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

Title

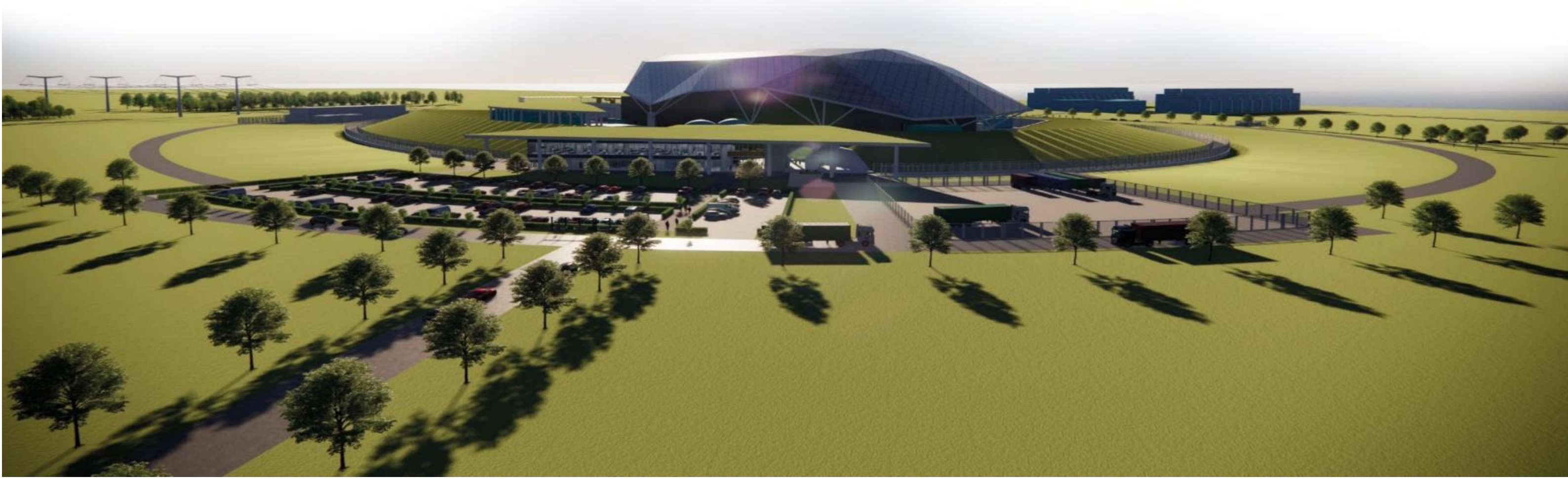
E3S Case Chapter 4: Reactor (Fuel & Core)

Executive Summary

This chapter of the Environment, Safety, Security, and Safeguards (E3S) Case presents the Reactor (Fuel & Core) of the Rolls-Royce Small Modular Reactor (RR SMR). It outlines the arguments and preliminary evidence available at the Preliminary Concept Definition (PCD) design stage to underpin the high-level Claim that the Reactor Core [JAC] is designed and substantiated to achieve functional and non-functional safety requirements through the plant's lifecycle and reduce risks to As Low As Reasonable Practicable (ALARP).

At PCD, the preliminary evidence includes the fuel and core design documentation at 'Iteration 5', including the high-level performance characteristics and optioneering conducted to develop the core design, and the design definition for the core components in the Reactor System [JA].

The full suite of evidence to underpin the claim is still in development, including full traceability of safety categorised requirements from the safety analysis, a complete set of non-functional system requirements from the E3S design principles, further development and optimisation of the core design to meet safety requirements, and ultimately substantiation of safety requirements.



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4.0 Introduction

4.0.1 Introduction to Chapter

Chapter 4 of the Rolls-Royce Small Modular Reactor (RR SMR) Environment, Safety, Security and Safeguards (E3S) Case forms part of the Pre-Construction Safety Report (PCSR), and is a supporting reference to the Generic Environment Report (GER) and Generic Security Report (GSR), which are Tier 1 reports in the E3S Case as defined in E3S Case Chapter 1: Introduction, Reference [1].

Chapter 4 presents the overarching summary and entry point to the design information for the fuel and core design of the RR SMR, as defined at Reference Design (RD) 5 level of design maturity.

4.0.2 Scope

The scope of this chapter for fuel and core covers the following physical components:

1. Reactor Vessel Internals [JAC10]
2. Fuel Assemblies [JAC20]
3. Neutron Sources [JAC30]
4. Core Assembly (covered by [JAC] components)
5. Control rods [JDE]

The scope covers justification of these core components for equilibrium cores, an initial core load and for any transitional cores, based on a single design concept of an 18 month, three batch cycle. All modes of operation (described in E3S Case Chapter 1: Introduction, Reference [1]) are included.

The following systems and components are excluded from the scope:

1. Reactor Pressure Vessel (RPV) [JAA] and internal mechanical structures, covered within E3S Case Chapter 5: Reactor Coolant System & Associated Systems, Reference [2]
2. Control Rod Drive Mechanisms (CRDMs) [JDA], covered within E3S Case Chapter 5: Reactor Coolant System & Associated Systems, Reference [2]
3. Fuel Handling Systems [F], covered within E3S Case Chapter 9: Auxiliary Systems, Reference [3]
4. Neutron and Temperature Sensors [JY], covered within E3S Case Chapter 7: Instrumentation & Control, Reference [4]

Design/Programme Maturity

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

The core design is undergoing constant optimisation to improve performance, increase safety and to reflect the changing requirements of the wider programme. As part of the core design optimisation, minor snapshots of the core design (known as iterations) are taken to provide a design baseline and to communicate any updated performance characteristics to any interfacing disciplines.

This revision of the PCSR provides a summary of 'Iteration 5' of the core design, including high-level performance characteristics and optioneering conducted to develop the core design to reduce risks to As Low As Reasonably Practicable (ALARP). The full suite of design and analysis evidence to achieve the claims placed on fuel and core will be developed as further iterations of the core design are developed (see Section 4.0.3).

4.0.3 Claims, Arguments, Evidence Route Map

The Chapter level Claim for E3S Case Chapter 4: Reactor (Fuel and Core) is:

Claim 4: The Reactor Core [JAC] is designed and substantiated to achieve functional and non-functional safety requirements through the lifecycle, and reduce risks to ALARP

A decomposition of this Claim into Sub-Claims, Arguments, and link to the relevant Tier 2 Evidence is provided in Section 4.10, Appendix A. For each lowest level Sub-Claim, the sections of this report providing the Evidence summary are also identified.

The complete suite of evidence to underpin the Claims in the E3S Case will be generated through the RR SMR design and E3S Case programme and documented in the Claims, Arguments, Evidence (CAE) Route Map, Reference [5], described further in E3S Case Chapter 1: Introduction, Reference [1].

4.0.4 Applicable Codes & Standards

The mechanical systems and components summarised in this report are designed in accordance with their safety classification, to the codes and standards outlined in Table 4.0-1, based on Reference [6].

Table 4.0-1: Mechanical Design Codes & Standards

Safety Classification	Design Basis Code
Very High Reliability (VHR)	American Society of Mechanical Engineers (ASME) III (Sub-section NB) and beyond code requirements
High Reliability (HR)	ASME III (Sub-section NB) and beyond code requirements
Class 1	ASME III

Safety Classification	**Design Basis Code**
Class 2	ASME III
Class 3	ASME III or Commercial standards e.g., ASME VIII, British Standard (BS) and European Standard (EN) BS EN 13445
Not Applicable (n/a)	Commercial standards e.g., ASME VIII, BS EN 13455

ASME III Code Class CS is the appropriate standard for reactor core and internals components. Additional codes and standards identified for the Reactor Core [JAC] include:

1. International Atomic Energy Agency (IAEA) Safety Specific Requirements (SSR) SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design. Reference [7]

2. IAEA Safety Specific Guide (SSG) SSG-52, Design of the Reactor Core for Nuclear Power Plants, Reference [8]

3. IAEA Safety Specific Guide SSG-73, Core Management and Fuel Handling for Nuclear Power Plants, Reference [9]

4.1 Summary Description

4.1.1 Requirements

The fuel and core design are being developed in accordance with the systems engineering design process, with design and performance requirements developed based on Relevant Good Practice (RGP) & Operating Experience (OPEX), summarised below.

Design Requirements

The fuel and core design is being developed against functional and performance requirements, which ensure the Reactor Core will operate safely, interface with the wider plant infrastructure and meet the overall objectives of the power station. At the highest level, the design requirements can be summarised as:

1. Generate Heat – the Reactor Core is required to generate 1358MW of thermal energy for a cycle length of 18 months
2. Transfer Heat – the Reactor Core is required to transfer thermal energy generated through fission to the reactor coolant. A safe margin to the Departure from Nucleate Boiling Ratio (DNBR) is required to be maintained through all operational modes including transients and frequent faults
3. Maintain negative fuel and coolant temperature coefficients of reactivity – by ensuring the Reactor Core has negative power coefficients of reactivity, the core will naturally be tolerant to power increasing faults and maintain load following and self-regulating behaviours
4. Control the release of radioactive material – the Reactor Core shall maintain barriers for limiting the release of radioactive material from the fuel pellets to the primary coolant, in normal and faulted conditions

The performance requirements for the core are summarised in {REDACTED FOR PUBLICATION Table 4.1-1.

{REDACTED FOR PUBLICATION Table 4.1-1: Performance Requirements}

Safety categorised functional requirements for the fuel and core are presented in Section 4.7.2 and will be developed further as the design matures.

4.1.2 Lattice Design

The core design utilises five unique lattice designs, meaning distribution of gadolinia pins within a particular fuel assembly axial slice. These designs include an undoped lattice (no gadolinia), two lattices with 32 gadolinia pins, a single lattice with 36 gadolinia pins and one lattice with 40 gadolinia pins. The distribution of gadolinia pins within each lattice is independent of the gadolinia content within the lattice. As the core design is developed further, the potential for simplification of lattice designs will be explored.

4.1.3 Fuel Assembly Design

The following two fuel assembly designs are utilised:

1. Type AE fuel, which is more reactive with higher fuel enrichments and lower gadolinia content

2. Type AF fuel, which is less reactive with lower enrichment and higher gadolinia and is, in general, loaded towards the centre of the core to reduce radial power peaking

The fuel enrichments and gadolinia content for each design is presented in Core Design Optimisation at Iteration 5, Reference [10]. Both fuel assembly designs are mechanically identical.

4.1.4 Reload Pattern

The reload pattern for the core is shown in {REDACTED FOR PUBLICATION Figure 4.1-1} Type AE fuel is loaded towards the core periphery and Type AF is located towards the core centre.

{REDACTED FOR PUBLICATION Figure 4.1-1: Equilibrium Core Loading Pattern}

Throughout the core, 14 unique fuel pins and 13 powder blends (pellet designs) are utilised. As the design develops the potential to further simplify the fuel design by consolidating gadolinia pin locations and powder compositions and adopting fewer lattice layouts will be explored.

4.1.5 Control Rod Types

Three Control Rod [JDE] types have been utilised for the design:

1. B_4C shutdown control rods (CRD 1)

2. SINCAD control rods (CRD 2)

3. SINCAD/B_4C control rods (CRD 5)

Annular SINCAD has been used in the sections of the control rods that will experience the highest neutron fluxes to reduce swelling effects and overall weight of the Rod Control Cluster Assembly (RCCA); however, this requirement will be confirmed through engagement with the control rod vendor.

During normal operation, only the SINCAD and the non-B_4C regions of the split control rods are inserted into the active core region, to minimise helium production from Boron ^{10}B neutron capture.

4.1.6 Control Rod Operations

The location of control rods in the core is presented in {REDACTED FOR PUBLICATION Figure 4.1-2, with the number representing the control rod type as per Section 4.1.5, noting those locations marked as ‘0’ do not have control rods and can be used for in-core instrumentation. There are 32 (octant symmetric) unrodded locations in the core.

{REDACTED FOR PUBLICATION Figure 4.1-2: Control Rod Layout}

The intention of the control rods is to move in individual groups, each moved in turn with a degree of overlap to manage power peaking as the core burns up throughout the cycle, whilst controlling axial offset.

4.1.7 Performance & Safety Evaluation

For Iteration 5, a full set of performance data has been generated to support fault studies and component and shielding design, Reference [11], and compared against the performance requirements outlined in {REDACTED FOR PUBLICATION Table 4.1-1, with the following conclusions:

1. Power Peaking: both the local power peaking and pin enthalpy rise factors are below the maximum performance requirement values

2. Axial Offset: variation in Axial Offset includes a swing that is comparable to the design range, i.e., a 20% swing through cycle, noting further reductions will be explored as the design develops

3. Shutdown Margin: variation in shutdown margin with the worthiest rod 100% withdrawn and a xenon free core with a coolant (and fuel) temperature of {REDACTED FOR PUBLICATION} (i.e., the most limiting conditions) has been calculated, with sufficient design margin throughout the cycle demonstrated

The requirements presented in Section 4.1.1 have largely been achieved by the design presented at ‘Iteration 5’:

1. Uranium cut-back has been incorporated into the physics methods and the resulting core models

2. A multi-bank control rod programme has been introduced which reflects RGP in Pressurised Water Reactors (PWRs) and reduces absolute axial offset

3. The number of control rods has been significantly reduced

4. The CRDM diameter has not yet been reduced, this is identified as a design objective for the next core iteration

5. B_4C and SINCAD have been selected as control rod materials, which improve the lifting mass requirements on the CRDMs and better reflect currently available materials

6. A core octant symmetry has been introduced

4.1.8 ALARP in Design Development

Several design options or ‘variants’ have been subject to optioneering, including consideration of how each option reduces overall risks are reduced to ALARP. The down-selection of the ‘Iteration 5’ design presented in this report has been selected over other variants based on:

1. Additional fresh fuel assemblies per reload cycle (e.g., without the use of steel (grey) control rods to provide finer power shape control) and optimised reload pattern increases the

overall reactivity of the core, resulting in an increased cycle length closer to the design target.

2. Optimisation of the lattice design to better control power peaking and through cycle reactivity swing, resulting in slightly improved axial offset and power peaking factors, and maintaining suitable shutdown margins for full shutdown and shutdown with a stuck rod.

3. A control rod programme that includes deeper rod insertion into the centre of the core at the start and end of cycle, resulting in improvements to power peaking factors and optimisation of the core performance.

More detailed information on design decisions is presented in the Core Design Optimisation at Iteration 5, Reference [10].

4.2 Fuel Design

Section Placeholder – to be populated in future revisions of the E3S Case

4.3 Nuclear Design

Section Placeholder – to be populated in future revisions of the E3S Case

4.4 Thermohydraulic Design

Section Placeholder – to be populated in future revisions of the E3S Case

4.5 Design of Reactor Control, Shutdown and Monitoring Systems

Section Placeholder – to be populated in future revisions of the E3S Case

4.6 Evaluation of Reactivity Control Systems

Section Placeholder – to be populated in future revisions of the E3S Case

4.7 Core Components

4.7.1 System and Equipment Functions

The primary purpose of the Reactor System [JA] is to generate nuclear heat and transfer it to pressurised water flowing through the core, for onward heat transfer to the secondary systems so that electrical power can be generated. The core must both generate and transfer the heat in a safe, controlled manner throughout the plant lifetime.

The Reactor System [JA] comprises:

1. RPV [JAA]

2. Integrated Head Package (IHP) [JAB]

3. Reactor Core [JAC], comprising:

    a. Reactor Vessel Internals [JAC10]

    b. Fuel Assemblies [JAC20]

    c. Neutron Sources [JAC30]

The baseline configuration for the Reactor System [JA] is illustrated by Figure 4.7-1, which shows the RPV, Closure Head (CH) and Internals. The Fuel Assemblies have been omitted from the image but the void where the assemblies would be placed can be seen within the Neutron Reflector, the lower support plate, and the bottom of the Upper Support Barrel.

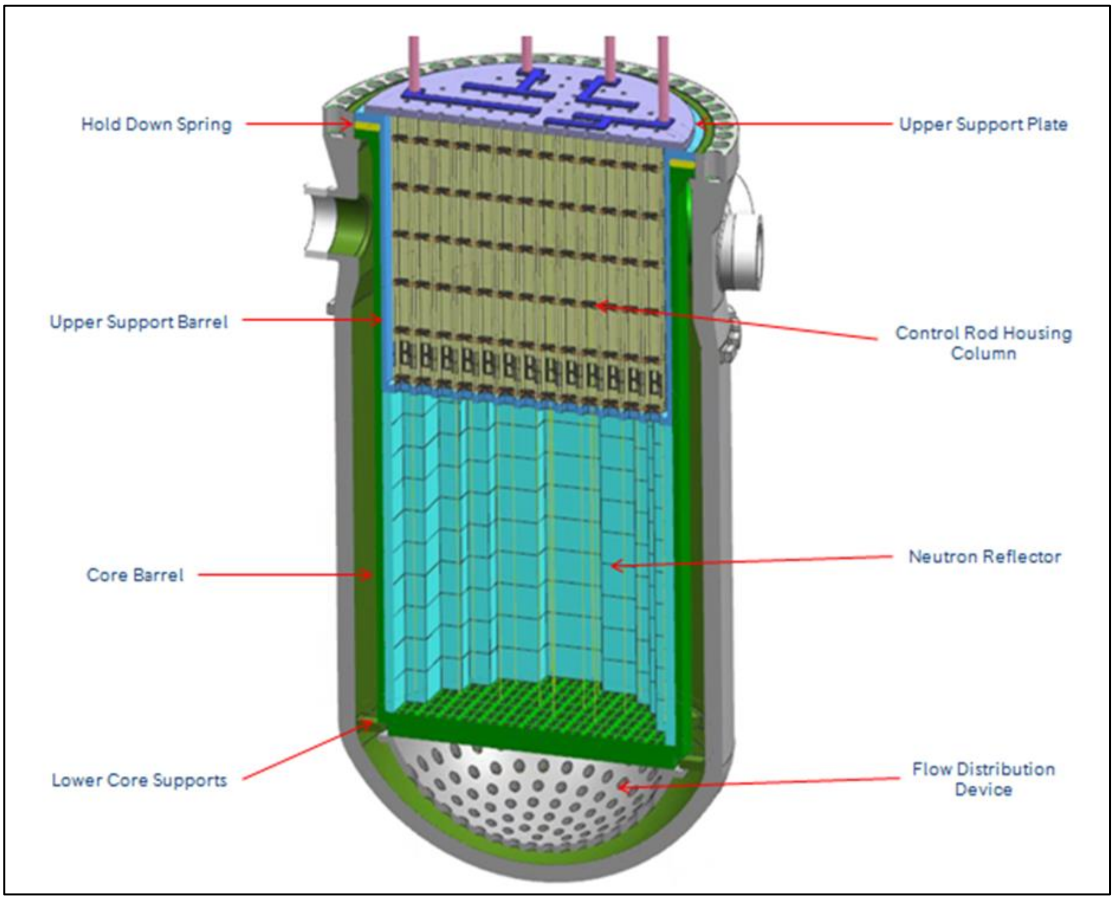

Figure 4.7-1: Reactor System [JA] Layout

The functions, requirements, and description of the RPV [JAA] & IHP [JAB] (and associated components) are presented in E3S Case Chapter 5: Reactor Coolant System & Associated Systems, Reference [2]. This section presents relevant information on the Reactor Core [JAC] and associated components.

4.7.2 Safety Design Basis

Functional Requirements

Safety categorised functional requirements are specified for the Reactor Core [JAC] based on the High-Level Safety Functions (HLSFs) they deliver, including the applicable plant states and operating modes. These are presented in Table 4.7-1.

The traceability of safety categorised functional requirements back to the HLSFs will be managed in the Dynamic Object-Oriented Requirements System (DOORS) requirements database. This traceability process is outlined in Deterministic Safety Methodology, Reference [12].

Table 4.7-1: Reactor Core [JAC] Safety Categorised Functional Requirements

DOORS ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JAC-R-1248	While in Modes 1, 2, 3, 4a, 4b, 5a, 5b, 6a, 6b or load follow operations, the Reactor Core System [JAC] shall transfer heat from the fuel to the reactor coolant	To Be Confirmed (TBC)	All	A
JAC-R-1272	The Reactor Core System shall direct coolant from the RPV inlets to the RPV outlets	TBC	All	A
JAC-R-1274	The Reactor Core System shall contain fuel	TBC	All	A
JAC-R-1275	The Reactor Core System shall control the composition and configuration of the Control Rods	TBC	All	A
JAC-R-1289	While in Mode 2, the Reactor Core System [JAC] shall shutdown on demand	TBC	2	A
JAC-R-1288	While in Modes 3, 4a, 4b, 5a, 5b, 6a and 6b, the Reactor Core System shall hold down reactivity	TBC	3, 4a, 4b, 5a, 5b, 6a and 6b	A
JAC-R-1335	The Reactor Core System shall control variable reactivity adjustments	TBC	All	A
JAC-R-1280	While in all modes of operation, the Reactor Core System [JAC] shall control the release of radiation	TBC	All	A
JAC-R-1281	While the Alternative Shutdown Function is in operation, the Reactor Core System shall mix soluble boron with the reactor coolant	Design Basis Condition (DBC) DBC-3ii	All	A

A significant number of non-functional performance requirements associated with the safety categorised functional requirements are also presented in the DOORS Reactor Core [JAC] Requirements Module. These are not repeated here.

Non-Functional System Requirements

A full set of non-functional system requirements are in development based on the E3S Principles, which will be systematically applied to each System, Structure and Component (SSC) as part of the systems engineering process. All requirements are subject to refinement and finalisation.

Safety Classification

The safety classification of the Reactor Core [JAC] is undertaken in accordance with the E3S Categorisation and Classification methodology outlined in E3S Case Chapter 3: E3S Objectives & Design Rules, Reference [13]. The components within the Reactor Core [JAC] are currently classified as followed:

1. Reactor Vessel Internals [JAC10]: Safety Class 1

2. Fuel Assemblies [JAC20]: Safety Class 1

4.7.3 Description of SSC

Reactor Vessel Internals [JAC10]

The Reactor Vessel Internals [JAC10] are a collection of structural components that are contained within the RPV [JAA] to form the main mechanical support structure for the Fuel Assemblies [JAC20], whilst also providing support to the Control Rods.

The lower section of the Reactor Vessel Internals [JAC10] holds the Fuel Assemblies [JAC20] in place. The lower internals consist of three main components:

1. The core barrel, which diverts coolant flow down the inside of the RPV [JAA] from the coolant inlets to flow distribution device. The core barrel lower support plate also interfaces mechanically with the fuel assemblies, providing radial and axial restraint

2. The flow distribution device, which diverts, straightens and distributes the coolant flow prior to entry into the inlet plenum

3. The radial neutron reflector, which helps to even the burnup of fuel at the core periphery by reflecting fast neutrons and helps to reduce radiation damage to the RPV

The upper internals take coolant from the outlet of the fuel assemblies and transfer it to the RPV [JAA] coolant outlets. The upper internals also provide support structures for the control rods and in-core instrumentation. The main components of the upper internals comprise:

1. The Upper Support Barrel which interfaces with the Fuel Assemblies [JAC20] to provide axial restraint and to impose a hold down force on the fuel assemblies

2. The Control Rod Housing Columns (CRHCs) which align and support the control rods and control rod drive shafts

The Reactor Vessel Internals [JAC10] include geometric features that ensure correct and safe alignment of these components with one another and other interfacing Reactor System [JA] components.

The upper internals are removed as a single assembly during each refuelling outage to provide necessary access to the fuel assemblies. The lower internals remain in position during refuelling outages and are only removed from the RPV [JAA] during long maintenance outages to support in-service inspections.

The RPV lower internals also contain support structures around the outer diameter of the core barrel. This will contain surveillance capsules containing material specimens to support the through-life justification of the RPV [JAA].

Key RPV Internals [JAC10] attributes are presented in Table 4.7-2.

Table 4.7-2: Key Attributes of the Reactor Vessel Internals [JAC10]

Design Detail	Value
Major Component Material	{REDACTED FOR PUBLICATION}
Core Barrel Flange Outer Diameter	{REDACTED FOR PUBLICATION}
Core Barrel Shell Outer Diameter	{REDACTED FOR PUBLICATION}
Core Barrel Shell Thickness	{REDACTED FOR PUBLICATION}
RPV Internals Height	{REDACTED FOR PUBLICATION}
Upper Internals Configuration	Support Barrel Configuration
Neutron Reflector Configuration	Heavy Reflector
Flow Distribution Device Configuration	Perforated Spherical Plate

Fuel Assemblies [JAC20]

The Fuel Assemblies [JAC20] are single components made of several sub-components that will be assembled by a fuel fabricator prior to delivery to the RR SMR site. The Reactor Core [JAC] comprises 121 fuel assemblies, all identical from a materials and geometry perspective; however, the precise distribution of fuel pellet types within the fuel assemblies will differ (see Section 4.1).

Neutron Sources [JAC30]

The Neutron Sources [JAC30] insert into the Fuel Assembly guide thimbles in a similar way to the Control Rods. The primary function of the Neutron Sources is to emit neutrons to provide a minimum core power level through sub-critical multiplication, ensuring a sufficient neutron flux is present at the ex-core detectors to monitor start-up events. After a period of powered operation, the intrinsic source of the fuel builds up, which provides a background power level and thus a measurable signal.

The requirement for and design of neutron sources is still in development and will be reported in a future revision of the E3S Case.

4.7.4 Materials

The major component forgings material for the Reactor Vessel Internals [JAC10] (core barrel, neutron reflector and flow distribution device) is SA-965M Grade F304LN stainless steel. The Fuel Assembly [JAC20] material is Uranium Dioxide (UO_2) with a maximum enrichment of 4.95%.

The description and justification of materials used for Class 1 SSCs are presented in E3S Case Chapter 23: Structural Integrity, Reference [14].

4.7.5 Interfaces with Supporting Systems

The key Reactor Core [JAC] interfaces are identified and managed within DOORS, including flow down of functional requirements, and described above.

4.7.6 SSC Operation

The Reactor Island Operating Philosophy, Reference [15], provides the overarching information on how the plant and operator maintain control of key functions across the six defined operating modes, including: the operating principles, required actions, means for transitioning between the operating modes, and relevant safety systems for each mode. This is summarised in E3S Case Chapter 13: Conduct of Operations, Reference [16].

4.7.7 Instrumentation & Control

The allocation of safety categorised functional requirements from the Reactor Core [JAC] to the Reactor Control & Instrumentation (C&I) System [JY], e.g., neutron flux or temperature sensors, is presented in the C&I Engineering Schedule, described further in E3S Case Chapter 7: Instrumentation & Control, Reference [4].

4.7.8 Monitoring, Inspection, Testing and Maintenance

An outline maintenance plan for the Reactor System [JA] is still to be developed. The ASME Boiler and Pressure Vessel Code identifies the following typical inspection activities:

1. Reactor Vessel Internals [JAC10]
    a. Instrumentation penetrations
    b. All welded connections
    c. Mechanical joints (e.g. flanged connections if utilised)
    d. Lagging integrity
    e. Test specimen collection
2. Fuel Assemblies [JAC20]
    a. Visual inspection
    b. Clad corrosion
    c. Fuel burnup
3. Control Rods [JDE]
    a. Control rod depletion

4. Instrumentation
    a. Reactor instruments calibration (temperature, neutron flux, level indication)

4.7.9 Radiological Aspects

No significant radiological aspects associated with the Reactor Core [JAC] operation have been identified during design decisions up to PCD.

4.7.10 Performance and Safety Evaluation

Compliance with Safety Categorised Functional Requirements

At PCD, verification strategies for the Reactor Core [JAC] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements are in development and stored in DOORS, including:

1. RELAP Thermal Hydraulic analysis for the core
2. Core Flow Rig Testing to validate RELAP analysis
3. Other testing led by the fuel and control rod vendor (e.g., cladding corrosion, critical heat flux, crud, fuel assembly mechanical properties and control rod drop)

Performance analysis has been conducted to support the concept design development of the core and its optimisation for 'Iteration 5', with conclusions summarised in Section 4.1.7.

Compliance with Non-Functional System Requirements

Verification activities to substantiate non-functional system requirements for the Reactor Core [JAC] are still to be determined.

4.7.11 Installation & Commissioning

An outline installation and commissioning plan for the Reactor System [JA] is still to be developed. Physics testing is expected to be a significant part of the Reactor Island commissioning strategy. The overall strategy for the RR SMR commissioning programme is presented in E3S Case Chapter 14: Plant Construction & Commissioning, Reference [17].

4.7.12 ALARP in Design Development

The design of the Reactor System [JA] has been developed in accordance with the systems engineering design process, which includes alignment to RGP and OPEX, design to codes and standards according to the safety classification, and a systematic optioneering process with down-selection of design options based on assessment against relevant safety criteria (as described in E3S Case Chapter 3: E3S Objectives & Design Rules, Reference [13]). Hazard identification studies have also been undertaken to support major design decisions.

4.8 Conclusions

4.8.1 Conclusions

Preliminary evidence is presented to support the overall chapter claim that 'The Reactor Core [JAC] is designed and substantiated to achieve functional and non-functional safety requirements through the lifecycle, and reduce risks to ALARP', which contributes to the overall E3S objective to protect people and the environment from harm, and the demonstration that risks are reduced ALARP.

At PCD, the preliminary evidence includes the fuel and core design at 'Iteration 5', including the high-level performance characteristics and optioneering conducted to develop the core design, and the design definition for the core components in the Reactor System [JA].

The full suite of evidence to underpin the claim will be developed in line with the CAE Route Map and reported in future revisions of the E3S Case, including full traceability of safety categorised requirements from the safety analysis, a complete set of non-functional system requirements from the E3S design principles, further development and optimisation of the core design to meet safety requirements, full suite of analyses for the fuel and core, and ultimately substantiation of all safety requirements.

4.8.2 Assumptions & Commitments on Future Dutyholder

None identified at this revision.

4.9 References

[1] RR SMR Report, SMR0004294/001, “E3S Case Chapter 1: Introduction,” March 2023.
[2] RR SMR Report, SMR0003984/001, “E3S Case Chapter 5: Reactor Coolant System & Associated Systems,” March 2023.
[3] RR SMR Report, SMR0003863/001, “E3S Case Chapter 9A: Auxiliary Systems,” March 2023.
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[16] RR SMR Report, SMR0004247/001, “E3S Case Chapter 13: Conduct of Operations,” March 2023.
[17] RR SMR Report, SMR0004289/001, “E3S Case Chapter 14: Plant Construction & Commissioning,” March 2023.
[18] RR SMR Report, EDNS01000961564/001, “System Outline Description for the SMR Reactor System [JA],” April 2021.

4.10 Appendix A: CAE Route Map

4.10.1 Chapter 4 Route Map

A preliminary Claims decomposition from the overall Chapter 4 Claim is summarised in Table 4.10-1, including the Tier 2 Evidence underpinning the Claims at PCD (i.e., summarised in Revision 1 of this report) and further Tier 2 Evidence still to be developed.

Table 4.10-1: CAE Route Map

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
The Reactor Core [JAC] is designed to achieve Safety Functional & Non-Functional System Requirements	Safety Functional & Non-Functional System Requirements are derived and justified based on sound safety principles and methods	-	A comprehensive set of functional requirements are derived in the safety analysis (Fault Schedule), placed on Structures, Systems & Components based on functions to be delivered during Plant States DBC-1 to DBC-5 Non-functional requirements are derived from the E3S principles and applied to the architecture of SSCs in accordance with their classification	Section 4.7.1–4.7.2	JAC-R DOORS Requirements Module	Revised DOORS Requirements Modules for [JAC]

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** **_*at PCD_**	**Underpinning Tier 2 Evidence** **_*to be developed_**
	Architecture is designed to achieve safety requirements, considering RGP & OPEX to reduce risks to ALARP	-	The preferred design solution has been developed following a structured systems engineering approach with evaluation against safety criteria supporting the decision-making process	Section 4.7.3–4.7.12	Reactor System [JA] System Outline Description, Reference [18]	Core Design Optimisation at Iteration 6 (and beyond)
				Section 4.1.2–4.1.8	Core Design Optimisation at Iteration 5, Reference [11]	
The Reactor Core [JAC] has been analysed using appropriate design methods, with appropriate acceptance criteria defined and justified with suitable margin	The Nuclear Design Basis (DBC 1, 2i, 2ii, 3i and 3ii) is clearly defined and justified	-	-	n/a	n/a	Fuel and Core Design Basis Summary
	The Thermal Hydraulics Design Basis (DBC 1, 2i, 2ii, 3i and 3ii) is clearly defined and justified	-	-			

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
	The Fuel Performance Design Basis (DBC 1, 2i, 2ii, 3i and 3ii) is clearly defined and justified	-	-			
	The Criticality Design Basis (DBC 1, 2i, 2ii, 3i and 3ii) is clearly defined and justified	-	-			
The Reactor Core [JAC] design has been substantiated to achieve its safety requirements through the lifecycle	Analysis demonstrates that all acceptance criteria defined in the design basis have been met	Analysis of the Nuclear Design demonstrates that all acceptance criteria defined in the design basis have been met	-	n/a	n/a	Fuel and Core Performance Analysis Summary

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
		Analysis of the Thermal Hydraulics Design demonstrates that all acceptance criteria defined in the design basis have been met	-			
		Analysis of the Fuel Performance demonstrates that all acceptance criteria defined in the design basis have been met	-			

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
		Analysis of Neutron Sources demonstrates that all acceptance criteria defined in the design basis have been met	-			
		Criticality analysis demonstrates that all acceptance criteria defined in the design basis have been met	-			

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
	The Reactor Core [JAC] safety requirements have been verified	-	Sound engineering judgement and methods have been used to develop verification activities to demonstrate safety requirements can be achieved	Section 4.1.7 & Section 4.7.10	Verification activities in DOORS Verification Modules	Fuel and Core Validation Summary
	Safety requirements have been verified through manufacturing, construction, installation, and commissioning	-	Processes and controls are designed to verify safety requirements during manufacturing, construction, installation, and commissioning	n/a	n/a	Installation and Commissioning Plans (TBC)

Level 1 Claims	**Level 2 Claims**	**Level 3 Claims**	**Arguments**	**Evidence Summary Sections within Chapter 4**	**Underpinning Tier 2 Evidence** ***at PCD**	**Underpinning Tier 2 Evidence** ***to be developed**
	Design can deliver its safety requirements during its operational life	-	The design identifies and facilitates Examination, Maintenance, Inspection and Testing (EMIT) activities commensurate with its safety classification to demonstrate its status, availability, and integrity in line with the design intent	n/a	n/a	EMIT Summary Report

4.11 Acronyms and Abbreviations

ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
B_4C	Boron Carbide
BS	British Standard
C&I	Control & Instrumentation
CAE	Claims, Arguments, Evidence
CH	Closure Head
CRD	Control Rod
CRDM	Control Rod Drive Mechanism
CRHC	Control Rod Housing Column
DBC	Design Basis Condition
DOORS	Dynamic Object-Oriented Requirements System
E3S	Environment, Safety, Security and Safeguards
EFPD	Effective Full Power Days
EMIT	Examination, Maintenance, Inspection and Testing
EN	European Standard adopted as a British Standard
F_q	Local Power Peaking Factor
FdH	Peak Pin Enthalpy Rise Factor
GER	Generic Environment Report
GSR	Generic Security Report
HLSF	High-Level Safety Function
HR	High Reliability
IAEA	International Atomic Energy Agency
IHP	Integrated Head Package

DNBR	Departure from Nucleate Boiling Ratio
n/a	Not Applicable
OPEX	Operating Experience
PCD	Preliminary Concept Definition
PCSR	Pre-Construction Safety Report
PWR	Pressurised Water Reactor
RCCA	Rod Control Cluster Assembly
RD	Reference Design
RGP	Relevant Good Practice
RPV	Reactor Pressure Vessel
RR SMR	Rolls-Royce Small Modular Reactor
SINCAD	Silver-Indium-Cadmium
SSC	System, Structure and Component
SSG	Safety Specific Guide
SSR	Safety Specific Requirement
TBC	To Be Confirmed
UO_2	Uranium Dioxide
VHR	Very High Reliability