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| ONR Assessment Report  Generic Design Assessment of the Rolls-Royce SMR – Step 2 assessment of Radiological Protection |



ONR Assessment Report

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**Report Title**: Step 2 assessment of Radiological Protection

**Authored by**: [Redacted]

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# Executive Summary

This report presents the outcomes of my radiological protection assessment of the Rolls-Royce Small Modular Reactor (SMR) as part of Step 2 of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA). This assessment is based upon the information presented in version 2 of Rolls-Royce SMR Limited’s Environmental, Safety, Security and Safeguards (E3S) case chapters and supporting documentation.

ONR’s GDA process calls for a step-wise assessment, which increase in detail as the project progresses. The focus of my assessment in this step was towards the fundamental adequacy of the Rolls-Royce SMR design and safety case, and the suitability of the methodologies, approaches, codes, standards and philosophies which form the building blocks for the design and generic safety and security cases.

I targeted my assessment, in accordance with my assessment plan, at the content of most relevance to radiological protection against the expectations of ONR’s Safety Assessment Principles (SAPs), Technical Assessment Guides (TAGs) and other guidance which ONR regards as relevant good practice.

I targeted the following aspects in my assessment of the Rolls-Royce SMR E3S case:

* The adequacy of the overall radiological protection, shielding and out of core criticality aspects of the E3S case, focussing, at this stage, on the adequacy of the claims and arguments.
* Demonstration, in principle, that the design is capable of enabling a future licensee to deliver compliance with the Ionising Radiations Regulations 2017 (IRR17).
* The methodology to demonstrate how doses to workers and any persons off the site will be reduced to as low as reasonably practicable (ALARP) under normal operating conditions.
* Demonstration that normal operation radiological source terms are reduced to ALARP, focusing at this stage, on the adequacy of the claims and arguments.
* The Requesting Party's (RP) approach to protect against an unplanned criticality associated with new fuel and spent fuel outside of the reactor.
* The RP’s approach to shielding substantiation and its role in optimising normal operations doses to workers and any persons off the site.

Based upon my assessment, I have concluded the following:

* In general, the scope, structure and content of the E3S case meet my expectations for this stage of GDA from a radiological protection perspective. Further work will need to be undertaken in Step 3 of GDA by the RP to develop the underlying evidence supporting the radiological protection claims and arguments.
* The RP has, in principle, specified suitable design standards which comply with the requirements laid out in IRR17, associated approved code of practice, and the principles laid out in the relevant SAPs. Further work is required by the RP to implement these design standards to demonstrate compliance with the relevant requirements.
* I consider the RP’s approach to set design targets, in line with ONR SAPs, to be reasonable at the end of Step 2. The RP has argued that the Rolls-Royce SMR design targets, underpinned by pressurised water reactor operating experience, will restrict normal operations doses below all legal limits and ONR SAP basic safety levels. I am satisfied that this approach is sufficient for a Step 2 assessment. Residual matters have been identified, which require the RP to develop detailed dose estimates for ONR SAPs Targets 1, 2 and 3 during Step 3. I will follow these matters up during my Step 3 assessment.
* I consider the RP’s approach for defining collective dose targets, with partial information on key plant parameters, as reasonable at the end of Step 2 for the Rolls-Royce SMR design. However, further information will be required, from the RP, on how collective dose targets have been implemented in the Rolls-Royce SMR design to reduce overall exposures. I consider this to be a residual matter, which I will follow up in Step 3.
* The RP has developed an adequate strategy which takes into account reducing occupational exposure risks, alongside other risks, as part of the ALARP optioneering process. This should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence during Step 3.
* The RP has a strategy to reduce radioactivity to ALARP, and has presented well-reasoned arguments. Initial evidence in the E3S submissions suggests that the boron free, potassium hydroxide, primary circuit chemistry will not significantly increase dose rates during normal operations, when compared to lithium hydroxide. Although further evidence is required during Step 3 in the form of design specific calculations, I am content with the RP’s approach to demonstrate the occupational exposure impacts from the primary circuit chemistry.
* I have identified residual matters which require further justification in Step 3 to ensure all reasonably practicable options have been considered in the design of the spent fuel pool, to prevent an unplanned criticality. The RP’s approach for out of core criticality safety are in line with SAP ECR.2. I judge this should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence in Step 3.
* At the end of Step 2, the RP has detailed a suitable approach to develop the shielding substantiation and defined its role in optimising normal operations doses to workers and any persons off the site. I have identified residual matters that will require the RP to further develop the E3S case evidence for the Rolls-Royce SMR shielding design in Step 3.

Overall, based on my assessment to date, and subject to the provision and assessment of suitable and sufficient supporting evidence, I have not identified any fundamental safety shortfalls that could prevent ONR permissioning the construction of a SMR power station based on the generic Rolls-Royce SMR design.

# List of Abbreviations

ACoP Approved Code of Practice

ALARP As low as is reasonably practicable

AR Assessment Report

BSL Basic Safety level (in SAPs)

BSO Basic Safety Objective (in SAPs)

CAE Claim, Argument and Evidence

CRDM Control Rod Drive Mechanism

E3S Environment, Safety, Security and Safeguards

GDA Generic Design Assessment

IAEA International Atomic Energy Agency

ILW Intermediate Level Waste

LL Legal Limit

IRR17 Ionising Radiations Regulations 2017

MCR Main Control Room

MCNP Monte Carlo N-Particle Transport Code

NEA Nuclear Energy Authority

NRW Natural Resources Wales

ONR Office for Nuclear Regulation

OCED Organisation for Economic Co-operation and Development

OPEX Operating Experience

PWR Pressurised Water Reactor

RGP Relevant Good Practice

RP Requesting Party

RPV Reactor Pressure Vessel

RQ Regulatory Query

SAP Safety Assessment Principle(s)

SMR Small Modular Reactor

SSC Structure, System and Component(s)

SSG Specific Safety Guide

TAG Technical Assessment Guide(s) (ONR)

UK United Kingdom

WENRA Western European Nuclear Regulators’ Association

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# Introduction

1. This report presents the outcomes of my radiological protection assessment of the Rolls-Royce Small Modular Reactor (SMR) as part of Step 2 of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA). This assessment is based upon the information presented in version two of Rolls-Royce SMR Limited’s Environmental, Safety, Security and Safeguards (E3S) case chapters (refs [1], [2], [3], [4], [5], [6], [7], [8], [9], [10] and [11]) and supporting documentation.
2. Assessment was undertaken in accordance with the requirements of the Office for Nuclear Regulation (ONR) Management System and follows ONR’s guidance on the mechanics of assessment, NS-TAST-GD-096 (ref. [12]). The ONR Safety Assessment Principles (SAPs) (ref. [13]), together with supporting Technical Assessment Guides (TAGs) (ref. [14]), have been used as the basis for this assessment.
3. This is a Major report (refer to NS-TAST-GD-108 (ref. [15])).
   1. Background
4. The ONR’s GDA process (ref. [16]) calls for a step-wise assessment of the Requesting Party's (RP) submissions with the assessments increasing in detail as the project progresses. Rolls-Royce SMR Limited is the RP for the GDA of the Rolls-Royce SMR design.
5. In April 2022 ONR, together with the Environment Agency and Natural Resources Wales (NRW), began Step 1 of the GDA for the generic Rolls-Royce SMR design. Step 1, which is the preparatory part of the design assessment process and mainly associated with initiation of the project and preparation for technical assessment in later steps, was successfully completed in 12 months.
6. Step 2 commenced in April 2023. This is the first substantive technical assessment step. The focus of ONR’s assessments in this step is towards the fundamental adequacy of the design and safety and security cases, and the suitability of the methodologies, approaches, codes, standards and philosophies which form the building blocks for the design and generic safety and security cases. The objective is to undertake an assessment of the design against regulatory expectations to identify any fundamental safety or security shortfalls that could prevent ONR permissioning the construction of a power station based on the design.
7. Prior to the start of Step 2, I prepared a detailed Assessment Plan for radiological protection (ref. [17]). This has formed the basis of this assessment and was also shared with the RP to maximise openness and transparency.
8. This report is one of a series of Assessments which support ONR’s overall judgements at the end of Step 2 which are recorded in the Step 2 Summary Report (ref. [18]).
   1. Scope
9. The assessment documented in this report is based upon the E3S case for the Rolls-Royce SMR as summarised in the E3S case chapters and supporting documentation.
10. The overall scope of the Rolls-Royce SMR GDA is described in (ref. [19]). Rolls-Royce SMR Limited has indicated that it intends to complete a three step GDA, with the objective of receiving a Design Acceptance Confirmation from ONR and have aligned their GDA scope with this objective. The GDA scope defines the generic plant and layout and includes all systems, structures and components that are identified as being important to safety, security and safeguards, all modes of operation, and all stages of the plant lifecycle.
11. However, given the step-wise assessment during GDA, information has not been submitted for all aspects within the GDA scope during Step 2. The following aspects of the E3S case are therefore out of scope of this assessment:

* Operating procedures, instruction, practices, and activities that are under the ownership of the future dutyholder (licensee).
* Site specific accident and exposure management under the Radiation (Emergency Preparedness and Public Information) Regulations 2019 (ref. [20]).
* Doses due to fault sequences, which will be covered in the fault studies Assessment Report (AR) (ref. [21]).
* In core criticality, which will be covered in the fuel and core AR (ref. [22]).
* Accident radiological source terms, which will be covered in the chemistry AR (ref. [23]).

1. My assessment has considered the following aspects:

* The adequacy of the overall radiological protection, shielding and out of core criticality aspects of the E3S case, focussing at this stage on the adequacy of the claims and arguments.
* Demonstration, in principle, that the design is capable of enabling a future licensee to deliver compliance with the Ionising Radiations Regulations 2017 (IRR17) (ref. [24]).
* The RP’s approach to ensuring exposures to workers and direct radiation doses to any persons off the site are as low as reasonably practicable (ALARP) under normal operating conditions.
* Demonstration that normal operation radiological source terms are well characterised, consider relevant Operating Experience (OPEX) and that radioactivity within the design is capable of being reduced to ALARP.
* The RP’s approach to protect against unplanned out of core criticality.
* The RP’s approach to implement an optimised shielding design.

# Assessment standards and interfaces

1. For ONR, the primary goal of the GDA Step 2 assessment is to reach an independent and informed judgment on the adequacy of a preliminary safety, security and safeguards case for the reactor technology being assessed.
2. ONR has a range of internal guidance to enable Inspectors to undertake a proportionate and consistent assessment of such cases. This section identifies the standards which have been considered in this assessment.
3. This section also identifies the key interfaces with other technical topic areas.
   1. Standards
4. The ONR Safety Assessment Principles (SAPs) (ref. [13]) constitute the regulatory principles against which the RP’s case is judged. Consequently, the SAPs are the basis for ONR’s assessment and have therefore been used for the Step 2 assessment of the Rolls-Royce SMR.
5. The International Atomic Energy Agency (IAEA) safety standards (ref. [25]) and nuclear security series (ref. [26]) are a cornerstone of the global nuclear safety and security regime. They provide a framework of fundamental principles, requirements and guidance. They are applicable, as relevant, throughout the entire lifetime of facilities and activities.
6. Furthermore, ONR is a member of the Western European Nuclear Regulators Association (WENRA). WENRA has developed Reference Levels (ref. [27]), which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors (ref. [28]).
7. The relevant SAPs, IAEA standards and WENRA reference levels are embodied and expanded on in the TAGs (ref. [14]). The TAGs provide the principal means for assessing the radiological protection aspects in practice.
   * 1. Safety Assessment Principles (SAPs)
8. The key SAPs applied within my assessment for radiological protection are:

* RP.1, RP.3, RP.6 and RP.7
* NT.1 Target 1, 2 and 3
* ECR.1 and ECR.2

1. Further details of the SAPs used in this assessment are recorded in Appendix 1.
   * 1. Technical Assessment Guides (TAGs)
2. The following TAGs have been used as part of this assessment:

* NS-TAST-GD-043 – Radiological Analysis - Normal Operations (ref. [29])
* NS-TAST-GD-096 - Guidance on Mechanics of Assessment (ref. [12])
  + 1. National and international standards and guidance

1. The following international standards and guidance have been used as part of this assessment:

* The Ionising Radiation Regulations 2017 (IRR17) and the associated Approved Code of Practice (ACoP) (ref. [24])
* IAEA, Format and Content of the Safety Analysis Report for Nuclear Power Plants, Specific Safety Guide (SSG) No. SSG-61 (ref. [30])
* IAEA, Criticality Safety in the Handling of Fissile Material, Specific Safety Guide No. SSG-27 (ref. [31])
  1. Integration with other assessment topics

1. I have worked closely with other topics as part of my radiological protection assessment. Similarly, other assessors sought input from my assessment. These interactions are key to the success of GDA to prevent or mitigate any gaps, duplications or inconsistencies in ONR’s assessment.
2. The key interactions with other topic areas were:

* Chemistry, which led the assessment on the adequacy and justification of the normal operation radiological source terms. Radiological protection has specifically provided input into the characterisation and minimisation of the normal operation radiological source terms. This will have a significant impact on dose, dose rates and shielding across the nuclear island.
* I have interacted with the Environment Agencies (Enviroment Agency and NRW) on:
  + the characterisation and minimisation of normal operation radiological source terms, and
  + radiation exposure to any persons off the site, specifically the impact of direct radiation shine.
* Nuclear Liabilities Regulation, for:
  + characterisation and minimisation of the normal operation radiological source terms, and
  + spent fuel interim storage, specifically the adequacy and shielding of these radioactive wastes.
* Fuel and core, on areas related to criticality safety. Radiological protection will specifically take the lead regarding criticality assessment for fresh and used fuel outside of the core.
  1. Use of technical support contractors

1. During Step 2, I have not engaged Technical Support Contractors to support my assessment of the radiological protection aspects of the Rolls-Royce SMR.

# Requesting party’s submission

1. Rolls-Royce SMR Limited submitted a series of E3S chapters, or summary reports, and other supporting references, which outline the E3S case for the generic Rolls-Royce SMR design. This section presents a summary of the RP’s safety case for radiological protection. It also identifies the documents submitted by the RP which have formed the basis of my radiological protection assessment of the Rolls-Royce SMR.
   1. Summary of the Rolls-Royce SMR design
2. The generic Rolls-Royce SMR design is a three loop Pressurised Water Reactor (PWR) with a target electrical power output of 470 MWe (from a thermal power of 1,358 MWth) and a design life of 60 years for non-replaceable components.
3. The Rolls-Royce SMR design has been developed by the RP based upon well-established PWR technology, in use all over the world. Innovation comes in the form of its modular approach to construction which would see the majority of the power station built in factory conditions and assembled on site.
4. The reactor itself is of a typical PWR design, including a steel Reactor Pressure Vessel (RPV) holding fuel assemblies, steam generators, reactor coolant pumps and piping, all held within a steel containment vessel. The reactor is equipped with a number of supporting systems for normal operations and a range of safety measures are present in the design to provide cooling, control criticality and contain radioactivity under fault conditions. Passive safety features are preferred to active components, reflecting the RP’s design philosophy.
5. From a radiological protection perspective three design choices are of particular relevance:

* The first is the modular approach, which may have implications for shielding, containment and control of contamination when the individual modules are assembled.
* The Rolls-Royce SMR design adopts a primary circuit operating chemistry regime that differs from that of other operating civil PWRs, in not using soluble boron and adding potassium hydroxide. This choice can have a wide ranging impact on plant operations, including on the generation, transport and behaviour of radioactivity around the plant. It also means there is no boron in the spent fuel pool for fuel handling activities.
* The third is an optimised design layout, that reduces unnecessary space. This may impact occupational exposures during all modes of normal operations.
  1. E3S case approach and structure

1. Rolls-Royce SMR Limited has chosen to develop its cases in a holistic manner, as an Environment, Safety, Security and Safeguards (E3S) case. The overall objective for the E3S case is to demonstrate that the design will ‘protect people and the environment from harm’.
2. This means that, although the case made for each of the E3S purposes (i.e. environment, safety, security and safeguards) will inevitably be different at the top level, it will draw upon common evidence outputs (as well as other non-common outputs) to substantiate each of the purposes. This is claimed to offer benefits in terms of clarity, integration and understanding impacts from any changes to the case.
3. The E3S case is being developed using a three-tier hierarchy and incorporating a Claim, Argument and Evidence (CAE) structure with the highest-level claims being derived from the RP’s own E3S principles. The highest level of the three tiers is the RP’s Tier 1 E3S chapters, with the lower tiers providing more detailed arguments and evidence. This is illustrated in Figure 1.

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**Figure 1: Claim, Argument and Evidence (CAE) structure within the E3S hierarchy** (ref. [1])

1. The structure of the E3S case largely aligns with the IAEA guidance for safety cases, Specific Safety Guide No. SSG-61 (ref. [30]), supplemented to include United Kingdom (UK) specific expectations and expanded to include the other E3S purposes.
   1. Summary of the requesting party’s E3S case for radiological protection
2. The aspects covered by the Rolls-Royce SMR E3S case in the area of radiological protection can be broadly grouped under two headings which are summarised as follows:

### Radiological protection

1. The RPs radiological protection aspects of the E3S case are summarised within chapter 12 (ref. [7]). The highest-level claim made in this chapter is that “exposures of ionising radiation are reduced to as low as reasonably practicable throughout the lifecycle of the facility”. This claim is broken down into 33 sub-claims, with the relevant arguments and evidence supporting the sub-claims captured in Tier 2 and Tier 3 documents.
2. The Rolls-Royce SMR strategy to ensure protection against exposure to radiation arising from work activities is set out in a series of radiological protection Tier 2 policy documents:

* Dose management policy (ref. [32]) provides the general dose management principles, relevant legislation and good practice, plant zoning, technical issues and key policy and design interfaces for the Rolls-Royce SMR design. It sets out the holistic approach to dose reduction for the Rolls-Royce SMR design during critical operation, refuelling outages and relevant examination, maintenance, inspection and testing activities whilst the plant is shutdown.
* Radioactive source term policy (ref. [33]) defines a structured approach to minimising the normal operation radiological source terms.
* Radiation shielding policy (ref. [34]) covers the general shielding principles, the shielding design process, radiation safety criteria, technical issues, design interfaces and analysis tools.

1. These radiological protection policies are used to communicate the legislative requirements that will be applied to the Rolls-Royce SMR design. The key principle that runs through these radiological protection policies is the hierarchy of controls, as defined in IRR17 Regulation 9(2) (ref. [24]).
2. In addition to the radiological protection policies outlined above, the RP has produced a more detailed set of design guidelines to provide guidance on the practical application of key radiological protection principles for plant designers. This guidance is based on good practices from UK and international operating plants and aims to provide a practical means to demonstrate compliance with the requirements of IRR17.
3. At the current stage of the Rolls-Royce SMR design, the RP has not carried out any detailed dose estimates for normal operations. The RP has aligned its dose targets for any person on the site, including other workers, any person off the site and any group workers with ONR SAP Targets 1, 2 and 3. The collective dose targets for workers have also been derived using ONR SAP Target 1. The RP has stated that:

* Exposures associated with the Rolls-Royce SMR design will be below their normal operation dose design limits during Step 3.
* Where available, initial dose estimates will be compared against the RP’s relevant dose targets.

1. The RP’s objective is to provide confidence that, based on the current design at the end of Step 2, the Rolls-Royce SMR design will be below their own relevant dose targets. The RP has acknowledged that reducing doses to ALARP can only be demonstrated via further design provisions and re-analysis during Step 3.

### Out of core criticality

1. The RP covers the mechanical aspects of auxiliary systems in chapter 9A (ref. [5]). The fuel route from receipt of fresh fuel through to transfer of spent nuclear fuel into dry cask storage and the handover to the spent fuel store is covered as part of the handling of nuclear equipment systems. The highest-level claim made in this chapter is that “auxiliary systems are conservatively designed and verified to deliver E3S functions through-life, in accordance with the E3S design principles, to reduce risks to ALARP”. This claim is broken down into sub-claims, with the relevant arguments and evidence supporting the sub-claims captured in Tier 2 and 3 documents (refs [35], [36], [37] and [38]).
2. These Tier 2 and 3 documents(refs [35], [36], [37] and [38]) detail the criticality safety design basis for handling of fuel in the Rolls-Royce SMR design. The RP presents a description of each activity where Rolls-Royce SMR fuel is handled, focusing on those parts that could affect nuclear criticality safety. Noting that many of the fuel handling activities are currently being designed, the RP has undertaken some preliminary criticality analysis. The RP’s aim, at this stage, is to demonstrate that for a concept design of a spent fuel rack the margin to criticality is above the minimum criticality safety margin for normal operating conditions.
   1. Basis of assessment: requesting party’s documentation
3. The principal documents that have formed the basis of my radiological protection assessment of the E3S case are:

* Chapter 12 of the E3S case (ref. [7]), which contains the highest-level summary of the RP’s case for radiological protection.
* The suite of documents that detail the radiological protection policies and guidance used by the RP for the development of the E3S case and generic design (refs [32], [33] and [34]).
* The RP’s documents detailing the initial dose estimates, shielding and targets for workers and any persons off the site (refs [39], [40], [41], [42], [43] and [44]).
* Chapter 9A of the E3S case (ref. [5]), which contains the RP’s highest-level claim and associated functional requirements for the out of core criticality topic area.
* The RP’s documents detailing their approaches, methods and analysis for out of core criticality (refs [35], [36], [37] and [38]).
* The Radiation Protection ALARP topic report (ref. [45]​).

# ONR assessment

* 1. Assessment strategy

1. I chose to target my assessment on areas which I judged to be the most safety significant in the context of the design and E3S case. The objective is to undertake an assessment of the design against regulatory expectations to identify any fundamental safety shortfalls that could prevent ONR permissioning the construction of a power station based on the design.
2. I targeted the following matters to fulfil the aims for the Step 2 assessment of the Rolls-Royce SMR:

* The RP’s E3S case to determine whether the approach, policies and guidelines are adequate for radiological protection, shielding and out of core criticality.
* The RP’s approach to demonstrate that the Rolls-Royce SMR design will, in principle, comply with the requirements of IRR17 (ref. [24]). This will include ensuring that the RP has:
  + suitable design standards for radiological protection
  + a suitable approach to restrict occupational exposures
  + a suitable approach to ensure occupational exposures will be below all legal dose limits and relevant SAPs Basic Safety Levels (BSLs)
  + a suitable approach for the designation of areas
* The methodology to demonstrate how doses to workers and any persons off the site will be reduced to ALARP under normal operating conditions.
* Demonstration that normal operation radiological source terms are well characterised, consider relevant Operating Experience (OPEX) and that radioactivity within the design is capable of being reduced to ALARP.
* The RP’s approach to protect against an unplanned criticality associated with new fuel and spent fuel outside of the reactor.
* The RP’s approach to shielding substantiation and its role in optimising normal operation doses to workers and any persons off the site.
  1. Assessment
     1. Radiological protection aspects of the E3S case

#### Radiological protection

1. Chapter 12 of the generic E3S case (ref. [7]) presents the overarching summary of the design and safety information for the radiological protection and shielding aspects of the Rolls-Royce SMR design.
2. The RP’s strategy to ensure protection against exposure to radiation and radioactive substances is set out in a series of Tier 2 radiological protection policy documents that include:

* Dose management policy (ref. [32])
* Radioactive source term policy (ref. [33])
* Radiation shielding policy (ref. [34])

1. I am satisfied that the radiological protection documentation, submitted by the RP, covers the full scope and contents that I would expect to see as part of a radiological protection safety case at the end of Step 2.
2. I consider that the E3S case has appropriate claims and sub-claims which cover the breadth of areas associated with radiological protection for normal operations. The arguments provide sufficient detail to explain the general approaches to satisfying the radiological protection claim and sub-claims and appear reasonable.
3. For the sub-claim regarding the minimisation of radioactivity, the underlying evidence will be covered across multiple discipline Tier 2 and 3 documents. This requires coordination, by the RP and ONR, to ensure that the approach to satisfying these claims is appropriately covered across the respective disciplines during Step 3.
4. In conclusion, I judge that the radiological protection E3S case is adequate for Step 2. This should enable the RP, in Step 3, to further develop the E3S case evidence to substantiate the associated radiological protection claims and arguments.

#### Out of core criticality

1. Chapter 9A of the generic E3S case (ref. [5]) covers the overarching out of core criticality claim and associated safety functional requirements for the Rolls-Royce SMR design.
2. The Rolls-Royce SMR strategy to restrict unintended criticality associated with new fuel and spent fuel outside of the reactor core is set out in a series of Tier 2 and Tier 3 documents. These include:

* Criticality design basis (ref. [35])
* Criticality modelling report (ref. [36])
* Criticality assessments for in-core and storage (ref. [37])
* Criticality validation and verification (ref. [38])

1. The RP’s out of core criticality safety assessment for the Rolls-Royce SMR design considers the route of the fuel through the reactor building from receipt to, and from, the reactor onto dry storage. This process and the associated faults which could give rise to an unplanned criticality have not fully been developed in Step 2. Despite this, the information provided at the end of Step 2 fulfils the areas I would expect to see in a safety case for out of core criticality. This should, in my opinion, enable the RP to further develop the E3S case evidence.
   * 1. Compliance with the IRR17
2. I sampled the dose management policy and chapter 12 of the E3S case (ref. [32] and [7]) to determine compliance against the requirements laid out in IRR17 (ref. [24]). These regulations have a wide range of requirements for working with ionising radiation, many of which focus on operational requirements which will be determined by a future licensee. As the Rolls-Royce SMR is still in the design phase many of these regulations are not relevant at this stage. Therefore, I focused my assessment on the following key areas to form a judgement on whether the Rolls-Royce SMR design will be capable of being built in accordance to the requirements laid out in IRR17 (ref. [24]):

* Restriction of exposure
* Dose limitation
* Designation of areas

#### Restriction of exposure

1. Restriction of exposure (IRR17 Regulation 9) covers a broad range of requirements. For a fundamental assessment of the Rolls-Royce SMR design, I have limited the scope of my assessment to gaining assurance that the RP is in compliance with IRR17 Regulation 9(1) and 9(2)(a) (ref. [24]):

* “IRR17 Regulation 9(1) specifies that every employer must, in relation to any work with ionising radiation that it undertakes, take all necessary steps to restrict so far as is reasonably practicable the extent to which its employees and other persons are exposed to ionising radiation.
* IRR17 Regulation 9(2) specifies that an employer in relation to any work with ionising radiation that it undertakes must:
  + “(a) so far as is reasonably practicable achieve the restriction of exposure to ionising radiation required under IRR17 Regulation 9(1) by means of engineering controls, design features and by the provision and use of safety features and warning devices;”

1. The associated ACoP (ref. [24]) for IRR17 Regulation 9(1) and (2) provides a practical means to comply with these regulations. The accompanying guidance paragraphs illustrate good practice for the relevant regulations and ACoP. Therefore, I reviewed the RP’s arrangements for compliance against the advice provided in the following ACoP and guidance paragraphs:

* IRR17 Regulation 9(1) ACoP paragraph 85, recommends that dose sharing should not be used as a primary means to keep exposures below legal limits.
* IRR17 Regulation 9(1) ACoP paragraph 86, recommends that dose control measures should make it unlikely that other workers, which would not normally be exposed to ionising radiation in the course of their work, would receive an effective dose greater than one mSv/y.
* IRR17 Regulation 9(2) guidance paragraph 101, recommends that for any work with ionising radiation, employers should take action to control the doses received by their employees and other people by means of engineering controls first. Only after these have been applied should they consider using supporting systems of work. Lastly, employers should provide PPE to further restrict exposure where this is necessary and reasonably practicable.
* IRR17 Regulation 9(2) guidance paragraph 102, recommends establishing control measures at an early stage which will help employers to effectively restrict exposure, for example when the facility or device is being planned and designed. This means that the dose control mechanisms can be incorporated into the construction of the facility

1. I reviewed the RP’s dose management policy (ref. [32]) and found appropriate reference to the hierarchy of controls for the restriction of exposure. To ensure this principle had been appropriately embedded into the RP’s arrangements I sampled the radiological protection guide for designers (ref. [46]). I found this document instructs designers to consider engineered controls before administrative controls, which is in line with IRR17 9(1)(a) guidance, and stipulates that dose sharing between workers should not be used as the primary means to restrict exposures. Specifying that if a choice must be made between restricting doses to individuals and restricting doses to groups of people, priority should be given to keeping individual doses as far below dose limits as reasonably practicable. I am satisfied that the RP’s arrangements for the hierarchy of controls and dose sharing appropriately reflect the intent of IRR17 9(1)(a), ACoP paragraph 85, and the associated IRR17 guidance paragraphs.
2. The RP has carried out an initial dose estimate on other workers which would not normally be exposed to ionising radiation in the course of their work during normal operations for the Rolls-Royce SMR design. This assessment is based on the reactor and primary circuit source terms and uses a maximum occupancy of 2000 hours. The peak annual dose to other workers was calculated to be 0.022 μSv/y (ref. [44]). Although, this dose estimate does not consider doses from all non-natural sources of radiation, the RP has committed to restricting doses to other workers in line with the intent of IRR17 ACoP paragraph 86 and SAPs Target 1 (ref. [13]). As the design develops, exposures from other non-natural source terms, such as activation of plant components and the Intermediate Level Waste (ILW) store, will be required to revise the dose estimate. I am satisfied that the RP has used an appropriate methodology, at the end of Step 2, to derive an initial dose estimate for other workers. Key areas have been identified by the RP to derive a detailed dose estimate for other workers in Step 3. I will follow this aspect up as a residual matter in my Step 3 assessment.
3. To avoid duplication, I have captured my judgements on the implementation of the hierarchy of controls principle in Section 4.2.3, which discusses, more broadly, the RP’s overall process to reduce occupational exposures to ALARP.
4. To conclude, I judge that the RP has a reasonable approach to demonstrate compliance against the requirements laid out in Regulation 9 (1) and (2). I have identified one residual matter, which I will follow up in Step 3.

#### Dose limitation

1. IRR17 Regulation 12 (ref. [24]) stipulates that “every employer must ensure that its employees and other persons within a class specified in Schedule 3 are not exposed to ionising radiation to an extent that any dose limit specified in Part I of that Schedule for such class of person is exceeded in any calendar year.”

**Table 1: IRR17 Schedule 3 Part 1- classes of persons to whom dose limits apply** (ref. [24])

|  |  |  |  |
| --- | --- | --- | --- |
|  | Dose limits (mSv/y) | | |
| Employees and trainees of 18 years and above | Trainees aged under 18 years | Other persons |
| Effective dose | 20 | 6 | 1 |
| Len of the eyes | 20 | 15 | 15 |
| Skin (averaged over 1 cm2 ) | 500 | 150 | 50 |

1. The SAPs (Ref. [13]) provides numerical targets that ONR inspectors use as an aid to form a judgement when considering whether radiological hazards are being adequately controlled and risks reduced to ALARP. SAPs targets quantify ONR’s risk policy. These targets include the BSL, which for Targets 1 and 3 are also legal limits (as stipulated within IRR17), and the Basic Safety Objective (BSO). The BSO is set at a point where the need for any further scrutiny of the risks by ONR would likely not be necessary. Tables 2, 3 and 4 provide the BSL and BSO targets for employees on the site including other workers, any group of workers on site, and any person off the site. The RP’s dose targets for normal operations are the same as ONR’s SAP Targets detailed in Table 2, 3, and 4.

**Table 2 - Normal operation for any person on the site** (ref. [13])

|  |  |
| --- | --- |
| SAP Target 1 & the RP’s dose target | Normal operation – any person on the site |
| Employees working with ionising radiation: | |
| BSL (Legal Limit (LL)) | 20 mSv/y |
| BSO | 1 mSv/y |
| Other employees on the site: | |
| BSL | 2 mSv/y |
| BSO | 0.1 mSv/y |

**Table 3 - Normal operation for any group on the site** (ref. [13])

|  |  |
| --- | --- |
| SAP Target 2 & the RP’s dose target | Normal operation – any group on the site |
| BSL | 10 mSv/y |
| BSO | 0.5 mSv/y |

**Table 4 – Normal operation any person off the site** (ref. [13])

|  |  |
| --- | --- |
| SAP Target 3 & the RP’s dose target | Normal operation – any person off the site |
| BSL (LL) | 1 mSv/y |
| BSO | 0.02 mSv/y |

1. For my assessment of the Rolls-Royce SMR design I focused on gaining confidence that the Rolls-Royce SMR will be below all effective dose limits and ONR SAP BSLs, specifically Target 1 (LL), Target 2 and Target 3 (LL).
2. **Target 1** – The assessment against Target 1 normally requires a dose estimate by the RP, which should be based upon the following design parameters (ref. [29]):

* Normal operation radiological source terms
* A mature shielding design
* The specific tasks expected to be undertaken during all modes of normal operation (including maintenance)
* Detailed occupancy models

1. As much of this information was not available at the end of Step 2, the RP has provided an initial normal operations dose target based solely on ONR SAPs Target 1. The RP has argued that dose targets will be used in the design phase to influence key design decisions, such as bulk shielding, to ensure restriction of exposure. In the absence of specific data for the Rolls-Royce SMR design, and a suitable SMR reference plant, I consider the RP’s approach to define a dose target in line with ONR SAP Target 1 to be acceptable for Step 2. The RP has undertaken analysis from PWR OPEX and concluded that the maximum individual dose for any person on the site will not exceed 10 mSv/y (ref. [42]). I am satisfied that the RP’s analysis (ref. [42]), though not conclusive, provides confidence that ONR SAP Target 1 BSL for any person on the site can be met. In Step 3, I will require the RP to produce a detailed dose estimate, underpinned by the design parameters highlighted in paragraph 67, which I will assess and compare with ONR SAP Target 1. I will follow this up as a residual matter.
2. **Target 2** – The assessment against Target 2 requires the RP to calculate the average effective dose for groups of workers, based on the type of work carried out. In the absence of a occupancy model or defined work requirements for all modes of normal operation, the RP was not able to define groups of workers at the end of Step 2. The RP has set its dose target at 10 mSv/y for any group on the site, in line with ONR SAP Target 2 BSL (ref. [42]). This dose target is also consistent with the RP’s assertion that any person on the site will not exceed 10 mSv/y. Insufficient detail has been provided by the RP, at the end of Step 2, for me to form a judgement against ONR SAP Target 2. I am, however, satisfied that the RP’s PWR OPEX analysis (ref. [42]) provides confidence that ONR SAP Target 2 BSL for any group on the site can be met. In Step 3 I will require the RP to define groups of workers on the site and generate a detailed dose estimate, which I will assess and compare with the ONR SAPs Target 2. I will follow this up as a residual matter.
3. **Target 3**- The initial dose to any persons off the site from reactor operations was undertaken by the RP. Using the best estimate source term for the primary circuit and a full-time occupancy of the maximum number of hours in a year (8760 hours) the RP calculated a bounding effective dose of 2.53E-02 µSv/y from direct shine for any person off the site (ref. [44]). The RP’s analysis of the dose from direct radiation, to a representative person, issignificantly lower than its own dose targets.
4. Target 3 requires doses from all pathways to be considered in the dose estimate. The RP was not able at the end of Step 2 to consider doses from the ILW store and spent fuel storage building, which based on OPEX from previous GDAs, accounts for the vast majority of off-site dose. The RP has reasoned that in the absence of dose data from these waste stores, a dose constraint will be used. This will be based on the dose rate at the site from direct shine to ensure that the total dose to any persons off the site meets its dose targets. I consider the RP’s approach for Target 3 to be appropriate for Step 2. In Step 3, I will require the RP to include doses from all pathways in the dose estimate, which I will assess and compare with ONR SAPs Target 3. I will follow this up as a residual matter during Step 3.
5. In conclusion, the RP has argued that defining dose targets for the Rolls-Royce SMR design will restrict doses during all modes of normal operations. Dose targets are used in the design process for nuclear power plants to influence key design decisions and restrict exposures (ref. [47]). The RP has aligned its dose targets with ONR SAPs Targets 1, 2 and 3. In the absence of detailed information on key design parameters, discussed in paragraph 67, I consider this to be a reasonable approach for the end of Step 2. Overall, I am satisfied that the RP’s PWR OPEX analysis (ref. [42]), though not conclusive, provides confidence that the RP can meet ONR SAP Targets 1, 2 and 3 BSLs. Three residual matters have been identified, which require the RP to develop detailed dose estimates, during Step 3, for employees on the site, employees off the site and any group on the site.

#### Designation of areas

1. IRR17 Regulation 17(1) (ref. [24]) requires employers to designate controlled areas if:
   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 mSv a year or an equivalent dose greater than 15 mSv a year for the lens of the eye or greater than 150 mSv a year for the skin or the extremities.”
2. The RP’s radiation zoning scheme is based on dose rates (ref. [32]). The zoning scheme require designers to designate a controlled area when the external dose rate in a given area exceeds 7.5 µSv/h, and a supervised area for dose rates below 7.5 µSv. This approach is aligned with ACoP paragraph 297 (ref. [24]). I am satisfied that the basis for the radiation zoning scheme is in line with the requirements laid out in IRR17 Regulation 17(1).
3. The objective of radiological zoning, as discussed in ONR SAPs RP.3 (ref. [13]), is to minimise exposures to workers by controlling access to areas of the plant with elevated dose rates and prevent the spread of radioactive material. I sampled the RP’s radiological zoning philosophy and the radiation protection guidance for designers (ref. [32], [46]) to form a view on how the zoning scheme restricts exposures. I found that the radiation and contamination zoning scheme:

* Uses a logical approach, based on existing operational power plants within the UK. For radiation zoning the RP uses R0 to R5, designations and for contamination zoning the RP uses C0 to C4. Both the radiation and contamination zoning schemes associate higher numbers with higher dose rates and higher contamination hazards respectively. I am satisfied that the radiological zoning scheme is aligned with Relevant Good Practice (RGP) from UK operating plants.
* Has been appropriately embedded into the design of the reactor island layout by means of radiation protection guidance (ref. [46]). The guidance to designers clearly references the radiation and contamination zoning schemes (discussed above) and specifies guidance on access control, radiation shielding thickness, contamination control features, ventilation requirements, access and egress arrangements. The guidance is, in my opinion, based upon established RGP from UK operating plants.

1. At the end of Step 2, the RP has not implemented the radiation and contamination zoning schemes or monitoring arrangements. Therefore, I have limited my sample to areas where information was available, taking due cognisance of any potential incomplete design parameters. I sampled dose rates within the reactor building hazard shield, focusing on the Main Control Room (MCR). The referenced document (Ref. [41]) indicates very high dose rates, and consequent doses above effective IRR17 legal limits within the MCR during normal operations. These doses are principally due to the incomplete shielding around the RPV interspace and the refuelling cavity base. I raised a Regulatory Query (RQ) RQ-01106 (ref. [48]) to request a fundamental justification for the location of the MCR. In response to the RQ, the RP stated that the Rolls-Royce SMR Control Facilities Description (ref. [49]) details a set of location requirements, which includes a provision to:

* Protect personnel inside the MCR, during normal operations, by ensuring dose rates in the MCR due to non-natural sources of radiation shall be <0.5 µSv/h.

1. This is an example of how the RP’s designation of areas scheme has been used, in the design phase, to identify unacceptable dose rates and influence shielding requirements to restrict exposures to workers. ONR SAPs RP.3 states that where doses forming a significant fraction of any statutory dose limit could be incurred in a matter of minutes during normal operations, access should be controlled by physical means and interlocks. Due to the access requirements for the MCR, restriction of access is not possible. Therefore, the RP has identified the need for more shielding to reduce exposures for MCR workers to below the level specified for IRR17 supervised area. I consider this approach to align with the intent of the SAPs and the requirements laid out in IRR17.
2. I am satisfied that the RP has defined an appropriate radiological designation scheme in line with IRR17 Regulation 17(1), associated ACoP, and the principles laid out in ONR SAPs RP.3. I will further examine the implementation of the radiation and contamination zoning scheme for the Rolls-Royce SMR design as part of my Step 3 assessment.
3. To conclude, I am satisfied that the RP has specified suitable design standards (ref. [32], [46]) which comply, in principle, with the requirements laid out in IRR17 and the associated ACoP, as well as the principles laid out in ONR SAPs (namely RP.3, RP.7). This should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence.
   * 1. Process for optimising occupational exposures to ALARP
4. For Step 2, the RP has provided the philosophies and processes which are being used to develop the Rolls-Royce SMR design. I sampled the following documents to determine if the reduction of all occupational exposures, alongside other risks, to ALARP had been appropriately embedded into the Rolls-Royce SMR design policies and procedures:

* E3S Chapter 12: Radiation Protection (ref. [7])
* Radiation Protection ALARP Topic Report (ref. [45])
* Dose management policy (ref [32])
* Radioactive source term policy (ref. [33])

1. I found that the RP’s policy and procedures describe a logical approach to restrict occupational exposures to workers and any persons off the site to ALARP. The RP’s overall strategy for the restriction of exposure prioritises the minimisation of source terms and the hierarchy of controls, as defined in Regulation 9(2) of IRR17, for controlling radiological hazard and mitigating against residual risks. Application of these strategies are considered in the ALARP design optioneering, which forms part of the RP’s overarching design definition review process (ref. [32]). In my opinion, the RP has implemented an appropriate system which takes into account occupational exposure risks, alongside other risks, as part of the ALARP optioneering process. I sampled a decision record from the optioneering process to form a view on how this has been implemented, my judgements are captured in Section 4.2.4.2.
2. In the absence of detailed dose estimates, collective dose targets can be a useful metric to gauge the overall radiation exposure management for a given nuclear power plant. The RP has evaluated the highest collective dose tasks from different PWRs (ref. [43]) and has argued that despite differences in reactor configuration and steam generator materials, high dose tasks at PWRs remain broadly similar. As this assumption is not underpinned at this stage; I have used these collective dose targets to form an indicative view on the adequacy of the design at the end of Step 2.
3. From PWR OPEX, the RP has defined a collective design dose target of 320 person.mSv per unit per year (ref. [42]), for a 10-year operating period. This is based on a collective dose target of 200 person.mSv for each year of power operation, and 6 outages at a collective dose target of 200 person.mSv. On this basis, the RP has concluded that the Rolls-Royce SMR design will be comparable with modern operating PWRs. Detailed dose estimates for the Rolls-Royce SMR design will be required for me to form a judgement on whether the RP meets RGP and ONR expectations regarding collective dose. The RP will undertake this detailed dose estimate during Step 3. The RP’s strategy for reducing collective occupational exposures during Step 3 (ref. [42]) includes identifying high dose tasks and implementing control measures, based on PWR OPEX, to reduce collective exposures. I consider the RP’s approach for defining collective dose targets to be reasonable at the end of Step 2. Further information will be required, from the RP, on how collective dose targets have been implemented in the Rolls-Royce SMR design to reduce overall exposures. This is a residual matter, which I will follow up in Step 3.
4. To conclude, I judge that the RP has developed a reasonable strategy which takes into account reducing occupational exposure risks, alongside other risks, as part of the ALARP optioneering process. This should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence at Step 3.

### Normal operation radiological source terms

1. Complex processes control the release and activation of corrosion products. This includes release, transport to the fuel surface, deposition, activation, release from fuel surfaces, and the subsequent uptake on out-of-core surfaces. The build-up of these corrosion products results in radiation fields, which account for the vast majority of worker dose. I have sampled and formed a view on (ref. [34]):

* the RP’s strategy for the derivation and justification of the normal operation source term, and
* the strategy for how radioactivity within the design has been reduced to ALARP.

#### Derivation and justification of the normal operation radiological source terms

1. It is important to gain confidence in the derivation and justification of the normal operations radiological source term as it will be used to underpin almost all technical assessment areas related to radiological protection, including worker dose, public dose and shielding design.
2. For Step 2, the RP produced a high-level strategy for developing and justifying the normal operations radiological source term along with a list of selected radionuclides (refs [50] and [51]). The assessment of this strategy was led by the chemistry specialist inspector, who found that the strategy for developing the normal operations radiological source term is consistent with UK RGP (ref. [23]). I am satisfied that the scope and breadth of the chemistry assessment sufficiently covers my interest in the derivation and justification of the normal operations radiological source term topic area. As a result, no further comment has been made on the derivation and justification of the source term in this AR.

#### Reduction of radioactivity to ALARP

1. The RP’s Rolls-Royce SMR radioactive source term policy (ref. [33]), identifies a range of mandatory and recommended practices that are to be adopted during the design of the Rolls-Royce SMR. I reviewed these practices focusing on material selection and relied mostly on the chemistry specialist inspector to form a view on the chemistry controls employed by the RP. I focused my assessment on the most novel aspects of the RP’s chemistry controls, specifically, the impact of potassium hydroxide as the alkalising agent on normal operations dose.
2. The choice of operating chemistry in the Rolls-Royce SMR, which does not include the use of soluble boron and lithium, is likely to reduce internal radiation exposures during normal operations. This is due to:

* The reduction of the amount of tritium produced during normal operations when compared with a PWR operating with lithium-boron chemistry. Both lithium and boron are susceptible to neutron activation in the primary circuit, which can result in a significant tritium source term. In PWR’s, this tritium source term can contribute to overall exposures through the internal dose pathway, especially for workers entering reactor containment during power.

1. The benefit from a reduction in tritium needs to be balanced against the formation of potassium-40, potassium-42 and sodium-24, all of which could contribute to worker dose. The RP has presented literature data (ref. [52]) which indicates that the use of potassium hydroxide as an alkalising agent will not significantly increase dose rates, during normal operations, when compared to lithium hydroxide. Although the RP has presented initial evidence to support both of these assertions, specific calculations are required to determine the contribution to operator dose from potassium for the Rolls-Royce SMR design. The RP will present this in Step 3.
2. From my sample of the RP’s Rolls-Royce SMR radioactive source term policy (ref. [33]), I found that the policy document had identified and used appropriate RGP to inform the source term reduction practices for the plant. Notably from OECD-Nuclear Energy Authority (NEA) radiation protection aspects of primary water chemistry and source term management (ref. [53]).
3. I further sampled how these controls would be used to minimise the generation of radioactivity in the primary circuit. I found the policy document (ref. [33]) clearly focuses on eliminating radionuclides (such as Co-60) before considering controls to mitigate the effects of radioactivity to workers and any persons off the site. This approach is in line with the hierarchy of controls specified in ONR SAP RP.7 and the IRR17 (ref. [13] and [24]).
4. Chemistry controls play an important role in the generation and transport of radionuclides within the primary circuit, as such, the RP has made a number of subclaims to underpin the proposed chemistry operating conditions. This is assessed in the chemistry AR (ref. [23]).
5. I sampled the decision record for the use of cobalt-based materials in the Control Rod Drive Mechanism (CRDM) ​(ref. [54]) to form a view on how the RP had implemented the measures specified in the Rolls Royce SMR radioactive source term policy. I found a number of issues with the optioneering process and raised a joint RQ-01170 (ref. [48]) with mechanical specialist inspectors. The RQ highlighted issues with the optioneering process, specifically, on how options were identified and compared from a dose perspective.
6. In the decision record, the RP selects conventional cobalt based CRDM and, in part, justifies this by stating that cobalt based alloys are commonly used on CRDM due to their high wear performance. The optioneering study discussed in the decision record is between two options, one of which contains cobalt within the CRDM and the other a new material, without cobalt, that requires a significant amount of research and development. Although the RP has provided some OPEX, further evidence is required from the RP to understand if all reasonable alternatives have been considered as part of this optioneering process. This will be followed up as a residual matter during Step 3.
7. In my opinion, due to the significant cobalt inventory associated with the CRDM, and the potential impact on exposure, the RP has not yet adequately demonstrated that all reasonable options to reduce and eliminate cobalt for the CRDM have been considered. During Step 3, I will seek further evidence from the RP that all reasonable options for minimising the quantities of cobalt-based material in contact with the primary circuit have been explored. I will also ensure that any dose comparison between options takes into account due consideration of doses across the lifecycle of the Structure, Systems and Components (SSC) being explored.
8. The management of the overall cobalt inventory at a plant level is an important part of the overall case to demonstrate that doses, for normal operations, have been reduced to ALARP. To ensure this is appropriately captured an RQ-01284 (ref. [48]) was raised by the chemistry specialist inspector, which sought clarity on where information on the cobalt inventory management would be captured. The RQ response (ref. [48]) clarified that information pertaining to the cobalt inventory would be captured under chapter 12 (radiological protection) (ref. [7]), with the requirements concerning material selection and surface finish, for the primary circuit, included in chapter 20 (chemistry) (ref. [9]). The RP has also committed to a new supporting report titled Minimisation of Radioactivity in Step 3 to support these claims. I am satisfied that the RQ response provides confidence that these multidiscipline aspects are being considered and that the overall case for the reduction of cobalt will be appropriately captured in the E3S case. I will follow up this residual matter as part of my Step 3 assessment in conjunction with the chemistry specialist inspector.
9. To conclude, I judge that the RP has a reasonable strategy to reduce radioactivity to ALARP, and has presented well-reasoned arguments. Initial evidence in the E3S submissions indicates that the use of potassium hydroxide, as an alkalising agent, will not significantly increase dose rates, during normal operations, when compared to lithium hydroxide. Although further evidence is required, in the form of design specific calculations, I am satisfied that the RP has defined a suitable approach to demonstrate, in Step 3, the occupational exposure impacts from the primary circuit chemistry. I have identified one residual matter which I will follow up in Step 3.

### Out of core criticality

1. Due to the maturity of the design, I was unable, at the end of Step 2, to form a definitive judgement on the entirety of the fuel cycle, from an out of core criticality perspective. Therefore, I sampled the RP’s out of core criticality arrangements, focusing on the RP’s spent fuel pool, and formed judgements against SAP principles ECR.1 and ECR.2 (ref. [13]).
2. The RP will use the nuclear criticality code Monte Carlo N-Particle Transport Code (MCNP) for their assessment (ref. [37]). The RP has agreed to carry out cross-check calculations using another code and nuclear data library, by an independent assessor. I judge this approach to be reasonable as it minimises the risk of systematic errors.
3. ONR’s expectation, based on ECR.1 and IAEA guidance SSG-27 (ref. [13], [31]), is that for a new reactor it should be possible to ensure criticality control of the fuel storage facilities through geometrical constraint alone. The RP’s approach uses fixed neutron absorber panels to control reactivity within the spent fuel pool. Soluble boron is not used in the Rolls-Royce SMR spent fuel pool design; this aligns with ONR expectations as it removes fault sequences associated with loss of boron concentration (ref. [35]). However, further substantiation is required from the RP to justify the use of fixed neutron absorber panels rather than geometrical constraints alone and demonstrate that risks have been reduced to ALARP. I will follow this up as a residual matter in Step 3.
4. The RP has stated that for fault conditions, a criticality safety criterion keff of 0.98 will be used. RQ-1159 (ref. [48]) asked for justification of this keff criterion, as this is higher than the generally accepted keff of 0.95. In their response (ref. [48]), the RP agreed to provide further evidence in Step 3 detailing the safety benefit achieved by using a higher criticality safety criterion. The RP also agreed to use appropriate sensitivity techniques to choose the critical benchmarks and statistical methods to estimate the validation bias. I consider this approach to be appropriate.
5. I sampled the RP’s Criticality Design Basis document (ref. [35]), which provides some fault conditions from the Rolls-Royce SMR Fault Schedule. These will be defined further by the RP in Step 3 to ensure that unintended criticality cannot occur unless at least two unlikely, independent, concurrent changes essential to criticality safety have occurred. I consider this approach to be reasonable and in line with ECR.2.
6. In conclusion, I have identified residual matters in the preceding paragraphs and will seek further justification in Step 3 to ensure all reasonably practicable options have been considered to prevent an unplanned criticality, in line with SAP ECR.1. I judge that the RP’s approach for out of core criticality safety are in line with SAP ECR.2. This should, in my opinion, enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence in Step 3.

### Shielding

1. The RP has identified a preliminary shielding concept design for the Rolls-Royce SMR, based on initial thicknesses of bulk shielding for primary circuit SSCs. Due to the maturity of the design I was unable to form a definitive judgement on the acceptability of the shielding design at the end of Step 2.
2. For my Step 2 assessment of the Rolls-Royce SMR design, I sampled the RP’s policy and process documents, detailed in the E3S case, to determine the adequacy of their approach to shielding substantiation.
3. I reviewed the RP’s shielding basis of design (ref. [34]) for the SMR reactor island and found the shielding approach was comparable with UK industry approaches. This document includes key information and assumptions for the RP’s shielding scheme which I judge should ensure consistent application of this data in all shielding assessments.
4. I reviewed the RP’s policy and design criteria for the shielding design. I consider that the principles specified in these documents were comparable with UK industry approaches to shielding design and should provide an appropriate basis for the RP to develop the Rolls-Royce SMR design in Step 3. I am also satisfied that the RP has defined a coherent shielding design process, which, I consider to be consistent with RGP. I therefore judge that the RP’s approach to deriving shielding substantiation is sufficient and has appropriately defined the role of shielding in optimising normal operations doses to workers and any persons off the site.
5. The RP has used the latest versions of the MCNP and Attila computer codes with current nuclear datasets for all shielding assessment work (ref. [41]). These codes are widely accepted in the nuclear industry, and therefore, I judge this is consistent with RGP.
6. The RP has identified a preliminary bulk shielding concept design, with limited substantiation. I have confidence that this concept design will limit any major impact on the modular layout as the shielding design progresses. This is a residual matter which I will take forward in to Step 3.
7. As part of my assessment of the RP’s shielding design I raised two RQ’s. RQ-01106 (ref. [48]) was raised in relation to high dose rates within the MCR, this has been discussed in section 4.2.2.3, and RQ-01034 (ref. [48]) which broadly covered the RP’s initial dose rate assessment within the reactor primary containment. The questions sought clarity on the methodology and justification used to calculate the initial dose rates inside of the reactor containment. The RP’s responses to RQ-01034 (ref. [48]) indicate that the initial dose rates were used to consider the feasibility of shielding around the RPV and to assess the preliminary shielding design. Therefore, the initial dose rate estimates were not intended to be representative of the final design, instead these estimates have been used to drive the development of the design and demonstrate the need for further shielding to reduce doses to ALARP. I judge this approach to be reasonable at the end of Step 2 and I will take this forward as a residual matter in Step 3.
8. In conclusion, I have identified residual matters in the preceding paragraphs that will require further substantiation in Step 3. The RP has identified a number of additional areas which require further shielding substantiation (ref. [34]). I am content that the RP will take this forward as normal business in Step 3. At the end of Step 2 the RP has detailed a suitable approach to develop the shielding substantiation and defined its role in optimising normal operations doses to workers and any persons off the site.

# Conclusions

* 1. Conclusions

1. This report presents the Step 2 radiological protection assessment for the GDA of the Rolls-Royce SMR design. The focus of my assessment in this step was towards the fundamental adequacy of the design and safety case. I have assessed the Tier 1 E3S chapters and relevant supporting documentation provided by Rolls-Royce SMR Limited to form my judgements. I targeted my assessment, in accordance with my assessment plan (ref. [17]), at the content of most relevance to radiological protection against the expectations of ONR’s SAPs, TAGs and other guidance which ONR regards as relevant good practice.
2. Based upon my assessment, I have concluded the following:

* In general, the scope, structure and content of the E3S case meet my expectations for this stage of GDA from a radiological protection perspective. Further work will need to be undertaken in Step 3 of GDA by the RP to develop the underlying evidence supporting the radiological protection claims and arguments.
* The RP has, in principle, specified suitable design standards which comply with the requirements laid out in IRR17, ACoP, and the principles laid out in the relevant SAPs. Further work is required by the RP to implement these design standards to demonstrate compliance with the relevant requirements.
* I consider the RP’s approach to set design targets, in line with ONR SAPs, to be reasonable at the end of Step 2. The RP has argued that the Rolls-Royce SMR design targets, underpinned by PWR OPEX, will restrict normal operations doses below all legal limits and ONR SAP BSLs. I am satisfied that this approach is reasonable for a Step 2 assessment. Residual matters have been identified, which require the RP to develop detailed dose estimates for ONR SAPs Targets 1, 2 and 3 during Step 3. I will follow these matters up during my Step 3 assessment.
* I consider the RP’s approach for defining collective dose targets, with partial information on key plant parameters, as reasonable at the end of Step 2 for the Rolls-Royce SMR design. However, Further information will be required from the RP on how collective dose targets have been implemented in the Rolls-Royce SMR design to reduce overall exposures. I consider this to be a residual matter, which I will follow up in Step 3.
* The RP has developed a reasonable strategy which takes into account reducing occupational exposure risks, alongside other risks, as part of the ALARP optioneering process. This should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence during Step 3.
* The RP has a reasonable strategy to reduce radioactivity to ALARP and has presented well reasoned arguments. Initial evidence in the E3S submissions suggests that the boron free, potassium hydroxide, primary circuit chemistry will not significantly increase dose rates during normal operations when compared to lithium hydroxide. Although further evidence is required during Step 3 in the form of design specific calculations, I am content with the RP’s approach to demonstrate the occupational exposure impacts from the primary circuit chemistry.
* I have identified residual matters which require further justification in Step 3 to ensure all reasonably practicable options have been considered in the design of the spent fuel pool to prevent an unplanned criticality. The RP’s approach for out of core criticality safety is in line with SAP ECR.2. I judge this should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence in Step 3.
* At the end of Step 2, the RP has detailed a suitable approach to develop the shielding substantiation and defined its role in optimising normal operations doses to workers and any persons off the site. I have identified residual matters that will require the RP to further develop the E3S case evidence for the Rolls-Royce SMR shielding design in Step 3.

1. Overall, based on my assessment to date, and subject to the provision and assessment of suitable and sufficient supporting evidence, I have not identified any fundamental safety shortfalls that could prevent ONR permissioning the construction of a power station based on the generic Rolls-Royce SMR design.
   1. Recommendations
2. My recommendations are as follows:

* Recommendation 1: ONR should consider the outcomes from my assessment as part of the decision to progress to Step 3 of GDA for the generic Rolls-Royce SMR design.

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# Appendix 1 – Relevant SAPs considered during the assessment

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| SAP No. | SAP Title |
| SC.2 | Safety case process outputs |
| SC.3 | Lifecycle aspects |
| EKP.1 | Inherent safety |
| FP.3 | Optimisation of Protection |
| FP.4 | Safety Assessment |
| FP.5 | Limitation of risks to individuals |
| FP.6 | Prevention of accidents |
| FP.8 | Protection of present and future generations |
| RP.1 | Normal Operation (Planned Exposure Situations) |
| RP.3 | Designated areas |
| RP.6 | Shielding |
| RP.7 | Hierarchy of control measures |
| NT.1 | Assessment against targets |
| ECR. 1 | Criticality Safety – Safety measures |
| ECR. 2 | Criticality Safety – Double Contingency approach |