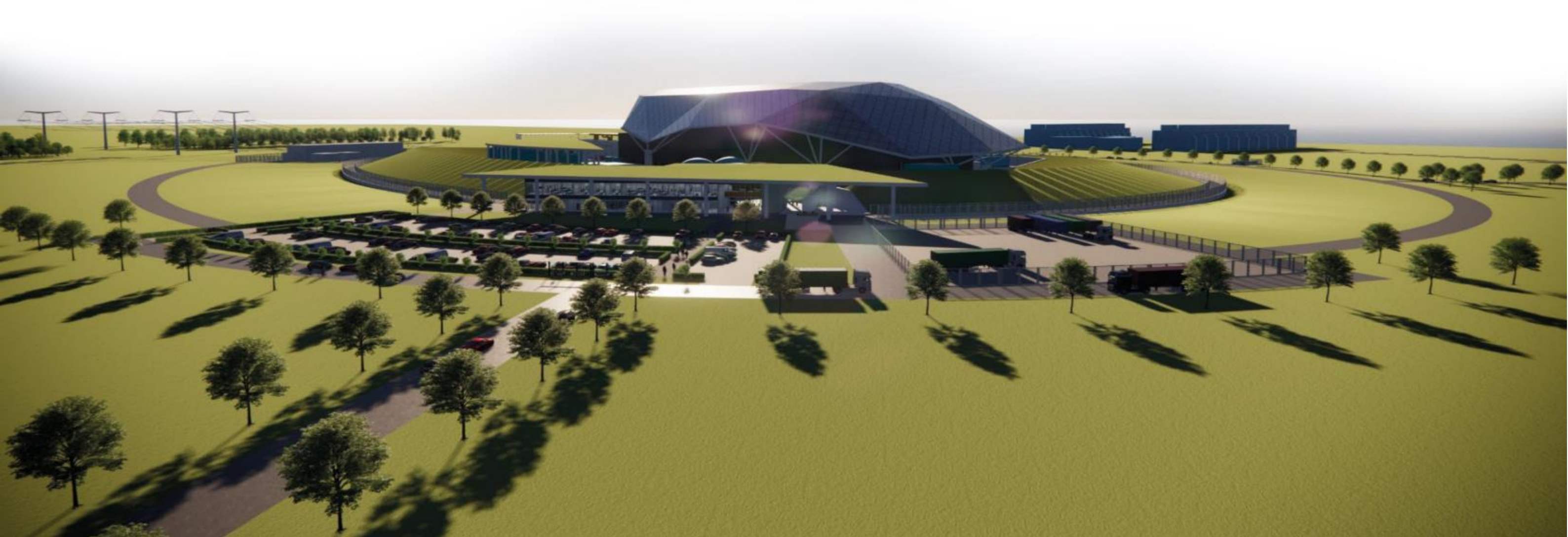
Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 12: Radiation Protection



Record of Change

Date	Revision Number	Status	Reason for Change
March 2023	1	Issue	First issue of E3S Case
February 2024	2	Issue	Incorporates information at Reference Design 7, aligned to Design Reference Point 1, including: • Updated description of radiation protection design features covering layout, waste discharges, post-accident accessibility, monitoring, shielding, and ventilation systems • Output of initial worker and public dose assessments and comparison against numerical targets
May 2024	3	Issue	Updated to correct revision history status at Issue 2 and minor template/editorial updates for overall E3S Case consistency

Executive Summary

Chapter 12 of the generic Environment, Safety, Security, and Safeguards (E3S) Case presents the overarching summary and entry point to the design and safety information for the radiation protection aspects of the Rolls-Royce Small Modular Reactor (RR SMR), to demonstrate that exposures of ionising radiation are reduced to as low as reasonably practicable (ALARP) throughout the lifecycle of the facility.

Radiation protection policies and design guidance for the RR SMR are developed based on relevant good practice (RGP) and operating experience (OPEX). These are embedded into the optioneering and design development processes to ensure appropriate design features are incorporated into the design through the application of the hierarchy of controls to minimise dose to ALARP, and ensure the design facilitates compliance with Ionising Radiations Regulations 2017 (IRR17). These design features are described within this chapter.

The demonstration of ALARP is supported by the assessment of dose to workers and the public, with comparison against basic safety levels (BSLs) and basic safety objectives (BSOs) providing confidence that the design of the RR SMR can achieve the numerical targets defined for the RR SMR, and through further design provisions and assessment can be demonstrated in all cases to reduce doses to ALARP.

Version 2 of the generic E3S Case is developed in support of the reference design 7 (RD7) design, corresponding to design reference point 1 (DRP1) for the generic design assessment (GDA). Further arguments and evidence are to be developed to underpin the top-level claim and to achieve the objective of the generic E3S Case, including further iterations of the shielding and dose assessments to inform the ongoing design and layout to reduce doses to ALARP.

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12.0 Introduction to Chapter

12.0.1 Introduction

Chapter 12 of the Rolls-Royce Small Modular Reactor (RR SMR) generic Environment, Safety, Security and Safeguards (E3S) Case presents the overarching summary and entry point to the design and safety information for the radiation protection aspects of the RR SMR.

12.0.2 Scope and Maturity

The radiation protection information presented within this chapter covers the following aspects:

- 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.

- 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).

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

- 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:

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

- Doses due to fault sequences (except for criticality associated with new fuel and spent fuel outside of the reactor), which will be covered in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [1].

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

- Derivation and justification of the primary normal operations Source Term, which is covered in E3S Case Version 2, Tier 1, Chapter 20: Chemistry [2] (downstream source terms such as radioactive waste system, decommissioning and activated structures source terms will be developed in conjunction with E3S Case Version 2, Tier 1, Chapters 11, 12, 20 and 21).

- Out of core criticality is primarily covered in E3S Case Version 2, Tier 1, Chapter 4: Reactor (Fuel and Core) [3] with associated SSCs detailed within E3S Case Version 2, Tier 1, Chapter 9A: Auxiliary Systems [4].

Version 2 of the generic E3S Case is based on the design at reference design 7 (RD7), corresponding to design reference point 1 (DRP1) for the generic design assessment (GDA).

Given the iterative nature of the design and supporting assessment, the dose and shielding assessments referenced within this revision of the report reflect the RD6 layout and design. These assessments have been used as inputs to inform the RD7/DRP1 design and ensure appropriate radiation protection design features are incorporated.

12.0.3 Claims, Arguments and Evidence Route Map

The overall approach to claims, arguments, evidence (CAE) and the set of fundamental E3S claims to achieve the E3S fundamental objective are described in E3S Case Version 2, Tier 1, Chapter 1: Introduction [5]. The associated top-level chapter claim for E3S Case Version 2, Tier 1, Chapter 12: Radiation Protection is:

Claim 12: Exposures of ionising radiation are reduced to as low as reasonably practicable throughout the lifecycle of the facility

A decomposition of this claim into sub-claims, and mapping to the relevant Tier 2 and Tier 3 information containing the detailed arguments and evidence, is presented in the E3S Case route map [6]. Given the evolving nature of the E3S Case alongside the maturing design, the underpinning arguments and evidence may still be developed in future design stages; the trajectory of this information, where possible, is also illustrated in the route map.

A proportionate summary of the arguments and evidence from lower tier information, available at the current design stage, is presented within this chapter. A mapping of the claims to the corresponding sections that summarise the arguments and/or evidence is provided in Appendix A (section 12.8).

12.0.4 Applicable Regulations, Codes and Standards

The primary United Kingdom (UK) legislation adopted in the design of the RR SMR is IRR17 [7] and the associated approved code of practice and guidance (ACOP) [8], 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:

- The Environmental Permitting (England and Wales) Regulations 2016 (EPR16) [9]
- The Health and Safety at Work Act etc. 1974 [10]
- The Management of Health and Safety at Work Regulations 1999 [11] – 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
- Nuclear Installations Act 1965 (NIA) [12] – 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) as may appear necessary or desirable in the interests of safety

- The Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR) [13] – this legislation sets out the requirements for planning for and managing the consequences of radiation emergencies arising from work with ionising radiation, supported by an accompanying ACOP [14].

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 recommendations and incorporates updates from the Basic Safety and Standards Directive (BSSD) [15], issued by the European Atomic Energy Community (Euratom). United States (US) codes and standards considered include US Nuclear Regulatory Commission (NRC) 10 CFR Part 20 and associated regulatory guides.

12.1 Optimisation of Protection and 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 [16] is set out in a series of radiation protection policy documents that are referred to throughout this chapter, including:

- Dose management policy [17], 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.

- Radioactive source term policy [18], which defines a structured approach to minimising the source term.

- Radiation shielding policy [19], 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 [7], 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 chapter.

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 chapter.

The radiation shielding policy that is 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 enables the hierarchy of controls principles to be optimised for reducing radiation exposures. It details the use of primary shielding, secondary shielding, SSC shielding, radioactive material transport container shielding and refuelling process shielding. The implementation of this is described further in section 12.3.2 of this chapter.

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 [20] are intended to provide additional guidance, on the practical application of radiation protection principles, 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):

- Water chemistry and material selection optimisation to reduce the source term
- Shielding design, such as:
    - Design of penetrations through shielded structures (pipework, heating, ventilation, and air conditioning (HVAC) ducts etc.) to reduce shine or scatter
    - Use of labyrinths in rooms containing very active sources where personnel access is required in preference to a heavy, shielded door, where reasonably practicable
- Containment and segregation of radioactive material, such as:
    - Features to ensure containment of radioactive contamination as close to source as possible
    - Segregation of active systems from non-active systems, and high dose systems from low dose systems
    - Segregation of pipework used to transfer high dose effluents and waste that may result in regular transient high dose rates
- 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)
- Design of SSCs to facilitate decontamination and flushing to reduce maintenance doses, and isolation to reduce the risk of spread of contamination
- Design of HVAC systems to consider airflows, adequate air changes, and risks of iodine and degassing phenomena
- Equipment and pipework design to minimise deposition of activity, through use of gradients and elimination of dead legs
- 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), a radioactive source store, a health physics counting laboratory, a

radiation protection control centre (RPCC), storge for health physics equipment including portable instrumentation, and dosimetry services

- Control of access and egress to radiation-controlled areas, contamination-controlled areas, and high dose rate areas
- Provision of installed monitoring equipment for radiation protection, as well as portable instrumentation
- Enabling innovative and emerging technologies that can be of benefit to radiation protection, such as remote monitoring and communications or robotics and drones.

These guidelines and policies inform design development through design optioneering (see section 12.1.3) with their implementation described further in Section 12.3 of this chapter. A general set of radiation protection design requirements are also established in the RR SMR requirements management system as non-functional system requirements, which are applied to SSCs in accordance with the processes described in E3S Case Version 2, Tier 1, Chapter 1: Introduction [5].

The Mechanical Radiation Protection - Design Principles Guidelines [21] provide designers with detailed guidance in how to implement a selection of mechanical radiation protection features, such as joggle boxes and shield doors.

The radioactive waste and decommissioning policy [22] also provides design guidance and principles pertinent to dose management aspects of ‘design for decommissioning’, described further in E3S Case Version 2, Tier 1, Chapter 21: Decommissioning and End of Life Aspects [23].

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 create a framework 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.

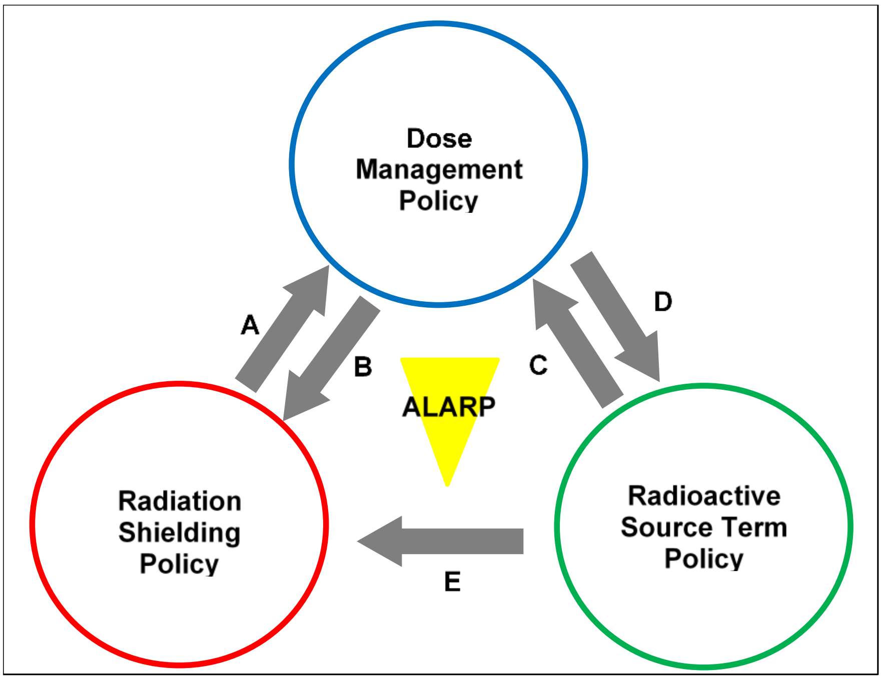

Figure 12.1-1: Radiological Protection Policy Interactions

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.
B3	Defines the dose, and dose rate targets for the radiation shield design
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.
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 and Best Available Techniques (BAT)

As the RR SMR is developed, the principles of ALARP and BAT are embedded into design decisions through the conduct design optioneering process [24] and associated design decision record template [25] that records the arguments and evidence in support of decisions reducing risk to ALARP and the use of BAT. The overall ALARP process includes input from and consultation with radiation protection subject matter experts.

The information recorded as part of the optioneering process includes a comprehensive review of 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 (described in section 12.1.1).

Key to the ALARP demonstration for radiation protection 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.

Hazard identification (HAZID) and hazard and operability (HAZOP) studies are also being undertaken as the design of SSCs mature [26], which include consideration of radiation protection to ensure aspects of IRR17 are addressed at the earliest possible stage. The proformas used to capture HAZID and HAZOP studies discussions include relevant sections around radiation and contamination.

The holistic ALARP case is presented in E3S Case Version 2, Tier 1, Chapter 24: ALARP Summary [27]. The ALARP case for radiation protection to reduce exposures to radiation fields and radioactive material is presented in the ALARP topic report for radiation protection [28]. The outputs of the application of ALARP processes for radiation protection is presented in sections 12.3 and 12.4.

12.2 Sources of Radiation

12.2.1 Contained and Immobile Sources of Radioactive Material

For critical operation, the primary sources of radiation are the reactor core, primary loops and interfacing primary components such as the steam generators. The size of the source is governed by the required reactor power level.

The penetrating primary sources consist of gamma and neutron radiations. Gamma radiation is created from a variety of mechanisms, either directly from the fission process or through secondary mechanisms such as activation of the primary coolant, or through neutron capture and scatter processes. Neutron radiation is primarily generated by the fission process and leakage from the core. However, secondary neutron sources can be created through high-energy gamma interaction with structural materials.

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.

Neutron and gamma leakage from the fission process in the core (item 2) will only be a concern during critical operation and will be mitigated by the presence of the primary and secondary shielding within primary containment. The RR SMR design criteria limit neutron leakage to less than 1.0E+05n/cm^2/s [19].

Many of these sources (primarily items 3, 4, 5, 7, and 8) will be of concern during critical operations but will then be processed by various plant systems that remove impurities from the primary circuit water or from the atmosphere, where they will become part of the source terms associated with the auxiliary, radwaste, or HVAC systems, or will be part of the routine discharges from the plant. They will also form a source term that will be of concern during outage activities when personnel enter primary containment, or when systems are broken into as part of EMIT, where they can form a source of radioactive contamination.

The reactor fuel (item 1) will remain a source of radiation for significant timescales after removal from the reactor, and dose to operators associated with the refuelling process during outages (including cask export operations, which will likely occur during critical operation) will be a major source of dose on the plant.

Activation products associated with structural or shielding materials (item 6) will pose a hazard during outage activities, particularly to personnel performing EMIT activities on metallic components close to the reactor core. They will also present a significant source term when the plant is decommissioned.

The RR SMR source terms are being developed in accordance with the source term policy [18] to minimise radioactivity. Arguments and evidence to demonstrate the minimisation of radioactivity (including chemistry choices, material choices, cobalt inventory, etc.) has been reduced to ALARP will be presented in Version 3 of the generic E3S Case.

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 the 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 pools
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.

During EMIT activities there will be areas where an elevated risk of radioactive airborne activity could be present. Mitigations to restrict any exposures have been incorporated within the design in line with the radiation protection design guidelines [20] for the RR SMR and the associated radiation protection policies that are described in section 12.1.2.

During the outage periods of the RR SMR there will be a potential risk of airborne contamination, due to the combination of significant work activities, additional staffing from external sources that are unfamiliar with the plant, 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.

The RR SMR design philosophy also ensures that the RR SMR is designed for decommissioning. 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 any historic reactor design shortfalls are avoided in the RR SMR.

12.3 Design Features for Radiation Protection

12.3.1 Facility and Equipment Design Features

12.3.1.1 Design Optioneering

The design optioneering process [24] and the design decision record [25] 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. Radiation protection design guidance [20] is utilised to support the decision-making process.

Design decisions relevant to radiological protection are summarised within the various systems engineering chapters of the E3S Case (chapters 4 to 11). The subsequent sections provide a summary of design decisions and development of SSCs pertinent to ensuring exposures are reduced to ALARP, with further detail provided in the radiation protection ALARP topic report [28].

12.3.1.2 Hierarchy of Controls

As defined in Regulation 9(2) of IRR17 and encapsulated in the ONR Safety Assessment Principles (SAPs), a hierarchy of controls must be adopted for controlling radiological hazard and mitigating against residual risks. The controls that need to be considered are:

1. Engineered controls and design features
2. Safety features and warning devices
3. A graded area classification system based on existing or potential levels of hazard
4. Safety documentation
5. Local Rules and administrative controls
6. Radiological measurements
7. Appointment of experts
8. Training and supervision of personnel
9. Personal Protective Equipment (PPE).

Within the above hierarchy there is further nuance to consider at the top end of engineered controls and design features, which are the primary items considered at the design stage. At the very top of this hierarchy sit passive, engineered features such as shield walls that perform their function simply by being present. Below that are active systems such as interlocks that require an activity, either automatic or performed by an operator, to perform their safety function.

Implementation of this hierarchy is a key requirement in ensuring that an ALARP solution is arrived at, and this consideration of ALARP and the hierarchy of controls is embedded into the RR SMR conduct design optioneering process [24] and engineer safe, secure, safeguarded and environmentally sound products [26], as described in section 12.1.3.

As part of the RR SMR design optioneering process, a structured approach and guidance is also provided to designers to minimise the source term [18], which is achieved through adoption of the following hierarchy of controls:

- 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.

- 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.

- 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.

- 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 reactor coolant system (RCS) coolant.

- Mitigation: generally the least effective of the controls described, 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.

12.3.1.3 Radiation and Contamination Zoning

The designation of classified areas is a requirement of UK law. IRR17 defines a ‘Controlled Area’ as:

“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 6.0 mSv a year or an equivalent dose greater than 15.0 mSv a year for the lens of the eye or greater than 150.0 mSv a year for the skin or the extremities."*

In addition, IRR17 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 1.0 mSv a year or an equivalent dose greater than 5.0 mSv a year for the lens of the eye or greater than 50.0 mSv a year for the skin or the extremities."*

The ultimate objective of radiological zoning is to minimise dose exposure to workers by controlling access to areas of the plant with elevated dose rates and potential radioactive contamination. The future licensee is expected to implement their own operational radiological zoning scheme.

During the design stage, RR SMR have implemented radiological zoning schemes that align with existing operational power plants, to ensure a successful future operational integration can be achieved. These are used to inform the design development, including access control, radiation shielding thickness, contamination control features, ventilation requirements, access and egress arrangements, and layout decisions summarised throughout section 12.3. The aim is to reduce the number of designated radiation and contamination zones through the design of the RR SMR in line with reducing doses to ALARP.

The basis of operational zoning due to external dose rates is shown in Table 12.3-1. The basis of radiological zoning for internal exposure is shown in Table 12.3-2. In line with IRR17, the area designations for both radiation and contamination are identified as un-designated (i.e., uncontrolled) areas, supervised areas, and controlled areas.

Further to this, controlled areas are sub-divided in a simple manner. For radiation zoning these are R0, R1, R2, R3, R4 and R5, with the higher number associated with the higher dose rates. These zones are based on ambient dose rate ranges and have been colour coded to aid in visually representing these zones on the plant. For contamination zoning these are C0, C1, C2, C3 and C4, with the increasing contamination hazard being associated with the higher number. This contamination zoning scheme is based on existing UK practice from operational plants, with values that support achieving the limits set out for C1 to C4 areas [29]; further justification is provided in the dose management policy [17].

Table 12.3-1: Radiation Zoning Scheme

Designation	Zone	Radiation Classification	Dose Rate Range	Comments
Un-designated Area	White	R0	<0.5 µSv h^{-1}	Doses in the undesignated area must be less than 1 mSv per annum.
Supervised Area	Green	R1	<7.5 µSv h^{-1}	As well as doses remaining below 1 mSv per annum. Supervised areas are designated where radiological conditions remain under constant review. High occupancy areas must comply with the <0.5 µSv h^{-1} dose rate limit to restrict doses below 1 mSv
Controlled Area	Yellow	R2	7.5 µSv h^{-1} to 25 µSv h^{-1}	Working time should be limited to ALARP, with typical dose rates in routinely accessed areas being lower than the 7.5 µSv h^{-1} lower limit
	Orange	R3	25 µSv h^{-1} to 100 µSv h^{-1}	The working time in this zone is limited to that which is strictly necessary, these areas should not be routinely entered.
	Red	R4	100 µSv h^{-1} to 500 µSv h^{-1}	The access is restricted with authorisation procedure being regulated. Doors must be single locked. These areas must not be routinely entered.
	Black	R5	>500 µSv h^{-1}	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. These areas must not be routinely entered.

Table 12.3-2: Contamination Zoning Scheme

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

12.3.1.4 Layout Design

The layout of Reactor Island is being iteratively designed in accordance with radiation protection guidance [20] and zoning guidance in section 12.3.1.3. At DRP1 key aspects of the layout related to radiation protection include:

- Radiation shielding solutions by means of a combination of civil structures and modular kit of parts (MKoP) barriers, which support the reduction of individual and collective dose below numerical targets (see section 12.4).
- Where adequate permanent shielding cannot be provided by the layout design, requirements are placed on SSCs for additional local shielding to be incorporated within their design.
- Where possible the layout has optimised shielding requirements with structural, segregation, and hazard protection requirements, including:
    - The hazard shield walls are conservatively designed to structural and hazard protection requirements such that it will also provide the necessary shielding to reduce doses to ALARP, to be confirmed through dose assessment.

  - ‘Active’ systems are located within structures that will minimise doses to ALARP.

- A West-East division of Reactor Island, centred around containment, has been produced to group areas containing active systems to the West, with the East side of Reactor Island considered the “clean” side. The main control room (MCR), which is continuously occupied, is located as far to the East side as possible whilst remaining within the hazard shield.

- A Reactor Island support building includes the primary health physics area, laboratory, radioactive source store and storage areas, with allocated space for a dedicated RPCC that is outside the radiation-controlled area [30].

At RD7/DRP1, further dose assessments are still required to support the demonstration of ALARP, however given the layout is being design in accordance with radiation protection RGP and guidance, the risks to the layout design are considered low. Further justification of the layout at RD7/DRP1 is described in the architectural and layout summary report [31], and further evidence of how the layout design reduces doses to ALARP is provided in the radiation protection ALARP topic report [28].

12.3.1.5 Minimisation of Radioactive Waste Discharges

The following sub-sections focus on the design features for the radioactive waste systems that are important to radiation protection in meeting the requirements of IRR17 in minimising worker dose and risk to ALARP whilst demonstrating BAT. In general, these systems are design in accordance with the radiation protection design guidelines [20] and policies described in section 12.1.1.

Full details of these systems are described in E3S Case Version 2, Tier 1, Chapter 11: Management of Radioactive Waste [32], and quantification of the radiological discharges is presented in E3S Case Version 2, Tier 1, Chapter 29: Quantification of Radioactive Effluent Discharges and Proposed Limits [33].

Aqueous Discharges

Liquid effluents may originate from the Chemical and Volume Control System (CVCS) [KB] and various drainage systems through the plant. These effluents are processed for recycle or discharge via the Liquid Radioactive Effluent Processing System [KNF].

The Liquid Radioactive Effluent Processing System [KNF] is designed to treat active liquid effluent to prioritise recycle over discharge. This includes abatement through backwashable pre-filters and Reverse Osmosis (RO) process using membrane separation to separate a purified permeate from a concentrated permeate, and connections to sampling systems.

The RR SMR has been designed to minimise tritium production in the coolant. However, tritium still represents a limiting factor for recycling of treated aqueous effluent as there are currently no cost-effective techniques for removing tritium from large volumes of aqueous effluent. The concentration of tritium in the primary coolant is considered to reach steady state during the routine power operation. However, tritium may accumulate in the primary coolant due to releases from the fuel in the event of fuel pin failures. Such accumulation can be managed through treatment and controlled reactor bleeds in the Liquid Radioactive Effluent Processing System [KNF].

Gaseous Discharges

Gaseous effluents may originate from the Processing and Treatment System for Gaseous Radioactive Effluent [KPL], nuclear HVAC System [KL], or Turbine Condenser Air Removal System [MAJ].

The Processing and Treatment System for Gaseous Radioactive Effluent [KPL] processes gaseous effluent from the primary circuit containing hydrogen and volatile fission products. The system design includes compressors delivering nitrogen cover gas to various systems in the Reactor Island, a recombiner for abatement of hydrogen, and delay beds for abatement of fission products prior to discharge to the stack. Provisions for sampling are available downstream of the delay beds. Dose monitoring is proposed for the ventilation air passing through the stack (rather than the delay bed outlet).

The HVAC System [KL] provides HVAC for designated and undesignated areas within the Reactor Island, to condition and supply air to the Reactor Island to maintain air quality, provide a pressure cascade through the building, maintain required conditions for both processes and occupants, and capture, transport and filter any airborne contamination prior to discharge. See section 12.3.3 for further details.

The Turbine Condenser Air Removal System [MAJ] removes non-condensable gases from the secondary circuit in the event of small primary-to-secondary leaks within the steam generator tubes. At RD7/DRP1, the design maturity of this system is low; any necessary provisions for abatement of discharges will be incorporated through the design development process described in section 12.3.1.1.

Sampling and Monitoring

The sub-systems within the Reactor Island Sampling Systems [KU] provide the functions to sample systems that can lead to aqueous and gaseous discharges, enabling characterisation before discharge or sentencing for re-treatment.

The Process and Emissions Radiation Monitoring System (PERMS) [KUK] provides direct monitoring of emissions associated with the HVAC systems [KL], including monitoring of discharges from the stack and monitoring of HVAC systems serving the MCR and supplementary control room (SCR). It also enables monitoring of process effluents by providing chemically representative samples of effluent for offline laboratory analysis.

Solid Waste

Solid radioactive waste for the RR SMR can be broadly divided into two categories:

- Wet solid radioactive waste including evaporator concentrates, resins, and backwashed filter solids, arising from the CVCS [KB], Spent Fuel Pool Purification and Cooling System [FAL] and Liquid Radioactive Effluent Treatment System [KNF]. Miscellaneous wet wastes (such as sludges, oils, and solvents) may also arise from the plant.

- Dry solid radioactive waste from the Reactor Island and the rest of the plant, e.g., filter casings and waste produced during maintenance.

The Solid Radioactive Waste Management System [KM] collects and treats radioactive solid effluents for storage or dispatch. The preferred treatment of dry intermediate level waste (ILW) is decontamination where the waste categorisation can be reduced to low level waste (LLW). If this is not possible, it shall be packaged unencapsulated to not foreclose future treatment and disposal options.

It is conservatively predicted that most wet solid waste will be ILW upon arising. However, some wet solid waste will decay to below ILW boundary after 2 cycles. Boundary ILW/LLW waste will be stored in duty-standby tanks and allowed to decay before treatment and disposal as LLW.

Given the high activity of resins and filter solids expected in the storage tanks, the design of the Solid Radioactive Waste Management System [KM] and associated storage tanks [32] includes features to minimise potential operator dose, including walls and shielding to restrict personnel access, wide sweeping bends and full-bore pipes to minimise potential for settling and blockages, and bunds beneath tanks to collect any leaks.

12.3.1.6 EMIT

The strategy and fundamental approach to the development of EMIT arrangements for SSCs [34] presents a wide range of EMIT drivers and objectives including safety, reliability, and availability. At DRP1, the approach developed is intended to inform the direction of travel for EMIT in the RR SMR design stage and details the scope and high-level approach to relevant EMIT considerations to be developed in the following phases.

This includes principles and guidance on the application of the ALARP principle to EMIT activities, balancing the benefits of maintenance against the competing negative effects in support of the ALARP demonstration to provide the right EMIT activities, at the right time, and how this is incorporated into RR SMR processes and procedures.

EMIT arrangements are still to be developed from these principles and guidance, which will be captured as through-life activities (TLAs) in the RR SMR requirements management database. The occupancy data obtained from these EMIT arrangements will also be used as inputs to the ongoing design of radiation shielding and assessment of doses to support the ongoing reduction of risk to ALARP.

12.3.1.7 Post-Accident Accessibility

The RR SMR is designed to facilitate effective emergency preparedness and response to accidents that may result in a radioactive release, with arguments and evidence to underpin this claim provided in E3S Case Version 2, Tier 1, Chapter 19: Emergency Preparedness and Response [35].

Chapter 19 sets out a significant body of treaties, laws, regulations, and guidance for design of the RR SMR based on RGP and OPEX. Of relevance to radiation protection is that IRR17 remains applicable to the occupational exposures that result from post-accident activities. Furthermore, REPPIR imposes duties on dutyholders/licensees/permit holders to identify the hazards arising from activities that have the potential to cause a radiation emergency, assess the consequences of the radiation emergency and liaise with the local authority.

Emergency response and control facilities for the RR SMR include the MCR, SCR, emergency response centre (ERC), technical support centre (TSC), operational support centre (OSC), access control point (ACP), offsite ERC and offsite TSC. These facilities are being designed to facilitate post-accident emergency response in accordance with RGP and OPEX, to ensure they remain habitable and dose to responders is minimised to ALARP [36].

Many of the functions of these facilities relate specifically to the ability of the control rooms to perform their functions in accident conditions, including design basis accident conditions and severe accident conditions. The MCR is being designed to maintain habitability and tenability, with the ability to transfer control between the MCR and SCR, and to maintain communication links between the facilities and the plant.

Specific requirements are also placed onto the MCR for post-accident scenarios, including (but not limited to) design to ensure individual personnel doses remain below numerical targets (<20 mSv) through shielding and HVAC design (noting the principle of ALARP still applies regardless of numerical targets), provision of diverse routes for access and egress, and provision of personal protective equipment (PPE) [36].

At RD7/DRP1, the layout of the RR SMR considers claims to facilitate emergency response [31]. The SCR is located outside the hazard shield in the Reactor Island Support Building, aligned in the East-West direction with the MCR, which is inside the hazard shield. This location is chosen such that no single postulated initiating event (PIE) inside the hazard shield which renders the MCR inoperable, can also disable the SCR.

The Accident Management System (AMS) [JRQ] supports on-site staff in making decisions for the management of accidents, providing monitoring instrumentation and systems for preventive and mitigative accident management. Further information is provided in E3S Case Version 2, Tier 1, Chapter 7: Instrumentation and Control [37].

12.3.2 Shielding

The RR SMR radiation shielding forms an essential part of the overall objective 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 shielding assessments described in the following sub-sections are undertaken in accordance with the RR SMR shielding policy [19], with further detail of the assessments and how they are supporting the design development and demonstration of ALARP provided in the radiation shielding topic report [38].

12.3.2.1 Reactor Island Shielding Basis of Design

The basis of the shielding assessment undertaken for DRP1 reflects the geometry and associated materials for SSCs within the primary containment, including the RPV, RPV internals, reactor core, refuelling cavity, integrated head package, steam generators, reactor coolant pumps, primary circuit pipework, pressuriser, refuelling pool, outer containment including the lower dome containment, reactor support structure and its preliminary neutron shielding designs, and additional structures and equipment of relevance for the radiation shielding calculations.

Full details are provided in the shielding basis of design report [39], which also includes detailed source term data for the reactor fuel and primary circuit, and an overview of the analytical codes and methodologies to be used in assessments.

Given the iterative nature of the E3S analysis to support the ongoing design development, the shielding assessment that is presented within this chapter is based on the RD6 layout. The RD6 shielding assessment has been used to further develop the continued evolutions of the layout, which has been issued as part of the DRP1, therefore shielding assessment will be reassessed for the RD7/DRP1 layout design and presented in Version 3 of the generic E3S Case.

Furthermore, at DRP1 the shielding design of other SSCs and radioactive material transport containers are still to be developed. Assessment for these areas will be presented in Version 3 of the generic E3S Case.

12.3.2.2 Primary and Secondary Shielding

The assessment of dose rates associated has identified the need to incorporate additional primary shielding at the top of the RPV to reduce dose rates in the interspace area around primary containment. Furthermore, assessment has identified the need for secondary shielding around the primary circuit, including the steam generators.

At DRP1, this shielding is incorporated into the RPV support structure and the reactor cavity seal and is likely to comprise of borated concrete material. The thickness of this shielding is being optimised against the need for a gap to allow for steam release to prevent pressure build-up during a loss of coolant accident (LOCA), as well as the accessibility requirements for the interspace area.

Operational dose rates are also assessed for other areas within the hazard shield, including the Auxiliary Block, Safeguards Block, MCR, and Fuelling Block. In all areas the dose rates were $<0.1\ \mu Sv\ h^{-1}$ and in many cases significantly lower.

12.3.2.3 Active Waste Systems Shielding

There are several active waste systems comprised of tanks, components and pipework that contain radioactive material produced via the treatment of reactor coolant, located downstream of the CVCS [KB] (see section 12.3.1.5).

Bulk shielding assessment of these systems has identified highest dose rates for the ILW Resin Storage Tank [KME20], and that most components require shielding. Space for shielding of these systems is allocated in the layout based on thicknesses that can minimise dose rates to ALARP, noting further refinement of the bulk shielding assessment is required to model penetrations in the shielding for pipework, HVAC, etc, and the final layouts of the components and pipework.

At DRP1, the shielding solutions are being explored through concrete shielding incorporated into the civil kit of parts (CKoP), shielding through the MKoP, or if necessary temporary shielding arrangements.

12.3.2.4 Minor Vessels Shielding

Bulk shielding assessment of the filters and ion exchange columns (IXCs) for both the Spent Fuel Purification System [FAL] and the CVCS [KB] has identified the need for shielding provision. At DRP1 space is incorporated into the layout for concrete shielding to be provided through the CKoP, the final choice of shielding material is yet to be decided upon and will be reported in future issues of the E3S Case.

Assessment of the heat exchangers and pipework for the CVCS [KB] has also identified the need for further shielding, at DRP1 space is incorporated into the layout for shielding to be provided through the MKoP.

Space for shielding of these systems is allocated in the layout based on thicknesses that can minimise dose rates to ALARP, noting further refinement of the bulk shielding assessment is required to account for refinement in source terms and final layouts. Once finalised, detailed assessments will be required to model penetrations in the shielding for pipework, HVAC, etc.

12.3.2.5 Fuel Handling Operations Shielding

The design thicknesses for the walls of the refuel pool, refuelling cavity, and spent fuel pool, as well as minimum water coverage for fuel racks and transiting fuel assemblies, are determined based on dose assessments. The assessment considers various fuel handling operations including integrated head package lifting operations for refuelling, using comparable OPEX to inform development the source term.

The outputs of this assessment and provision of space for fuel handling systems have been incorporated into the layout of the Fuelling Block and within primary containment, where the size and shape of the pool structures is a significant factor.

12.3.3 Ventilation

The RR SMR HVAC systems [KL] provide the primary means for minimising the levels of airborne contamination in occupied areas, providing decontamination of inflows through filtration to prevent, So Far As Is Reasonably Practicable (SFAIRP), 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 systems [KL] are designed to UK and international regulations, codes and standards, [20]. RGP and guidance, on ventilation system design for nuclear reactors [29] [40], is also taken into account. The HVAC systems [KL] condition and supply air to the Reactor Island to maintain air quality, provide a pressure cascade through the building, maintain required conditions for both processes and occupants, and capture, transport and filter any airborne contamination. This filtration is performed by dedicated High Efficiency Particulate Air (HEPA) filters.

The key design and performance criteria for the HVAC systems [KL] 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 12.3-2.

The design of the HVAC systems [KL] also aims to reduce occupational dose that could occur from changeout of the HEPA filters. The filters are designed to a safe change configuration, in line with UK RGP, so that the contamination captured by the filters is contained during changeout operations, minimising risk to maintenance personnel.

No shielding is provided on the HEPA filters, informed by OPEX from other operating nuclear power plants where the dose rates on filters during normal operation are low, which is expected to be the case for the RR SMR design.

The need for temporary shielding during HEPA change operations will be explored as the assessment of fault modes is progressed. Requirements are also placed onto the HVAC systems [KL] to ensure MCR habitability in fault and accident conditions [36] (section 12.3.1.7).

Further information on the HVAC systems [KL] is provided in E3S Case Version 2, Tier 1, Chapter 9A: Auxiliary Systems [4].

12.3.4 Monitoring of Individuals and Working Areas

The RR SMR radiation protection design guidelines [20] specify the need for installed and portable instrumentation, to ensure radiological monitoring and alarming upon high dose rates and high airborne activity concentrations. The guidelines specify that such systems are capable of being read remotely by radiation protection personnel outside the radiation-controlled area in line with RGP.

These guidelines are being implemented into the RR SMR design through a dedicated Radiation Monitoring [CR] system, covered in E3S Case Version 2, Tier 1, Chapter 7: Instrumentation and Control [37], noting at RD7/DRP1 the maturity of this system is low. The locations of monitoring instrumentation are to be strategically placed based upon the associated radiological risks throughout the plant, informed by dose and airborne activity assessments (see section 12.4).

Furthermore, space is allocated the layout of the Reactor Island support building for the storage, function checking, energy calibration and maintenance of portable instrumentation, a health physics laboratory, and an RPCC. The RPCC will allow remote monitoring of worker doses in real time via teledosimetry (among other functions), so that the dose rate and dose workers are getting can be monitored in real time.

Further information on the design of the Radiation Monitoring [CR] system and the development of other areas/systems such as the RPCC will be presented in future revisions of the generic E3S Case.

12.4 Dose Constraints and Dose Assessment

12.4.1 Radiological Safety Criteria

The RR SMR numerical dose criteria for normal operation are derived from the ONR 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, and are aligned with the full list of RR SMR numerical targets presented in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives & Design Rules, Reference [41]. Further justification of these limits is provided in the dose management policy [17].

The dose criteria are consistent with international recommendations for dose limits, which are derived from European recommendations based on the ICRP. As such, a dose management policy based on UK legislation will in most cases 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.

Table 12.4-1: Individual Dose Criteria for Normal Operations

Description	**Annual Dose (mSv)**	
	BSL	**BSO**
Employees (Classified Radiation Workers)		
Effective dose in a single year to any individual radiation worker on site	20.0	1.0
Average effective dose to defined groups of radiation workers at a particular site or managed by single operator	10.0	0.5
No person shall receive effective doses to organs greater than the statutory dose limit defined in IRR 2017	Statutory Limit	-
Employees (Non-Radiation Workers)		
Effective dose to an individual	2.0	0.1
Other Persons		
Effective dose to other persons, e.g., a typical member of the public of the critical group from operations and discharges from the whole site	1.0	0.02

Collective dose targets are also established for the RR SMR. Whilst not a legal requirement, it is good practice to compare annual doses with a view to employing further dose reduction measures. As a starting reference point, a BSL of 200.0 person-mSv per plant (ten times the individual dose limit) and BSO of 20.0 person-mSv per plant (one tenth of the proposed collective dose BSL) will be assumed for critical operations.

Supplementary dose limits of 200 and 20 person-mSv per plant for the BSL and BSO respectively will be applied during years where a shut down operations and maintenance occurs. During the periods of shut down operations and maintenance the annual combined dose limit will be 400 person-mSv and 40 person-mSv per plant. These levels will be reviewed and revised as the design progresses.

Supplementing the dose criteria is a set of plant dose rate targets. These are of special importance for the concept design stage. These plant dose rate targets are used early in the concept study stages of the design in the absence of a plant occupancy model. As the design matures doses will then be driven by the dose criteria.

These targets are referenced in the SMR Radiation Shielding Policy [42] and will be used as an initial success criterion for SSCs with regards to shielding requirements.

12.4.2 Normal Operations Exposure Assessments

The following sub-sections summarise the initial worker and public dose assessments during power operations and shutdown/refuelling for normal operations (including plant states design basis condition (DBC)-1 and DBC-2i for abnormal conditions). The dose assessments are based on the RD6 layout and design and are used as a baseline to inform development of the design features at RD7/DRP1 described in section 12.3. The initial dose assessments are compared against numerical targets in section 12.4.1 to provide confidence that the design can achieve the BSLs and can be reduced to ALARP, driving towards the BSOs.

The initial dose assessments summarised in this chapter will continue to be updated in each revision of the generic E3S Case as the design matures and RR SMR operations and maintenance data is developed. Issue 3 of the E3S Case will also include assessment of dose to intervention personnel responding to accidents, which are not covered at RD7/DRP1.

Further detail of the dose assessments and how they are supporting the design development and demonstration of ALARP is provided in the worker and public dose topic report [43]. The outputs from these assessments are summarised in sections 12.4.2.1 to 12.4.2.3.

12.4.2.1 Worker Dose

Fuel Handling Operations

Initial worker dose assessments for fuel handling operations have been undertaken based on the shielding arrangements for the RPV and fuelling block, described in sections 12.3.2.2 and 12.3.2.5 respectively. OPEX data described in [44] has also been utilised to inform dose rates in the reactor cavity, refuel pool, and spent fuel pool, as well as data on operational tasks.

For new fuel import and refuel activities outside of primary containment, the collective dose is estimated to be 6.7 person-mSv in a typical outage, or 10.4 person-mSv during a worst-case outage. The highest dose individual activity for this process is assessed to be vacuum can sipping during fuel assembly reconstruction at 2.2 person-mSv, and a maximum individual dose of 0.3 mSv.

For fuel handling operations within primary containment, the collective dose is estimated to be 30 person-mSv in a typical outage, or 48.3 person-mSv for a worst-case outage. The most onerous task is not performed every outage, which is drive rod removal, which leads to a collective dose of 8.9 person-mSv and a maximum individual dose of 4.5 mSv. The most onerous task performed in a typical outage is loading fuel into the core, which leads to a collective dose of 5.8 person-mSv and a maximum individual dose of 2.9 mSv.

Cask loading operations are estimated based on OPEX as a cask solution for RR SMR is still to be selected at RD7/DRP1, with a collective dose for a single cask estimated to be 6.5 person-mSv on average, with a maximum individual dose of 1.94 mSv. Cask loading is deemed a critical operation in relation to the collective dose targets specified in section 12.4.1.

Comparison of doses against numerical targets in in section 12.4.1 illustrates that the design for fuel handling operations will not challenge BSLs. There is also significant scope to optimise the operations and the design as it matures to drive doses to ALARP and towards the BSOs, including remote operations, additional shielding, and further optimisation of the source terms. Updated dose assessments reflected these design developments will be presented in Issue 3 of the E3S Case.

Maintenance Dose Assessment

Initial worker dose assessments to operators cover maintenance activities during power operations and shutdown. At DRP1, the internal and external dose assessment utilises OPEX data for comparable plants described in [45] to identify the highest dose tasks, to determine an estimate of the collective dose uptake for the RR SMR. This assessment indicates that the RR SMR will be able to meet the collective dose BSL and can be driven towards the BSO as specific maintenance tasks for the RR SMR are developed.

The assessment also indicates that the RR SMR design will ensure that average dose to employees working with ionising radiation will be below the BSO, and that maximum individual doses will be driven down towards the BSO value such that they will be ALARP.

12.4.2.2 Operations within Hazard Shield

Initial worker dose assessments cover operations at power within the hazard shield. Dose rates are calculated at various tally points in areas within the hazard shield, including the auxiliary block, safeguards block, MCR, fuelling block, and the interspace. In all areas outside of the interspace dose rates are <0.1 μSv h^{-1}.

The dose assessment provides confidence that the annual dose (during normal operations) for all areas within the hazard shield (other than the interspace) will be below the BSO and that the design can reduced doses to operators from the reactor to ALARP. The annual dose to MCR operators is calculated between 7.8 and 41 μSv.

Elevated dose rates are seen in the interspace, which will be reduced to ALARP through the provision of additional design features, this could include additional local shielding to eliminate or minimise dose rates to ALARP, and/or provision of access controls to restrict occupancy in the interspace area. The outputs of this assessment will be presented in Issue 3 of the generic E3S Case.

12.4.2.3 Other Workers and the Public Dose

Initial external dose assessments cover the other workers onsite and members of the public during power operations, for the reactor and primary coolant source terms. Doses are calculated using dose rate contours across the site, described in [46], and a 2000-hour occupancy for other workers and 8760-hour occupancy for members of the public.

The peak annual dose to other workers is 0.022 μSv at the peak of the berm. The peak annual dose to a member of the public is calculated to be 0.065 μSv at the 100 m fall off location, or 0.026 μSv at the site fence.

In all cases, the annual dose assessment to other workers and the public provide confidence that doses can be well below the BSOs and can be further reduced to ALARP through implementation of additional design features described above.

The assessment does not consider dose from future storage facilities such as the ILW store or interim spent fuel store due to low design maturity of these facilities. Dose constraints are placed onto the design of these facilities with the aspiration to ensure worker and public dose is reduced to below BSOs [43], as described in section 12.4.1 and [42].

12.5 Radiation Protection Programme

A radiation protection programme describing the administrative measures, equipment, instrumentation, facilities, and procedures for the RR SMR will be developed by the future dutyholder/licensee/permit holder, consistent with the development of operational programmes in E3S Case Version 2, Tier 1, Chapter 13: Conduct of Operations. This is captured as a commitment on the future dutyholder/licensee/permit holder:

Commitment on Future dutyholder/licensee/permit holder C12.1: *The future dutyholder/licensee/permit holder shall develop a radiation protection programme describing the administrative measures, equipment, instrumentation, facilities, and procedures for the RR SMR.*

12.6 Conclusions

12.6.1 ALARP, BAT, Secure by Design, Safeguards by Design

The RR SMR is being designed in accordance with radiation protection policies that are based on UK and international RGP and OPEX and incorporate the principles of ALARP. These policies are embedded into the design through the application of the design decision-making process and through specification of requirements onto the design. Evidence of the application of these processes at RD7/DRP1 is demonstrated in the radiation protection design features presented in this chapter.

The assessment presented demonstrates that radiation worker doses are below BSLs, noting the assessment is iterative and used to inform the ongoing design of shielding and other design features to further reduce doses towards BSOs. All other worker and public doses are currently assessed to be well below BSOs.

At RD7/DRP1, it is concluded that there is high confidence that the design will, in all cases, be able to reduce doses to ALARP.

12.6.2 Assumptions and Commitments on Future Dutyholder / Licensee / Permit Holder

Table 12.6-1: Assumptions and Commitments on Future Dutyholder/Licensee/Permit Holder

Assumption/Commitment	ID	Description
Commitment	C12.1	The future dutyholder/licensee/permit holder shall develop a radiation protection programme describing the administrative measures, equipment, instrumentation, facilities, and procedures for the RR SMR

12.6.3 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’ [5]. 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 12 is ‘exposures of ionising radiation are reduced to ALARP throughout the lifecycle of the facility’.

The arguments and evidence presented to meet the generic E3S Case objective at Version 2 include radiation protection policies and design guidance that communicate the principles and requirements of IRR17, which are embedded into the design decision and optioneering processes. A general set of radiation protection design requirements are also established in the RR SMR requirements management system as non-functional system requirements, which are applied to SSCs through engineering processes. The application of these processes supports the ongoing design of the RR SMR 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.

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. Initial dose assessments also provide confidence that the design of the RR SMR can achieve the numerical targets defined for the RR SMR [41] and in all cases reduce doses to ALARP.

Further arguments and evidence to underpin claims will be developed in line with the E3S Case Route Map [6] and reported in future revisions of the generic E3S Case, which will further build confidence that the RR SMR can deliver its fundamental E3S objective. This broadly includes:

- Arguments and evidence to demonstrate the minimisation of radioactivity (including chemistry choices, material choices, cobalt inventory, etc.).

- Development of EMIT activities to develop RR SMR occupancy data for shielding and dose assessment.

- Further iterations of current shielding assessments to inform the shielding design, including assessments for the hazard shield, and additional assessments for SSCs and radioactive material transport containers.

- Further development of the Radiation Monitoring [CR] system and its design for radiation protection, for example location based on dose rates.

- Development of downstream sources terms and further iterations of the current worker and public dose assessments to demonstrate reduction of dose to ALARP during normal operation, and additional dose assessments for intervention personnel responding to accidents.

12.7 References

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12.8 Appendix A: Claims, Arguments, Evidence

Table 12.8-1 provides a mapping of the claims to the corresponding sections of the chapter that summarise the arguments and/or evidence. The full decomposition of claims and link to underpinning Tier 2 and Tier 3 information containing the detailed arguments and evidence is presented in the E3S Case Route Map [6]. The route map includes the trajectory of Tier 2 and Tier 3 information as the generic E3S Case develops, which will be incorporated into Tier 1 chapters as it becomes available and in line with generic E3S Case issues described in [5].

Table 12.8-1: Mapping of Claims to Chapter Sections

Claim	**Section of Chapter 12 containing Arguments / Evidence summary**
Primary Water Chemistry minimises radioactivity	12.2
Material selection aims to minimise secondary activation of SSC's	*Primarily covered in* [2]
The Primary shielding design is optimised to minimise dose rates to ALARP	12.3.2.2
The Secondary shielding design is optimised to minimise dose rates to ALARP	12.3.2.2
SSC shielding design is optimised to minimise dose rates to ALARP	12.3.2.3, 12.3.2.4
Radioactive material transport container shielding design is optimised to minimise dose rates to ALARP	*To be covered in next version of E3S Case*
Refuelling process shielding design is optimised to minimise dose rates to ALARP	12.3.2.5
Radiation Protection requirements for dose reduction through the lifecycle of the RR SMR are based on RGP and OPEX	12.1.1
EMIT operations are designed to meet Radiation Protection requirements and minimise exposures to ALARP	12.3.1.6
Ventilation systems minimise exposures to ALARP	12.3.3
Overall layout is optimised to minimise exposures to ALARP	12.3.1.4
Layout of Safety Systems is optimised to minimise exposures to ALARP	
Layout of Fuelling Systems is optimised to minimise exposures to ALARP	
Layout of Containment Systems and Interspace to minimise exposures to ALARP	
Layout of Waste Systems is optimised to minimise exposures to ALARP	
The RR SMR design and layout includes facilities for monitoring and decontamination of operators and equipment	
The compact design upholds the principles of ALARP	

Claim	**Section of Chapter 12 containing Arguments / Evidence summary**
Access to and between Controlled and Supervised Areas will be suitably controlled to minimise exposures to ALARP and prevent the spread of radioactive material	12.3.1.3
Dose to operators is <BSLs and <BSOs and in all cases ALARP	12.4.2.1
The RR SMR design allows future operators to implement routine monitoring regime and alarm systems at suitable locations to alert operators to the presence of radiation and contamination, both locally and within the Control Room	12.3.4
Design does not preclude options for the implementation of future radiation protection innovations and technologies	12.1.1
Radioactivity is minimised	12.2 *Primarily covered in* [2]
Reactor island shielding philosophy reduces doses ALARP	12.3.2
ILW waste store design reduces doses ALARP	*To be covered in next version of E3S Case*
Dry fuel store Design Reduces doses ALARP	*To be covered in next version of E3S Case*
Radiation monitoring system on all radioactive discharge routes ensure discharges are ALARP with alarms to alert operators to out of scope conditions.	12.3.4
Solid radioactive waste minimisation through material selection and construction methodologies	12.3.1.5
The RR SMR design minimises liquid effluent discharges to ALARP	12.3.1.5
Dose to public is <BSLs and <BSOs and in all cases ALARP	12.4.2.3
Access and egress for operators or site personnel to deliver required actions following an initiating event	12.3.1.7
The tenability of control rooms is maintained under a variety of initiating events.	12.3.1.7
The RR SMR design incorporates the ability to maintain information transfer during initiating events and after	12.3.1.7
Exposure to intervention personnel responding to accidents is below UK dose targets and minimised to ALARP	*To be covered in next version of E3S Case*

12.9 Abbreviations

ACOP	Approved Code of Practice and guidance
ACP	Access Control Point
ALARP	As Low As Reasonably Practicable
BSL	Basic Safety Level
BSO	Basic Safety Objective
CAE	Claims, Arguments, Evidence
CKoP	Civil Kit of Parts
CVCS	Chemistry and Volume Control System
DRP	Design Reference Point
E3S	Environment, Safety, Security and Safeguards
EMIT	Examination, Maintenance, Inspection and Testing
EPR16	Environmental Permitting (England and Wales) Regulations 2016
Euratom	European Atomic Energy Community
GDA	Generic Design Assessment
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HEPA	High Efficiency Particulate Air
HPV	Heavy Pressure Vessel
HVAC	Heating, Ventilation, and Air Conditioning
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate-Level Waste
IRR17	Ionising Radiations Regulations 2017
IXC	Ion Exchange Column
LC	Licence Condition

LLW	Low Level Waste
LOCA	Loss of Coolant Accident
MCR	Main Control Room
MEP	Mechanical, Electrical and Plumbing
MKoP	Modular Kit of Parts
NIA	Nuclear Installations Act 1965
NRC	Nuclear Regulatory Commission
ONR	Office for Nuclear Regulation
OPEX	Operating Experience
OSC	Operational Support Centre
PERMS	Process and Emissions Radiation Monitoring System
PPE	Personal Protective Equipment
PWR	Pressurised Water Reactor
RCS	Reactor Coolant System
RD	Reference Design
REPPIR	Radiation (Emergency Preparedness and Public Information) Regulations 2019
RGP	Relevant Good Practice
RPCC	Radiation Protection Control Centre
RPE	Respiratory Protective Equipment
RPV	Reactor Pressure Vessel
RR SMR	Rolls-Royce Small Modular Reactor
SAP	Safety Assessment Principle
SCR	Supplementary Control Room
SFAIRP	So Far As Is Reasonably Practicable
SSC	Structure, System and Component
TLA	Through-Life Activity
TSC	Technical Support Centre

UK	United Kingdom
US	United States