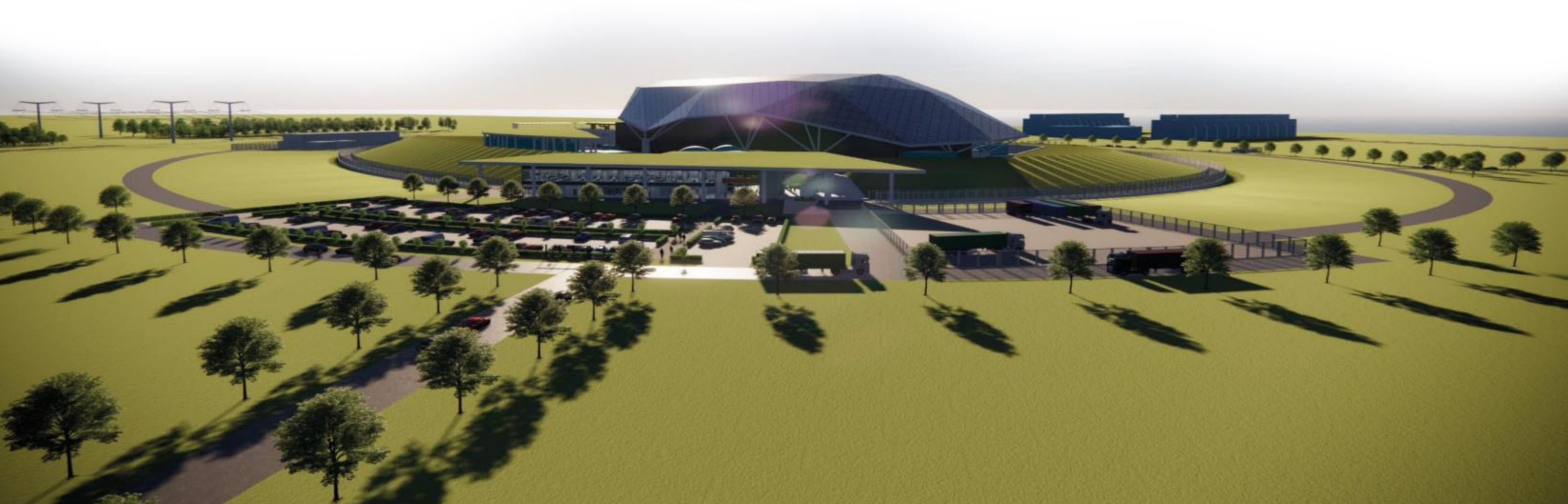
Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 21: Decommissioning and End of Life Aspects



Record of Change

Date	Revision Number	Status	Reason for Change
March 2023	1	Issue	First issue of E3S Case
March 2024	2	Issue	Updated to include further detail from: • The Disposability Case • The Decommissioning and Waste Management Plan, including initial waste estimates • High level information relating to decommissioning requirements is also included.
May 2024	3	Issue	Updated to correct revision history status at Issue 2. Chapter changes include: • Addition of ONR principles for decommissioning and reference to IRRs • Clarity on RR SMR responsibilities to enable licensee to determine decommissioning strategy • Addition of forward actions • Minor template/editorial updates for overall E3S Case consistency.

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 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 encompasses the activities required to return the nuclear site to an unrestricted, de-licensed condition; or return the site to an agreed state so that the land can be used for suitable alternative uses.

The RR SMR is designed to enable implementation of a strategy of prompt dismantling and decommissioning. The details of this strategy are outlined, including the seven stages of 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).

Decommissioning requirements to be considered during design are derived from a review of applicable international and national regulations, guidance, and good practice and these are captured within the RR SMR requirements database (DOORS) and form part of engineering decision making process and options reports.

The decommissioning waste management plan (DWMP) provides an estimated basis for liability costs, and a review of the funded decommissioning costs in addition to an overview of the types of wastes generated during the decommissioning phases, and the proposed treatment and disposal routes.

The opportunities for optimisation of decommissioning aspects within 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.

Going forward, further detail is to be provided to underpin the overall claim, through development of the main supporting evidence. This includes the decommissioning strategy (to consider any impact resulting from the development of the decommissioning source term), the development of a proposed sequence for decommissioning, the decommissioning waste management plan (to provide additional detail on waste volumes, fingerprints and funding of decommissioning costs) and the disposability case (to confirm the disposability of the wasteforms). Development and verification of a complete set of decommissioning design requirements is also required and is expected to be included in subsequent issues of the chapter.

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21.0 Introduction to Chapter

21.0.1 Introduction

Chapter 21 of the Rolls-Royce small modular reactor (RR SMR) environment, safety, security and safeguards (E3S) case presents the overarching approach to the decommissioning aspects of the RR SMR. Version 2 of the generic E3S case is based on design reference point 1 (DRP1) for the generic design assessment (GDA) process. The design principles are established and the approaches to support decommissioning aspects of the RR SMR design are adopted in the design development process. The conclusions of this chapter provide a forward look of information still to be developed for chapter 21 to achieve the generic E3S case objective.

21.0.2 Scope and maturity

The scope of this chapter covers:

- The approach to decommissioning following a review of international and national regulations and guidance
- The approach to the RR SMR decommissioning strategy and describes the stages for decommissioning
- The process adopted for optimisation of decommissioning aspects during the design phase, and the allocation and capture of decommissioning requirements
- An overview of RR SMR's decommissioning and waste management plan (DWMP), including a summary of waste types that will need to be managed during the decommissioning phases of the facility
- Areas within the design that consider safety during the decommissioning phase and provides examples of the design decisions that support waste minimisation
- Considerations for the end-state for a RR SMR site
- Conclusions and forward look to further work required.

The RR SMR design information presented in this chapter is largely based on the design definition at a DRP1 (RD7) level of design maturity.

The approach to decommissioning is outlined within the decommissioning strategy and decommissioning plan, and going forward these will be reviewed in order to verify the assumptions made (for example, in terms of waste management arrangements), and also to provide further detail especially in terms of decommissioning design requirements which are still in development.

21.0.3 Claims, arguments and evidence route map

The generic E3S Case objective at Version 2 is 'to provide confidence that the RR SMR design will be capable of delivering the E3S fundamental objective as it developed from a concept design into a detailed design' [1]. This confidence is built through development and underpinning of top-level claims across each chapter of the E3S Case, through supporting arguments and evidence.

The chapter level claim for E3S case Version 2, Tier 1 Chapter 21: Decommissioning and 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

This high-level claim is decomposed into sub-claims, within the claims, arguments, evidence (CAE) route map [2]. The lowest level sub-claims are identified in 21.8.1 (Appendix A), with a link to the sections of this report providing the evidence summary and reference to the evidence documentation available at this stage.

The complete suite of evidence to underpin the claims in the E3S case will be generated throughout the RR SMR design and E3S case programme documented in [2], and described further in [1].

21.0.4 Applicable regulations, codes and standards

The decommissioning strategy and general principles employed for the RR SMR design and E3S case are derived from the following regulations and guidance, which are used to derive a set of requirements within RR SMR requirements database (DOORS) to guide and inform the facility design.

International Atomic Energy Agency on decommissioning

The International Atomic Energy Agency (IAEA) has recognised two primary decommissioning strategies in developing IAEA safety standards [3]. These primary strategies are:

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

- 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 facilities: general safety requirements (GSR), part 6 [3] provides a set of requirements on the following eight topics:

- Protection of people and the environment

- Responsibilities associated with decommissioning

- Management of decommissioning

- Decommissioning strategy

- Financing of decommissioning
- Planning for decommissioning during the lifetime of the facility
- Conduct of decommissioning actions
- 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 [4]; 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. This requirement no longer applies to the UK (post Brexit) but was re-interpreted under the Transboundary Radioactive Contamination Direction [5]. This Direction ensures that the EA consider whether the plans for disposal of radioactive waste are liable to result in radioactive contamination of notifiable countries. This is undertaken via public consultations on new, or variations on existing environmental permits. Thus, consultation and approvals will need to be obtained for any disposals to be made resulting from facility decommissioning.

The Western European Nuclear Regulators Association (WENRA) developed a working group focused on waste and decommissioning which has developed four sets of safety reference levels (SRLs) [6], which reflect expected practices in four thematic areas to be implemented in the member states. The four thematic areas are listed below and feed into IAEA safety standards:

- Decommissioning
- Storage of radioactive waste and spent fuel
- Disposal of radioactive waste
- Processing of radioactive waste.

The International Atomic Energy Agency on radioactive waste management

IAEA safety standard [7]; sets out the system for the classification of radioactive waste.

IAEA specific safety requirements [8]; 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 standard [9]; sets out the application of the concepts of exclusion, exemption and clearance to materials that are characterised by the lowest activity concentrations.

IAEA safety standard [10]; sets out the international regulations for the safe transport of radioactive material.

National regulations and guidance on decommissioning and radioactive waste management

An updated framework for the long-term management of higher activity radioactive waste (HAW) [11]; 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 and Disposal of Higher Activity Waste, [12] and Geological Disposal of Higher Activity Radioactive Waste: Community Engagement and Siting Processes [13].

The UK Strategy for Managing Radioactive Discharges [14] is in line with IAEA safety principles, and alignment with these is subject to the demonstration of the BAT.

Office for Nuclear Regulation (ONR) 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 [15]. The objective of decommissioning a nuclear installation is to remove the hazards and restore the site to an agreed end-state where it may have its nuclear site licence revoked by ONR. The process can be broken down into distinct stages, including:

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

- Stage 2 – EITHER prompt dismantling, where 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; OR deferred dismantling, where preparations are made 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

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

Initially, in compliance with site licence condition 35 (LC35), 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 their 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) [16].

The ONR's Safety Assessment Principles include nine principles for decommissioning [17], and these principles (below) inform the RR SMR considerations.

DC.1 – Facilities should be designed and operated so that they can be safely decommissioned.

DC.2 - A decommissioning strategy should be prepared and maintained for each site and should be integrated with other relevant strategies.

DC.3 - The safety case should justify the continuing safety of the facility for the period prior to its decommissioning. Where adequate levels of safety cannot be demonstrated, prompt decommissioning should be carried out and, where necessary, prompt remedial and operational measures should be implemented to reduce the risk.

DC.4 - A decommissioning plan should be prepared for each facility that sets out how the facility will be safely decommissioned.

DC.5 - Facilities should be made passively safe before entering a care and maintenance phase.

DC.6 - Documents and records that may be required for decommissioning purposes should be identified, prepared, updated, retained and owned so that they will be available when needed.

DC.7 - Organisational arrangements should be established and maintained to ensure safe and effective decommissioning of facilities.

DC.8 – The management system should be reviewed periodically and modified as necessary prior to and during decommissioning.

DC.9 - A safety case should be provided to demonstrate the safety of the decommissioning plan and its associated decommissioning activities and then kept up to date as the work progresses.

UK regulations on permitting

The Environmental Permitting (England and Wales) Regulations 2016 (as amended) (EPR2016) [18], requires demonstration of BAT to justify specific approaches or practices giving rise to radioactive waste, and 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 relevant good practice (RPG) should be explicit in all site strategies, whether construction and operation or decommissioning programmes and activities.

The EA is responsible for regulating all disposals of radioactive waste on and from sites in England and Wales. Schedule 23 of [18] provides the underlying justification for the environmental permit application for the disposal and discharge of radioactive waste from such a site. Specific guidance on the management of radioactive materials on nuclear licensed sites is given in [19].

Radioactive substances regulation: objectives and principles

The EA published the radioactive substances regulation objectives and principles [20] to provide a standardised framework for technical assessments and judgements undertaken by the agency. Although it is not their prime purpose, these principles 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.

There are several generic developed principles for decommissioning (DEDP) [21], including:

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

- 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.

- Principle DEDP3 – Considering decommissioning during design and operation. Facilities should be designed, built and operated using best available techniques (BAT) to minimise the impacts on people and the environment of decommissioning operations and the management of decommissioning wastes.

- 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.

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

The principles applicable to radioactive waste management are the radioactive substance management (including waste disposal) developed principles (RSMDP):

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

- 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.

- 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.

- 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.

- RSMDP9 – Characterisation: Radioactive substances should be characterised using BAT to facilitate their subsequent management, including waste disposal.

- RSMDP10 – Storage: Radioactive substances should be stored using BAT so that their environmental risk and environmental impact are minimised and that subsequent management, including disposal is facilitated.

- 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.

At the end-of-life, in order to ensure that the site is brought to a condition at which It can be released from radioactive substances regulation, an operator is required to do so using a process which protects the health and interests of people and the integrity of the environment, in line with guidance [22]. This guidance outlines a number of principles and requirements which also have a bearing on facility decommissioning.

Nuclear Installations Act

In accordance with the Nuclear Installations Act 1965 (NIA) [23], an organisation wishing to carry out prescribed nuclear activities must apply for, and be granted, a nuclear site licence 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 site licence requires an EPR permit for the disposal of radioactive waste, and for the keeping or use of mobile radioactive sources, regulated by the EA.

Ionising Radiation Regulations

In accordance with the Ionising Radiation Regulations (IRR) 2017 [24] where the design of new facilities is being considered for work with ionising radiation, the employer must consider the construction, commissioning and operation of the facility together with its maintenance and decommissioning to ensure that exposure will be restricted as far as reasonably practicable during the life-span of the facility.

ONR's license conditions applicable to decommissioning and radioactive waste management

All nuclear site licenses granted under NIA include 36 standard conditions [25]. The licence conditions that are considered relevant to decommissioning, management of radioactive and nuclear materials on site are:

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

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 [26] but has since been subsumed into UK law [27].

The hierarchy prioritises the prevention and reduction of waste, followed by reuse and recycling and lastly the optimisation of its final disposal. Further detail regarding the WMH and its application to all waste streams generated by an RR SMR is provided [28] and significant consideration is given to decommissioning wastes as a significant quantity of wastes will be produced within this category.

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

Low Level Waste (LLW) Repository Ltd [29]; provides specific guidance for the application of the waste management hierarchy in the UK for radioactive wastes.

Serco [30]; provides specific guidance in the context of managing higher activity wastes.

Best available techniques (BAT)

Best available techniques are processes, facilities or methods of operation at the forefront of development, they are practicable to apply and suitable to limit waste arisings and disposals. Application of BAT requires consideration of a broad range of options that will be relevant to the selection of the optimum solution including the safety in operation and the financial outlay involved, as well as environmental aspects. BAT applies throughout the lifetime of a process, from design to implementation, operation, maintenance and decommissioning.

Further information regarding the RR SMP approach to design optimisation through the application of BAT is provided [31]. RR SMR demonstration of BAT is provided [32], and breaks down high level claims relating to the prevention and minimisation of waste including aspects of particular interest to decommissioning operations.

21.1Decommissioning Strategy

21.1.1 Introduction

Decommissioning is the final phase in the overall lifecycle of the RR SMR and it is the responsibility of the dutyholder to make appropriate arrangements to ensure this is undertaken. To facilitate this there is a requirement for RR SMR to outline how and when a site would be decommissioned during early stages of the planning and design stages. This will ensure that appropriate steps are taken to prevent or mitigate decommissioning challenges and risks. A decommissioning strategy will provide guidance on the process to meet the required end state, and includes the required activities which support disposal, including processing, packaging, conditioning and storage. It will also consider the key decisions which need to be addressed and identifies the assumptions, objectives and goals to meet the strategy.

The initial decision is to confirm the best overall approach for RR SMR's decommissioning strategy, and this is undertaken following the Conduct Design Optioneering process (C3.2.2-2) [33]. The decommissioning options under consideration include:

- Prompt/continuous dismantling and decommissioning - commences as soon as possible after end of generation, with onsite intermediate conditional storage requirements.
- Deferred dismantling which includes two options: -
  - Deferred dismantling of intermediate level waste (ILW), removal of non-ILW materials from end of generation (EoG), which includes non-radioactive as well as low level waste (LLW).
  - Deferred radiological dismantling including ILW and LLW, with non-radioactive waste dismantling after EoG as previously.
- Entombment - encase the reactor island in concrete, becoming a waste site for perpetuity.

The decommissioning strategy selected for RR SMR is to design a facility to enable prompt and continuous decommissioning, noting that individual systems will be decommissioned at different times in the overall sequence in order to enable demonstration of ALARP, BAT. This aligns with the UK government policy, IAEA guidance and agrees with RR SMR policy [34], and there are numerous examples where this has been employed with beneficial outcomes.

The following design objectives have been considered as well as the potential benefits and disbenefits associated with each of the options outlined above. This list is not exhaustive, and only clear differences between options are highlighted here, for each of the design objectives [35].

- **Minimise normal operation and maintenance dose to as low as reasonably practicable (ALARP) levels:** There will be a limited decay period prior to decommissioning activities, likely using remote handling techniques 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, and the potential to reduction the hazard associated with the decommissioning of individual systems through optimisation of the decommissioning sequence.

- **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.

- **Minimise cost of decommissioning:** There are higher costs associated with immediate (versus delayed) decommissioning due to the need for interim storage of wastes and remote handling systems. However, the cost implication of providing maintenance of existing equipment for use for immediate decommissioning, would be less than providing care and maintenance for systems and facilities over the long term (delayed decommissioning).

- **Maximise use of proven technology (minimise development cost/risk):** International technology exists for decommissioning pressurised water reactor (PWR) projects.

- **Maximise site availability and flexibility:** Prompt decommissioning of areas of low or no contamination could facilitate re-purposing of site facilities, for example as decontamination or interim storage areas. In addition, this allows early site clearance and delicensing, potentially making the land available for other uses – decades earlier than deferred decommissioning strategy.

Further consideration of the sequencing of decommissioning of the various systems will be required as the detailed design progresses further. This is anticipated to include a range of influencing factors (including those outlined within [17]) and consulting a wide range of stakeholders order to ensure the flexibility of potential approaches which may ultimately be adopted by the dutyholder.

21.1.2 Strategy requirements

The RR SMR decommissioning strategy [36] provides a high-level timeline for the decommissioning stages, with a more detailed decommissioning schedule in development, considering each system and the requirements for them following the end of power generation. This will inform the layout design, by considering the optimal placement of systems and components given their overall usage and lifetime. Further information is also provided in [37]. The strategy is based on the following four expectations:

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

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

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

- 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, RR SMR Radioactive waste and decommissioning policy framework [34] requires the following:

- 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.

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

- 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.

- 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) [28]. 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.

- As the design is evolving, changes may impact the decommissioning strategy which will require frequent updates. Changes which occur during plant operations can also affect the strategy and thus updates are also required (on a 10 yearly basis) during the lifetime of the facility.

21.1.3 Preferred strategy

Prompt and continuous decommissioning seeks to decommission the station as quickly as possible, with decontamination and dismantling operations commencing 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 [38].

Prompt 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 [39]. In addition, the IAEA notes that generally, "*immediate dismantling is the preferred strategy, as it avoids transferring the burden of decommissioning to future generations*" [40].

It is worth noting 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 [3]. However, it is noted there may be aspects of decommissioning a modular design which effect the sequencing of decommissioning which will require further consideration.

It is recognised that there may 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 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.

21.1.4 Strategy implementation

The strategy document sets out initial proposals for seven phases of decommissioning (with approximated timeframes) that could take place over a total of approximately 110 years. There is potential for the timing of these phases to be amended as information regarding the decommissioning source term is refined providing further clarity on likely estimated doses experienced during the different phases. The proposed phases include:

- 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.

- Phase 2 (5-20 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 intermediate spent fuel store (ISFS) will be carried out using the operational fuel handling equipment, procedures, and safety case. Retrieval, processing and packaging of operational wastes (for example, 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 (for example the SFP and associated systems), but any that become redundant at shutdown will be removed as soon as practicable.

- Phase 3 (5-20 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, noting that there is the potential for re-use of the turbine island area to site this facility. Radiological surveys, excavation of structures and delicensing activities will also occur during this stage.

- 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 finalised (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. There is potential for some site clearance to occur during this phase if benefit could be provided by reducing the area of land covered under the site license.

- 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).

- 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.

- 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 RSR environmental permits and the nuclear site license rescinded.

It is noted that depending on site specific requirements, these phases may be flexible and can be done in parallel as they may not need to be done at the plant site itself. There is potential for the timescales to be reduced, especially if the GDF becomes available during this time.

As discussed, the decommissioning strategy is continually evolving and a number of further actions have been identified relating to providing further detail in relation to the overall decommissioning sequence. These actions will be addressed in future issues of the E3S case.

21.2 Facilitating Decommissioning during Design

21.2.1 Introduction

The RR SMR design employs a requirements led approach, as described in [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 through reducing the complexity of decommissioning, which is a key consideration during each stage of the facility design [41].

21.2.2 Decommissioning requirements

As design concepts for structures, systems and components (SSCs) are developed, they are down selected through the Conduct Design Optioneering process (C3.2.2-2) [33], including evaluation against the design objectives [41]. 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:

- 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 21.0.4)

- 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, as well as RGP, a set of key E3S principles were derived to inform the design and layout of plant, systems, and buildings to facilitate decommissioning. These principles are captured as transverse requirements in line with the CAE route map [2].

The requirements are collated within the requirements database, in line with RR SMR management system processes, and will be substantiated as part of process C3.2.2-2.

One of the key topic areas includes the minimisation of the quantity of contaminated waste generated and a number of requirements relate to preventing or reducing the spread of contamination. Examples of related requirements include:

- Design shall provide for isolation between areas containing radioactive and hazardous materials, and those which do not

- Layout shall limit the spread of contamination with appropriate structures and barriers

- Provision of secondary containment for liquid systems including suitable leak detection measures

- Use of coatings and surface finishes to prevent contamination, or enable decontamination of structures or equipment

- Penetrations, cracks and crevices to be minimised to reduce trapping of contamination.

It is noted that there are opportunities for optimisation of the decommissioning aspects within the RR SMR design, including modularisation (simplifying dismantling, handling, packaging, and transportation activities) and the deployment of standardised RR SMR plants (standardising decommissioning plans, sharing equipment and processing facilities). It is recognised, however, that particular aspects of using a modular design approach may result in a different range of decommissioning challenges (for example, an increased quantity of decoupling operations) which require consideration by the appropriate experts and stakeholders. System design description reports for engineering systems include a requirement to consider decommissioning aspects, and in particular plant layout concepts will continue to develop these aspects in line with any design modifications.

21.2.3 Structures, systems and components

The facility waste management systems, in addition to ancillary services, will be required during the decommissioning process, and the requirements at each of the decommissioning stages are considered and included in the system design. A summary of the main systems is provided in Table 21.2-1.

Table 21.2-1: Waste management systems required during decommissioning

System	Requirement during decommissioning
Waste Management Systems	
[KNF] Liquid Radioactive Effluent Treatment System	Effluents generated during active decommissioning will require treatment and discharge. [KNF] system, or similar will be required throughout this active period.
[KPL] Gaseous Radioactive Effluent Treatment System	Removed as part of RI decommissioning.
[KTA] Reactor Island Drainage System	Removed as part of RI decommissioning.
[KMA], [KME] Solid Radioactive Waste Management System	Operational ILW will require storage [KME30] pending the availability of the GDF. ILW and LLW will be generated during active decommissioning and [KMA], [KME] systems are likely to remain.
[FKA] Component Decontamination System	System likely to remain during decommissioning to decontaminate smaller equipment items.
[GM] Non-Active Wastewater Drainage and Treatment Systems	Parts of this system are likely to remain after active decommissioning, including domestic supply and treatment systems.

System	Requirement during decommissioning
Decommissioning Waste Management Systems	Additional systems will be installed for sentencing, segregation, packaging of solid and liquid wastes during decommissioning for ILW, LLW, very low level waste (VLLW) and conventional waste. For example, a decommissioning waste handling facility may be created within the turbine hall (once emptied / removed). Systems for packaging and removal of wastes required during active decommissioning.
[KLA], [KLB], [KLC], [KLE], [KLF], [KLL], KLR] HVAC Systems	Heating, ventilation and air-conditioning (HVAC) systems will be required for each area during decommissioning operations and will be removed once all operations in the individual areas have been completed.
[FAL], [FAB10], [FAB20], [FAF], [FCL], [FDB] Spent Fuel Storage Systems	SF cooling and purification systems will be required until the end of the required cooling period (up to 20 years after EoG). Dry storage [FDB] will be required until the GDF is available for SF disposal.
Other relevant systems	
[PA], [PB], [PE] Cooling water supplies	Essential Services Water System to supply water for SF cooling systems. Auxiliary Cooling and Make-up System outfall required to enable continued effluent discharge.
[GA], [GC] Potable water supply	Supply to firewater distribution system, demineralised water
Electrical supply and distribution	A modified / new electrical supply and distribution system will be required to account for the change in supply requirements within these lifecycle phases.
Back-up generators and diesel storage	Required to maintain emergency power supplies to SF systems.

A comprehensive list of SSCs required during the decommissioning phases is still in development, in conjunction with the specific functional requirements of the systems, and further work will be required as the detailed design progresses.

21.3 Decommissioning and Waste Management Plan

21.3.1 Introduction

An initial generic decommissioning and waste management plan (DWMP) [42] has been produced and will continue to be developed, as the detailed systems design progresses.

The plan provides greater detail in terms of the 7 phases of the decommissioning programme (outlined above), and the facilities that are likely to be required to undertake the processes once appropriate approvals, licenses, assessments have been undertaken. The estimated basis for liability costs, and a review of the funded decommissioning costs are provided in addition to waste information.

21.3.2 Radioactive waste management arrangements

E3S Case Chapter 11 [43] provides a description of the sources of radioactive waste generated throughout the lifecycle of the RR SMR facility, across all media. An estimation of likely waste volumes is provided for operational wastes, but highlights work is still required to provide waste data for the various types of decommissioning wastes. A summary of the potential treatment and disposal routes is also provided for the waste streams identified.

In addition, the RR SMR IWS [28] sets out the strategy for managing all operational wastes arising from RR SMR, noting that a number of these operational waste streams will need to be managed during the decommissioning phases of the facility. Decommissioning wastes (type and volumes) will vary between the phases of decommissioning, and a decommissioning inventory is being compiled which will be summarised in updates of the DWMP. A high-level summary of the main waste streams which need to be managed during the decommissioning period is provided in Appendix B, with further information regarding quantities and activities being provided as detailed design information becomes available.

The main radioactive materials generated after final shutdown and defueling of the plant has occurred will be classed as being either activated or contaminated structures and equipment.

Activated structures are generated as a result of neutron bombardment and activation and will include the structures in and around the reactor pressure vessel, including elements of the primary coolant circuit and associated shielding. Activation of structures is limited through use of heavy reflectors to reduce neutron leakage. Contaminated structures will include primary coolant circuit equipment, including steam generators, and associated heat exchangers, pumps and storage tanks. Some building surfaces within the reactor island and fuel handling areas, plus associated drainage and effluent treatment systems will also be contaminated.

The activity of the materials will be dominated by the presence of activated corrosion products with a small contribution from fission products and a small allowance made for the potential contribution from fission products resulting from fuel cladding failures during the lifetime operation. Building surfaces are more likely to be dominated by tritium.

Many features incorporated into the RR SMR design are intended to reduce the production of activated corrosion products, including the selection of materials used in the design and controls imposed upon the construction, for example the control of cobalt content within steel. The major contributor to the contamination of surfaces is activated corrosion products, and a number of aspects have been included in the design to limit the generation of these products. Some examples include the control of coolant chemistry and the use of corrosion inhibitors within coolant, the use of steel or coatings to cover floors and walls which may be in contact with radioactive effluents.

The greatest quantity of decommissioning waste will be during phases 2 and 3 of the programme (defueling / POCO, and reactor decommissioning) as a large proportion of the radioactive and hazardous materials are removed during this period. Waste types will include both radioactive and non-radioactive wastes, across solid, liquid and gaseous media. Smaller quantities of waste will be generated during phases 5, 6 and 7, as the higher activity wastes are transferred to a disposal facility for long term management and the remaining buildings are removed.

A more detailed consideration of potential sources of radioactive materials which could become waste or require decontamination during decommissioning operations is being undertaken. This is in line with the estimation of expected volumes and activity of wastes to inform subsequent stages of the design process which consider more detailed requirements for equipment decontamination and waste handling and storage.

In relation to liquid and gaseous effluents, these will both be generated during decommissioning operations. Liquid effluents result from the removal of process fluids (cooling / heating fluids) and are generated from cleanout and decontamination operations. The intention will be to utilise the existing radioactive effluent treatment processes where possible such that effluents can be treated and re-used / discharged via the sea outfall. Aerial effluents will also be generated either as dust or fume from dismantling and demolition operations, and during equipment cleanout. The aerial effluent will be captured, monitored and discharged by the existing ventilation / extract systems, where possible. If necessary, local temporary containments may be erected for decontamination and size reduction of specific items, which will have local filtered extract facilities. As the discharge stack is removed a suitable discharge point and appropriate monitoring arrangements will be required throughout decommissioning operations.

The future work identified within the decommissioning plan (predominantly to be undertaken at the latter end of facility operations and during phase 1 of decommissioning) includes consideration of: staffing levels, the need to re-configure the electrical supply and distribution system, and consideration of potential changes needed to the active effluent treatment system. Some key elements from [43], [28] are included below.

21.3.3 Waste disposal

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 case

The term ‘disposability assessment’ can refer to two separate (but related) processes that are undertaken in different contexts, defined as follows:

- **GDA disposability case** – this refers to provision of information as to the potential waste types and generic waste packaging approaches proposed 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 to confirm suitability.

- **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. The process is staged at conceptual, interim and final LoCs as the level of detail and confidence is developed (LoCs provided post GDA).

Obtaining an LoC for all of the HAW streams to be produced by the RR SMR is 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 report [44] presents initial information to NWS regarding the provenance, nature and quantity of all RR SMR higher activity waste (HAW) from all lifecycle stages, the management approaches including handling, conditioning and quality control, strategies for interim storage and export to the GDF, and the environmental, radiological and other principles which will be applied in achieving these objectives and purpose. A key aspect will be demonstrating the HAW and the proposed approaches are 'within the envelope' of UK and international nuclear industry OPEX and RGP.

The design of the RR SMR is maturing and so a number of key, underpinned assumptions have been made in the assessment regarding the timing of GDF availability; waste acceptance criteria; secondary circuit wastes; the SF dry storage container; GDF transport/disposal container; the decommissioning waste container; the application of decay storage; use of cement conditioning; and the ion exchange resin types to be used.

The report identifies the main decommissioning waste streams (summarised in Appendix B) and provides an overview of the proposed management approach, considering RPG from across the industry for each waste stream. In terms of packaging requirements, the majority of waste streams have no specific container type identified and further work will be required to confirm the requirements. However, the assessment does consider the general disposability of the various waste streams [44] and indicates that a number of wastes streams are expected to be of high similarity to existing PWR waste streams which are destined for GDF. There is, therefore, a reasonable level of confidence that these wastes could be made suitable for disposal at GDF. For other features or components which are not directly comparable to existing PWR facilities, including some reactor pressure vessel (RPV) internals and primary circuit components, there is a lower level of surety that the wastes can be rendered suitable for GDF disposal and further work is required to increase level of confidence in terms of disposability.

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.

A baseline DWMP has been compiled and forward actions have been identified to assist in the development of the required detail. Future work is focused around development of a decommissioning source term, sequencing and plans, and a breakdown of the costing structure.

21.4 Provision for Safety during Decommissioning

21.4.1 Introduction

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

- 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

- 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 key aspects of the RR SMR design minimises waste and provides a description of the decontamination strategy and access for people and equipment during the various stages of decommissioning. It is noted, however, that there is minimal OPEX available for consultation when considering decommissioning of modular reactors and the aspects of the design where there is a potential detriment in terms of overall safety. The more bespoke elements of the design will be considered futher to strengthen the overall ALARP case.

21.4.2 Waste and dose minimisation

In line with the BAT principles described in section 21.0.4 above, the following list highlights some examples of how the design of RR SMR minimises waste and associated worker dose:

- The facility design aims to minimise the overall plant footprint, which in turn minimises the quantity of materials used in the build which could potentially become contaminated.

- Segregation of equipment containing radioactive materials from ancillary equipment will reduce unnecessary cross contamination or irradiation of equipment.

- Physical barriers are used to prevent spread of radioactive material, both permanent and temporary, and the aim is to optimise the plant layout to make use of structures and components to provide additional barriers or shielding.

- Use of heavy reflectors to minimise neutron leakage and subsequent activation of materials.

- Component materials of construction are chosen to limit the potential for material activation, and techniques such as electropolishing may be employed, where appropriate, to reduce generation of radioactive corrosion products (crud) which can prove problematic especially during maintenance and decommissioning operations.

- 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.

- Coolant chemistry: Additives will be dosed to the reactor coolant to reduce corrosion and generation of activated particulates within the system reducing maintenance and decommissioning doses.

- The use of low or no-cobalt hard-facing components to reduce the potential for crud generation, within primary pipework and steam generators, reducing maintenance dose and legacy waste issues which can prevent immediate decommissioning of the plant.

- 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).

- Interim storage of resins/concentrates: The interim storage of these waste streams (until availability of GDF) may allow the total ILW volumes from these streams to be reduced, as there may be potential to mix these streams and / or waste may decay sufficiently to be suitable for disposal as LLW.

- Back-washable filters (to remove particulates from the coolant system): This reduces the generation of crud within the coolant system and use of washable filters reduces the number of waste packages by 75 % (averaged over a 10-year period) by reducing ILW filter packages and reducing overall ILW storage volume.

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

More detail on the waste types, categories, and management of operational wastes, is provided in [28]. Further information relating to how particular aspects of the RR SMR design apply BAT in minimising wastes will be provided within individual BAT reviews which will present appropriate evidence, following the approach outlined in [31].

Secondary wastes are generated by the processes employed during the decommissioning phases, and these depend on the process area and type of materials generated.

Contaminated materials require decontamination (generating liquid effluents which require treatment prior to discharge), before the equipment is dismantled and size reduced (generating aerial effluents collected within the HVAC systems), and items are then packaged for dry, cooled storage (also connected to HVAC systems / environmental controls).

Activated materials require dismantling and size reducing (generating aerial effluents collected by HVAC systems), underwater cooling / decay storage (generating liquid effluents for treatment), followed by packaging for dry, cooled storage (connected to HVAC systems).

The Liquid Radioactive Effluent Treatment System [KNF] will be retained for treatment of decontamination effluents generated in the early phases of the overall process, which will enable recycle and re-use of these liquors to reduce the quantity of discharges. The decision to retain or replace this system into the later phases of decommissioning will require further consideration once greater information is available in terms of expected effluent quantities and levels of contamination.

The retention of area HVAC system will depend on the suitability of the system considering the work being undertaken within the area, or whether dedicated local extract units are required for particular operations. In addition, once the statutory discharge stack has been demolished, the provision and approval of temporary discharge points will need consideration.

21.4.3 Decontamination

A number of approaches are employed to prevent contamination of materials to reduce generation of contaminated waste (as highlighted above). However, some equipment will become contaminated due to the nature of their function, and thus will require decontamination.

The process of decontamination of smaller equipment items will be an on-going waste-generating activity as it will be undertaken from plant commissioning, during operations and through active decommissioning. It will be required for equipment and tools affected by radiological and non-radiological contaminants (for example, used personal protective equipment, pumps, pipework, and hoses). Decontamination of these items is planned to be undertaken by the component decontamination system [FKA], which is still in development and more information will become available as the design matures.

Decontamination of larger items and the primary circuit is more uncertain at this stage but it is anticipated there will be the requirement for a decommissioning decontamination and dismantling facility to process the larger equipment items outside the hot cell. As the turbine island is due for removal early in the overall decommissioning sequence the aim is to provide a suitable facility within this area once the space has been cleared. Further work is required to determine the requirements and the overall design for this future facility.

21.4.4 Access for the removal of waste

From early in the design process, human factors are considered, including a space reservation for personnel access 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) [45], has been created and 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.

Human factors assessments of the layout are planned for all lifecycle modes, including decommissioning. These assessments shall consider access for personnel and the equipment required to complete the decommissioning activities. This will include consideration of engineering measures required to reduce potential employee dose rates and the need to employ robotic techniques or tooling to allow remote handling to further minimise employee exposure, and drone technology has also been demonstrated in industry for tasks such as plant dose rate surveys. Decommissioning source term(s) are in development to provide estimations of potential doses to workers during decommissioning operations, which in turn will assist with optimising the layout design and tooling requirements for the operations and estimating required manning levels.

Data collection forms a crucial aspect of modern plant design to ensure continuous improvement in management of safety. Radiological data from a range of sources, including personal dosimeters, fixed radiation detectors, dose rate surveys in specific plant areas, coolant sampling and waste activity data can all be used for trend analysis which has an application in many scenarios, including informing the planning of safe decommissioning operations.

21.5 End of Life Aspects for the Decommissioned Site

21.5.1 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.

21.5.2 End state definition

When all the radioactive waste has been managed safely, the facilities have been cleared and the site is returned to a pre-agreed state, with the regulators and the planning authority, decommissioning is complete and the site can be released from RSR. Guidance is provided on the requirements for release of sites from RSR [22]

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

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

The site may be delicensed in sections; for example, the SF Store and the ILW store may remain a licensed site until the stores have been dismantled and removed, while other clean areas are de-licensed. So there is the potential that end states for different parts of the site will be reached at different times. Any decision relating to the future use of a site will be set out in a site-specific decommissioning strategy and will relate to the site's previous use.

For strategic decommissioning decisions to continue, there is an assumption the site will be remediated to allow for unrestricted access. Buildings will be 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. A site-specific DWMP (with a 10 yearly review), is required for any permitted site in the UK in conjunction with a site-wide environmental safety case (SWESC). This is captured as a 'Commitment on the Future Permit / Dutyholder / Licensee' in section 21.6.2 below.

21.6 Conclusions

21.6.1 ALARP, BAT, secure by design, safeguards by design

The approaches, methods, and requirements set out in this chapter are being applied to the ongoing development of the design, analysis, and verification of SSCs, to ensure the E3S fundamental objective can be met by the RR SMR at all lifecycle stages. Their application enables the design and analysis outputs presented throughout the E3S Case to provide a suitable demonstration that risks are and/or will be reduced to ALARP, apply BAT and ensure secure by design and safeguards by design.

21.6.2 Assumptions and commitments on future dutyholder

Table 21.6-1: Assumptions and commitments on future permit/dutyholder/licensee

Reference	Assumption/Commitment	Description
FA21.1	Development of site specific DWMP, SWESC	Owner to develop RR SMR generic plan to include site specific requirements (reviewed throughout plant lifetime)
FA21.2	Development of record management strategy	Strategy for retention of relevant safety and radiological data to inform site specific decommissioning plans

21.6.3 Conclusions and forward look

The generic E3S Case objective at Version 2 is ‘to provide confidence that the RR SMR design will be capable of delivering the E3S fundamental objective as it developed from a concept design into a detailed design’ [1]. This confidence is built through development and underpinning of top-level claims across each chapter of the E3S Case, through supporting arguments and evidence. The top-level claim for chapter 21 is ‘The RR SMR is designed to facilitate decommissioning safely with risks reduced to ALARP, and using BAT 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 a summary of:

- Relevant International and UK Regulations, guidance and RGP that inform the design through the development of decommissioning requirements
- The decommissioning strategy
- The decommissioning waste management plan
- The disposability case

- End-state site considerations.

Baseline reports for each of these workstreams have been produced and are to be reviewed and updated in-line with the CAE route map to ensure that decommissioning considerations are embedded into RR SMR design processes. This will ensure that outputs can support the claim that decommissioning risks are reduced to ALARP.

A number of forward actions are identified within the supporting Tier 2 reports [36], [42] and these will be addressed in subsequent editions of the individual reports and this chapter. The key aspects highlighted in this document relating to the further development of decommissioning requirements include:

- A balanced consideration of the decommissioning aspects bespoke to the SMR modular design (for example due to the increased numbers of disconnections, the smaller facility footprint)
- Consideration of the wider safety issues relating to the proposed sequencing of system decommissioning, including those arising during the different phases of decommissioning (for example, dose implications, security of the facility) including the relevant stakeholders
- There is need for a comprehensive list of the SSCs which will be required during the decommissioning phases, as well as the specific functional requirements of the systems
- An understanding of the service requirements during the decommissioning phases to inform future decisions of whether existing facilities can be re-used or whether service modifications will be required
- Further design development of decommissioning decontamination facilities is necessary. These will also be captured in subsequent issues of this chapter.

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[43] Rolls-Royce SMR SMR0004502 Issue 3, “E3S Case Version 2 Tier 1 Chapter 11: Management of Radioactive Waste,” 2024.

[44] Rolls-Royce SMR SMR0007665 Issue 1, “Disposability Case Report,” 2023.

[45] Rolls-Royce SMR SMR0003975 Issue 1, “Target Audience Description,” Jan 2023.

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21.8 Appendices

21.8.1 Appendix A: Claims, Arguments, Evidence

Table 21.8-1 provides a mapping of the claims to the corresponding sections of the chapter that summarise the arguments and/or evidence. The full decomposition of the claims and the link to underpinning Tier 2 and Tier 3 information containing the detailed arguments and evidence is presented in the E3S Case route map [2].

Table 21.8-1: Mapping of claims to evidence

Claim	Reference for Arguments / Evidence
Relevant Codes and Standards for decommissioning underpin RR SMR	Section 21.1
RGP and OPEX for decommissioning are considered during design of RR SMR	Section 21.1
SSCs that form the scope of decommissioning are clearly identified	Section 21.3 Design for decommissioning requirements on DOORS
Requirements for safe decommissioning are correctly assigned to relevant SSCs	Section 21.3 Design for decommissioning requirements on DOORS
Features to prevent radioactive contamination and limit its spread are incorporated into the design	Section 21.4.2, [46]
Material choices minimise activation of structures, plant and equipment	Section 21.4.2
Suitable decontamination facilities / techniques are incorporated into the design	Section 21.4.3
The layout is optimised to facilitate decommissioning	Area layout reports, for example [37]
Decommissioning doses are minimised to ALARP	Section 21.4, Decommissioning source term under development
Decommissioning waste routes are clearly identified	Section 21.3, [28]
Radioactive and non-radioactive wastes are segregated	Section 21.3, [42]
Decommissioning strategies are prepared, maintained and integrated into other relevant strategies	Section 21.2, [36]
Decommissioning strategies justify continuing safety prior to decommissioning	Section 21.4, [36]

Claim	Reference for Arguments / Evidence
Decommissioning strategies maximises the potential reusability of plant, equipment and materials when the facility reaches the end of its operating life, and minimise the quantity of radioactive waste produced when decommissioned	Section 21.4.2

21.8.2 Appendix B: Wastes managed during decommissioning

Table 21.8-2 below provides an initial estimate of waste types and volumes which require management during the decommissioning stages of the facility lifecycle. The estimated arisings have been taken from [43] and package types from [44].

Table 21.8-2: Table of waste estimates

Waste Nature	Estimated Arisings	Number / Type of Waste Packages
HLW		
Spent fuel assemblies Main radionuclides – Cs-137, Sr-90, Pu-239/240, U-238.	Up to 47 assemblies / year 1876 in total	0.4 – 0.8 / SF dry casks year 25 – 75 in total
Failed fuel rods	TBD, when failure rates have been determined	
Dry HLW/ILW		
NFCC: neutron detectors (SPND) Main radionuclides – Co-60, Ni-63, V-52. Fission detectors (MPFD) Main radionuclides – Co-60, Ni-63, Cs-137, Sr-90, Pu-239 /240.	0.35 assemblies / year 14 in total 2 probes per cycle 80 probes in total	TBD
Dry ILW (NFCC)		
Control assemblies, thimble plugs, neutron sources, thermocouple lances, ultra-sonic filters, control rod housings Main radionuclides – Co-460, Ni-63, Ag-110m, Cf-252	712 control assemblies in total 8 neutron sources in total 45 control rod housings in total Others TBD	TBD
Operational ILW DAW		
Metallic, maintenance wastes Main radionuclides – Co-460, Ni-63	0.38 – 1.5 m^3 / year	1 off 500 litre drum / year

Decommissioning ILW		
RPV Main coolant lines Main radionuclides – Co-460, Ni-63	TBD	
RPV shielding material Main radionuclides – Co-460, Ni-63, Ca-41, C-14, Cl-36	TBD	
Recombiners Main radionuclides – H-3	TBD	
Wet ILW		
Organic resins Main radionuclides – C-14, Cs-137, Sr-90, Co-60, Ni-63, Cl-36.	3.03 m^3 / year 121.2 m^3 total	Up to 24 off 500 litre drums / year
Filter solids Main radionuclides – Co-60, Ni-63	2.4 m^3 / year 96 m^3 total	Up to 2 off 500 litre drums / year
Sludges Main radionuclides – Co-60, Ni-63	3.81 m^3 / year 152.4 m^3 total	TBD
Dry ILW/LLW Operational		
Removable cartridge filters Main radionuclides – Co-60, Ni-63	TBD	
Reverse osmosis membranes Main radionuclides – Cs-137, Sr90, Co-60, Ni-63.	Up to 9.6 m^3 total	TBD
DAW – dry contaminated items Main radionuclides – H-3, C-14, Cs-137, Sr-90, Co-60, Ni-63.	Up to 37.5 m^3 / year Up to 1500 m^3 total	TBD
Dry ILW/LLW Decommissioning		
Activated charcoal Dismantling waste Main radionuclides – H-3, I-129/131, Cs-137, Sr-90, Co-60, Ni-63.	TBD	

Wet ILW/LLW		
Organic resins Main radionuclides – C-14, Cs-137, Sr-90, Co-60, Ni-63, Cl-36.	0.71 m^3/ year 28.4 m^3 total	TBD
Concentrates Main radionuclides – H-3, Cs-137, Sr-90.	2.54 m^3 152.4 m^3 total	TBD
Oils / solvents Main radionuclides – H-3, C-14, Cs-137, Sr-90, Ni-63	1.5 m^3 / year 60 m^3 total	TBD

21.9 Glossary of Terms 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
DEPD	Developed Principles for Decommissioning
DOORS	Dynamic Object-Oriented Requirements System
DRP1	Design Reference Point 1
DWMP	Decommissioning and Waste Management Plan
E3S	Environmental, Safety, Security and Safeguards
EA	Environment Agency
EIADR	Environmental Impact Assessment of Decommissioning Regulations
EoG	End of Generation
EPR	Environmental Permitting (England and Wales) Regulations 2016
EURATOM	European Atomic Energy Community
FAP	Funded Administration Plan
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GSR	General Safety Requirement
HAW	Higher Activity Waste
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
IEX	Ion Exchange
IRR	Ionising Radiation Regulations
ISFS	Intermediate Spent Fuel Store

IWS	Integrated Waste Strategy
LoC	Letter of Compliance
LLW	Low Level Waste
NDA	Nuclear Decommissioning Authority
NIA	Nuclear Installations Act 1965
NRW	Natural Resources Wales
NWS	Nuclear Waste Services
ONR	Office for Nuclear Regulation
OPEX	Operating Experience
POCO	Post Operational Cleanout
PWR	Pressurised Water Reactor
RD	Reference Design
REPs	Regulation Environmental Principles
RO	Reverse Osmosis
RGP	Relevant Good Practice
RP	Requesting Party
RR SMR	Rolls-Royce Small Modular Reactor
RSMDP	Radioactive Substance Management Developed Principle
RSR	Radiological Substances Regulations
SEPA	Scottish Environment Protection Agency
SF	Spent Fuel
SSC	Structure, System and Component
SWESC	Site-wide Environmental Safety Case
TAD	Target Audience Description
WENRA	Western European Nuclear Regulators Association
WMH	Waste Management Hierarchy