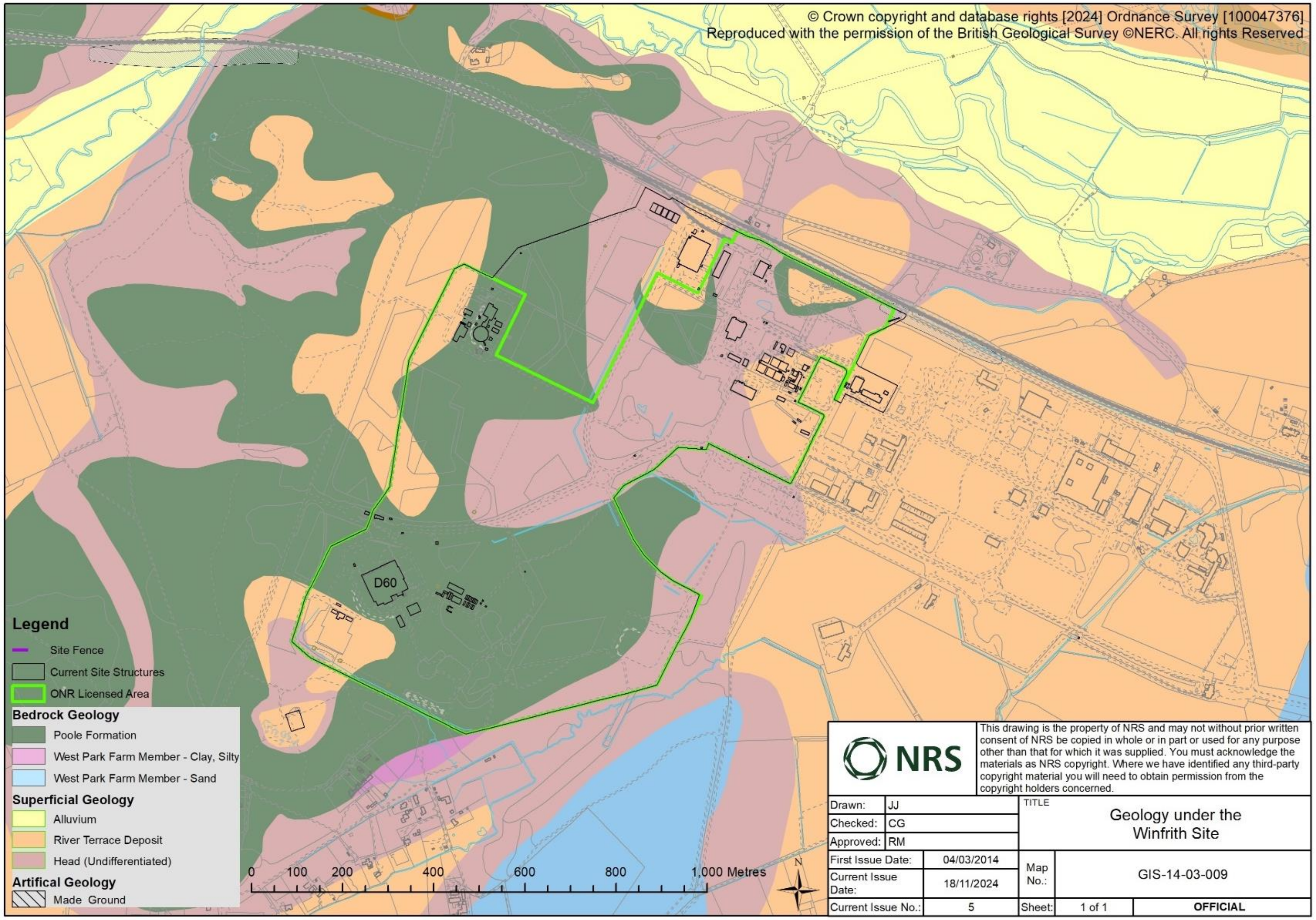

Figure 5.13: Bedrock and superficial geology of the Winfrith site [151, Fig.4].

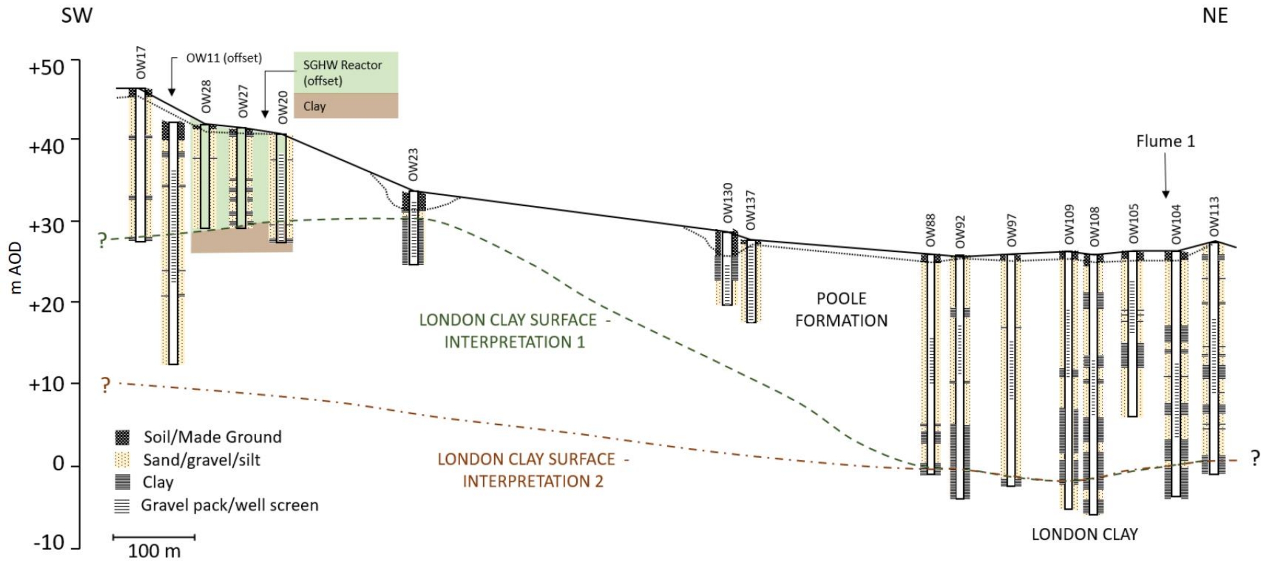

Figure 5.14: Geological cross-section south-west to north-east across the Winfrith site illustrating both conceptual interpretations for the southern part of the site [21, Fig.604/21].

Soil Natural Background

271 Understanding the natural background concentrations on-site is required to allow determination of whether site operations, or implementation of the end state, have or will alter the levels of contaminants present on-site, and if so, to what extent.

272 In 2022, sampling on and around the Winfrith site was undertaken to assess the concentrations of naturally occurring radionuclides as well as any positively identified anthropogenic and cosmic radionuclides in the heathland on and around the site (in which site activities had not previously taken place) [20, §4.1.3; 152]. A statistical methodology [152] was applied to reduce bias associated with the presence of samples with concentrations below the level of detection (LOD) and activities of radionuclides resulting from historical weapons testing and nuclear accidents. The average measured activities for selected radionuclides are given in Table 5.3 and are compared with the EPR16 exclusion levels [1, Sch.23, Part 3, Tab.2].

273 In almost all instances the Winfrith sample averages are below the EPR16 exclusion levels, with the exception of ^{232}Th which is at the exclusion level. The reason for these elevated concentrations is unclear; it is noted that U-Th fuel was used in the Dragon reactor, but there are no records of any incidents involving this. Anthropogenic radionuclides from historical weapons testing and nuclear accidents, including ^{137}Cs and $^{239/240}$Pu, have higher concentrations in shallower samples and, in undisturbed soils, are restricted to depths <0.3 m. Their presence in deeper samples is attributed to mixing in areas of Made Ground [152].

Table 5.3: Soil background radiological concentrations for samples from the Winfrith site [153, Tab.2] compared to the EPR16 exclusion levels [1, Sch.23, Part 3, Tab.2].

Analyte	Average Activity Winfrith Site (Bq g^{-1})	EPR16 Exclusion Levels (Bq g^{-1})
Gross Alpha	0.122	-
Gross Beta	0.123	-
^{238}U	0.0126	1
^{232}Th	0.010	0.01
^{235}U	0.0006	1
^{40}K	0.035	-
^{3}H	0.017	100
^{14}C	0.004	10
^{137}Cs (<0.3m)	0.0020	1
^{137}Cs (all samples)	0.0013	1
^{238}Pu	0.00003	0.1
$^{239/240}$Pu (< 0.1m)	0.00088	0.1
$^{239/240}$Pu (Full Depth)	0.00047	0.1

274 Information on the background levels of non-radiological substances has been collected through several sampling exercises [20, §4.1.2; 153]. Soil samples were taken within the top 1 m in "undeveloped / heathland" areas of the site. These data were compared with UK mean concentrations in soils published by the EA [154, §4]. Comparison of these data (Table 5.4) reveals that the site concentrations are lower than national background concentrations.

Table 5.4: Soil background chemical concentrations for samples on the Winfrith site [153, Tab.1] and mean UK rural soil concentrations [154, §4].

Analyte	On-site Soil Mean Concentration (mg kg^{-1})	Mean UK Rural Soils Concentration (mg kg^{-1})
Arsenic	1.7	10.9
Chromium	5.8	34.4
Cobalt‡	0.94	-
Copper	2.9	20.6
Lead	5.1	52.6
Nickel	2.9	21.1
Zinc	8.63	81.3

‡ Only semi-quantitative data are available for UK rural soil cobalt concentration so a meaningful comparison with Winfrith data cannot be made.

275 pH data were collected from soil samples taken across the site to understand the risks to habitats associated with backfilling the SGHWR and Dragon voids with primarily concrete-based demolition arisings, which could lead to increased alkalinity. The results indicate an

average value of 6.7 [153, §2.4]. A slight increase in soil pH with depth was observed, indicating that surface processes play a role in creating lower soil pH.

Resource Potential - Geology

276 The east Dorset area surrounding the site has historically been exploited for a range of natural resources which mostly comprise three main groups of materials [20, §4.3]:

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

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

Climate

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

279 Historical rainfall data (1961 to 2004) are available from the site rain gauge. The average annual rainfall over that period was 915 mm [21, §3.2]. This is consistent with publicly available rainfall data for the area; the Hurn weather station recorded an average annual rainfall of 840.5 mm over the period 1957 to October 2020 [21, §3.2]. The site rainfall trend is consistent with local trends - it is typically wetter in winter and drier in summer, with average site winter (November–February) monthly rainfall roughly double that of the average summer (June–September) monthly rainfall.

Hydrology and Drainage

280 The site can be broadly split into two natural catchments [21, §3.4] (Figure 5.15). The northern catchment is approximately 69.75 ha and drains the majority of the site to the north-east and east towards Flume 1 and the Frome Ditch surface water features. The southern catchment is smaller, approximately 14.2 ha, and drains south and south-east towards the River Win.

281 Rainfall runoff at the site is primarily drained through an extensive network of surface water and land drains that were built during the late 1950s. The drainage network broadly comprises [21, §3.5.1]:

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

282 Surface water and rubble drains reduce the areas of waterlogging and the risk of flooding on the site. Groundwater flowing north-eastwards across the site is intercepted by the network of rubble drains [21, §3.5.2]. The discharge of groundwater to surface water also occurs to the Frome Ditch and the River Frome. Surface water flow is mostly routed along roads, especially Monterey Avenue (the main north-east to south-west road near SGHWR). Across the site, depressions in the land surface produce surface water ponds, which are mostly fed by rainfall and some by shallow groundwater.

283 Flume 1 receives most of the water from the on-site surface water drainage network. From Flume 1, water flows through the culvert beneath the railway into the Frome Ditch before reaching the River Frome.

284 The two main rivers close to the site are the River Frome, located approximately 300 m to the north of the site and which flows towards the east, and its tributary, the River Win, located south and east of the site. The River Win discharges into the River Frome around 1.5 km east-north-east of the site.

285 Flow data for the River Frome for the period 1965 to 2021 indicates the mean flow rate is 6.72 $m^3 s^{-1}$ [20, §5.2]. The River Win has been gauged for flow by the EA and the calculated mean flow rate near the site for the period 1975 to 2022 is 0.038 $m^3 s^{-1}$ [20, §5.2].

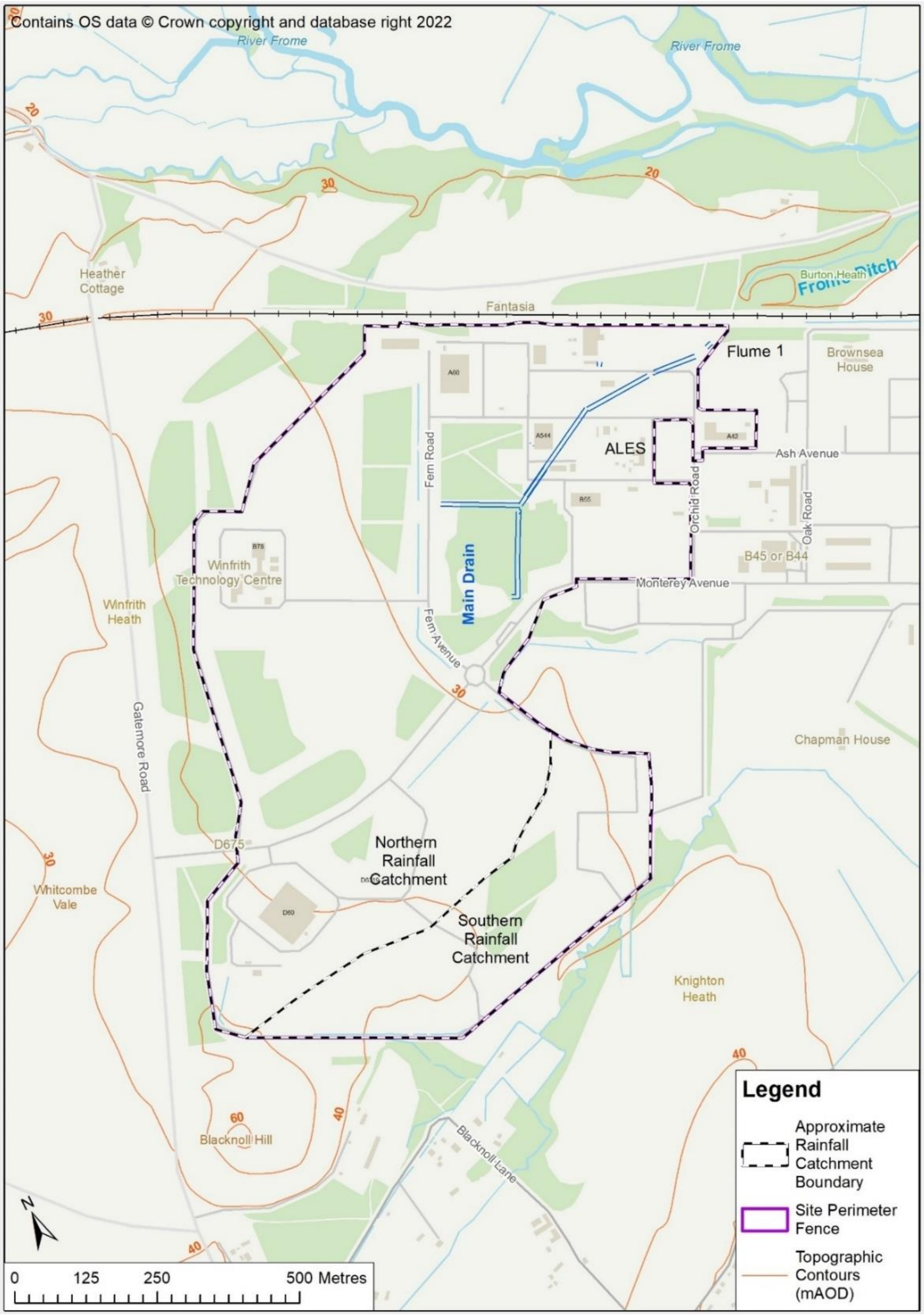

Figure 5.15: Overview of the Winfrith site hydrology [21, Fig.604/10].

Hydrogeology

286 The geology of the site can be divided into three hydrogeological units [21, §6.1]: the Poole Formation and superficial geology, the London Clay and the Portsdown Chalk.

- The superficial geology, comprising Made Ground, River Terrace deposits and Head deposits, may be combined with the Poole Formation and treated as a single hydrogeological unit due to their similar properties [21, §6.1]. This is defined as a secondary aquifer. The hydraulic conductivity within this combined formation is highly variable across the site due to the varying amounts of clay, sand and gravel [21, §6.4].

- The London Clay Formation comprises both sand-rich and clay layers. Where clay layers dominate, this layer forms a barrier to vertical flow, whereas the sand-rich zones may facilitate the local vertical movement of groundwater.
- The Portsdown Chalk beneath the site is understood to be transmissive and is classified as a principal aquifer by the EA. The aquifer in the Portsdown Chalk Formation is the most likely unit to be targeted by any future abstraction boreholes [21, §6.3.2].

287 The hydrogeology of the site is dominated by the near-surface sands of the Poole Formation and the Quaternary deposits that affect shallow groundwater flow. On a small scale, local flow is difficult to predict due to localised sandy and clay beds within the Poole Formation. Figure 5.16 presents a graphical summary of the hydrogeological interpretation of the Winfrith site.

288 The groundwater flow around the site largely mirrors the surface topography [21, §8.1.2]. The majority of the groundwater beneath the site flows in a north and north-easterly direction towards the River Frome while a portion flows more easterly towards the River Win. The drainage divide between these flows is positioned south of the SGHWR. Modelling [21, §7.1.2] predicts that in drought conditions all groundwater flow on site is towards the River Frome.

289 Groundwater discharge locations include both natural and man-made features, including [21, §8.1.4]:

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

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

291 The depth to groundwater ranges between 1 m and 6 m across much of the site, lowest along the eastern boundary of the site and beyond to the Dorset Innovation Park, and increasing to around 9 m in the vicinity of the SGHWR and Dragon reactor. There is a thin unsaturated zone (less than 1 m thick) immediately west of the Monterey roundabout, which is an area of mire/wet heath that shows water rising to surface level following rainfall [21, §7.1.2].

292 On- and off-site borehole measurements for the period 2003 to 2020 do not show a long-term changing trend in the groundwater levels across the site [21, §7.1.1]. Seasonality in groundwater level is observed, with levels peaking around January after the typically higher rainfall during the winter months, and with levels at their lowest around August. The seasonal range is typically around 1 m, reducing to between 0.4 m and 0.6 m in the north of the site [21, §7.1.1].

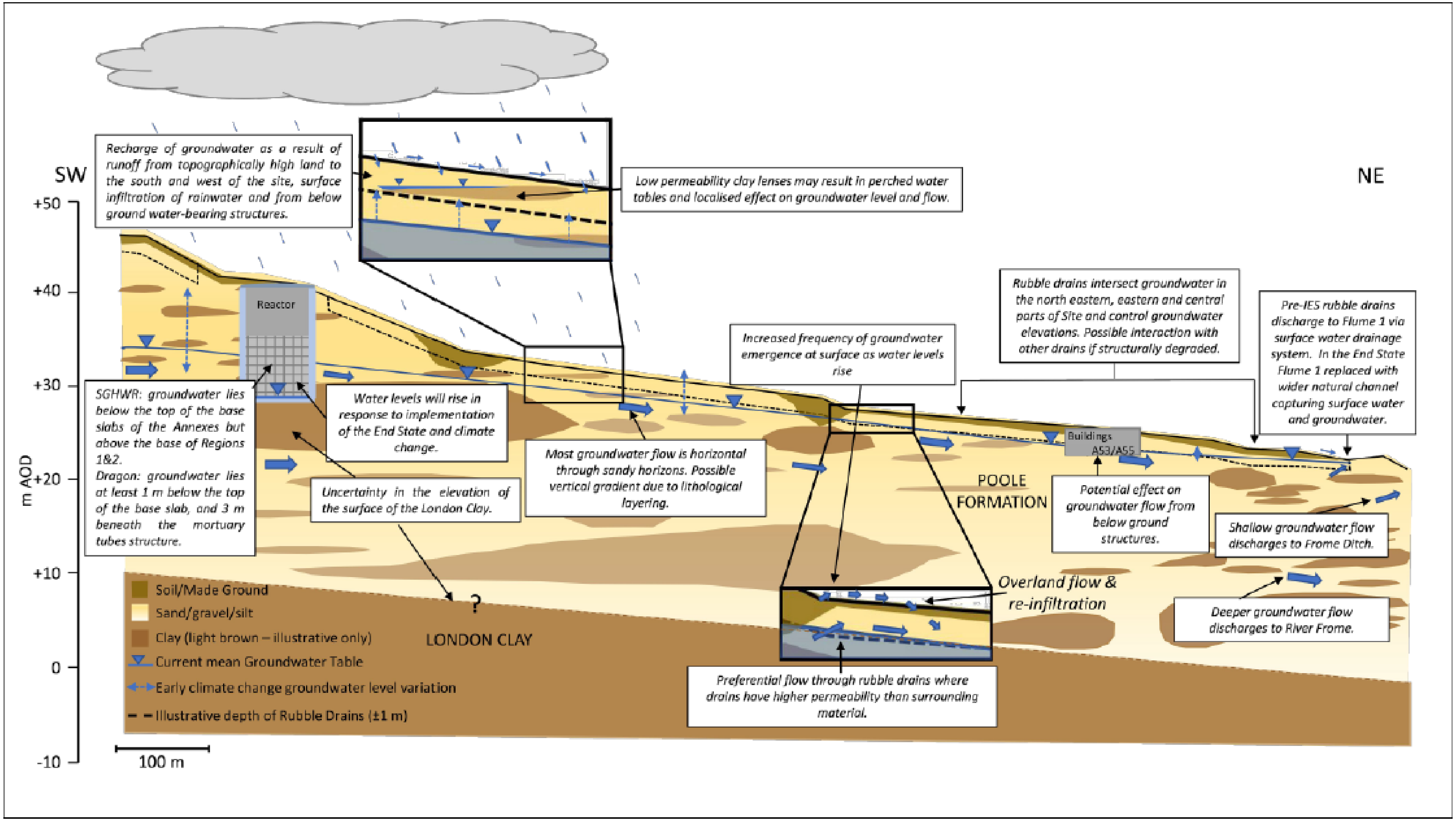

Figure 5.16: Summary hydrogeological interpretation of the Winfrith site (modified from [21, Fig.604/51]).

Hydrogeochemistry

293 The chemistry of the site controls how contaminants travel in groundwater (solubility and retardation). The chemistry also impacts the value of groundwater and how likely it is to be used as a resource for abstraction.

294 Groundwater beneath the site is fresh (has a total dissolved solids content of less than 1,000 mg l^{-1}) and is potentially suitable for use as drinking water.

295 The sulphate concentration in groundwater potentially impacts the integrity of concrete structures over long time periods. The sulphate concentrations measured in groundwater around the SGHWR and Dragon reactors (~20 mg l^{-1}) correspond to the least aggressive chemical environments [21, §9.3].

296 The heathland has a median pH typically less than 5.5 (and as low as 4). In other areas of site the pH rises to neutral (pH 7). Surrounding the SGHWR the groundwater pH changes from around 5 on its upgradient side to above 6 on its down gradient side, but a similar change in groundwater pH does not occur at the Dragon reactor. The transition in groundwater pH at the SGHWR appears to be associated with the change in ground cover rather than the SGHWR structure [21, §9.4.2]. The pH downgradient of the SGHWR varies between 5.7 and 7.0 with a mean value of 6.2 [21, §9.4.1]. The pH in shallow groundwater (<2 m bgl) can be as low as 4, which may be due to rainfall recharge and the impact of Sphagnum.

297 The effect of changes in the pH associated with sorption behaviour varies for different radionuclides. For those elements which sorb by surface complexation, sorption generally decreases with decreasing pH. This is true for cobalt and nickel, trivalent actinides (e.g. Ac, Am, Cm) and the lanthanides (e.g. Sm, Eu, Gd) [155, §3.1].

Resource Potential - Ground and Surface Water

298 Both groundwater and surface water in the surrounding area are exploited as a drinking water resource and for agricultural use (i.e. for crops and livestock). There are a number of groundwater abstraction stations within 5 km of the site (Figure 5.17), which are mostly small to medium-sized [20, §5.5]. Based on the aquifer classification, it is possible, although unlikely, for groundwater within the shallow aquifers around the site to be used as a future resource [21, §6.3.2]. However, it is most likely that any abstraction borehole would be into the Portsdown Chalk aquifer, which is classed by the EA as a principal aquifer[15], rather than the shallower Poole Formation, which is classed as a secondary A aquifer[16].

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

[15] A principal aquifer refers to strategically important rock units that have high permeability and water storage capacity.

[16] A secondary A aquifer is capable of supporting water supplies at a local rather than strategic scale.

300 Figure 5.17 shows a number of medium to large-sized surface water abstraction sites. Although the River Frome is a SSSI, this does not prevent other parties from requesting abstraction licences from the EA, who would determine if there is sufficient water availability. Therefore, surface water within the River Frome represents a potential future resource.

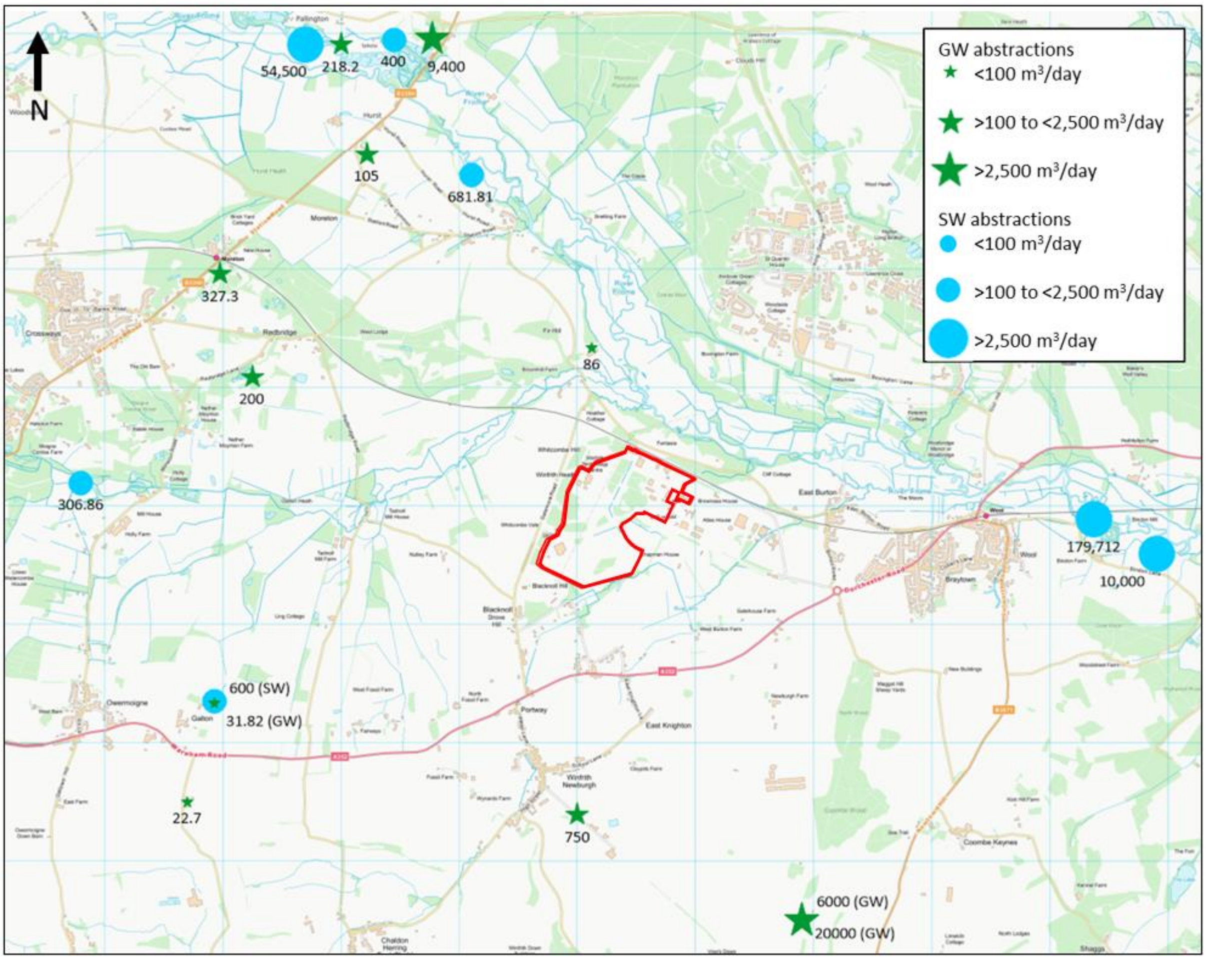

Figure 5.17: Location of licensed groundwater and surface abstractions (December 2020). Edited based on [21, Fig.604/23].

Natural Disruptive Events and Processes

301 The potential for natural disruptive events and processes to occur and their relative magnitude at the Winfrith site are discussed in the Site Description Report [20] and are summarised here. Over longer timescales, the potential for natural disruptive events increases as a consequence of climate change (Section 5.3.4).

Erosion

302 As the site is over 5 km from the coast, coastal erosion is not expected to impact the site.

303 The principal types of surface erosion are soil erosion, through wind or rainfall, and fluvial erosion because of river movement. Soil erosion is of concern across the UK and particularly in the Winfrith region due to the agricultural land use, but mapping by the European Soil Data Centre [156] indicates local soil erosion rates are in the lowest category. Erosion is also of concern for heathlands, with special consideration being given to understanding heaths near

urban areas in Dorset [157; 158]. One of the main causes of erosion is public access and associated trampling of soils [159, Tab.1]. The clay-to-silt content of soils will affect erosion, with more silty soils more susceptible to erosion, while more clay-rich soils are less susceptible [160, §4.4].

304 The Winfrith Heaths are susceptible to burning as heathland flora is flammable [161]. Hot, dry summers and arson are the most common causes of burning, with four heath fires recorded locally between 2011 and 2020 [20, §3.3.6]. Fires not only damage the local environment, but can lead to significant erosion as bare soils will be more readily eroded by wind and rain. Heathland fires affecting the site cannot be ruled out but are not expected to significantly increase surface erosion as burned heather should continue to protect the soil until regrowth is established. A surface vegetation fire is unlikely to allow heat to penetrate to the envisaged depth of the low permeability membrane in the proposed engineered cap. Planned public access routes and maintenance tracks across the site will also function as a firebreak and prevent/limit the spread of wildfire throughout the site [11, Tab.1-6].

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

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

Flood

307 The majority of the Winfrith site is not at risk of surface water flooding. However, some small areas of the site range from low to high risk in localised areas, particularly between the Dorset Innovation Park and the River Win [162] (Figure 5.18). Site operators have not recorded any historical flood events of note as having occurred on the site [20, §5.6].

308 There is a flood risk to the north of the site from the floodplain of the River Frome, and to the east and south of the site from the River Win, but the site itself is in Zone 1 and so has a low probability of flooding from rivers and sea [163]. The current (and future) risk of tidal flooding on-site is low due to the average elevation (>25 m AOD) and the discharge point of the River Frome being a significant distance away in Poole harbour [164, §4.3].

309 Groundwater modelling of the site has assessed the current risk of groundwater flooding [165][17] and shows that during periods of average recharge this is limited to regions near the Frome Ditch, the site of the old Zebra reactor and several other regions off-site. Further modelling of the site at the planned end state has assessed the effect of changes to drainage and land use and is described in Section 5.3.3.

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

[17] This groundwater modelling has largely been superseded by work reported in the Hydrogeological Interpretation Report [21], which uses a revised approach to defining recharge and is more appropriate for assessing groundwater responses to climate change. The conclusions from EA flood risk assessment [165] relating to current flood risks are considered to remain valid.

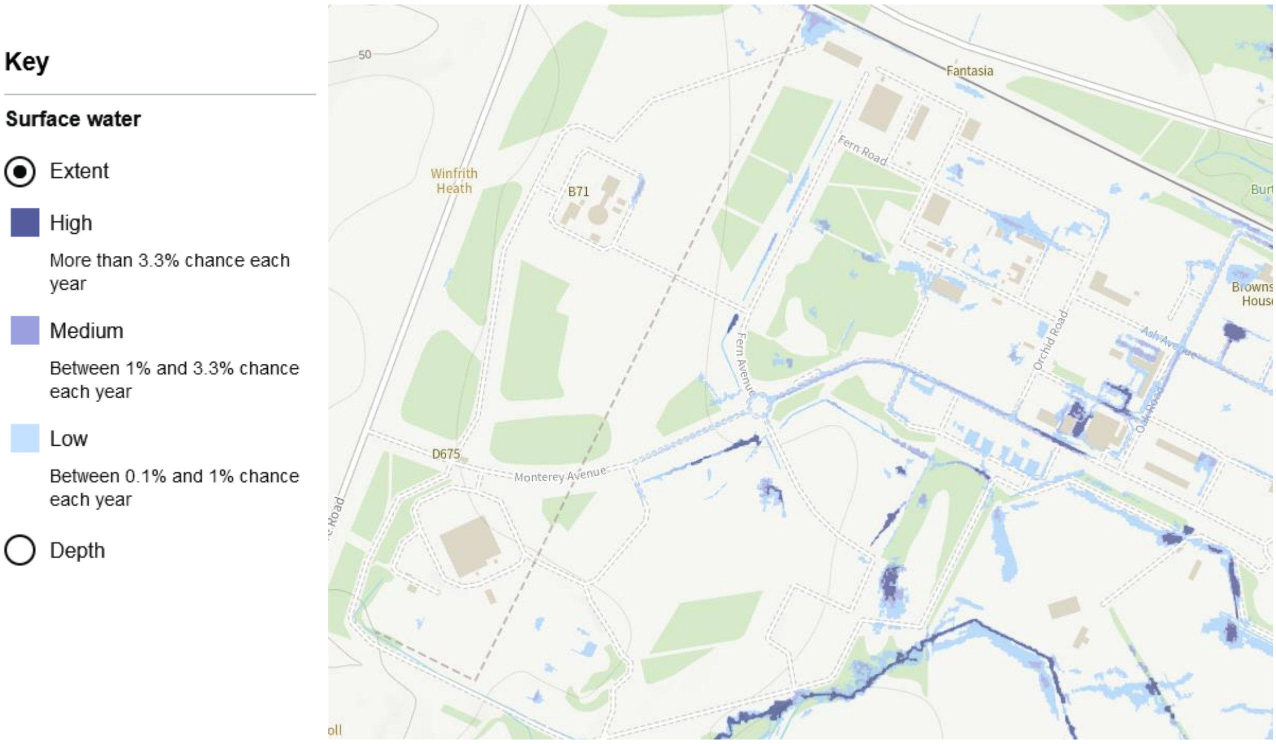

Figure 5.18: Surface water flood risk map for the site [162]. © Crown copyright.

Seismicity

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

312 The British Geological Survey (BGS) [166] assesses Dorset as the joint least active of the UK seismic zones considered. The low likelihood of large earthquakes occurring in the area coupled with only minor ground motions means that the seismic hazard is likely to be insignificant for the Winfrith end state [20, §4.2.2].

Glaciation

313 There is considerable uncertainty in the timescale over which the global surface air temperature will remain elevated compared to present and how far into the future it might be until the next glacial period. The IAEA [167] suggests two potential future timings of the next glacial inception: around 50,000 years after present and around 100,000 years after present. However, icesheets did not reach as far south as Winfrith at the last global maximum and any future glaciation event is expected to have a similar pattern. Therefore, glaciation is not expected to impact the Winfrith end state.

Local Human Habits

314 Two habits and land use surveys of the Winfrith area have been conducted by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) on behalf of the EA in 2003 [168] and 2019 [33] to support assessment of potential radiation exposure pathways. The survey area consists of a terrestrial survey, covering all land and freshwater watercourses within 5 km

of the site centre, and an aquatic survey, covering tidal waters and intertidal areas and the adjacent offshore area from Portland Bill to St Alban's Head.

315 Broadly similar activities were observed across the two surveys. The main use of land in the terrestrial survey region is for farming, and both CEFAS surveys identified 35 working arable and pastoral farms and up to three small holdings in the survey area. Several households have drinking water supplied from boreholes. Livestock access water from the River Frome, springs, stream water and water from a borehole, in addition to mains water.

316 Activities occurring within 1 km of the site boundary include: commercial activities at Dorset Innovation Park and in other small businesses; farming; operation of the Wool Sewage Treatment Works to the north of the site; residence in properties in the village of East Knighton to the south of the site and at a handful of properties to the north and south-west of the site; leisure activities in the nature reserve (e.g. walking, dog walking and horse riding); and growing of fruits and vegetables and the collection of wild food.

Habitats, Designations and Protected Species

317 Parts of the Winfrith site are designated under the Winfrith Heath SSSI, as well as the Dorset Heaths Special Area of Conservation (SAC) and Dorset Heathlands Special Protection Area (SPA) and Ramsar Site (Figure 5.19). Due to the presence of groundwater dependent vegetation, the extent of Winfrith Heath SSSI has also been identified as a Groundwater Dependent Terrestrial Ecosystem (GWDTE) by the EA. However, it should be noted that M16 (*Erica tetralix* – *Sphagnum compactum* wet heath) is the only plant community associated with the Winfrith Heath SSSI which is dependent on groundwater and this plant community is only found in certain parts of the SSSI [169].

318 The habitat types identified as part of the National Vegetation Classification (NVC) survey undertaken on the designated parts of the site (i.e. those that are within the Winfrith Heath SSSI) in summer 2022 included H2 dry heath, H3 humid heath and M16 wet heath / mire [20, §2.3]. In addition, areas of MG5 and MG1 grasslands were recorded within the site. Areas of built environment, plantation woodlands and low value grasslands (focused within the east of the site) were not subject to the NVC survey. The baseline habitats were surveyed using the NVC methodology and then described using the UK Habitat Classification system [11, §2.2] (Figure 5.20). Within the Winfrith site, the main designated features requiring consideration are mire and wet heathland habitats, with the designated habitats generally associated with acidic conditions [169].

319 Protected species surveys were undertaken in 2022 and 2023 [170] to determine the potential of the site to support these species, and to establish a baseline value for the site. Habitats and species identified included: a maternity roost for common pipistrelle and soprano pipistrelle bats; evidence for the presence of great crested newt; and 58 species of birds using the site (including all three ground-nesting species of the Dorset Heathlands SPA - the woodlark, Dartford warbler, and nightjar). All six of the UK's native species of reptiles were recorded during the reptile survey including two rare species, the smooth snake and the sand lizard. Potential badger foraging activity was identified. Evidence of other mammals was also noted, including fox, deer, hedgehog and rabbit.

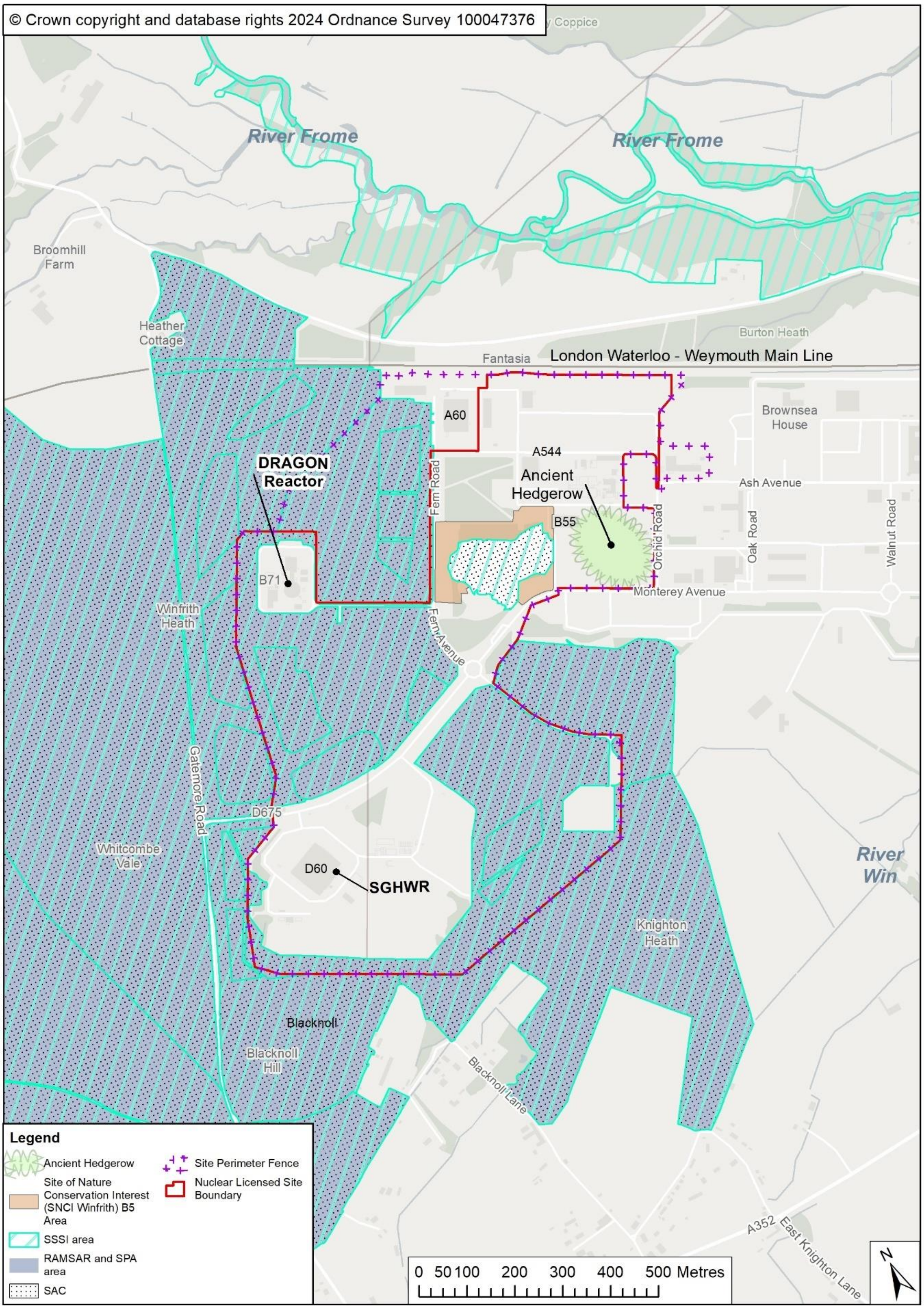

Figure 5.19: Habitat designations on the Winfrith site (NRS, November 2024).

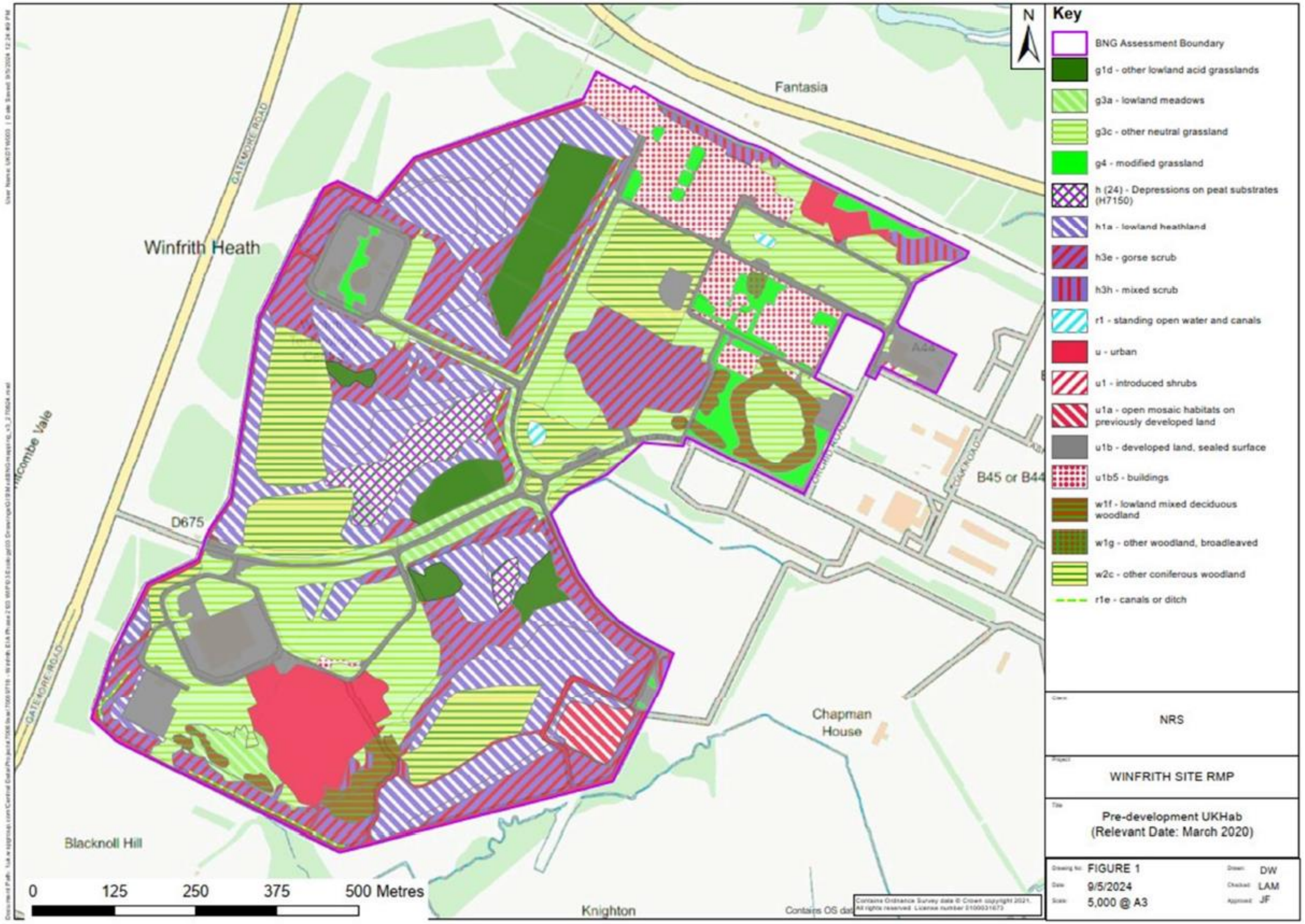

Figure 5.20: Habitat baseline in 2022 using the UK Habitat Classification methodology [11, Fig.7-1].

5.3.2 Site Monitoring and Land Quality Management

D.3	Routine environmental monitoring is undertaken to improve understanding of the environmental conditions in and around the site and will be used to monitor the on-site disposals until the SRS. Results from the existing environmental monitoring programmes provide a baseline against which changes associated with the local hydrology, hydrogeology and radioactive and non-radioactive contamination can be assessed. There is a clear strategy for land quality management and an appropriate process is in place to systematically manage and demonstrate delivery of the End Point Specification in each zone of the site.

Baseline Dataset

320 A programme of land quality and groundwater characterisation to assess the presence, or demonstrate the absence, of chemical and radiological contamination commenced in 2004 and is ongoing. This characterisation provides a substantial dataset that can be analysed to observe and understand any trends, both in contaminants and in hydrology. Routine monitoring and additional sampling will continue until the SRS.

Land Quality Management (LQM)

321 The overall objective of the LQM strategy, consistent with regulatory expectations [171], is to take all reasonably practicable measures to prevent contamination and to ensure any existing contamination is managed to mitigate both environmental and safety risks. There is a land quality management plan [172] and a programme of works to ensure the land on site meets the requirements for release or is appropriately managed and accounted for.

322 In order to systematically manage and demonstrate the process of land quality management, the site has been sub-divided into several zones based on process history (Figure 5.21). For each zone, the likelihood of contamination being present is evaluated from review of historical records of land and building usage with particular emphasis on plant, infrastructure or events which could have caused contamination of the ground, and by considering drawings and maps as well as environmental monitoring data. All available information is collated and assessed to define the risk of contamination being present.

323 The scale of the investigation programme and the type of investigation required in each zone depends greatly on the likelihood of contamination. For example, where the review of historic records establishes that a land area has had no previous potentially contaminating use then the level of site investigation will initially be limited to confirmatory monitoring. Where evidence of historical contamination is identified, either from records or sampling, these areas will be further assessed, and where necessary remediated to meet requirements for the next planned land use. The status and outcome of the investigations and any remediation is recorded on the Land Quality Register [47; 173].

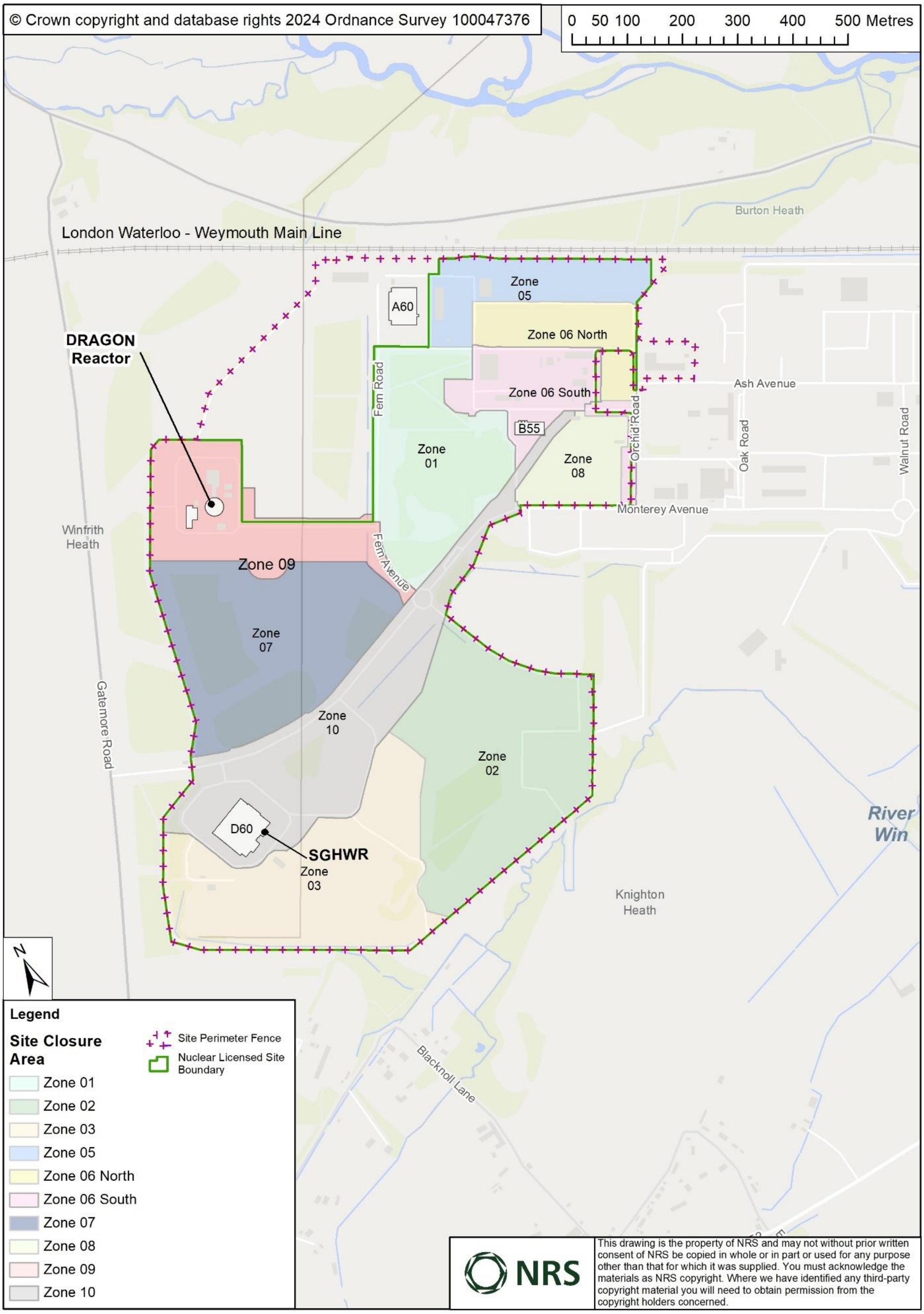

Figure 5.21: Winfrith site plan showing the land quality management site closure zones (NRS, November 2024). Zone 04 is the Sea Discharge Pipeline and is not shown.

Groundwater Monitoring

324 A site-wide groundwater monitoring programme has been in place since 2002. The network and the monitoring programme have evolved over the years to increase the geographical coverage in response to the identification of land quality areas of concern.

325 Since 2014, groundwater samples have been collected quarterly [172, §8] for chemical and radiochemical analysis. Samples are also collected from surface water locations. The programme is reviewed annually and will be continued until there is regulatory agreement to cease monitoring [172, §8].

326 The current groundwater monitoring programme [172, App.C] targets three specific areas of the site where groundwater contamination has been identified, namely Zone 5 (nickel, zinc and chlorinated solvent contamination), Zone 1 (hydrocarbon contamination) and Zone 3 (radiological contamination) (Figure 5.21).

327 Groundwater quality for radionuclides is generally good (Table 5.5), with only occasional results in excess of the World Health Organisation (WHO) drinking water guidelines for radioactivity. No actions are proposed in respect of groundwater quality for radioactivity beyond the continued process of site decommissioning.

Table 5.5: Radiochemical background values (Bq l^{-1}) for groundwater at the Winfrith site 2005 – 2021 [153, Tab.4].

Analyte	No. of samples	Positive Detections	Arithmetic Mean	Standard Deviation	95%ile	DWS	WHO
Gross Alpha (as Am-241)	158	132	0.112	0.083	0.257	0.1	0.5
Gross Beta (as Cs-137)	158	137	0.154	0.093	0.336	1.0	1.0
Tritium	158	60	5.92	5.32	18.1	100	10,000

DWS - The Water Supply (Water Quality) Regulations 2016, Schedule 2 Regulation 2, Indicator Parameters [174].
WHO - Guidelines for Drinking-water Quality. World Health Organization, 4th Edition.
Note: Only filtered samples have been used. LOD values have been excluded from the mean and 95th percentile calculation.

328 Monitoring for zinc, nickel and solvent contamination in groundwater continues in the northern area of the site to inform risk assessments and review of remediation options. The groundwater contamination is historical. At present there is no proposal for active remediation of the groundwater contamination; however, this position is in review. The concentrations of trichloroethene (TCE) and its degradation products in the groundwater in the A5 area are essentially stable or declining. TCE levels at the Flume Outfall remain below the Environmental Quality Standard (EQS) value. It is proposed to continue to monitor groundwater and surface water to confirm these trends [172, §8].

329 Dissolved hydrocarbon compounds were found in the redundant Fire Test Area (Zone 1) [175] so two additional monitoring boreholes were installed. Monitoring of three downgradient boreholes and one upgradient has not detected dissolved hydrocarbon compounds (all results were less than the limit of detection). Monitoring of the two boreholes adjacent to the redundant Fire Test Area is on-going [172, §8].

330 Groundwater monitoring will continue through to the SRS. Any groundwater contamination identified through the monitoring programme will be assessed, reported to relevant authorities and managed appropriately. The Stewardship Plan sets out details of the groundwater monitoring plans and the process that will be followed for analysing, reporting and recording the data collected [9, §7].

Zone Close-out Process

331 Each zone (Figure 5.21) will be assessed and characterised to demonstrate that the end point has been met. The end points for each zone are summarised in Table 5.6. The process and evidence requirements reflect the operational uses of the site and the agreed end points [45].

332 A zone close-out report will be produced for each zone once sufficient information is available to demonstrate that the End Point Specification [43] has been met, including the physical and radiological status of the land and structures. A site close-out report will be prepared based on the individual zone reports, with the aim of demonstrating that all End Point Specifications have been met [45].

Table 5.6: Summary of planned site closure zone end points (edited from [45]).

Zone ID	Description	Radiological Interim End Point Summary
1	Former fire test facility	Below regulatory thresholds
2	Zebra	Below regulatory thresholds
3	D69[18] / EAST	Below regulatory thresholds
4	Sea Discharge Pipeline	Below regulatory thresholds
5	A56/A58[19]	Below regulatory thresholds
6 N	ALES	Below regulatory thresholds
6 S	A59	Below regulatory thresholds
7	Dragon heathland	Below regulatory thresholds
8	Gardeners compound	Below regulatory thresholds
9	Dragon	Permitted in-situ disposal of activity
10	SGHWR	Permitted in-situ disposal of activity
11	Permit only land	Below regulatory thresholds
12	Non-regulated land	N/A

[18] D69 refers to the supernatant pump house facility (now demolished).

[19] A56 and A58 are now-demolished buildings that were used for solid and liquid waste management activities.

5.3.3 Evolution due to Interim End State Implementation

D.4	A passive water management approach will be implemented in the end state that minimises flood risk to neighbours and maximises the potential to generate a sustainable wet-heathland habitat. Assessment of the potential impact of implementing the end state on the site hydrogeology shows non-significant changes in the average site groundwater level and no change in groundwater flow direction.

333 A key aim of the restoration is for the site to have a passive water management approach in the end state that minimises flood risk to neighbours and maximises the potential to generate a sustainable wet-heathland habitat [21, §3.5.3]. Decommissioning of the drainage network as part of the site-wide decommissioning programme will necessitate an alternative water management approach to appropriately manage risks to neighbours. To minimise the risk of site flooding, mitigation measures will be put in place, key to which is the implementation of a valley mire in the north-east of the site (Figure 5.22). The mire will be periodically inundated with surface water following rainfall and is likely to be wet/waterlogged in winter and dry in summer [11, §4.1 and §5]. Rainfall across site will either infiltrate the soils or run-off overland towards the mire. During flood events, water will attenuate (i.e. be held up) in the mire and will discharge over a number of hours to constrain the impact on downstream flows [11, Tab.6-1].

334 The actions required to achieve this passive water management include decommissioning the existing surface water drainage network, removing the drainage capacity, removing hardstanding (roads and pavements) and structures on the site, and creating a depression where the mire can form. The mire will act as a surface water catchment in place of Flume 1, to moderate surface water flows to the pipe under the railway line and into the Frome Ditch. Following this work, most surface water will drain via the mire to the Frome Ditch [176, §B.1.3]. Changes in average groundwater level as a result of the implemented end state are predicted to be small (0.4 m at SGHWR and 0.3 m at Dragon [21, §7.2.3]) and would not negatively impact neighbours or the next planned land use. Changes in drainage combined with climate change will also affect ecological evolution, as discussed in Paragraphs 349 to 350.

335 Groundwater flow on site occurs predominantly in the Poole Formation, largely mirroring surface topography. Groundwater modelling [11, App.B, §4] predicts that groundwater after the IEP will continue to flow in a north-easterly direction from the Dragon reactor complex and north and north-east from SGHWR. Flow will emerge at various locations across the site, primarily in the area west of the Monterey roundabout and the mire in the north of the site, and into the low-lying Frome Valley (Figure 5.23). In some conditions, groundwater from the SGHWR may also flow towards the Dragon reactor complex (Figure 5.23), where it would join the flow from Dragon, eventually entering the River Frome. Flow paths from the A59 area were not modelled, but given the proximity of A59 to the mire and the relatively shallow water table in the area, it is possible that releases from A59 could emerge in the mire as well as flow to the River Frome.

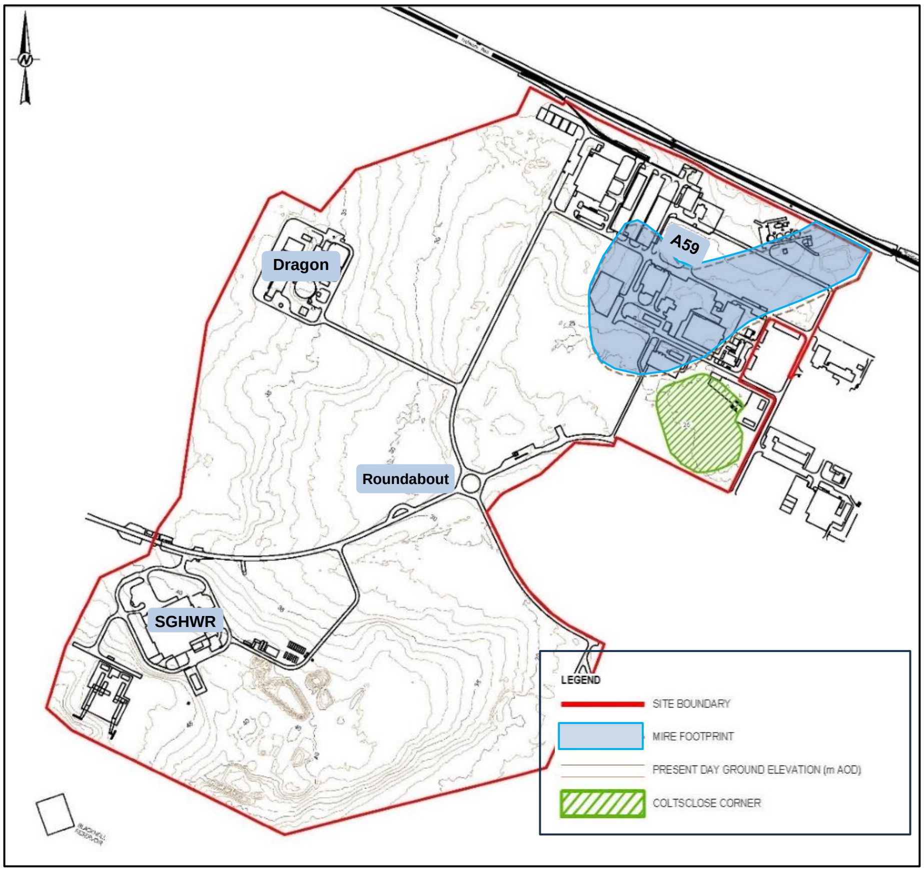

Figure 5.22: Current site topography with the location of the proposed mire indicated (mire design as of December 2023). Edited from WSP [177].

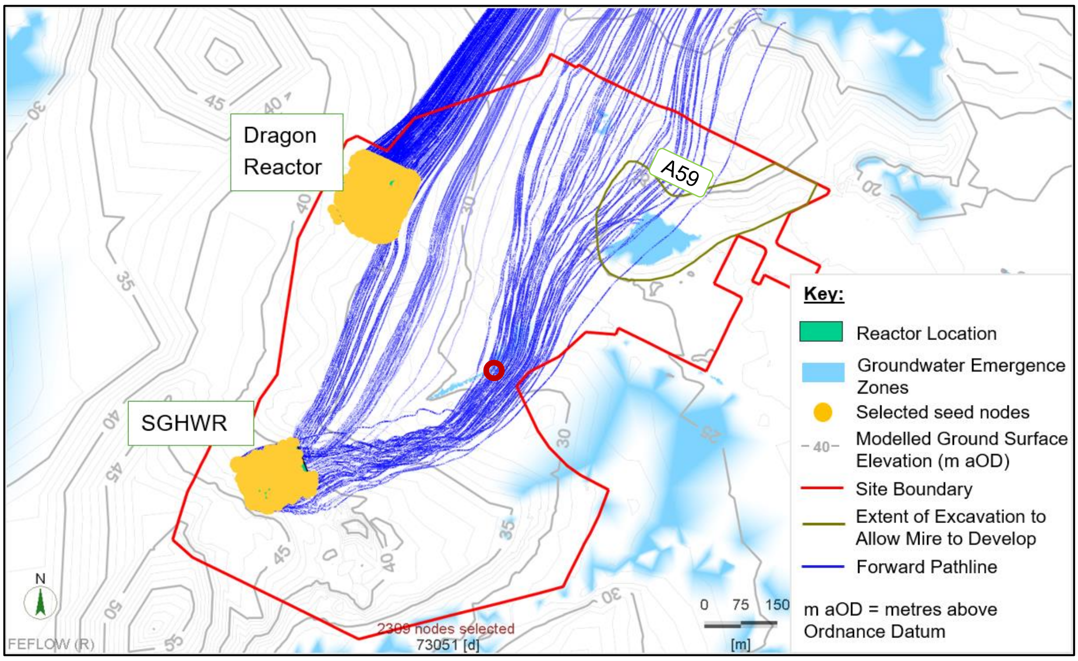

Figure 5.23: Modelled groundwater emergence and forward pathlines from the SGHWR and Dragon reactor complex for the proposed site at the IEP and the reference climate simulation in January 2033. Edited from [11, Fig.4-12]. The ⭘ indicates the approximate Monterey roundabout location.

5.3.4 Future Evolution of the Site and Surrounding Region

D.5 The potential impact of climate change on site groundwater has been assessed using UK Climate Projection data. International understanding of the long-term changes in climate have informed the radiological and non-radiological risk assessments, and the iterative development of the landscape design.

Climate Change

336 The climate will continue to change after the IEP, whether due to natural variations or human-induced climate change, and this will impact the site hydrogeological conditions and hence the potential for release of contaminants to the environment. The expected changes are discussed in detail in the Site Description [20], Hydrogeological Interpretation [21] and Conceptual Site Model (CSM) [19] reports, with a summary provided below.

Future Groundwater Elevations to 2100

337 Climate projections performed by the Meteorological Office indicate that summer and winter temperatures in south-west England will increase over the next century, whilst winters will get wetter and summers drier [20, §6.1.1]. The changes in ground conditions caused by these climate variations will produce changes in flood risk. Increased winter rainfall may produce larger flooding events, whilst hotter, drier summers can lead to compaction of the soil, preventing infiltration and further increasing surface run-off. There may also be an increased risk of heathland fires.

338 The UK Climate Projections (UKCP) is a climate analysis tool that is used to assess many potential future climate scenarios. Using the UKCP09 scenarios[20], the Centre of Ecology and Hydrology (CEH) produced 11 simulations of potential future UK climate to assess a range of outcomes. The impacts of these climate change projections on groundwater recharge have been assessed by the BGS in the EA-commissioned *National Groundwater Recharge Assessment under Climate Change* project [179]. This work assessed the potential impacts of each of the 11 simulations on recharge of groundwater as a reasonable assessment of what may happen in the future. Data extracted from this model for the area local to Winfrith have been used in the groundwater flow model to represent a cautious central estimate (CCE) and a reasonable worst-case (RWC) assessment of what might happen to groundwater for 2045-2069 (2050s) and 2075-2099 (2080s) [180].

339 The assessments completed assume groundwater levels will rise to allow a pessimistic assessment of risks, but a reduction in groundwater recharge due to climate change is also possible. Due to the availability of data, the groundwater flow model considers the 11 simulations generated by the CEH based on the International Panel on Climate Change (IPCC) SRES scenario A1B (a medium emissions scenario), which assumes rapid economic growth with a balanced emphasis on energy sources. Many other scenarios are possible, which could result in drier or wetter conditions, and climate projections are frequently updated. The IAEA [181] emphasises that "*projections should not be considered as predictions, since alternative scenarios for greenhouse gas and aerosol emissions have very different climatic consequences*

[20] UKCP18 data have now been published, but daily recharge data for the Winfrith area using the latest simulations are not yet available. Comparison between UKCP09 and UKCP18 scenarios [178] for a nearby site concluded that the future modelled groundwater elevation at the Winfrith site would be little different if recharge were calculated using the RCP8.5 high emissions scenario of UKCP18.

and there is also the potential for geoengineering approaches to limiting the impact of greenhouse gas emissions".

340 Table 5.7 summarises the calculated average groundwater levels for the SGHWR and Dragon reactor complex for the CCE and RWC climate simulations in the 2050s and 2080s, and identifies the percentage of time that groundwater is estimated to be higher than the top of the base slabs of the structures. Figure 5.24 shows the variation in groundwater levels with time over the 2080s model period. For the CCE simulation, the highest modelled groundwater level at any point is 1.1 m above the base of the SGHWR South Annexe and 0.8 m above the base of the Dragon reactor, but for most of the modelled period the groundwater remains beneath these components [19, §7.1.3]. For the RWC simulation, the groundwater levels are modelled to be on average a little higher and the frequency with which groundwater rises above the top of the base of the South Annexe and Dragon reactor increases slightly.

341 The removal of surface water drainage combined with climate change is modelled to result in incidences of groundwater emergence to surface over the next century during wetter months. For the CCE simulation, groundwater emergence for SGHWR is modelled to be west of the roundabout on Monterey Avenue and emergence for Dragon is in low-lying land close to, and in, the River Frome. When considering the RWC simulation the locations of groundwater emergence and the pattern of pathlines from the SGHWR and Dragon reactor complex are unchanged from those of the CCE simulation [19, §7.1.3].

Table 5.7: Average groundwater elevations assuming the CCE and RWC climate simulations in the Winfrith groundwater flow model for the 2050s and 2080s, as well as the percentage of the assessed period that the groundwater is higher than the relevant reactor base slab (extracted from [21, Tab.604/7]). The top of the South Annexe base slab is at 35.40 m AOD and the top of the Dragon reactor base slab is at 27.34 m AOD.

	SGHWR		Dragon Reactor Complex	
	Average groundwater elevation (m AOD)	**Percentage of time groundwater elevation is higher than the base**	**Average groundwater elevation (m AOD)**	**Percentage of time groundwater elevation is higher than the base**
Modelled 2050s with the CCE recharge	33.6	100% (Region 1&2) 4% (South Annexe) 0% (North Annexe)	24.9	5% (Dragon reactor) 0% (Mortuary holes)
Modelled 2080s with the CCE recharge	34.0	100% (Region 1&2) 4% (South Annexe) 0% (North Annexe)	25.1	2% (Dragon reactor) 0% (Mortuary holes)
Modelled 2080s with the RWC recharge	34.1	100% (Region 1&2) 12% (South Annexe) 0% (North Annexe)	25.3	9% (Dragon reactor) 0% (Mortuary holes)

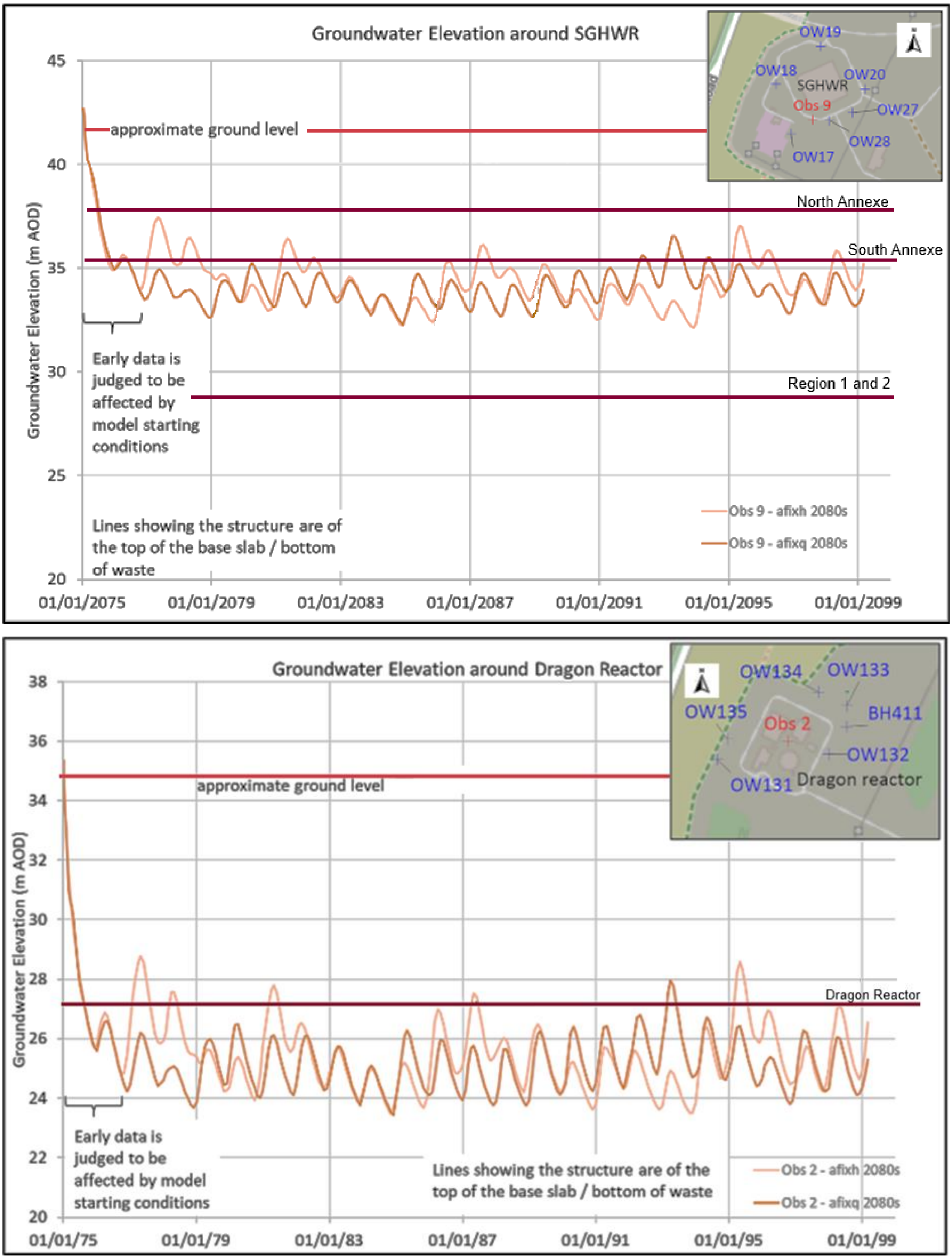

Figure 5.24: Modelled hydrographs for the 2080s at the SGHWR (top) and Dragon (bottom) for the CCE (dark orange) and RWC (pale orange) groundwater recharge simulations (modified from [21, Fig.604/41]). Horizontal lines show the approximate ground level and basement elevations of the key features in each reactor.

Climate Change and Groundwater Levels Beyond 2100

342 The IAEA [181] provides a summary of modelling conducted for climate change over four time periods. On the shortest timescales (up to 1,000 years), the IAEA [181] observes that the processes with the most impact are those associated with recovery from the disturbance associated with disposal facility construction (e.g. resaturation of concrete) and degradation of engineered components. Although the disposals at Winfrith are not purpose-built disposal facilities, a similar emphasis is placed in the risk assessment modelling on the resaturation of the low permeability structures and their content, and on the degradation of the concrete and dissolution of contaminants.

343 On timescales of up to about 10,000 years, the overall landscape is likely to remain similar in form to that observed at the present day, whereas the climate is likely to be as warm, or somewhat warmer, than at the present day [181]. Thus, the climate-influenced processes of relevance to assessment models are likely to be similar to those of relevance at the present day, though their relative importance may change.

344 There is considerable uncertainty in the timescale over which the global surface air temperature will remain elevated compared to present and how far into the future it might be until the next glacial period [181]. However, icesheets did not reach as far south as Winfrith at the last global maximum and any future glaciation event is expected to have a similar pattern.

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

Climate Change and Cap Resilience

346 The mechanisms by which components of the proposed engineered cap may degrade over the long-term have been reviewed [148]. Under climate change conditions involving acute effects of extreme hot and dry weather events desiccation cracking of the cap mineral layer (Figure 5.10) is possible, but only if the layer is exposed at, or becomes very close to, the surface. The protecting cover soils in the conceptual cap design will prevent the mineral layer from being affected by desiccation cracking.

347 An increase in cap infiltration is expected as a consequence of oxidation of the polyethylene layer and the infiltration rate will become progressively controlled by the geosynthetic clay layer (GCL), for which no mechanisms for long-term degradation have been identified [148]. There is uncertainty as to the extent of the degradation of the polyethylene geomembrane in the proposed cap as a result of increased average annual temperature caused by climate change. To account for this, the risk assessments have assessed the sensitivity to increased degradation rates (Chapter 7).

348 The joint regulators' position statement on the use of UKCP18 data [182] requires that any proposals for a nuclear development/installation have a high level of climate resilience built-in from the start and that the proposals can be adapted over their predicted lifetimes to remain resilient to a credible maximum climate change scenario. In support of this, the cap performance review [148] recommends sandy cover soils are selected to reduce the potential for desiccation cracking to occur. Additionally, the Stewardship Plan [9, §7.3] includes requirements for periodic inspection of the cap to verify their integrity and detect changes.

Ecological Evolution

349 Any predicted increases in groundwater levels, whether due to implementation of the end state or climate change, may transition local habitats from H2/H3 (dry/humid heathland) towards M16 (wet heathland (mire)), although other factors such as temperature changes (associated with climate change) and site management are also likely to play an important role in determining the future composition and distribution of the plant communities [169, §3]. Therefore, it may be the case that the predicted groundwater changes would lead to a shift in the distribution of plant communities but not reduce the overall quantity or diversity of designated site qualifying features. However, there is significant uncertainty regarding the precise changes that might occur because of climate change, particularly given that there will be other influencing factors.

350 The proposed end states for SGHWR and Dragon will result in increased groundwater pH over long timescales as surface water and groundwater interact with cementitious material contained in the below-ground structures. Changes to the pH of the soil could potentially influence the development of different ecological habitats and species. The potential for the proposed SGHWR[21] end state to impact the designated heathland habitats has been assessed using a hydroecological model [169; 183]. The most sensitive receptors to groundwater with potentially elevated pH are the designated habitats (H2, H3 and M16), which are all typically associated with consistently low (acidic) pH levels. Decommissioning of the drainage network acting in combination with climate change will alter groundwater pH in the vicinity of the mire and wet heathland vegetation communities. The potential changes to groundwater pH are assessed in the HRA (Section 7.9).

5.4 Characterising and Understanding the Inventory

351 The WMP [8] lists and summarises all waste currently on the Winfrith site, including waste intended for both on-site and off-site management. The end state inventory discussed in this section relates only to the features proposed to remain on-site.

352 The proposed end states for SGHWR and the Dragon reactor complex include on-site disposal of radioactive waste and deposit of recovered non-radioactive waste via a combination of:

- disposal in-situ of the radioactive below-ground structures associated with the SGHWR and Dragon reactor buildings (as summarised in Section 5.1), which are defined as radioactive waste;
- disposal for a purpose of radioactive waste (demolition arisings), with the purpose being infilling below-ground voids in the SGHWR and Dragon structures as part of land restoration; and
- use of non-radioactive (out-of-scope) waste (demolition arisings) in a deposit-for-recovery (DfR) operation, also for the purpose of infilling unwanted below-ground voids in the SGHWR and Dragon structures as part of land restoration.

353 These disposals and deposits are associated with both radioactive and non-radioactive contamination. Based on the current understanding of the site history and geometry combined with characterisation data, radiological and non-radiological inventories for the proposed end state have been calculated. Development of the inventory is an ongoing process and further

[21] The scope excluded consideration of the Dragon end state because groundwater and alkalinity modelling indicates that any groundwater from this location would discharge into the River Frome and be within the normal pH range of the river by the time it gets there [169].

information will become available as decommissioning and end state implementation proceeds. The sections below describe in turn:

- the overall framework for managing inventory information and uncertainties, including the basis for the inventory estimates used in the permit application and how additional characterisation data arising in the future will be used;
- the calculation of material volumes and masses, which are a key input to inventory estimation and have been consistently applied throughout this permit application and other application documents;
- the current reference estimate radiological inventory of the disposals and deposits expected to remain on site at the end state, and alternative radiological inventories derived using more pessimistic assumptions to explore the effect of key uncertainties for each feature; and
- the current reference estimate non-radiological inventory of the disposals and deposits expected to remain on site at the end state.

354 The A59 area inventory considered in the risk assessment is also presented in this section, but it does not form part of the permit application as the contamination levels remaining at the IEP will be OoS of RSR.

5.4.1 Inventory Management and Ongoing Characterisation

D.6	Strategic characterisation approaches have been developed to support demonstration of compliance with the emplacement acceptance criteria (EAC) and to improve understanding of the radiological and non-radiological hazards and reduce associated uncertainties. The Staged Inventory Management Plan (SIMP) defines the characterisation needs through the remainder of the decommissioning lifecycle. Characterisation activities are planned and implemented in a manner proportionate to the risk and uncertainty, and apply relevant industry best practice such as the data quality objective (DQO) methodology.

355 Staged inventory management plans[22] have been developed to demonstrate how radiological and non-radiological characterisation gaps will be addressed prior to implementation of the proposed disposals. These are set out in the SIMP [22], the aims of which are to:

- ensure that wastes disposed of or deposited meet the EAC, and are consistent with the assumptions in the SWESC and the underpinning risk assessments, and therefore the anticipated permit conditions;
- ensure that characterisation is proportionate to the quality and confidence level required for the risks involved and is sufficient to exclude non-compliant materials; and
- define final inventories for the disposals.

356 Future characterisation will be directly based on the uncertainties already identified in the radiological and non-radiological inventories. Prioritisation of future radiological

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22 Staged inventory management plans set out the overall approach to development of the inventory estimate, identifying where further characterisation is essential or supporting only. They do not set out the specific characterisation details to be implemented (e.g. sampling locations, characterisation technique to be used, locations of measurements to be taken etc.), as these will developed as each strategic characterisation activity is undertaken.

characterisation will take account of the qualitative assessment of confidence in inventory estimates for each component.

Timing of Characterisation

357 Further characterisation of the SGHWR and Dragon structures will be integrated with the decommissioning, demolition and implementation (of the disposal) programme, with optimal opportunities for further characterisation identified. This approach avoids unnecessary worker risk and nugatory work due to cross-contamination. Characterisation of material in the existing D630 rubble mounds will be undertaken at the time of its emplacement into the below-ground reactor voids, for the same reasons.

358 Characterisation of structures will be undertaken prior to demolition where possible because the majority of the radiological contamination lies on the material surface and this will be most easily assessed in-situ. However, some areas will only become accessible through the demolition process and in-process characterisation will be required.

Characterisation Plans

359 The SIMP:

- defines the known gaps associated with the inventory for each process area, based on the assessment of uncertainties, assumptions and gaps in the associated radiological and non-radiological inventories and risk assessments; and
- identifies when characterisation is best accomplished, given the on-going decommissioning and proposed demolition programme.

360 Characterisation will be undertaken in accord with the company standard on characterisation management, S-324 [184]. Individual characterisation plans will be produced to:

- sub-divide the reactors into process areas, using Data Quality Objective (DQO) principles, based on the scope of historical operations and therefore likely common contamination profiles;
- define the appropriate approach to sample selection based on DQO principles (i.e. biased / bounding or statistically significant) based on the uncertainties and data needs; and
- identify approaches and techniques to collect and manage samples to ensure valid data.

Characterisation Records and Data Use

361 A concise characterisation report is produced for each process area. All data collected will be retained within the IMAGES database in accordance with procedures for record retention (Section 3.4.5), ensuring that characterisation outcomes are readily available and traceable.

362 The data collected will be assessed against the existing inventory, used to underpin future updates of the radiological and non-radiological risk assessments and the SWESC, and to support uncertainty management via the UMM (Section 3.4.6).

363 A further key use of characterisation data will be assessment against the criteria set out in the EAC, to determine whether material is suitable for emplacement.

Characterisation Programme

364 Characterisation of the SGHWR and Dragon end states will evolve through three key stages:

- **Stage 1**: Characterisation acquisition to support the permit variation application.
- **Stage 2**: Characterisation acquisition following the submission of the permit variation application up to the time when demolition and implementation of the disposals starts.
- **Stage 3**: Characterisation acquisition through the period of decommissioning and demolition work, which occurs after permit approval and up until the disposals are completed.

365 Stage 1 characterisation has informed the inventories and assessments that form part of this permit application, and hence the claims and arguments made in this SWESC, and is complete.

366 In Stage 2 characterisation plans will be based on defining the areas of most significant uncertainty that can be usefully resolved whilst core retrieval and waste processing is on-going. These areas will be targeted for further characterisation as relevant parts of the structures become accessible.

367 Stage 3 recognises that some areas of both the Dragon and SGHWR structures will only become available for characterisation during the decommissioning process. Through this phase, wastes being generated or moved will be characterised and assessed to confirm they meet the EAC and determine whether they are suitable for use in the disposal/recovery operations.

368 The following key uncertainties are expected to be addressed as priorities through further characterisation in Stages 2 and 3:

- SGHWR mortuary tubes fingerprint and activity level; and
- Dragon Purge Gas Pre-Cooler (PGPC) spill activity level post-decontamination.

369 Additionally, opportunistic characterisation will take place throughout Stages 2 and 3 as appropriate, to build confidence in existing inventory estimates.

FP.11 Undertake strategic characterisation to support demonstration of compliance with the EAC and to improve understanding of the radiological and non-radiological hazards and reduce associated uncertainties.

5.4.2 Material Volumes and Masses

D.7	A detailed description of the voids and material proposed to be emplaced in the below-ground SGHWR and Dragon building structures has been developed. These values, together with related assumptions about material densities and bulking/compaction factors, are used consistently to assess potential impacts from the proposed disposals.

SGHWR and Dragon Reactor Complex

370 Void and infill volumes and underpinning assumptions relating to the SGHWR and Dragon structures are set out in the CSM [19, §2.4]. The total volume of structural concrete that will be left in-situ is estimated to be 7,366 m^3 for SGHWR and 5,100 m^3 for Dragon [185; 186] (Table 5.8).

Table 5.8: Volumes of structural concrete to be left in-situ in the proposed end states for the SGHWR and Dragon reactor complex. Values are taken from spreadsheets supporting the non-radiological inventory [185; 186] except for the B78 foundations value which was provided separately [187].

SGHWR		**Dragon**	
Feature / component	**Volume (m^3)**	**Feature / component**	**Volume (m^3)**
Region 1	973	B70 foundations	3,242
Region 2	3,097	B70 in-situ structures	982
South Annexe	2,367	Mortuary hole structure	371
North Annexe	929	B78 foundations	505
Total	**7,366**	**Total**	**5,100**

371 All material generated in demolition of the above-ground structures (including B78) that meets the EAC will be emplaced within the associated below-ground voids. An excess void volume is expected for both the SGHWR and Dragon structures, which will be filled with material from the existing D630 rubble mounds.

372 A summary of the void and infill volumes used for inventory derivation and in the risk assessments is presented in Table 5.9. Total void space has been calculated taking into account the remaining internal structures as they are currently understood [188]. The Design Substantiation Report [25] and supporting references detail the generation and use of large concrete blocks from the above-ground demolition and their emplacement in the SGHWR and Dragon voids. Estimated volumes for demolition arisings have been calculated based on the in-situ volumes of above-ground structures and assuming that the demolition and emplacement results in a combined bulking and self-compaction factor of 1.22. It is assumed that the entire below-ground void volumes will be filled with waste/recovered material.

Table 5.9: Summary of void and infill volumes for the SGHWR and Dragon reactor complexes [19, Tab.606/7].

Region/ structure	**Per region / structure**			**Per reactor complex**		
	Void Volume (m^3)	**Volume Occupied by Blocks (m^3)**	**Remaining Void Volume (m^3)**	**Remaining Void Volume (m^3)**	**Volume of Emplaced Demolition Arisings Generated In-situ (m^3)**	**Void Volume to be Filled using D630 Stockpile Material (m^3)**
SGHWR Region 1	11,649	6,300	5,349	23,439	5,840	17,599
SGHWR Region 2	3,425	None	3,425			
SGHWR North Annexe	4,164	None	4,164			
SGHWR South Annexe	10,501	None	10,501			
Dragon – within Wall C	1,891	400	1,491	6,144	5,045	1,099
Dragon – outside of Wall C	4,653	None	4,653			

373 The assessment of void and material balance is based on the current understanding of the structures and the demolition programme. As structural modifications (both installations and removals) are on-going to allow core retrieval, there may be marginal changes to volume estimates prior to implementation of proposed on-site disposals. These volumes will be reconciled through the detailed design process.

374 The relative proportion of radioactive and non-radioactive demolition arisings to be used in the below-ground voids is currently uncertain. Therefore, the concrete volumes have been deliberately double-counted in both the RSR and DfR permit applications to ensure robust and bounding risk assessments that are flexible to future change[23].

A59 Area

375 Volumes of contaminated soil in the A59 area are summarised in Table 5.10. The area will be remediated to OoS levels prior to IEP. Although the area will be remediated, the entire current volumes are conservatively included in the radiological risk assessment (with an OoS inventory).

Table 5.10: Summary of contaminated volumes and related parameters for the A59 area [149, Tab.4.11]. The table gives values including the entire Pit 3 / PSA and A591 / HVA areas, ignoring any future remediation that may take place in these areas (Section 5.1.3).

Feature	PSA / Pit 3 Area	A591 / HVA Area	Rest of A59	A59 Total
Area (m^2)	440	82	3,229	**3,751**
Thickness (m)	2.5	4.25	2.5	**-**
Volume (m^3)	1,100	347	8,070	**9,520**
Density ($kg\ m^{-3}$)	2,000	2,000	2,000	**-**
Mass (kg)	2.20E+06	6.95E+05	1.61E+07	**1.90E+07**

5.4.3 Radiological Inventory

D.8 A detailed and cautious but credible description of the nature, magnitude and distribution of the radiological inventory for the proposed disposals has been developed to support both the demonstration of environmental safety and optimisation.

376 The radiological inventory for the proposed on-site disposals, together with the data and assumptions supporting it, is described in detail in the Radiological Inventory Report [17]. Reference activity estimates (considered to be cautious but credible) have been built through detailed consideration of the operational history of the facilities, the mechanisms by which the facility became radioactive (i.e. neutron activation and/or contamination), and review of the available characterisation and neutron activation modelling data. Where necessary, the inventory estimates have been developed using a number of assumptions, making use of other knowledge and experience.

[23] The same total volume of demolition arisings is considered in both applications. The non-radiological risks associated with the entire volume are considered in the HRA, and the radiological risks are considered in the PA assuming that the entire volume is radioactive. Therefore, any future change in the proportions of material that would be classed as radioactive or non-radioactive are bounded by the assessments undertaken.

377 Whilst conservative assumptions have been made to develop the reference inventory, the estimates must still be credible (i.e. not overly conservative), otherwise appropriate optimisation assessments cannot be made. To understand the impact of inventory uncertainty, the identified gaps, uncertainties and assumptions have been used to [17]:

- Support a qualitative assessment of the confidence in the inventory estimates [17, §4]. This assessment reflects the confidence in the calculated inventory and how significant each area may be in the overall inventory. A red-amber-green scoring system has been used to clearly identify key uncertainties to guide future characterisation effort. All components were allocated green or amber scores except where noted in the sections below.
- Support calculation of alternative, more conservative, inventory estimates to test the robustness of the overall case. The alternative inventory estimates pessimistically assume maximum, rather than average, radioactivity levels for most components. The alternative inventories for those components are calculated using the highest activities measured for each radionuclide across all characterisation samples, and therefore are not feasible in reality. Where appropriate, the alternative inventory estimates also account for variations in possible radionuclide fingerprints or contamination volume.

378 Separate inventory estimates have been derived for individual areas within the SGHWR and Dragon reactor complex that are distinctly different in radiological fingerprint, amount, or spatial extent of contamination or activation. These estimates have been aggregated for consideration in the radiological risk assessment. All inventory data in the following sections are presented for a date of 01/01/2027 (this was assumed, for the purposes of the risk assessments, to be the earliest date for the start of implementation of the disposals).

379 A more detailed summary of the assumptions, characterisation data and approach used to derive reference and alternative inventory estimates for each of the features considered in the radiological risk assessment can be found in Section 3.3.4 of the radiological PA [23]. This also sets out the activity concentrations in components of each of the features as well as variation in fingerprints.

SGHWR

380 A number of sources contributing to the SGHWR on-site disposal radioactive inventory have been identified, including activity derived from neutron activation of the reactor bioshield and activity resulting from surface contamination. The Radiological Inventory Report [17, §2.3] summarises the three main sources of contamination in the SGHWR as follows:

- The reactor primary circuit was directly in contact with the fuel and was the primary heat transfer medium. The primary circuit was contaminated due to activation and corrosion of the metal core components and transport through the circuit. The primary circuit also held a significant inventory of ^{137}Cs and tritium from fission products and activation of the light (ordinary) water coolant.
- The moderator circuit contained deuterated water (D_2O) during operation. Exposure to high neutron fluxes led to significant tritium and ^{14}C activities in the circuit during operations.
- The ponds and fuel route had greater contact with spent fuel and therefore different proportions of radionuclides present than other areas of the facility.

381 The contamination of any particular room in the SGHWR structure is dependent on the relative influence of the three contaminant sources and decommissioning and decontamination work since operations ceased.

382 The SGHWR mortuary tubes inventory is uncertain; they are the only SGHWR component to be allocated a red score for overall confidence and significance in the Radiological Inventory Report [17, Tab.4.1]. The inventory is not supported by any sample data as the mortuary tubes cannot be accessed at this time as they contain active items due to be processed as intermediate-level waste (ILW) alongside wastes arising from the core. However, a cautious approach to the potential inventory that could remain in the mortuary tubes following removal of the active items has been applied based on conservative assumptions for the potential sources of residual activity in the tubes (e.g. assuming contamination sources include the reactor core, moderator circuit, ponds and activation) and the volume of material contaminated (see [17, §2.11.2]). Following removal of the stored wastes, further characterisation, inventory refinement and decontamination will be completed[24].

383 The total estimated reference radiological inventory for the SGHWR end state at 01/01/2027 is 6.12E+05 MBq, which is increased by a factor of 9.7 to 5.91E+06 MBq when assuming the alternative inventory estimate. The bioshield forms the highest proportion (59%) of the total reference inventory due to its high average activity concentrations, despite a relatively small overall mass. The dominant radionuclides by activity in the SGHWR reference inventory are tritium, ^{137}Cs, ^{152}Eu, ^{63}Ni and ^{90}Sr.

Dragon Reactor Complex

384 The majority of the radiological inventory present in the proposed Dragon reactor complex disposal is associated with the bioshield, which is activated. The remaining inventory is associated with low-level contamination in the building paint, walls and floors of the B70 and B78 building structures. In the B70 reactor building the inventory derives from a number of sources [17, §3.3]:

- Operational activities reactor operations generated ^{137}Cs as a fission product and this is commonly identified in the building contamination[25].
- Historically, ^{3}H dials (Betalites) were stored at the -25' (-7.62 m) below ground floor level in the outer annulus, the leaking of which led to some contamination.
- There is patchy contamination (^{3}H, ^{137}Cs and ^{60}Co) elsewhere in the facility from decommissioning, found primarily in the paint layer.
- Decommissioning and waste management activities, including the core retrieval, have the potential to redistribute contamination within the facility as remote drilling, sawing and laser cutting may generate gaseous contamination.
- An earlier spill during decommissioning operations associated with the PGPC requires further characterisation and decontamination [189]. The PGPC spill inventory has been allocated a red score for overall confidence and significance in the Radiological Inventory Report [17, Tab.4.2] as it is not currently supported by sampling data and is dependent on the decontamination to be undertaken. To ensure a robust assessment, it has been assumed that the activity of the spill is at the upper limit of the LLW activity definition. However, a recent BAT assessment [189] has identified that the preferred approach is to decontaminate the area to 200 Bq g^{-1}.

385 As well as containing the spent and fresh fuel stores, the B78 building has been used for decommissioning and waste management activities. Characterisation data demonstrates that

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[24] The contents of the SGHWR mortuary tubes are currently scheduled for the last ILW retrieval and processing campaign, partly due to their relative inaccessibility and partly due to uncertainty in the inventory.

[25] The Dragon reactor operated for a short period, from 1965 to 1975. The relatively short operating period and the long decay timescales since operation mean that many shorter-lived radionuclides are not detected.

levels of general contamination are comparable to and have a similar source term to B70. This assumption was used in deriving the B78 inventory.

386 The primary mortuary hole structure in building B78 was used to store spent fuel. Following defueling of the Dragon reactor, the mortuary hole structure was also used to house various wastes from other facilities, which gives the potential for different sources of contamination [17, §3.3]. A recent (2023) systematic sampling campaign has significantly reduced uncertainty in the mortuary hole inventory estimate.

387 The total estimated reference radiological inventory for the Dragon reactor complex end state at 01/01/2027 is 7.23E+03 MBq, which is increased by a factor of 3.5 to 2.55E+04 MBq when assuming the alternative inventory estimate. The majority of the Dragon inventory is associated with the B70 below-ground disposal - the backfill from the above-ground Dragon demolition and from the rubble mounds forms the highest proportion (54%), followed by the bioshield (21%). The backfill dominates the inventory due to the large volume over which it is applied. The same five radionuclides dominate the Dragon inventory as for the SGHWR inventory (^{3}H, ^{137}Cs, ^{90}Sr, ^{152}Eu and ^{63}Ni).

A59 Area

388 The best-estimate reference inventory for the contamination in the former A59 area at the present day satisfies OoS criteria. However, owing to the spotty nature of the contamination and challenges in the historical remediation undertaken, uncertainty in the reference estimate suggests that some parts of the A59 area could be in-scope of RSR. NRS plans to further remediate the A59 area to ensure that the OoS criteria can be met with confidence. As such, the alternative inventory estimate considered in the radiological risk assessment has been developed assuming that the activity remaining following the planned remediation just satisfies OoS criteria while retaining the same fingerprint proportions as for the reference inventory estimate.

389 The modelled reference radiological inventory for the A59 area at 01/01/2027 is 5.49E+03 MBq, which is increased by a factor of 5.0 to 1.30E+04 MBq when assuming the alternative inventory estimate. The majority of the inventory (70%) is associated with the A59 Other Area because, despite its low activity concentration, it has a large volume. The A591 / HVA area contributes 24% while the remaining Pit 3 / PSA area contributes only 6% due to its low average activity concentration. The A59 area has a slightly different fingerprint to SGHWR and the Dragon reactor complex, with the five dominant radionuclides including ^{238}U and ^{234}U as well as ^{63}Ni, ^{90}Sr and ^{137}Cs.

Summary of the Assessed Radiological Inventory

390 Many of the radionuclides present in the Radiological Inventory Report [17] have low activities and/or have short half-lives, such that they cannot contribute significantly to future radiological risk. Therefore, for the risk assessment the inventory was screened to target effort on those radionuclides potentially significant to risks to people and the environment [23, App.B]. Radionuclides with half-lives less than one year or greater than the age of the Earth (effectively stable) and radionuclides calculated to have a maximum activity concentration less than 1% of the OoS values of EPR16 were screened out. Following screening, 51 radionuclides were considered in the assessment. The inventory presented in this sub-section includes only radionuclides screened into the assessment.

391 Table 5.11 summarises the total activity and top five contributing radionuclides for the reference and alternative case radiological inventory estimates. The SGHWR inventory is by far the dominant contributor, forming 98% of the total reference inventory.

Table 5.11: The reference and alternative inventories considered in the radiological risk assessment for an activity date of 1 January 2027.

Reference Inventory							
		SGHWR		Dragon		A59	
Total (MBq)	In-situ	5.27E+05		3.35E+03		5.49E+03	
	Infill	8.15E+04		3.88E+03		0.00E+00	
	Total	6.09E+05		7.23E+03		5.49E+03	
Top 5 nuclides	1	4.88E+05	H-3	4.26E+03	H-3	2.66E+03	Ni-63
	2	4.13E+04	Cs-137	1.89E+03	Cs-137	9.39E+02	Sr-90
	3	1.89E+04	Eu-152	3.65E+02	Sr-90	5.33E+02	U-238
	4	1.62E+04	Ni-63	2.04E+02	Eu-152	5.19E+02	U-234
	5	1.33E+04	Sr-90	1.42E+02	Ni-63	3.50E+02	Cs-137
Remaining nuclides		3.15E+04	-	3.66E+02	-	4.97E+02	-
Approx Displacement Volume (m^3)		46,123		10,460		9,519	
Alternative Inventory							
		SGHWR		Dragon#		A59	
Total (MBq)	In-situ	5.68E+06		1.39E+04		1.30E+04	
	Infill	2.00E+05		1.16E+04		0.00E+00	
	Total	5.88E+06		2.55E+04		1.30E+04	
Top 5 nuclides	1	5.00E+06	H-3	2.05E+04	H-3	7.59E+03	Ni-63
	2	2.77E+05	Eu-152	2.19E+03	Cs-137	1.95E+03	Sr-90
	3	1.48E+05	Cs-137	7.73E+02	Sr-90	8.10E+03	Cs-137
	4	1.34E+05	Ni-63	6.28E+02	Eu-152	5.64E+02	Pu-241
	5	6.11E+04	Ca-41	3.05E+02	Ba-133	5.35E+02	U-238
Remaining nuclides		2.58E+05	-	1.11E+03	-	1.52E+03	-

A second alternative inventory for Dragon has been derived to consider a Pu-containing fingerprint, but this has a negligible effect on total activity and risk compared to the alternative inventory presented and is not shown in the table.

5.4.4 Non-radiological Inventory

D.9 A detailed description of the nature and magnitude of non-radiological materials expected to remain as part of the proposed on-site disposals has been developed to support both the demonstration of environmental safety and holistic optimisation. The inventory of the proposed on-site disposals includes: i) non-radiological, non-hazardous materials; ii) non-radiological hazards associated with, or potentially interacting with, radioactive waste; and iii) non-radiological hazards not associated with radioactive waste.

392 The non-radiological materials expected to remain on the site at the end state are described in the site-wide Non-radiological Inventory Report [18]. The report is supported by several underlying reports and spreadsheets [185; 186; 190; 191] which present non-radiological data associated with the:

- above and below-ground radioactively contaminated structures forming the proposed SGHWR and Dragon reactor complex disposals;
- above and below-ground OoS structures across the Winfrith site that will either remain in-situ or be re-used as demolition arisings;
- existing spoil (soil and rock) mounds from previous excavation works (such as SGHWR construction) that are intended to remain in-situ at the end state; and
- existing stockpiled rubble and spoil material that is expected to be used for infilling below-ground voids on site.

Non-radiological Materials Inventory

393 The Non-radiological Inventory has been prepared to represent the materials expected to remain on the site as part of the proposed end states for the SGHWR and Dragon structures. and incorporates inputs from radioactive and non-radioactive wastes and materials (non-wastes). The Non-radiological Inventory includes in-situ structures and void infill material derived from both demolition of the above-ground structures and existing stockpiles of demolition rubble, as summarised in Table 5.12.

394 The SGHWR and Dragon reactor complex structures and the D630 rubble stockpile contain a mixture of concrete, brick and masonry[26]. The CSM [19, §3.2.1] estimates the proportion of brick in the D630 stockpile to be between 19% and 30%, and the proportion in the above-ground SGHWR structure to be approximately 13%. The Dragon reactor complex structure is assumed to be 100% concrete. The in-situ structures also contain a percentage of structural steel and re-bar, which is discussed under the section on non-radiological hazards below.

Table 5.12: In-situ concrete and demolition material volumes forming the proposed SGHWR and Dragon reactor complex end states.

	SGHWR		Dragon	
	Volume (m^3)	**Mass (te)**	**Volume (m^3)**	**Mass (te)**
Structural concrete remaining in-situ	7,366	17,678	5,100	12,240
Concrete blocks emplaced in reactor voids	6,300	15,120	400	960
Reactor structure demolition arisings emplaced in voids	5,840	11,489	5,045	9,925
D630 stockpile material emplaced in voids	17,599	34,621	1,099	2,162

395 In addition to the structures forming part of the proposed disposals, the non-radiological inventory includes the following:

- Existing made ground from the original construction of the site. This constitutes a total volume of approximately 49,100 m^3 of compacted soil and rock. The largest is the SGHWR Construction Mound with a volume of 46,100 m^3 [18, Tab.2].

[26] These materials would be classified as non-hazardous if demonstrated not to be contaminated.

- Approximately 20,600 m^3 of future arisings from facilities and structures outside of the SGHWR and Dragon reactor complex that are yet to be demolished, but will be managed off-site via appropriate routes [18, Tab.3; 192].
- Existing sub-surface drains, structures, slabs and foundations greater than 1 m bgl that will be decommissioned at the end state. Sub-surface structures that are less than 1 m bgl, such as roadways and paths, are not included as they are assumed to be removed in accordance with the End Point Specification [43][27].

Non-radiological Hazards Associated with the On-site Disposals

396 Materials making up the proposed on-site disposals, including both the in-situ structures and the below-ground void infill, may contain components that potentially represent a non-radiological hazard. The derivation of the non-radiological contaminant inventory (from both the above-ground SGHWR and Dragon structures and the existing D630 stockpile) is set out in detail in the CSM [19, §3.2] and are assessed in the hydrogeological risk assessment (Section 7.9).

397 The concrete in the SGHWR and Dragon reactor complex structures, and in the D630 rubble stockpile, is assumed to be a typical construction concrete of one part Ordinary Portland Cement, two parts sand and three parts gravel. Concrete can impact the pH of water through leaching of the hydroxide ion which can raise the pH in water. This is considered in the non-radiological risk assessment discussed in Section 7.9.

398 Small quantities of concrete containing barium are known to be present in both the SGHWR (parts of the secondary and primary containment) and Dragon (bioshield) [17, §2.8 and §3.4.2]. The volumes present are small enough that it has been ignored when deriving volumes and masses [190, §4], but the potential risk from barium is considered in the non-radiological risk assessment (Section 7.9).

399 The non-radiological hazards associated with the proposed SGHWR and Dragon end states can be summarised as follows, with more detail provided in the reports referenced:

- Chemical components in concrete and brick demolition arisings: Conservative estimates have been derived for total and leachable inventory masses of inorganic contaminants, and total inventory masses of organic contaminants [19, Tab.606/24 and Tab.606/25].
- Rebar and structural metal: Rebar that forms part of the SGHWR and Dragon structures will remain in-situ at the end state. Estimates for the amount of iron and other mild steel components present in this inventory have been made [185; 186]. The majority of the non-structural metal will be removed during decommissioning and consigned for recycling. Structural steel will be left where removal would either be detrimental to the stability of structures or would be extremely difficult or dangerous to remove [193].
- Asbestos: Bulk and friable asbestos has been removed from the SGHWR and Dragon reactor complex and disposed of at licensed off-site facilities. Minor amounts of residual asbestos cast into concrete and present as splatters, termed ‘snots’, remain on walls and in penetrations in SGHWR [194, §2.1.1]. A Best Available Technique (BAT) assessment [194] demonstrated that the preferred approach to managing small amounts of residual asbestos is to seal surfaces and leave it in place to minimise the risk posed to workers from removal operations.

[27] Materials will be disposed of off-site or, if appropriate, used in site landscaping (including cap construction).

The only identified asbestos present in the Dragon reactor complex is blocks between the bioshield and the metal thermal shield [190, §7.2.1]. The asbestos blocks will be removed during decommissioning [190, §7.2.1].

Sampling of the D630 rubble mounds detected no asbestos fibres above the detection limit of 0.001% asbestos content [190, §7.3.1]. However, three fragments of chrysotile-containing materials were identified during a 2018 walkover [195]. Any asbestos material present in rubble will be removed during sorting prior to use as infill material.

- Paint: Paint has been used over many decades to protect structural steel from corrosion and surfaces such as floors are painted. Older paint formulations contained chemicals that are now considered to be hazardous. Paint is routinely removed during the decommissioning and decontamination process, but it is inevitable that a small mass of paint will be present in the disposals. Sampling and analysis [19, §3.1.6] has shown that paint within the SGHWR structure contains quantities of several hazardous chemicals.
- Fibreglass: Fibreglass (consisting of glass fibres encapsulated within epoxy resin) was used to line the SGHWR ponds to prevent water egress. A BAT assessment [196] concluded that in-situ disposal of the fibreglass is the best available technique for its long-term management. There is no fibreglass in the Dragon reactor complex.
- Oil: Oil was used extensively throughout the SGHWR in plant and equipment such as the turbines. While oil spills resulting from operations within the SGHWR have been cleaned up, residual oil stains are present in some areas. The oil stains have been characterised through sampling and analysis [197]. A BAT assessment [198] concluded that leaving the oil-stained concrete in-situ is the best available technique for its long-term management.

  There is no history of oil spills or plant with significant quantities of oil within the Dragon reactor complex [198, §5]. Visual surveys identified three small oil stains, each affecting an area less than 1 m^2 [199]. The areas are superficial and oil contamination within Dragon will be removed during decommissioning [190, §7.2.2].

Other Non-radiological Hazards

400 The non-radiological hazards on the Winfrith site not associated with the proposed SGHWR and Dragon reactor complex end state are recorded in the Winfrith Land Quality Register [47] and in Appendix A of the Non-radiological Inventory [200].

Remaining Uncertainties

401 The uncertainties associated with the non-radiological inventory are set out in [18, §3.9; 200], along with any future actions proposed in accordance with the UMM.

6 Optimisation

Claim: Optimisation
Strategic options assessments have demonstrated that the preferred approach of disposing of radioactive wastes on the Winfrith site as part of the site end state is optimised. This end state presents the best overall approach when assessing a range of safety, environmental and social factors relating to management of wastes generated on the site. Evaluation of specific waste management and design options for the on-site disposals to optimise their configuration is ongoing and will continue until their implementation.

6.1 Optimisation Process

O.1 NRS procedures are used to ensure that Best Available Technique (BAT) and optimisation assessments are undertaken consistently and with sufficient scope to ensure that radiological risks are as low as reasonably achievable (ALARA), and that the assessments are appropriately documented.

402 Radiological risks from the site must be demonstrated to be ALARA in order for the site to be released from RSR. This is expressed in GRR Principle 2 [6, ¶A2.9]:

> *"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."*

403 This optimisation principle is divided into two requirements in the GRR: optimisation of waste management options (Requirement R1 [6, ¶A3.2]) and optimisation of on-site disposals (Requirement R13 [6, ¶A4.92]).

404 The first of these requirements, Requirement R1, concerns optimisation at a strategic level. It requires that a systematic, proportionate process is followed in selecting optimised waste management options. This includes undertaking options assessments to inform strategic decisions on final radioactive waste disposition routes, including whether the final dispositions should be off-site or on-site. Selected options must enable the site to be released from RSR in accordance with the requirements of the GRR.

405 Requirement R13 concerns optimisation at a tactical level. Where optimisation under Requirement R1 has identified an on-site disposal option to be the preferred approach, Requirement R13 concerns the design, construction and implementation of that disposal to ensure exposures are ALARA [6, ¶A4.93] throughout the regulated period and afterwards.

406 The Winfrith site permit sets the regulator's requirements for using BAT in ensuring optimised management of its radioactive wastes [7, §2.3.2]:

> *"The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to this permit to: (a) minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment; (b) minimise the volume of radioactive waste disposed of by transfer to other premises; (c) dispose of radioactive waste at times, in a form, and in a manner so as to minimise the radiological effects on the environment and members of the public."*

407 The process and approach used to conduct robust BAT assessments for managing its radioactive waste is set out in standard procedure S-391 [201][28]. This procedure specifies a staged and rigorous approach to assessing options, both strategic and tactical, to define the preferred approach. This approach can be summarised as follows:

- A long list of options is prepared to consider all potentially available options. This is often prepared through a literature search, review of approaches across the nuclear industry and a review of approaches outside the nuclear industry.
- The long list is screened against a set of minimum requirements, such as legal compliance and feasibility.
- A short list of credible options is developed to fully understand the potential benefits and detriments associated with each option.
- An options assessment panel (OAP) is formed for significant decisions, such as those concerning on-site disposals.
- The OAP will define the attributes or factors to be used in assessing the relative performance of options. Attributes are selected from a predefined list of attributes that includes safety, environmental and socioeconomic factors such as worker safety, carbon footprint and impact on local communities.
- The OAP assesses and scores all credible options against each attribute to provide an attribute-by-attribute rating. The preferred approach is determined by identifying which option performs best overall.
- For significant decisions, to test the robustness of the output, a sensitivity analysis is conducted by putting different weightings on different attributes.

408 A critical component in defining the preferred management approach for the large concrete structures has been engaging with the local community in the options assessment process to determine their views on the available options. In alignment with Requirement R4, community views have been incorporated through inviting members of the community to participate in assessment workshops and by asking the community their priorities in decision-making (Section 4.2).

409 This BAT process has been used to define the end state for the site, including the SGHWR and Dragon structures, and also other structures and contamination associated with the site.

410 A full discussion of the optimised approach to waste management through the remainder of the site lifecycle is presented in the WMP [8]. However, the outcomes of key optimisation studies are summarised here to support the safety arguments made in this SWESC.

6.2 Strategic Optimisation of Waste Management (R1 Optimisation)

O.2	Strategic options assessments have demonstrated that leaving some radioactive structures on site is optimal in comparison to attempting a site end state free of radioactive substances.

411 The Winfrith site end state was identified through a comprehensive and transparent optioneering process, including extensive engagement with regulators, the local community

[28] BAT assessments are conducted in line with management system requirements valid at the time of authoring. Early assessments for Winfrith end state proposals were conducted under the RSRL management system, which was extant at the time. Irrespective of the age, management system requirements were compliant with regulatory requirements and industry best practice.

and other stakeholders (see Chapter 4). Strategic options assessments were completed to define the preferred end state for all facilities and areas of radioactively-contaminated ground on the site.

6.2.1 SGHWR and Dragon Rector Complex Structures

412 Strategic options assessments have demonstrated that on-site disposal is the preferred approach for the lightly-contaminated large structures and activated concrete associated with the SGHWR and Dragon reactor complex. The approach to identification of the optimal strategy for management of the concrete structures included:

- engaging with stakeholders to ensure that the site's end state is informed by their priorities and is supported by the local community;
- identifying those facilities which include significant below-ground structures that could be modified to enable on-site disposals to occur; and
- assessing the optimised approach for decommissioning and waste management of the remaining facilities.

413 A BAT assessment was undertaken for SGHWR to define the optimised end state, with specific consideration of options for on-site disposal [39]. Stakeholder engagement was central to the assessment and three workshops were undertaken, concerned with characterising the options and gathering stakeholder views [39; 202; 203]. The output from the initial workshops identified two credible options for the SGHWR structure:

- Option S1: Full excavation.
- Option S2: Below-ground structure left in-situ and decontaminated to a level required to ensure protection of people and the environment as set out in an environmental safety case.

414 These options assumed that:

- The backfill in Option S1 would be determined by the need to be compatible with the large, excavated hole.
- The backfill in Option S2 would need to be compatible with the needs of the environmental safety case (and would probably require further optimisation).

415 The final workshop agreed that Option S2 (involving on-site disposal of the below-ground structures and backfilling with suitable demolition rubble) performed best across a broad range of relevant attributes[29] as it offered a more sustainable solution for materials/waste management than Option S1. The key reasons for choosing this option were:

- Option S2 performed well across eight attributes, with Option S1 only performing better in one attribute (timescale for unrestricted access).
- Option S2 offers greater scope for a more sustainable solution for materials/waste management than Option S1.
- Option S2 minimises the number of lorry movements required - stakeholders do not want to experience significant numbers of lorries carrying radioactive waste off site on local roads which are not built to accommodate them.

[29] The attributes were based on the NDA Value Framework [204] and included factors such as radiological dose, conventional safety, transport, visual impact, environmental discharges, complexity, implementation timescales and cost.

- Option S2 can take advantage of the GRR and any change to the regulatory framework, and can be further optimised.
- Option S2 can accommodate change and new data.
- Both options ensure that the agreed landscape of heathland with public access can still be achieved.
- Option S2 was considered to have the lowest overall cost for the SGHWR end state.
- Option S2 supports the NDA's end state aspirations for Winfrith as set out in the NDA Strategy. Option S2 provides a showcase for implementation of the proposed changes to regulations in managing nuclear sites in a manner proportionate to the risk, demonstrating value for money without compromising safety and security. Option S1 enforces the view that current legislation drives excessive clean-up.

416 A sensitivity analysis was completed to test the robustness of the outcome to uncertainties and risks. This was completed by weighting certain attributes or changing parameters such as cost. Uncertainties and risks considered included the inventory, the cost, the time required to vary the RSR permit and the risk of a permit variation being rejected. Mitigations for all of the assessed uncertainties/risks were identified and as such the preferred option was considered to be robust.

417 The workshop attendees noted that a substantial amount of assessment and further optimisation would be required to demonstrate the overall performance of the proposed disposals. Additionally, the regulators noted that the planned regulatory changes would need to be implemented to allow eventual delicensing and surrender of environmental permits. The necessary regulatory changes have been on-going since 2017.

418 An assessment of the optimised end state for the Dragon reactor complex was completed in 2017 [40]. The features of the Dragon reactor complex identified as possible candidates for in-situ disposal were the sub-surface reactor concrete structure (most significantly the reactor bioshield), the mortuary holes structure and the thermal shield.

419 The credible options assessed for the Dragon reactor structure were:

- Option D1: Leave the sub-surface (1 m below ground level) bioshield in-situ. Infill the voids with rubble from demolition of the above ground part of the bioshield and reactor building and other suitable rubble material from on-site sources.
- Option D2: Remove all LLW from the reactor structures (mostly from the bioshield) and emplace it in the SGHWR basement. Infill the void with OoS decommissioning material from on-site sources.
- Option D3: Remove all LLW from the reactor structures (mostly from the bioshield) and dispose of it in a suitably permitted facility off-site. Infill the void with OoS decommissioning material from on-site sources.

420 The assessment identified Option D1 to be the favoured option due to it having the least environmental impact, causing the least disturbance and being the least expensive. It was noted that this conclusion was dependent on further optimisation in line with GRR Requirement R13 (Section 6.3) and a detailed radiological risk assessment (Section 7).

421 The credible disposal options for the Dragon primary mortuary hole structure were identified as:

- Option M1: Stabilise the structure and make a case for it to be disposed of as an in-situ disposal of radioactive waste.

- Option M2: Remove the structure in its entirety and backfill/re-profile the void. Fill material would need to be suitable for placement in contact with groundwater and subject to an appropriate risk assessment.

422 Option M1 was identified to be the favoured option for the primary mortuary hole structure due to it having the lowest cost and resulting in the least additional environmental impact. However, as for the reactor structure, this conclusion was dependent on further optimisation in line with GRR Requirement R13 (Section 6.3) and a detailed radiological risk assessment (Section 7).

423 As the volumes of concrete for the Dragon reactor complex are much lower and the below-ground void volumes smaller, the relative benefits of on-site disposal are more marginal and the case was more finely balanced than for SGHWR. The decision in favour of SGHWR on-site disposal was made prior to, and did inform, the decision for on-site disposal of Dragon.

6.2.2 Contaminated Land

A59 Area

424 An options assessment [49] was undertaken to determine the optimal management route for the two discrete areas of contamination within the former A59 footprint identified as containing spotty contamination that is potentially in-scope of RSR (part of the Pit 3 / PSA APC and all of the A591 / HVA APC). The assessment identified a long list of potential options and through a series of workshops subjected these to technical assessment prior to defining the short list of options for assessment. These were:

- Option 1: Manage the contaminated ground in-situ.
- Option 2: Excavate the parts that are potentially in-scope of RSR and, following assay, either dispose of the material through established off-site routes or set the material aside for reuse as infill, if appropriate.

425 The two options were assessed for each of the areas of contamination separately against safety, environmental, technical and socio-economic attributes. The assessment of the options against the selected attributes followed a ‘reasoned argument’ approach and relative scoring comparing the options.

426 The preferred approach for both areas of contamination is removal / remediation for slightly different reasons.

- The Pit 3 / PSA contamination is relatively shallow and easy to excavate. Therefore, it is relatively low risk and low cost to excavate the contamination and manage off-site and there is a clear preference for Option 2.
- The A591 / HVA contamination is deeper and more technically complex to remediate. However, as the risks associated with the remediation are low and it can be completed for a marginally greater cost, excavation has been selected as the preferred option. This is because it directly supports the NDA’s clean-up mission and removes any long-term liability.

Rest of Site

427 Residual radioactive contamination associated with Drawpit H on the former active-sludge pipeline route and the former D69 supernatant pump house facility has been remediated to OoS levels after this was identified as the preferred option [8].

428 Other radiological land quality APCs potentially above OoS levels associated with the ALES facility and the active drains are considered together with the structures below.

6.2.3 Sea Discharge Pipeline

429 An options assessment to identify the preferred strategy for the Sea Discharge Pipeline was completed in 2018 [51]. Credible options for the potential end state were systematically identified, characterised and assessed by a combined project team using a structured approach. This approach was considered in workshops attended by the NDA, EA, Dorset Council and a range of local stakeholders, including landowners. The assessment used a zone-based approach to identify the optimised solution for local conditions, ensuring landowner views, technical challenges and safety issues were appropriately reflected.

430 For zones associated with shallow and marine sections of the Pipeline, the optimised end state was defined as full removal of all Pipeline structures and systems and surrender of the RSR permit. The key arguments supporting the preference for removal of the Pipeline in these zones were that it:

- eliminates the long-term risk to members of the public and the environment from later inadvertent exposure of an in-situ disposal (either by inadvertent human intrusion or erosion of the covering material);
- provides the lowest financial risk and highest certainty of success;
- provides the lowest lifecycle cost, once liability fees are accounted for;
- reduces project uncertainty / risk to enable the NDA to complete its mission; and
- is consistent with decommissioning approaches in other regulated industries and government guidance for offshore pipelines.

431 The depth of the Pipeline in the MoD Lulworth and Bovington Firing Range and the current and planned land use meant this zone required further technical underpinning to inform the options assessment:

- The greater burial depth and presence of unexploded ordnance in the MoD range increases the risk to workers for options that involve excavation of the Pipeline.
- Early site visits indicated that the groundwater levels are close to the Pipeline burial depth, which may prevent a disposal in-situ being compliant with groundwater regulations.

432 Following site investigation and further assessment, the preferred option for this zone of the Pipeline in the MoD range is also excavation and management via an off-site facility [52]. This is the preferred approach as the presence and sensitivity of groundwater would make it difficult to demonstrate compliance of in-situ disposals with groundwater regulations. Removal of the deeper sections of the Pipeline in the MoD range will also enable efficiency savings in transport and waste management.

6.2.4 Active Liquid Effluent System (ALES) Facility

433 A BAT assessment undertaken for the ALES facility [205] concluded that the preferred decommissioning and waste management strategy is to remove all the facility structures and manage via appropriate off-site disposal routes for the following reasons:

- The limited contamination of the above and below-ground concrete is likely to be OoS or be easily decontaminated to OoS levels.

- A surplus of demolition material is expected to be generated at ALES, compared to the available below-ground void space.
- For active ducts, where the effectiveness of decontamination cannot be assumed, the effort of removal (and disposal off-site) is less than the effort to make the disposal case.
- Contaminated soil is known to be at the surface and is restricted to localised leak or spill points. Therefore, it can easily be removed (and disposed of off-site) during decommissioning.

6.2.5 Site Drains, Inspection Chambers and Soak Aways

434 As the majority of the site drains, inspection chambers and soakaways are shallow, they are relatively easy to remove and making a technical case to leave them in place would be difficult due to their surface proximity to the surface. Therefore, the default preferred approach is to remove any contaminated drains, inspection chambers and soakaways, as set out in the Winfrith Drains Strategy [206] and End Point Specification [43]. The default approach for non-active drains is for these to be sealed and left in-situ, and the area made safe.

6.3 Optimisation of On-site Disposals (R13 Optimisation)

O.3 Waste management and design options for the final configuration of the proposed disposals have been assessed. Provisionally optimised configurations for each on-site disposal have been defined by considering the relative performance of the different options against agreed attributes. These assessments considered option feasibility, effectiveness, impact on risk and feedback from stakeholder engagement.

435 Requirement R13 of the GRR requires that all features identified for on-site disposal are themselves subject to optimisation to ensure that the radiological and non-radiological risks to people and the environment are ALARA. This optimisation process at Winfrith will continue through the detailed design and implementation phases of the proposed on-site disposals. Therefore, an optimised design of the SGHWR and Dragon reactor complex on-site disposals is being developed in stages:

- The conceptual design has been developed and has been accepted in accordance with the Harwell/Winfrith Design Management Process [107]. It is documented in the Design Substantiation Report [25], which in turn is underpinned by a series of engineering assessments. The purpose of the conceptual design is to demonstrate that the disposal will meet the design's functional requirements [25, Tab.1], which include requirements related to safety and environmental performance.
- The detailed design will be developed once the permit application for on-site disposal has been approved. At this point the design of the SGHWR and Dragon reactor complex disposals will be further developed to ensure that the disposals are fully optimised. This work will be undertaken in partnership with the demolition contractors for both facilities.

436 To support development of the engineering concept design for the proposed on-site disposals, a BAT workshop was held in 2020 to identify external stakeholder views [138]. The workshop was attended by representatives from the EA, the ONR, Dorset Council, Dorset Wildlife Trust and Natural England. The workshop objective was to gather stakeholders views on the process for defining the engineering design and the key design issues, with a view to understanding the decision-making drivers.

6.3.1 Demolition Approach

437 The techniques considered for demolishing the above-ground structures included ‘conventional demolition’, using long reach machinery, and ‘piece-meal demolition’, where demolition is more controlled with operatives undertaking cutting operations. It was concluded that a hybrid demolition approach is the preferred method, consisting of conventional demolition with long-reach tools for the bulk of the buildings, along with block cutting for the robust concrete walls and cells [25]. This approach minimises risk to operatives while producing a compliant disposal.

438 Further optimisation of the demolition approach and development of demolition and decommissioning processes, procedures, radiation and contamination control will be undertaken in the detailed design phase.

439 The recent structural integrity assessment [143] concluded that the thick-walled below-ground structures of the SGHWR primary containment and turbine hall will retain their structural integrity through demolition and backfilling. Some temporary propping of basement walls and retaining walls may be necessary. The assessment [143] also concluded that the thick-walled below-ground structures of the Dragon reactor building will retain their structural integrity through demolition and backfilling works.

440 The implemented disposal configurations will be captured in ‘as built’ records and through the records stipulated in the CQAP.

6.3.2 Sealing Penetrations

441 There are various penetrations in the below-ground structures of the SGHWR primary containment and turbine hall, including large openings for the vent stack exhaust pipes and the redundant cooling water mains [143] (see Figure 5.3). Penetrations in boundary structures, including those associated with groundwater ingress, will be filled and appropriately sealed prior to backfilling [25, §4.2.6] to prevent flow paths for direct discharges developing. The exact approach to sealing each penetration will be defined as part of detailed design, following optimisation.

442 Penetrations in the boundary structures of the Dragon reactor building will be appropriately sealed, in line with the optimised approach, prior to backfilling [25, §A8].

443 Engineering measures implemented to seal penetrations will be captured in the CQAP as a record of the disposals.

6.3.3 Backfill Materials

444 There are a number of voids in the below-ground structures at SGHWR and the Dragon reactor complex that will need to be backfilled as part of the proposed reactor end states. The list includes voids where preliminary screening suggests that there are multiple credible backfill options, where there are no credible alternatives, and where a backfill is already in place, albeit further characterisation of the void may be needed.

445 At this conceptual stage a reference backfill has been chosen for each void based on expert judgement, as discussed in the backfill optimisation assessment [207]. The judgements are supported by the radiological and non-radiological risk assessments, which have confirmed that the end state concept designs using the reference backfills met all regulatory requirements (Section 7).

446 Where alternative backfill options exist the backfill options were compared in workshops (e.g. [138]) using the NRS optimisation process S-391 [201]. This used a range of discriminatory technical, environmental and safety attributes and assessment of performance against compliance requirements to distinguish between options to identify optimal backfills. Following the workshops, an increased understanding of the reactor basements has also contributed to the assessment, as well the experience preparing the Design Substantiation Report [25] and the assessment of reactor below-ground structural integrity [143].

447 Table 6.1 shows the results of the optimisation assessment, while Table 6.2 shows the voids where there was judged only one credible backfill.

Table 6.1: Preferred backfills for the key below-ground voids with alternative backfill options.

Below-ground Void	Preliminary Backfill Preference	Back-up Backfill Option(s)
SGHWR Region 1: Primary Containment	**Reference case**: Blocks with demolition/D630 rubble on top	**Alternative A**: Layered blocks, with cementitious material used to fill gaps between the blocks, with demolition/D630 rubble on top. **Alternative B:** Cementitious material added to the blocks up to an agreed level where it is optimal to do so, with demolition/D630 rubble on top.
SGHWR Region 2: Turbine Hall	**Reference case**: Demolition/D630 rubble only	No requirement for a back-up
SGHWR Region 2: Delay Tank Room and Steam Labyrinth	**Reference case**: Demolition/D630 rubble only	**Alternative D:** Reference case, with additional work where it is optimal to do so to seal leak paths in the boundary structures which may lead to direct discharges.
Dragon Main Building: within Wall C	**Reference case**: Blocks with demolition/D630 rubble on top	No requirement for a back-up

Table 6.2: Below-ground voids with only one credible backfill option.

Below-ground Void	Only credible backfill option
SGHWR Region 1: Octagonal Sump	Recently filled with concrete as part of core retrieval preparation works.
SGHWR Region 1: Coffer dams	Pea-gravel filled voids, with the option of cementitious material added as a plug above the gravel and below the coffer dam caps to be considered at the detailed design stage.
SGHWR: South Annexe	SGHWR demolition rubble supplemented by D630 rubble (see discussion in Section 6.3.9).
SGHWR: North Annexe	As the North Annexe will be above the water table at all times the reference case rubble backfill is appropriate and there is no need for an alternative backfill.

Below-ground Void	Only credible backfill option
SGHWR, part of South Annexe: Room 258	As Room 258 will be above the water table at all times the reference case rubble backfill is appropriate
SGHWR, part of South Annexe: 7.5’ Cooling Tower Pipes	Penetration to be sealed with rubble filling the void on the disposal-side.
Dragon Main Building: Outside wall C	Dragon reactor complex demolition rubble supplemented by D630 rubble if needed.
Dragon Service Duct outside the Dragon main building	Dragon reactor complex demolition rubble, noting that if there is a weakness in the Service Corridor base, then a grout layer may need to be added to the base at the detailed design stage to reduce the chance of a direct discharge.
Dragon mortuary holes outside the Dragon main building	Cementitious backfill chosen as the only credible option because filling the holes with concrete blocks or rubble will not be feasible.

448 It is recognised there remains uncertainty regarding whether ongoing reactor decommissioning will impact the final backfill choice. The concerns that need resolution include:

- gaining access into some currently closed-off below-ground voids, especially at SGHWR;
- carrying out physical, chemical and radiological characterisation where key data gaps exist;
- determining which walls and floors will be removed as part of end state preparations;
- understanding what engineering measures may be needed within the voids ahead of backfilling to ensure safety and continuing environmental protection;
- receiving RSR Permit conditions on permit approval where they might impact backfill choice; and
- carrying out the end state detailed design.

449 As the uncertainties cannot yet be removed or reduced, as more data will only become available over the rest of the decommissioning programme, then this backfill optimisation assessment is at a preliminary stage. There will be a continued need to maintain backfill choice flexibility as new data arises, as the changes might alter the preferred choices set out here.

6.3.4 Engineered Cap

450 The SGWHR and Dragon reactor complex will be covered by an engineered cap designed to limit rainwater infiltration and hinder inadvertent intrusion. The risk assessments have shown that a moderately engineered cap design would be sufficient to satisfy the GRR technical requirements (see Chapter 7). The optimal engineered cap design will be determined as part of the detailed design phase.

451 Conceptual designs for the engineered caps have been developed for the proposed SGHWR (Figure 6.1) and Dragon reactor complex (Figure 6.2) disposals [19, §5.3]. It is assumed that a single cap will be emplaced over both the below-ground B70 Dragon reactor structure and the B78 floor slab, including the mortuary hole structure [19, §5.3]. The cap designs provide flexibility regarding landscape options and the types of planting above the disposals.

452 The risk assessment models consider a range of options for the cap in terms of thickness and water infiltration rate. For SGHWR, a reference cap thickness of 4.0 m has been assumed, with alternative thicknesses of 2.25 m and 3.0 m. Due to the lower radiological and non-radiological risks associated with the Dragon reactor complex, a thinner cap is possible, with a reference thickness of 3.8 m assumed and alternative cases of 1.5 m and 2.5 m. For all potential cap designs, the disposals meet relevant regulatory criteria, with better performance associated with thicker, more highly engineered caps.

453 Degradation of the cap is also considered in the risk assessments. The model results demonstrate that even if the cap degrades twice as quickly as anticipated, concentrations of all radiological and non-radiological contaminants in groundwater are well below compliance criteria (see Sections 7.3, 7.4, 7.9 and 7.10).

454 Cap climate change resilience has been considered ([148]; Section 5.3.4), with the review recommending that the following points are considered during future cap optimisation:

- Whilst there is scope to optimise the design (e.g. reassessing thickness of cover soils and drainage layers, or selection of low permeability layers), it should be demonstrated that any alternative allows no more infiltration than assumed in the risk assessments.
- Any design optimisation should maintain protection of the low permeability cap components. For example, the cover soils, geotextile and granular human intrusion/drainage layers of the conceptual design provide confidence that the low permeability layers will remain unexposed to more extreme temperatures, increased intensity rainfall events and/or higher wind intensity.

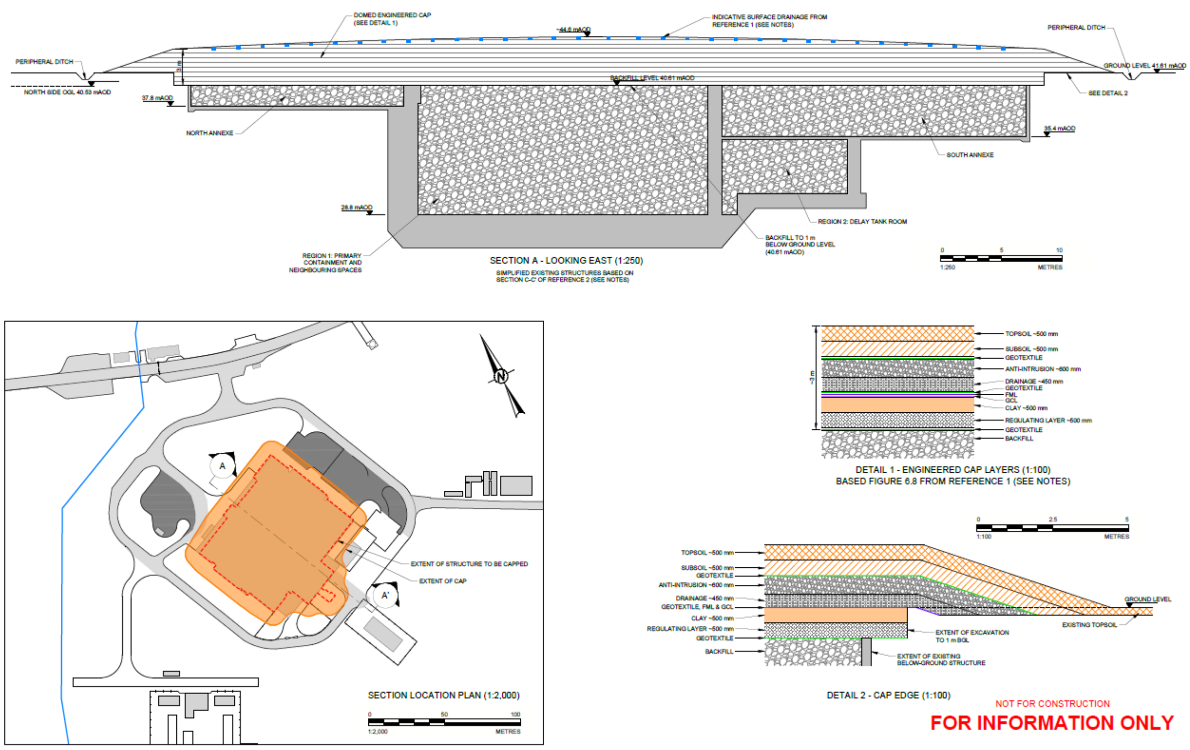

Figure 6.1: Schematic representation of the conceptual SGHWR engineered cap [19, Fig.606/19].

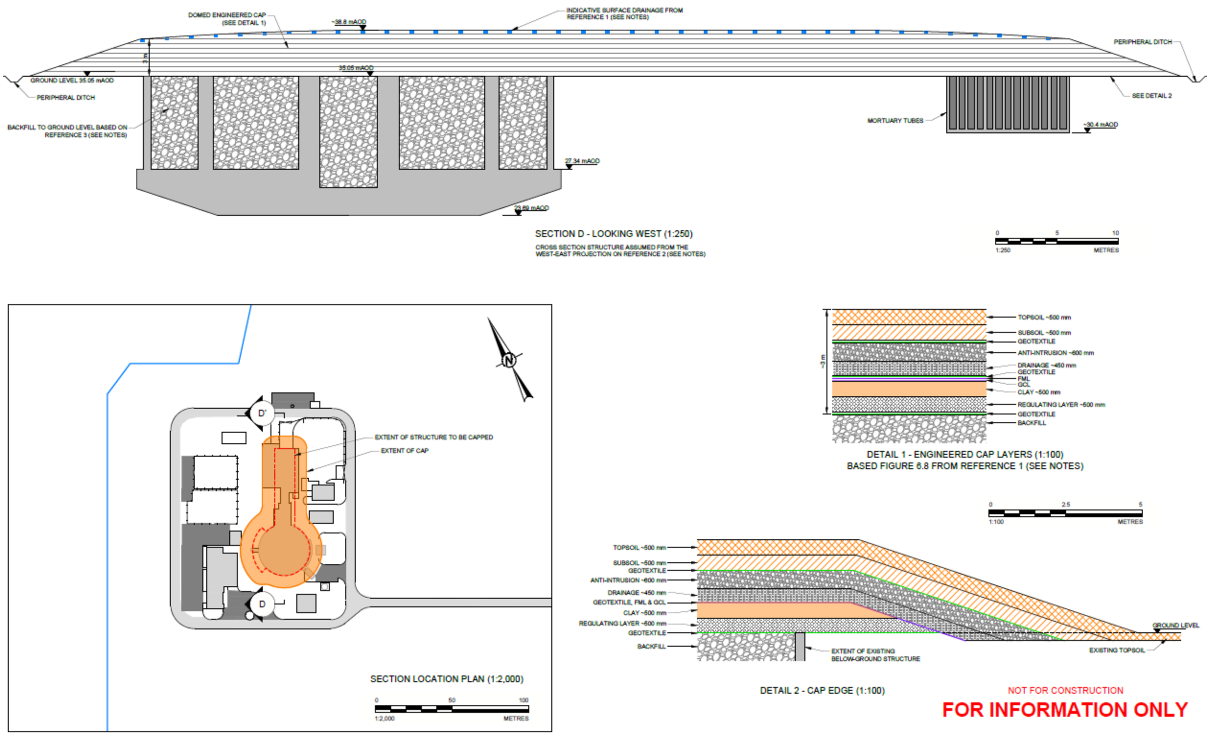

Figure 6.2: Schematic representation of the conceptual Dragon reactor complex engineered cap [19, Fig.606/20].

6.3.5 Drainage Above the Cap

455 In order to promote surface water run-off from the cap, a series of shallow stone drains positioned within the cap surface layer will drain to shallow ditches at the toe of the cap (Figure 6.3). As the cap is expected to undergo some settlement and movement these drains will provide positive drainage routes and help prevent ponding. By draining water away from the cap in this passive manner, an additional layer of ‘defence in depth’ against rainwater ingress is provided. Optimisation of the layout and size of the drains, erosion and drainage routes will be considered in the detailed design stage.

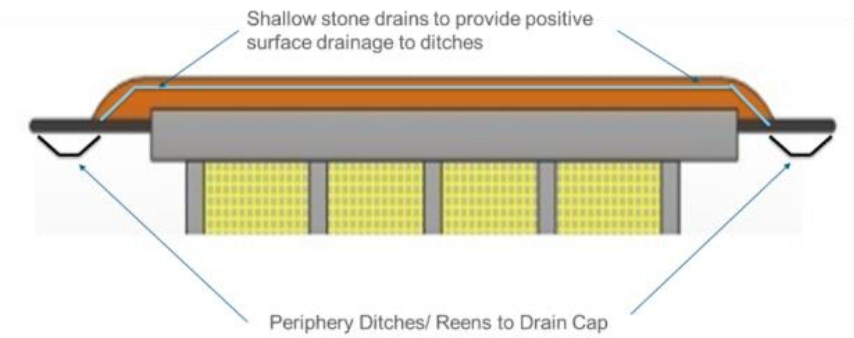

Figure 6.3: Draft drainage concept [25, Fig.A5].

6.3.6 Dragon Reactor Building Demolition Cut Line

456 An options assessment has been undertaken to determine the optimum position of the line where demolition stops and in-situ disposal begins (known as the demolition cut line) [208].

Dragon sits in a slight depression which poses technical challenges in excavating to 1 m below ground level. The options assessment aimed to define the preferred demolition cut line with these specific local conditions. The assessment considered two options:

- Option 1: Demolition to 1 m below ground level.
- Option 2: Demolition to ground level.

457 For both options, there is sufficient void space to accommodate the demolition arisings. The assessment identified Option 2 to be the BAT option. The discriminating factors were reduced dose and conventional risks to workers; it is also technically less complex and lower cost to complete. Option 1 was determined to perform better for public dose (from inadvertent human intrusion) and the risk of long-term intervention; however, the differences in these factors were small.

6.3.7 Optimisation of the Dragon Reactor Complex Disposal - PGPC Spill Contaminated Concrete

458 An options assessment has been undertaken to determine the optimised approach to the contaminated concrete as a result of the PGPC contaminated liquid spillage [189]. The options considered within this study were:

- Option 1: Decontamination of PGPC contaminated concrete to 200 Bq g^{-1} activity concentration (a level which is consistent with the EAC [26]).
- Option 2: Decontamination of PGPC contaminated concrete to the upper LLW boundary (12 GBq te^{-1} beta/gamma).

459 The assessment identified Option 1 to be the BAT option. This option has been selected as preferred as improvements in long-term performance can be achieved with negligible additional dose to operatives and waste generation. Additionally, higher levels of activity would pose challenges in regulatory permissioning of the Winfrith end state if remediation was only undertaken to the upper LLW limit.

460 Note that contamination to the limit of the LLW definition has been assessed as part of the radiological risk assessments presented in Chapter 7 and has negligible impact in comparison to the risk and dose criteria set out in the GRR.

6.3.8 Optimisation of the SGHWR Disposal - Options for Non-Concrete Components

461 A number of detailed BAT assessments have been completed to address specific uncertainties in defining the disposability of certain SGHWR components, as part of the further optimisation of the proposed on-site disposal. These include:

- SGHWR fibreglass pond liners [196]. The BAT analysis for the fibreglass pond liners assessed options of complete removal or leaving in-situ. It was concluded that the option of in-situ disposal of the fibreglass pond liners is the BAT option. The key discriminating factors were that in-situ disposal would result in lower worker dose and conventional safety risk and is the simplest (and likely cheapest) option to deploy.
- SGHWR residual oil contamination [198]. The BAT analysis for residual oil contamination concerned any mineral oil contamination remaining in the structure. The assessment considered two options, destructive decontamination of the structure (potentially compromising structural elements) or leaving oil residue in-situ in the concrete structure. The BAT assessment was supported by a risk assessment that demonstrated that the environmental risks would be within regulatory thresholds. The BAT assessment identified that in-situ disposal out-performed full decontamination of

the oil, due to reduced worker radiological and conventional safety risk, and lower deployment difficulty/costs.

- SGHWR encast and in-room metals [193]. The BAT analysis for structural metal and rebar considered the management of metals that that are intrinsic to the structure. These are:
  - steel rebar used within reinforced concrete;
  - steel pipes and support beams that pass through thick concrete walls (which will be cut flush to the wall surface); and
  - other steel pipes and supporting beams within rooms (not encased within walls) that would be challenging to remove without affecting the structural stability of the area.

  The analysis compared two options, inclusion of structural metal and rebar or full removal of all metal. In-situ management was identified as the BAT option, with the key discriminating factors being reduced radiological and conventional safety risks, reduced transport miles, reduced deployment difficulty and associated reduced costs.

- SGHWR residual asbestos [194]. The BAT analysis for residual asbestos considered any residual asbestos that may remain in the structure following bulk asbestos removal. This primarily relates to asbestos in difficult to access areas, painted in asbestos and encast (cast into concrete) asbestos. The analysis considered the two options of complete removal or in-situ disposal. In-situ management was identified as the BAT option, with the key discriminating factors being reduced worker dose and intrinsic safety risk, lowest deployment difficulty and least cost. There were no attributes identified where removal of the residual asbestos performed better than in-situ management.

6.3.9 SGHWR South Annexe

462 The South Annexe engineering and backfill approach was optimised slightly differently due to a number of technical challenges surrounding the building construction and groundwater levels under some climate change scenarios. The optimisation assessment was carried out to address how best to manage the regulatory “prohibition” on direct discharges requirement for the SGHWR South Annexe [209]. A list of eleven options was compiled in consultation with appropriate subject matter experts and performance against the selected attributes for each option was reviewed at a workshop.

463 The BAT option is to backfill the South Annexe with no re-engineering or additional grouting. All modelled scenarios, including climate change scenarios, define any discharges to be indirect with no excess risk to the environment. However, re-engineering the structure would pose a significant worker risk due to the structural modifications required, would use additional raw materials and result in additional road transports and carbon production. Therefore, as there are minimal risk benefits from re-engineering but significant detriments and impacts, the preferred approach is to backfill with no additional engineering measures. The compliance case for this option has been presented to the EA and this option has been adopted for the SWESC [210].

6.4 Future Optimisation Assessments

O.4 Optimisation assessments will continue to be undertaken and reviewed to support decisions about future decommissioning of the site (GRR Requirement R1) as well as optimisation of the proposed on-site disposals (GRR Requirement R13).

464 As explained in the GRR [6, ¶A2.12], optimisation is a continuing, forward-looking and iterative process that involves continually questioning whether everything reasonable has been done to reduce risks. Optimisation studies will continue to be undertaken as further information becomes available and the decommissioning programme progresses. The current end state proposals are at a conceptual stage and further optimisation will be required during the detailed design stage.

465 At current, there is no identified need for further optimisation under GRR Requirement R1, as all structures and contaminated land identified on-site have been assessed. However, should additional contamination be identified further optimisation in accordance with Requirement R1 will be completed. Additionally, the existing optimisation assessments are based on a number of assumptions (i.e. depth of contamination at ALES). Should any of these assumptions be identified as inaccurate, the existing optimisation assessments may need to be re-assessed.

466 During the detailed design phase, additional assessments pertaining to demolition, disposal and waste management will be undertaken as new information (e.g. from characterisation) and expertise (e.g. from the demolition contractor) become available and the concept design will be revisited before physical works commence. Some of the key work areas for future optimisation, including both finalising an optimised end state configuration and the methods by which the configuration can be achieved, include:

- Engineered cap design. For example, the cap thickness, overall geometry, profile, load requirements, material layers and interface with the existing void walls and ground floor slabs.
- Sealing of boundary structures in both reactors. This will consider the optimal methods and approach to sealing penetrations in the boundary structures.
- Demolition and backfilling processes. For example, the demolition sequence (i.e. the order in which components of the structures will be demolished) is yet to be determined and a BAT assessment will be completed to determine whether there is an optimum work sequence to reduce damage to the below-ground structures.

FP.12 Undertake optimisation assessments to support decisions about decommissioning of site features as new information is identified and to refine the design and implementation of the site end state.

7 Demonstration of Environmental Safety

Claim: Demonstration of Environmental Safety
Methodologies have been developed to cautiously and proportionately assess the risks to humans and the environment from the proposed end state, both during and after release of the site from RSR. These assessments show that the potential risks are consistent with regulatory requirements, including quantitative criteria, and that the proposed on-site disposals will not result in appreciable impacts beyond those caused by background levels of radioactivity and contaminants in the environment.

467 Requirements R9 to R12, R14 and R15 of the GRR require operators to confirm that the public and environment are protected against radiological and non-radiological hazards (see Table 3.1). To address these requirements, multiple assessment models have been developed to determine radiological and non-radiological risks associated with the proposed on-site disposals at the site and associated with site decommissioning in general. Calculated potential impacts have been compared with relevant quantitative criteria to demonstrate that people and the environment are protected.

7.1 Qualitative Understanding: Safety Functions and Strength in Depth

S.1 A qualitative understanding of the future evolution of the proposed on-site disposals has been established. This understanding provides the basis for quantitative modelling to assess radiological and non-radiological risks and define mitigation measures, where required. The environmental safety functions associated with the disposals, geosphere and biosphere provide multiple independent benefits to overall environmental safety. This provides reassurance that even if one environmental safety function is not realised in accordance with expectations, others will ensure that environmental safety is not compromised.

468 On-site disposal of radioactive wastes by in-situ disposal and/or DfaP differs from disposal in a dedicated purpose-built disposal facility in terms of the extent to which engineered barriers are present and can be substantiated/quality-checked. There are, nevertheless, aspects of the below-ground structures, deposited wastes, capping materials, geosphere and biosphere that can affect risk likelihood and magnitude. These aspects are considered as "safety functions" for the proposed disposals and can assist the development of models and support the identification of mitigation measures in optimisation studies.

469 The IAEA defines a safety function as *"a specific purpose that must be accomplished for safety for a facility or activity to prevent or to mitigate radiological consequences of normal operation, anticipated operational occurrences and accident conditions"* [211]. This definition generally results in the term being used in relation to engineered barriers. This is acknowledged in the GRR, which uses the broader term "environmental safety functions", which is defined in the GRR glossary [6, §C2] as:

> *"The various ways in which components of the disposal system may contribute towards environmental safety, such as the geology providing a physical barrier function and also having chemical properties that help to retard the migration of radionuclides."*

470 Environmental safety functions encompass all functions provided by the below-ground structures, deposited wastes and overlying cap(s), the geosphere and the biosphere, that contribute towards environmental safety. For the Winfrith site, associated environmental safety functions result in one or more of the following benefits:

- **Containment –** Delaying the release and retarding the migration of contaminants away from their source.
- **Isolation** – Isolating the waste from the biosphere and humans.
- **Attenuation –** Decreasing contaminant concentrations.

471 The identification and review of environmental safety functions was used to inform the risk assessments. Further details on each of the environmental safety functions and their associated underpinning are presented in the radiological risk assessment [23, App.C.3] and are summarised in Table 7.1.

472 Although the proposed disposals are based on existing structures which have not been designed to be a purpose-built disposal facility, their nature and configuration has undergone a robust process of structural assessment and optimisation in accordance with GRR requirements. This process will continue throughout end state implementation. The optimisation process has considered the safety functions of all components and their interactions as part of a multi-barrier system to isolate and contain the waste, with a focus on long-term passive safety. The key features of the disposals that contribute to this system are:

- The low-hazardous nature of the waste forming the disposals. Only lightly contaminated LLW structures will remain in-situ; all plant, loose items and higher-activity waste will be removed and managed off-site. This ensures that the end state radiological inventory is low in comparison to the inventories of purpose-built disposal facilities. This is illustrated for total radioactivity in Table 7.2. In addition, a significant proportion of the radiological inventory is associated with short-lived radionuclides, decay of which will reduce the radiological hazard substantially over a relatively short period. The non-radiological inventory is primarily composed of concrete and brick, with small percentages of other materials. The restricted quantities of hazardous properties present also support the inherent environmental safety of the proposed end state.
- The concrete nature of the structures in the disposals. Only concrete structures (together with any steel components that cannot be easily removed) will be disposed of in-situ. The concrete provides an alkaline chemistry to retard migration of certain radionuclides that will persist over a long timescale.
- The structural integrity of the concrete making up the most contaminated structures (SGHWR and Dragon bioshields, SGHWR Region 1 and 2 boundary structures). This limits groundwater ingress, delaying mobilisation of radionuclides and hazardous chemicals, and allowing the radiological inventory to decay before any migration to the geosphere. The hydraulic degradation of the intact concrete surrounding the disposals will be sufficiently slow that the structure will be intact for hundreds to thousands of years under the expected evolution conditions.
- The engineered caps to be emplaced over the SGHWR and Dragon disposals. These will slow infiltration of rainwater and leaching of the waste above the water table, and also fulfil an isolation function, providing a physical barrier to human intrusion and reducing doses received as a result of site occupancy activities.
- The hydrogeological conditions in the surrounding geosphere and biosphere will lead to dilution of radionuclides and non-radiological contaminants in groundwater and their dispersion along geosphere flow paths. Sorption in the geosphere delays contaminant transport in the environment, allowing further retardation and, in some cases attenuation (e.g. radionuclide attenuation by decay), such that concentrations emerging in the accessible environment are at safe levels.

473 The radiological and non-radiological risk assessments assume that these features perform together as designed. However, the safety margins are assessed through alternative assessment cases and variant scenarios which explore the impact if one of these functions is impaired or absent. The results presented in Sections 7.3, 7.4 and 7.9 show that, in nearly all such cases, impacts remain consistent with the relevant constraints and guidance levels, demonstrating strength in depth.

Table 7.1: Summary of the environmental safety functions and their underpinning [23, App.C.3].

Environmental Safety Function	
Relatively small inventory	Although not strictly a function, the inventory can be managed (e.g. the using the EAC) and, via limitation of the source term, contributes towards safety; it is therefore treated as an environmental safety function for the purposes of this discussion. The relatively small radioactive inventory (in comparison to existing near-surface waste disposal facilities) associated with the proposed on-site disposals at Winfrith limits the radiological consequences. • The total activity of the proposed on-site disposals directly impacts the doses/risks received, with lower activities, generally, proportionally decreasing doses/risks when considered on a per radionuclide basis. When compared to UK LLW near-surface disposal facilities (such as LLWR and D3100) and landfill sites suitable for the disposal of very low level radioactive waste (such as Clifton Marsh and Lillyhall), the total activity estimate for the proposed on-site disposals is relatively small (Table 7.2). • A significant proportion of the activity reported in the Winfrith inventory is associated with relatively short-lived radionuclides. For example, 79% of the total 2027 inventory activity is associated with ^{3}H (12-year half-life). This means that the total activity of the proposed on-site disposals will decrease rapidly. There is expected to be substantial radioactive decay of shorter-lived radionuclides, and hence this reduces the radiological hazard. • Similarly, the EAC limit the chemical, biological and physical properties of both the in-situ structure and the wastes used in backfilling to manage the attendant risks.

Hydraulic characteristics of the disposals	The hydraulic characteristics of the proposed on-site disposals (including the engineered caps over SGHWR and Dragon) will limit the transport of radionuclides and non-radiological contaminants to the geosphere and biosphere.
	• For the in-situ disposals, the radioactive inventory is in most cases present within a near-surface contaminated layer of concrete. Thus, radionuclides other than those actually on surfaces will not be instantly available for transport by advection; the slower process of diffusion to the surface of the contaminated layer will first be required.
	• Intact undegraded concrete structures have hydraulic properties that greatly limit advection, especially very low hydraulic conductivity. Thus, whilst undegraded:
	  ○ The SGHWR and Dragon caps will limit infiltration (from rainfall) entering the parts of the near field containing the inventory. This is expected to reduce infiltration from that of the average recharge for the area of 279 mm y^{-1} to only 5 mm y^{-1} when installed [23, §5.2.1].
	  ○ The intact concrete structures will limit advection into (from groundwater) and out of (from groundwater and infiltration) the near field. The current hydraulic conductivity of the intact structures is calculated to be 4.4×10^{-11} m s^{-1} and will take hundreds, if not thousands of years, to degrade to a conductivity equivalent to that of the surrounding Poole Formation (2.7×10^{-4} m s^{-1}) [23, §5.2.1].

Environmental Safety Function	
	• The majority of the proposed on-site disposals are positioned above the water table, and thus will only ever be partially saturated, even with increased infiltration over time (Section 5.3). For such disposals: o The lower degree of saturation will limit rates of diffusion out of the near-surface contaminated layers associated with in-situ disposals. o The rate of radionuclide advection will differ to that below the water table, as it will be driven by the downward infiltration of rainwater, which will be limited by the SGHWR and Dragon reactor complex caps. • Over time, the in-situ structures and engineered caps will degrade through both physical and chemical processes (Section 5.3.4). Such degradation is likely to alter the hydraulic properties (especially porosity and hydraulic conductivity) of intact concrete, leading to higher rates of infiltration into and flows of leachate out of the proposed on-site disposals. However, review of hydraulic concrete degradation has shown that, when not accelerated by external events or processes, degradation occurs relatively slowly, over hundreds to thousands of years. A conservative value of 1000 y has been assumed for complete hydraulic degradation of the in-situ structures [23, §5.2.1].
Chemical characteristics of the disposals	The chemical characteristics of the proposed on-site disposals provide containment (retardation) of some key radionuclides, limiting their mobility. • Radionuclides that sorb strongly to concrete will have limited mobility, retarding their release and increasing their travel time. For example, there is a difference of more than four orders of magnitude for uranium between intact and fully degraded concrete (2.0×10^{1} m^3 kg^{-1} to 1.1×10^{-4} m^3 kg^{-1}), and more than an order of magnitude difference for radium (1.0×10^{-1} m^3 kg^{-1} to 1.4×10^{-2} m^3 kg^{-1}) and lead (3.0×10^{0} m^3 kg^{-1} to 2.5×10^{-2} m^3 kg^{-1}) [23, §D.2.3]. • The chemical degradation rate of concrete and its constituent minerals is sufficiently low to continue to contain radionuclides that sorb strongly to concrete for a considerable period. Leaching of concrete involves gradual removal of the mineralogical components of the concrete as a result of interaction with flowing water, which changes the sorption properties of the concrete. An estimate for the time required for complete cement dissolution based on the mass of concrete present in SGHWR Regions 1 and 2, the maximum engineered cap infiltration rate and the volume of water passing through the cement, is calculated to be over 50,000 years [23, §5.2.1]. This estimate cautiously assumes all infiltrating water contacts all the cement of the concrete as it flows into the ground surrounding the structure, rather than passing only through cracks in the concrete (which is what would be expected, at least initially).
Physical characteristics of the engineered caps	In addition to the hydraulic benefits discussed above, the engineered caps over SGHWR and the Dragon reactor complex also provide shielding from external irradiation ("shine") emanating from the proposed on-site disposals. The degree of attenuation achieved varies based on the characteristics (e.g. thickness, density and extent) of the caps, but those proposed for Winfrith are metres thick and, combined with the relatively small inventory, mean that the radiation doses from shine are not a concern (Section 6.3.4). The engineered caps also hinder inadvertent human intrusion by increasing isolation from the surface and making excavation harder (e.g. by inclusion of a thick cobble anti-intrusion layer; Section 5.1.3).

<table>
<tr><th colspan="2">Environmental Safety Function</th></tr>
<tr><td>Geosphere and biosphere hydrological conditions</td><td>The hydrological conditions of the geosphere and biosphere promote dilution and dispersion of radionuclides.
Radionuclides and non-radiological contaminants, released from the proposed on-site disposals, will enter saturated portions of the near field and will be transported downgradient in groundwater through the geosphere.
• The flow rate through the geosphere will directly impact the dilution of radionuclides and non-radiological contaminants in the groundwater, with higher flow rates decreasing concentrations at the points of groundwater emergence.
• The dimensions of the geosphere flow path will alter the dispersion potential of radionuclides and non-radiological contaminants and thus their downgradient concentrations, with the magnitude of dispersion often related to the length of a pathway, and radionuclide sorption (see below) or chemical buffering. The width of the below-ground SGHWR structure (over 81 m) and the length of the transport pathways (1,350 m to the River Frome; 300 m to the surface near Monterey roundabout and the proposed mire) provides a considerable volume for dilution and dispersion.
The hydrological conditions of the biosphere are also expected to lead to dilution and dispersion of radionuclides and non-radiological contaminants. Biosphere transport processes are primarily hydraulically driven, and include soil infiltration, throughflow and river transport. These transport processes will dilute concentrations within the biosphere. For example, any contaminated releases to the proposed mire will be diluted with other surface and groundwater contributions, and releases to the River Frome will be diluted by upstream river flows (the mean river flow rate is 6.72 $m^3 s^{-1}$ (see Paragraph 285). Contaminated river water used for field irrigation will also be further dispersed when spread across fields and then further diluted by rainfall.</td></tr>
<tr><td>Geosphere and biosphere radionuclide retardation</td><td>The sorption of radionuclides and non-radiological contaminants on to geosphere and biosphere materials is expected to provide retardation (and in some cases attenuation) within the geosphere.
• The sorption of radionuclides and non-radiological contaminants on to geosphere materials will lead to their retardation (and in some cases attenuation through decay or chemical reactions) within the geosphere. Some radionuclides sorb strongly to geosphere materials; concentrations of such radionuclides in groundwater will reduce over the geosphere pathlength as they partition between the solid and aqueous phases. For example, uranium sorbs more strongly to Poole Formation material than fully-degraded concrete (the Kd value increases from 1.1×10^{-4} $m^3 kg^{-1}$ to 1.5×10^{-2} $m^3 kg^{-1}$) [23, §D.2.3 and §D.3]. If a radionuclide also happens to be relatively short-lived, decay could lead to significant attenuation of activity prior to biosphere release. For example, strontium also has an increase of two orders of magnitude between its sorption potential to degraded concrete compared with Poole Formation clay, and with its significantly shorter half-life (28.8 y for ^{90}Sr), is likely to decay substantially before interacting with the biosphere.
• Some radionuclides and non-radiological contaminants sorb strongly to biosphere materials, such as the soils and sediments in the region surrounding the site. For the proposed on-site disposals and geosphere, sorption aids in limiting the migration of strongly sorbing radionuclides from entering the biosphere and thus generally decreasing doses/risks to receptors[30].</td></tr>
</table>

30 Conversely, sorption within the biosphere will generally act to limit dilution and dispersion of radionuclides and thus could increase doses/risks to receptors that interact with relevant materials (directly or via food chains).

Table 7.2: Comparison of the Winfrith end state radiological inventory in relation to the Trawsfynydd 2023 proposed Ponds Complex disposal inventory and the permitted inventories of existing waste disposal facilities [23, Tab.C.1].

Site / Facility	Total Activity (TBq)	Volume (m^3)	Activity Concentration (MBq m^{-3})
Winfrith	0.6 (2027)	66,000	9
Trawsfynydd	0.2 (2022)	5,200	40
Lillyhall	5	582,000	10
Clifton Marsh	80	210,000	380
LLWR	22,000	1,400,000	15,700
D3100	15	175,000	90

Table 7.3: Summary of material composition data for proposed reactor end states [194; 196; 197; 198; 212; 213; 214; 215].

Material	SGHWR		Dragon Reactor Complex	
	Mass (tonnes)	%	Mass (tonnes)	%
Concrete (above ground)*	22,184	51.4	10,026	49.7
Brick (above ground)*	3.317	7.7	0	0
Concrete (below ground)	14,400	33.4	7,745	38.4
Rebar (below ground)	2,240	5.2	2,080	10.3
Structural steel (below ground)	993	2.3	312	1.5
ACM	10	0.02	0	0
Fibreglass	10	0.02	0	0
Oil	0.01	2.32E-05	0	0
Total	43,153		20,162	

* Using an assumed density of 2,300 kg m^{-3}.

7.2 Quantitative Models

S.2 To provide quantitative understanding of the key processes and potential impacts of the proposed on-site disposals, models have been developed to assess the different ‘pathways’ by which contaminants might be released, migrate and enter the accessible biosphere. This includes assessing the expected evolution of the proposed disposals and the site, as well as potential alternative scenarios. Modelling also considered key uncertainties to determine their impact. Assessment results are compared from each pathway to take account of the timing and location of potential impacts, and hence whether an individual could be exposed via multiple pathways.

For example, Cm, Eu, Am and Ra are some of the more strongly sorbing elements to soil in the proposed inventory [23, §D.4.2].

474 Prior to presenting the assessed radiological and non-radiological risks associated with the proposed disposals, Section 7.2 describes the quantitative models that have been developed to assess those risks. This section summarises:

- the criteria against which regulatory compliance is compared;
- the pathways and behaviours by which contamination could reach humans and the environment as a result of the proposed on-site disposals;
- the assessment cases and alternative scenarios that consider the impact of uncertainty and explore the robustness of the system; and
- the assessment models that have been developed.

7.2.1 Radiological Dose and Risk Assessment Models

Assessment Criteria

475 Quantitative radiological criteria associated with assessed doses to members of the public are defined in three of the GRR requirements:

– **The dose constraints during the period of RSR** (Requirement R9 [6, ¶A4.23]): *"During the period of radioactive substances regulation the effective dose, from the authorised site, to a representative person shall not exceed a source-related dose constraint and a site-related dose constraint*: *0.3 mSv per year from any source from which radioactive discharges are made; and 0.5 mSv per year from the discharges from any single site".*

  A "source" is defined in the GRR as "*a facility, or group of facilities, which can be optimised as an integral whole in terms of radioactive waste disposals"* [6, p.A15]. Specific to the site-related dose constraint, a "site" is defined as *"any number of sources with contiguous boundaries at a single location (for example 'A' and 'B' power stations), irrespective of whether different sources on the site are owned or operated by the same or by different organisations"* [6, p.A16]. At Winfrith, comparison with the site-related dose constraint requires consideration of the combined impacts of the Winfrith and neighbouring Tradebe Inutec nuclear sites.

- **The risk guidance level after release from RSR** (Requirement R10 [6, ¶A4.30]): *"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"*.

  For all the dose rate calculations reported in the radiological assessments, the probability of a dose being received is cautiously assumed to be one. As such, radiological impacts can be expressed as a dose rate, with comparisons made against the dose rate equivalent of the risk guidance level (~0.017 mSv y^{-1}) [6, ¶A4.35]. This approach allows for the estimated radiological impacts both during the period of and after release from RSR to be presented together as dose rates.

- **The dose guidance level** (Requirement R11 [6, ¶ A4.56]): *"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 (e.g. to people occupying land or buildings contaminated by spread or use of excavated radioactive material), while values towards the upper end of the range are applicable only to transitory exposures (e.g. to people undertaking intruding excavations).

476 All three criteria refer to effective doses received by a "representative person" (RP). The GRR defines an RP as *"an individual receiving a dose that is representative of the more highly exposed individuals in the population"* [6, p.C10].

477 Note that Requirements R12 (natural disruptive processes) and R14 (protection of the environment) can also be addressed via numerical modelling. Requirement R12 may be compared to either the risk or dose guidance level depending on the type of disruptive process and the potential for local concentrations of radionuclides. For Requirement R14 there are no statutory criteria but a conservative screening criterion of 10 μGy h^{-1} for populations of non-human organisms in designated conservation sites is suggested in the GRR (see Section 7.8 for further discussion).

Exposure (Dose) Pathways

478 A "dose pathway" is a mechanism or process that could lead to RPs or non-human organisms potentially receiving a radiation dose. The radiological assessments undertaken consider the dose pathways relevant to each of the proposed on-site disposals, the local surrounding region and the activities through which RPs may be exposed. The calculated potential doses are then compared with the relevant GRR quantitative requirements. Three overarching radiological dose pathways have been identified.

479 **Direct radiation from a source** – The GRR specifically identifies this dose pathway in guidance associated with Requirement R9 ("*assessment of effective dose should take into account… direct radiation from each source on-site"* [6, ¶A4.26]). Direct irradiation of RPs during the period of RSR is possible as the public will be able to access the site for recreational use. However, the site will still be managed [9] such that residence on the site will not be possible and RPs will be limited to transitory exposure scenarios. After release from RSR, uncontrolled use would be possible, which could lead to prolonged exposure scenarios.

480 **Migration of radionuclides from a source –** The migration of radionuclides away from the site of disposal is discussed in guidance for both Requirement R9 [6, ¶A4.26] and R10 [6, ¶A4.33]. Under expected evolution conditions there are two main release mechanisms that could lead to the migration of radionuclides from a source:

- ***Aqueous release*** – For the in-situ disposal features, aqueous release of radionuclides is expected after the below-ground concrete containing structure saturates, starts to degrade and there is water outflow. Above and below the water table, aqueous release will be driven by rainfall and groundwater infiltration into the disposals, respectively. Over time, this will lead to the transport of radionuclides into the surrounding environment. This dose pathway is assessed starting from the date of implementation of each on-site disposal (see Table 7.5) and is considered in relation to both Requirement R9 and R10.
- ***Gaseous release*** – No gaseous disposal pathways have been identified for the proposed on-site disposals. Knowledge from disposal sites that accept higher levels of radioactivity [216, §6.1.1] has shown that the only radionuclides of concern for gaseous release are those that can form in the disposals. No gaseous exposure pathways of significance have been identified for the Winfrith disposals based on the following considerations [23, App.C.2.3]:
    - Tritium (^{3}H) is the dominant radionuclide in the SGHWR and Dragon inventories (see Section 5.4.3). Due to its relatively short half-life (12.3 y), tritium is primarily

of concern during the operational period and early post-closure period only. The disposals are primarily formed from concrete so there is limited potential for gas production. Additionally, the levels of tritium present in the proposed disposals are so low that, even if there were a release mechanism, the radiological dose would be negligible.

- Carbon-14 comprises only 0.9% of the SGHWR inventory and 0.5% of the Dragon inventory [17]. The lack of organic material in the proposed disposals to produce gas, and the slow release of ^{14}C from the wastes, means this pathway is not significant.
- Isotopes of radon (^{222}Rn and ^{220}Rn) and their precursors are present as only a minor constituent of the inventory (e.g. ^{226}Ra forms 0.08% of the SGHWR inventory [17]). Given the small inventories, radon and thoron gas production would be insignificant.

Therefore, the radiological impacts associated with migration from a source discussed in the remainder of this chapter only consider aqueous releases from the proposed on-site disposals.

481 **Disruption of a source** – The GRR highlights two types of disruption that should be considered:

- ***Inadvertent human intrusion*** into a source – GRR Requirement R11 is associated with the potential for future inadvertent human intrusion after release of the site from RSR. Note that the GRR highlights that intentional intrusion associated with full knowledge of the existence, location and nature of the radioactive substances need not be considered [6, ¶A4.58].
- **Natural disruption of a source** – GRR Requirement R12 is associated with natural disruptive processes after release from RSR. It requires demonstration that *"people will be adequately protected in the case of natural disruptive processes which expose radioactive waste or contamination, or impair protective barriers"* [6, ¶A4.84]. For the Winfrith site, the risks posed by natural disruptive processes, such as erosion, flooding, seismicity and glaciation, are low (see Section 5.3.1) and are not expected to lead to the disruption of the site or the development of additional dose pathways. In the unlikely situation that these processes occur, they could potentially enhance aqueous release from the proposed disposals. Where justified, the impact of natural disruptive processes has been modelled through the consideration of variant scenarios (e.g. the impact of a major earthquake) and the incorporation of processes into the conceptual models (e.g. groundwater level rises).

482 In addition to the above two types of disruption, the source (the reactor buildings) will also be disrupted during the demolition process, giving rise to contaminated dust and process water. These potential dose pathways occurring during implementation of the proposed disposals will be assessed as part of the detailed design phase and controlled through nuclear site management arrangements (see Sections 3.4.8 and 7.3.2), such that their impact will be trivial. Therefore, impacts during implementation are not discussed further in this sub-section.

483 Table 7.4 summarises the identified dose pathways of relevance and the assessments in which they are considered. The models used to calculate the potential doses arising from these three overarching pathways are summarised in the sub-sections below and are set out in the radiological PA [23]. The PA includes a detailed discussion of relevant dose pathways, activities and associated RPs, including those screened both in and out of this assessment, and the justification for those decisions. Table 7.5 summarises key dates considered in the radiological assessments.

Table 7.4: Summary of the identified public dose pathways of relevance to the proposed on-site disposals once implemented, mapped to the radiological assessments in which they are considered.

Dose Pathway	Radiological Assessment
Aqueous releases of radionuclides both before and after release of the site from RSR	Considered within the **natural evolution** assessment
Natural disruption of a source after release of the site from RSR	
Direct radiation from a source after release of the site from RSR	**Site occupancy** assessment
Inadvertent human intrusion into a source after release of the site from RSR	**Human intrusion** assessment

Table 7.5: Assumed key site decommissioning and management dates and their relation to the radiological risk assessment. The dates are assumptions for the purpose of the risk assessment only.

Date	Description
2027	Date of activity estimates in the Radiological Inventory Report [17]. Natural evolution assessment model start date for the site. Radioactive decay of all feature inventory estimates commences.
2029	Dragon reactor complex end state implemented (facility decommissioned, waste emplaced in below-ground voids and engineered cap implemented). The below-ground structures are assumed to be dry to this point. From the date of disposal implementation, the natural evolution model assumes that concrete degradation and water infiltration (for those features below the water table) starts and radionuclide releases are possible.
2032	SGHWR end state implemented (facility decommissioned, waste emplaced in below-ground voids and engineered cap implemented). As for the Dragon reactor complex, material degradation, saturation and radionuclide releases are assumed to be possible in the natural evolution model.
2036	The site IEP is achieved and public access permitted (date assumed for assessment purposes only). The site continues to be managed with sufficient control to prevent inadvertent intrusion and site residency, but members of the public can access the site and may be subject to external irradiation from sub-surface contamination.
2066	SRS achieved (marks transition between GRR Requirements R9 and R10). Human intrusion is assumed to be possible. Site occupancy model considers the potential for site residency, as well as general site access. This is a cautious assumption as planning controls will remain in place.

Assessment Cases and Variant Scenarios

484 When assessing the safety of waste disposals, it is important to consider how the performance of the disposal system may evolve over time. This requires that the different factors that could influence its performance, and their evolution, to be taken into account. This is achieved through the formulation and analysis of a set of scenarios and assessment cases, the approach to which is set out in the radiological risk assessment [23, App.C]. These terms are defined by the IAEA [217, ¶5.37 and ¶5.38]:

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

485 In the end state site radiological risk assessment, the expected evolution scenario "reference" assessment case (the Reference Case) considers the expected evolution of the Winfrith site based on the current understanding of the proposed on-site disposals, site characteristics and the surrounding region, and how these are expected to evolve (see Chapter 5 and Natural Evolution sub-section below). In order to consider uncertainties and to aid future optimisation, 36 alternative cases and variant scenarios have also been considered:

- "Alternative" assessment cases investigate the impact of parameter uncertainty in the Reference Case. Each alternative assessment case investigates the effect of varying a single parameter or a set of related parameters. The assessment cases include alternative values for the radiological inventory, concrete porosity and density, sorption parameters, biosphere uptake factors and mire outflow rates.
- "Variant configuration" scenarios investigate potential options for the configuration of the proposed on-site disposals. For example, different engineering options have been considered such as changing the size of the proposed concrete blocks, replacing the blocks with rubble, grouting the voids, and changing the thickness of the cap.
- "Variant concept" scenarios investigate uncertainty in the conceptual model. For example, variant scenarios include consideration of cap degradation time, concrete degradation, different flowpaths and different interpretations of climate change. While all variant concept scenarios are considered credible, each has a different probability of occurrence.

486 Additionally, the GRR acknowledges that some scenarios *"involve future events so uncertain that it may not be appropriate to undertake numerical risk assessments for comparison with the risk guidance level, as this could distort the overall picture of risks"* [6, ¶A4.48]. A subset of scenarios considered are classed as "what-if" scenarios. Such scenarios consider highly speculative and unlikely future outcomes that do not reflect uncertainty in the proposed disposals, but can be used to explore the system response to hypothetical events and situations. These "what-if" scenarios have considered extreme climate change where groundwater levels are arbitrarily assumed to rise to 1 m below the ground level, and instantaneous hydraulic failure of the in-situ structural concrete and engineered cap from the first day of the disposal implementation.

Natural Evolution

487 The potential radiological impacts from natural evolution of the proposed on-site disposals at the Winfrith site have been assessed. The Winfrith natural evolution assessment model has been developed to consider radionuclide aqueous release and transport, based on the same CSM as used for the non-radiological risk assessment [19]. The model was developed to address GRR Requirements R9, R10 and R12, and consists of three discrete but interacting modules, based on the source-pathway-receptor linkage:

- The near field, which comprises the source from which radionuclides may be released and the local environs (volumes within the structures or void infill where radionuclides from the source can be transported, in flowing water, to the geosphere).

- The geosphere, the pathway through which releases are transported in flowing groundwater to the surrounding biosphere.
- The biosphere, the area normally inhabited by living organisms into which transported radionuclides may be released (e.g. to the ground surface and surface waters). The model calculates the radiological doses that might be received by humans and non-human organisms.

488 The site-specific model has been implemented in the GoldSim software package (Version 14.0) [218; 219]. GoldSim is a leading software platform used internationally to conduct radioactive waste disposal assessments, with UK examples including the Low Level Waste Repository (LLWR) and Dounreay LLW Disposal Facilities. The parallel hydrogeological risk assessment of the Winfrith end state is also implemented in GoldSim (Section 7.2.2). The overall period considered in the model runs (at least 100,000 years) is sufficient to capture the maximum potential impacts from the disposals. Model implementation is discussed in detail in Chapter 5 of the PA report [23]. Key aspects of the assessment approach are summarised here.

Expected Evolution of the On-site Disposals (Near-field Module)

489 The processes introduced below are presented schematically in Figure 7.1.

490 The proposed disposals encompass several below-ground concrete buildings that form the SGHWR and Dragon reactor complex, most of which are robust, steel reinforced and are currently in good condition. These structures are expected to retain their integrity and constitute a barrier to groundwater flow (if below the water table) at the IEP and beyond. Exceptions to an assumption of concrete integrity after the disposal implementation have been identified (although there are mitigations that can be employed [143]):

- The SGHWR Annexes are described as being susceptible to cracking, deterioration and joint failure due to their construction [220].
- Wall A of the Dragon reactor building is a conventional concrete structure, expected to crack during end state implementation [221].
- Wall C of the Dragon reactor building is not a full cylinder as it has at least one access gap [222].

491 The SGHWR Annexes and the Dragon reactor are currently above the groundwater level and are expected to remain so in the near-term evolution. However, these structures are modelled as being in contact with groundwater in a limited number of climate change scenarios (Table 5.7).

492 The proposed on-site disposals that form the “near field” are capped below-ground redundant structures left in-situ and infilled with demolition arisings. These disposals have hydraulic characteristics that limit the transport of water into and radionuclides out of the disposals, and chemical characteristics that provide containment (retardation) of some key radionuclides.

493 For the natural evolution assessment, active maintenance of the on-site disposals is assumed to cease upon their completion. Over time, the concrete structures will degrade through a combination of physical and chemical degradation processes. The concept for concrete degradation used in the assessment comprises two key processes: cracking caused by rebar corrosion (which increases the hydraulic conductivity of the concrete over centuries until it eventually provides no resistance to water flow); and dissolution of the cement until all that remains is the concrete aggregate [19].

494 Degradation of the structures will increase the likelihood of a defect (e.g. crack or joint failure) developing that could allow water into and radionuclides out of the in-situ disposals. Rainfall could infiltrate through cracks or joints in the cap and groundwater could seep in along cracks or joints in the walls or floors of the structure (if located below the water table). Depending on the retention properties of the structures, water entering the disposals could either flow out relatively unimpeded along cracks or joints, or potentially build up within the infilled voids. The water balance in and out of the structures and the water level within the voids is calculated in the natural evolution model as a function of the hydraulic integrity of the feature walls and floors, the concrete degradation status, infiltration though the cap and the local water table.

495 The transport of radionuclides within the in-situ disposals is expected to vary based on the characteristics of the contaminated components. In general, contamination will travel from areas of high concentration to low by diffusion, and this will be the main driver of radionuclide transport out of near-surface contaminated layers. Additionally, advection will be the main driver for radionuclide transport through cracks, construction joints and rubble infill material. Flow pathways (e.g. cracks and failed joints) into and out of the structures will develop as the structures degrade over time, increasing flow rates.

496 Transport of some of the radionuclides within the disposals is expected to be retarded by sorption, whereby contaminants can be held up in solid materials such as concrete. Different radionuclides are affected by different sorption processes, and some radionuclides sorb strongly while others weakly. For example, the main sorption mechanism for caesium and strontium is ion exchange, which can result in significant delay to their transport from the disposal and release to the environment. For radioelements that sorb strongly to concrete (such as uranium and plutonium), sorption is expected to reduce and/or delay their transport out of the disposals.

497 Chemical degradation processes will lead to changes in the chemical environment of the disposal. The key parameter of interest is pH, due to its importance in determining the sorption behaviour of radionuclides. The main chemical degradation process associated with changes in pH is concrete leaching, with the initially high concrete pH gradually reducing over thousands of years. The effect of changes in the pH on sorption behaviour varies for different radionuclides, though typically sorption is highest for most radionuclides at high pH [223, Tab.7-7 to 7-10]. Therefore, leaching of concrete will tend to reduce radionuclide sorption within the disposals over thousands of years, and increase the potential for transport of contaminants from the disposal. It is cautiously estimated, based on site-specific calculations, that it would take more than 50,000 years for complete cement dissolution to occur [19] and this concrete chemical degradation period is assumed in the Reference Case calculations.

498 After thousands of years the concrete of the proposed disposals will completely degrade. At that time, the radioactivity within the disposals will be greatly reduced, either due to decay of radionuclides or through their aqueous release to the local geosphere and groundwater.

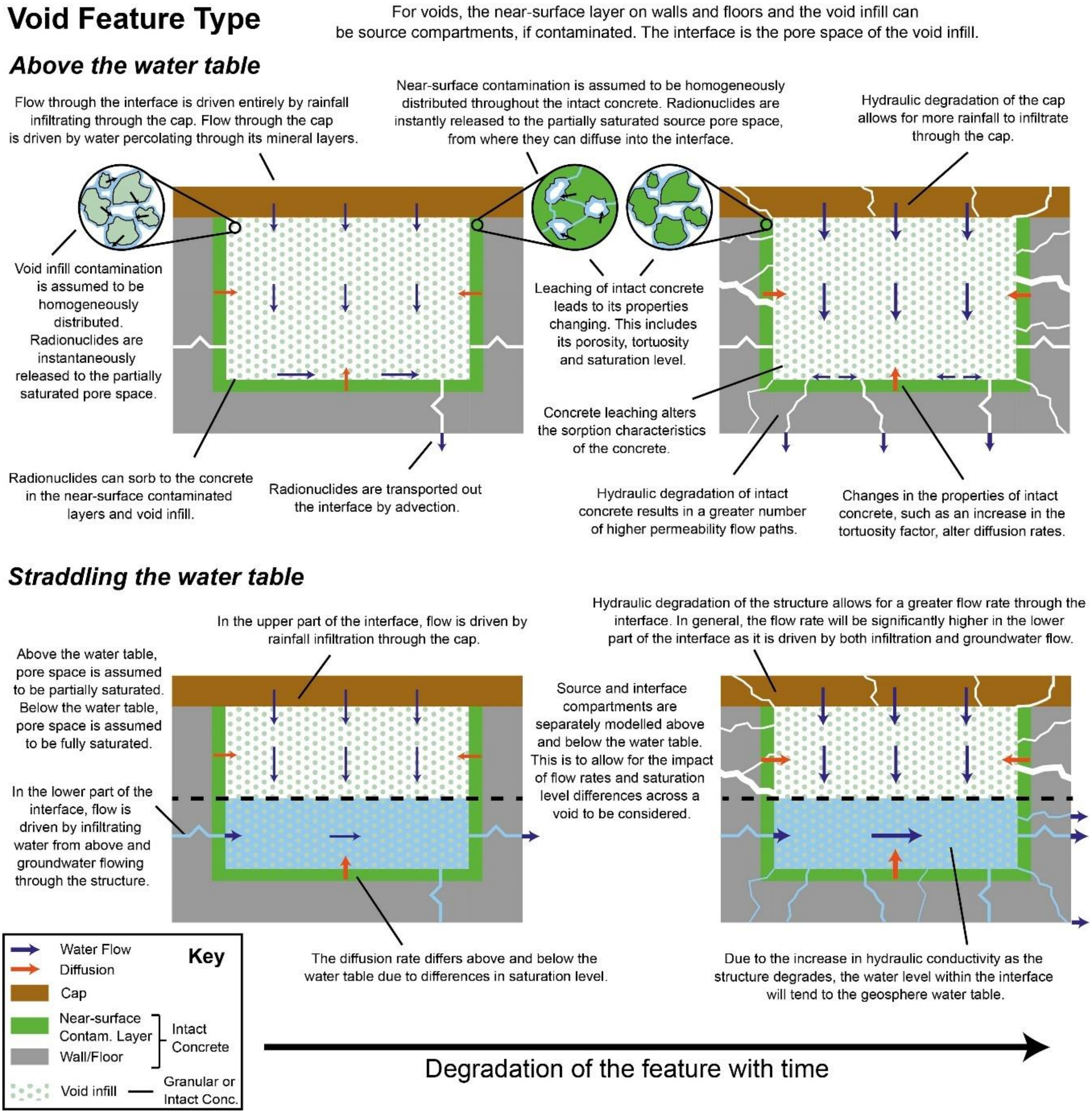

Figure 7.1: Schematic of near-field vault/pond radionuclide transport. Note that comments for straddling the water table highlight key differences only.

Evolution of the Winfrith Site and Surrounding Region (Geosphere and Biosphere Modules)

499 Radionuclides released from the on-site disposals will travel through the local geosphere and enter the biosphere. The hydrogeological conditions of the geosphere and biosphere (Section 5.3.1) are expected to lead to dilution and dispersion of radionuclides. In addition, as with the concrete in the disposals, radionuclides will sorb to the clays and soils in the geosphere and biosphere, leading to their retardation (and in some cases attenuation due to radioactive decay in transit).

500 The modelling assumes that the site has achieved its IEP, as set out in the End Point Specification [43] (Section 2.3). Removal of the surface drainage and hardstanding when implementing the end state will result in a modest increase in groundwater levels due to greater infiltration and recharge (0.4 m at SGHWR and 0.3 m at Dragon [21, §7.2.3]; Section 5.3.3).

501 Groundwater will continue to flow in a north-easterly direction from the Dragon reactor complex and north and north-east from the SGHWR after the IEP (Figure 7.2). Flow will emerge in the area west of the Monterey roundabout and extend into the proposed mire north and east of Monterey roundabout, into the River Frome or to the low-lying marshy ground surface in the Frome Valley. Under some conditions groundwater may also flow from SGHWR towards the Dragon reactor complex before eventually entering the River Frome. Lacking explicit modelling data, it is assumed that releases from the A59 area (although OoS), could emerge in the mire as well as flow to the River Frome.

502 The climate in the region of the Winfrith site will continue to change after the IEP. Climate simulation data suggest that groundwater levels may rise in the future but the direction of groundwater flow is expected to remain unchanged. Some simulations indicate that there will be increased instances of groundwater emergence during wetter months, but generally to the same locations.

503 There are two distinct points at which the biosphere module interacts with the geosphere in the end state configuration: an area of on-site land/mire and the River Frome. Therefore, the biosphere module is modelled as three compartments, reflecting the current or proposed site and surroundings (Figure 7.3):

- On-site **Land/Mire** – Modelling of groundwater emergence locations (see Section 5.3.4) suggests that releases from SGHWR may emerge in the area of land west of the Monterey roundabout. In wet periods this release could travel as surface water to the proposed mire, but SGHWR groundwater releases may also emerge directly in the mire. The on-site land from the west of Monterey roundabout extending to the eastern end of the proposed mire is modelled as a single compartment where releases from SGHWR (and the OoS A59 area) may lead to contamination of the soil and surface waters. The land may be boggy and waterlogged during wetter periods, containing ephemeral shallow pools, but may also be dry at other times. RPs may make use of the land when it is wet or dry.
- **River Frome** – Releases from all the on-site disposal features will eventually reach the River Frome, some via the mire. Relevant RPs are conservatively assumed to interact with the River at the entry point, rather than at locations downstream of the entry point where they would have been diluted. Both the river water and the upper sediment layer present on the river bed and river banks are modelled.
- Off-site **Field** – The Field compartment is assumed to be located neighbouring the River Frome, on the opposite side of the river from the Winfrith site where there are fields currently in use for grazing and crops. The Field compartment is assumed to be contaminated by contact with contaminated river water, whether by the river flooding the field and/or the river water being abstracted and used to irrigate the field.

504 The modes through which humans (RPs) might be exposed to radioactivity released from the on-site disposals and present in the biosphere include:

- Ingestion of radionuclides present in water, food and soil.
- Inhalation of air containing radionuclide-bearing dust.
- External irradiation from contaminated media, including sediment, soil and water.

1

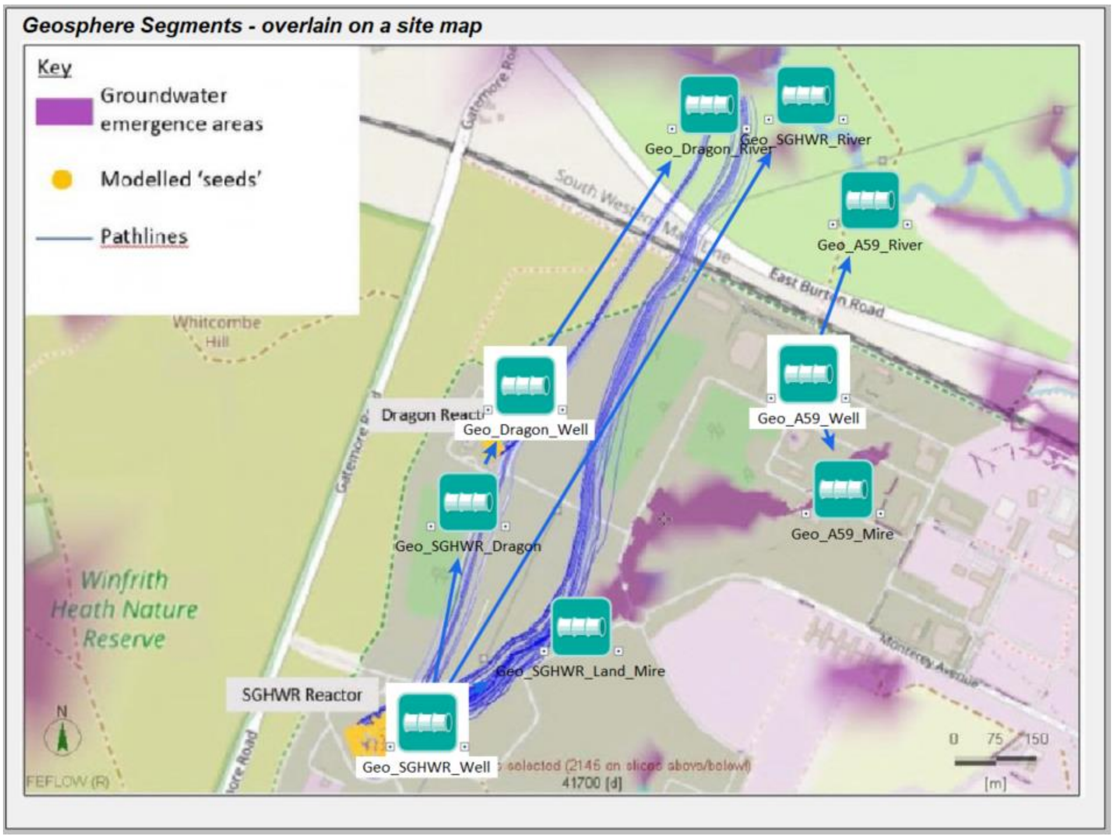

Figure 7.2: Screenshot from the natural evolution model geosphere module showing the geosphere compartments superimposed on a site plan, illustrating possible groundwater pathlines and emergence locations at the IEP.

505 The seven RPs considered in the natural evolution assessment represent the current habits of the local population and reasonably foreseeable habits for the site after the IEP has been achieved:

- Angler RP – Recreational fishing on contaminated water and consuming contaminated fish.
- River Paddler RP – Recreational sports or games in contaminated water.
- Mire Mudder RP – A recreational event such as a “tough mudder” obstacle course in a contaminated mire.
- Park User RP – Activities such as dog walking, picnicking or playing on contaminated ground, and eating wild foods such as berries.
- Construction Worker RP – Constructing residential or commercial buildings on contaminated ground.
- Farmer RP – Using contaminated water to irrigate crops or feed animals and ploughing contaminated soil, as well as eating their entire meat and vegetable (potatoes, green and root vegetables) intake from their farm’s produce.
- Smallholder RP – Farming of both crops and animals on contaminated ground, including manual working and ploughing the soil, and living in a house built on contaminated

ground. Consuming a high proportion of their annual food intake from their smallholding's produce.

506 As part of a variant scenario, a Well Abstractor RP is also considered, who is assumed to sink a well immediately downstream of each disposal and drink contaminated water.

507 Some of the considered RP activities would not be possible during the period between the IEP and SRS because the site will continue to be managed such that living or working on the site would be prevented (e.g. the Smallholder RP). However, these RPs (Construction Worker, Farmer and Smallholder) are still possible during the period of RSR if contaminated river water were used to irrigate, or were to flood, land beyond the site boundaries (e.g. fields on the opposite side of the River Frome).

508 Annual dose rates calculated using the natural evolution model for each of the RPs presented above and comparison to the quantitative GRR requirements is presented in Sections 7.3 and 7.4. The natural evolution assessment model was also used to calculate potential doses to non-human organisms, using the built-in reference organism database in the ERICA tool (Section 7.8).

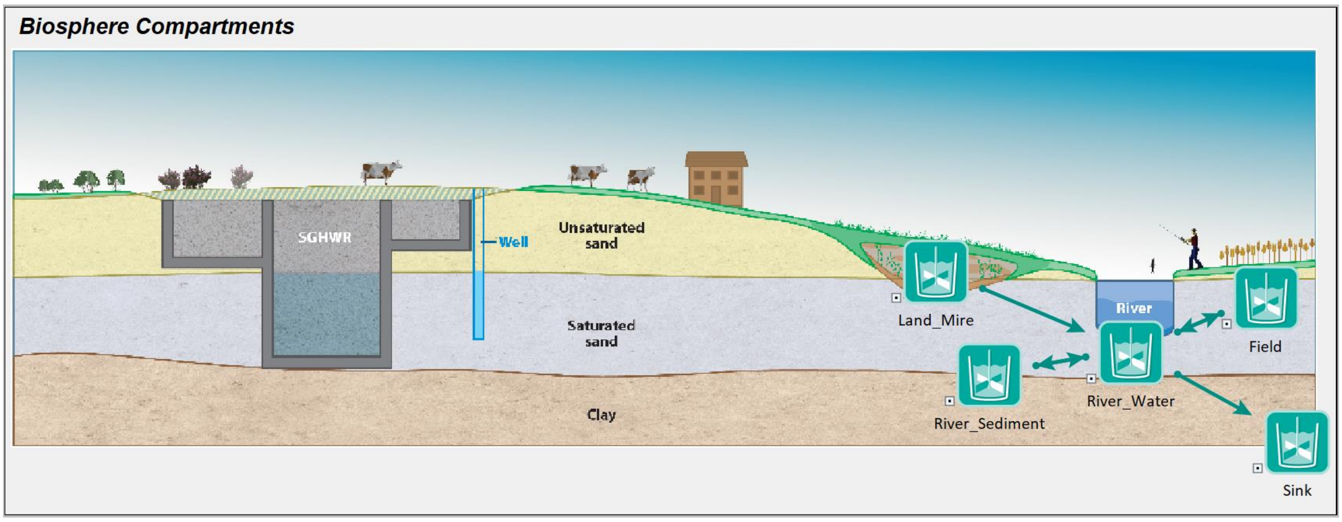

Figure 7.3: Screenshot from the natural evolution GoldSim model biosphere module showing the biosphere compartments superimposed on a stylised graphic of the SGHWR and biosphere compartments (Land/Mire, River and Field).

Site Occupancy

509 Site occupancy scenarios consider exposure to external irradiation only as the residual contamination is not at the surface and is assumed to be undisturbed. The GRR radiological criteria considered for the site occupancy assessments are the same as those for the natural evolution assessment (see GRR Requirements R9 and R10 in Paragraph 475).

510 MicroShield® version 11 [224; 225] has been used to carry out the dose assessments. The software allows the user to input inventory data (with an inbuilt decay functionality), source dimensions and material densities. For complex structures with varying geometries and multiple sources (e.g. infill material, contaminated walls etc.) such as the proposed disposals, each radiation source is modelled separately and the doses summed.

511 Three RPs are considered in the site occupancy assessment:

- Dog Walker RP - Walking above buried contamination without intruding into it.
- Camper RP - Camping above buried contamination without intruding into it.
- Caravan Dweller RP - Living above buried contamination without intruding into it.

512 Living above the disposals would not be possible in the period between the IEP and SRS because the site will continue to be managed. Therefore, the Caravan Dweller RP is only considered possible after the SRS. The results of the site occupancy assessment are presented in Sections 7.3 and 7.4.

Inadvertent Human Intrusion

513 The radiological impacts of inadvertent human intrusion (GRR Requirement R11) are assessed through a series of scenarios, cautiously assuming that there would be no effective control of activities at the site after its release from RSR. Owing to the thickness of the engineered caps to be emplaced above the disposals, the key potential intrusion events for the SGHWR and Dragon reactors are deep excavations to build foundations for structures, such as wind turbines, or drilling of boreholes as part of site investigations (as illustrated in Figure 7.4). For the A59 area the radioactivity is closer to the surface so shallower excavations, such as for site redevelopment and archaeological investigation, could result in exposure to radioactively contaminated material.

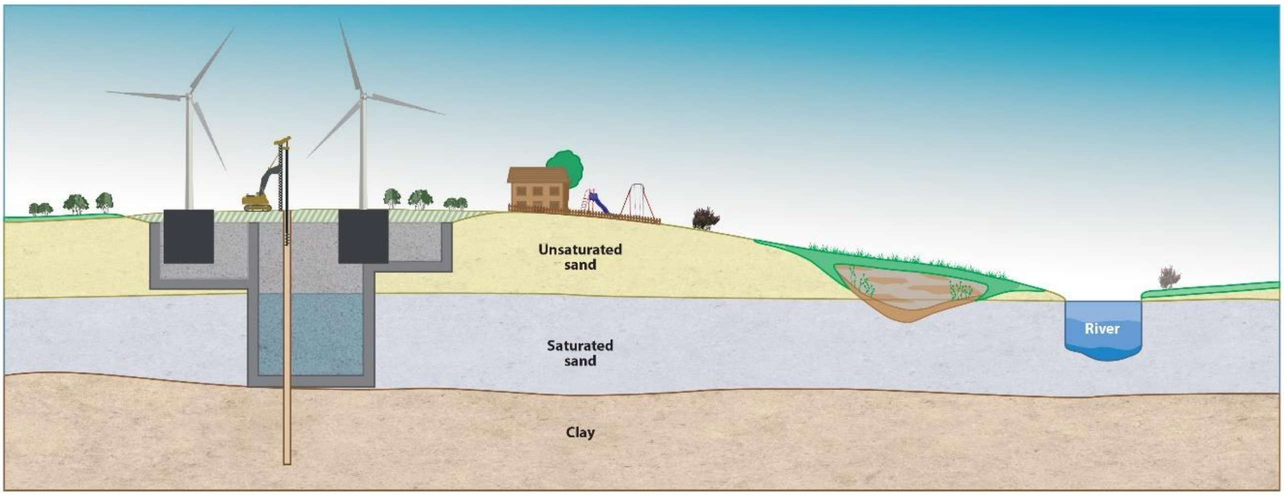

Figure 7.4: Illustration of the inadvertent human intrusion events assessed for the SGHWR disposal (in grey), such as drilling boreholes and constructing wind turbines, and building houses and playgrounds atop excavated contaminated material. Diagram not to scale.

514 Assessment of inadvertent human intrusion events has been undertaken using the NRS Generic Intrusion Methodology (GIM) tool (Version 2.1.3) [226; 227]. GIM assesses a range of intrusion styles and extents, and several post-excavation processing, transport and land-use scenarios. The overall approach of GIM is intended to be cautiously realistic, such that key events and processes are adequately addressed, but also such that the outputs of the assessment are not unduly conservative. The RPs considered in GIM include:

- Borehole Driller RP - Drilling of an exploratory borehole that intersects contaminated material.

- Investigator / Laboratory Analyst RP - Geotechnical investigations involving interactions with contaminated material, including borehole drilling, trial pit excavation and laboratory analysis of cores and samples.
- Excavator RP - Excavation of contaminated ground for construction during development for either residential or commercial use.
- Resident RP - A housing development built using contaminated rubble and/or on landscaped using contaminated radioactive material.
- Play Area RP - Contaminated aggregate spread on land which is then used for a play area by members of the public of all ages.
- Land Use RP - Development of a farm or smallholding on contaminated rubble. It is assumed that sufficient degradation of the rubble and mixing with other materials occurs to allow crops to be grown and animals grazed.

515 More details of the methodologies employed can be found in [23, §7; 226]. The results of the human intrusion assessment are presented in Section 7.4.

7.2.2 Non-Radiological Risk Assessment Models

Assessment Approach

516 GRR Requirement R15 (see Table 3.1) sets out the environment agencies' expectation that operators demonstrate that the level of protection against non-radiological hazards associated with the radiological hazards is consistent with applicable national standards. A non-radiological risk assessment has been undertaken to support demonstration of compliance with GRR Requirement R15 and to meet the needs of the DfR activity Environmental Permit application.

517 EA guidance [95] explains that where a void within a below-ground structure is filled with radioactive waste, the below-ground structure left in-situ should be considered together with the waste disposals in determining whether a groundwater activity will occur. This guidance [95, p.9] lists "types of disposals" of radioactive waste, that correspond to "disposal for a purpose" in the GRR, that are *"likely to be also groundwater activities"*. EA guidance for groundwater activities [228] encourages a tiered approach to hydrogeological risk assessment, with more detailed assessment being undertaken where the risk of groundwater pollution is greater. The three tiers are:

- Tier 1 – qualitative risk screening;
- Tier 2 – generic quantitative risk assessment (GQRA); and
- Tier 3 – detailed quantitative risk assessment (DQRA).

518 A tiered non-radiological risk assessment of the proposed SGHWR and Dragon reactor complex end states [24] has been completed.

519 A Tier 1 qualitative risk screening aims to *"assess whether the potential discharge from your activity is acceptable and so will not require further assessment"* [228]. Possible reasons given for the potential discharge being acceptable are [228]:

- *"The discharge has acceptably low concentrations of hazardous substances, or in concentrations that are the same as the natural background levels in the groundwater (whichever is the higher concentration)".*

- *"The discharge has concentrations of non-hazardous pollutants that are within the relevant environmental standards, or in concentrations that are the same as the natural background levels in the groundwater".*
- *"There's a very low risk to groundwater-fed receptors due to the presence of unproductive drift or unproductive bedrock strata (and there are no aquifers present or near your activity) and remoteness from surface waters".*
- *"The volume or hydraulic loading rate of the discharge is so small such that only minimal dilution in underlying groundwater will be needed to avoid pollution by non-hazardous pollutants".*

520 A Tier 2 GQRA *"involves a relatively simple assessment of the impact your activity may have on water quality, including groundwater"* and to carry it out *"you must use conservative (worst case) assumptions"* [228]. It should seek to *"demonstrate that the proposal poses little likelihood of unacceptable inputs to groundwater".* A Tier 2 GQRA is carried out for sources identified as requiring further assessment at Tier 1.

521 Following Tier 1 and 2 screening, a Tier 3 DQRA has been completed for sources identified as requiring further assessment at Tier 2. Tier 3 DQRA [24] of the SGHWR and Dragon reactor complex end states was undertaken via numerical modelling using PHAST for alkalinity and GoldSim for substances other than alkalinity.

522 PHAST is a computer programme, developed by the U.S. Geological Survey, that simulates solute transport in saturated groundwater flow systems and uses a version of the PHREEQC programme for geochemical thermodynamic calculations. PHREEQC is routinely used in the nuclear industry to simulate reactions in water and between water and geological materials. PHAST has been used to model contaminant migration from radioactive waste disposal sites in Europe and to support assessment of uranium release from the LLWR.

523 GoldSim has been used routinely in the past to support Environment Agency non-radiological projects, for example validation of LandSim v2.5 [229] and development of Waste Acceptance Criteria for landfill. GoldSim is used routinely in the nuclear industry for performance assessment and hydrogeological risk assessment and was initially developed to assess nuclear repository performance. The parallel radiological performance assessment of the Winfrith end state is implemented in GoldSim (Section 7.2.1).

524 The radiological and non-radiological risk assessments are based on the same CSM [19], although the non-radiological risk assessment timescales are shorter. The modelled hydraulic degradation of the caps and concrete structures is complete after 1,000 years and the modelled water flows become constant shortly after. The GoldSim model was run for 20,000 years to allow the peak concentration of each contaminant to be modelled. The PHAST model was run until the modelled pH in groundwater downgradient of the disposals had increased and become steady.

Assessment Criteria

525 In contrast to radiological assessment, non-radiological DQRA is concerned with assessing whether the aqueous concentrations of assessed contaminants are below compliance limits (target concentrations) at compliance points.

526 The compliance point for hazardous substances has been established below the water table in the Poole Formation immediately downgradient of the disposals/deposits. This is also where the EA has requested that a hypothetical abstraction well is located to assess risk from

potentially migrating radionuclides (classified as hazardous substances) in the radiological performance assessment.

527 The compliance point for non-hazardous pollutants has been established below the water table in the Poole Formation between the disposals/deposits and the nearest groundwater receptor, which is surface water, or the root zone of a groundwater-fed ecological system. The location of plausible future abstraction points is required to be considered by the EA when establishing compliance points [228]. The Poole Formation is a Secondary A aquifer that could be exploited in future although given the relatively thin saturated zone and the intention to return the land to open heathland this is unlikely. Nevertheless, the compliance point for non-hazardous pollutants has been established 50 m downgradient of the SGHWR and Dragon reactor.

528 For groundwater activities, the compliance limits at the hazardous substances' compliance point are the higher of either the minimum reporting value or the natural background concentration of the substance. This is because compliance points have been established at locations where no discernible concentrations of hazardous substances are allowed if an input of hazardous substances is to classed as prevented.

529 EA guidance [228] explains "*The target concentration (also known as a compliance limit) is a concentration at the compliance point that must not be exceeded. Provided the target concentration is met, the relevant environmental standard for the receptors should also be met or complied with. Where the compliance point is the receptor, the target concentration will be set as the relevant environmental standard or natural background groundwater quality*."

530 The DQRA has assessed the risk associated with a change in groundwater pH due to water migrating from the deposits/disposals that has contacted demolition arisings. Groundwater from around the SGHWR is interpreted to discharge to an area west of the Monterey roundabout. This area has a M16 NVC community (*Erica tetralix – Sphagnum compactum* wet heath) that is part of the wet heaths, which is a 'qualifying feature' of the Dorset Heaths SAC. *Sphagnum* acts as an 'ecosystem engineer' and currently maintains a low pH environment in the near-surface of this area of mire. Decommissioning the Winfrith site's rubble drains could allow bicarbonate-rich deeper groundwater to discharge into the mire endangering the *Sphagnum* [183]. This, as well as the effects of future climate change, will alter groundwater pH in the vicinity of the mire. Therefore, the assessment conservatively assumes that implementation of the end state and climate change have removed the *Sphagnum* species that act to lower pH. No reliance is placed on the species lowering the pH or buffering the discharges from the disposals.

531 The hydro-ecological assessment [183, §5.3.1] explains that an increase in pH in the root zone to pH 7 would support habitats and species associated with broadly neutral conditions, albeit with a reduction in the designated qualifying feature habitats. The transition to habitats that can tolerate groundwater with neutral pH could, in theory, result in a community that is of high ecological value (as present elsewhere within the SAC). On this basis pH compliance for groundwater has been assessed against a requirement to avoid the mire exceeding pH 7 [24, §3.2]. For reasons of consistency and simplicity, the pH compliance limit established for SGHWR has also been used for the groundwater pathway downgradient of the Dragon reactor complex. Groundwater flowing from the Dragon reactor complex discharges into, and close to, the River Frome, which is less sensitive to pH than the acid mire. The compliance limit established for the groundwater pathway from SGHWR is therefore protective of receptors downgradient of the Dragon reactor complex.

532 The pH compliance limit is shown in Table 7.6 along with the selected compliance limit concentrations for dissolved substances included in the DQRA.

Table 7.6: Compliance limits (target concentrations) used in the Tier 3 DQRA [24, Tab.611/6].

Contaminant	Contaminant Classification	Selected Compliance Limit Concentration ($\mu g\ l^{-1}$ except for pH)	Source of Selected Compliance Limit Concentration[a]
Hydroxide (assessed as pH)	Non-hazardous	7	Described in Paragraphs 530 to 531
Chromium (III)	Non-hazardous	4.7	Freshwater annual average environmental quality standard [230]
Chromium (VI)	Hazardous	1	Limit of quantification [231]
Copper	Non-hazardous	12	Mean concentration in background groundwater [232]
Lead	Hazardous	0.2[b]	Limit of quantification [231; 232]
Zinc	Non-hazardous	27	Mean concentration in background groundwater [232]
PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153 and PCB-180	Hazardous	0.001	Minimum reporting value [233]
TPH-CWG >C10-C12 aromatic fraction	Hazardous	10	Minimum reporting value (typical laboratory limit of detection)
TPH-CWG >C12-C16 aromatic fraction	Hazardous	10	Minimum reporting value (typical laboratory limit of detection)
TPH-CWG >C16-C21 aromatic fraction	Hazardous	10	Minimum reporting value (typical laboratory limit of detection)

[a] The tabulated compliance limit for pH is for groundwater at the mire. Otherwise, the compliance limits are for the described compliance points for hazardous substances and non-hazardous pollutants. EA guidance [228] allows for the non-hazardous pollutant compliance limit for DQRA to include attenuation between the compliance point and the receptor but this has been cautiously ignored except when assessing pH.

[b] The mean concentration of lead in background groundwater is 3 $\mu g\ l^{-1}$ [232]. The DQRA ignores the background concentration of lead and uses a compliance based on a laboratory limit of quantification.

Reference and Variant Scenarios

533 A reference scenario model was constructed for the DQRA that is a cautious estimate of the expected evolution of the end states. Parameter values were based on site-specific data where possible. Uncertainties were systematically identified and treated via cautious assumptions. For example, cautious assumptions were made for the rate at which rainfall infiltrates the cap.

534 Sensitivity analysis has been completed to understand how uncertainties affect the modelled outcome. Analysis is based on the recommendations of the uncertainty assessment presented in the Conceptual Site Model Report [19]. The scenarios addressing model uncertainty in the assessment are presented in Table 7.7 and those addressing conceptual uncertainty are presented in Table 7.8.

Table 7.7: Scenarios selected to assess sensitivity to model uncertainty in the Tier 3 DQRA [24, Tab.611/11].

Uncertainty	Reference scenario	Variant scenario to support sensitivity analysis
Evolution of the effective hydraulic conductivity of the concrete structures	Model with cautious estimate of concrete degradation rate in SGHWR Regions 1 and 2	Two variant scenarios: (i) Model with faster early time concrete degradation rate compared to reference scenario (ii) Model with slower early time concrete degradation rate compared to reference scenario
Evolution of the rate of cap infiltration	Model with a cautious estimate of the SGHWR and Dragon cap degradation rate	Model with a faster cap degradation rate compared to the reference scenario
Frequency and extent of groundwater inundation to the SGHWR South Annexe and the Dragon reactor basement	Groundwater rises above the SGHWR South Annexe and the Dragon reactor basement to a level and with a frequency consistent with that of a cautious central estimate of future recharge calculated assuming a scenario of medium future global atmospheric emissions	Groundwater rises above the SGHWR South Annexe and the Dragon reactor basement to a level and with a frequency consistent with that of a reasonable worst case of future recharge calculated assuming a scenario of medium future global atmospheric emissions

Table 7.8: Scenario selected to assess sensitivity to conceptual uncertainty in the Tier 3 DQRA [24, Tab.611/12].

Uncertainty	Reference scenario	Alternative scenario to support sensitivity analysis
Frequency and extent of groundwater inundation to the SGHWR South Annexe and the Dragon reactor basement under the worst possible conditions of climate change	Groundwater rises above the SGHWR South Annexe and the Dragon reactor basement to a level and with a frequency consistent with that of a cautious central estimate of future recharge calculated assuming a scenario of medium future global atmospheric emissions	Assume an alternative scenario in which groundwater rises above (and subsequently falls below) the SGHWR South Annexe and the Dragon reactor basement to the maximum modelled water level every year.

535 Uncertainties in parameter values were systematically considered [24, §5.3.3]. For many of these, use of cautious parameter values in the reference case was considered to be sufficient, and others were considered to be addressed by the alternative and variant scenarios described above. However, additional scenarios assessing sensitivity to parameter uncertainty were defined. For example, substances were assumed not to biodegrade in the Poole Formation, additional inventory was considered, and alternative groundwater chemistry was modelled.

536 Further details of the Tier 3 assessment approach are presented in Chapter 5 of the HRA [24]. The assessments results are presented in Section 7.9.

7.3 Radiological Impacts During the Period of RSR

S.3 Radiological safety during the period of RSR is and will be managed, and impacts controlled and monitored, such that doses to members of the public are ALARA. The sum of cautiously estimated annual effective doses via all pathways and from all sources is less than the applicable regulatory dose constraint.

7.3.1 Current Radiological Impacts

S.4 Releases are managed to comply with the current environmental permit aqueous and gaseous discharge limits and monitoring activities demonstrate radiological impacts are well below the GRR Requirement R9 dose constraint in relation to these discharges.

Radiological Impacts from Current Site Discharges

537 Releases are managed to comply with the current environmental permit [7] and radiological impacts are well below the regulatory source-related dose constraint. Table 7.9 summarises the total aqueous and gaseous permitted discharges from the site and the total discharges made per year in 2022 and 2023, as an indication of current and near future discharges. The actual discharges are many orders of magnitude lower than those permitted.

538 The dose rates associated with the radioactive (aqueous and gaseous) discharges from the site are calculated retrospectively, with annual doses of 7 μSv y^{-1} in 2019 [234], 8 μSv y^{-1} in 2020 [235], 7 μSv y^{-1} in 2021 [236], 6 μSv y^{-1} in 2022 [237]. These doses are more than 30 times lower than the 0.3 mSv y^{-1} GRR Requirement R9 source-related dose constraint.

Table 7.9: Total aqueous and gaseous discharges from the Winfrith site in 2022 and 2023.

Route		Radionuclide	Permitted annual limit	Calendar year	
				2022	2023
Total aqueous discharges (GBq y^{-1})	Via inner pipeline	H-3	4.0E+04	6.5E-01	3.6E-01
		Cs-137	1.98E+03	5.03E-02	4.15E-02
		Alpha	1.4E+01	3.9E-04	3.9E-04
		Other radionuclides	9.8E+02	7.92E-03	1.01E-02
	Via outer pipeline	H-3	1.5E+02	6.96E-02	7.02E-02
		Alpha	2.0E+00	6.78E-04	6.17E-04
		Other radionuclides	1.0E+00	1.52E-03	1.61E-03

Route	Radionuclide	Permitted annual limit	Calendar year	
			2022	2023
Total gaseous discharges (GBq y^{-1})	H-3	4.95E+04	6.50E+00	4.56E+00
	C-14	5.9E+00	1.34E-01	1.31E-01
	Alpha	2.0E-03	1.22E-06	8.42E-07
	Other radionuclides	5.0E-03	1.26E-05	4.76E-05

Radiological Impacts from Direct Radiation

539 The overall assessed doses to members of the public from gamma radiation were 0.5 μSv y^{-1} in 2019[31] [234], 14 μSv y^{-1} in 2020 [235], 6 μSv y^{-1} in 2021 [236] and 28 μSv y^{-1} in 2022 [237].

540 As part of effectively managing legacy wastes, in 2022 drums of encapsulated sludge were moved from the treated radioactive waste store for packaging pending off-site dispatch to the LLWR. Final dispatch of the waste to LLWR occurred in March 2024. In accordance with management system requirements a dose rate assessment was completed for this operation to ensure doses to local residents were appropriately assessed and managed. The dose rate for a resident living in proximity to the site was 28 μSv y^{-1} [237; 238, p.3] in 2022 and 54 μSv y^{-1} [239, Tab.1.1] in 2023, approximately an order of magnitude lower than the source-related dose constraint. Future doses from direct radiation are not expected to increase beyond these values, but this does depend on the decommissioning activities undertaken, their location and surrounding containment. That said, all future doses from direct radiation will be maintained below the dose constraint and optimised to ensure that they are ALARA.

7.3.2 Radiological Impacts from Reactor Building Demolition and End State Implementation

S.5	Releases during works to demolish the reactor buildings and implement the end state will be managed to ensure that radiological impacts are ALARA.

541 Potential public doses resulting from implementation of the proposed on-site disposals will be calculated as part of detailed design and mitigation measures defined. Associated BAT studies and other activities will be undertaken when the detailed engineering design and implementation plan is developed to ensure that potential releases are optimised. Whilst future demolition activities have not yet been quantitatively assessed, they will be planned and undertaken in such a way so as to ensure that the combined dose rates are below the relevant GRR radiological criteria, the permitted discharge limits and are ALARA.

[31] Note that the 2019 value is based on a dog-walker (200 hours per year), not a resident (6,333 hours indoors with a shielding factor of 0.2, and 919 hours outdoors) as in the 2020 and 2021 assessments, which was the critical group for subsequent assessments.

7.3.3 Radiological Impacts of the Implemented On-site Disposals

S.6 The natural evolution and site occupancy assessment models consider the radiological impacts from releases to groundwater from the on-site disposals and direct radiation. In the period between implementing each on-site disposal and reaching the SRS the calculated annual effective dose for all relevant receptors is significantly less than the GRR Requirement R9 source-related dose constraint (0.3 mSv y^{-1}).

542 Assessments estimating the radiological impacts following implementation of each on-site disposal, prior to release from RSR (2066), have been completed [23]. These assessments consider the expected evolution scenario (Reference Case and alternative cases) and variant and "what-if" scenarios.

543 Note that human intrusion into the on-site disposals will not be possible during the period of RSR as the site will continue to be managed[32]. Therefore, this section considers the natural evolution of the site and relevant site occupancy RPs only. In these assessments, RPs have been defined assuming cautious habits but based in part on present-day and observed activities of the local population (Section 5.3.1). The Smallholder RP represents a cautious assessment of a possible future activity.

Natural Evolution – Expected Evolution Reference Case

544 Assessments estimating the radiological impacts resulting from natural evolution (aqueous release) of the proposed end state have been undertaken using a radionuclide transport model developed in the GoldSim platform [23], as discussed in Section 7.2.1. The expected natural evolution scenario is defined based on the current understanding of the proposed on-site disposals, site characteristics and the local surrounding region, and how these are expected to evolve over time (undisturbed by human intrusion). A realistic but cautious approach is applied, with conservative assumptions made where appropriate (see Section 7.11.3).

545 The site will be accessible to the public after the IEP, once the disposals have been implemented and restoration activities are complete. However, some of the considered RP activities would not be possible during this period due to on-going stewardship and management of the site. Therefore, the Construction Worker, Farmer and Smallholder RPs would not be possible on-site (in the Land/Mire biosphere model compartment). The neighbouring Field compartment is outside the land holding and stewardship, so such RPs are cautiously assumed to be possible off-site. Potential impacts to all RPs in the natural evolution model are assessed from the point at which the disposals are implemented.

546 The potential dose rates to humans as a function of time in the period to the SRS for the expected evolution scenario Reference Case assessment are shown in Figure 7.5. The calculated dose rates for each of the RPs at the SRS (2066) are summarised in Table 7.10. For all of the credible RPs during this period, dose rates for the Reference Case are more than four orders of magnitude below the GRR Requirement R9 source-related dose constraint (0.3 mSv y^{-1}). During the period of RSR, the highest calculated dose is for the Smallholder RP in the off-site Field compartment (3.6E-06 mSv y^{-1}). Ingestion of contaminated foodstuffs is the dominant exposure mode, with it being the largest contributor to peak dose rates for all RPs that consider ingestion.

[32] There will also be development controls after the SRS, but it is pessimistically assumed that development and intrusion occurs despite these.

547 Of the modelled features, the A59 area is the dominant dose-contributing feature during the period of RSR for all RPs, although significantly below the respective dose constraint. Even though associated with an OoS inventory, the remaining radioactivity in the A59 area is not contained by a concrete structure, has the shortest release pathway to the receptors and is already in contact with groundwater, which leads to its dominance at early times (releases from the reactor disposals dominate after the SRS; see Section 7.4.1). The dominant dose-contributing radionuclide to the Smallholder (Field) RP at 2066 is ^{238}U from the A59 area.

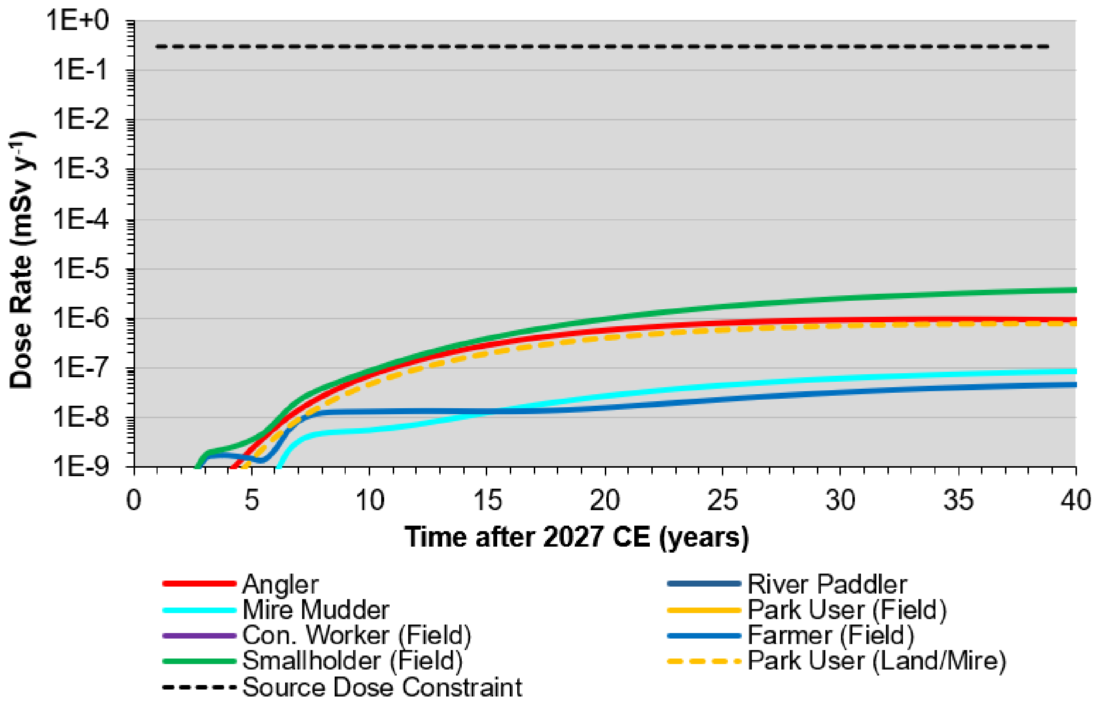

Figure 7.5: Dose rates over time to each credible RP in the period of RSR from natural evolution of the proposed Winfrith end state in the Reference Case assessment. The dashed black line shows the dose constraint to the assumed SRS date (2066, or 39 years after model start). Note that this figure only shows calculated dose rates down to 1E-9 mSv y^{-1}; the River Paddler and Construction Worker (Field) RP dose rates are below this level. The Construction Worker, Farmer and Smallholder RPs on the Land/Mire compartment are not possible prior to the SRS.

Table 7.10: Dose rates to each credible RP at the assumed SRS date (2066) arising from natural evolution of the proposed Winfrith end state in the Reference Case assessment.

RP	Dose Rate at 2066 (mSv y^{-1})
Angler	9.49E-07
River Paddler	5.44E-10
Mire Mudder	8.35E-08
Park User (Field)	6.56E-10
Construction Worker (Field)	1.10E-10

RP	Dose Rate at 2066 (mSv y^{-1})
Farmer (Field)	4.53E-08
Smallholder (Field)	3.64E-06
Park User (Land/Mire)	7.81E-07

Site Occupancy

548 Assessments estimating the radiological impacts resulting from site occupancy above the proposed on-site disposals have been undertaken using MicroShield® [23].

549 For the time between the IEP and the SRS when the public will be able to access the site for recreational use but it is still managed, two RPs have been identified for site occupancy assessment: a dog walker and a camper. For a dog walker, an average occupancy time of 470 hours per year is assumed based on an analysis of questionnaire data collected by wardens on Dorset's Urban Heaths [240]. For a camper, an occupancy time of 384 hours per year is assumed based upon four trips of four nights each on the proposed disposals, assuming 24-hour occupancy.

550 The calculated annual effective doses to all RPs from external irradiation are at least four orders of magnitude below the dose constraint in 2036 (the assumed IEP date). As migration of radionuclides away from the source will occur over time, along with radioactive decay of short-lived nuclides, the dose rate at the 2066 SRS date will be even lower for these RPs. The Dog Walker RP, with a slightly greater annual occupancy time, receives the highest dose for all features, with the maximum occurring when assumed to spend the entire dog-walking period above the assumed A59 Other Areas feature (of 9.5E-06 mSv y^{-1}).

Alternative Cases and Variant and “What-if” Scenarios

551 The results for the alternative cases and variant scenarios considered can be summarised as follows:

- For the natural evolution alternative cases all calculated dose rates are more than three orders of magnitude beneath the dose constraint, and all variant configuration, concept and “what-if” scenarios also remain below the dose constraint during the period of RSR.
- For all alternative cases and variant scenarios considered in the site occupancy assessment, the calculated annual effective doses to all the RPs for SGHWR, Dragon and A59 are at least two orders of magnitude below the dose constraint.

7.3.5 Combined Radiological Impacts

S.7 The combined dose rates from Winfrith during the period of RSR, when also accounting for the possible contribution from the adjacent Tradebe Inutec site, are calculated to be significantly below the GRR Requirement R9 site-related dose constraint (0.5 mSv y^{-1}).

NRS Winfrith Site

552 During the period of RSR, there are expected to be multiple exposure pathways, although these would not necessarily arise at the same time or be received by the same receptor. The exposure pathways and indicative dose rates[33] associated with the NRS Winfrith site are:

- permitted discharges associated with ongoing operation and decommissioning of the site (approximately 8E-03 mSv y^{-1} in 2020; Section 7.3.1);
- direct radiation originating from facilities on the site (5.4E-02 mSv y^{-1} in 2023; Section 7.3.1);
- releases during demolition works (not yet calculated but will be assessed and optimised as part of the detailed design process; Section 7.3.2);
- releases from natural evolution of the proposed on-site disposals (<4E-06 mSv y^{-1} at 2066; Section 7.3.3); and
- direct radiation from the proposed on-site disposals (<1E-05 mSv y^{-1} at 2066; Section 7.3.3).

553 The same receptor would not receive doses from all the identified NRS Winfrith site exposure pathways, especially as releases from the proposed disposals will not reach the biosphere at the same time as the ongoing above-ground decommissioning activities. Nonetheless, if it is unrealistically assumed that all exposures take place at the same time and are received by the same receptor, the combined total dose rate would still only be approximately one fifth of the 0.3 mSv y^{-1} source-related dose constraint[34] and approximately a tenth of the 0.5 mSv y^{-1} site-related dose constraint (not including the Tradebe Inutec site). This dose is dominated by currently permitted site activities, with negligible contribution from the proposed disposals.

Tradebe Inutec Site

554 Comparison to the GRR Requirement R9 site-related dose constraint of 0.5 mSv y^{-1} should take account of the neighbouring Tradebe Inutec nuclear site (see Paragraph 475).

555 The Tradebe Inutec site operates next to the NRS Winfrith site under a separate nuclear site licence and environmental permit [29]. No aqueous discharges are permitted to the local environment from the Tradebe Inutec site, but gaseous discharges up to the limits specified in Table **7.11** are permitted. The table also shows the total discharges made in 2023, as an indication of current and near future discharges, which are orders of magnitude lower than those allowed by the environmental permit.

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[33] The dose rates assumed are the peak values across the last 4-5 years of available data.
[34] Comparison to the source-related dose constraint is conservative as discharges associated with the entire NRS Winfrith site correspond to multiple sources (i.e. operating facilities, waste stores, and the SGHWR and the Dragon reactor complex proposed disposals).

Table 7.11: Total gaseous discharges from the Tradebe Inutec site in 2023 [239, Tab.A1.1].

Route	Radionuclide	Permitted annual limit	Calendar year 2023
Total gaseous discharges (GBq y^{-1})	H-3	1.95E+04	2.94E+02
	C-14	3.0E+01	2.04E-07
	Alpha	1.0E-04	1.08E-07
	Other radionuclides	1.0E-04	4.80E-07

556 Retrospective dose data have not been obtained for the Tradebe Inutec site, but the NRS Winfrith permit has higher gaseous discharge limits than Tradebe Inutec for all nuclides other than ^{14}C, which would suggest that the Tradebe Inutec radiological impacts would be bounded by that of the NRS Winfrith site. The dose associated with Tradebe Inutec gaseous discharges in 2023 has been estimated using the EA's Initial Radiological Assessment Tool [241, Tab.2], which is used for initial conservative screening assessments. Using the Dose Per Unit Release (DPUR) values for the atmospheric release scenario and worst-case age group local resident family (assuming ^{241}Am for alpha and ^{137}Cs for other), a dose of 1E-03 mSv y^{-1} in 2023 is estimated.

557 The 2023 annual assessment report of radioactivity in food and the environment and the public's exposure to radiation (RIFE) reports a public dose of 1E-03 mSv y^{-1} in 2023 for direct radiation from the Tradebe Inutec site [239, Tab.1.1].

558 It is assumed that the Tradebe Inutec site continues to operate throughout the period that the NRS Winfrith site remains subject to RSR. On that basis, the potential for combined dose pathways is assessed assuming a resident RP living in proximity to the site is exposed to radiation from both permitted sites, and assuming that the public dose in 2023 is representative of future doses. The combined dose from all sources from both sites could be approximately 0.06 mSv y^{-1} whilst the site remains in its current configuration (~13% of the site-related dose constraint of 0.5 mSv y^{-1}). After the IEP is reached and permitted discharges from the NRS Winfrith site have stopped, doses to a receptor would be dominated by direct radiation and gaseous discharge from the Tradebe Inutec site, but still much less than 1% of the site dose constraint.

7.4 Radiological Impacts After the Period of RSR

S.8	Radiological dose and risk to the public after the period of RSR have been assessed for all credible scenarios and pathways, including natural evolution aqueous release pathways, site occupancy and inadvertent human intrusion. The assessments focus on a broadly expected evolution of the local environment but account for uncertainties regarding the disposal system, geosphere, radionuclide release, and radionuclide migration and exposure processes.

7.4.1 Natural Evolution

S.9	The calculated radiological impacts from natural evolution of the proposed end state after release of the site from RSR are significantly below the GRR Requirement R10 risk guidance level (RGL) for the Reference Case. All alternative scenarios are also below the RGL except for two calculations, which result from cautious modelling approaches. Dose rates are also below the RGL in scenarios considering the unlikely "what-if" situation of impairment of protective barriers resulting from natural disruptive processes (GRR Requirement R12).

Reference Case

559 The total calculated peak annual dose rates resulting from natural evolution of the proposed Winfrith end state in the Reference Case assessment are summarised in Table 7.12 for each of the RPs, whilst dose rates as a function of time after the assumed SRS date of 2066 are shown in Figure 7.6.

560 The RGL applies after the SRS date and all RP activities are conservatively assumed to occur (i.e. they are presented as conditional doses and assume that the probability of the RP being exposed to radiation is equal to unity). However, not all scenarios are equally likely. For example, given the evidence of local habits, it is likely that a receptor will walk across the site in the future or fish at some point along the River Frome. However, the probability of someone living on the site, growing crops and raising livestock, and doing so directly on the small area of land potentially contaminated by releases from the disposals, has a much lower probability. Nonetheless, all the RPs considered in the assessment are conservatively assumed to occur.

561 For all of the RPs, peak dose rates in the Reference Case are more than an order of magnitude below the dose rate equivalent of the GRR R10 risk guidance level (~0.017 mSv y^{-1}). The highest peak dose rate (3.0E-04 mSv y^{-1}) is associated with the Smallholder RP in the on-site Land/Mire compartment, occurring around 56,800 years in the future. This RP is assumed to reside, grow and consume vegetables and fruit, and raise and consume livestock, on land contaminated by groundwater releases from the SGHWR and A59 area.

562 The next highest peak doses occur for the Farmer RP, also in the Land/Mire compartment, and then the Smallholder RP located on the off-site Field irrigated with water from the River. All peak dose rates occur more than 50,000 years in the future except for the Mire Mudder and Construction Worker (Land/Mire) RPs, which occur after 50 years and are associated with A59 releases to the Land/Mire.

563 Two maxima in the dose rate plots are observed. The first, after 1,000 years, corresponds to the time at which the in-situ concrete structures are assumed to have hydraulically degraded. The second maxima, which corresponds to the peak dose rate for most RPs, occurs after 50,000 years due to the concrete structures reaching the point of full chemical degradation and the remaining inventory finally being released from the SGHWR and Dragon reactor complex concrete structures, thus demonstrating the degree of containment provided by the system. However, it is noted that the dose only varies by approximately an order of magnitude over thousands of years for many RPs (Figure 7.6).

564 Ingestion of contaminated foodstuffs is the largest contributor to peak dose rates for all RPs that consider ingestion. For the on-site Smallholder (Land/Mire) RP, ingestion of animal foodstuffs and terrestrially-grown plants are the dominant sources.

Table 7.12: Peak dose rates for each RP arising from natural evolution of the proposed Winfrith end state in the Reference Case assessment. The time of peak dose rate and the dominant dose-contributing radionuclide are also shown. Note that the time of the peak is for the total dose across all radionuclides; the peak for the dominant radionuclide does not necessarily occur at the same time.

RP	Peak Dose Rate (mSv y^{-1})	Time of peak after 2027 (y)	Dominant radionuclide
Angler	1.52E-06	58,272	Pb210
River Paddler	7.06E-10	51,176	Pb210
Mire Mudder	9.36E-08	52	U238
Park User (Field)	3.05E-09	59,669	Pb210
Construction Worker (Field)	3.31E-10	51,246	U238
Farmer (Field)	2.49E-07	58,872	Pb210
Smallholder (Field)	5.58E-05	55,768	Ac227
Park User (Land/Mire)	1.67E-06	57,047	Pb210
Construction Worker (Land/Mire)	2.29E-07	51	U238
Farmer (Land/Mire)	1.21E-04	56,743	Pb210
Smallholder (Land/Mire)	2.99E-04	56,777	Pb210

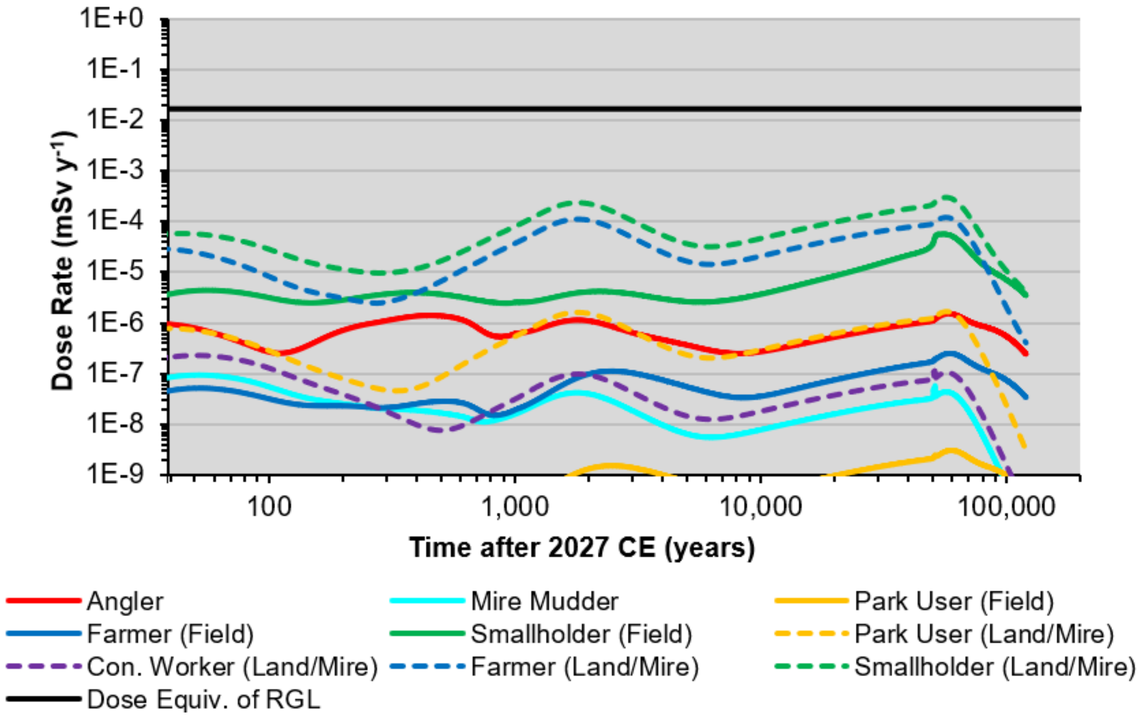

Figure 7.6: Dose rates over time for each RP for the post-RSR period (2066 onwards) from natural evolution of the proposed Winfrith end state in the Reference Case assessment. The solid black line shows the dose rate equivalent of the regulatory RGL. Note that this figure only shows calculated dose rates down to 1E-9 mSv y^{-1}; the River Paddler and Construction Worker (Field) RP dose rates are below this level.

565 Figure 7.7 shows the top five dose-contributing radionuclides to the Smallholder (Land/Mire) RP: ^{90}Sr, ^{238}U, ^{226}Ra, ^{210}Pb and ^{227}Ac. Key radionuclides across all the RPs considered are ^{90}Sr (all RPs except the Smallholder (Field)), ^{129}I (Angler, Mire Mudder and Farmer (Field) RPs), ^{210}Pb (all RPs), ^{226}Ra (all RPs except Angler, Mire Mudder and Smallholder (Field) RPs), and certain actinides – ^{227}Ac, ^{229}Th, ^{230}Th, ^{231}Pa, ^{234}U, ^{235}U, ^{238}U, ^{240}Pu and/or ^{241}Am (all RPs).

566 As would be expected due to the size of its inventory, relatively short half-life and weak sorption potential to undegraded concrete, the ^{90}Sr peak dose rate for all RPs occurs within the first hundred years. Whilst very long-lived, ^{129}I is mobile and peaks between 100 and 1,000 years. The peak dose rates for ^{210}Pb, ^{226}Ra and the actinides generally occur later, between around 1,000 and 60,000 years, due to their greater sorption potential to undegraded concrete and their longer half-lives, and the time required for decay and in-growth of daughter radionuclides.

567 Releases of these radionuclides from the SGHWR and Dragon reactor complex disposals occur after the concrete associated with the near field has hydraulically and chemically degraded (leading to the observed peaks over 1,000 years and 50,000 years, respectively, in the future). This also explains the apparent "spike" in ^{238}U release in Figure 7.7 when any remaining uranium is released from the concrete structures as the sorption coefficient for uranium switches to the low value associated with degraded concrete. However, some actinides show peak dose rates at around 100 years. For example, ^{234}U for the River Paddler and Mire Mudder RPs and ^{238}U for the Construction Worker and Smallholder RPs (both Field and Land/Mire); these peaks are associated with releases from the OoS A59 area, which has a total uranium inventory about half that of SGHWR but which is not contained within a concrete structure.

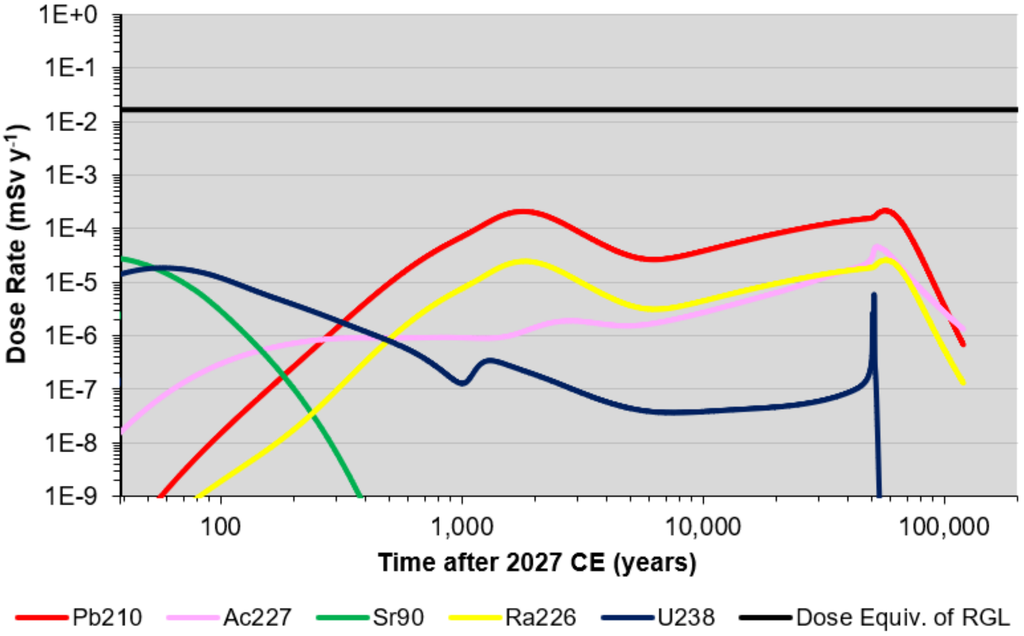

Figure 7.7: Dose rates for the top five dose contributing radionuclides for the post-RSR (2066 onwards) Reference Case assessment for the Smallholder (Land/Mire) RP.

568 As illustrated by Figure 7.8, the proposed SGHWR disposal is the dominant contributor to the peak dose for the Smallholder (Land/Mire) RP. This holds true for all RPs except for the Mire Mudder and Construction Worker (Land/Mire) RPs, where the OoS A59 area dominates. The

OoS A59 area is also the dominant contributor in the first 1,000 years for all RPs. The Dragon reactor complex is always the smallest dose contributor. The dominant radionuclides associated with releases from the SGHWR are primarily ^{210}Pb, ^{226}Ra, ^{227}Ac, ^{231}Pa, ^{235}U and ^{238}U, with the peak dose occurring between 50,000 and 60,000 years after the IEP. The time of peak dose for the OoS A59 area occurs much earlier, between 30 and 120 years after the model start and is dominated by ^{90}Sr and ^{238}U, but is about two orders of magnitude lower than the RGL. The SGHWR ^{238}U inventory is more than double that of the A59 area and the ^{90}Sr inventory is more than an order of magnitude greater, but the lack of attenuating and sorbing concrete structure means that releases from A59 can occur earlier.

569 When considering the individual end state inventory components (Figure 7.9), the SGHWR bioshield has the highest total inventory in the Reference Case but forms one of the lowest contributors to dose due to the time required for release of the activity from the bioshield and through the SGHWR Region 1 structure. The highest dose-contributing components are generally SGHWR Region 1, and the SGHWR South and North Annexes with ^{210}Pb and actinides, and the OoS A59 Other component, with ^{90}Sr and actinides. SGHWR Region 1 has the second-highest inventory of all the features, containing the Primary Containment, Ponds and mortuary tubes. The other three SGHWR components have relatively large inventories compared to the other Dragon and A59 area component, but are at least an order of magnitude lower than that of SGHWR Region 1. The concrete in the SGHWR Annexes is assumed to be hydraulically degraded from the model start, but as they are above the groundwater table releases are limited by rainwater infiltration through the cap.

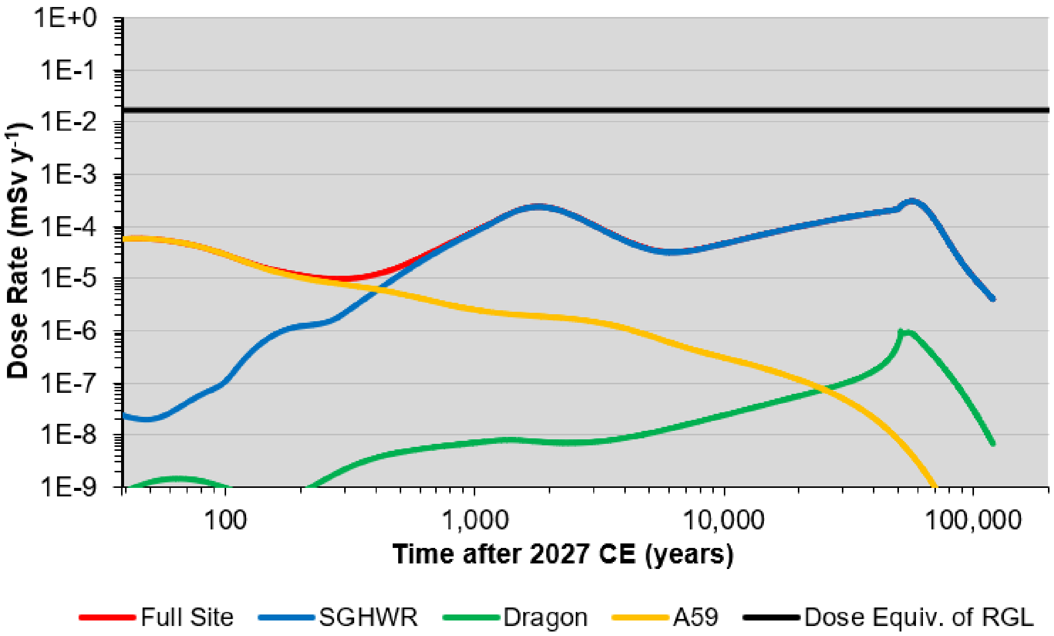

Figure 7.8: Dose rates for the three modelled on-site sources for the post-RSR (2066 onwards) Smallholder (Land/Mire) RP in the Reference Case assessment.

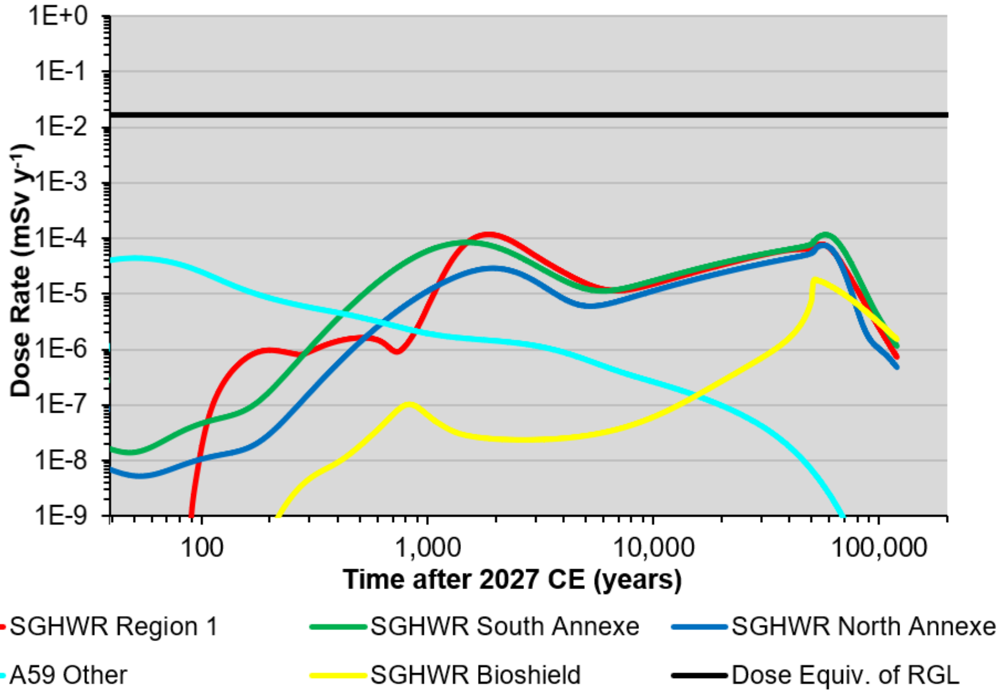

Figure 7.9: Dose rates for the top five dose-contributing individual components for the post-RSR (2066 onwards) Smallholder (Land/Mire) RP in the Reference Case assessment.

Alternative Cases and Variant and "What-if" Scenarios

Alternative Assessment Cases

570 The results of the natural evolution alternative assessment cases summarised here are discussed in detail in the radiological PA [23, §10.1.3].

571 The Smallholder (Land/Mire) RP continues to receive the highest dose rate of all the RPs, across every alternative assessment case considered where this RP is possible. In all but one of the cases considered, dose rates to all RPs remain below the dose rate equivalent of the RGL.

572 For the RPs that are assumed to ingest contaminated foodstuffs, there is a direct correlation between dose and biosphere uptake factors (how much radioactivity can be taken up into foodstuffs). Assuming minimum uptake factors reduces the peak dose rate by about an order of magnitude; assuming maximum uptake factors leads to the peak dose rate for the Farmer and Smallholder RPs in the Land/Mire compartment exceeding the dose rate equivalent of the RGL by about a factor of ten after 1,000 years[35] (see Figure 7.10). However, it is important to recognise the uncertainty in the uptake factors for various foodstuffs – this alternative calculation case considers the extremes of the parameter value range for every radionuclide (the Reference Case assumes the best estimate values). In addition, these calculations conservatively assume that the RP activities occur. As discussed above, the probability of a smallholder living directly on the contaminated area in the future is expected to be low. Whilst farming in the area is a probable activity, doing so on a contaminated area that is designated

[35] Biosphere uptake factors vary by foodstuff and radionuclide, but the range is often two to four orders of magnitude between the minimum and maximum values. The values assumed in the radiological risk assessment are reported in [23, §D.4.3].

as protected heathland with development controls is much less likely, as is assuming that the Farmer RP's entire meat and vegetable intake is contaminated.

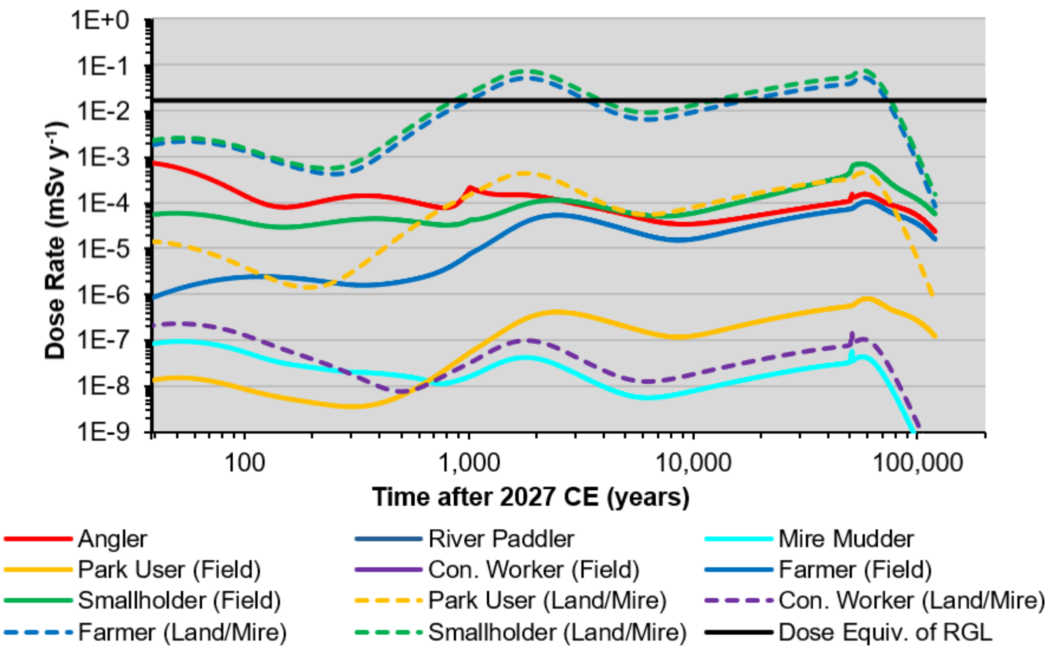

Figure 7.10: Post-RSR period (2066 onwards) dose rates over time to each RP arising from natural evolution of the proposed Winfrith on-site disposals in Alternative Assessment Case EE.1.14 (maximum biosphere uptake factors).

573 The alternative assessment cases suggest that uncertainty in the following parameters is likely to have the greatest impact on RP dose rates:

- alternative inventories;
- radioelement partition coefficients for concrete, Poole Formation material and biosphere soil and sediment;
- biosphere uptake factors for radionuclide transfer from the environment into food products; and
- average annual mire outflow rates to the river.

Variant Concept Scenarios

574 The results of the natural evolution variant concept scenarios summarised here are discussed in detail in the radiological PA [23, §10.2.1].

575 In all but one of the variant concept scenarios (water abstraction), peak dose rates to all RPs remain below the dose rate equivalent of the RGL.

576 The highest dose rate of the variant concept scenarios is calculated for a Well Abstractor RP who is assumed to abstract and consume groundwater released from a well 1 m down-gradient of each of the three modelled on-site sources. Figure 7.11 shows that the conditional dose rate for the Well Abstractor RP for a well located downstream of the SGHWR and Dragon reactor complex on-site disposals is always below the dose equivalent of the RGL, and so there is no exceedance associated with the proposed disposals.

577 As discussed in Sections 1.3 and 5.2, the modelled A59 area inventory satisfies RSR OoS criteria and so does not form part of the GRR permit application. However, it was included in the PA to ensure a robust transparent assessment and to inform understanding of future site monitoring results once the proposed reactor disposals have been implemented. The conditional dose rate for a well associated with the OoS A59 area slightly exceeds the dose equivalent of the RGL in the years following the release from RSR until about 2125, with a peak dose of 4.1E-02 mSv y^{-1} occurring at the point of assumed release from RSR and dominated by ^{90}Sr and ^{238}U (Figure 7.11).

578 The well abstraction scenario is cautious and it is unlikely that an RP would receive such a radiological impact for several reasons (see [23, §10.2.1] for full details):

- The scenario assumes the receptor meets their entire annual drinking water needs from the one well.
- The CEFAS regional habits surveys [33; 168] suggest construction of a residential well is relatively uncommon in the local area. There are commercial abstraction wells in the area, but where abstraction occurs on a commercial basis, monitoring of radioactivity in drinking water is required so any contamination would be known.
- It is most likely that an abstraction borehole would be sunk into the confined Chalk aquifer below the London Clay, as it would be more productive, rather than potentially contaminated groundwater in the Poole Formation (see Paragraph 298).
- There is a low probability of future groundwater abstraction being located on the site or between the site and the River Frome, particularly due to the natural environment designations currently applied (see Paragraph 299).
- Given the large land area over which a well could be sunk, it is unlikely that a well would be sunk such that it intercepts exactly the migrating contamination, particularly at high concentration. The calculation is bounding, as it assumes that the well is drilled immediately adjacent to (1 m downstream) of each source and does not account for transverse dispersion in the groundwater.
- The OoS A59 area exceedance only occurs over a relatively narrow time window (2066-2125), with the calculated dose below the dose rate equivalent of the RGL for the majority of the modelled 100,000-year timeframe.
- Using the CEFAS well frequency data and a conservative estimate of the land area potentially contaminated between the A59 area and the River Frome indicates a probability of sinking a well into this area of 1E-03. When multiplied by the calculated peak dose rate, the associated peak risk would be at least two orders of magnitude below the RGL (2E-09 y^{-1} for the A59 area).

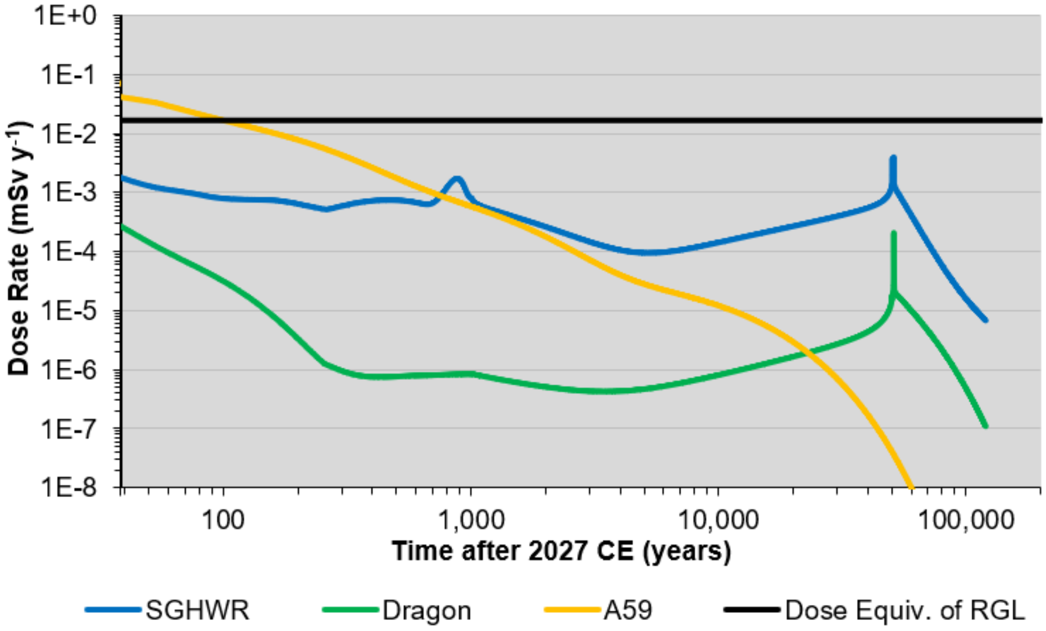

Figure 7.11: Dose rates for the Well Abstractor RP in the variant concept scenarios post-RSR (2066 onwards), with a well located 1 m down-gradient of each modelled on-site source.

579 All other variant concept scenarios result in doses below the dose equivalent of the RGL. Of the other variant concept scenarios, those with the most significant impact are seasonally fluctuating groundwater levels and assuming the entire flow path from SGHWR and A59 reaches the Land/Mire compartment.

Variant Configuration Scenarios

580 The five variant configuration (or design) scenarios considered (e.g. changing concrete block size, replacing blocks with rubble, or grouting all voids) in the radiological PA [23, §10.2.2] have negligible impact on the peak dose rates for all RPs (a maximum change of 4%) and all remain below the dose rate equivalent of the RGL. The negligible impact of these engineering configuration changes on the calculated dose rates indicates that radiological dose is unlikely to be a key driver when defining the detailed design.

"What-if" Scenarios

581 The two "what-if" scenarios in the radiological PA [23, §10.3] consider highly speculative situations that are not credible future outcomes. As such, they do not reflect the general uncertainty in the evolution of the disposal system but can be used to bound worst-case events – these are identified as instantaneous hydraulic failure of the concrete structures from the start of disposal implementation (e.g. due to a large earthquake damaging the near field) and extreme climate change with groundwater to 1 m below surface-level. In both of these "what-if" scenarios, peak dose rates to all RPs remain below the dose rate equivalent of the RGL.

Natural Disruptive Events

582 The risks posed by natural disruptive processes on the site are low (see Section 5.3.1) and are not expected to lead to the disruption of the waste or barriers over timescales relevant to peak radiological impacts from on-site disposal. However, some processes could potentially enhance aqueous release from the modelled on-site sources at the site if they were to occur.

Where justified, the potential impact has been quantitatively assessed through incorporation into the natural evolution assessment conceptual models. For example, alternative and variant cases have considered climate change (higher rainfall) leading to higher groundwater level rises or changes in flow path proportions, and enhanced degradation of the engineered caps through surface erosion or desiccation. Extreme climate change with groundwater levels to 1 m below surface level and the impact of a large earthquake are also considered in the "what-if" scenarios. The above discussion shows that people and environment continue to be adequately protected in these scenarios.

583 The impact of high magnitude but rare events, such as an earthquake, could lead to significant disruption of the disposal system. Natural disruptive processes of sufficient magnitude to compromise the disposal system are not expected at Winfrith over timescales relevant to peak radiological impacts. Despite this, the "what-if" case considering instantaneous hydraulic failure of the concrete structures can be considered to represent the potential impact of a large earthquake. Even in this case the peak dose rates for all RPs remain beneath the dose rate equivalent of the RGL.

7.4.2 Site Occupancy

S.10 The calculated radiological impacts from occupancy above the proposed on-site disposals after release from RSR are at least an order of magnitude below the GRR Requirement R10 risk guidance level for the Reference Case and all but one of the alternative scenarios considered.

Reference Case

584 Three RPs have been identified for inclusion in the site occupancy assessment for the period after the SRS when no controls on use of the site are assumed: a dog walker, a camper and a caravan (static-home) dweller. It is assumed that the caravan is conservatively located on top of the on-site disposals and is lived in year-round, giving rise to a conservative occupancy time of 8,760 hours [242]. Dog Walker and Camper RP occupancy times are assumed to be the same as for the pre-SRS receptors (see Section 7.3.3).

585 The calculated annual effective doses to all the RPs for all features are several orders of magnitude below the dose rate equivalent of the RGL. The Caravan Dweller RP, with its year-round occupancy, receives the highest dose for all features, with the maximum occurring for residence above the OoS A591/HVA Area (1.0E-04 mSv y^{-1}). Doses for the Caravan Dweller RP from the Dragon reactor complex and SGHWR are all below 1E-11 mSv y^{-1}.

Alternative Cases and Variant Scenarios

586 The results for alternative cases and variant scenarios show that the calculated annual effective doses to all the RPs for SGHWR and Dragon modelled on-site sources are at least three orders of magnitude below the dose rate equivalent of the RGL.

587 The calculated annual effective doses to the dog walker and camper RPs are below the dose rate equivalent of the RGL when considering the OoS A59 area in 2066. Only when considering the unrealistic variant scenario of a caravan dweller lying horizontally for an entire year with no cover material directly above the OoS A591/HVA area in 2066 is a dose comparable to that of the RGL calculated (2.4E-2 mSv y^{-1} compared to 1.7E-2 mSv y^{-1}). Even discounting how unrealistic this scenario is, the ground survey that will be completed as part of remediation of the A59 area and the site closure process will ensure that there is appropriate clean cover material in place.

7.4.3 Inadvertent Human Intrusion

S.11	The calculated radiological impacts from inadvertent human intrusion into SGHWR Region 1 could potentially result in exceedances of the GRR Requirement R11 dose guidance level for the Reference Case inventory. However, this is due to the SGHWR mortuary tubes which are yet to be accessed, characterised and cleaned. Intrusions into all other proposed on-site disposals result in doses below the relevant GRR dose guidance levels for the Reference Case and all alternative scenarios.

Reference Case

588 Potential doses as a result of excavating material have been estimated using GIM [226; 227]. The majority of the scenarios considered in GIM involve long term exposure to contaminated/activated material and should be compared with the lower end of the GRR Requirement R11 dose guidance level range (3 mSv y^{-1} for prolonged exposures). However, some of the exposure scenarios considered in the human intrusion assessment could result in transitory exposures to workers involved in drilling or excavation, and these should be compared with the upper end of the GRR R11 annual dose guidance level range (20 mSv in total).

589 Figure 7.12 to Figure 7.14 present the potential annual doses from inadvertent human intrusion into each of the modelled on-site features for the Reference Case. It is cautiously assumed that intrusion occurs in 2066, the first point at which it is assumed that there are no controls preventing intrusion (despite the expectation that development controls will be in place). Doses to excavation workers are presented as well as doses to infants if the excavated material were to be used following the intrusion. Doses to adults using the excavated material are not presented as they are bounded by the infant doses. For use of land following the excavation, the two most bounding scenarios are presented: infant 'play area user' and 'land user'.

590 All calculated doses to excavation workers for transitory intrusions at 2066 into any of the three modelled features are below the 20 mSv dose guidance level.

591 Across all three modelled features, the only calculations exceeding the 3 mSv y^{-1} prolonged exposure dose guidance level assuming the reference inventory at 2066 are those to infant land users associated with intrusions into SGHWR Region 1 (23.8 mSv y^{-1}; Figure 7.12). However, this SGHWR Region 1 intrusion dose is primarily attributed to the cautious residual inventory estimated to remain in the SGHWR mortuary tubes at the end state. This inventory estimate is uncertain, as the tubes have yet to be accessed to remove their content. Once the stored wastes have been removed the tubes will be characterised and cleaned (see Paragraph 382).

592 If the estimated SGHWR mortuary tube end state inventory is excluded from the intrusion assessment, then all intrusion cases considered at 2066 are beneath the dose guidance level (the maximum dose for intrusion into SGHWR still occurs for an infant land user, but is for intrusions into Region 2 and the South Annexe with a dose of 0.10 mSv y^{-1}). If the SGHWR mortuary tubes are excluded, then the highest calculated dose across all three modelled features is for an infant land user following intrusion into the Dragon reactor building with 0.60 mSv y^{-1} (Figure 7.13).

593 For all modelled features, the intrusions resulting in the greatest dose are frequently to infant land users from large excavations, and the largest radionuclide dose contributor is typically ^{90}Sr (although ^{241}Am is also significant for intrusions into the Dragon reactor complex).

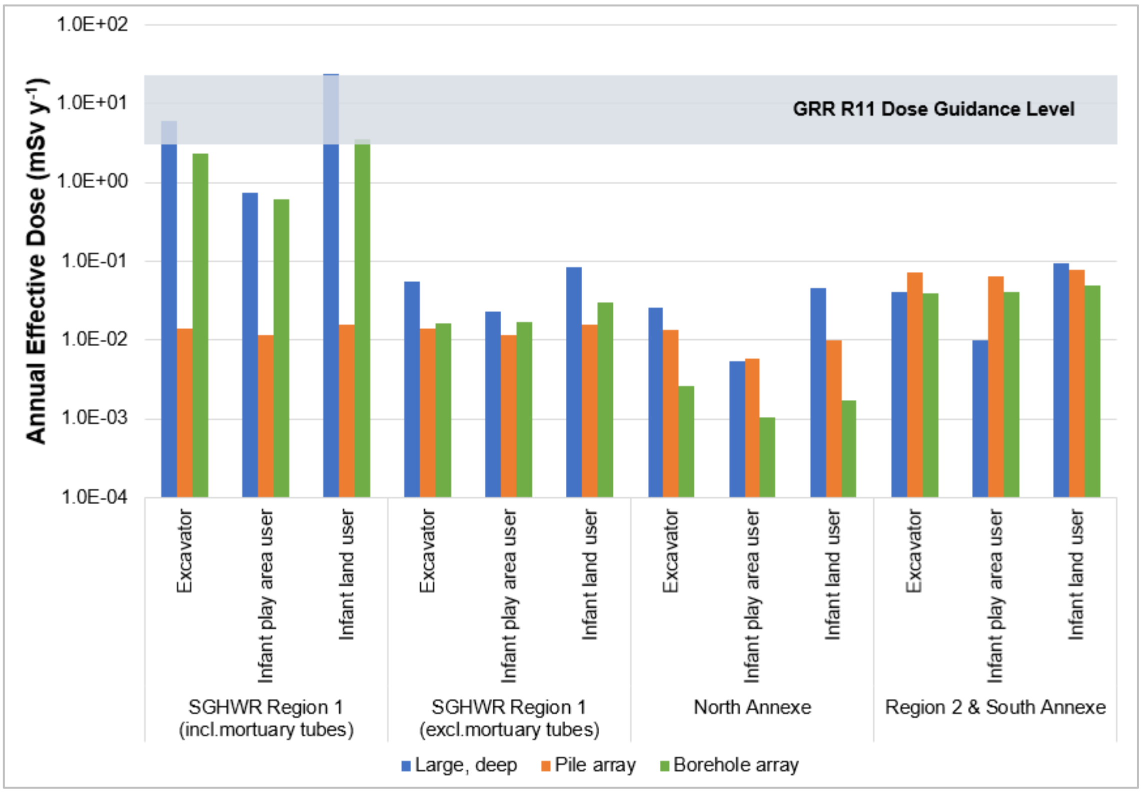

Figure 7.12: Doses to receptors from human intrusion into SGHWR for the Reference Case at 2066. The R11 dose guidance level range of 3 mSv y^{-1} to 20 mSv in total is indicated by the grey shaded band.

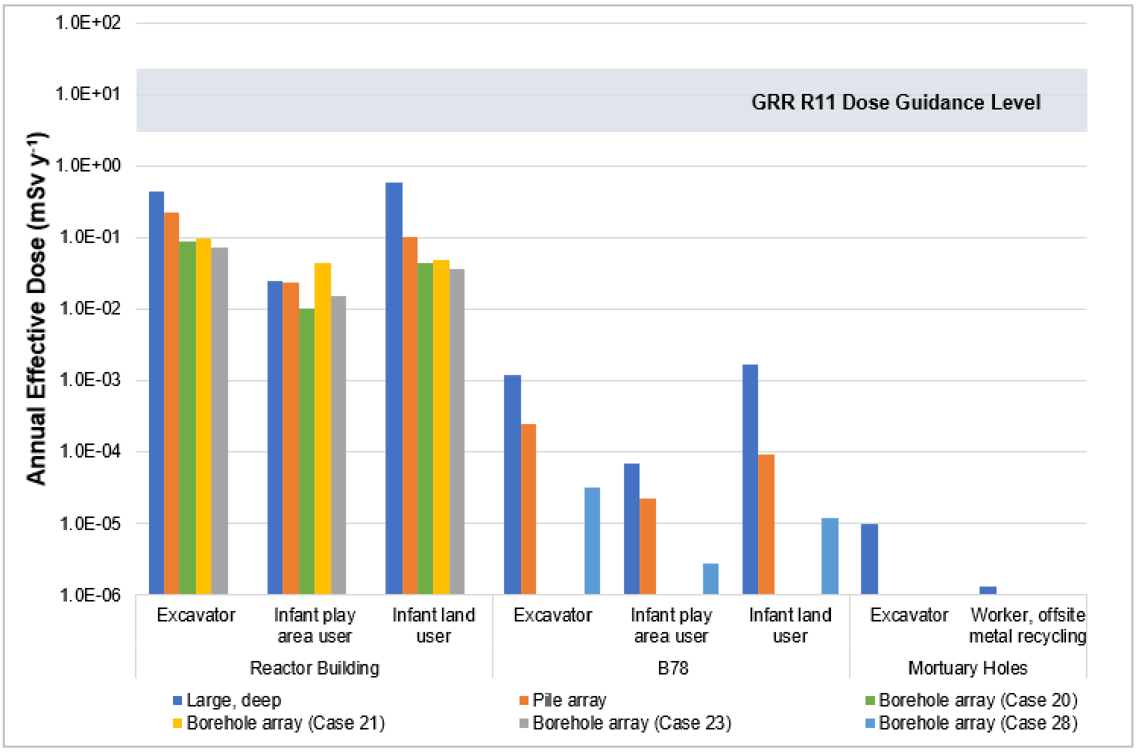

Figure 7.13: Dragon reactor complex human intrusion annual doses in 2066 for the Reference Case. The R11 dose guidance level range of 3 mSv y^{-1} to 20 mSv in total is indicated by the grey shaded band.

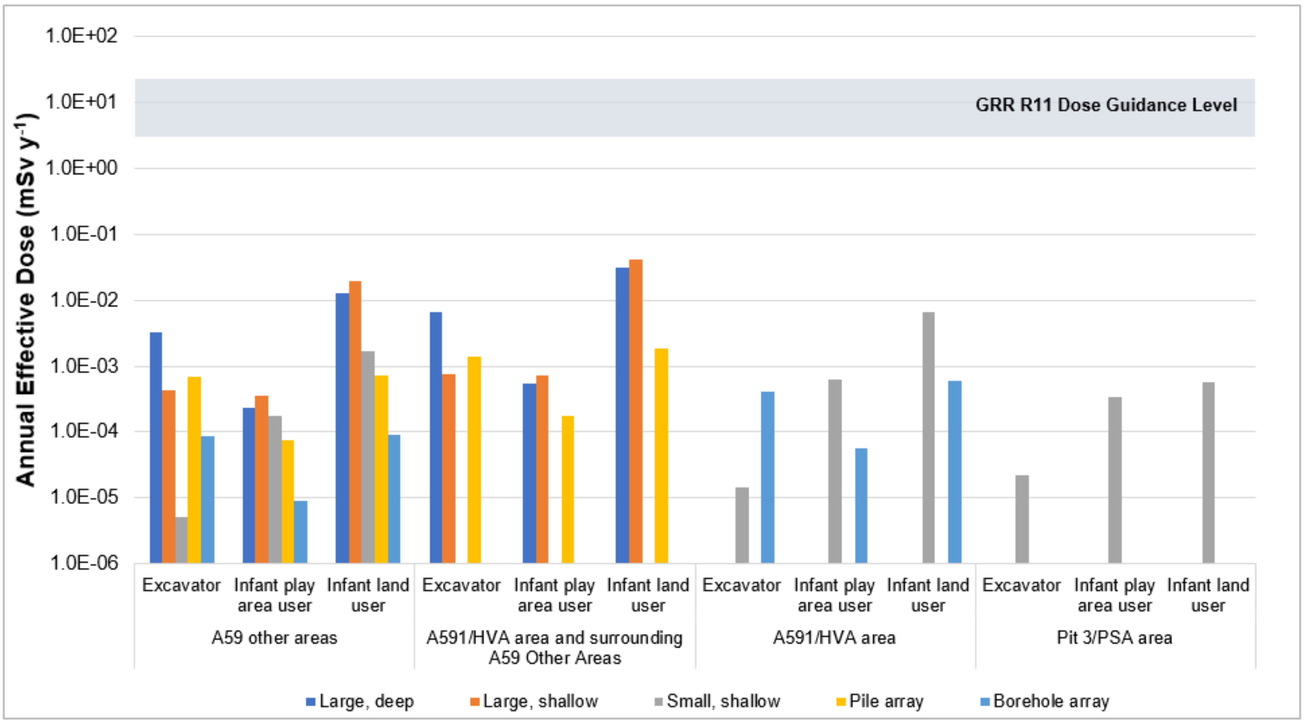

Figure 7.14: A59 area human intrusion annual doses in 2066 for the Reference Case. The R11 dose guidance level range of 3 mSv y^{-1} to 20 mSv in total is indicated by the grey shaded band.

Alternative Cases and Variant Scenarios

594 The alternative cases and variant scenario calculations undertaken consider: intrusion prior to 2066 (to inform programme optimisation); thinner cap/cover material thicknesses (to inform optimisation of the engineered caps and to consider uncertainty in the thickness of cover material above A59); and alternative inventory cases to consider the impact of uncertainty in the reference disposal inventory estimate. The key findings are as follows:

- None of the variant case calculations undertaken result in a change to the overall conclusions for SGHWR, the Dragon reactor complex or A59 area - provided that the SGHWR mortuary tube inventory estimate is excluded from the calculations, all doses are below the dose guidance level in all of the variant cases.
- Doses from borehole intrusions into SGHWR and the Dragon reactor building disposals are insensitive to cap thickness due to the assumed depth of the intrusion exceeding the combined thickness of cap and in-situ disposal for all cap thicknesses assessed. Doses from large, deep intrusions, boreholes and piles into the B78 building floor slab are insensitive to cap thickness for the same reason.
- Doses from large, deep intrusions, piles and boreholes into A59 are insensitive to the thickness of cover material due to the depth of these intrusions exceeding the combined thickness of the cover material and the A59 feature for all thicknesses assessed.

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

Potential Exposure to Radioactive Articles

596 The GRR states that *"assessments should also take into account radioactive articles that people might encounter as a result of inadvertent human intrusion"* [6, ¶A.80] and *"as a result of natural disruptive processes uncovering them."* [6, ¶A.90]

597 A radioactive article is a distinct item of waste that, by its characteristics, is recognisable as unusual or not of natural origin and could be a focus of interest. Such interest could arise out of curiosity or because of the potential for recovery and recycling/re-use of materials. Exposure to such articles at the Winfrith site would only be possible as a result of inadvertent human intrusion (i.e. as a result of excavating and/or processing/reuse of excavated material) because the extent of natural erosion needed to expose the waste would be much greater than is considered plausible.

598 Apart from structural and embedded metal in the concrete of the reactors, all other metallic items will be removed during deplanting and pre-demolition activities. Some pipework will remain embedded in concrete blocks or pieces of broken concrete that are emplaced in the below-ground void spaces. Additionally, small quantities of some other non-concrete/masonry materials may be included in the demolition rubble and be emplaced in the voids (e.g. cables) where they cannot be removed through segregation. However, these materials are not expected to be radioactively contaminated (or only very lightly contaminated, for example, by dust during demolition activities) and would represent a very small percentage of the disposals. Therefore, no radioactive articles with any significant radioactivity are expected to be left on-site and thus, additional assessments are not required.

Potential Exposure to Fuel Particles

599 The GRR does not explicitly refer to fuel particles. However, safety cases for near-surface disposal and the SWESC for on-site disposal at Trawsfynydd consider the potential impact of such particles [258, §3.2.4]. Winfrith was assessed and declared fuel free in 1995. Therefore, explicit assessments have not been carried out for Winfrith fuel particles or particulate as the presence of fuel particles within the proposed on-site disposals at Winfrith is considered very unlikely:

- Fuel from the SGHWR was stored in fuel element ponds prior to off-site transport. All fuel has been sent off-site and the ponds have been drained. A limited cleaning operation was completed using water jetting and decontamination agents prior to fixing remaining contamination using a waterproof paint. Health physics monitoring has also been carried out during the characterisation campaign. Characterisation and monitoring activities did not identify the presence of any fuel particles. There is no historic evidence of fuel element degradation during storage that would lead to fuel particles remaining in the ponds.
- The primary mortuary holes in the Dragon reactor complex were used to store fuel elements and various waste items from the PIE facility in A59. The mortuary holes have been emptied, cleaned and surveyed. No evidence of fuel particles has been found.

7.4.4 Combined Radiological Impacts

S.12 The combined dose rate from the Winfrith site after the period of RSR, when also accounting for ongoing permitted discharges from the adjacent Tradebe Inutec site and assuming exposure of the same receptors, is below the dose rate equivalent of the GRR Requirement R10 risk guidance level.

600 After the period of RSR, there would be no authorised discharges from the site but there are still expected to be multiple exposure pathways. These include exposure to releases from natural evolution of the proposed on-site disposals, direct radiation from site occupancy, inadvertent human intrusion into buried radioactivity, and direct radiation and gaseous discharges from the neighbouring Tradebe Inutec site. Table **7.13** summarises the results of dose rate assessments presented above for the different sources of radioactivity associated with the Winfrith site after release from RSR.

601 The largest potential dose is associated with inadvertent human intrusion and subsequent material spread (6.0E-01 mSv y^{-1} in 2066[36]), but as human intrusion is not considered to be part of the expected evolution of the site, such a dose is not considered in combination with other site sources. Even if intrusion were to occur, it is not likely that the same receptor would be subject to exposure from other site sources.

602 Of the remaining exposure pathways, those associated with the Tradebe Inutec site are dominant over those from the proposed disposals on the NRS Winfrith site. The date at which operations on the Tradebe Inutec site will end is unknown; as the site is expected to continue operating in the long-term it is conservatively assumed in this SWESC that it continues to operate indefinitely.

603 In considering the potential for additive doses to the same receptor, the differences in the Reference Case RP scenario assumptions should be considered:

- The Smallholder (Land/Mire) RP aqueous release pathway assumes year-round residency on contaminated land west of Monterey roundabout extending to the eastern end of the proposed mire, and ingestion of foodstuffs grown in and raised on that land.
- The Caravan Dweller RP direct radiation/site occupancy pathway assumes year-round residency in a static caravan above the disposals (with the maximum dose associated with living directly above the A591/HVA area).
- The Tradebe Inutec site dog walker RP direct radiation pathway assumes a regular dog walker along the perimeter fence closest to the facility.
- The dose equivalent to the Tradebe Inutec gaseous discharge has been estimated using the EA generic DPUR rates for a local resident family living 100 m from the source and growing food on land contaminated by gaseous deposition 500 m away [241, p.19].

604 Clearly, the same receptor cannot live 100% of their time in each of three places and walk a dog in a fourth location. There could be some overlap between these areas on the NRS Winfrith site, but there are more than 500 m between the Monterey roundabout and the A59 area, and over 300 m between A59 and the Tradebe Inutec site. However, addition of these four calculated potential doses would be bounding of a combination of these activities and locations throughout the year; the resulting dose rate is 2.4E-03 mSv y^{-1}, which is lower than the dose rate equivalent of the RGL applicable after the period of RSR (1.7E-02 mSv y^{-1}).

605 The above assumes that gaseous releases and direct radiation from the Tradebe Inutec site in the future remain comparable to those made in 2023. For example, if the receptor were exposed to the entire annual permitted gaseous discharge from the Tradebe Inutec site (equivalent to a dose rate of 2.1E-02 mSv y^{-1} using the same DPUR approach as in Paragraph 556), this alone would exceed the dose rate equivalent of the RGL. However, no

[36] This assumes that the SGHWR mortuary tubes are cleaned such that the maximum dose is associated with intrusion into the Dragon reactor building disposal.

account is taken of the probability of the same RP receiving each of these exposures, nor that the peak dose would occur at the same time, and this would substantially reduce the risk.

606 Furthermore, after release of the NRS Winfrith site from RSR, the permitted operator of the Tradebe Inutec site would be required to ensure that its discharges, when combined with legacy releases from Winfrith, meet regulatory requirements. Any future variations to the Tradebe Inutec permit would also need to take account of the disposals on the neighbouring site.

Table 7.13: Summary of calculated dose rates from different sources on the Winfrith site after the period of RSR.

Source	Pathway	Dose rate (mSv y^{-1})	Discussion
Tradebe Inutec site	Direct radiation	1.0E-03	Assessed direct radiation dose rate from RIFE (Paragraph 557).
	Gaseous discharge	1.0E-03	Dose rate to the local resident family calculated using the worst case DPUR value and Tradebe's 2023 gaseous discharge (see Paragraph 556).
Proposed on-site disposals after release from RSR	Natural evolution	3.0E-04	Peak dose rate to the Smallholder (Land/Mire) RP after the period of RSR for the Reference Case (Table 7.12).
	Direct radiation	1.0E-04	Maximum annual calculated dose rate to a site occupier after the period of RSR for the Reference Case – the Caravan Dweller RP located over the A591/HVA area (Paragraph 585).
	Human intrusion	6.0E-01	Maximum annual calculated dose rate from inadvertent human intrusion into the Dragon reactor complex disposal for the Reference Case (assuming exclusion of the SGHWR mortuary tube residual inventory) (Paragraph 592).

7.5 Significance of the Calculated Radiological Impacts

S.13 Environmental monitoring demonstrates that the impact of current radiological releases from the site on the local population and the environment are low, particularly when compared to naturally-occurring background radiation. The long-term radiological risk assessment demonstrates that the impacts from natural evolution of the proposed on-site disposals will not appreciably increase dose rates above background levels of radioactivity in the environment.

7.5.1 Comparison to Background

607 Everyday doses from background radiation are considerably higher than the regulatory guidance levels that are applied to demonstrating the safety of the proposed site end state. The average dose from naturally-occurring radiation within the UK is around 2.6 mSv y^{-1}. The main sources of radiation giving rise to everyday doses are illustrated in Figure 7.15 [243]. In some parts of the UK, these doses are higher owing to localised higher concentrations of radionuclides in rocks and soil and increased emissions of radon. For example, the average dose from naturally occurring radiation in Cornwall is around 7.3 mSv y^{-1} [243, Fig.12]. The average dose from naturally-occurring radiation in Dorset is just below 2 mSv y^{-1}, a little lower than the UK average [243, Fig.12]. Similarly, the arithmetic average concentration of naturally-

occurring radon gas in homes in the electoral ward of Wool near Winfrith is only 18 Bq m^{-3}, compared to a UK average of 101 Bq m^{-3} [244].

608 Figure 7.15 shows that the post-RSR dose equivalent of the risk guidance level is roughly equivalent to one hundredth of the UK average background radiation dose (~0.02 mSv y^{-1} compared to 2.6 mSv y^{-1}). Therefore, the calculated potential doses associated with the proposed on-site disposals, which are below the regulatory guidance level, are not significant compared to average doses from everyday sources of radiation. Thus, the proposed Winfrith end state will not appreciably increase background concentrations of radioactivity in the environment.

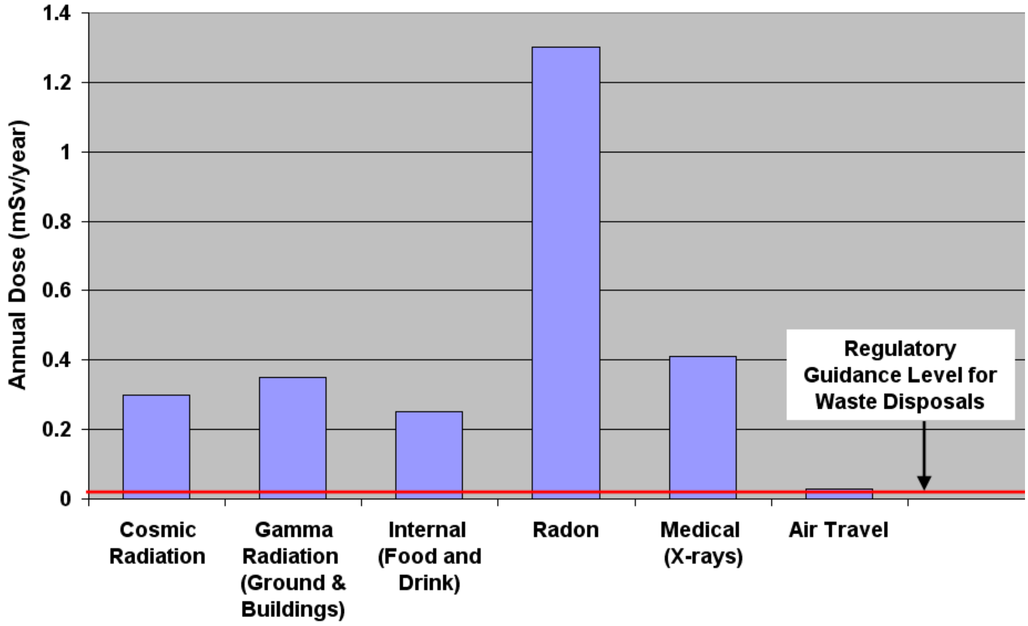

Figure 7.15 Average annual doses from natural and everyday (e.g. medical and air travel) sources of radiation in the UK [243]. The regulatory dose guidance level of ~0.02 mSv y^{-1} is calculated from the GRR risk guidance level assuming a probability of exposure of one**.**

609 Table 7.14 compares the calculated peak activity concentrations in the natural evolution model for each radionuclide over all times to Winfrith natural background concentrations in soil and groundwater. The calculated concentrations are typically orders of magnitude lower than the site background levels in both soil and water. Even when conservatively calculating the total gross alpha and beta concentrations the calculated radiological impacts from the proposed disposals are substantially lower than those already present.

Table 7.14: Comparison of calculated peak activity concentrations, per radionuclide, in soil and water in the natural evolution model compartments with natural background concentrations in soil and groundwater at Winfrith (Table **5.3** and Table **5.5**). The gross alpha and beta values are conservatively calculated by summing the peak concentrations for all relevant radionuclides irrespective of whether the time of peak dose is coincident.

Nuclide	Peak Soil Concentration ($Bq\ g^{-1}$)		Peak Water Concentration ($Bq\ l^{-1}$)		Winfrith Background	
	Field	Mire	River	Mire	Soil ($Bq\ g^{-1}$)	Groundwater ($Bq\ l^{-1}$)
H-3	2.55E-07	1.91E-05	1.35E-03	1.91E-01	1.70E-02	5.92
C-14	2.04E-08	4.14E-06	3.13E-06	2.49E-04	4.00E-03	
Cs-137	2.65E-12	1.57E-08	9.66E-11	1.31E-08	1.30E-03	
Th-232	2.27E-12	1.00E-12	4.86E-12	5.28E-13	1.00E-02	
U-235	7.51E-08	2.98E-05	1.01E-06	1.49E-04	6.00E-04	
U-238	3.64E-07	3.19E-04	1.01E-05	1.59E-03	1.26E-02	
Pu-238	2.04E-10	4.39E-07	4.63E-09	5.94E-07	3.00E-05	
Pu-239	2.87E-08	2.15E-05	2.26E-07	2.90E-05	4.70E-04	
Pu-240	3.05E-08	2.32E-05	2.44E-07	3.13E-05		
Gross Alpha	1.12E-06	8.65E-04	2.30E-05	3.58E-03	1.22E-01	1.12E-01
Gross Beta	9.83E-07	7.58E-04	1.38E-03	1.96E-01	1.23E-01	1.54E-01

7.5.2 Comparison to Present-day Discharges

610 For NRS Winfrith annual retrospective dose assessments between 2019 and 2023, the total dose from all exposure pathways was between 8 and 54 $\mu Sv\ y^{-1}$, with direct radiation accounting for the majority of the dose in all but one year and the remainder from permitted radioactive discharges [234; 235; 236; 237; 238; 239].

611 The potential radiological impacts of the proposed on-site disposals are less than those associated with present-day activities. Doses from natural evolution peak at less than 1 $\mu Sv\ y^{-1}$ for the Smallholder RP in the Land/Mire compartment in the Reference Case thousands of years in the future (Figure 7.6) and doses from direct radiation (site occupancy) are less than 0.1 $\mu Sv\ y^{-1}$ for the caravan dweller above the remediated A59 area at the SRS (Section 7.4.2).

7.5.3 Continued Safety Beyond the Quantitative Assessment Timeframe

612 The quantitative radiological risk assessments have been run to beyond the time of peak impact. Doses arising from site occupancy and human intrusion activities are expected to fall over time and therefore are highest at the IEP (for transient site occupancy activities) or the SRS (for all other activities). Doses have been calculated at these times, and at earlier times to inform further optimisation and decision-making. In addition, where GRR Requirement R11 dose guidance levels are exceeded at the SRS in the Reference Case, doses have been calculated at times beyond 2066 to identify when the calculated dose falls below the dose guidance level. Therefore, doses and impacts beyond the timescales of quantitative assessment will not exceed those presented in this Chapter.

7.6 Requirement for a Transboundary Assessment

S.14 The calculated dose rates for the proposed on-site disposals are significantly below the threshold criteria at or above which a transboundary assessment is required. Additionally, no 'exceptional pathways' for transboundary exposures have been identified. Therefore, a transboundary assessment is not required. No transboundary impacts are expected.

613 An assessment of doses to members of the public in other countries is only required if certain radiological criteria (relating to doses to local RPs), as set out in EA guidance to form RSR-C5 [99], are met. These criteria are addressed in the following sub-sections.

614 Note that no exceptional pathways of exposure to EU Member States and/or Norway (e.g. involving the export of foodstuffs) either during or after the period of regulation have been identified for the Winfrith site.

7.6.1 During the Period of RSR

615 A transboundary assessment is required if the effective dose from the proposed on-site disposal to a local RP during the period of RSR is greater than or equal to 10 µSv y^{-1}, equivalent to 0.01 mSv y^{-1}.

616 Table 7.10 shows that the highest dose rate in the Reference Case assessment for natural evolution during the period of RSR, considering the credible RPs, is to the Smallholder RP in the off-site Field compartment, peaking at around 3.6E-06 mSv y^{-1} (0.004 µSv y^{-1}) at the assumed SRS date. This peak dose rate is three orders of magnitude below the dose rate criterion at which a transboundary assessment is required (10 µSv y^{-1}).

617 No alternative assessment cases or variant (including "what-if") scenarios result in dose rates that exceed 10 µSv y^{-1} during the period of RSR.

7.6.2 After the Period of RSR

618 A transboundary assessment is required if the assessed radiological risk from the proposed on-site disposal to a local RP after release from RSR is greater than or equal to 6E-05 per year.

619 Table 7.12 and Figure 7.6 show that the highest dose rate in the Reference Case assessment for natural evolution after the period of RSR is to the Smallholder RP in the Land/Mire compartment, peaking at around 3.0E-04 mSv y^{-1} in around 56,800 years. This peak dose rate is several orders of magnitude below the dose rate equivalent (1 mSv y^{-1}) of the radiological risk criterion (6E-05 per year) at which a transboundary assessment is required.

620 No alternative assessment cases or variant (including "what-if") scenarios result in dose rates that exceed 1 mSv y^{-1} after the period of RSR.

7.6.3 Expected Transboundary Impacts

621 Although, as demonstrated above, a transboundary assessment is not legally required, the potential transboundary impacts of the proposed disposals have nevertheless been considered as part of a thorough approach to demonstrating the overall safety of the site end state.

622 Transboundary impacts under normal conditions are more likely if gaseous releases are expected. For the proposed Winfrith disposals, the potential for the release of tritium, ^{14}C and radon gas was considered [23, App C.2.3] (see Paragraph 478). It was concluded that no

gaseous exposure pathways exist that could lead to significant doses to local RPs. Therefore, no transboundary impacts from gaseous releases are expected.

623 Aqueous releases via groundwater are the only other mechanism by which the proposed disposals could result in transboundary impacts under normal conditions. However, since the Winfrith site is located a significant distance from its nearest foreign settlement (approximately 110 km to the north-west tip of the Cotentin peninsula in France) across the English Channel, and all other foreign settlements are separated from the site by a larger expanse of sea, there is no likelihood of transboundary impacts from aqueous releases under normal conditions.

624 Transboundary impacts may also occur as a result of accidental (unplanned) releases. An aircraft crash into the SGHWR disposals, generating contaminated dust which is aerially transferred off-site, is taken to be a worst-case reference accident in terms of releases with potential transboundary impacts. The radiological consequences of an aircraft crash into the SGHWR in its current state have been calculated as part of the decommissioning safety case. In this assessment, the public risk was calculated to be 1.56E-12 per year [245, §4.1.20.6], which is many orders of magnitude below the Basic Safety Objective of 1E-06 per year for risk from all activities on-site [246, §4.4.4]. Since this assessment is bounding of any later stage of decommissioning (when the SGHWR inventory will be lower), including the end state (when it will be entirely underground), and any transboundary impacts would be greatly attenuated owing to the large distances involved, it can be confidently stated that transboundary impacts as a result of accidental releases from the proposed disposals are not expected.

7.7 Consideration of Criticality Safety

S.15 The radiological inventory for the proposed on-site disposals has been reviewed to consider the potential for nuclear criticality. Only ^{235}U is present at more than the theoretical minimum critical mass under ideal conditions for criticality. However, criticality is not credible at the IEP when considering the distribution of ^{235}U across the disposals. In the long term no drivers for preferential accumulation of uranium at sufficient concentration for criticality have been identified and criticality is, therefore, not judged to be credible.

625 Radionuclides that can undergo fission are known as fissionable nuclides. Fissionable nuclides that can undergo fission when they interact with low energy, slow moving neutrons (thermal neutrons) are said to be fissile. For such nuclides, when the neutron energy is reduced, the chance of fission increases and the mass of the fissile nuclide required for nuclear criticality (a self-sustaining nuclear chain reaction) is reduced. Water, because of its hydrogen content, is an efficient neutron moderator. The most likely means by which criticality could occur would be if a sufficient mass of fissile nuclides was able to accumulate at a single location in the presence of water. Should criticality occur, it could give a fatal radiation dose to anyone in close proximity, add fission products to the inventory, modify the actinide inventory, and affect the configuration and performance of the disposals. Drawing on the underpinning assessment [247], this section discusses the potential for critical masses of fissile nuclides to occur both now and in the future.

7.7.1 Fissionable Inventory

626 The only fissionable nuclide expected to be present with a mass greater than the theoretical minimum critical mass (MCM) under ideal conditions for criticality, for both the reference and alternative inventories, is ^{235}U (the MCM is 0.8 kg at 100 wt%). The reference inventory estimates about 5.5 kg across the entire site at an average ^{235}U enrichment of 3.4 wt%, rising to 53.5 kg and 8.3 wt% for the alternative inventory [247, §2.1]. This inventory is primarily

associated with SGHWR. Both the Dragon reactor complex and the A59 area inventories are insufficient for criticality and are not considered further.

627 The SGHWR ^{235}U inventory is distributed across the feature, but the most significant amounts are associated with the bioshield and backfill, which are the only components to contain more than the MCM for the reference inventory. The bioshield contains an estimated 2.9 kg of ^{235}U in the reference inventory estimate and 43.1 kg of ^{235}U in the alternative inventory estimate. These inventories would be distributed across the bioshield structure. As no other uranium isotopes were included in the analytical suite for the two cores from which bioshield characterisation data were derived, there is no sensible estimate of the enrichment. The SGHWR used slightly enriched fuel, with enrichments of 3.5 wt%, 4.5 wt% and 5.5 wt% reported [248]; enrichment values above this are not expected in the facility.

628 Uranium-235 of artificial origin could only be present in the bioshield concrete if the concrete had been in direct contact with fuel, for example as a result of breakage or cladding failure, of which there are no records. Even if such events had occurred, artificial ^{235}U could only be present as surface contamination in the uppermost layer of the concrete. The majority of the ^{235}U in the bioshield concrete inventory estimate is in the activated concrete volume rather than the surface contamination component, and it is not credible that this could be of artificial origin. There is also significant ^{235}U in the paint layer. If ^{238}U had been included in the analytical suite, it would likely have been shown to be present in significant quantities throughout the bioshield concrete and paint, potentially demonstrating a natural origin for much of the accompanying ^{235}U as well as giving a realistic, much lower enrichment value.

629 A spherical optimally-moderated ^{235}U accumulation in a cementitious grout of 30% porosity is calculated to require over 100 kg at 3 wt% and 10 kg at 10 wt% for criticality [247, §3.4.1]. Critical masses increase as porosity decreases, so for the concrete assumed in the PA (15% porosity for undegraded concrete and 26% for degraded concrete [23, Tab.D.19]), the minimum mass would be higher still. Comparison of the reference and alternative masses of ^{235}U calculated to be present in the bioshield (and indeed all SGHWR components) are therefore unlikely to be sufficient for criticality even if it was all co-located in an ideal spherical geometry.

630 In addition, the nature of the Winfrith inventory, which is in the form of contamination across multiple parts of the building structure, means that it is highly unlikely that the entire fissile inventory would be present in a single location, especially in the form of an optimally moderated and reflected sphere. The potential for distributed concentrations of fissile material to result in criticality can be determined by considering the lowest concentration for which an infinite mass could be critical (i.e. the infinite sea concentration). The infinite sea concentration for ^{235}U at 100 wt% is 12.2 kg m^{-3} in water [249, Tab.2], decreasing to around 9 kg m^{-3} in saturated grout [249, Tab.15] and around 2 kg m^{-3} in soil [250, Tab.C-1 and C-2]. The ^{235}U concentration in the bioshield is 9.3E-03 kg m^{-3} for the reference inventory (1.4E-01 kg m^{-3} for the alternative inventory) and much lower in the backfill, which is substantially below that required for criticality. Therefore, it is not considered credible that criticality could occur in the SGHWR in its end state configuration.

7.7.2 Potential for Post-disposal Criticality

631 The section above considers the potential for criticality at the present day and the IEP, when material is distributed across large disposal volumes. However, there is also a need to consider the potential for accumulation of fissile material over long timescales after the IEP.

632 As the concrete structures in the disposals degrade in the long term, radionuclides will be leached and transported from the disposals, with the rate of migration influenced by solubility and sorption behaviour. From the point where radionuclides enter the groundwater,

radionuclides will migrate through the Poole Formation to the point of groundwater emergence [23, §5.3.1]. As fissile nuclides move away from the disposals, the risk of criticality as a result of accumulation of dissolved fissile material will become less likely. In particular, as water carrying dissolved fissile radionuclides moves away from the disposal location, it may interact with other groundwater flows; mixing of such flows will result in dilution and lower fissile concentrations. If direct mixing does not occur, diffusion and dispersion along the radionuclide transport path will anyway act to reduce the fissile nuclide concentration, albeit more slowly.

633 For cementitious conditions, such as in the concrete structures and backfill forming the disposals, highly alkaline local conditions will result. Sorption of fissile radionuclides will be higher in the near field than in the acidic heathlands, and radionuclide solubility is likely to be lower in the near field. Therefore, outside of the cementitious environment of the disposals, the migration of fissile materials is expected to be quicker and the likelihood of accumulation lower.

634 Once fissile material reaches the River Frome, it will be significantly diluted and accumulation could no longer occur. There is potential for some accumulation in intermediate locations along the flow paths (such as the mire); however, the results from the radiological risk assessment indicate low uranium concentrations in the Field and Land/Mire compartments and no reason for preferential accumulation of uranium in a small volume has been identified.

635 Based on the above analysis, it is judged that criticality after the IEP is not credible because:

- The total masses of all of the fissile isotopes, except ^{235}U, are less than the minimum required for criticality under the most pessimistic conditions conceivable. Only for SGHWR is the total ^{235}U mass larger than that required for criticality under idealised conditions.
- Fissile material will be widely distributed throughout the disposals, primarily in the form of dilute surface contamination, and will be present in unfavourable geometries for criticality.
- Fissile isotopes will be mixed with much larger quantities of neutron absorbers and diluents that will further limit the potential for criticality (primarily concrete and some steel).
- In the long term, any credible accumulation or concentration of ^{235}U will not be sufficient to result in criticality.

7.8 Radiological Impacts to Non-human Organisms

S.16 The calculated radiological impacts to non-human organisms associated with the proposed on-site disposals are below the relevant dose rate screening criteria for all modelled terrestrial and freshwater organisms. Therefore, non-human organisms will be adequately protected both during and after release of the site from RSR.

636 GRR Requirement R14 requires that operators 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"* [6, ¶A4.97], and that specifically *"discharges and migration of radionuclides on or from a decommissioned site might have a detrimental effect on the environment"* [6, ¶A4.98]. Therefore, an assessment of non-human organisms has been conducted in relation to natural evolution of the proposed on-site disposals [23].

637 Consistent with the suggested approach in the GRR [6, ¶A4.100], assessments of potential dose to non-human organisms have been made using the ERICA assessment tool (Version

2.0). The ERICA assessment tool applies a three-tiered approach to calculating dose rates: Tier 1: Risk Screening, Tier 2: Generic Quantitative and Tier 3: Detailed Quantitative.

638 A Tier 1 assessment, aimed at high-level screening, applies simplified but conservative assumptions, aiming to identify areas or receptors of negligible concern or where there may be a requirement for further assessment. Tiers 2 and 3 allow more user-defined options (including the addition of isotopes to the default list) and the use of site-specific data, where available. Dose rates are calculated for a series of generic organisms defined as representative for assessing the impacts of radiation within terrestrial and freshwater ecosystems. Further details on the methodology employed, and how it interlinks with the natural evolution assessment model, are presented in the radiological risk assessment [23].

639 A Tier 2 assessment[37] was run against the most conservative default ERICA dose rate screening criterion of 10 µGy h^{-1}, with the full suite of ERICA reference organisms for the appropriate ecosystem, for three separate biosphere compartments: Field, Land/Mire and River Frome. This screening criterion is sufficiently conservative to assume that no adverse effects are expected in non-human populations below this. The GRR [6] notes that this value is also used by the UK environment agencies for the initial assessment of doses from sites in designated conservation areas.

640 The Land/Mire was modelled both as a terrestrial ecosystem and as a freshwater ecosystem (representing the possible dry and wet states of the proposed mire) to bound the expected impacts. Several other conservatisms were built into the assessment, including the assumption that (in the absence of detailed ecological data) sensitive ecological receptors would be exposed to the maximum environmental media concentrations.

641 For the majority of organisms the largest contribution to dose is from ^{226}Ra. In the Field compartment the main contributions are also associated with ^{14}C, ^{234}U, ^{238}U, ^{210}Pb and ^{227}Ac. For the Land/Mire and River compartments contributions are also associated with ^{90}Sr, ^{234}U, ^{241}Am and ^{227}Ac.

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

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

[37] To ensure that the calculated dose rates sufficiently reflect the inventory, assessments have been carried out at Tier 2 to enable additional radionuclides to be added.

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

7.9 Impacts from Non-radiological Hazards

S.17 Tier 1 and 2 assessments of the non-radiological risks associated with the on-site disposals demonstrate an acceptable risk for many substances. A more detailed Tier 3 assessment for the remaining substances found that the risks posed to groundwater and its associated receptors are acceptable. This demonstrates that the proposed SGHWR and Dragon reactor complex end states provide a standard of protection against non-radiological hazards that is consistent with that provided by national standards.

7.9.1 Assessment of Risks to Controlled Waters from the Proposed SGHWR and Dragon Reactor Complex Disposals

645 The Winfrith non-radiological risk assessment (HRA) [24] presents a tiered hydrogeological risk assessment of the proposed SGHWR and Dragon reactor complex end states, based on the non-radiological inventories for the proposed disposals and the conceptual site model. The HRA assesses the risk from the non-radioactive waste used as backfill, the non-radioactive structural elements (defined as land in-situ) and the non-radioactive properties of the radioactive wastes, both in-situ and used for the purpose of backfilling voids.

Tier 1 Assessment

646 Tier 1 qualitative risk screening was carried out on all components of the end states of the SGHWR and Dragon reactor complex. Table 7.15 presents the contaminants from components of the end state where potential releases were identified as acceptable and therefore these need no further risk assessment.

Table 7.15: Contaminants for which no further risk assessment is required along with a summary of the screening justification.

Contaminant	Screening justification
Contaminants bound within concrete in reinforced concrete structures, concrete blocks and the Dragon reactor mortuary hole structure, with the exception of the hydroxide ion (that can generate high pH in water) leached from concrete blocks	• Concrete structures are not known as commonly having detrimental effect on groundwater quality. • The solid phase concentration in concrete of some contaminants is lower than that found naturally in soils at the Winfrith site. • Leachable concentrations of all inorganic substances in samples of concrete from SGHWR are less than the limits for acceptance at an inert landfill site. • There is no persuasive evidence in groundwater monitoring data that the SGHWR structure has affected groundwater quality.
Contaminants bound within structural steel and rebar in concrete structures and blocks	• Discharge from the rebar in concrete structures and blocks is expected to have non-discernible concentrations of hazardous substances. • Non-hazardous pollutants are expected to be well within the relevant environmental standards.

Contaminant	Screening justification
Contaminants bound within paint	• The mass of residual paint is low and only a small fraction is water available. • Discharge of water that has contacted paint will have acceptably low concentrations of hazardous substances. • Concentrations of non-hazardous pollutants are within the relevant environmental standards or are equivalent to natural background levels in groundwater.
Contaminants bound within fibreglass	• Potential contaminants bound within the fibreglass have sufficiently low mobility that there is no pollutant linkage to groundwater [196].
The following hydrocarbon fractions in oil staining of structures: >C8-C10 aromatic compounds (including benzene, toluene, ethylbenzene and xylene), >C16-C21, >C21-C35 and >C35-C44 aliphatic compounds and all 16 analysed polycyclic aromatic hydrocarbon species	• The inventory of >C8-10 aromatic fraction is significantly less than 1 g. Even if the entire mass were instantaneously available to water the dilution afforded by the volume of water accumulated in Regions 1 and 2 will result in acceptably low concentrations. • >C16-C21, >C21-C35 and >C35-C44 aliphatic compounds have low toxicity and low solubility and mobility in water. • The concentrations of polycyclic aromatic hydrocarbons are lower than acceptance criteria for an inert landfill.
Arsenic and mercury in demolition arisings	• Concentrations in concrete are judged to be at or below the background concentrations in soils.
Constituents of emplaced non-waste materials that will be used to implement the end state of the Dragon reactor mortuary holes as well as to prepare the structures for the disposals/deposits	• Materials will be selected on the basis that they are non-polluting.

647 Further details on the specific justifications supporting these screening decisions are presented in Section 2.1 to 2.9 of the HRA [24].

Tier 2 Assessment

648 In a Tier 2 GQRA, porewater concentrations of contaminants in the demolition arisings were calculated and compared with compliance criteria selected from water quality standards that are set at levels sufficient to protect groundwater and surface water[38]. The calculated porewater concentration of the following contaminants was lower than the selected compliance criteria: antimony, barium, cadmium, chloride, fluoride, molybdenum, nickel, selenium and sulphate. The GQRA demonstrated that there are no unacceptable inputs to groundwater from these contaminants and therefore these need no further risk assessment. The Tier 2 GQRA was insufficient to demonstrate an acceptable risk from alkalinity and several inorganic and organic contaminants as summarised in Table 7.16.

[38] Compliance limits and compliance points (the point along the groundwater flow pathway where the defined compliance limit must not be exceeded) are set on a case-by-case basis as part of the HRA and may be different for hazardous substances and non-hazardous pollutants [24, §3]. At Winfrith, the default values are surface water environmental quality standards, but these have been "sense-checked" against a range of other standards and a judgement made for each contaminant [24, Tab.611/6].

649 Further details supporting the Tier 2 assessment outcomes are presented in Sections 4.1 to 4.3 of the HRA [24].

Table 7.16: Summary of contaminants requiring DQRA [24, Tab.611/10].

Component in the SGHWR and Dragon reactor complexes	Contaminants
Concrete blocks	Alkalinity (pH)
Demolition arisings	Alkalinity (pH)
	Chromium (as Cr(III) and Cr(IV)), copper, lead and zinc
	PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153 and PCB-180
Oil-stained concrete (SGHWR Regions 1 and 2 only)	TPH-CWG[39] >C10-C12, >C12-C16 and >C16-C21 aromatic fractions

Tier 3 Assessment

650 Modelling of the reference scenario demonstrated that the risk for all modelled contaminants is acceptable [24, §6.1].

651 Concentrations in groundwater of all modelled contaminants in both the SGHWR and Dragon reactor complex end states are well below compliance criteria [24, Tab.611/14 and 611/15], despite the conservative assumptions made. Table 7.17 shows the contaminants and features for which the peak concentrations were closest to their compliance limits and the times of their peaks.

Table 7.17: Contaminants for which the peak concentrations in the Tier 3 DQRA were closest to their compliance limits for the three different types of contaminants modelled. The table shows the ratio of the compliance limit to its modelled concentration and so is a measure of safety – a value less than one would be non-compliant. Summarised from [24, Tab.611/14 and 611/15].

Type	Contaminant	Feature	Compliance limit / Peak concentration	Time of peak after the IEP (y)
Metals	Chromium (VI)	SGHWR	2.8	1218
TPH	C10-C12 Aromatics	SGHWR	163	764
PCB[40]	PCB-101	Dragon	11.3	1251

652 The PHAST modelling results demonstrate that the maximum pH in groundwater is lower than the compliance criterion, despite the conservative assumptions made (Section 7.11.3).

653 An assessment of cumulative effects was also undertaken as groundwater flow modelling has shown that, under some circumstances, groundwater flows from the SGHWR to beneath the

[39] Total Petroleum Hydrocarbon Criteria Working Group.

[40] The PCBs are associated with paint adhered to the concrete demolition arisings.

Dragon reactor complex. The Tier 3 assessment concluded that cumulative impacts will not cause an unacceptable risk to groundwater [24].

654 The model results of the variant and alternative scenarios summarised in Table 7.7 and Table 7.8, and the additional scenarios addressing parameter uncertainties, demonstrated that risks are acceptable for all modelled contaminants, thereby providing confidence that the outcomes of the reference scenario are robust [24, §6.2].

655 Based on the three tiers of risk assessment it is concluded that the non-radiological hydrogeological risk from the envisaged SGHWR and Dragon reactor complex end states to controlled waters is acceptable.

7.9.2 Assessment of Risks to People from the Proposed SGHWR and Dragon Reactor Complex Disposals

656 Risks to people from potentially hazardous material within the on-site disposals could arise via contaminant migration in water or via direct contact with the hazardous material:

- Selection of appropriate criteria in the non-radiological risk assessment, as described in Section 7.2.2, provides assurance that people will be protected from migration of contaminants in water. Calculated concentrations in groundwater are below compliance levels and therefore pose limited risk to people (Section 7.9.1).
- As described in Section 5.1.3, engineered caps, incorporating a layer to hinder human intrusion, will be placed over the below-ground disposals of radioactive waste and deposits of recovered non-radioactive waste and will hinder direct contact of people with contaminated material.

657 The Town and Country Planning Act 1990 requires assessment of risks to human health via an Environmental Impact Assessment (EIA). The EIA has identified no unacceptable impacts on human health from the proposed SGHWR and Dragon reactor complex disposals.

7.9.3 Risks to People and the Environment from Other Non-radiological Hazards

658 As decommissioning of the Winfrith site continues, future activities will be planned such that the risks to people and the environment posed by non-radiological hazards are consistent with the requirements of national standards. This includes ensuring all land quality issues are managed suitable to the risk, in accordance with national frameworks.

659 Non-radiological land and groundwater quality issues are assessed and managed through the zone close-out process (Section 5.3.2) and current groundwater monitoring programme. The process for assessing non-radiological hazards is set out in the final site survey protocol [251]. Where contamination of land or groundwater is identified, a conceptual site model and remediation options appraisal (equivalent to a BAT assessment) will be undertaken to determine the appropriate management approach in accordance with relevant EA guidance.

7.10 Protection of Groundwater and Surface Waters

S.18	The proposed on-site disposals will not pose an unacceptable risk to the quality of groundwater and surface waters. (i) Direct discharges of pollutants into groundwater are avoided for the anticipated life of the permit for those parts of the structures that are in contact with groundwater (currently SGHWR Regions 1 and 2). The remaining parts of the disposals are above the current and modelled future typical maximum upper water level during the anticipated life of the permit. (ii) The risk assessments demonstrate that the risks to groundwater and surface water associated with indirect inputs of radiological and non-radiological hazardous substances and non-hazardous pollutants to groundwater are acceptable.

7.10.1 Avoiding Direct Discharges to Groundwater

660 Paragraph 20(2)(j) of the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017 (WER 2017) places a *"prohibition of direct discharges of pollutants into groundwater"* and goes on to explain:

> *"direct discharges of pollutants into groundwater" means the discharge of pollutants into groundwater without percolation through the soil or subsoil".*

661 EA guidance [95, p.32] explains:

> *"In an assessment of an application for a radioactive waste disposal, we would consider that a direct input occurs if the pollutant is introduced at any location below the typical maximum upper level of the saturated layer of an unconfined aquifer. "Typical" in this context would employ a representative winter water table level, based on hydrogeological records and/or expert opinion, and discounting extremes in weather, or artificial suppression by engineering techniques such as pumping.*
>
> *Environment Agency internal guidance states that an input (discharge) is direct if:*
>
> - *the discharge goes into an open, artificial structure like a shaft, borehole or well that extends down to or into the water table*
> - *the discharge uses a natural feature like a swallow hole with rapid flow to the water table – meaning a travel time of minutes"*

662 The North and South Annexes of the SGHWR and all of the Dragon reactor complex are above the current and modelled future typical maximum upper groundwater level for the anticipated life of the permit. Any discharges from waste placed in these structures will be to the unsaturated zone and thereby indirect.

663 For disposals that are not entirely above the typical maximum upper level of the saturated layer the EA guidance [95, p.36] explains how operators should base their case for compliance with the prohibition on direct discharges. One approach is:

> - *"a natural in-situ or engineered attenuation layer, or an in-situ structure surrounding the waste (or both), set between the emplaced waste and the groundwater that have been shown by a groundwater risk assessment to 'prevent and limit' inputs of pollutants to groundwater."*

664 The guidance also requires supporting arguments are made to show that the engineering provides an appropriate degree of protection from a direct discharge on the basis of its:

- *"thickness;*

- *permeability;*
- *absence of penetrations providing direct pathways to groundwater;*
- *behaviour during aging and degradation;*
- *structural integrity under loading; and*
- *other properties that contribute to the attenuation of pollutants migrating through it.”*

665 The EA’s guidance [95, p.36] limits the duration for which demonstration of compliance with the ‘prohibition’ condition is required to the anticipated life of the environmental permit:

> *“The assessment of whether a direct discharge is likely to occur should consider the anticipated life of the permit, as far into the future as is reasonably practicable.”*

666 The Design Substantiation Report [25] defines boundary structures that have a role in avoiding direct discharges of pollutants into groundwater. It describes the dimensions and configuration of the boundary structures and provides evidence for their current integrity and how they will react through the demolition and backfilling process. The Design Substantiation Report and supporting assessments demonstrate that the structural integrity of the below-ground structures of the SGHWR and Dragon reactor is generally very good because they were built to be robust and water-tight for safety and environmental protection purposes. Nevertheless, the report sets out means to repair and/or appropriately seal defects and deliberate penetrations of the boundary structures. It summarises assessments of the continued integrity of the boundary structures as the above-ground structures are demolished and the below-ground basements are infilled and covered with an engineered cap.

667 The CQAP [128] explains how implementation of the end states of the SGHWR and Dragon reactor complex will be carried out in a manner that is consistent with the above claims. Amongst other things it describes:

- Appropriate controls before structures are demolished and demolition arisings are placed in the below-ground basements. This includes CQA controls on enhancing the environmental protection function of the below-cutline structures and controls on pre-demolition planning.
- CQA of in-process characterisation and backfilling, and in-process engineering verification.
- CQA in construction of the caps.

7.10.2 Prevent and Limit

668 EPR16 implements the ‘prevent and limit’ requirements of the GWDD. Paragraph 6 of Schedule 22 of EPR16 explains for groundwater activities that:

> *“For the purposes of implementing the Water Framework Directive and the Groundwater Directive, the regulator must, in exercising its relevant functions, take all necessary measures -*
>
> *a) to prevent the input of any hazardous substances to groundwater, and*
>
> *b) to limit the input of non-hazardous pollutants to groundwater so as to ensure that such inputs do not cause pollution of groundwater.”*

669 The results of the non-radiological risk assessment [24] (as summarised in Section 7.9) and radiological risk assessment [23] (as summarised in Sections 7.3 and 7.4) demonstrate that

inputs to groundwater (and surface water) of radiological and non-radiological hazardous substances and non-hazardous pollutants are acceptable.

7.11 Confidence in the Assessments

S.19 The SWESC and supporting documents have been developed by suitably qualified and experienced personnel using expert judgement, sound science and engineering. The modelling and analysis used industry best practice, structured methodologies, made appropriately conservative assumptions, and has systematically considered uncertainty. Computer models and data have been verified. The SWESC and key supporting assessments have been reviewed by internal and external experts.

670 Further confidence in the Winfrith radiological and non-radiological risk assessments is provided by a variety of means, including:

- application of sound science;
- adoption of formal methodologies requiring structured consideration of uncertainty;
- adoption of cautious modelling assumptions where necessary to address uncertainty;
- comparison of alternative assessment cases, variant scenarios and uncertainty treatment approaches against other similar assessments;
- verification of computer models and data; and
- peer review and regulatory review.

671 Each of these means of assurance is discussed further below.

7.11.1 Application of Sound Science

672 The application of sound science has been achieved through production of the SWESC itself and its supporting documents, many of which have been checked through internal and external peer review. Internationally experienced consultants have been used to undertake and review the Winfrith end state assessments. These contractors have worked on many national and international waste management programmes, and have reviewed international literature to identify the most relevant and robust methodologies, data, software and models on which to base the assessments. For example, this includes:

- use of IAEA guidance for best practice in the approach to performance assessment [57; 58];
- use of IAEA and ICRP internationally-agreed data compilations, as well as those made available by the EA and other UK government organisations; and
- use of the latest available climate change information within assessments.

673 The approaches taken to the assessments therefore represent a consolidation of “held in common” expert judgement across many relevant projects.

674 Through work by contractors for other programmes, including other NRS sites, the Dounreay LLW Disposal Facilities and LLWR, the Winfrith end state team maintains an awareness of scientific developments in in-situ disposal, wider LLW management and risk assessment, both within and outside the UK. Knowledge of such developments feeds into the Winfrith assessments and optimisation analyses, including review of past decisions, and planning for future iterations.

7.11.2 Formal Methodologies and Treatment of Uncertainty

675 In accordance with the application of sound science, the Winfrith assessments have been based on a formal development process that conforms to internationally accepted methodologies and means that all necessary aspects of the assessment are considered.

676 The formalised methodology requires a structured approach to scenario development and treatment of uncertainty. In the end state risk assessments all relevant safety- and configuration-related uncertainties have been systematically considered [23, App.C; 24, §5.2 and §5.3]. Where such uncertainties are not addressed through cautious parameterisation or modelling, and it cannot be argued that they are unlikely to negatively influence performance or are bounded by another uncertainty, they are addressed through alternative assessment cases and variant (including "what-if") scenarios.

677 These additional cases and scenarios have been used to test the boundaries and robustness of the case. The analyses show that, even allowing for unexpectedly poor performance of different features of the proposed disposals, the Winfrith end state will provide a level of safety consistent with the regulatory radiological protection guidance [6] and non-radiological equivalents. None of the uncertainties threaten the claims and arguments presented in this SWESC. The uncertainties management methodology (UMM, [123]) will continue to be applied to ensure that uncertainties are tracked, reduced where possible, and that reduced uncertainties are reflected in future updated assessments.

7.11.3 Conservatism

678 Appropriate conservatisms have been built into the Reference Case assessments of radiological and non-radiological risks, ensuring that the results are credible but cautious. Key conservatisms include [23, Tab.4.1; 24, §5.2]:

- Radiological risk assessment (all models):
  - The reference inventory is a cautious but credible estimate of the activity expected to remain on site at the IEP.
  - High-rate values for RP habits (e.g. site occupancy times and amount of foodstuffs ingested) are cautiously assumed, based on local survey area data.
  - In dose calculations, all scenarios are assumed to occur (probability of one), which is conservative for some RPs.
- Radiological risk assessment (natural evolution model):
  - Thin contaminated layers are conservatively assumed for in-situ structures and concrete blocks, resulting in shorter timescales required for contaminant diffusion.
  - Radionuclides associated with rubble are cautiously assumed to be instantaneously available for release from the source material to porewater.
  - No credit is taken for any part of the end state structures inhibiting flow other than the thick reinforced SGHWR Region 1 and 2 boundary structures and the Dragon floor slab.
  - Transport pathways are assumed to be cautiously narrow, and at the shorter end of credible distance ranges.
  - All groundwater is cautiously assumed to emerge at a single location to a surface water feature or area of land.

- No credit is taken for attenuation of radionuclides in the unsaturated zone.

- Radiological risk assessment (site occupancy and human intrusion models):
  - No radionuclides are assumed to migrate from the disposals, so the maximum (decayed) inventory always contributes to dose; this assumption is increasingly conservative over time.
- Non-radiological risk assessment (HRA):
  - Instantaneous release of hydrocarbon compounds and PCB congeners into water is cautiously assumed.
  - Selection of cautious values for coefficients of contaminant partition with demolition arisings and the Poole Formation.
  - Cautious assessment of the inventory mass of hydrocarbon compounds.
  - Use of pessimistic degradation rates for PCB congeners in the Poole Formation and no account is taken of volatilisation of PCB congeners.
  - Dilution of contaminants in groundwater by infiltrating rainfall downgradient of the reactor basements is ignored.
  - Leaching of alkalinity from solid material and source depletion is cautiously discounted; water in demolition arisings is conservatively assumed to be permanently saturated with portlandite.
  - No credit is taken for the significantly lower leachability of concrete blocks (all demolition arisings are assumed to be broken concrete in the models).
  - Vertical dispersion in both the GoldSim and PHAST models, and additionally transverse dispersion in the GoldSim model, is conservatively discounted.
  - No credit is taken for attenuation of contaminants in the unsaturated zone.

679 It is likely that more realistic modelling would result in lower calculated impacts compared to those presented in this SWESC. The results presented in the SWESC demonstrate compliance with the regulatory requirements and guidance.

7.11.4 Comparison Against Similar Assessments

680 The final step in the methodology followed to develop the set of alternative assessment cases and variant scenarios in the radiological risk assessment[41] [23, Fig.4.1] was the review of scenarios against similar assessments and an appropriate FEP (features, events and processes) list for higher-risk disposal sites. This allows the identification and rectification of any gaps. A review was carried out against:

- Assessment cases considered in the environmental safety cases of existing UK near-surface disposal facilities [252; 253].
- The Dounreay Low-Level Waste (LLW) FEP List [254, App.1]. Whilst this list was developed specifically for the Dounreay LLW Disposal Facilities, it outlines all the FEPs

[41] A systematic review was only conducted for the natural evolution assessment. An equivalent process is not deemed necessary to report at this stage for the human intrusion and site occupancy radiological assessments, since these are more straight-forward and the software used to implement them is much more constrained than for the natural evolution assessment. Nevertheless, previous similar assessments have been reviewed and used to inform the approach taken for Winfrith.

presented in the Nuclear Energy Agency (NEA) International FEP List[42] [255] and the IAEA Improvement of Safety Assessment Methodologies (ISAM) FEP List [256].

681 These reviews demonstrated the comprehensiveness of the scenarios and assessment cases identified and did not result in any additional cases.

7.11.5 Use of Computer Models and Data

682 Consistent with the use of sound science, the assessments have used internationally or nationally recognised computer software. GoldSim, used for the natural evolution radiological assessment and the non-radiological assessment, is a modelling tool that has been used elsewhere to conduct assessments of radioactive waste disposal facilities in the UK (e.g. the LLWR, Dounreay LLW Disposal Facilities and the NDA geological disposal facility for higher activity radioactive wastes), the US (Yucca Mountain), Spain (ENRESA), France (ANDRA) and Japan (NUMO). Therefore, GoldSim-RT has been used for the Winfrith natural evolution assessment with a high degree of assurance that it is fit for purpose. The use of GoldSim in the HRA follows its routine use in the nuclear industry for HRA, and to support non-radiological EA projects, such as the validation of LandSim v2.5 [229] and development of waste acceptance criteria for landfill. PHAST and PHREEQC, as used to model alkalinity in the HRA, are routinely used in the nuclear industry for similar assessments.

683 The commercially available MicroShield® program and NRS's Generic Intrusion Methodology (GIM) tool were used for radiological site occupancy and human intrusion assessments respectively. These tools are well-established and have been used in similar assessments (e.g. [258]).

684 All software used is subject to ongoing quality assurance by its developers. In addition, where computational routines have been developed specifically for the Winfrith calculations, independent internal verification exercises have been undertaken as part of the project. Independent internal verification of all input data and model-supporting spreadsheets has also been undertaken. Model and data verification activities for the radiological risk assessment are summarised in Section 10 of the PA report [23].

685 Throughout the process of developing the assessments, subject-matter experts have been consulted and involved to ensure that the data used and assessment cases considered align with current understanding of decommissioning activities and optimisation plans, and that assumptions and inferences made are credible.

686 Overall, these verification exercises provide confidence that the assessment computer models accurately implement the appropriate mathematical models described in the CSM [19], PA [23] and HRA [24] documentation, and that input data is correct and appropriate.

7.11.6 Peer Review and Regulatory Review

687 The development of the risk assessments has built upon a multi-year programme of work initiated as part of a "lead and learn" exercise trialling the Draft GRR (the 2016 consultation document) and continued following formal issue of the GRR in 2018. This has included gaining

[42] Note that the NEA International FEP list has since been updated; the latest issue, Version 3, was published in 2019 [257]. However, it is noted in Version 3 that near-surface disposal is beyond the scope of the list [257,§1.2], which is not the case for Version 1 [255, Tab.3].

feedback on the programme of work from those in the environment agencies who have been tasked with developing and planning the implementation of the GRR.

688 As required by the GRR, NRS has used "*independent peer review to build confidence in their WMP and SWESC*" [6, ¶2.3.14]. Given their significance, the following documents have been peer reviewed using specialist independent contractors: this SWESC, the CSM [19], the radiological PA [23] and the HRA [24]. Details on the reviewers, the feedback gathered and changes made are recorded in peer review close-out documents (e.g. the review of this SWESC is recorded [259]).

8 Forward Programme

689 Forward programme activities have been identified throughout this SWESC. These activities will be undertaken to ensure that the agreed Winfrith site end state and next planned land use of heathland with public access is delivered, and the site can be released from RSR, through a process which protects the health and interests of people and the integrity of the environment.

690 Future activities will also be influenced by dialogue with regulators and stakeholders, and following identification of new information. The work needs to be phased with regard to the completion of other activities, such as decommissioning, and tied in with the development of future issues of this SWESC and implementation of the site end state.

691 The identified forward programme activities are listed below in the order they were first raised in this report. However, note that the order is not intended to reflect any perceived relative importance. In addition, many of the identified forward programme activities are rolling actions, in the sense that they relate to activities and assessments that have already been successfully undertaken and only an awareness of developments that may impact the previous work needs to be maintained. Equally, some activities will always be ongoing, such as engagement with regulators and other stakeholders, and items that are already requirements of the management system. Other activities, such as incorporating new characterisation data and investigating recent SGHWR water ingress, will be undertaken in the near term.

FP.1 Maintain a WMP and SWESC for the lifetime of the Winfrith site RSR permit.

692 Both the WMP [8; 16] and SWESC will be maintained as an ongoing activity until the site is released from RSR. As discussed in Section 3.4.11, updates of the WMP and SWESC will be produced as necessary to support implementation and permitting of the end state. The documents will be updated at significant milestones, at routine intervals and when an application is made to the EA to revoke the RSR permit. It is recognised that updates to these documents and their underpinning assessments will be necessary as decommissioning and site end state implementation proceeds, work to address uncertainties is completed, and detailed optimisation and design is undertaken. NRS has also specified a 10-year minimum review period [9].

FP.2 Establish implementation and delivery plans for control of the works to demolish the reactors and safely implement the on-site disposals in line with NRS management system requirements and quality controls.

693 There is an overarching process to appropriately control works including managing exposure risks to the public and ensure that contractor processes are acceptable and compatible with those at Winfrith. In the near-term specific arrangements will be put in place to control works to demolish the reactors and implement on-site disposal safely, in accord with the requirements in the CQAP and CEMP, ensuring that the structural integrity of the in-situ structures is retained. These arrangements will include application of the EAC and management of the site through the Stewardship Plan.

FP.3 Data storage arrangements beyond the IEP to be developed in accordance with regulatory and local authority requirements, as well as good practice in the nuclear industry.

694 Current record-keeping arrangements for cataloguing, storing and accessing records at Winfrith up to the site's IEP will continue. The arrangements beyond the IEP up to the SRS have yet to be agreed with the NDA; however, the location for records beyond the IEP will not be on site.

FP.4 Revise the EAC following determination of the RSR and DfR permit applications to be consistent with the issued permits.

695 Physical, chemical, radiological and biological EAC have been developed for the disposal on the Winfrith site of radioactive waste and deposit of recovered non-radioactive waste. The EAC will be revised following determination of the RSR and DfR permit applications to be consistent with any conditions included in the permits.

FP.5 Establish the management procedures necessary for site stewardship, including detailed monitoring, analysis and communications plans.

696 The Site Stewardship plan will be revised as the end state is implemented and management arrangements put in place to take effect from the IEP. This will include development and agreement of the monitoring plan with the EA, and the associated analysis and reporting plans, as well as regulatory and stakeholder communication plans for the stewardship period.

FP.6 Continue dialogue with the EA regarding determination of the permit application, implementation of the end state, and management of the environmental permits, SWESC and WMP.

697 A key requirement to achieving the end state is ongoing dialogue with the EA over regulatory expectations and approaches to key issues. Regular meetings with the EA have been held and further meetings are envisaged as needed to discuss technical issues as they arise.

FP.7 Continue dialogue with the other regulatory bodies regarding other necessary permissions and site restoration.

698 As discussed in Section 4.1.2, NRS will continue to engage with other regulatory bodies. This includes the MMO in relation to removal of the marine section of the Sea Discharge Pipeline, and ongoing discussions with Dorset Council and Natural England regarding development of the site for its next planned use and planning consent.

FP.8 Continue to engage with members of the local community and other stakeholders throughout the remaining permit period.

699 A non-technical summary of the proposed Winfrith end state application to support dialogue with stakeholders has been developed and will be updated as necessary. Engagement with communities and stakeholders will continue during the remaining permit period.

FP.9 Investigate recent (2024) SGHWR water ingress and identify appropriate and optimised remediation options where this could become a direct discharge to groundwater.

700 In 2024, increased water ingress into the SGHWR basement has been observed. The reasons for this and the routes that the ingress takes are currently being investigated. Whilst this might be a sporadic occurrence, if the water ingress is due to increased groundwater levels, then understanding of the structural integrity will be important. Some structural repairs are expected to curtail the current water ingress. The optimised approach will be used to implement appropriate repairs.

FP.10 Ensure that the detailed design of the proposed on-site disposals is optimised, is consistent with the SWESC and underpinning assessments, and is in accordance with the functional requirements.

701 Detailed designs for the proposed on-site disposals will be developed following determination of the permit application and will account for the permit conditions, information gained from the ongoing characterisation activities and optimisation assessments. If required, the radiological and non-radiological risk assessments will be updated to reflect changes in the design.

FP.11 Undertake strategic characterisation to support demonstration of compliance with the EAC and to improve understanding of the radiological and non-radiological hazards and reduce associated uncertainties.

702 Strategic radiological and non-radiological characterisation will be undertaken to support demonstration of compliance with the EAC and to improve understanding of the radiological and non-radiological hazards and reduce associated uncertainties (Section 5.4.1). The SIMP defines the characterisation needs through the remainder of the decommissioning lifecycle. Future characterisation will be directly based on the uncertainties already identified in the radiological and non-radiological inventories. It will be undertaken in a manner proportionate to the risk and uncertainty, and will apply relevant industry best practice (e.g. using the DQO methodology).

FP.12 Undertake optimisation assessments to support decisions about decommissioning of site features as new information is identified and to refine the design and implementation of the site end state.

703 Optimisation assessments will continue to be undertaken and reviewed to support decisions about future decommissioning of the site (GRR Requirement R1) as well as optimisation of on-site disposal (GRR Requirement R13). Indeed, the current end state proposals are at a conceptual stage and will be optimised during detailed design. Currently known aspects that will be subject to further optimisation include the design of the engineered cap, how the voids will be backfilled, and site surface water management. Further optimisation assessments will be summarised in future issues of the SWESC.

9 Summary

704 Safety (that is, protection of workers, people and the environment from hazards) is central to all processes and activities contributing to the Winfrith end state. This SWESC demonstrates that the Winfrith site, including the proposed on-site disposals, meets the regulatory requirements for protection of people and the environment from radiological and non-radiological hazards during the period of RSR and beyond.

705 Figure 9.1 presents the five claims made and underpinned in this SWESC and maps how they correspond to the GRR principles and requirements (repeated from the GRR [6, Fig.2]).

706 Table 9.1 sets out the claims and arguments for delivery of a safe, optimised end state that have been presented throughout this document.

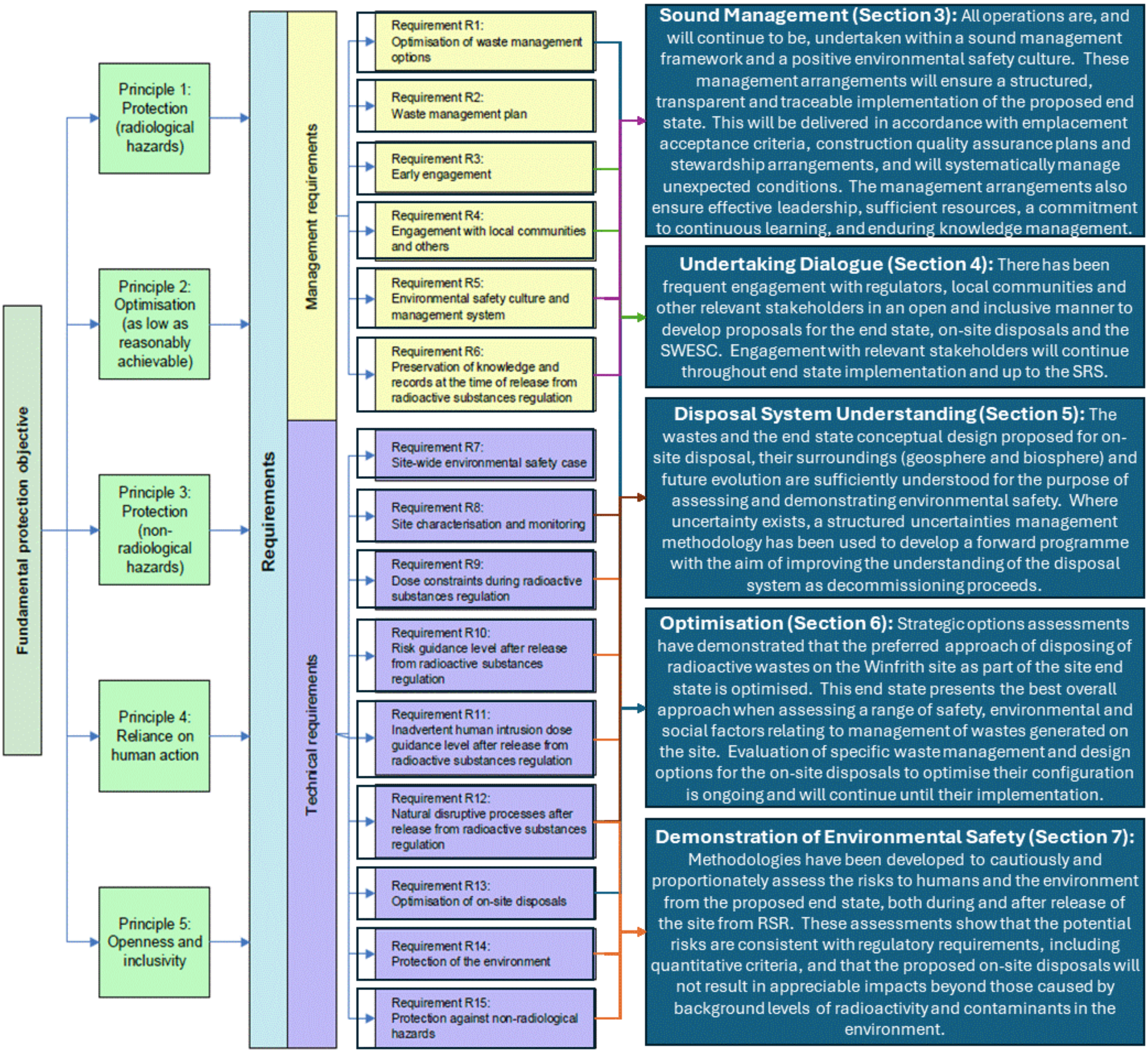

Figure 9.1: SWESC claims (right-hand side) and their corresponding GRR principles and requirements (left-hand side; repeated from the GRR [6, Fig.2]). Note that Requirement R7 is not linked to any claims as the provision of this document itself, which encompasses all claims, is considered to fulfil this requirement, and Requirement R2 is not linked to any claim as the WMP is a separate Tier 1 document.

Table 9.1: Claims and arguments made in this SWESC. The left-hand column gives the heading of the SWESC section presenting each argument and the associated evidence, while the right-hand column identifies the relevant GRR Requirement(s).

Claim and arguments		Related GRR Requirements
Claim: Sound Management (Chapter 3): All operations are, and will continue to be, undertaken within a sound management framework and a positive environmental safety culture. These management arrangements will ensure a structured, transparent and traceable implementation of the proposed end state. This will be delivered in accordance with emplacement acceptance criteria, construction quality assurance plans and stewardship arrangements, and will systematically manage unexpected conditions. The management arrangements also ensure effective leadership, sufficient resources, a commitment to continuous learning, and enduring knowledge management.		
Regulatory Framework (Section 3.2)	M.1: There is an established framework of international and national principles, regulation and guidance that is integrated into the NRS management system. This ensures that the proposed on-site disposals will be implemented in a manner that protects the health and interests of people and the integrity of the environment, both during the period of regulation and afterwards.	Requirement R5
Approach to Ensuring Environmental Safety (Section 3.3)	M.2: There is a clear strategy for demonstrating compliance with the principles and regulatory requirements of radioactive waste management, key to which is the principle that safety is central to all processes and activities.	Requirement R5
Management System (Section 3.4)	M.3: All operations are, and will continue to be, undertaken within a sound management framework, including work contributing to this SWESC.	Requirement R5
Environmental Safety Culture (Section 3.4.2)	M.4: NRS is committed to high standards of environmental safety and quality, as formalised in the Winfrith Site Manual and the overarching Environment, Health, Safety, Security and Quality (EHSS&Q) management system. As a result, there is a positive environmental safety culture at Winfrith.	Requirement R5
Planning and Control of Work (Section 3.4.3)	M.5: There is an overarching process to appropriately control works and ensure that contractor processes are acceptable and compatible with those at Winfrith. Specific arrangements will be put in place to control works to demolish the reactors and implement on-site disposal safely.	Requirement R5

Claim and arguments		Related GRR Requirements
Integration of the SWESC and Other Site Activities (Section 3.4.4)	M.6: The programme of work for decommissioning at Winfrith is being carried out according to an ordered plan. The plan for defining and delivering the end state is integrated into the site decommissioning plan. The consistency of the SWESC (and supporting assessments) is validated through routine interfaces and ensuring ownership of documents by appropriate technical and project authorities.	Requirement R5
Knowledge Management and Record-keeping (Section 3.4.5)	M.7: There are procedures to ensure effective knowledge management now and for the future. This includes managing information assets to ensure that the information recorded is fit for purpose, available to the appropriate information users, and is backed-up and archived appropriately. Records are kept in a form suitable for long-term preservation and access.	Requirement R6
Uncertainty Management (Section 3.4.6)	M.8: An uncertainties management methodology ensures that uncertainties in the knowledge base, decision-making and assessments are taken into account. The uncertainty management system is used to assess and monitor uncertainties, and to steer future work to address and better understand key uncertainties to support future decisions.	Requirement R5
Quality Management (Section 3.4.7)	M.9: Deliverables are produced within audited and accredited quality management systems and NRS has systems and tools in place to monitor the quality of deliverables. The quality system includes: (i) working arrangements for production, review and ownership of documents, data and models; (ii) processes to ensure use of suitably qualified and experienced personnel; (iii) a graded approach to quality assurance, with independent assessment and peer review; (iv) staged design development; (v) implementation quality assurance plans; and (vi) verification and validation monitoring arrangements.	Requirement R5
Environmental Impacts During End State Implementation (Section 3.4.8)	M.10: All operations required to implement end state plans will be appropriately managed, controlled and monitored to minimise the environmental impacts in accordance with management system requirements. Appropriate systems will be put in place to minimise and control secondary waste generation, dust during cutting and demolition, water management for dust suppression and cutting, and noise and transport impacts on the local community.	Requirement R5
Application of Emplacement Acceptance Criteria (Section 3.4.9)	M.11: In the context of environmental safety of waste disposals, use of systematically derived acceptance criteria will ensure that disposals are undertaken in conformity with the SWESC. Physical, chemical, radiological and biological emplacement acceptance criteria (EAC) have been developed for the proposed on-site disposal of radioactive waste and deposit of recovered non-radioactive waste.	Requirement R5

Claim and arguments		Related GRR Requirements
Site Stewardship (Section 3.4.10)	M.12: Management control arrangements (termed stewardship arrangements) for the site have been developed to ensure effective assessment and monitoring of the site for the period between completion of active decommissioning and reaching the SRS. The arrangements control how the site will be maintained and the monitoring that will build confidence that the disposals behave as anticipated in this SWESC.	Requirement R5
Development and Maintenance of the SWESC (Section 3.4.11)	M.13: Company management arrangements have been established to ensure that the SWESC and associated WMP are reviewed and updated on a regular basis, and that a clear audit trail is maintained.	Requirement R7
Claim: Undertaking Dialogue (Chapter 4): There has been frequent engagement with regulators, local communities and other relevant stakeholders in an open and inclusive manner to develop proposals for the end state, on-site disposals and the SWESC. Engagement with relevant stakeholders will continue throughout end state implementation and up to the SRS.		
Interaction with the Regulators (Section 4.1)	U.1: Relevant regulators have been engaged throughout the development of proposals for the site end state and on-site disposals since 2016 and will continue to be engaged as appropriate until the SRS is achieved. In addition to the EA, this includes engagement with other regulators and authorities whose responsibilities cover some aspects of the environmental impacts of decommissioning the site and on-site disposal, including the Office for Nuclear Regulation (ONR), Dorset Council and its planning authority, Natural England and the Marine Management Organisation (MMO).	Requirement R3
Interaction with Local Communities and Stakeholders (Section 4.2)	U.2: A high priority has been attached to stakeholder engagement and the views of the site's stakeholders are sought and taken into account when developing the decommissioning and restoration plans for the site. Engagement with local communities and stakeholder groups in an open and inclusive manner is a key priority.	Requirement R4
Claim: Disposal System Understanding (Chapter 5): The wastes and the end state conceptual design proposed for on-site disposal, their surroundings (geosphere and biosphere) and future evolution are sufficiently understood for the purpose of assessing and demonstrating environmental safety. Where uncertainty exists, a structured uncertainties management methodology has been used to develop a forward programme with the aim of improving the understanding of the disposal system as decommissioning proceeds.		

Claim and arguments		Related GRR Requirements
Understanding of the Features for On-site Disposal (Section 5.1)	D.1: The Winfrith site features proposed for on-site disposal are sufficiently well understood in terms of their operational history, engineering, geometry/extent and material properties. This has allowed relevant components (for inventory derivation and modelling of potential impacts) to be identified, and material volume calculations to be undertaken. Conceptual designs for the disposals have been developed consistent with the current system understanding and optimisation assessments undertaken to date, and by considering reasonably engineered and safely implementable options.	Requirement R8
Understanding of the Site at the Present Day (Section 5.3.1)	D.2: A detailed description of the current characteristics of the site and the local surrounding region has been developed to support both the demonstration of environmental safety and optimisation. Development of this understanding has involved desk studies, site investigations and detailed quantitative modelling.	Requirement R8
Site Monitoring and Land Quality Management (Section 5.3.2)	D.3: Routine environmental monitoring is undertaken to improve understanding of the environmental conditions in and around the site and will be used to monitor the on-site disposals until the SRS. Results from the existing environmental monitoring programmes provide a baseline against which changes associated with the local hydrology, hydrogeology and radioactive and non-radioactive contamination can be assessed.	Requirement R8
Evolution due to Interim End State Implementation (Section 5.3.3)	D.4: A passive water management approach will be implemented in the end state that minimises flood risk to neighbours and maximises the potential to generate a sustainable wet-heathland habitat. Assessment of the potential impact of implementing the end state on the site hydrogeology shows non-significant changes in the average site groundwater level and no change in groundwater flow direction.	Requirement R8
Future Evolution of the Site and Surrounding Region (Section 5.3.4)	D.5: The potential impact of climate change on site groundwater has been assessed using UK Climate Projection data. International understanding of the long-term changes in climate have informed the radiological and non-radiological risk assessments, and the iterative development of the landscape design.	Requirement R8
Inventory Management and Ongoing Characterisation (Section 5.4.1)	D.6: Strategic characterisation approaches have been developed to support demonstration of compliance with the emplacement acceptance criteria (EAC) and to improve understanding of the radiological and non-radiological hazards and reduce associated uncertainties. The Staged Inventory Management Plan (SIMP) defines the characterisation needs through the remainder of the decommissioning lifecycle. Characterisation activities are planned and implemented in a manner proportionate to the risk and uncertainty, and apply relevant industry best practice such as the data quality objective (DQO) methodology.	Requirement R8

Claim and arguments		Related GRR Requirements
Material Masses and Volumes (Section 5.4.2)	D.7: A detailed description of the voids and material proposed to be emplaced in the below-ground SGHWR and Dragon building structures has been developed. These values, together with related assumptions about material densities and bulking/compaction factors, are used consistently to assess potential impacts from the proposed disposals.	Requirement R8
Radiological Inventory (Section 5.4.3)	D.8: A detailed and cautious but credible description of the nature, magnitude and distribution of the radiological inventory for the proposed disposals has been developed to support both the demonstration of environmental safety and optimisation.	Requirement R8
Non-radiological Inventory (Section 5.4.4)	D.9: A detailed description of the nature and magnitude of non-radiological materials expected to remain as part of the proposed on-site disposals has been developed to support both the demonstration of environmental safety and holistic optimisation. The inventory of the proposed on-site disposals includes: i) non-radiological, non-hazardous materials; ii) non-radiological hazards associated with, or potentially interacting with, radioactive waste; and iii) non-radiological hazards not associated with radioactive waste.	Requirement R8
Claim: Optimisation (Chapter 6): Strategic options assessments have demonstrated that the preferred approach of disposing of radioactive wastes on the Winfrith site as part of the site end state is optimised. This end state presents the best overall approach when assessing a range of safety, environmental and social factors relating to management of wastes generated on the site. Evaluation of specific waste management and design options for the on-site disposals to optimise their configuration is ongoing and will continue until their implementation.		
Optimisation Process (Section 6.1)	O.1: NRS procedures are used to ensure that Best Available Technique (BAT) and optimisation assessments are undertaken consistently and with sufficient scope to ensure that radiological risks are as low as reasonably achievable (ALARA), and that the assessments are appropriately documented.	Requirement R5
Strategic Optimisation of Waste Management (Section 6.2)	O.2: Strategic options assessments have demonstrated that leaving some radioactive structures on site is optimal in comparison to attempting a site end state free of radioactive substances.	Requirement R1

Claim and arguments		Related GRR Requirements
Optimisation of On-site Disposals (Section 6.3)	O.3: Waste management and design options for the final configuration of the proposed disposals have been assessed. Provisionally optimised configurations for each on-site disposal have been defined by considering the relative performance of the different options against agreed attributes. These assessments considered option feasibility, effectiveness, impact on risk and feedback from stakeholder engagement.	Requirement R13
Future Optimisation Assessments (Section 6.4)	O.4: Optimisation assessments will continue to be undertaken and reviewed to support decisions about future decommissioning of the site (GRR Requirement R1) as well as optimisation of the proposed on-site disposals (GRR Requirement R13).	Requirement R13
Claim: Demonstration of Environmental Safety (Chapter 7): Methodologies have been developed to cautiously and proportionately assess the risks to humans and the environment from the proposed end state, both during and after release of the site from RSR. These assessments show that the potential risks are consistent with regulatory requirements, including quantitative criteria, and that the proposed on-site disposals will not result in appreciable impacts beyond those caused by background levels of radioactivity and contaminants in the environment.		
Qualitative Understanding: Safety Functions and Strength in Depth (Section 7.1)	S.1: A qualitative understanding of the future evolution of the proposed on-site disposals has been established. This understanding provides the basis for quantitative modelling to assess radiological and non-radiological risks and define mitigation measures, where required. The environmental safety functions associated with the disposals, geosphere and biosphere provide multiple independent benefits to overall environmental safety. This provides reassurance that even if one environmental safety function is not realised in accordance with expectations, others will ensure that environmental safety is not compromised.	N/A
Quantitative Models (Section 7.2)	S.2: To provide quantitative understanding of the key processes and potential impacts of the proposed on-site disposals, models have been developed to assess the different ‘pathways’ by which contaminants might be released, migrate and enter the accessible biosphere. This includes assessing the expected evolution of the proposed disposals and the site, as well as potential alternative scenarios. Modelling also considered key uncertainties to determine their impact. Assessment results are compared from each pathway to take account of the timing and location of potential impacts, and hence whether an individual could be exposed via multiple pathways.	Requirement R9, Requirement R10, Requirement R11, Requirement R12

Claim and arguments		**Related GRR Requirements**
Radiological Impacts During the Period of RSR (Section 7.3)	S.3: Radiological safety during the period of RSR is and will be managed, and impacts controlled and monitored, such that doses to members of the public are ALARA. The sum of cautiously estimated annual effective doses via all pathways and from all sources is less than the applicable regulatory dose constraint. *Current Radiological Impacts (Section 7.3.1)* S.4: Releases are managed to comply with the current environmental permit aqueous and gaseous discharge limits and monitoring activities demonstrate radiological impacts are well below the GRR Requirement R9 dose constraint in relation to these discharges. *Radiological Impacts from Reactor Building Demolition and End State Implementation (Section 7.3.2)* S.5: Releases during works to demolish the reactor buildings and implement the end state will be managed to ensure that radiological impacts are ALARA. *Radiological Impacts of the On-site Disposals (Section 7.3.3)* S.6: The natural evolution and site occupancy assessment models consider the radiological impacts from releases to groundwater from the on-site disposals and direct radiation. In the period between implementing each on-site disposal and reaching the SRS the calculated annual effective dose for all relevant receptors is significantly less than the GRR Requirement R9 source-related dose constraint (0.3 mSv y-1). *Combined Radiological Impacts (Section 7.3.4)* S.7: The combined dose rates from Winfrith during the period of RSR, when also accounting for the possible contribution from the adjacent Tradebe Inutec site, are calculated to be significantly below the GRR Requirement R9 site-related dose constraint (0.5 mSv y-1).	Requirement R9

Claim and arguments		Related GRR Requirements
Radiological Impacts After the Period of RSR (Section 7.4)	S.8: Radiological dose and risk to the public after the period of RSR have been assessed for all credible scenarios and pathways, including natural evolution aqueous release pathways, site occupancy and inadvertent human intrusion. The assessments focus on a broadly expected evolution of the local environment but account for uncertainties regarding the disposal system, geosphere, radionuclide release, and radionuclide migration and exposure processes. *Natural Evolution (Section 7.4.1)* S.9*:* The calculated radiological impacts from natural evolution of the proposed end state after release of the site from RSR are significantly below the GRR Requirement R10 risk guidance level (RGL) for the Reference Case. All alternative scenarios are also below the RGL except for two calculations, which result from cautious modelling approaches. Dose rates are also below the RGL in scenarios considering the unlikely “what-if” situation of impairment of protective barriers resulting from natural disruptive processes (GRR Requirement R12). *Site Occupancy (Section 7.4.2)* S.10: The calculated radiological impacts from occupancy above the proposed on-site disposals after release from RSR are at least an order of magnitude below the GRR Requirement R10 risk guidance level for the Reference Case and all but one of the alternative scenarios considered. *Inadvertent Human Intrusion (Section 7.4.3)* S.11: The calculated radiological impacts from inadvertent human intrusion into SGHWR Region 1 could potentially result in exceedances of the GRR Requirement R11 dose guidance level for the Reference Case inventory. However, this is due to the SGHWR mortuary tubes which are yet to be accessed, characterised and cleaned. Intrusions into all other proposed on-site disposals result in doses below the relevant GRR dose guidance levels for the Reference Case and all alternative scenarios. *Combined Radiological Impacts (Section 7.4.4)* S.12: The combined dose rate from the Winfrith site after the period of RSR, when also accounting for ongoing permitted discharges from the adjacent Tradebe Inutec site and assuming exposure of the same receptors, is below the dose rate equivalent of the GRR Requirement R10 risk guidance level.	Requirement R10, Requirement R11, Requirement R12

Claim and arguments		Related GRR Requirements
Significance of Calculated Radiological Impacts (Section 7.5)	S.13: Environmental monitoring demonstrates that the impact of current radiological releases from the site on the local population and the environment are low, particularly when compared to naturally-occurring background radiation. The long-term radiological risk assessment demonstrates that the impacts from natural evolution of the proposed on-site disposals will not appreciably increase dose rates above background levels of radioactivity in the environment.	Requirement R10, Requirement R11, Requirement R12
Requirement for a Transboundary Assessment (Section 7.6)	S.14: The calculated dose rates for the proposed on-site disposals are significantly below the threshold criteria at or above which a transboundary assessment is required. Additionally, no 'exceptional pathways' for transboundary exposures have been identified. Therefore, a transboundary assessment is not required. No transboundary impacts are expected.	N/A
Consideration of Criticality Safety (Section 7.7)	S.15: The radiological inventory for the proposed on-site disposals has been reviewed to consider the potential for nuclear criticality. Only ^{235U} is present at more than the theoretical minimum critical mass under ideal conditions for criticality. However, criticality is not credible at the IEP when considering the distribution of ^{235U} across the disposals. In the long term no drivers for preferential accumulation of uranium at sufficient concentration for criticality have been identified and criticality is, therefore, not judged to be credible.	Requirement R7
Radiological Impacts to Non-human Organisms (Section 7.8)	S.16: The calculated radiological impacts to non-human organisms associated with the proposed on-site disposals are below the relevant dose rate screening criteria for all modelled terrestrial and freshwater organisms.	Requirement R14
Impacts from Non-radiological Hazards (Section 7.9)	S.17: Tier 1 and 2 assessments of the non-radiological risks associated with the on-site disposals demonstrate an acceptable risk for many substances. A more detailed Tier 3 assessment for the remaining substances found that the risks posed to groundwater and its associated receptors are acceptable. This demonstrates that the proposed SGHWR and Dragon reactor complex end states provide a standard of protection against non-radiological hazards that is consistent with that provided by national standards.	Requirement R15

Claim and arguments		Related GRR Requirements
Protection of Groundwater and Surface Waters (Section 7.10)	S.18: The proposed on-site disposals will not pose an unacceptable risk to the quality of groundwater and surface waters. (i) Direct discharges of pollutants into groundwater are avoided for the anticipated life of the permit for those parts of the structures that are in contact with groundwater (currently SGHWR Regions 1 and 2). The remaining parts of the disposals are above the current and modelled future typical maximum upper water level during the anticipated life of the permit. (ii) The risk assessments demonstrate that the risks to groundwater and surface water associated with indirect inputs of radiological and non-radiological hazardous substances and non-hazardous pollutants to groundwater are acceptable.	Requirement R15
Confidence in the Assessments (Section 7.11)	S.19: The SWESC and supporting documents have been developed by suitably qualified and experienced personnel using expert judgement, sound science and engineering. The modelling and analysis used industry best practice, structured methodologies, made appropriately conservative assumptions, and has systematically considered uncertainty. Computer models and data have been verified. The SWESC and key supporting assessments have been reviewed by internal and external experts.	Requirement R15

10 References

1 The Stationery Office Limited, *The Environmental Permitting (England and Wales) Regulations 2016,* (S.I. 2016/1154), The Stationery Office Limited, December 2016.

2 The Stationery Office Limited, *The Environmental Permitting (England and Wales) (Amendment) Regulations 2018*, (S.I. 2018/110), The Stationery Office Limited, January 2018.

3 The Stationery Office Limited, *The Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018*, (S.I. 2018/428), The Stationery Office Limited, March 2018.

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Appendix A Uncertainties Assessment

A1 Table A.1 summarises the single safety-related uncertainty with a significance rating of **high** identified in the development of the SWESC and the underpinning assessments that are included in the NRS Uncertainties Management Database (UMD). Uncertainties are numbered in the form WIN-XX-YYY, where XX is an abbreviation for the report in which the uncertainty is identified.

Table A.1: Uncertainties identified during development of the SWESC.

UMD Reference No.	Feature, Event or Process subject to Uncertainty	Description of Uncertainty	Treatment of Uncertainty / Statement of Assumption	Action required – December 2020	Interim Review – October 2024
WIN-SWESC-002	GRR and groundwater regulation	The interpretation of groundwater regulation is being reviewed by the regulator. The findings may change decommissioning decisions.	Decisions to-date at Winfrith have addressed the GRR and other guidance from the regulators. A final position from the regulators on implementation of the GRR with respect to groundwater protection is not expected before the permit application is submitted.	Magnox is preparing its case for compliance with groundwater legislation ahead of any guidance provided by the EA based on discussions with the EA. To support this, significant work is in hand to (i) better understand groundwater behaviour, at Winfrith, especially during the climate change scenario beyond 2050, using BGS national recharge data, (ii) develop a strategy for compliance, (iii) produce engineering designs for the proposed disposals at SGHWR and Dragon (iv) undertake non-radiological and radiological performance assessments based on the above. In addition, Magnox is in regular contact with the EA in order to understand the EA's likely direction of travel and present its output from its in-hand work, with the aim of ensuring the EA is aware of Magnox's programme and results.	Strategy for achieving compliance with Water Environment Regulations "Prohibition" for the SGHWR and Dragon reactor End States completed March 2021, ES(20)P329 [210]. Radiological and non-radiological risk assessments completed, climate change scenarios understood and recorded in report, concept designs for disposals completed.

Appendix B Regulatory Compliance Crosswalks

B1 Appendix B presents a series of tables detailing the applicable regulatory requirements and guidance, with references to sections of the SWESC or underlying reports containing material that addresses each requirement or guidance point.

- Section B.1 addresses requirements in Schedule 23 of the Environmental Permitting (England and Wales) Regulations 2016 (EPR16) as requirements of the GRR;
- Section B.2 addresses requirements under Schedules 21 and 22 of the EPR16;
- Section B.3 addresses requirements under the Environmental Protection Act 1990 (EPA90);
- Section B.4 addresses requirements under the Town and Country Planning Act 2017 (TCPA17);
- Section B.5 addresses requirements relevant to the ONR site licence conditions; and
- Section B.6 addresses the requirements for Deposit for Recovery (DfR).

B.1 Schedule 23 of EPR16 – Radioactive Substances Regulations

B2 The EA regulates activities involving radioactive substances under Schedule 23 of EPR16. The GRR [260] provides guidance on what operators need to do when they are planning and carrying out their work to decommission and clean-up their sites in order to ultimately achieve release from radioactive substances regulation.

Table B.1: Requirements under Schedule 23 of EPR16 taken from the GRR [260].

ID	Requirement / Guidance	Where Addressed
GRR-R1	**Requirement R1. Optimisation of waste management options.** Operators should use a proportionate process to select options, for managing radioactive waste arising from decommissioning and clean-up, that are optimised. This process shall ensure that the radiological risks to individual members of the public and the population as a whole are kept as low as reasonably achievable (ALARA) taking account of economic and social factors. The process should also consider the need to manage radiological risks to other living organisms and to manage the non-radiological hazards associated with radioactive waste.	NRS has put considerable effort into the optimisation of plans for the Winfrith site, consulting with all stakeholders. The optimisation process is undertaken at several scales and with several foci, including the site, individual features, waste types and waste streams. The process is, and will remain, ongoing throughout the period of control, including regular review of past decisions. *See*: Arguments O.1 to O.4. *Key References*: [261; 262; 263; 264; 265; 266].
GRR-R2	**Requirement R2. Waste management plan.** Operators should prepare a waste management plan (WMP) to manage the programme of disposals of radioactive waste from their nuclear site, and implement the plan to achieve the site reference state.	A waste management plan report outlining optimisation of waste management at the site has been developed and an associated WMP spreadsheet presents the waste management route for all wate types at the site. The approach to developing the WMP was peer reviewed in 2019. The WMP will be implemented through NRS standard procedures and processes as appropriate. In relation to on-site disposals, waste will be managed through application of the emplacement acceptance criteria (EAC) prepared for Winfrith and issued in tandem with this SWESC. *See*: Sections 1 and 3.4, 3.4.8, Arguments M.2, M.5, M.6, M.7, M.11, D.8, D.9 and O.3. *Key References*: [261; 267; 268].

ID	Requirement / Guidance	Where Addressed
GRR-R3	**Requirement R3. Early engagement.** Operators should engage as early as possible with the relevant environment agency.	NRS has regular engagement with the EA at Winfrith and has involved the EA in its stakeholder meetings on end state decisions. The EA is also involved at higher-level strategic discussions regarding nuclear decommissioning in the UK. *See*: Section 4.1, Arguments U.1, and O.3. *Key References*: [269; 270; 271; 272; 273].
GRR-R4	**Requirement R4. Engagement with local communities and others.** Operators should engage with local communities, ONR, the planning authority, other interested parties and the public on their developing WMP and SWESC.	NRS has involved all key stakeholders including the local communities in its stakeholder meetings on end state decisions. NRS has also consulted with the relevant stakeholders, such as the planning authority, through its applications for permission for planning and revocation of the nuclear site licence as part of the decommissioning process. *See*: Section 4, Arguments M.12, U.2, O.2 and O.3. *Key References*: [274].
GRR-R5	**Requirement R5. Environmental safety culture and management system.** Operators should maintain a positive environmental safety culture appropriate to the activities being undertaken on site and should have a management system, organisational structure and resources sufficient to provide the following functions: (a) planning and control of work; (b) the application of sound science and good engineering practice; (c) commissioning of appropriate research and development; (d) provision of information; (e) documentation and record-keeping (see also Requirement R6); and (f) quality management.	NRS has a culture that places EHSS&Q considerations at the heart of its plans and practices. This culture is evident in the development of the decommissioning strategy for Winfrith. NRS has a set of generic process documents regarding items such as planning, developing safety cases, waste management and record keeping that are implemented in site-specific procedures. The Winfrith Site Manual summarises and signposts to the relevant procedures for works undertaken on the site. *See*: Section 3, Arguments M.1 to M.13. *Key References*: [275; 276].
GRR-R6	**Requirement R6. Preservation of knowledge and records at the time of release from radioactive substances regulation.** Operators shall manage and retain adequate records of their site's journey to completion of all planned work involving radioactive substances and also, where necessary, provide adequate records of the controls applied up to the site reference state being achieved along with the required validation monitoring data. Operators should provide	NRS has a generic process for knowledge management record keeping and this is consistent with practice at Winfrith. Plans for validation monitoring up to release from RSR and for record keeping are being developed. These details are to be presented in the Stewardship Plan for the site. *See*: Section 3.4.5, Argument M.7. *Key References*: [277; 278].

ID	Requirement / Guidance	Where Addressed
	these records in a form suitable for long-term preservation and access, and should propose arrangements for the long-term safe-keeping and management of the records.	
GRR-R7	**Requirement R7. Site-Wide Environmental Safety Case.** Operators should maintain a site-wide environmental safety case (SWESC) to demonstrate that people and the environment will be adequately protected from ionising radiation and any associated non-radiological hazards, both before and after their site is released from radioactive substances regulation.	This SWESC presents the claims and arguments and summarises the supporting evidence for the environmental safety of the Winfrith site. It is supported by a series of more detailed Tier 2 and Tier 3 reports. The SWESC considers safety now and in the future, presenting the optimised plans for the site. It will evolve as decommissioning progresses. The approach to developing this SWESC and the SWESC itself have been peer reviewed. *See*: Sections 1 and 3, and all Arguments. *Key References*: [279; 280].
GRR-R8	**Requirement R8. Site characterisation and monitoring.** Operators should carry out a programme of site characterisation and monitoring to provide information needed to support the WMP and SWESC. The programme shall include appropriate validation monitoring to provide technical confirmation that progress towards the site reference state is as expected or to validate that the site reference state has been achieved.	NRS has undertaken a significant amount of site characterisation and monitoring at Winfrith in order to develop the radiological and non-radiological inventories, and thus identify the pathways whereby it might impact receptors. This characterisation has informed remediation and end state plans. NRS is committed to continual and ongoing characterisation to constrain key uncertainties, and will continue to undertake monitoring to demonstrate compliance with regulations/permits and validate expectations. *See*: Section 5; Arguments M.8, M.9, M.12, D.1 to D.9. *Key References*: [277; 281; 282; 283; 284; 285; 286].
GRR-R9	**Requirement R9. Dose constraints during the period of radioactive substances regulation.** During the period of radioactive substances regulation the effective dose, from the authorised site, to a representative person shall not exceed a source related dose constraint and a site-related dose constraint.	Doses to the public from current permitted discharges from the site are below the regulatory dose constraint. Doses are not expected to change significantly as a result of decommissioning activities, but appropriate permissions will be sought if a need is identified. After the IEP, assessments for the anticipated on-site disposition of radioactivity show that the dose constraint will be met. The additional impacts to the representative persons from the Tradebe Inutec site are small. Modelled doses during decommissioning and after the IEP are presented in the Radiological Performance Assessment. *See*: Section 7, Arguments M.8, S.1 to S.7 and S.16. *Key References*: [287].

ID	Requirement / Guidance	Where Addressed
GRR-R10	**Requirement R10. Risk guidance level after release from radioactive substances regulation.** Operators should demonstrate through the SWESC that, after release from radioactive substances regulation, the assessed risk from the remaining radiological hazards to a representative person should be consistent with a risk guidance level of 10-6 per year (that is, a risk of death or heritable defect of 1 in a million per year due to exposure to ionising radiation.	Taking into account the optimised end state and the on-site disposals, the radiological risks to the public will still be below the regulatory risk guidance level beyond the period of RSR. Radiological risks to users of the rivers or the land are very small. The risks are slightly higher for the low possibility in the future of a well sunk into contaminated groundwater and used for drinking and crop irrigation. However, the risks are still compliant with the risk guidance level. The assessments take account of expected changes in the long-term, such as those associated with degradation of engineered materials and climate change. *See*: Arguments M.8, S.1, S.2, S.8 to S.12, and S.16. *Key References*: [287].
GRR-R11	**Requirement R11. Inadvertent human intrusion dose guidance level after release from radioactive substances regulation.** Operators should assess the potential consequences of inadvertent human intrusion into any local concentrations of radioactive substances on the site after release from radioactive substances regulation. The assessed effective dose to a representative person during and after the assumed intrusion should not exceed a dose guidance level in the range of around 3 millisieverts per year (3 mSv/y) to around 20 millisieverts in total (20 mSv). Values towards the lower end of this range are applicable to prolonged exposures, while values towards the upper end of the range are applicable only to transitory exposures.	Doses to workers who might inadvertently disturb contamination after the site has been released from RSR have been assessed. Similarly, these scenarios also consider doses to the public that might use the disturbed area and/or disturbed material. Assuming disturbance immediately after the SRS, the calculations of dose for expected levels of contamination gives results that are below the lower regulatory dose guidance level of 3 mSv y^{-1} as long as the SGHWR mortuary tubes are characterisation and cleaned if required. *See*: Arguments M.8, S.1, S.2, S.8 and S.11. *Key References*: [287].
GRR-R12	**Requirement R12. Natural disruptive processes after release from radioactive substances regulation: application of risk guidance level and dose guidance level.** Operators should show in the SWESC that people will be adequately protected in the case of natural disruptive processes which expose radioactive waste or contamination, or impair protective barriers after the site is released from radioactive substances regulation.	The assessments that support the SWESC have considered the potential for natural disruptive processes in the future and their possible impacts. No relevant natural processes have been identified. The performance of engineered structures, such as the degradation of concrete walls, has been modelled as part of sensitivity analyses. These analyses show that doses and risks remain below the relevant guidance levels under such circumstances. *See*: Arguments M.8, S.2 and S.9. *Key References*: [281; 287].

ID	Requirement / Guidance	Where Addressed
GRR-R13	**Requirement R13. Optimisation of on-site disposals.** Operators shall, through a process of optimisation, ensure that the radiological risks to individual members of the public and the population as a whole, from the on-site disposal of radioactive waste, are kept as low as reasonably achievable (ALARA) taking into account economic and social factors. Radiological risks shall be optimised throughout the period of radioactive substances regulation and afterwards, as far as can be judged at the time when relevant actions are taken. The process should also consider the need to manage radiological risks to other living organisms and to manage the non-radiological hazards associated with radioactive waste.	Since demonstrating that on-site disposal of features is the optimal end state, NRS has continued to optimise plans for the on-site disposals. The optimisation process takes account of the decommissioning process as a whole in developing a concept design for each on-site disposal feature, and optimisation for particular materials associated with a feature, such as residual asbestos. The optimisation process considers both radiological and non-radiological hazards, as well as other economic and societal factors. Optimisations will be ongoing throughout the decommissioning cycle with continual updates and improvements where applicable. *See*: Section 6.3, Arguments D.1, O.1, O.3 and O.4. *Key References*: [261].
GRR-R14	**Requirement R14. Protection of the environment.** Operators shall assess the radiological effects of the site on the environment with a view to showing that all aspects of the environment are adequately protected, both during the period of, and after release from, radioactive substances regulation**.**	NRS is committed to protection of the environment as a whole in addition to the protection of human health. This includes the consideration of potential impacts of our proposals on non-human organisms in our optimisation and decision-making processes. No significant radiological impacts on non-human organisms are anticipated based on assessment of the concept designs. The radiological impacts of the site now and in the future are below the levels of natural radiation in the environment. *See*: Arguments M.8, S.2, M.10, S.13, S.16, S.17 and S.18. *Key References*: [287; 288].
GRR-R15	**Requirement R15. Protection against non-radiological hazards.** 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.	NRS has undertaken an assessment of both radiological and non-radiological hazards associated with the proposed on-site disposals. Where hazards are apparent, remediation and management strategies have been developed for the potential impacts. The level of protection provided against all non-radiological hazards at Winfrith is appropriate and consistent with national standards. *See*: Arguments M.11, M.12, D.1 to D.5, D.9, O.3, S.1 to M.10, S.17 and S.18. *Key References*: [288].

B.2 Schedules 22 and 21 of EPR16 – Groundwater and Surface Water Protection

B3 Schedule 21 of EPR16 concerns surface water protection and implements the European Water Framework Directive (WaFD). Schedule 22 of EPR16 and guidance provided by the EA [289] reflect the requirements of the EC Ground Water Daughter Directive (GWDD). In order to avoid or control groundwater "pollution", the GWDD requires that groundwater activities of hazardous substances are "prevented" and that groundwater activities of non-hazardous pollutants are "limited". The requirements for meeting these terms are set out in Table B.2.

Table B.2: Requirements for groundwater and surface water protection under Schedules 22 and 21 of EPR16.

ID	Requirement / Guidance	Where Addressed
GWDD-1	An input of any hazardous substance to groundwater is "prevented" and does not require a permit (or exclusion) if: • There is no discernible concentration of the hazardous substance in the input into groundwater; or • There is no discernible concentration of the hazardous substance in groundwater immediately down-gradient of the input; and • All "necessary and reasonable measures" to avoid the input have been taken. If all "necessary and reasonable measures" are demonstrated but there is still an input of discernible concentration into groundwater, the regulator may "prevent" pollution by setting conditions on the associated activity permit.	Surface and groundwaters at Winfrith have been characterised and are monitored on a quarterly basis. NRS will monitor contaminants in groundwater that might occur in the future owing to ongoing Winfrith activities and materials remaining after the IEP. These data have been compared against screening values to show that the requirements of Schedules 23 and 22 of EPR16 are met. If the values are exceeded, further assessment and potential mitigation actions will be taken. Numerical modelling of groundwater contaminants has been undertaken in the Hydrogeological Risk Assessment for hazardous compounds (Cr(VI), Pb, and PCB Congeners: 28, 52, 101, 119, 138, 153 and 180). Future surface and groundwater monitoring arrangements after the IEP are presented in the Stewardship Plan for the site. *See*: Arguments D.1 to D.5, D.8, D.9, S.1, S.2, S.6, S.9, S.17 and S.18. *Key References*: [277; 286; 287; 288; 290; 291]

ID	Requirement / Guidance	Where Addressed
GWDD-2	For non-hazardous materials, the input of any non-hazardous substance to groundwater is “limited” and does not require a permit (or exclusion) if: • The input is of a concentration that will not result in any actual or significant risk of pollution to groundwater and presents no danger of deterioration in the groundwater; and • All “necessary and reasonable measures” to avoid the input have been taken. As with hazardous substances, if all “necessary and reasonable measures” are demonstrated but there is still an input of non-hazardous substances into groundwater that is likely to cause deterioration, the regulator may “limit” pollution by setting conditions on the associated activity permit.	Surface and groundwaters at Winfrith have been characterised and are monitored on a quarterly basis. NRS will monitor contaminants in groundwater that might occur in the future owing to ongoing Winfrith activities and materials remaining after the IEP. These data have been compared against screening values that show the requirements of Schedules 23 and 22 of EPR16 are met. If the values are exceeded, further assessment and potential mitigation actions will be taken. Numerical modelling of groundwater contaminants has been undertaken in the Hydrogeological Risk Assessment for non-hazardous compounds (Cr(III), Cu, Zn, and aromatic hydrocarbon fractions (C10-C12, C12-C16 and C16-21). Future surface and groundwater monitoring arrangements after the IEP are presented in the Stewardship Plan for the site. *See*: Arguments D.1 to D.5, D.8, D.9, S.1, S.2, S.6, S.9, S.17 and S.18. *Key References*: [277; 286; 287; 288; 290; 291]
WAFD-1	Schedule 21 of EPR16 concerns surface water protection and implements the European Water Framework Directive (WaFD). Schedule 21 and the WaFD requires controls on discharges of ‘poisonous, noxious or polluting matter’ to surface waters. The assessment of potential inputs to surface waters must be undertaken to determine whether this definition is being met. Schedule 21 contains no exclusion for small/discernible concentrations in discharges of hazardous substances, as identified for groundwater.	Surface and groundwaters at Winfrith have been characterised and are monitored on a quarterly basis. NRS will monitor concentrations of pollutants in surface waters that might occur in the future owing to ongoing Winfrith activities and materials remaining after the IEP. These data have been compared against screening values that show the requirements of Schedule 21 of EPR16 are met. *See*: Arguments D.1 to D.5, D.8, D.9, S.1, S.2, S.6, S.9, S.17 and S.18. *Key References*: [287; 288; 291].

B.3 Contaminated Ground and Land Quality

B.3.1 Non-radioactively Contaminated Ground

B4 Part 2A of the Environmental Protection Act 1990 (EPA90) defines "contaminated land" as any land that appears *"to be in such a condition, by reason of substances in, on or under the land that significant harm is being caused, or there is significant possibility of such harm being caused"* or *"significant pollution of controlled waters is being caused or there is a significant possibility of such pollution being caused"*. In this definition, "harm" means harm to human health or to various organisms. There is statutory and non-statutory guidance on the meaning of "significant" and "significant possibility" for radioactive and non-radioactive contaminated land, and how to conduct a risk assessment to evaluate whether land is contaminated. Part 2A of EPA90 applies to land in its current use, including any use for which planning permission has been granted. Nuclear licensed sites are defined under Part 2A as "special sites" and contaminated land on Winfrith is regulated by the EA. With regard to radioactive contamination, the EA apply the requirements and criteria in the GRR, and these are discussed in Appendix B.1. However, there are non-radiological hazards at Winfrith and there is the potential for non-radioactively contaminated ground that is not associated with any radioactive contamination. In this context, the requirements of meeting Part 2A of EPA90 are discussed here. The requirements are based on addressing the questions in the regulatory Guiding Principles for Land Contamination (GPLC), although it should be recognised that these are only for general guidance under EPA90 and regulatory requirements specific to non-radiological contamination may be applied at nuclear and non-nuclear sites.

Table B.3: Requirements for non-radioactively contaminated ground based on the GPLC.

ID	Requirement / Guidance	Where Addressed
GPLC-1	*Key questions [292, Annex 1]*: Do you understand the CLR11 process?	For prioritisation and categorisation of Areas of Potential Concern (APC), NRS has followed a methodology based upon the Nuclear Industry Group for Land Quality (NIGLQ) guidance for Qualitative Risk Assessment for Land Contamination. NRS follows the Environment Agency's Land Contamination Risk Management (LCRM) guidance (the successor guidance to CLR11; https://www.gov.uk/government/publications/land-contamination-risk-management-lcrm). A tiered approach to risk assessment is adopted that starts with developing a conceptual site model. Potential pollutant linkages are assessed by tiered risk assessment. Where risks associated with pollutant linkages cannot be shown to be acceptable, a remedial options assessment is undertaken and the optimal remedial solution then implemented. Following remediation, verification is undertaken to demonstrate that the risk has been reduced to an acceptable level. NRS maintains and continually updates its Land Quality Register [293] to accurately reflect the best understanding and categorisation of APCs at the site. *See*: Arguments D.2, D.3, D.9, O.1, S.2 and S.18. *Key References*: [294; 295].

ID	Requirement / Guidance	Where Addressed
GPLC-2	*Key questions [292, Annex 1]*: Have you set objectives for the scheme?	The overall aim for land quality management at Winfrith is to return the designated land to a condition suitable for the next planned use. The next planned use of the land, and thus the success criteria for the scheme, is heathland with public access. Zone-specific desk studies and characterisation are used to form an opinion on the presence of a source. Risk assessment uses site knowledge to judge the severity of potential impacts and the likelihood of consequences occurring. *See*: Sections 1, 2.3, 3.3 and 5.3.2, Arguments M.12, U.1, U.2, D.2, D.3, O.1 to O.3. *Key References*: [294; 295]
GPLC-3	*Risk assessment [296, Section 1]*: Do you know the history of your site? Checklist 1 of [297].	In determining the possibility of contamination at Winfrith, consideration has been given to past activities. These past activities are detailed in the zone-specific desk studies. *See*: Arguments D.1, D.2 and O.1. *Key References*: [294; 295]
GPLC-4	*Risk assessment [296, Section 1]*: Have you identified all sources of contamination?	A comprehensive register of potentially contaminated land (in the Land Quality Register) is maintained for Winfrith. The development of this register considers potential sources of contamination. *See*: Arguments D.1, D.2, D.7 to D.9, and O.1. *Key References*: [285; 293].
GPLC-5	*Risk assessment [296, Section 1]*: Have you identified all relevant potential receptors – present or future?	The assessments consider present-day and potential future receptors. *See*: Arguments O.1 to O.3, M.8 and S.2. *Key References*: [288].
GPLC-6	*Risk assessment [296, Section 1]*: Do you have a preliminary conceptual model? Checklist 2 of [297].	In accordance with the Environment Agency's LCRM guidance, NRS developed conceptual model for areas of land contamination as the first step in developing an appropriate management strategy. *See*: Arguments O.1, M.8 and S.2. *Key References*: [286].
GPLC-7	*Risk assessment [296, Section 1]*: Have you carried out an appropriate generic or site-specific risk assessment?	Site-specific risk assessments have been used to judge the severity of potential impacts and the likelihood of a consequence occurring from contamination in zones at Winfrith. The risk assessments take account of the next planned use for the land. *See*: Section 7, Arguments S.1 to S.19. *Key References*: [288].

ID	Requirement / Guidance	Where Addressed
GPLC-8	*If there is an unacceptable risk continue to:* *Options appraisal [296, Section 2]:* Have all remediation options been identified? Checklist 3 of [297].	Where the characterisation of areas of potential concern demonstrates that a satisfactory land condition cannot be achieved for the present time and/or for the IEP, remediation will be carried out. The first step in determining the appropriate remediation option is to identify all remediation options including by reference to Environment Agency guidance (e.g. https://claire.co.uk/information-centre/water-and-land-library-wall/41-water-and-land-library-wall/190-identification-of-feasible-remediation-options-info-oa1). *See*: Argument D.3, and O.1 to O.4. *Key References*: [294; 295; 298].
GPLC-9	*Options appraisal [296, Section 2]:* Have you undertaken a detailed evaluation of options?	Remedial options will be evaluated through a BAT optioneering process aligned to Environment Agency guidance (LCRM: Stage 2 options appraisal; https://www.gov.uk/government/publications/land-contamination-risk-management-lcrm/lcrm-stage-2-options-appraisal). The BAT optioneering process is demonstrated by the decisions being evaluated for dealing with the residual TCE contamination. *See*: Arguments O.1 to O.4. *Key References*: [295].
GPLC-10	*Options appraisal [296, Section 2]:* Do you have a remediation strategy	The current remediation strategies for land quality issues are set out in the Land Quality Plan. The strategy will be used in the Zone Close Out process. As noted, the overall objective for land quality management at Winfrith is to return the designated land to a condition suitable for heathland with public access. *See*: Arguments M.2, M.3 and D.3. *Key References*: [294; 295; 298].
GPLC-11	*Implementation of the remediation strategy [296, Section 3]* Has your implementation plan been agreed by all parties? Checklist 4 of [297].	Remediation plans are integrated to meet the needs of different projects. NRS engages frequently with regulators and with other key stakeholders through groups such as WESTG, meetings and presentations, and publication of plans. Remediation strategies are reviewed by the appropriate regulators. *See*: Arguments M.5, M.6, U.1 and U.2. *Key References*: [294; 295].
GPLC-12	*Implementation of the remediation strategy [296, Section 3]* Has your remediation work been verified? Checklist 5 & 7 of [297].	NRS reviews all works undertaken at Winfrith to ensure that they are conducted as planned or, if not, an appropriate alternative course of action is taken. Monitoring is conducted as necessary to provide assurance that remediation measures achieve their objectives. *See*: Arguments M.6, M.7, M.9, U.1 and U.2. *Key References*: [277; 291].

ID	Requirement / Guidance	Where Addressed
GPLC-13	*Implementation of the remediation strategy [296, Section 3]* Do you have any necessary long-term maintenance or monitoring plans in place? Checklist 6 & 8 of [297].	NRS conducts an environmental monitoring plan to demonstrate compliance with the Winfrith environmental permit and to support management of non-radiological land contamination. NRS plans to ensure land is put into a state suitable for the next planned use of the land (heathland with public access). Infrastructure requiring maintenance or monitoring necessary to ensure non-radiological land contamination remains in a satisfactory state is not envisaged to remain after the IEP. *See*: Arguments M.1, M.2, M.3, M.9, M.12, M.13 and D.3. *Key References*: [277; 291].
GPLC-14	*Implementation of the remediation strategy* [*296, Section 3]* Have you met your objectives?	Characterisation is ongoing at Winfrith. Monitoring will continue and will be used to demonstrate that remediation actions are successful in contributing to returning the site to a condition suitable for its next planned use. *See*: Arguments M.12, D.3, O.1 to O.4. *Key References*: [277; 291].

B.3.2 Land Quality Management

B5 ONR and EA set out their expectations for Land Quality Management (LQM) in [299]. These expectations are set out as requirements in Table B.4 to be mapped to the arguments in Section 5.3.2.

Table B.4: Requirements for land quality management on nuclear licensed sites based on [299].

ID	Requirement / Guidance	Where Addressed
LQM-1	*We expect licensees and operators to manage the land quality at nuclear licensed sites in ways that:* a) prevent unacceptable activities in terms of land and groundwater protection taking place; and	NRS manages its activities at Winfrith such that unacceptable impacts on land and groundwater quality are prevented. *See*: Section 3, Arguments M.1, O.1, O.2, O.3, O.4, M.10, S.3, S.8, S.13 to S.18. *Key References*: [287; 288; 295].
LQM-2	*We expect licensees and operators to manage the land quality at nuclear licensed sites in ways that:* b) ensure that any risks to people and the environment associated with land quality are promptly and properly managed.	NRS has prioritised its remediation activities to focus on the key areas of concern as identified by the Land Quality Register [293]. For the future, the site will be left in a condition that is suitable for its planned use (heathland with public access), safe for people and the environment. *See*: Section 3, Arguments M.1, O.1, O.2, O.3, O.4, M.10, S.3, S.8, S.13 to S.18. *Key References*: [291; 295].
LQM-3	To do this, we expect licensees and operators to have a robust strategy for the management of land quality at their sites, implemented through a single LQM plan that addresses issues holistically and takes due account of radioactive and non-radioactive substances.	A land quality management plan has been developed for the Winfrith site that adopts a risk-based assessment of areas of potential concern and establishes a close out process zone by zone on the site that prioritises and addresses the radiological and non-radiological issues remaining to be resolved before the IEP. *See*: Arguments M.1, O.1, O.2, O.3, O.4, M.10, S.3, S.8, S.13 to S.18. *Key References*: [295; 298].
LQM-4	*The development of both the strategy and plan should be systematic and the approach to their development and management should be fully integrated and iterative. They should address our expectations that operators should:* prevent new land contamination, so far as is reasonably practicable;	The land quality management plan establishes a close out process zone by zone on the site that prioritises and addresses the radiological and non-radiological issues remaining to be resolved before the IEP. This includes stopping any new land contamination by ceasing or modifying processes and practices as necessary. *See*: Arguments M.1 to M.3, M.5 and O.1. *Key References*: [294; 295; 298].

ID	Requirement / Guidance	Where Addressed
LQM-5	*… operators should:* understand the land quality and contamination characteristics of the site, so as to inform decisions on land quality management;	The land quality management plan is supported by a large amount of work that has been undertaken to characterise the Winfrith site. This is summarised in this SWESC. A risk assessment for areas of potential concern uses this characterisation to prioritise addressing radiological and non-radiological land management issues. *See*: Arguments D.1, D.2, D.4 to D.9, O.1 and O.2. *Key References*: [287; 288; 294; 295; 298].
LQM-6	*… operators should:* assess the options for LQM taking due account of sustainable development;	The land quality management plan considers the options for addressing radiological and non-radiological land management issues by order of priority. The identification of viable options takes account of sustainability and the next planned use of the land. *See*: Arguments M.1, O.1 and O.2. *Key References*: [295].
LQM-7	*… operators should:* identify and prioritise LQM activities;	The land quality management plan uses a risk assessment to prioritise addressing radiological and non-radiological land management issues. *See*: Arguments M.1 and O.1. *Key References*: [295].
LQM-8	*… operators should:* apply the waste management hierarchy;	The land quality management plan minimises the production of waste. Waste production also comes under the remit of the NRS Integrated Waste Strategy and the WMP. These outline the strategy for managing radioactive and non-radioactive materials and wastes on the Winfrith site. They establish principles of sustainability, BAT, passivity, and the application of the waste hierarchy. *See*: Arguments O.1 to D.1, M.1 and M.6. *Key References*: [267; 295].
LQM-9	*… operators should:* ensure sufficient and competent resources are allocated to implement LQM activities	Resourcing issues and responsibilities for land quality management activities are covered by the NRS process for environmental management and the Winfrith Site Manual. *See*: Arguments M.1 and M.5. *Key References*: [275; 300].
LQM-10	*… operators should:* engage with stakeholders (including the regulators) from an early stage;	NRS engages with regulators and other stakeholders on a regular basis concerning all activities at Winfrith including land quality management. *See*: Arguments U.1 and U.2. *Key References*: [270; 271; 272; 273; 274].
LQM-11	*… operators should:* develop the safety case / radioactive and non-radioactive waste management arrangements for land quality management;	This SWESC and the WMP provide the safety case and waste management arrangements for land quality management at Winfrith. *See*: Section 3.3, Arguments M.1 to M.6. *Key References*: [261; 267].

ID	Requirement / Guidance	Where Addressed
LQM-12	*… operators should:* avoid the creation of radioactive wastes in forms which may foreclose options for safe and effective long-term waste management;	The WMP sets out the plans for safe and effective management of anticipated radioactive and non-radioactive wastes on the Winfrith site. The plans apply the principles of sustainability, BAT, passivity, and the waste hierarchy. *See*: Arguments M.1 to M.3. *Key References*: [261; 267].
LQM-13	*… operators should:* ensure that risks are as low as reasonably practicable/achievable (or otherwise minimised as appropriate for non-radioactive contamination); and	The land quality management plan and this SWESC consider both radiological and non-radiological contamination, and priorities are based on their assessed risk. *See*: Arguments O.1 to O.3 and M.1. *Key References*: [287; 288; 294; 295; 298].
LQM-14	*… operators should:* maintain fit-for-purpose land management records and manage relevant knowledge appropriately.	NRS applies a consistent process for knowledge management and the creation and keeping of records at Winfrith across all of its activities. *See*: Arguments M.1 and M.7. *Key References*: [278].

B.4 Town and Country Planning

B6 The activities needed to implement the Winfrith site end state include tasks which require planning permission. The current intention is that a number of applications for planning permission will be made to Dorset Council. These include one application for all the development required at the main site to achieve the agreed interim end state and a separate planning application for the development associated with the terrestrial part of the Sea Discharge Pipeline. A scoping report for the EIA associated with the main site to achieve the agreed interim end state has been submitted to the Dorset Council [302]. A separate EIA screening and scoping opinion will, if required, be submitted for the development associated with decommissioning of the Pipeline. The EIA scoping report for the main site considers the environmental context and the potential environmental impacts of the proposed development required at the site to achieve the agreed interim end state. Under Part 1 Section 4 of the Town & Country Planning (Environmental Impact Assessment) Regulations 2017 [301], the factors and their interactions listed in Table B.5 are to be considered within any EIA submitted for scoping after 16 May 2017. Table B.5 details where the information to be covered by the EIA is addressed in this SWESC and supporting documents.

Table B.5: Requirements for planning under Part 1 Section 4 of the Town & Country Planning (Environmental Impact Assessment) Regulations 2017.

ID	Requirement / Guidance	Where Addressed
TCPA-1	*The EIA must identify, describe and assess in an appropriate manner, in light of each individual case, the direct and indirect significant effects of the proposed development on:* a. Population and human health	Impacts on the public are considered in this SWESC. The characteristics of the local population are described. The assessments take account of expected changes in the long-term, such as those associated with climate change. *See*: Arguments D.2, O.2, O.4, S.3, S.7, S.12, S.13 and S.17. *Key References*: [287; 288; 302].
TCPA-2	*The EIA must identify, describe and assess in an appropriate manner, in light of each individual case, the direct and indirect significant effects of the proposed development on:* b. Biodiversity, with particular attention to species and habitats protected under any law that implemented Directive 92/43/EEC(a) and Directive 2009/147/EC(b)	This SWESC describes the characteristics of the local environment, including biodiversity. The impacts on non-human organisms of different proposals are considered. *See*: Arguments M.11, D.1, D.2, D.4, D.5, O.2, S.1, S.2 and S.16. *Key References*: [287; 288; 303].
TCPA-3	*The EIA must identify, describe and assess in an appropriate manner, in light of each individual case, the direct and indirect significant effects of the proposed development on:* c. Land, soil, water, air and climate	This SWESC describes the characteristics of the local environment, including the geology, hydrogeology, surface hydrology, land use and climate. The impacts of different proposals are considered. *See*: Arguments D.1 to D.5, O.2, S.1, S.2 and S.16 *Key References*: [287; 288; 303].

ID	Requirement / Guidance	Where Addressed
TCPA-4	*The EIA must identify, describe and assess in an appropriate manner, in light of each individual case, the direct and indirect significant effects of the proposed development on:* d. Material assets, cultural heritage and the landscape	This SWESC describes the characteristics of the local environment, including the material assets and the landscape. The impacts of different proposals are considered. A conceptual landscape management plan has been developed and a restoration management plan building on this has been completed. *See*: Arguments D.2, O.2. *Key References*: [281; 303].
TCPA-5	*The EIA must identify, describe and assess in an appropriate manner, in light of each individual case, the direct and indirect significant effects of the proposed development on:* e. The interaction between the factors referred to in sub-paragraphs (a) to (d) as set out above in this table.	This interaction between all of the factors described above are considered in the optimisation and BAT studies undertaken for decommissioning of the site. These studies support development of plans for different projects at the Winfrith site. *See*: Arguments M.2, D.2, O.2. *Key References*: [287; 288; 303].
TCPA-6	EIA Reports are also to include the expected effects deriving from the vulnerability of the development to major accidents and disasters.	The vulnerability of options to external events with regard to radiological and non-radiological hazards is considered in the assessments supporting optimisation and BAT studies undertaken for decommissioning of the site. These studies support development of optimised plans for the Winfrith site. *See*: Arguments O.2, S.9, S.12 and S.13. *Key References*: [287; 288].

B.5 Nuclear Site Licence

B7 The ONR and EA provide joint regulation of environmental protection and waste management on nuclear licensed sites [304]. However, the ONR is also responsible under the Nuclear Installations Act 1965 (NIA65) [305] for the licensing of nuclear installations. Any organisation wanting to install or operate a prescribed nuclear installation needs a nuclear site licence. Each nuclear site licence is unique to its site. NIA65 requires ONR to attach to each nuclear site licence such conditions as it considers necessary or desirable in the interests of safety. ONR maintains a set of standard conditions [306]. These have been applied, as appropriate, in the Winfrith nuclear site licence. The parts of these conditions that concern environmental protection and land quality management are set out in Table B.6 based on ONR guidance on land quality management [307].

Table B.6: ONR requirements from standard Licence Conditions [306; 307] applied in the Winfrith nuclear site licence that relate specifically to environmental protection, land quality management and implementation of the end state.

ID	Requirement / Guidance	Where Addressed
ONR-1	Licence Condition 32: Accumulation of radioactive waste	The WMP describes the arrangements for minimising the production of waste as far as is reasonably practicable, and for management of waste arisings in accordance with ONR approval. *See*: Section 3.3, Arguments M.1, M.2 andS.1. *Key References*: [261; 267].
ONR-2	Licence Condition 33: Disposal of radioactive waste	NRS will ensure that radioactive waste is disposed of as ONR may specify and in accordance with the environmental permit. The SWESC and WMP summarise the optimisation of the arrangements. Detailed interpretations and details of the waste and its management are presented in the Radiological and Non-radiological Inventory reports, Radiological Performance Assessment, Hydrogeological Risk Assessment and the Emplacement Acceptance Criteria. *See*: Section 3.3, Arguments O.2 to O.4, M.1 and M.2. *Key References*: [261; 267; 268; 283; 285; 287; 288].
ONR-3	Licence Condition 34: Leakage and escape of radioactive material and radioactive waste	Radioactive material and radioactive waste at Winfrith are controlled or contained so that they cannot leak or otherwise escape from such control or containment. Past incidents are remediated as needed. *See*: Arguments O.1 to O.4, M.1 and M.2. *Key References*: [267; 290; 295].
ONR-4	Licence Condition 35: Decommissioning	The current strategy for decommissioning forms the basis for further optimisation. *See*: Arguments D.3, O.2 to O.4. *Key References*: [284; 290].

ID	Requirement / Guidance	Where Addressed
ONR-5	*Licence conditions relating to safety documentation and review:* Licence Condition 14: Safety documentation Licence Condition 15: Periodic review Licence Condition 23: Operational rules Licence Condition 25: Operational records	NRS applies a consistent process for knowledge management and the creation and keeping of records at Winfrith across all of its activities. Safety cases are produced for all operations as needed. This SWESC provides an environmental safety case for the site. Key documents produced for NRS are subject to independent review. *See*: Arguments M.1, M.2, M.3, M.4, M.7 and S.19. *Key References*: [275; 278].
ONR-6	*Other licence conditions that will need to be specifically addressed in implementing the end state:* Licence Condition 2: Marking of the site boundary Licence Condition 36: Organisational capability	NRS has developed a stewardship plan for site arrangements post-IEP. *See*: Section 3.4.10, Arguments M.12, D.3, O.2 to O.4. *Key References*: [277].

B.6 Deposit for Recovery

B8 The EA provides regulation of recovery operations on land [308]. The EA grants two types of Deposit for Recovery (DfR) permit: Standard Rules and Bespoke Rules Permits. The EA's standard rules [308] have been applied, as appropriate, in the Winfrith Deposit for Recovery application. Conditions of a Standard Rules Permit addressed in the Winfrith DfR application are set out in Table B.7.

Table B.7: Conditions of a Standard Rules Permit addressed in the Winfrith Deposit for Recovery application.

ID	Requirement / Guidance	Where Addressed
DFR-1	… operators shall manage and operate the activities: in accordance with a written management system that identifies and minimises risks of pollution, including those arising from operations, maintenance, accidents, incidents, non-conformances and those drawn to the attention of the operator as a result of complaints and using sufficient competent persons and resources.	NRS has a culture that places EHSS&Q considerations at the heart of its plans and practices. This culture is evident in the development of the decommissioning strategy for Winfrith. NRS has a set of generic process documents regarding items such as planning, developing safety cases, waste management and record keeping that are implemented in site-specific procedures. The Winfrith Site Manual summarises, and sign-posts to the relevant procedures for works undertaken on the site *See:* Arguments M.1 to M.12. *Key References:* [275].
DFR-2	… operators shall: Comply with the requirements of an approved competence scheme	NRS is operating the DfR programme under the WAMITAB competence scheme. *See:* Arguments M.1 and U.1. *Key References:* [309; 310].
DFR-3	The operator is only authorised to carry out the activities specified in [308, Tab 2.1].	NRS has a clear Site Wide Materials Management Plan detailing sources and origin of materials to be deposited. EAC have been prepared for Winfrith and issued in tandem with this SWESC. *See:* Arguments M.1 and M.11. *Key References:* [268; 311].
DFR-4	…operators shall: Not deviate from the approved waste recovery plan without prior written approval from the Environment Agency.	NRS has a clear strategy for waste recovery. Whilst ongoing characterisation and optimisation is undertaken throughout decommissioning and demolition, any deviations will only occur following written agreement from the EA and confirmed updates to the Winfrith EAC. *See:* Arguments M.1, U.1 and M.11. *Key References:* [268; 311; 312].
DFR-5	…the activities shall: Not extend beyond the site.	NRS will only place material for recovery into the two reactor basements. *See:* Arguments M.1 to M.12, D.3 and D.7. *Key References:* [290; 312].

ID	Requirement / Guidance	Where Addressed
DFR-6	Wastes shall only be accepted if it is a type listed in Table 2.5 of the standard rules [308, Tab 2.5], it meets the additional restrictions in that table; and (a) it is inert waste, with the exception of topsoil, peat, soil from cleaning and washing beet and road planings; and (b) appropriate measures have been taken to ensure that the waste is free from contamination; and (c) it has been identified as a suitable waste in the approved waste recovery plan; and (d) its chemical, physical and biological characteristics make it suitable for its intended use on the site.	NRS will appropriately characterise the D630 stockpile and determine the suitability of use as backfill. In addition, EAC have been issued in tandem to this SWESC detailing the physical, chemical, and biological properties of wastes that are to be emplaced. *See:* Arguments M.11, M.13, D.2 and D.6. *Key References:* [268; 284].
DFR-7	Any waste that does not comply with all of the conditions of [308, Tab 2.5] or fit the description of the waste recorded in [308, § 2.6.1] shall be rejected and shall be: (a) Removed from the site; or (b) Moved to a designated quarantine area pending removal.	NRS has developed Emplacement Acceptance Criteria (EAC) detailing the biological, chemical and physical characteristics of the demolition material that is acceptance for use in filling the below-ground voids. Any waste that does not meet these criteria will be segregated and disposed of off-site. Stockpiled materials such as D630 will undergo a sort and segregate process to remove non-compliant materials. *See:* Arguments M.11. *Key References:* [261; 267; 268].

B.7 References

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