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Title

E3S Case Chapter 21: Decommissioning & End of Life Aspects

Executive Summary

This chapter of the Environment, Safety, Security, and Safeguards (E3S) Case presents the decommissioning aspects of the Rolls-Royce Small Modular Reactor (RR SMR). The report outlines the arguments and preliminary evidence available at the Preliminary Concept Definition (PCD) design stage to underpin the high-level Claim that the RR SMR is designed to facilitate decommissioning safely with risks reduced to As Low As Reasonably Practicable (ALARP), and using Best Available Techniques (BAT) for environmental protection.

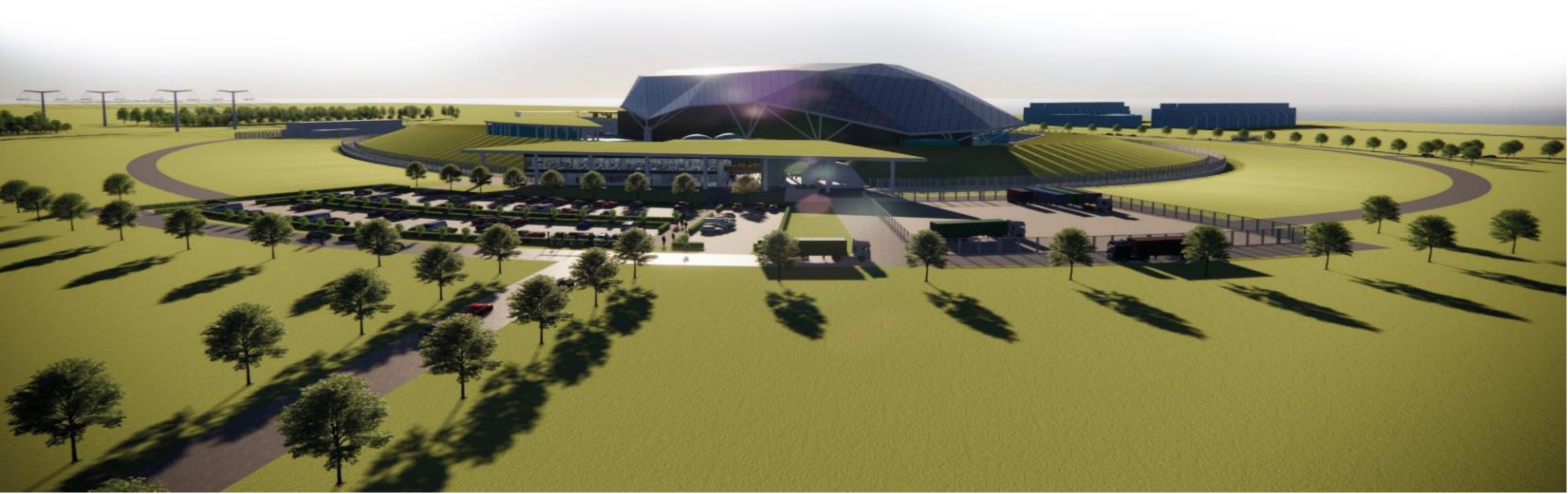
Decommissioning deals with redundant nuclear facilities that have reached the end of their operational life, and activities to return the nuclear site to an unrestricted, de-licensed condition; or return the site to a state so that the land can be used for suitable alternative uses.

RR SMR decommissioning principles are presented based on a review of applicable international and national regulations and guidance. The decommissioning strategy selected for RR SMR is immediate decommissioning, with the details of this strategy outlined, including the seven stages to decommissioning (Pre-closure Preparatory Work; Defueling and Post Operational Cleanout; Reactor De-commissioning; Intermediate Level waste (ILW) and Spent Fuel (SF) Storage; Remobilisation for Waste Disposal; ILW and SF Disposal; Final Site Clearance and Delicensing of Site for Re-Use).

This report presents a high-level summary of the Decommissioning Strategy, which all support risk reduction to ALARP.

The opportunities for decommissioning in the RR SMR design include modularisation (simplifying dismantling, handling, packaging, and transportation activities) and the deployment of standardised RR SMR plants (standardising decommissioning plans, sharing equipment and processing facilities). Options on waste minimisation, design opportunities for decommissioning and options for the end-state for the RR SMR are also presented.

At PCD, further evidence is to be developed to underpin the overall claim, including development and verification of decommissioning design requirements, and further development of the Decommissioning Strategy and Waste Management Plan.



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21.0.1 Introduction to Chapter

Chapter 21 of the Rolls-Royce Small Modular Reactor (RR SMR) Environment, Safety, Security & Safeguards (E3S) Case forms part of the Pre-Construction Safety Report (PCSR) and is a supporting reference to the Generic Environment Report (GER), as defined in E3S Case Chapter 1: Introduction, Reference [1].

Chapter 21 presents the overarching summary and entry point to the decommissioning aspects of the RR SMR, as defined at Reference Design (RD) 5 level of design maturity.

21.0.2 Scope

The scope of this chapter covers:

1. Section 21.1: sets out RR SMR's approach to decommissioning following a review of international and national regulations and guidance
2. Section 21.2: introduces RR SMR's approach to its decommissioning strategy and describes the stages for decommissioning
3. Section 21.3: describes the process for considering decommissioning at the design phase
4. Section 21.4: provides a brief outline of RR SMR's decommissioning plan
5. Section 21.5: highlights provisions within the design that consider safety during the decommissioning phase and summarises the design decisions that support waste minimisation
6. Section 21.6: states considerations for the end-state for Rolls-Royce SMR's sites
7. Section 21.7: Conclusions

Design/Programme Maturity

RR SMR design information presented in this revision of the PCSR is largely based on the design definition at the end of Preliminary Concept Definition (PCD), which is an interim design stage representing RD5 level of design maturity.

At PCD, principles for decommissioning and radioactive waste management are identified to inform the early design, however decommissioning design requirements are still in development. The overall decommissioning approach has been defined, noting the decommissioning strategy and plan for RR SMR is still in development.

21.0.3 Claims, Arguments, Evidence Route Map

The Chapter level Claim for E3S Case Chapter 21: Decommissioning & End of Life Aspects is:

Claim 21: The RR SMR is designed to facilitate decommissioning safely with risks reduced to As Low As Reasonably Practicable, and using Best Available Techniques for environmental protection

A decomposition of this Claim into Sub-Claims, Arguments, and link to the relevant Tier 2 Evidence is provided in Appendix A. For each lowest level Sub-Claim, the sections of this report providing the Evidence summary are also identified.

The complete suite of evidence to underpin the Claims in the E3S Case will be generated through the RR SMR design and E3S Case programme and documented in the Claims, Arguments, Evidence (CAE) Route Map, Reference [2], described further in E3S Case Chapter 1: Introduction, Reference [1].

21.1General Principles & Regulations

21.1.1 Introduction

Decommissioning focuses on redundant nuclear facilities that have reached the end of their operational life and to return the nuclear site to an unrestricted, de-licensed condition; or return the site to a state so that the land can be used for suitable alternative uses, Reference [3].

A key part of decommissioning is the management of waste; this includes the physical and characterization of waste, facility and site decontamination, the storage and management of waste to site clearance stage.

This section sets out RR SMR decommissioning principles based on a review of international and national regulation and guidance.

21.1.2 Decommissioning Principles

The RR SMR principles for decommissioning are set out in RR SMR's Radioactive Waste and Decommissioning Policy Framework, Reference [4]; these principles are based on Government policy, compliance with regulation and consider international and regulator guidance and stakeholder view.

Other key guidance documents include the Office for Nuclear Regulations' (ONR) Safety Assessment Principles, Reference [5] and the joint guidance on the Basic Principles of Radioactive Waste Management from ONR, Environment Agency (EA), Natural Resources Wales (NRW) and the Scottish Environment Protection Agency (SEPA), Reference [6]. RR SMR's thirteen principles for decommissioning are captured below:

1. The nuclear safety of the facility and of operations, radioactive waste management and decommissioning will comply with all applicable United Kingdom (UK) legislation and be consistent with UK government policy

2. Radioactive waste management will follow the waste hierarchy (see Section 21.1.3) approach to waste minimisation (both quantity and activity) as far as is reasonably practicable, namely:

    a. Prevention and/or reduction i.e., minimisation

    b. Preparing for reuse

    c. Recycling

    d. Disposal

3. The principles of Integrated Waste Management (IWM) will be used to define an optimised programme for all wastes (radioactive and non-radioactive) on a nuclear site; including, their programme for all wastes (radioactive and non-radioactive) on a nuclear site, plus their management methods and end-points

4. The Best Available Techniques (BAT) methodology will be used to determine how the generation of radioactive wastes (in terms of activity and volume) can be prevented, or minimised as far as is reasonably practicable, and how the risks and other detriments that will arise from managing the wastes which cannot be avoided can be reduced below statutory limits and as low as reasonably practicable

5. In addition to its generation, the total quantity of radioactive waste accumulated on site during operations will be minimised (as far as is reasonably practicable)

6. The BAT approach will also be used to ensure that the radioactive waste generated will be characterised and segregated to facilitate subsequent safe and effective subsequent management, and to justify the prevention of the mixing of radioactive substances with other substances where this might compromise subsequent effective management or increase impacts and risks (to human health or the environment)

7. Radioactive waste will be stored in a passively safe condition and accordance with good engineering practice

8. Radiological hazards will be reduced systematically and progressively with radioactive waste generated being processed into a passively safe state as soon as is reasonably practicable

9. Radioactive waste management and decommissioning strategies will be integrated with other relevant strategies

10. Records of relevant information will be generated and preserved as appropriate

11. Facilities will be designed and operated so that they can be safely decommissioned

12. Decommissioning will be scheduled to be carried out as soon as is reasonably practicable, taking all relevant factors into account (i.e., planning commences several years before the site stops operating)

13. A decommissioning plan will be prepared for each facility that sets out how the facility will be safely decommissioned

International and national regulations applicable to the decommissioning of the RR SMR are described in Sections 21.1.4 and 21.1.5.

21.1.3 Key Concepts for Waste Management

The Waste Management Hierarchy

The Waste Management Hierarchy (WMH) was first introduced into policy in the European Community in 1975 as part of the Waste Framework Directive [7] but has since been subsumed into UK law as part of the Environmental Protection Act and through Brexit changes, see UK legislation, Reference [8].

The waste hierarchy priorities the prevention and reduction of waste, followed by reuse and recycling and lastly the optimisation of its final disposal, see below:

1. Prevention; use less material in design and manufacture, keep products for longer and use less hazardous materials

2. Prepare for re-use; check, clean, repair, refurbish whole items or spare parts

3. Recycling; turn waste into a new substance or product, includes, if meets quality protocols

4. Other recovery; anaerobic digestion, incineration, with energy recovery, gasification and pyrolysis which produce energy and materials from waste

5. Landfill and incineration without energy recovery

Waste should be prevented or reduced (minimised) at source as far as possible to secure the conservation of resources and avoid issues of subsequent management. Where waste cannot be prevented, waste products or materials should, where appropriate, be reused directly or refurbished then reused. Waste materials should then be recycled or processed into a form that allows them to be reclaimed as secondary raw materials where appropriate. Where useful secondary materials cannot be reclaimed the energy content of waste should be recovered (though in general the scope for this is more limited for radioactive material). All waste will be disposed of: - solid waste to a controlled land fill, gaseous through monitored and filtered routes, and aqueous through controlled discharge routes, which are permitted.

Whilst designing a facility, decontamination of that facility should be taken into account, to facilitate decontamination activities and minimise radiological waste.

Best Available Techniques

BAT is a term that was already in use prior to its adoption in the nuclear industry as the successor to the use of Best Practicable Environmental Options (BPEO) and Best Practicable Means (BPM). All of these approaches are intended, whether at the strategic level (for BPEO) or at a more technical, waste-stream or process level (for BPM), to be the latest stage of development of processes, facilities or methods of operation which is practicable and suitable to limit waste arisings and disposals, also taking into account a broad range of options that will be relevant to the selection of the optimum solution such as the safety in operation and the financial outlay involved. BAT applies throughout the lifetime of a process, from design to implementation, operation, maintenance and decommissioning.

Identification and implementation of BAT requires a balanced judgement of the benefit derived from a measure (e.g. to reduce radioactive waste production) and the cost, efforts and risks of its introduction. The level of effort expended to resolve an issue, and to record the selection process, should be proportionate to the scale of the challenge, the range of options available and the extent to which established good practice can be used to assist in the decision-making process. Nonetheless, guidance and precedent make clear that in the context of the optimum solution identified, any measures that could be adopted to further reduce risk to health, time, trouble or other costs involved would be “grossly disproportionate” to the benefit.

21.1.4 International Safety Regulations and Standards for Decommissioning and Radioactive Waste Management

International Atomic Energy Agency on Decommissioning

The International Atomic Energy Agency (IAEA) has recognised two primary decommissioning strategies in developing IAEA safety standards Reference [9]; these primary strategies are:

1. Immediate dismantling. Dismantling commences soon after permanent shutdown of the plant with radioactive material being removed

2. Deferred dismantling. Following removal of the nuclear fuel from the facility (for nuclear installations), all or part of a facility containing radioactive material is either processed or placed in such a condition that it can be put in safe storage and the facility maintained until it is subsequently decontaminated and/or dismantled

The IAEA Safety Standard on Decommissioning of Activities: GSR, Part 6, Reference [9] provides a set of requirements on the following eight topics:

1. Protection of People and Protection of the environment

2. Responsibilities Associated with Decommissioning

3. Management of Decommissioning

4. Decommissioning Strategy

5. Financing of Decommissioning

6. Planning for Decommissioning during the Lifetime of the facility

7. Conduct of Decommissioning Actions

8. Completion of Decommissioning Actions and Termination of the Authorization of Decommissioning

The European Community on Decommissioning Activities

The consolidated version of the Treaty establishing the European Atomic Energy Community, 2010/C 84/01 Reference [10]; states that decommissioning is one of the activities for which the European Commission requires a submission by governments of Member States under Article 37 (or the European Atomic Energy Community (Euratom) Treaty), identifying the potential impacts on Member State countries of the decommissioning strategy.

The International Atomic Energy Agency on Radioactive Waste Management

IAEA Safety Standards Series No. GSG-1 Reference [11]; sets out the system for the classification of radioactive waste.

IAEA Specific Safety Requirements No. SSR-5 Reference [12]; sets out the basic requirements for the safe disposal of radioactive waste that may be produced during the operation and decommissioning of nuclear facilities.

IAEA Safety Standards Series No. RD-G-1.7 Reference [13]; sets out the application of the concepts of exclusion, exemption and clearance to materials that are characterised by the lowest activity concentrations.

The IAEA Safety Standard SSR-6 Reference [14]; sets out the international Regulations for the Safe Transport of Radioactive Material.

21.1.5 National Policy, Strategy, Regulations and Guidance on Decommissioning and Radioactive Waste Management

UK Policy on Radioactive Waste Management

An updated framework for the long-term management of higher activity radioactive waste Reference [15]; states the UK Government, along with many of the world's major nuclear nations, believes the safest option is to dispose of this higher activity radioactive waste in a geological disposal facility, where the waste is packaged and isolated in a series of vaults and tunnels deep underground. This will ensure that no harmful amount of radioactivity ever reaches the surface.

As radioactive waste management is a devolved matter, the UK Government has responsibility for the policy only in England. The Department for Energy Security and Net Zero is the government department with the policy responsibility for nuclear decommissioning and managing radioactive waste and materials. Government delivery agencies, commercial operators and regulators implement and deliver their respective missions within this framework.

For RR SMR, it is worth highlighting the following Welsh Policy documents: Management, Reference [16] and Disposal of Higher Activity Waste and Geological Disposal of Higher Activity Radioactive Waste: Community Engagement and Siting Processes, Reference [17].

The UK Strategy for Radioactive Discharges Reference [18] is in line with IAEA safety principles, that compliance is subject to the demonstration of the BAT.

Office for Nuclear Regulation Guidance on Decommissioning

The ONR define decommissioning as a process of dealing with redundant nuclear facilities that have reached the end of their operational life, Reference [3]. The objective of decommissioning a nuclear installation is either:

1. Stage 1 - Post-operational clean out: where the bulk of the radioactive material, such as used nuclear fuel, is removed from the facility

2. Stage 2a – Deferred dismantling: making preparations through removal of residual radioactive waste and other plant items prior to putting the facility into a defined period of care and maintenance to accrue the benefits of radioactive decay prior to final dismantling OR

3. Stage 2b – Prompt dismantling: initial work is to remove residual radioactive material and waste prior to the demolition of structures; and remediation of land to meet an agreed end-state

4. Stage 3 – Final site clean-up to a point where the site may have its nuclear site licence revoked by ONR

Initially, all licensees must produce a clear decommissioning strategy that will demonstrate how all operational and proposed plants can be decommissioned safely at the end of its operational life. For larger decommissioning projects or projects containing a high nuclear risk, ONR may require the licensee to divide the project into series of sequential stages with the objective of each stage to deliver significant hazard reduction.

As part of the decommissioning process, there is a requirement to assess the potential environmental impact of projects to decommission nuclear facilities through the Environmental Impact Assessment of Decommissioning Regulations (EIADR) Reference [19].

For more information on ONR's Safety Assessment Principles for Decommissioning and Radioactive Waste Management, see Reference [5].

Environment Agency on Decommissioning

The EA have several generic devolved principles for decommissioning in the Regulation Environmental Principles (REPs), Reference [20]; these are:

1. Principle DEDP1 – Decommissioning Strategy. Each site should have a decommissioning strategy that is updated and refined at appropriate intervals

2. Principle DEDP2 – Decommissioning Plan. There should be a decommissioning plan for each facility and this should be updated and refined throughout its operating life and during decommissioning

3. Principle DEDP3 – Considering Decommissioning during Design and Operation. Facilities should be designed, built and operated using best available techniques to minimise the impacts on people and the environment of decommissioning operations and the management of decommissioning wastes

4. Principle DEDP4 –Discharges during Decommissioning. Aerial or liquid radioactive discharges to the environment during decommissioning should be kept to the minimum consistent with the decommissioning strategy for the site

5. Principle DEDP5 – Legacy Wastes. Decommissioning strategies and plans should provide for the timely characterisation, retrieval, conditioning and packaging of legacy radioactive wastes

UK Regulations on Permitting

The Environmental Permitting (England and Wales) Regulations 2010 Reference [21]; BAT are used to justify specific approaches or practices giving rise to radioactive waste; as this is a requirement within the terms of permits issued. The operator is required to have a management system, organisational structure and resources sufficient to comply with limitations and conditions stipulated within the permit. The principle of applying "best practice" should be explicit in all site strategies, whether construction and operation or decommissioning programmes and activities.

Despite the current Scottish Government's requirement to move away from fission nuclear power, this is a devolved position, Scotland do store their own waste through regulation under EA (S)R 2018, see References [22] and [23],and near surface storage for High Active Waste (HAW).

UK Guidance for Managing Waste

Low Level Waste (LLW) Repository Ltd Reference [24]; provides specific guidance for the application of the WMH in the UK for radioactive wastes.

Serco Reference [25]; provides specific guidance in the context of managing higher activity wastes.

UK Radioactive Substances Regulation

Specific guidance on the management of radioactive materials on nuclear licensed sites is given in Reference [26]. Under the Environmental Permitting (England and Wales) Regulations 2010 (as amended) (EPR2010) Reference [21], the Environment Agency is responsible for regulating all disposals of radioactive waste on and from sites in England and Wales. Schedule 23 of the EPR2010 (and subsequent amendments) provides the underlying justification for the environmental permit application for the disposal and discharge of radioactive waste from such a site.

Radioactive Substances Regulation Environmental Principles

The Environment Agency published the Radioactive Substances Regulation REPs Reference [27] to provide a standardised framework for technical assessments and judgements undertaken by the Environment Agency. Although it is not their prime purpose, the REPs are also of value to current and potential operators and owners of facilities and sites where radioactive substances are used and radioactive wastes are generated and managed.

The relevant REPs applicable to radioactive waste management in the Radioactive Substance Management (including Waste Disposal) Developed Principle (RSMDP) are:

1. RSMDP1 – Radioactive Substances Strategy: A strategy should be produced for the management of all radioactive substances

2. RSMDP3 – Use of BAT to minimise waste: BAT should be used to ensure that production of radioactive waste is prevented and where that is not practicable, minimised with regard to activity and quantity

3. RSMDP4 – Methodology for Identifying BAT: BAT should be identified by a methodology that is timely, transparent, inclusive, based on good quality data, and properly documented

4. RSMDP8 – Segregation of Wastes: BAT should be used to prevent the mixing of radioactive substances with other materials, including other radioactive substances, where such mixing might compromise subsequent effective management or increase environmental impacts or risks

5. RSMDP9 – Characterisation: Radioactive substances should be characterised using the best available techniques so as to facilitate their subsequent management, including waste disposal

6. RSMDP10 – Storage: Radioactive substances should be stored using the best available techniques so that their environmental risk and environmental impact are minimised and that subsequent management, including disposal is facilitated

7. RSMDP11 – Storage in a Passively Safe State: Where radioactive substances are currently not stored in a passively safe state and there are worthwhile environmental or safety benefits in doing so then the substances should be processed into a passively safe state

Nuclear Installations Act

In accordance with the Nuclear Installations Act 1965 (NIA) Reference [28], an organisation wishing to carry out prescribed nuclear activities must apply for, and be granted, a Nuclear Site Licence (NSL) by the ONR, before it commences the installation of a nuclear safety-related plant. The NIA specifies many of the regulatory requirements for radioactive substances on nuclear licensed sites. The keeping and use of radioactive materials and accumulation of radioactive wastes is regulated by the ONR. However, the holder of a NSL requires an EPR2010 (and subsequent amendments) permit for the disposal of radioactive waste, and for the keeping or use of mobile radioactive sources, regulated by the Environment Agency.

ONR's License Conditions applicable to Decommissioning and Radioactive Waste Management

All nuclear site licenses granted under NIA include 36 standard conditions Reference [29]. The licence conditions that are considered relevant to decommissioning, management of radioactive and nuclear materials on site are:

1. Condition 4: Restrictions on nuclear matter on the site
2. Condition 5: Consignment of nuclear matter
3. Condition 32: Accumulation of radioactive waste
4. Condition 33: Disposal of radioactive waste
5. Condition 34: Leakage and escape of radioactive waste
6. Condition 35: Decommissioning

21.2 Decommissioning Strategy

21.2.1 Introduction

To decide the best approach for RR SMR's Decommissioning Strategy, the engineering optioneering process (C3.2.2-2) has been followed, Reference [30]. The decommissioning options under consideration were:

1. Prompt/continuous dismantling - commences as soon as possible after end of generation, with onsite intermediate conditional storage requirements

2. Deferred dismantling which includes two options: -

    a. deferred dismantling of Intermediate Level Waste (ILW), removal of non-ILW materials from End of Generation (EoG), which includes non-radioactive as well as LLW or

    b. deferred radiological dismantling including ILW and LLW, with non-radioactive waste dismantling after EoG as previously

3. Entombment - encase the reactor island in concrete, becoming a waste site for perpetuity

Option 1, prompt/immediate decommissioning, is selected as the most suitable decommissioning strategy, as this complies with the UK Government policy, IAEA guidance and agrees with RR SMR policy, Reference [4].

Underpinning this decision, the following design objectives have been considered (associated arguments included); this list is not exhaustive, as only clear differences between options are highlighted here, for all design objectives, see Reference [30].

1. **Minimise normal operation and maintenance dose to ALARP Levels:** There will be a limited decay period prior to decommissioning activities, likely to use remote handling to minimise risk to operators during dismantling. This option has the advantage of quickly passivating the radiological hazard. However, further consideration is required to assess double handling of packages during storage in the decommissioning waste store.

2. **Minimise environmental impact:** showing compliance with BAT principles for minimisation of conventional and radioactive waste and ensuring sustainable development: There is the possibility to utilise existing process water in decommissioning activities to minimise the generation and discharge of additional liquid effluent. This will minimise the requirement for waste production during the maintenance and monitoring period, it also reduces the risk of failure of the facility, once no longer in operation.

3. **Minimise cost of decommissioning:** There are higher costs associated with decommissioning and interim storage of wastes and remote handling systems. However, the cost implication of maintaining existing equipment for use in decommissioning in the short term, would be less than maintaining equipment e.g., cranes over a long term (option 2).

4. **Maximise use of proven technology (minimise development cost/risk):** International technology exists for decommissioning Pressurised Water Reactor (PWR) projects.

5. **Maximise site availability and flexibility:** Prompt decommissioning could facilitate early site clearance and delicensing, potentially making the land available for other uses – decades earlier than deferred decommissioning strategy.

21.2.2 Prompt Decommissioning

Prompt/continuous decommissioning seeks to decommission the station as quickly as possible, whilst recognising that there will be external constraints which may require the timescale from reactor closure to site de-licensing to be extended.

The most likely reason for such an extension would be unavailability of a Geological Disposal Facility (GDF). Although, a GDF should be operational at the time of decommissioning, it may not be available to the operator until sometime after decommissioning has started, potentially a few decades, as legacy waste may be given priority access (to a GDF) to reduce hazards at Nuclear Decommissioning Authority (NDA) sites.

In addition, there is uncertainty surrounding the throughput rate that a GDF will be able to achieve. As a result, decommissioning waste from new build Nuclear Power Plants (NPPs) may need to be stored on-site, and the stores themselves will need to be decommissioned once the remainder of the site has been cleared.

Decontamination and dismantling operations commence shortly after the final shutdown. Work progresses in a series of phases or as a single project until an approved end state, including the release of the facility or site from regulatory control, has been reached, Reference [31].

Immediate decommissioning may be able to take advantage of the availability of the knowledge and experience of staff that have operated the facility at the end of operations which may still be available and avoids maintenance/asset care costs over an extended period.

Immediate decommissioning is consistent with UK Government policy and guidance, evidenced by The Base Case in Reference [32].

The IAEA notes that generally, "*immediate dismantling is the preferred strategy, as it avoids transferring the burden of decommissioning to future generations*", Reference [33].

It is worth nothing that Operating Experience (OPEX) from other PWRs has shown that there is no benefit to delaying decommissioning, as the nuclides with long half-lives will not meet their half-life during the period of delay. International guidance also states that the preferred option is for immediate dismantling, see Reference [9].

21.2.3 Decommissioning Strategy

At PCD design stage, the RR SMR Decommissioning Strategy is in development. The Decommissioning Strategy is based on the following four expectations:

1. In general, decommissioning should be carried out as soon as it is reasonably practicable, taking account of all relevant factors

2. Hazards associated with the plant or site should be reduced in a progressive and systematic manner

3. Full use should be made of existing routes for the disposal of radioactive waste

4. Remaining radioactive material and radioactive waste should be put into a passively safe state for interim storage pending future disposal or other long-term solution

At a high level, the Decommissioning Strategy is outlined below, the original reference for this list can be found in RR SMR *Radioactive Waste and Decommissioning Policy Framework*, Reference [4]. As this reference was written before the creation of the Safety Reports and the Decision File on the Decommissioning Strategy, this list has been updated to reflect these changes.

1. At all times the health and safety of the workforce, general public and the environment will be adequately protected. A key requirement of the strategy is that inequitable burdens will not be imposed upon future generations

2. When undertaking design of the RR SMR due account will need to be taken to enable the decommissioning of the NPP at the end of the operational life to be conducted safely

3. When undertaking design, the BAT process will be used to determine the best available techniques to use. In the BAT process all aspects will be considered to ensure that the best overall outcome is arrived at

4. When undertaking design, operation and decommissioning due consideration will be given to minimising the volume and activity of radioactive wastes and volumes of non-active wastes that will produced; this will take due account of the Integrated Waste Strategy (IWS). In addition, due consideration will be given to dose minimisation to ensure that risks are reduced to ALARP, for example, decommissioning will likely use remote handling

The decommissioning strategy will consider the following, Reference [34]:

1. Modularisation – how the interdependency between modules impacts decommissioning activities

2. Operator specific – Decommissioning & Waste Management Plan (10 yearly review), any permitted site in the UK will have to have a Site-Wide Environmental Safety Case (SWESC) and Waste Management Plan in place

3. Operational experience for future – capture factors that impact decommissioning (i.e., plant modifications)

As the design is evolving, significant changes may impact the Decommissioning Strategy.

21.2.4 Stages of Decommissioning

The IWS sets out the seven stages for decommissioning (with approximated timeframes) that will take place over a total of ~110 years, Reference [35]; these are:

1. Phase 1 (~5 years): Pre-closure Preparatory Work: This work will commence approximately five years prior to final cessation of generation to avoid delays in the transition to decommissioning. Key regulatory submissions in support of this phase include (but are not limited to) the final core safety case, the Detailed Decommissioning Plan/Near-Term Work Plan, and revisions to the licence compliance arrangements

2. Phase 2 (~5-10 years): Defueling and Post Operational Cleanout (POCO): Defueling (involving initial cooling of Spent Fuel (SF) in the Spent Fuel Pool (SFP) and transfer to the SF store; see below) will be carried out using the operational fuel handling equipment, procedures, and safety case. Retrieval, processing and packaging of operational wastes (e.g., filters, in line with operational procedures), along with decontamination of the primary circuit, will take place in the early stages of decommissioning. Turbine island decommissioning will take place after the completion of defueling. Various systems will need to remain operational to support the above tasks, but any that become redundant at shutdown will be removed as soon as practicable

3. Phase 3 (~4-6 years): Reactor De-commissioning: All remaining plant, equipment and buildings (including the reactor and primary circuit but excluding the ILW and SF stores) will be decommissioned, and the associated waste managed, at this stage. A Decommissioning Waste Management Facility will be required for decontamination and dismantling operations (at PCD, it is envisaged that a facility inside the berm will not be used to minimise delays and ensure enough space to decommission). Radiological surveys, excavation of structures and delicensing activities will occur during this stage as well

4. Phase 4 (~70 years): ILW and SF Storage: The volumes of operational and decommissioning waste to be managed at this stage are uncertain, and the required stores are in the preliminary stages of design'. Therefore, the nature of the storage is not yet known (and will be updated in future issue of the E3S Case), but this phase is planned to be largely quiescent with primarily non-routine activities (including maintenance, inspections, and recladding of buildings) taking place

5. Phase 5 (~2 years): Remobilisation for Waste Disposal: This phase will align in terms of timing with the GDF becoming available for the acceptance of ILW. Personnel will be mobilised to the site to retrieve ILW packages and transfer them offsite (for GDF disposal), and the ILW store will be demolished once this is complete (leaving only the SF store/Hot Cell buildings on site)

6. Phase 6 (~5-10 years): ILW and SF Disposal: This phase will commence with the refurbishment of the Hot Cell building (for repackaging), after which the SF casks will be retrieved from the SF store, and the SF repackaged into the GDF-compliant containers in the Hot Cell for offsite transfer (GDF disposal). All remaining materials and wastes will be managed in accordance with the waste hierarchy

7. Phase 7 (~6 years): Final Site Clearance and Delicensing of Site for Re-Use: This final stage will involve the removal and clearance of all remaining structures and materials followed by monitoring, remediation and landscaping activities such that decommissioning can be completed, and Radiological Substances Regulations (RSR) environmental permits and the nuclear site license rescinded

21.3 Facilitating Decommissioning during Design

21.3.1 Introduction

This section highlights, at a high-level, design considerations for decommissioning activities.

21.3.2 Decommissioning Requirements

The RR SMR programme is following a design-led, E3S-informed approach, as described in E3S Case Chapter 1: Introduction, Reference [1], which includes a consistent set of design objectives that have been defined for the RR SMR project to direct the progression of the design architecture/solutions based on market and functional needs. This includes minimising environmental impact and complexity during decommissioning.

As design concepts for Structures, Systems and Components (SSCs) are developed, they are down selected through the design decision-making process, including evaluation against the design objectives. As such, SSCs are designed in a manner that supports minimisation of decommissioning complexity and the environmental impacts of decommissioning.

Decommissioning must be considered as part of initial design and of design change. When undertaking design work or making a design change, two separate requirements need to be considered for RR SMR:

1. The regulatory requirement that decommissioning must be considered in the design and design change process (see UK Nuclear Safety Legislation and Environmental Permitting Legislation in Section 21.1)

2. Financial implications of the design change so that they can be reported, where appropriate, under the Funded Administration Plan (FAP) arrangements, as required by the Energy Act 2008

From a review of international and national regulations and guidance (detailed in Section 21.1), the following provides key principles to inform the design and layout of plant, systems, and buildings to facilitate decommissioning, noting these will be formalised into design requirements in line with the CAE Route Map, see Appendix A: CAE Route Map.

All requirements must be in place by Definition Review (DR3), for more information on the Definition Review Process, see Engineering Process C3.2.1-2.

All requirements are referenced within the requirements database Dynamic Object-Oriented Requirements System (DOORS) and will be substantiated, as part Engineering Develop Verification Strategy Process (C3.1.2):

1. The design life of plant and systems must include its continued use during decommissioning where appropriate

2. Avoid where possible the use of embedded pipework, ducts and equipment in floors and walls

3. Avoid where possible the use of potentially radioactive underground tanks, sumps, ducts and drains

4. Pools, sumps, and trenches in concrete floors should be lined with a suitable corrosion resistant material to protect from contamination and to facilitate clean-up and by providing corrosion-resistant tanks

5. Radioactive and non-radioactive systems and areas should be kept separate

6. Special consideration should be given to the design of systems such as active drains or pipes passing through conventional plant areas

7. Pipes and ductwork installations should be designed to minimise the hold-up and deposition of 'crud' and active dust particulates

8. Segregation / interconnection of systems and services and their potential change of use during decommissioning should be considered

9. System design and plant layout should facilitate segmentation, where necessary, of large, contaminated or activated items for easy removal

10. Easy, safe access should be incorporated into the design for characterisation, decontamination, disassembly and handling of plant using proven, simple working practices

11. Facilities such as lifting beams and hoists for handling of plant during construction and / or operational maintenance will facilitate decommissioning

12. The number of components in the design should be minimised

13. Modular design should be employed that will facilitate construction as well as dismantling (by reversing the construction sequence)

14. Special provision should be made for dealing with plant and systems, such as evaporators for liquid waste, which can lead to high dose exposure and other problems during dismantling

15. Facilities, lay-down areas and space for interim management and handling of components and waste packages during decommissioning should be provided (i.e., buffer storage facilities)

16. The design should incorporate suitable access to allow intact removal of large plant items such as steam generators and large pumps

17. Plant installation handling features should remain where practicable

18. Penetrations, cracks, crevices and joints that may trap contaminants should be minimised

19. All porous surfaces should be sealed against ingress of activity and other hazardous chemicals

20. Special surface finishes or polishing treatments should be employed where appropriate to prevent adherence of contamination or penetration into the surface of materials

21. Overdesign of shielding should be avoided, bearing in mind that the design of a biological shield involves a balance between structural aspects and minimising activation

22. The footprint of structures should be minimised reducing the amount of construction materials (concrete and steel), thus reducing the decommissioning waste

23. The design should minimise the generation of mixed hazardous wastes as far as practicable

24. The segregation of radioactive waste streams should be incorporated into the plant design

25. The use of hazardous materials, or those which become hazardous during operation, should be minimised

26. Storage facilities for radioactive wastes and spent fuel should consider the full lifetime of the site and should be expandable

27. Monitoring systems for the early detection of leaks and contamination should be employed

28. Secondary containment of pipework carrying active liquids should be employed, fitted with appropriate leak detection

29. Provision should be made for the decontamination of systems during operational life

30. Provision of decontamination facilities should be made for maintenance and clean-up purposes

31. The generation of active materials in steel components and concrete should be minimised by limiting the trace elements which become particularly radioactive during neutron activation in operation. These include in particular: Cobalt, Nickel, Niobium and Silver. Consequently, stainless steels should be utilised only where necessary for safety and design performance reasons

32. Samples of material subject to neutron activation should be taken and appropriately stored, with adequate records of the source etc., so that they are available when required at end of life

33. The design should incorporate activation monitoring arrangements for the reactor and immediately surrounding area

34. The design of records management systems must consider the format of the stored record, the media upon which it is stored, the cataloguing of the record and its accessibility when required at end of life for decommissioning

35. Use of bolted connections instead of welded connections in steelwork structures

36. Specification of increased concrete cover on certain faces of reinforced concrete structures to aid future removal (via scabbling) of the most highly contaminated surface layers, potentially leaving the rest of the concrete to be decommissioned conventionally

37. Specification of features to assist the subsequent removal of the structures e.g. inclusion of conduits embedded within Reinforced Concrete (RC) structures, through which wire saws can be inserted to aid final break up and removal of the structures

38. Avoid the use of pre-stressed concrete

Further guidance and examples of design features to facilitate decommissioning activities [36] that will be used to inform design requirements include:

1. Easy isolation of systems
2. Systems designed with minimum interdependencies
3. Easy disassembly allowing heavy component replacement
4. Choice of materials, with the aim of reducing risks resulting from high dose rate from radioactive material and reducing the amount of long half-life radioisotopes. Especially, materials leading to formation of Cobalt 60 (^{60}Co) and Carbon 14 (^{14}C) shall be minimised
5. Achievement of good surface condition for potentially contaminated components, facilitating subsequent decontamination
6. Ready accessibility and easy removal of components and internals in order: to minimise the radiation exposure to the personnel; and to reduce the number of personnel required for Decommissioning work
7. Provision of systems to monitor and record leakage throughout the lifetime of the plant at strategically chosen points (i.e., use of double containment to minimise escape into environment)
8. Avoid the installation of radioactive pipelines and/or channels inside concrete structures or soil

21.3.3 Waste Management

The RR SMR IWS sets out the strategy for managing 'operational' wastes arising from RR SMR, Reference [35]. Decommissioning wastes (type and volumes) will vary between the phases for decommissioning, the Decommissioning Plan will address this in more detail, see Appendix A: CAE Route Map.

21.3.4 Radioactive Waste Management Arrangements

Radioactive waste management arrangements are covered in E3S Case: Chapter 26: Radioactive Waste Management Arrangements, Reference [37]. As this links closely to Decommissioning, some key aspects are summarised in this section.

Waste Package Records

Waste package records will need to be produced for all waste packaged in the RR SMR, and the Nuclear Waste Services (NWS) requirement for this is captured in the 'Waste Package Data and Information Recording Requirements' document. At the time of writing initial discussions had taken place but formal proposals for capturing and recording data will be endorsed as part of the Letter of Compliance (LoC) process (see above), but the general requirements to capture data as waste is being packaged are understood.

Disposability Assessment

The term 'Disposability Assessment' can refer to two separate (but related) processes that are undertaken in different contexts, defined as follows:

1. **Generic Design Assessment (GDA) Disposability Assessment** – this refers to a preliminary judgement as to the potential acceptability for proposed generic waste packaging approaches. This process is led by the Requesting Party (RP) undertaking GDA through issue of a report outlining the proposed waste packaging approaches (along with underpinning information) which is assessed by regulators and NWS

2. **NWS Disposability Assessment** – this refers to the process led and managed by the Waste Management Directorate of NWS, which is initiated when a waste producer approaches NWS with a specific packaging proposal (i.e., for particular containers and waste stream or streams). The proposal is formally assessed using a detailed procedure that considers multiple technical aspects of the waste, containers and associated information records, and leads to acceptance and endorsement (or rejection) through issue of a LoC, a process which is staged to conceptual, interim and final LoCs as the level of detail and confidence is developed)

Obtaining an LoC for all of the HAW streams to be produced by the RR SMR will be one of the key aims in terms of Radioactive Waste Management, and the GDA Disposability Case is the first step in that process. The Disposability Case is anticipated, evidence is in development in line with the CAE Route Map and will be summarised in future revisions of the E3S Case, see Reference [34].

The Disposability Case will outline the waste types, primarily SF and HAW, along with specific streams (e.g., Self-Powered Neutron Detectors, (SPNDs)) and provide a high-level description of geological disposal (including broad concept options and potential host geologies) and packaging concepts for different waste types (High Heat Generating Waste / Low Heat Generating Waste).

Waste package/management records are an inherent and crucial aspect of the Disposability Assessment/LoC process that the operator of the RR SMR will have to undertake in order to demonstrate disposability of waste packages. For more information, see Reference [34].

An NWS Disposability Assessment Report for ILW & SF is in development, in line with the CAE Route Map, and will be summarised in future revisions of the E3S Case, see Reference [34].

21.4 Decommissioning and Waste Management Plan

21.4.1 Introduction

The generic Decommissioning and Waste Management Plan is in development, in line with the CAE Route Map, and will be summarised in future revisions of the E3S Case, see Reference [34].

The Plan will include the estimated basis for liability costs, a description of generated wastes, with a high-level view of the steps to dismantle the RR SMR reactor (i.e., decontamination, dismantling, waste removal and clearance of the site following the cessation of operations); there will also be a review of the funded decommissioning costs.

21.5 Provisions for Safety during Decommissioning

21.5.1 Introduction

Within the design of RR SMR, there are opportunities for decommissioning, two key ones are:

1. The RR SMR design philosophy of modularisation provides significant opportunities for decommissioning, as dismantling, size reduction (where possible) handling, packaging and transportation activities are simplified

2. The deployment of multiple RR SMRs in the UK (and/or internationally) could provide the opportunity for OPEX, equipment (i.e., dismantling) and technique sharing for different lifecycle phases (including decommissioning), standardisation of decommissioning plans and strategies and radioactive waste processing facilities across multiple sites

This section highlights how the design of RR SMR minimises waste, and a description of the decontamination strategy and access for people and equipment during the various stages of decommissioning.

21.5.2 Waste Minimisation

In line with the BAT principles described in Section 21.1, the following list highlights how the design of RR SMR minimises waste:

1. Boron (and lithium)-free (potassium-based) chemistry: Boron-free chemistry (which is enabled using potassium-based pH control) provides a considerable reduction in tritium generation and greatly increases effluent recycling possibilities/minimisation of liquid discharges in normal operation and reduces the requirement for evaporators to process liquid waste (minimising waste), which can lead to high dose exposure and other problems during dismantling

2. Replacement of heavy-duty evaporator with Reverse Osmosis (RO) followed by vacuum evaporator for volume reduction: This allows 95-98% recycling of effluent, reduces Ion Exchange (IEX) resin waste, reduces volume of concentrates (as the boron-free chemistry permits a higher volume reduction factor)

3. Decay storage of resins/concentrates: The decay storage of these waste streams (in place of direct disposal) will allow the total ILW volumes from these streams to be reduced significantly

4. Back-washable filters: This reduces waste packages by 75% (averaged over a 10-year period) by reducing ILW filter packages and reducing overall ILW storage volume. The advantages of using back-washable filters are identified as follows:

    a. Does not require opening reactor coolant pressure boundary

    b. Does not require a filter change machine

    c. Reduces operator burden and dose

  d. Enables delayed build of the ILW store

5. Co-packaging of wet LLW waste: This reduces the total number of LLW packages that will be required for offsite management

6. Cementation of ILW waste: This provides a flexible, turnkey method for treatment

The waste stream produced by the systems described above, applying the minimisation philosophy described above, as described in detail in the following section.

For more details on the waste types, categories, and management of operational wastes, see Reference [35].

21.5.3 Decontamination

An ongoing waste-generating activity will be decontamination, which will be undertaken from commissioning and early operations onwards. This will be required for equipment and tools affected by radiological and non-radiological contaminants (e.g., used personal protective equipment, pumps, pipework, hoses etc., noting that the decontamination of larger items and the primary circuit is uncertain at this stage).

Decontamination is planned to be undertaken by the component decontamination system; as this system is still in development, more information will be available as the design matures.

21.5.4 Access of Personnel and Machines for the Removal of Waste

From early in the design process, human factors are considered, including a space reservation for people in the design when making decisions on location and spacing of structures, systems, and equipment. Space reservations not only accommodate safe operation, but also commissioning, maintenance, and decommissioning activities. Anthropometric data have been applied in the definition of the space reservation requirements for humans.

A Target Audience Description (TAD), Reference [38], has been created by Human Factors competent persons that gives a description of the different types of personnel that will interact with the RR SMR facility, systems and equipment throughout its lifecycle, and their capabilities and physical characteristics. The TAD applies to all areas of RR SMR and is referenced within the requirements database DOORS.

The overall aim of the TAD is to convey the human physical characteristics and design constraints arising from a defined, future 'user population', to help ensure the design of the RR SMR facility, systems and equipment adequately accommodates everyone who is expected to interact with the plant at all lifecycle stages. The TAD is currently in development in line with the CAE Route Map.

21.6 End-of-Life Aspects for the Decommissioned Site

21.6.1 Introduction

The end-of-life aspects for the decommissioned site occur in Stage 7: Final Site Clearance and Delicensing of Site for Re-Use.

During this phase, site clearance, monitoring, remediation, and landscaping activities (if required) take place. If decommissioning base line assumptions are not met, site licenses and permits will need to be reviewed.

21.6.2 End State Definition

When all facilities have been cleared and the site is returned to a pre-agreed state, with the regulators and the planning authority, decommissioning is complete.

There are three possible states that a site is expected to meet:

1. Delicensed to greenfield, if built on greenfield
2. Return to previous state, if built on existing site
3. Clean-up site to next planned use

The site may be delicensed in sections; for example, the Spent Fuel Store and the ILW store may remain a licensed site until the stores have been dismantled and removed.

There is an expectation that end states for different parts of the site will be reached at different times (i.e., the Spent Fuel Stores and the ILW Stores and Reactor Island).

For decommissioning activities to continue, there is an assumption the site will be remediated to allow for unrestricted access, on the assumption that buildings are confirmed to be radiological clean, following decontamination activities to meet ONR's 'no danger' criteria and to meet environmental regulations.

A site-specific Decommissioning Strategy will set out the decisions on future use and expectations for site delicensing, as these decisions relate to previous land use. This is captured as a 'Commitment on the Future Dutyholder/Licensee':

Commitment on Future Dutyholder/Licensee C21.1: The future dutyholder/licensee shall develop a site-specific Decommissioning Strategy to set out the decisions on future use and expectations for site delicensing.

21.7 Conclusions

21.7.1 Conclusions

Preliminary evidence is presented to support the overall chapter claim that 'The RR SMR is designed to facilitate decommissioning safely with risks reduced to As Low As Reasonably Practicable, and using Best Available Techniques for environmental protection', which contributes to the overall E3S objective to protect people and the environment from harm, and the demonstration that risks are reduced ALARP.

The preliminary evidence presented includes decommissioning principles that inform the design through the development of decommissioning requirements (currently under development), the decommissioning strategy and end-state site considerations.

Once complete, these activities mean that decommissioning will be embedded into RR SMR processes early in design stage (Optioneering), such that outputs can support reduction of decommissioning risks to ALARP.

Further evidence to support the ALARP position will be developed as the design progresses, including the definition of design requirements from the design principles, verification of design requirements, and further development of the Decommissioning Strategy and Waste Management Plans, these will be developed in line with CAE Route Map.

21.7.2 Assumptions & Commitments on Future Dutyholder/Licensee

Table 21.7-1: Assumptions and Commitments on Future Dutyholder/Licensee

Assumption/Commitment	ID	Description
Commitment	C21.1	The future dutyholder/licensee shall develop a site-specific Decommissioning Strategy to set out the decisions on future use and expectations for site delicensing

21.8 References

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21.9 Appendix A: CAE Route Map

21.9.1 Chapter 21 Route Map

A preliminary Claims decomposition from the overall Chapter 21 Claim is summarised in Table 21.9-1, including the Tier 2 Evidence underpinning the Claims at PCD (i.e., summarised in Revision 1 of this report) and further Tier 2 Evidence still to be developed.

Table 21.9-1: CAE Route Map

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary within Chapter 21**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***in development**
The design incorporates features to facilitate decommissioning	-	-	The decommissioning principles and regulations that the RR SMR shall adhere to are identified	Section 21.1	Radioactive Waste and Decommissioning Policy Framework [4]	-
	-	-	Requirements for decommissioning are placed onto the design	Section 21.3	n/a	Design for Decommissioning Requirements DOORS Modules

Level 1 Claims	Level 2 Claims	Level 3 Claims	Arguments	Evidence Summary within Chapter 21	Underpinning Tier 2 Evidence ***at PCD**	Underpinning Tier 2 Evidence ***in development**
	-	-	Measures are adopted in the design and operation to ensure safety and BAT during decommissioning	Section 21.5	Integrated Waste Strategy [35] Target Audience Description [38]	Design for Decommissioning Verification DOORS Modules
Decommissioning strategies are identified that can be undertaken safely as soon as is reasonably practicable	-	-	-	Sections 21.2, 21.6	Integrated Waste Strategy [35] SMR Decommissioning Strategy Decision File [30]	Decommissioning Strategy
A programme for decommissioning activities is prepared for the generic design				Section 21.4	n/a	Decommissioning and Waste Management Plan

21.10 Acronyms and Abbreviations

ALARP	As Low As Reasonably Practicable
BAT	Best Available Technique
BPEO	Best Practicable Environmental Options
BPM	Best Practicable Means
CAE	Claims, Arguments, Evidence
DOORS	Dynamic Object-Oriented Requirements System
E3S	Environmental, Safety, Security and Safeguards
EA	Environment Agency
EIADR	Environmental Impact Assessment of Decommissioning Regulations
EoG	End of Generation
EURATOM	European Atomic Energy Community
FAP	Funded Administration Plan
GER	Generic Environment Report
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
HAW	High Active Waste
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
IEX	Ion Exchange
IWS	Integrated Waste Strategy
LoC	Letter of Compliance
LLW	Low Level Waste
NDA	Nuclear Decommissioning Authority

NIA	Nuclear Installations Act
NPP	Nuclear Power Plant
NRW	Natural Resources Wales
NSL	Nuclear Site Licence
NWS	Nuclear Waste Services
ONR	Office for Nuclear Regulation
OPEX	Operating Experience
PCSR	Pre-Construction Safety Report
POCO	Post Operational Cleanout
PWR	Pressurised Water Reactor
RC	Reinforced Concrete
RD	Reference Design
REPs	Regulation Environmental Principles
RO	Reverse Osmosis
RP	Requesting Party
RR SMR	Rolls-Royce Small Modular Reactor
RSMDP	Radioactive Substance Management (including Waste Disposal) Developed Principle
RSR	Radiological Substances Regulations
SEPA	Scottish Environment Protection Agency
SF	Spent Fuel
SFP	Spent Fuel Pool
SPND	Self-Powered Neutron Detector
SSC	Structure, System and Component
SWESC	Site-Wide Environmental Safety Case
TAD	Target Audience Description
UK	United Kingdom
WMH	Waste Management Hierarchy