Partner Document Number	Partner Document Issue /Revision	Retention category:
n/a	n/a	A

Title

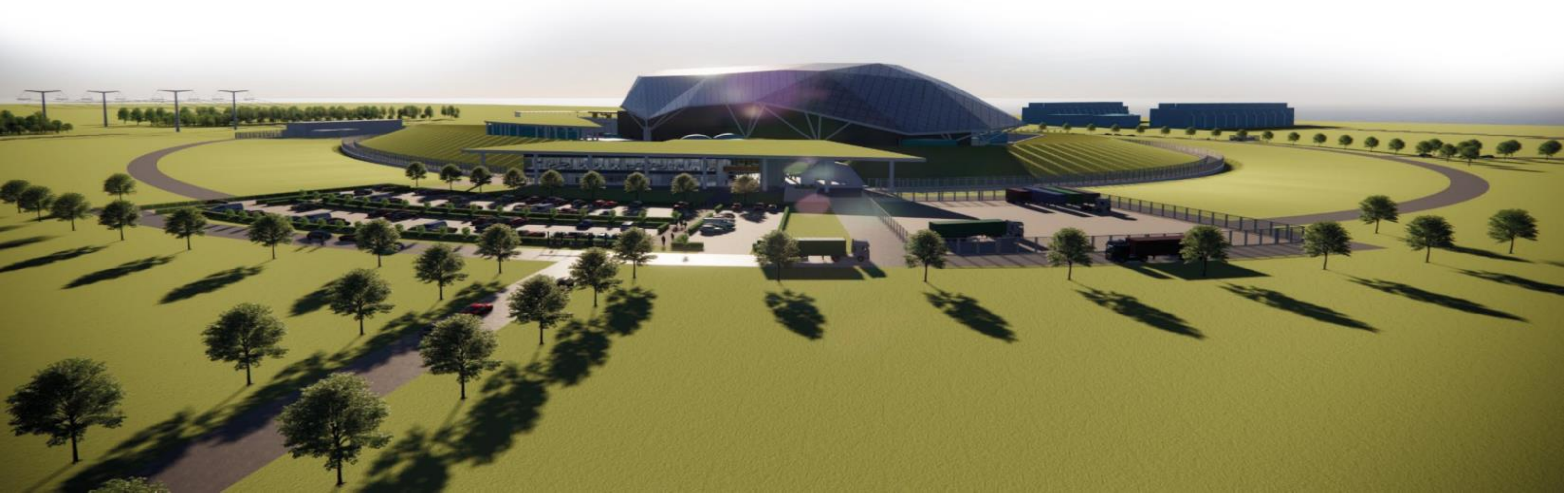
E3S Case Chapter 12: Radiation Protection

Executive Summary

This chapter of the Environment, Safety, Security, and Safeguards (E3S) Case for the Rolls-Royce Small Modular Reactor (RR SMR) outlines the arguments and preliminary evidence, available at the Preliminary Concept Definition (PCD) design stage, to underpin the high-level Claim that Radiological Protection measures are incorporated into the RR SMR design to minimise exposures of ionising radiation to employees and other persons during normal operations and reduce risks throughout the lifecycle of the plant to As Low As Reasonably Practicable (ALARP).

Radiation protection policies and design guidance are developed and described to inform the optioneering and design development processes and facilitate the design of the RR SMR to minimise dose to ALARP through the application of the hierarchy of controls, and ensure the design facilitates compliance with Ionising Radiations Regulations 2017 (IRR17). Preliminary evidence of the application of these policies is presented, including examples of design decisions for Structures, Systems and Components (SSCs) and layout that are pertinent to ensure exposures are reduced to ALARP, and the provision of shielding.

The evidence at PCD supports the position that RR SMR can minimise dose and reduce exposures to ALARP, noting further evidence to support the Claim and overall ALARP demonstration is being developed through the ongoing design programme, including detailed shielding assessments to support the design, dose assessments and comparison against numerical dose criteria, and demonstration of criticality safety for new fuel and spent fuel transported and stored outside of the reactor.



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12.0 Introduction

12.0.1 Introduction to Chapter

This report presents Chapter 12 of the Rolls-Royce Small Modular Reactor (RR SMR) Environment, Safety, Security & Safeguards (E3S) Case. Chapter 12 forms part of the Pre-Construction Safety Report (PCSR) and is a supporting reference to the Generic Environment Report (GER) and Generic Security Report (GSR), as defined in E3S Case Chapter 1: Introduction, Reference [1].

Chapter 12 presents the overarching summary and entry point to the design and safety information for the Radiation Protection aspects of the RR SMR, as defined at Reference Design (RD) 5 level of design maturity.

12.0.2 Scope

The Radiation Protection information presented within this chapter covers the following aspects:

1. Design for normal operations during all operational modes (Modes 1 through to 6B) over a full, 10-year operational cycle, allowing for the inclusion of all planned outage types, inclusive of relevant Examination, Maintenance, Inspection and Testing (EMIT) activities

2. Demonstration that the design of Structures, Systems and Components (SSCs), and with consideration of infrastructure and layout, can enable a future licensee to deliver compliance with Ionising Radiations Regulations 2017 (IRR17)

3. Exposures associated with post-accident accessibility and unintended criticality associated with new fuel and spent fuel outside of the reactor

4. Evaluation of exposures against numerical targets (Basic Safety Level (BSL) and Basic Safety Objective (BSO)), using Operating Experience (OPEX) from comparable reactor operations to support demonstration of As Low As Reasonably Practicable (ALARP) for collective dose, maximum individual dose and individual averages for onsite workers and members of the public, for the full lifecycle from commissioning to operation, refuelling, and final decommissioning and disposal

The following areas are excluded from the scope of this chapter:

1. Operating procedures, instructions, practices, and activities that are under the ownership of the future dutyholder/licensee

2. Doses due to fault sequences, except for criticality associated with new fuel and spent fuel outside of the reactor

3. Radiography practices associated with Heavy Pressure Vessels (HPV) & Mechanical, Electrical and Plumbing (MEP) factories

4. Derivation and justification of the Source Term, which is covered in E3S Case Chapter 20: Chemistry, Reference [2]

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. The radiation protection design and analysis are being progressed in line with the design programme to inform the design development and the demonstration that exposures to workers and the public are reduced to ALARP.

At PCD, this report describes radiation protection policies and design guidelines that have been developed to set out the radiation protection principles that inform the design of the RR SMR, which are embedded into the early design through the design optioneering process. A shielding basis of design has also been developed to set out the key parameters and assumptions for future shielding assessments.

Further radiation protection evidence is being developed to support the design programme in achieving high-level Claims, see Section 12.0.3.

12.0.3 Claims, Arguments, Evidence Route Map

The Chapter level Claim for E3S Case Chapter 12: Radiation Protection is:

Claim 12: Radiological Protection measures are incorporated into the RR SMR design to minimise exposures of ionising radiation to employees and other persons during normal operations and reduce risks throughout the lifecycle of the plant to ALARP

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 [3], described further in E3S Case Chapter 1: Introduction, Reference [1].

12.0.4 Applicable Regulations, Codes & Standards

The primary United Kingdom (UK) legislation adopted in the design of the RR SMR is IRR17, Reference [4] and the associated Approved Code of Practice and guidance (ACOP), Reference [5], which set out the minimum legal duties for work with ionising radiation and forms a framework that, if followed, ensures that exposure to ionising radiation arising from work activities is reduced to ALARP and does not exceed the dose limits specified within the regulation.

Other UK legislation adopted for the design of RR SMR includes:

1. The Environmental Permitting (England and Wales) Regulations 2016 (EPR16), Reference [6]

2. The Health and Safety at Work Act etc. 1974, Reference [7]

3. The Justification of Practices Involving Ionising Radiation Regulations 2004, Reference [8]

4. The Management of Health and Safety at Work Regulations 1999 (Reference [12]) – This legislation forms the basis for the requirement to perform, record and maintain risk assessments, which are a key component of the requirements coming out of IRR17

5. Nuclear Installations Act 1965 (NIA) (Reference [13]) – This legislation sets out the conditions under which a nuclear power plant, such as the RR SMR, is installed and operated, and allow the Office for Nuclear Regulation (ONR) to attach to the required site license such Licence Conditions (LCs) (Reference [14]) as may appear necessary or desirable in the interests of safety

6. The Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR) (Reference [15]) – This legislation sets out the requirements for planning for and managing the consequences of radiation emergencies arising from work with ionising radiation. This legislation is supported by an accompanying ACOP (Reference [16])

International standards and guidance adopted for the RR SMR include the International Atomic Energy Agency (IAEA) Standards and International Commission on Radiological Protection (ICRP) publications, noting IRR17 is derived from the ICRP, and the European recommendations based on the ICRP.

12.1 Optimisation of Protection & Safety

12.1.1 Radiological Protection Policies

The RR SMR provides adequate protection against exposure to radiation and radioactive substances. The RR SMR strategy to ensure protection against exposure to radiation and radioactive substances and compliance with E3S Design Principles, Reference [9], is set out in a series of radiation protection policy documents that are referred to throughout this report, including:

1. Dose Management Policy, Reference [10], which provides the general dose management principles, relevant legislation and good practice, plant zoning, technical issues and key policy and design interfaces for the RR SMR. It sets out the holistic approach to dose reduction for the RR SMR during critical operation, refuelling outages and EMIT activities whilst the plant is shutdown

2. Radioactive Source Term Policy, Reference [11], which defines a structured approach to minimising the source term

3. Radiation Shielding Policy, Reference [12], which covers the general shielding principles, the shielding design process, radiation safety criteria, technical issues, design interfaces and analysis tools/methods

These radiation protection policies are used to communicate the legislative requirements that must be applied to the RR SMR design, as outlined in Section 12.0.4. The key element of the radiation protection policies is the hierarchy of controls, where the means to minimise the exposure to radioactive material follows the ICRP justification, optimisation, and dose limitation model.

There is no single control, approach or solution that can be applied across the entire RR SMR design. Therefore, each radiation protection policy has adapted the hierarchy of controls to suit its need and in each case directs the design engineer to use the most effective method of reducing exposures first.

The Dose Management Policy focuses on reducing the source of radiation, increasing the distance between operators and the radiation source, decreasing the exposure time, and shielding the radiation source. It highlights key considerations that design engineers must embed into the design include regulatory requirements, dose targets for normal operations, dose targets under fault conditions, radiological designation of areas, minimisation of doses during maintenance, dose management during defuel and refuel, airborne contamination and decommissioning. The implementation of this is described further in Section 12.3 and 12.4 of this report.

The primary objective of the hierarchy of controls used in the Source Term Policy is to minimise radioactive sources, it does so by focusing on each of the following topic areas: elimination, prohibition and substitution, localisation and minimisation, immobilisation, and mitigation. It expands each of the areas in detail, informing the design engineers how key considerations can be applied using design measures. The implementation of this is described further in Section 12.3 of this report.

The Radiation Shielding Policy that will be adopted throughout the design stage of the RR SMR provides guidance to shielding analysts/designers throughout the major design phases. The application of appropriate shielding throughout the reactor lifecycle will enable the of hierarchy of controls principles to be optimised for reducing radiation exposures. It details the use of primary shielding, secondary shielding, structures, system and component shielding, radioactive material transport container shielding and refuelling process shielding. The implementation of this is described further in section 12.3.2 of this report.

The practical implementation of the hierarchy of controls, throughout the radiation protection policy documents, ensures that any potential received doses are ALARP. This requires that the design functions understand the policy requirements and appropriately apply them to the RR SMR design. This reduces the radiation exposures throughout the reactor life cycle being considered, i.e., design, commissioning, operation (including EMIT), decommissioning, and disposal.

In addition to the radiation protection policies outlined above, a more detailed set of design guidelines is provided in Reference [13]. These guidelines are intended to provide additional, more detailed guidance to the designers to ensure that good practice in radiation protection during the design stage is captured and applied during the design of the RR SMR in line with the requirements of IRR17, covering (but not limited to):

1. Water chemistry and material selection optimisation to reduce the source term

2. Shielding design, such as;

    a. Design of penetrations through shielded structures (pipework, Heating, Ventilation and Air Conditioning (HVAC) ducts etc.) to reduce shine or scatter

    b. Use of labyrinths in rooms containing very active sources where personnel access is required in preference to a heavy, shielded door, where reasonably practicable

3. Containment and segregation of radioactive material, such as;

    a. Features to ensure containment of radioactive contamination as close to source as possible

    b. Segregation of active systems from non-active systems, and high dose systems from low dose systems

    c. Segregation of pipework used to transfer high dose effluents and waste that may result in regular transient high dose rates

4. Radiation and contamination zoning schemes to support design and layout, including room placement and ventilation configuration (airflow cascades in controlled areas from areas of lower contamination to those of higher contamination)

5. Design of SSCs to facilitate decontamination and flushing to reduce maintenance doses, and isolation to reduce the risk of spread of contamination

6. Design of HVAC systems to consider airflows, adequate air changes, and risks of iodine and degassing phenomena

7. Equipment and pipework design to minimise deposition of activity, through use of gradients and elimination of dead legs

8. Building and room layout to ensure personnel are kept away from radiation sources unless required and reduce the time spent near them to a minimum, and provision of locations within the building layout for Personal Protective Equipment (PPE), Respiratory Protective Equipment (RPE), and dosimetry services

9. Control of access and egress to radiation controlled areas, contamination controlled areas and high dose rate areas

10. Provision of installed monitoring equipment for radiation protection, as well as portable instrumentation

At PCD, these guidelines and policies inform design development (see Section 12.1.3), their implementation described further in Section 12.3 of this report. They will also be used to inform a general set of radiation protection design requirements that will be formalised in the RR SMR requirements management system DOORS (Dynamic Object-Oriented Requirements System) as non-functional system requirements prior to the final concept definition design stage.

A Radioactive Waste and Decommissioning Policy, Reference [14], also provides design guidance and principles pertinent to dose management aspects of 'design for decommissioning', described further in E3S Case Chapter 21: Decommissioning & End of Life Aspects, Reference [15].

12.1.2 Policy Interfaces

By their nature and content, the Dose Management, Radioactive Source Term, and Radiation Shielding policies are complementary. The three radiation protection policies work together to reduce normal operation radiation doses to employees and the other persons to below legal limits, and to levels which are demonstrated to be ALARP. Radiation doses to components and equipment are also minimised so that safe operation can be demonstrated to the end of their respective design lifetimes. The interactions between the radiation protection policies are illustrated in Figure 12.1-1 and Table 12.1-1.

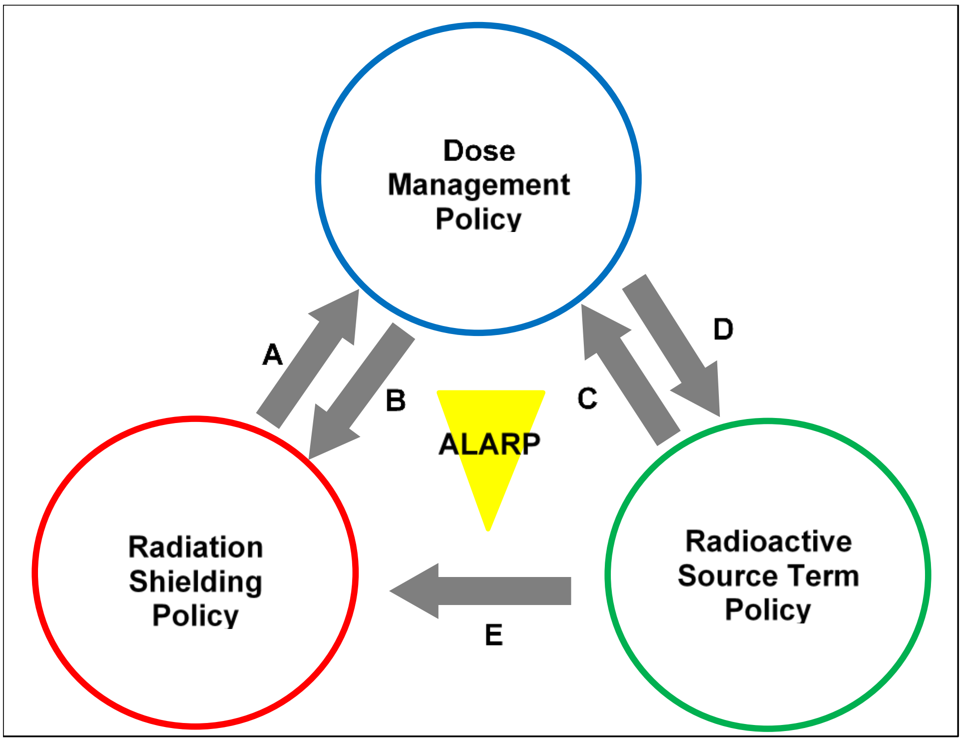

Figure 12.1-1: Radiological Protection Policy Interactions

Table 12.1-1: Radiological Protection Policy Interactions

Interaction ID	Description
A1	Definition of the codes and methods for predicting dose rates for use in dose assessments.
A2	Defines the dose, dose rate and flux leakage targets for the radiation shield design.
A3	Outlines the ALARP principle and its applicability to dose reduction and the necessity to demonstrate and ALARP shield design.
B1	Defines the national and international dose limits applicable to the dose management and ALARP (shield) design.
B2	Defines the requirement for radiation shielding to protect employees, other persons, and plant components/equipment.
C1	Identifies the key drivers for Radioactive Source Term Reduction
C2	Defines the Hierarchy of Controls for Source (and dose) reduction.
C3	Identifies the key considerations for reducing the activation products of dissolved and suspended impurities, including corrosion products, and activation products of chemical additives to the coolant.

Interaction ID	Description
C4	Provides a comprehensive review of the design options, techniques, and philosophies for primary coolant source term minimisation.
C5	Provides both requirements and recommendations to support decision making related to project engineering and safety.
D1	Outlines the ALARP principle and its applicability to dose, and by extension, radioactive source term reduction.
E1	Definition of primary coolant-based radiation sources that need to be considered from a radiation shielding perspective.

12.1.3 ALARP in Decision Making Process

As the RR SMR is developed, the principle of ALARP is embedded into design decisions through the Conduct Design Optioneering Process C3.2.2-2 and associated Design Decision Record template, Reference [16], that records the arguments and evidence in support of decisions reducing risk to ALARP.

The information recorded as part of the optioneering process includes a comprehensive review of Relevant Good Practice (RGP) and OPEX to support identification of options, and evaluation of options and their impact on E3S. Embedded within this evaluation is the consideration of the radiation protection impacts, with options evaluated against the guidance provided in the Radiological Protection policies (see Section 12.1.1).

Key to the ALARP demonstration is the application of the hierarchy of control (as defined in IRR17), which is implemented when evaluating the benefits and detriments of each design option, to ensure passive engineered safety features are prioritised rather than active systems or operator action.

The focus is to not concentrate solely on the potential dose rates but on the potential dose uptake of individuals carrying out routine and non-routine operations. The layout and access requirements ultimately determine the eventual optimisation of doses and demonstrate ALARP.

Options are also compared against numerical dose targets, or where there is insufficient quantitative information available early in the design process, a qualitative judgement may be made (such as comparison with RGP). A balance may be needed to minimise both collective dose and individual dose, with priority given to reducing individual dose to ALARP.

This information is used to support a decision analysis, undertaken as part of a multi-disciplinary review including E3S and the Radiation Protection Technical Lead and/or the Radiation Protection Adviser acting as key stakeholders, resulting in down-selection of design solutions.

Further information on the decision-making process is presented in E3S Case Chapter 24: ALARP Summary, Reference [17]. Application of the process for radiation protection at PCD is described further in Section 12.3.

12.1.4 Interactions with other Chapters

Radiation protection plays a vital role in ensuring that the RR SMR design is ALARP, as such it is a cross-cutting topic that has many interactions with other E3S Case chapters. These interactions will be conveyed throughout the claims, arguments and evidence that will be produced in the development of the E3S Case.

Key interactions are predominantly associated with reactor chemistry, human factors, environment, fuel and core, fault studies and severe incidents, radioactive waste, and decommissioning. These are areas of importance due to potential impacts that the application of radiation protection can have when ALARP is applied holistically.

12.2 Sources of Radiation

12.2.1 Contained & Immobile Sources of Radioactive Material

For the RR SMR, the radioactive sources (at power) comprise constituents from the following eight principal production routes:

1. Reactor fuel, including original fuel material, fission products and higher actinides formed by neutron capture and decay
2. Neutron and gamma leakage from the fission process in the core
3. Activation products of the reactor coolant (water) and dissolved gases
4. Activation products of dissolved and suspended impurities, including corrosion and wear products
5. Activation products of chemical additives to the coolant
6. Activation products of structural and shielding materials
7. Fission of 'tramp' uranium present in fuel cladding and structural steels and Nickel-based alloys
8. Activation products of the atmosphere inside containment in high flux regions

Radioactive source terms arise during normal operation from interaction of material with neutrons in the reactor core. This interaction can be direct or, in a few cases, indirect. Indirect interactions are primarily due to proton activation, with the proton flux resulting from neutron-material activation.

The RR SMR source terms are being developed and will be presented in E3S Case Chapter 20: Chemistry, Reference [2].

12.2.2 Sources of Airborne Radioactive Material

Airborne contamination can arise from a variety of sources in the RR SMR, including radioactive noble gases, aerosols and particulate fission products and actinides. The following non-exhaustive list of exposure pathways provides some examples that will be considered for the design:

1. Release outside of primary containment from primary to secondary circuit leak (via Steam Generators)
2. Release from removal of Reactor Pressure Vessel (RPV) head during refuelling process
3. An undetected primary circuit leak
4. Activation of air via neutron activation near to the reactor vessel during power operation (argon-41 production pathway)

5. Evaporation from the refuelling/spent fuel ponds

6. Maintenance operations (including outage)

7. Decommissioning operations

The RR SMR design philosophy is to minimise dose from airborne activity to negligible levels, such that airborne contamination does not constitute a primary dose exposure pathway during normal power and shut down operations.

It is recognised that during maintenance activities that there will be areas where an elevated risk of radioactive airborne activity could be present. At this stage in the design, it has not been possible to accurately quantify this potential; however, mitigations to restrict any exposures have been incorporated within the design in line with the radiation protection design guidelines for the RR SMR and the associated radiation protection policies.

During the outage periods of the RR SMR there will be a potential risk of airborne contamination, this is due to the combination of significant work activities, additional staffing from external sources that are unfamiliar with the design, and access to areas that would usually have little to no occupancy. As with routine maintenance the application of the radiation protection policies and design guidelines will be used to mitigate any potential release and spread of contamination caused by these activities.

Ongoing Hazard Identification (HAZID) and Hazard and Operability (HAZOP) studies of the concept design are also used to formally identify potential mechanisms for airborne contamination hazards and identify measures to ensure any shortfalls are addressed prior to final concept design.

Furthermore, the design philosophy ensures that the RR SMR is designed for decommissioning through the policies outlined in Section 12.1.1. This will enable any dose uptake caused by airborne contamination from the eventual post operation clean out and dismantling to be optimised to be ALARP. As the decommissioning strategies and plans are developed further, key OPEX will be gathered from ongoing decommissioning projects and operational Pressurised Water Reactors (PWRs), with the intention that historic reactor design shortfalls are avoided in the RR SMR.

12.3 Design Features for Radiation Protection

12.3.1 Facility & Equipment Design Features

Design Optioneering

The Design Optioneering Process and the Design Decision Record, Reference [16], described in Section 12.1.3, is fundamental in formally documenting the ALARP argument associated with any high-level decisions made. This is a key reference point that is utilised for gathering evidence that optimisation and dose limitations have been incorporated within the decision process.

Design decisions relevant to radiological protection are summarised within the various engineering chapters of the E3S Case. At PCD, examples of design decisions and development of SSCs pertinent to ensuring exposures are reduced to ALARP include (but are not limited to):

1. Cognisant of the decontamination activities required when performing reactor cavity drain down during refuelling in PWRs, the Refuelling Pool [FAF] and Refuelling Cavity [FAE] are designed for a flood-up approach for refuelling based on RGP and OPEX, to provide bulk water shielding and minimise dose rates during refuelling activities, with upper internals, fuel, and core barrel removed under water

2. The RR SMR boron-free chemistry regime enables the use of potassium hydroxide (KOH) as the pH raiser rather than lithium hydroxide (LiOH) that is used in conjunction with boric acid in traditional PWR designs, offering potential benefits such as mitigation of fuel cladding corrosion and reduction in the tritium source term

3. The Chemistry and Volume Control System (CVCS) [KB] design has selected backwashable filters to enable automation of filter changes and remote cleaning, which significantly reduces the need for filter changes compared to traditional PWR filtering methods, in turn reducing operator dose uptake during EMIT

4. Design of the liquid effluent tanks in the Processing & Treatment System for Liquid Radioactive Effluent [KNF] with suitable materials and sloping structure towards the suction line at the bottom, to minimise accumulation of particulates

5. Given the high activity of resins and filter solids expected in the storage tanks in Temporary Storage for Intermediate-Level Waste (ILW) [KME20], waste storage tanks are being designed to be walled in and shielded such that personnel access to the tanks is not possible. Design features to minimise the potential for settling and blockages are also being implemented, such as wide sweeping bends and full-bore pipes, as well as design to prevent leaks, with bunds beneath each tank providing a form of secondary containment. The tanks will also be connected to the active HVAC System [KL] to minimise the risks associated with airborne activity

6. Minimisation of plant equipment and components where possible to reduce the maintenance burden and associated operator doses, such as the decision to utilise the existing High Pressure Injection System (HPIS) [JND] to deliver boron in support of the Alternative Shutdown Function (ASF) [JD02] rather than additional pumps and components

7. Design of the steam generators incorporate an integral crossflow preheater, which permits a reduction in heat transfer area that can reduce the quantity of Nickel-58 released from the steam generator tubes into the reactor coolant due to corrosion, in turn reducing the quantity of Cobalt-58 generated due to activation

8. Selection of materials that result in low activation, for example, stainless steel cladding of the pressuriser helps to minimise the build-up of corrosion products in the Reactor Coolant System (RCS) coolant

Source Term Minimisation

As part of the RR SMR design development process, a structured approach and guidance is provided to designers to minimise the source term, Reference [11], which is achieved through adoption of the following hierarchy of controls:

1. Elimination: systems, components and materials intended to deliver an identified requirement or function should be assessed for their potential impact on source term, with a goal to eliminate design features, components or practices that could contribute to the source term

2. Prohibition & Substitution: where elimination of components or design features is not possible and they are necessary to fulfil design requirements, then their design should be such that materials known to have a highly deleterious impact on the source term are avoided and are substituted for other materials with a reduced impact on source term. For example, hard facings are known to release particulate material that can become activated, dependent upon the material used

3. Minimisation & Localisation: if components, design features or materials known to contribute to the source term must be used in the reactor as they are the only means of delivering a function, then the design should be such that their use is minimised. In this context, minimisation refers to parameters such as number of components, material mass and wetted surface area. Each specific application should be assessed on its own merits to ensure that effective minimisation has been achieved. Minimisation also applies directly to materials inadvertently added to the reactor such as impurities in structural materials, chemical additives and other water treatment media. Specifications should be formulated such that impurities that contribute to the radioactive source term are minimised. Localisation encompasses assessment of each specific location in the context of the reactor source term. For example, materials located in the reactor core will have a high residence time in the neutron flux and even small masses of certain materials could result in high activities

4. Immobilisation: Material will only contribute to the radioactive source term if it interacts with the neutron flux in the reactor core. Therefore, even highly detrimental materials can be prevented from contributing to the source term if they are immobilised in systems and components away from the reactor core and RPV. Immobilisation can be achieved by numerous means such as optimisation of chemistry to minimise corrosion and/or solubility or encapsulation (for example, through use of coatings) to avoid contact with RCS coolant

5. Mitigation: This is generally the least effective of the controls described here. Nonetheless, it should still be applied with the same rigour as the other controls and in some cases is the only control that can be realistically applied. Mitigation is defined as lessening the impact of radioactive source term once it is generated. This lessening of impact can be

achieved by removing source term material from the RCS (e.g., through filters, ion exchange resins, etc.) or use of methods that prevent accumulation in undesirable locations

High-level requirements (shall) and recommendations (should) based on the hierarchy of controls for source term minimisation are specified for the RR SMR design, summarised in Table12.3-1. These are specified as non-functional system requirements in DOORS and applied to the design of systems and components through the design development process (described in E3S Case Chapter 1: Introduction, Reference [1]).

Table 12.3-1: Source Term Minimisation Requirements and Recommendations

DOORS ID	Source Term Minimisation Requirements
Transverse-R-544	All uses of cobalt-containing alloys in the RR SMR shall be explicitly agreed by the SMR Chief Engineer and are to be accompanied by an E3S assessment. This applies to the RCS and all systems that could potentially interface with the RCS, during all phases of operation including fault conditions
Transverse-R-545	All uses of silver in the RR SMR shall be explicitly agreed by the SMR Chief Engineer and are to be accompanied by an E3S assessment. This applies to the RCS and all systems that could potentially interface with the RCS, during all phases of operation including fault conditions
Transverse-R-546	All uses of antimony in the RR SMR shall be explicitly agreed by the SMR Chief Engineer and are to be accompanied by an E3S assessment. This applies to the RCS and all systems that could potentially interface with the RCS, during all phases of operation including fault conditions
Transverse-R-547	All material selection decisions shall consider the impact on source term. This includes the selection of metallic and non-metallic materials and applies to the RCS and all systems that could potentially interface with the RCS, during all phases of operation including fault conditions
Transverse-R-549	All material specifications for primary water wetted surfaces in the RCS and connecting systems in the RR SMR shall contain a maximum value for cobalt. This value shall be consistent with current nuclear industry good practice at the time the specification is produced
Transverse-R-551	Potassium hydroxide and potassium/hydroxide ion exchange resins used in the RR SMR shall contain sodium as an impurity <0.05 wt%, consistent with analytical grade potassium hydroxide
Transverse-R-552	The RR SMR shall adopt zinc injection in the form of depleted zinc acetate. The level of depletion shall be consistent with industry good practice at the time
Transverse-R-553	All dose chemical specifications shall be formulated to take account of potential contaminants and their impact on source term. This applies to all chemicals injected into the RCS and systems that could

	potentially interface with the RCS, during all phases of operation including fault conditions
Transverse-R-555	Any use of a neutron source shall be accompanied by an E3S assessment that considers all aspects of the design to demonstrate that risks have been reduced so far as is reasonably practicable
Transverse-R-556	The primary coolant chemistry specification shall be accompanied by an E3S assessment that considers all aspects of the design and demonstrates that risks have been reduced so far as is reasonably practicable
Transverse-R-560	The CVCS shall be designed to minimise concentrations of radionuclides in the primary coolant during all phases of operation
DOORS ID	**Source Term Minimisation Recommendations**
Transverse-R-540	The number of components with wear surfaces in the primary circuit should be minimised so far as is reasonably practicable
Transverse-R-557	Manufacturing processes and surface finish should be considered as part of the material selection process and E3S assessment for all materials that makeup the primary water wetted surfaces in the RCS and connecting systems
Transverse-R-566	Consideration should be given to the potential benefits of Ultrasonic Fuel Cleaning (UFC) technology to the RR SMR and, if appropriate, the design developed such that UFC can be encompassed in the most effective manner
Transverse-R-552	The RR SMR design should not preclude the ability to decontaminate the RCS and associated systems

Containment & Segregation

RR SMR is being designed such that radioactive contamination is contained within the systems of the plant where it is generated. Where this is not possible, radioactive contamination will be confined as close to the source as reasonably practicable, which is in line with UK and international best practice.

Where reasonably practicable, active, and non-active systems will be physically separated and segregated from each other, as will low dose systems from high dose systems. Items requiring regular inspection or instruments requiring regular reading will be segregated from high dose areas and located such that they can be inspected or read from low dose areas, or consideration will be given to the use of cameras or other appropriate means to allow remote inspection.

Non-functional system requirements for containment and segregation are being developed from the E3S design principles (outlined in E3S Case Chapter 3: E3S Objectives and Design Rules, Reference [18]), to inform the layout of the design, and specific radiation protection requirements are being developed based on policies and guidelines (outlined in Section 12.1.1). Evidence against these requirements will be reported in future revisions of the case in line with the CAE Route Map.

Radiation & Contamination Zoning

The designation of classified areas is a requirement of UK law. IRR17 defines a 'Controlled Area' as [4]:

"Every employer must designate as a controlled area any area under its control which has been identified by an assessment made by that employer (whether pursuant to regulation 8 or otherwise) as an area in which—

1. *it is necessary for any person who enters or works in the area to follow special procedures designed to restrict significant exposure to ionising radiation in that area or prevent or limit the probability and magnitude of radiation accidents or their effects; or*

2. *any person working in the area is likely to receive an effective dose greater than 6.0mSv a year or an equivalent dose greater than 15.0mSv a year for the lens of the eye or greater than 150.0mSv a year for the skin or the extremities."*

In addition, IRR states:

"An employer must not intentionally create in any area conditions which would require that area to be designated as a controlled area unless that area is for the time being under the control of that employer."

Similarly, IRR17 defines a 'Supervised Area' as:

"An employer must designate as a supervised area any area under its control, not being an area designated as a controlled area—

1. *where it is necessary to keep the conditions of the area under review to determine whether the area should be designated as a controlled area; or*

2. *in which any person is likely to receive an effective dose greater than 1.0mSv a year or an equivalent dose greater than 5.0mSv a year for the lens of the eye or greater than 50.0mSv a year for the skin or the extremities."*

An approach for a radiological zoning scheme for RR SMR is presented in Table12.3-2, based on OPEX from other UK nuclear facilities and the requirements of IRR17. The designations identified un-designated (i.e., uncontrolled) areas, supervised areas, and a series of controlled areas. The controlled areas are colour coded according to likely dose rate range in the area. For bounding dose calculations in supervised and controlled areas, the maximum number of working hours in a year is conservatively based on a 48-hour week for 48 working-weeks in a year.

Table 12.3-2: Example RR SMR Zoning Rates for PCD

Designation	Zone	Dose Rate (DR) Range	Comments	Max. Residency Time in a Year (Hours)[1]
Un-designated Area	White	Less than 2.5μSv/hr	Full time working in this zone would result in a full body dose of less than 6mSv in a year.	8000
Supervised Area	Green	2.5μSv/hr < DR < 7.5μSv/hr	Full time working in this zone would result in a full body dose of greater than 6mSv, and less than the BSL.	2666
Controlled Area	Yellow	7.5μSv/hr < DR < 25.0μSv/hr	Working time should be limited to ALARP	800
	Orange	25.0μSv/hr < DR < 100.0μSv/hr	The working time in this zone is limited to that which is strictly necessary	200
	Red	100.0μSv/hr < DR < 1.0mSv/hr	The access procedure is regulated	20
	Brown	1.0mSv/hr < DR < 10.0mSv/hr	Access is prevented by a physical barrier. The doors are double locked. The access procedure is strictly regulated. An individually named authorisation is compulsory for entering these zones	2
	Purple	10.0mSv/hr < DR < 100.0mSv/hr		0.2
	Black	DR > 100mSv/hr		<0.2

[1] This is the total number of hours an employee could occupy a specific zone, assuming the upper bound dose rate, before breaching the BSL (20mSv/yr)

This radiological zoning scheme will inform the design development, including access control and room layout and placement, in particular locating areas with potentially higher dose rates away from areas of potentially lower dose rates and those areas anticipated to require more routine access.

An approach for a contamination zoning scheme for RR SMR is presented in Table 2.3-3, based on OPEX from existing UK practice and justified in the Radiation Protection Design Guidelines, Reference [13].

Table 12.3-3: Contamination Zoning Scheme

<table>
<tr><th>Area Designation</th><th>Criteria</th><th colspan="2">Notes</th></tr>
<tr><td>Undesignated Area: C0</td><td>An area not designated under IRR17</td><td colspan="2">Radioactive content of any item shall meet the requirements of EPR16 Schedule 23, Part 6</td></tr>
<tr><td>Supervised Area: C1</td><td>An area where conditions shall be kept under regular review</td><td colspan="2">Less than C2 limits</td></tr>
<tr><td>Controlled Area</td><td>Radionuclide</td><td colspan="2">Radioactivity Lower Limit</td></tr>
<tr><td rowspan="2">Contamination Controlled Area: C2</td><td>Alpha emitters</td><td colspan="2">0.4Bq/cm^2</td></tr>
<tr><td>Radionuclides not otherwise specified (including Tritium)</td><td colspan="2">4Bq/cm^2</td></tr>
<tr><td rowspan="6">Contamination Controlled Area: C3</td><td rowspan="2">Where alpha emitting radionuclides may be disregarded</td><td>Alpha limit</td><td>Not applicable (n/a)</td></tr>
<tr><td>Beta limit</td><td>10Bq/m^3</td></tr>
<tr><td rowspan="2">Where alpha and beta emitting radionuclides are present</td><td>Alpha limit</td><td>0.01Bq/m^3</td></tr>
<tr><td>Beta limit</td><td>2Bq/m^3</td></tr>
<tr><td rowspan="2">Where tritium is present, and alpha and (other) beta emitting radionuclides may be disregarded</td><td>Alpha limit</td><td>n/a</td></tr>
<tr><td>Beta limit</td><td>1.0E+4Bq/m^3</td></tr>
<tr><td>Contamination Controlled Area: C4</td><td>As per C3</td><td colspan="2">>100× lower C3 level</td></tr>
</table>

This ‘design’ contamination zoning scheme will inform the contamination control design features, including decontamination facilities, ventilation configuration to ensure air flows from areas of lower contamination to higher contamination, spacing for barrier control and sub-change areas, and layout such that contamination areas are consolidated for more efficient access control.

As the plant design develops, further division of controlled areas will be based upon the levels of radiation, surface contamination and airborne activity, measured and/or expected as the result of planned work activities. Evidence of radiation protection requirements informing the design and layout will be presented in future revisions of the E3S Case.

Decontamination, Flushing & Isolation

RR SMR incorporates flushing capability where possible to decontaminate effluent systems with clean water prior to maintenance activities, thereby reducing direct dose rates and/or reducing airborne activity concentrations where the system needs to be opened for maintenance.

Where necessary, RR SMR systems and components include isolation capability to permit maintenance activities being carried out.

Where appropriate, provision is made for the placement of decontamination pans, sinks, or equivalent in the design, appropriately sized to the equipment to be decontaminated and accounted for in the provision of services (e.g. water, drains) and the location of HVAC extracts.

All surfaces will be designed to be easily decontaminated, including consideration of surface coatings and finishes, polishing, eliminating potential contamination traps, and material selection.

Specific radiation protection requirements are being developed based on policies and guidelines (outlined in Section 12.1.1), evidence against these requirements will be reported in future revisions of the case in line with the CAE Route Map.

Equipment & Piping Design

The RR SMR includes pipework, valves, vessels, pumps, heat exchangers and other components that are in contact with radioactive material, the design of which will minimise the deposition of activity, taking due cognisance of the planned contents of the components, including their associated source term, chemical composition, pH, etc.

This includes the use of gradients, the removal of right angle bends and unnecessary flow restrictions, the elimination of dead legs, low points and other contamination traps, the ability to flush the system and drain from the lowest point of the component, component layout for ease of maintenance access, provision of space for temporary shielding, provision of lifting points, provision of inspection ports and manway covers, and provision of nozzles for attachment of flushing equipment.

The number of valves will be minimised and valve types that are completely sealed will be selected where practicable to reduce potential for inadequate sealing leading to leaks.

Equipment and piping, and their layout, are designed to facilitate EMIT. Any requirements for grinding, cutting, drilling and other activities that could lead to spread of contamination are eliminated so far as is reasonably practicable.

Specific radiation protection requirements are being developed based on policies and guidelines (outlined in Section 12.1.1), evidence against these requirements will be reported in future revisions of the case in line with the CAE Route Map.

Building & Room Layout Design

The RR SMR layout considers Radiation Protection guidelines to ensure that instances where lower classification areas are accessed via higher classification areas are eliminated where reasonably practicable.

For example, the Reactor Island [R01] layout has been separated into north and south zones. The north zone will predominantly contain rooms/equipment anticipated to have much lower dose rates, such as duty Electrical, Control and Instrumentation (EC&I) equipment, as well as the main access routes for the buildings. The south zone will predominantly contain rooms/equipment anticipated to have higher dose rates, such as ILW tanks. Further demarcation across the levels of Reactor Island [R01] also considers separating higher dose rate equipment, such as locating spent resin tanks on the basement level of the south zone away from main access routes.

The building layout for radiation protection includes locating circulation routes, waiting areas, change areas, control rooms, areas containing instruments or equipment that require regular reading or inspection, and other areas of high occupancy, such that the design prevents workers from unnecessarily entering or loitering in high radiation areas and minimises their time in those areas.

A driving element of the maturing reactor layout is the impact that compact design has on the potential radiation exposures to the workforce. This is critical with regards to EMIT, and justification is compiled to demonstrate that any exposures to radiation is maintained ALARP. The use of the definition review process, HAZID and HAZOP studies, formal radiation protection advice and the design decision record all aid the documentation of the practical application of ALARP.

During periods of enhanced EMIT the RR SMR layout is considerate towards the additional influx of maintenance personnel regarding equipment, waste, and welfare facilities. In addition to this it will have to facilitate additional temporary controlled areas, dosimetry distribution capabilities, access requirements and optimise the potential storage and laydown areas.

Further evidence to support justification of RR SMR layout will be developed as the design matures, informed by the radiation and contamination zoning schemes presented in Table 12.3-2 and Table 12.3-3, to ensure that instances where lower classification areas are accessed via higher classification areas are eliminated, where reasonably practicable.

Access Control

Access controls within controlled and supervised areas for RR SMR fall under a range of requirements outlined within the IRR17, Reference [4]. To ensure compliance with legislation and demonstrate that access controls are appropriately represented at PCD, three primary forms of access control are considered for RR SMR:

1. Control of access to and egress from the main Radiation Controlled Area (RCA), including access and egress through a single location with appropriate barrier controls, suitably sized change rooms, provision of monitoring and alarm equipment, and evacuation routes

2. Control of access to and egress from contamination controlled areas, including access through a dedicated sub-change area, designed in accordance with Reference [19]

3. Control of access to high dose rate areas outlined in Table 12.3-2, including single locks for access control to permanent red areas, and two independent locks for access control to permanent brown, purple and black areas. Any door or access to black areas, shall, where practicable, be equipped with safety devices (e.g., a system interlock) that will inhibit plant or apparatus whilst entry is possible

Specific radiation protection requirements are being developed based on policies and guidelines (outlined in Section 12.1.1), evidence against these requirements will be reported in future revisions of the case in line with the CAE Route Map.

Decommissioning

The Radioactive Waste and Decommissioning Policy (Reference [14]) outlines recommendations for the ‘design for decommissioning’, with those that are pertinent to dose management incorporated into the Dose Management Policy, Reference [10], and are summarised in Table

12.3-4 below. These are specified as non-functional system requirements in DOORS and applied to the design of systems and components through the design development process.

Table 12.3-4: Decommissioning Recommendations Applicable to Dose Management

DOORS ID	Decommissioning Requirements
To Be Confirmed (TBC)	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
TBC	Radioactive and non-radioactive systems and areas should be kept separate
TBC	Pipes and ductwork installations should be designed to minimise the hold-up and deposition of ‘crud’ and active dust particulates
TBC	Easy, safe access should be incorporated into the design for characterisation, decontamination, disassembly, and handling of plant using proven, simple working practices
TBC	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
TBC	Penetrations, cracks, crevices, and joints that may trap contaminants should be minimised
TBC	All porous surfaces should be sealed against ingress of activity and other hazardous chemicals
TBC	Special surface finishes or polishing treatments should be employed where appropriate to prevent adherence of contamination or penetration into the surface of materials
TBC	The use of hazardous materials, or those which become hazardous during operation, should be minimised
TBC	Monitoring systems for the early detection of leaks and contamination should be employed
TBC	Provision of decontamination facilities should be made for maintenance and clean-up purposes
TBC	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: Co, Ni, Nb, and Ag. Consequently, stainless steels should be utilised only where necessary for safety and design performance reasons
TBC	The design should incorporate activation monitoring arrangements for the reactor and immediately surrounding area

Design for Plant Operations and EMIT

During in-service plant operation, plant maintenance and inspection activities inside the reactor island are anticipated to contribute a significant proportion of the collective employee dose. Additionally, the dose burden is amplified the longer the plant is operated for. This is due to cumulative radiation source build-up effects in the primary coolant and on primary wetted surfaces, coupled with periodic maintenance outages and the increased likelihood of non-routine maintenance being required on the plant. It is therefore imperative that a range of practices, measures and design features are considered to minimise dose exposure to maintenance employees.

A non-exhaustive list of dose reductions options is presented in the Dose Management Policy, Reference [10], developed based on a review of existing engineering good practice and by looking ahead to the exploitation of wider industry technologies, including:

1. Cobalt and Source Term minimisation/mitigation (described in Section 12.3.1)

2. Distance from Source:

   a. use of robotics for very high dose rate environments, such as wall-crawling robot technology for inspection of RPV circumferential welds, nozzles and pipework, and drone technology for plant dose rate surveys

   b. careful design of tooling to increase their distance from sources of radiation, effective for operations such as fuel handling

   c. design of components, system, and plant to minimise dose, including locating of manual valves away from high dose rate areas, provision of easily removable shielding, accessible fastenings, and adequate space for tooling and equipment

   d. use of wearable augmented reality technology to overlay information onto the live scenery, which could be a colour codes indication of how ‘hot’ or active a component or location is. Gamma camera technology is available to generate dose rate information data

   e. provision of permanent or temporary engineered barriers to support zoning and demarcation of high dose rate areas or rooms, with interlocks for access control

   f. remote replenishment of Ion Exchange Column (IXC) resin used for effective chemistry control

3. Minimisation of Exposure Time:

   a. employee training tools using rigs and Virtual Reality (VR) for operations that cannot be automated

   b. effective scheduling of EMIT activities, such as grouping component specific tasks to avoid repetition of preparation and scheduling high dose activities at the end of a maintenance period to maximise source decay

   c. elimination or minimisation of EMIT activities based on OPEX and best practice

4. Radiation Shielding (described in Section 12.3.2)

These options will be considered and where viable reviewed through the design decision process.

Design for Defuel and Refuel

Activities directly related to refuelling are likely to account for a significant, repetitive portion of the total fuel cycle dose exposure, and to overall individual exposure for many of the plant's highest dose employees. Therefore, minimisation of radiation exposure during defuel/refuel will form a key part of the through-life dose reduction strategy.

Refuelling facility design coupled with careful consideration of the defuel/refuel process will form the basis of dose minimisation, achieved by development of a realistic occupancy model which in combination with dose rate predictions for occupied areas to drive improvements to the plant design and procedures.

Key considerations for minimising radiation exposure to workers during defuel/refuel activities are outlined in the Dose Management Policy, which are considered in the defueling and refuelling design development presented in E3S Case Chapter 9A: Auxiliary Systems, Reference [20]. These include:

1. Efficient Integrated Head Package (IHP) removal process that avoids or minimises direct shine from a dry RPV
2. Design of facilities to minimise contamination, such as provision of cooling filtration and ion exchange for the Spent Fuel Pool (SFP) [FAB10], and use of wet processes to minimise airborne release
3. Design of refuelling equipment and procedures in line with the following philosophies:
    a. Aim to install any temporary shielding using remote means (e.g., craning)
    b. Minimise the number of personnel required for refuelling procedures in high dose environments
    c. Use remote tooling/equipment and/or robotics where practicable
    d. Easy to clean/decontaminate tools and containers
4. Design components around the IHP, e.g., Control Rod Drive Mechanisms (CRDMs), with simple and robust interfaces to enable reliable removal and installation
5. Use of shielded containers where components are removed for prolonged periods of time
6. Provision of monitoring and ventilation of airborne activity

12.3.2 Shielding

The RR SMR radiation shielding forms an essential part of the overall strategy to reduce the dose to individuals to levels that are ALARP throughout the full lifecycle of the plant from initial commissioning, operation, refuelling, and final decommissioning and disposal.

The Radiation Shielding Policy, Reference [12], covers the key areas of general shielding principles, radiation safety criteria and legislation, technical issues, design interfaces, and analysis tools/methods, with more detailed shielding design requirements specified in the Radiation Protection Design Guidelines, Reference [13].

The shielding design process is summarised in Figure 12.3-1.

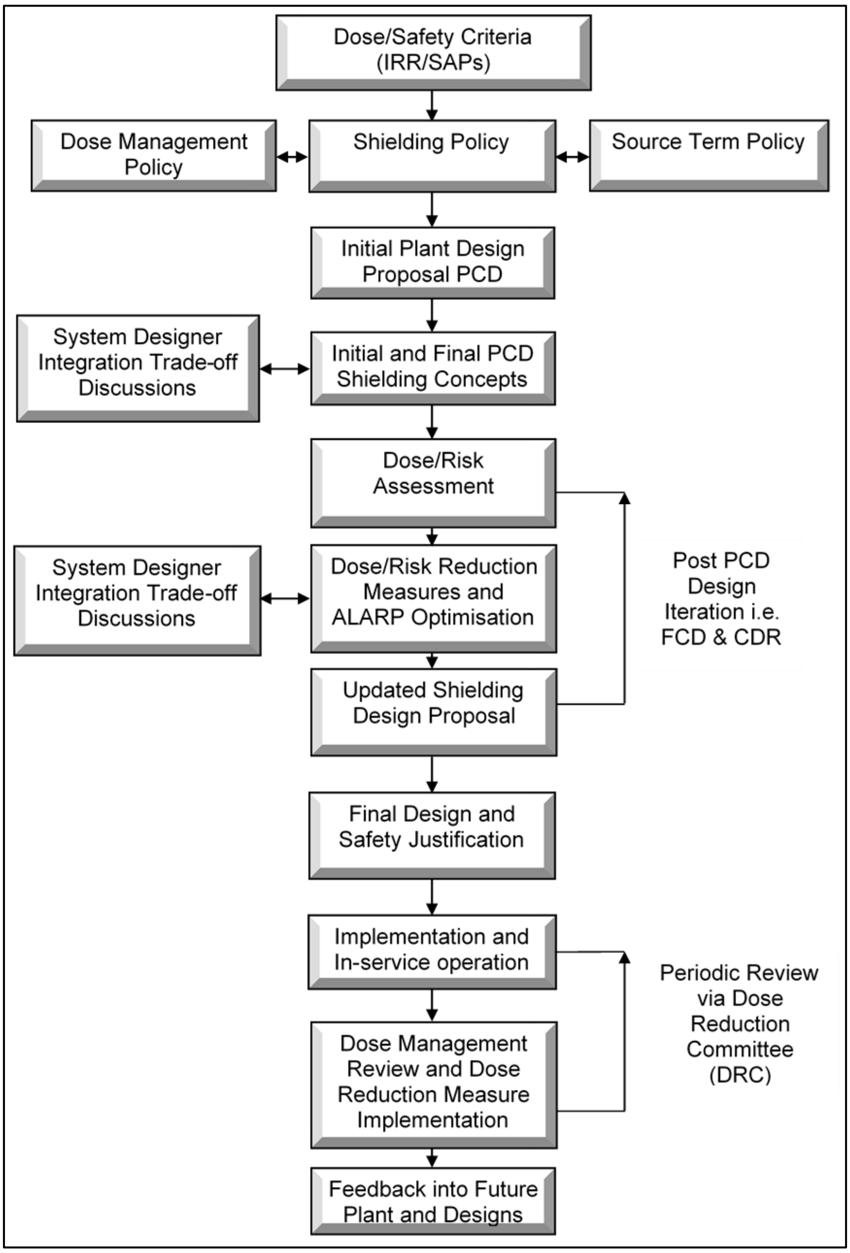

Figure 12.3-1: RR SMR Shielding Design Process

Based on the radiation source terms that could give rise to increased doses, the key SMR radiation shielding types have been split into several distinct themes outlined below:

1. Primary shielding; located directly around the RPV and IHP, designed to shield against neutrons, and capture gamma-rays and fission gamma-rays emanating from the reactor core. Due to the plant geometry, the primary shielding will also provide some shielding

from the coolant N-16 gamma-ray emissions. Components such as steam generators or the pressuriser will be made of relatively thick steel shells partially filled with water and hence will offer a degree of shielding

2. Secondary shielding: expected to form part of the plant containment structure to reduce dose rates/doses outside of the plant primary containment. This is needed to shield residual radiation leaking from the primary shield and the remaining sources indirectly related to the fission process. For the SMR plant the principal radiation source affecting the secondary shielding would be from the activation of oxygen in the primary coolant passing through the core to produce N-16, which decays with a short half-life emitting high energy gamma-rays from the primary circuit loops and Steam Generator tubes. The next most significant contribution would be from neutron capture gamma-rays from primary shield neutron interactions. To a lesser extent neutron streaming through gaps around the primary coolant nozzles and IHP would also require consideration in the secondary shielding assessment

3. SSC shielding; additional shielding (over and above the component shell) may be required to shield the radiation sources from large vessels and components, etc. to reduce plant shut-down maintenance worker doses and possibly (in the case of steam generators and the pressuriser) to reduce the mass of secondary shielding required. Typically, the radiation sources would be from activated coolant and deposited surface contamination associated with crud and tramp fission product/actinides. However, vessel/component shielding could also be added to the primary loops and Steam Generators to reduce the amount of secondary shielding needed to reduce the plant operation N-16 gamma-ray dose rates to acceptable levels

4. Radioactive material transport container shielding; for moving radioactive material within the reactor island to secondary storage locations and ponds, and/or off-site transport. Typically, this would be material such as fuel and activated solid, liquid, or gaseous waste. Containers associated with the handling of detector/monitor calibration sources would also be covered by this type of shielding as would coolant sample system shielding and health physics inspection glove box type shielding where required

5. Refuelling process shielding; associated with the movement of spent fuel and RPV internals (e.g., core barrel) from the core into storage ponds during refuelling outages. This type of shielding would largely be provided by the water covering the fuel/components and concrete and/or steel making up the pond and movement route structural walls

The first two types of shielding above are largely concerned with the radiation source associated with the ‘at power’ normal operation of the SMR plant, whereas the last three types would mainly be concerned with shut-down operation when workers may enter the reactor island structure.

At PCD, radiation shielding assessments are still being developed. The Reactor Island Radiation Shielding Basis of Design, Reference [21], presents the key information and assumptions for the assessment of energy deposition into the primary shielding structures and the dose rate in and surrounding containment. The outputs of shielding assessments will be reported in a future revision of the E3S Case.

12.3.3 Ventilation

The HVAC system provides the primary means for minimising the levels of airborne contamination in occupied areas, providing decontamination of inflows through filtration to prevent, so as far as is reasonably practicable, recirculation of airborne contamination to employees and to prevent release of airborne activity to the other persons during normal operations.

The radiation protection design philosophy is to minimise dose from airborne activity to negligible levels through containment. Furthermore, the structured approach to minimising the source term, e.g., through boron-free chemistry regime and material selection, support hazard reduction and potential airborne contamination such that ventilation can provide effective risk management under normal operating conditions.

The HVAC is being designed to UK and international guidance and RGP, including in Reference [22], which provides international guidance on ventilation system design for nuclear reactors and has been adopted as a British Standard.

The HVAC system will ensure correct cascade airflow from lower to higher contamination classified areas, and never from higher to lower contamination classified areas, informed by the classification scheme outlined in Table 12.3-3 and by the standards detailed in Reference [22]. The design will include adequate air changes within rooms to maintain airborne contamination concentrations at acceptable levels, with appropriate abatement of discharges achieved using delay beds prior to release and safe-change filters following RGP.

Where temporary contamination-controlled areas are required to be set up for maintenance activities such as breaks of containment, Mobile Extraction Units (MEUs) will be used to manage the risk of airborne contamination as required.

Specific radiation protection requirements are being developed based on policies and guidelines (outlined in Section 12.1.1), which will be placed onto the design of the HVAC system, noting verification evidence for compliance against these requirements will be presented in E3S Case Chapter 9A: Auxiliary Systems, Reference [20] as the design of the HVAC system matures.

12.3.4 Monitoring

The RR SMR will include installed radiation monitoring instrumentation for monitoring and alarming upon high dose rates and high airborne activity concentrations, strategically placed based upon the associated radiological risks throughout the plant. The locations will be informed by dose assessments (see Section 12.4), and where practicable, will be capable of being read remotely by radiation protection personnel without the need to enter the RCA.

The RR SMR will include appropriate facilities for the storage, function checking, energy calibration and maintenance of portable instrumentation, a health physics laboratory, and appropriate facilities to implement a personal dosimetry programme (assuming the use of Electronic Personal Dosimeters (EPDs) or equivalent technologies) to allow monitoring of employee doses by radiation protection staff based outside the RCA in a Radiation Protection Control Room, in line with international good practice.

Opportunities for remote and smart monitoring techniques to support outages and maintenance activities will also be explored as the design and outage/maintenance schedules are progressed. Further evidence of monitoring systems and techniques will be presented in future revisions of the E3S Case as the design matures.

12.4 Dose Criteria & Dose Assessment

12.4.1 Radiological Safety Criteria

Dose Criteria

The RR SMR numerical dose criteria for normal operation are derived from the ONR Safety Assessment Principles (SAPs) Targets 1 – 9, including BSLs and BSOs for whole-body effective dose to individual workers and the public. These are presented in Table 12.4-1, extracted from the full list of RR SMR numerical targets presented in E3S Case Chapter 3: E3S Objectives & Design Rules, Reference [18].

Table 12.4-1: RR SMR Numerical Targets for Normal Operation

Metric	Shall be lower than (BSL)	Should be lower than (BSO)
Annual effective dose for any site worker that works with ionising radiation	20mSv	1mSv
Annual effective dose for any site worker that does not work with ionising radiation	2mSv	0.1mSv
Average annual effective dose to defined groups of employees working with ionising radiation	10mSv	0.5mSv
Annual effective dose for any person off the site	1mSv	0.02mSv
Hourly dose rate to non-human species	n/a	40μGy

The dose criteria are consistent with international recommendations for dose limits, which are derived from European recommendations based on the ICRP. Therefore, a dose management policy based on UK legislation will also ensure compliance with international standards. In practice, the design of the RR SMR will drive towards minimisation to doses to ALARP irrespective of these limits, with comparison to RGP and OPEX.

Dose Rate Targets

At concept design stage, when the plant occupancy model it is not sufficiently mature to estimate operational, maintenance and refuelling doses, the dose criteria is supplemented by a set of dose rate targets.

Dose rate targets are defined and justified in the Radiation Shielding Policy and presented in Table 12.4-2, used to design shielding structures to minimise doses.

Table 12.4-2: Concept Design Dose Rate Targets at Full Power

Description	PCD Target (μSv/hr)
Everywhere outside of the secondary shielding/plant primary containment boundary during at-power operation	2.5
Contact with all components within the reactor island 24 hours after shut-down (shielding of the primary loops may be impractical but should be considered as a design decision)	2.5
Neutron flux leakage from primary shield	<1.0E+05n/cm^2/s
The primary shield will reduce activation in the reactor hall to negligible levels compared with other background sources	Negligible

The values in Table 12.4-2 have been used as a high-level targets that have enabled PCD to be developed, these bounding values will be amended as the design and radiation protection guidance matures. This will be governed by ALARP and reviewed against RGP, OPEX and legislative requirements.

As the design progresses and a plant occupancy model is developed, the radiation protection aspects of the design will be driven by the dose criteria.

12.4.2 Normal Operations Exposure Assessments

Normal operations exposure assessments and comparison against dose criteria will be undertaken as the design is developed. This will include internal and external dose assessments to workers based on plant operations and EMIT activities during power operation and shutdown/refuelling, and external dose assessments to the public. It will also cover high frequency abnormal conditions (plant state Design Basis Condition (DBC)-2i).

The outputs of exposure assessments will be reported in a future revision of the E3S Case.

12.4.3 Post-Accident Exposure Assessments

Exposure assessments will be developed to evaluate the dose to intervention personnel during emergency response in the event of fault conditions (plant states DBC-2ii, DBC-3 and DBC-4) and design extension conditions (DECs) in line with REPPIR.

The outputs the post-accident accessibility assessments will be reported in a future revision of the E3S Case.

12.5 Conclusions

12.5.1 Conclusions

Preliminary evidence is presented to support the overall chapter claim that 'Radiological Protection measures are incorporated into the RR SMR design to minimise exposures of ionising radiation to employees and other persons during normal operations and reduce risks throughout the lifecycle of the plant to ALARP', which contributes to the overall E3S objective to protect people and the environment from harm, and the demonstration that risks are reduced ALARP.

Radiation protection policies and design guidance have been developed to communicate the principles and requirements of IRR17, which have steered PCD design decisions and optioneering to minimise radioactive source terms and facilitate the design of the RR SMR to minimise dose to ALARP through the application of the hierarchy of controls. Examples of the application of these policies and guidelines are presented throughout the report.

Ongoing HAZID and HAZOP studies undertaken early in the design stages strengthen the application of radiation protection throughout the RR SMR, with identification of potential radiation and contamination hazards and incorporation of measures to address any shortfalls.

Radiation protection policies and guidance will be formalised into a set of design requirements in DOORS prior to the final concept definition. Verification evidence against these requirements will be reported in future revisions of the E3S Case as the design matures.

The complete suite of evidence to underpin the claim will be developed in line with CAE Route Map and reported in future revisions of the E3S Case, including detailed shielding design and analysis, development of dose assessments, and demonstration of criticality safety for new fuel and spent fuel transported and stored outside of the reactor.

12.5.2 Assumptions & Commitments on Future Dutyholder/ Licensee

The design of the RR SMR is being developed to facilitate compliance with IRR17. Assumptions and Commitments on the future dutyholder/licensee to ensure compliance arrangements for IRR17 will be identified as the design matures and reported in future revisions of this chapter.

12.6 References

[1] RR SMR Report, SMR0004294/001, “E3S Case Chapter 1: Introduction,” March 2023.
[2] RR SMR Report, SMR_TBC/001, “E3S Case Chapter 20: Chemistry,” March 2023.
[3] RR SMR Report, SMR0002155/001, “E3S Case Route Map,” March 2023.
[4] HM Government, “The Ionising Radiations Regulations 2017 SI 2017/1075,” January 2018.
[5] HSE, “Work with ionising radiation, Ionising Radiations Regulations 2017, Approved Code of Practice and guidance,” 2018.
[6] HM Government, “The Environmental Permitting (England and Wales) Regulations 2016 SI 2016/1154,” December 2016.
[7] HM Government, “Health and Safety at Work etc. Act 1974 c37,” July 1974.
[8] HM Government, “The Justification of Practices Involving Ionising Radiation Regulations 2004 SI2014/1769,” July 2004.
[9] RR SMR Report, SMR0001603/001, “Environment, Safety, Security and Safeguards Design Principles,” August 2022.
[10] RR SMR Report, SMR0000635/001, “Dose Management Policy,” May 2022.
[11] RR SMR Report, SMR0000512/001, “Radioactive Source Term Policy,” July 2022.
[12] RR SMR Report,SMR0000636/001, “Radiation Shielding Policy,” May 2022.
[13] RR SMR Report, SMR0001861/001, “Radiation Protection Design Guidelines for the RR SMR,” October 2022.
[14] RR SMR Report, EDNS01000490009/001, “Radioactive Waste and Decommissioning Policy Framework,” February 2017.
[15] RR SMR Report, SMR0004599/001, “Decommissioning & End of Life Aspects,” March 2023.
[16] RR SMR TS-DD-02, “RR SMR Decision Record Template”.
[17] RR SMR Report, SMR0004487/001, “E3S Case Chapter 24: ALARP Summary,” March 2023.
[18] RR SMR Report, SMR0004589/001, “E3S Case Chapter 3: E3S Objectives & Design Rules,” March 2023.
[19] IRPCG, “Changeroom Design, Operation and Maintenance - A Nuclear Industry Code of Practice,” July 2006. [Online]. Available: http://www.irpcg.co.uk/images/library/changerooms.pdf.
[20] RR SMR Report, SMR0003863/001, “E3S Case Chapter 9A: Auxiliary Systems,” March 2023.
[21] RR SMR Report, SMR0003376/001, “Reactor Island Radiation Shielding Basis of Design,” November 2022.
[22] BS ISO 26802:2010, Nuclear Facilities - Criteria for the design and the operational containment and ventilation systems for nuclear reactors, August 2010.

12.7 Appendix A: CAE Route Map

12.7.1 Chapter 12 Route Map

A preliminary Claims decomposition from the overall Chapter 12 Claim is summarised in Table 12.7-1, 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 12.7-1: CAE Route Map

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary within Chapter 12**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
Radiological Protection measures are incorporated into the RR SMR design to minimise exposures of ionising radiation to employees and other persons throughout the	The RR SMR Source Term is minimised	-	A structured approach to minimise the RR SMR Source Term is adopted in line with the hierarchy of controls, with specification of requirements placed on the design	Section 12.3.1	Source Term Policy, Reference [11]	-

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary within Chapter 12**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
lifecycle of the plant	The RR SMR shielding is designed and substantiated to minimise exposures to ALARP	The Primary shielding design is optimised to minimise dose rates to ALARP	The design of shielding is based on achieving dose rate targets, which are derived and justified in the Radiation Shielding Policy to support minimisation of dose to levels that are ALARP	Section 12.3.2	Radiation Shielding Policy, Reference [12] Reactor Island Shielding Basis of Design, Reference [21]	Shielding Assessments for evolving design
		The Secondary shielding design is optimised to minimise dose rates to ALARP				
		SSC shielding design is optimised to minimise dose rates to ALARP				
		Radioactive material transport container shielding design is optimised to minimise dose rates to ALARP				

Level 1 Claims	Level 2 Claims	Level 3 Claims	Arguments	Evidence Summary within Chapter 12	Underpinning Tier 2 Evidence **at PCD*	Underpinning Tier 2 Evidence **to be developed*
		Refuelling process shielding design is optimised to minimise dose rates to ALARP				
	Radiation Protection requirements for dose reduction are derived for the lifecycle of the RR SMR based on RGP & OPEX	-	A set of Radiation Protection policies derive the principles and design requirements, supporting reduction of doses in line with IRR17	Section 12.1	Source Term Policy, Reference [11] Radiation Shielding Policy, Reference [12] Dose Management Policy, Reference [10] Radiation Protection Design Guidelines for the RR SMR, Reference [13]	Radiation Protection Requirements set in DOORS

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary within Chapter 12**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
	The Site and Plant Facility Layout is designed to meet Radiation Protection requirements and minimise exposures to ALARP	-	Radiation Protection requirements are applied through the systems engineering design development process and recorded in the SMR Design Decision Record	Section 12.3.3	Radiation Protection Design Guidelines for the RR SMR, Reference [13]	Layout Design Reports (TBC) / Radiation Protection Summary Report
	SSCs are designed to meet Radiation Protection requirements and minimise exposures to ALARP	-		Section 12.3.1	System Descriptions, reported across E3S Case Radiation Protection Design Guidelines for the RR SMR, Reference [13]	System Descriptions, reported across E3S Case Radiation Protection Summary Report

Level 1 Claims	Level 2 Claims	Level 3 Claims	Arguments	Evidence Summary within Chapter 12	Underpinning Tier 2 Evidence **at PCD*	Underpinning Tier 2 Evidence **to be developed*
	Ventilation systems are designed to meet Radiation Protection Requirements and minimise exposures to ALARP	-		Section 12.3.3	Radiation Protection Design Guidelines for the RR SMR, Reference [13]	System Descriptions for HVAC System (/revision of E3S Case Chapter 9A: Auxiliary Systems)
	The RR SMR includes monitoring and alarm systems at suitable locations to alert operators to the presence of radiation and contamination, both locally and within the Control Room	-		Section 12.3.4	Radiation Protection Design Guidelines for the RR SMR, Reference [13]	DOORS Verification Modules for Radiation Protection Requirements (summarised in Radiation Protection Summary Report)

Level 1 Claims	Level 2 Claims	Level 3 Claims	Arguments	Evidence Summary within Chapter 12	Underpinning Tier 2 Evidence ***at PCD**	Underpinning Tier 2 Evidence ***to be developed**
	Plant Operations and EMIT are designed to meet Radiation Protection requirements and minimise exposures to ALARP	-		Section 12.3.1	System Descriptions, reported across E3S Case Radiation Protection Design Guidelines for the RR SMR, Reference [13]	DOORS Verification Modules for Radiation Protection Requirements (summarised in Radiation Protection Summary Report)
	Access to and between Controlled and Supervised Areas will be suitably controlled to minimise exposures to ALARP and prevent the spread of radioactive material	-	Radiological and contamination zoning schemes are developed to inform the design and spacing requirements, which facilitates a future operational zoning scheme	Section 12.3.1	Dose Management Policy, Reference [10] Radiation Protection Design Guidelines for the RR SMR, Reference [13]	Radiological and contamination zoning schemes

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary within Chapter 12**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
	The RR SMR design and layout includes facilities for monitoring and decontamination of operators and equipment	-		Section 12.3.1	Radiation Protection Design Guidelines for the RR SMR, Reference [13]	Layout Design Reports (TBC) / Radiation Protection Summary Report
Risks to employees and other persons from the harmful effects of ionising radiation during normal operations, EMIT and post-accident recovery are demonstrated to be below UK dose targets and minimised to ALARP	Dose Targets and Limits are defined and justified	-	Numerical dose criteria have been derived from UK good practice	Section 12.4.1	E3S Design Principles, Reference [9]	-
	Internal and external doses to workers during normal power operations and EMIT are below UK dose targets and minimised to ALARP	-	-	Section 12.4.2	n/a	Operational Dose Uptake (Entire Site) Report

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary within Chapter 12**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
	External doses to the public during normal power operations and EMIT are below UK dose targets and minimised to ALARP	-	-	Section 12.4.2	n/a	Operational Dose Uptake (Entire Site) Report
	Exposure to intervention personnel responding to accidents is below UK dose targets and minimised to ALARP	-	-	Section 12.4.3	n/a	Operational Dose Uptake (Entire Site) Report
Criticality risks associated with new fuel and spent fuel transported and stored outside of the reactor are minimised to ALARP	-	-	-	n/a	n/a	Criticality Design Basis

12.8 Acronyms and Abbreviations

ACOP	Approved Code of Practice and guidance
ALARP	As Low As Reasonably Practicable
ASF	Alternative Shutdown Function
BSL	Basic Safety Level
BSO	Basic Safety Objective
CAE	Claims, Arguments, Evidence
CRDM	Control Rod Drive Mechanism
CVCS	Chemistry and Volume Control System
DBC	Design Basis Condition
DEC	Design Extension Condition
DOORS	Dynamic Object-Oriented Requirements System
DR	Dose Rate
EC&I	Electrical, Control and Instrumentation
E3S	Environment, Safety, Security and Safeguards
EMIT	Examination, Maintenance, Inspection and Testing
EPD	Electronic Personal Dosimeters
EPR16	Environmental Permitting (England and Wales) Regulations 2016
GER	Generic Environment Report
GSR	Generic Security Report
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HPIS	High Pressure Injection System
HPV	Heavy Pressure Vessels
HVAC	Heating, Ventilation, and Air Conditioning
IAEA	International Atomic Energy Agency

ICRP	International Commission on Radiological Protection
IHP	Integrated Head Package
ILW	Intermediate-Level Waste
IRR17	Ionising Radiations Regulations 2017
IXC	Ion Exchange Column
LC	Licence Condition
MEP	Mechanical, Electrical and Plumbing
MEU	Mobile Extraction Unit
n/a	Not applicable
NIA	Nuclear Installations Act 1965
ONR	Office for Nuclear Regulation
OPEX	Operating Experience
PCD	Preliminary Concept Definition
PCSR	Pre-Construction Safety Report
PPE	Personal Protective Equipment
PWR	Pressurised Water Reactor
RCA	Radiation Controlled Area
RCS	Reactor Coolant System
RD	Reference Design
REPPIR	Radiation (Emergency Preparedness and Public Information) Regulations 2019
RGP	Relevant Good Practice
RPE	Respiratory Protective Equipment
RPV	Reactor Pressure Vessel
RR SMR	Rolls-Royce Small Modular Reactor
SAP	Safety Assessment Principle
SSC	Structure, System and Component
SFP	Spent Fuel Pool

TBC	To Be Confirmed
UFC	Ultrasonic Fuel Cleaning
UK	United Kingdom
VR	Virtual Reality