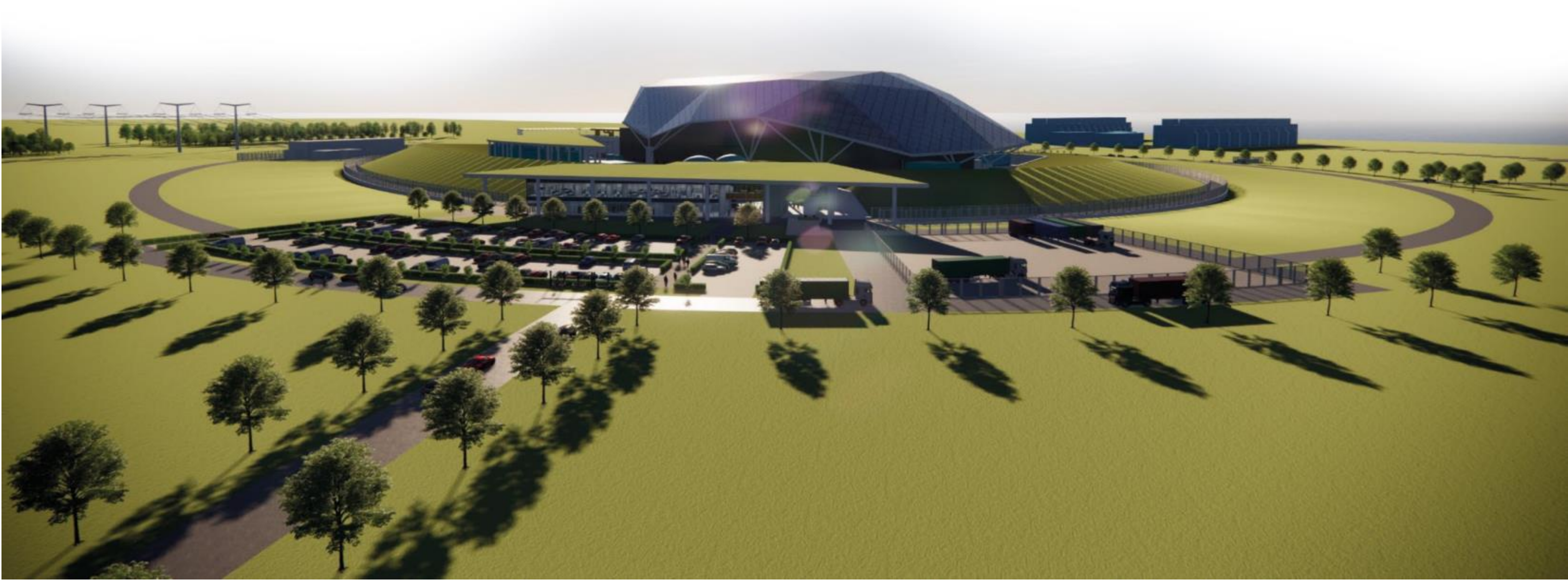
Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 5: Reactor Coolant Systems and Associated Systems



Record of Change

Date	Revision Number	Status	Reason for Change
March 2023	1	Issue	First issue of E3S Case
March 2024	2	Issue	It incorporates revisions and new design developments of the Reactor Coolant Systems and Associated Systems based on Reference Design 7, aligned to Design Reference Point 1, including additional designs details and developments on systems included in the first issue.
May 2024	3	Issue	Updated to correct revision history status at Issue 2. Chapter changes include: • Additional detail within the conclusions for how arguments and evidence presented meet the generic E3S objective Minor template/editorial updates for overall E3S Case consistency.

Executive Summary

Chapter 5 of the generic Environment, Safety, Security, and Safeguards (E3S) Case presents the reactor coolant system and associated systems of the Rolls-Royce Small Modular Reactor (RR SMR).

The chapter outlines the arguments and evidence to underpin the high-level claim that the RR SMR reactor coolant systems and associated systems are conservatively designed and verified to deliver E3S functions through-life, in accordance with the E3S design principles, to reduce risks to as low as reasonably practicable (ALARP), apply best available techniques (BAT) and ensure secure by design and safeguards by design.

The structures, systems and components (SSCs) covered include the Reactor Coolant System (RCS) [JE], Reactor Pressure Vessel (RPV) [JAA], Reactor Coolant Pump System [JEB], Steam Generation System [JEA], Reactor Coolant Pipework System [JEC], Reactor Coolant Pressurising System [JEF], Reactor Coolant Pressure Relief System [JEG], Chemistry and Volume Control System (CVCS) [KB], and Cold Shutdown Cooling System (CSCS) [JNA].

The fundamental safety functions (FSFs) to be delivered by each SSC are presented, with the assignment of safety categorised functional requirements to achieve them. Non-functional system requirements derived from the E3S design principles are also presented. The design definition presented for each system is developed based on relevant good practice (RGP) and operating experience (OPEX). It is developed and evaluated in accordance with the E3S design principles through the integrated E3S and engineering processes, including design to codes and standards according to the safety classification, down-selection of options in accordance with criteria to ensure risks are reduced to ALARP, apply BAT, and are secure by design and safeguards by design, and confirmatory performance analysis. This provides confidence that claims can be met when the full suite of arguments and evidence is developed. No functional requirements for environment, security and safeguards are identified the SSCs within the scope of the chapter.

Version 2 of the generic E3S Case is developed in support of reference design 7 (RD7) design, corresponding to design reference point 1 (DRP1) for the generic design assessment (GDA). Further arguments and evidence are to be developed to underpin the top-level claim, including continued iterative E3S analysis and finalisation of E3S requirements, detailed design development of all SSCs, and verification and validation of E3S requirements.

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5.0 Introduction

5.0.1 Introduction

Chapter 5 of the Rolls-Royce Small Modular Reactor (RR SMR) generic Environment, Safety, Security and Safeguards (E3S) Case presents the overarching summary and entry point to the design and E3S information for the reactor coolant system and associated systems of the RR SMR.

5.0.2 Scope and Maturity

The list of structures, systems, and components (SSCs) that are included in the scope of this chapter is provided in Appendix B (section 5.17).

The scope of this chapter covers the design definition for each SSC, including allocation of E3S requirements and E3S categorisation and classification, design description, and verification and validation (V&V) activities. It covers the mechanical design aspects, however the selection of materials and justification of the integrity of SSCs is covered in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

All E3S requirements that are assigned to SSCs within this chapter follow the methods described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2]. Safety categorised functional requirements are aligned to delivery of the fundamental safety functions (FSFs) of control of fuel temperature (CoFT), control of reactivity (CoR), confinement of radioactive material (CoRM) and control of radiation exposure (CoRE), which are decomposed into high-level safety functions (HLSFs) in the fault schedule and flow to SSCs; the demonstration that HLSFs can be achieved for bounding fault sequences is presented in detail in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [3].

Version 2 of the generic E3S Case is based on reference design 7 (RD7), corresponding to design reference point 1 (DRP1) for the generic design assessment (GDA). At RD7, the safety functions to be delivered by each SSC are presented, with the assignment of safety categorised functional requirements to achieve them. No functional requirements for environment, security and safeguards are identified for SSCs in the scope of chapter 5 at RD7, noting SSCs are designed in accordance with E3S and engineering processes that include development against principles for environment, security, and safeguards. The design definition presented is based on the design maturity of each respective SSC at RD7. Validation and verification activities for SSCs are presented and will be developed and undertaken through detailed design.

5.0.3 Claims, Arguments, Evidence Route Map

The overall approach to claims, arguments, evidence (CAE) and the set of fundamental E3S claims to achieve the E3S fundamental objective are described in E3S Case Version 2, Tier 1, Chapter 1: Introduction [4]. The associated chapter level claim for E3S Case Version 2, Tier 1, Chapter 5: Reactor Coolant Systems and Associated Systems is:

Claim 5: The Reactor Coolant System and Associated Systems are conservatively designed and verified to deliver E3S functions through-life, in accordance with the E3S design principles, to reduce risks to ALARP, apply BAT and in line with secure by design and safeguards by design

A decomposition of this claim into sub-claims and mapping to the relevant Tier 2 and Tier 3 information containing the detailed arguments and evidence, is presented in the E3S Case Route Map [5]. Given the evolving nature of the E3S Case alongside the design, the underpinning arguments and evidence may still be developed in at detailed design; the trajectory of this information, where possible, is also illustrated in the route map.

A proportionate summary of the arguments and evidence from lower tier information, available at the current design stage, is presented within this chapter. A mapping of the claims to the corresponding sections that summarise the arguments and/or evidence is provided in Appendix A (section 5.16).

5.0.4 Applicable Regulations, Codes and Standards

The SSCs summarised in this chapter are designed in accordance with the E3S design principles [6], which are developed based on United Kingdom (UK) and international regulations, guidance, and practices, as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2].

The mechanical systems and components summarised in this chapter are designed in accordance with their safety classification. Relevant codes and standards are identified in Table 5.0-1.

Table 5.0-1: Mechanical Design Codes and Standards

Safety Classification	Design Basis Code
VHR	American Society of Mechanical Engineers (ASME) III (Sub-section NB) and beyond code requirements
HR	ASME III (Sub-section NB) and beyond code requirements
Class 1	ASME III
Class 2	ASME III
Class 3	ASME III or Commercial standards, for example ASME VIII, British Standard BS EN 13445
n/a	Commercial standards, for example ASME VIII, BS EN 13455

5.1 Summary Description

The reactor coolant and associated systems for the RR SMR summarised within this chapter include:

- Reactor Coolant System (RCS) [JE]: an overall summary of system is described in section 5.3
- Reactor Pressure Vessel (RPV) [JAA]: described in section 5.4
- Reactor Coolant Pump System [JEB]: described in section 5.5
- Steam Generation System [JEA]: described in section 5.6
- Reactor Coolant Pipework System [JEC]: described in section 5.7
- Reactor Coolant Pressurising System [JEF]: described in section 5.8
- Reactor Coolant Pressure Relief System [JEG]: described in section 5.11
- Chemistry and Volume Control System (CVCS) [KB]: described in section 5.13.1
- Cold Shutdown Cooling System (CSCS) [JNA]: described in section 5.13.2.

5.2 Materials

Materials selected for the reactor coolant system and associated systems are described within individual sections of this chapter. The justification for structural integrity is presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.3 Reactor Coolant System and Reactor Coolant Pressure Boundary

5.3.1 System and Equipment Functions

The primary function of the RCS [JE] is to utilise heated coolant from the Reactor System [JA] to generate steam, which can be transferred to the Steam System [LB] to facilitate the generation of electricity during normal operation.

The RCS [JE] is comprised of the following subsystems and supporting functions:

- Steam Generation System [JEA]; provides the function of transferring heat from reactor coolant to secondary coolant to generate steam which is delivered to the Turbine Island [T01] via the Main Steam System [LBA]

- Reactor Coolant Pump System [JEB]; provides the function of generating coolant flow to support heat transfer for both the Steam Generation System [JEA] and the Reactor System [JA]

- Reactor Coolant Pipework System [JEC]; comprised of three trains, each consisting of a hot leg that transfers coolant from the Reactor System [JA] to the Steam Generation System [JEA], and a cold leg that returns coolant to the Reactor System [JA] via the Reactor Coolant Pump System [JEB]

- Reactor Pressurising System [JEF]; provides pressure control for the Reactor Coolant System [JE] and the Reactor System [JA] and limits pressure changes during normal duty and faulted operation

- Reactor Pressure Relief System [JEG]; provides overpressure protection to the Reactor Coolant Pressure Boundary.

The system contributes to the achievement of FSFs of CoR, CoFT, and CoRM during normal operation, and supports the FSFs delivered by the Reactor Reactivity Control Systems [JD] and Reactor Heat Removal Systems [JN] during fault conditions (DBC-2ii, DBC-3i, DBC-3ii and DBC-4). Further details are presented in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2] and Chapter 6: Engineered Safety Features [7].

5.3.2 Design Basis

5.3.2.1 Functional Requirements

Safety categorised functional requirements specified for the RCS [JE] based on the HLSFs they deliver are presented in are presented in Table 5.3-1 based on [8].

Table 5.3-1: RCS [JE] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Mode(s) of Operation	Safety Category
JE-R-1911	The Reactor Coolant System [JE] shall contain and confine Reactor Coolant at the system's specified design pressure and temperature	All	A
JE-R-1863	The Reactor Coolant System [JE] shall contain and confine Secondary Coolant at the system's specified design pressure and temperature	All	A
JE-R-1780	While in Modes 1 or 2, the Reactor Coolant System [JE] shall circulate reactor coolant	1, 2	C
JE-R-1785	While in Modes 1 or 2, the Reactor Coolant System [JE] shall generate steam	1, 2	C
JE-R-1793	While in Modes 1, 2, 3, 4a, 4b or 5a, the Reactor Coolant System [JE] shall control coolant pressure	1 to 5a	C
JE-R-1879	While in Modes 1, 2, 3, 4a, 4b or 5a, the Reactor Coolant System [JE] shall protect against overpressure in the RCS [JE] and the Reactor System [JA]	1 to 5a	A
JE-R-1410	While the Condenser Decay Heat Removal (DHR) function is in operation, the Reactor Coolant System [JE] shall transfer heated coolant from the Reactor System [JA] for Steam Generation	All	C
JE-R-1413	While the Passive Decay Heat Removal Safety Measure (PDHR) [JN02] function is in operation, the RCS [JE] shall transfer heated coolant from the Reactor System [JA] for the generation of steam	All	B
JE-R-1417	While the PDHR [JN02] Safety Measure is in operation, the Reactor Coolant System [JE] shall generate heated steam.	All	B
JE-R-1410	While the plant is in a normal state, while in High Temperature Heat Removal (HTHR) V1 (Condenser Decay Heat Removal (CHDR) duty), the Reactor Coolant System [JE] SHALL transfer heat from the Reactor System [JA] to the Steam system [LB] to reduce the temperature and pressure of the Primary Circuit.	All	C
JE-R-1891	While the plant is in a faulted state, while in HTHR V2 (CDHR faulted), the Reactor Coolant System [JE] SHALL transfer heat from the Reactor System [JA] to the Steam system [LB] to reduce the temperature and pressure of the Primary Circuit.	All	C

Requirement ID	Functional Requirement	Mode(s) of Operation	Safety Category
JE-R-1893	While the turbine has tripped, while in HTHR V4 (ASD / CHR Full Load Rejection) the Reactor Coolant System [JE] SHALL transfer heat from the Reactor System [JA] to the Steam system [LB] to maintain the temperature and pressure of the Primary Circuit.	All	C
JE-R-1423	While in All modes of operation, the Reactor Coolant System [JE] shall generate sufficient flow to prevent fuel failure prior to reactor shutdown.	All	A
JE-R-1962	While in All modes of operation, the Reactor Coolant System [JE] shall generate sufficient flow to prevent fuel failure prior to reactor shutdown.	All	B

The safety categorised functional requirements for the RCS [JE] are flowed down and allocated to relevant sub-systems and/or components in [9]. Non-functional performance requirements associated with the safety categorised functional requirements are allocated in [8].

No environment, security or safeguards functional requirements are assigned at RD7/DRP1.

5.3.2.2 Non-Functional System Requirements

Non-functional system requirements are allocated to the RCS [JE] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], summarised in Table 5.3-2.

Table 5.3-2: RCS [JE] Non-Functional System Requirements

Requirement ID	Non-Functional System Requirement
JE-R-1918	Where the design baseline for redundancy requires redundancy in capacity through increased number of trains, the designer shall ensure the trains are sufficiently diverse, so as to not undermine the redundant capacity upon failure of operating train.
JE-R-1837	SMR systems that contain radioactive material shall be designed to prevent spread of that radioactive material beyond their boundary.
JE-R-2075	SMR systems shall not contain more nuclear inventory than is required to fulfil their requirements.
JE-R-2078	Fluid systems that contain radioactive material shall not feature dead legs or crud traps.

5.3.2.3 E3S Classification

Safety Classification

The safety classification of the RCS [JE] is undertaken in accordance with the methodology outlined in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules [2]. The safety class for each RCS [JE] component is presented in

Table 5.3-3, with further justification provided in [10].

Table 5.3-3: Safety Classification of Key RCS [JE] Components

Component	Subcomponent	Safety Class
Steam Generator	Primary Pressure Retaining Components	1 (VHR) (shell, tubesheet) 1 (tubes)
	Secondary Pressure Retaining Components	1 (VHR)
	Miscellaneous internals (e.g. tube supports)	1
Reactor Coolant Pump	Pump Hydraulic Casing	1 (VHR)
	Other pressure retaining components	1
	Flywheel	2
Reactor Coolant Pipework System	Large Bore Pipework	1
	Small Bore Pipework or pipework protected by a flow restricting orifice	2
Pressuriser	Pressuriser Vessel	1 (VHR)
Pressure Relief	Pressure Relief Valves	1

Environment, Security and Safeguards Classification

No environment, security, or safeguards classification is assigned at RD7/DRP1.

Seismic Performance Classification

No seismic performance classification is assigned at RD7/DRP1.

5.3.3 Description

The baseline architecture for the RCS [JE] consists of three vertical u-tube Steam Generators (SGs) with associated pipework loops and a single Reactor Coolant Pump (RCP) [JEB] in each loop, mounted to the SG outlet. The configuration of the SG, pipework and pump layout in each loop ensures a robust thermal driving head for natural circulation (NC) flow during fault conditions. The system also contains a pump induced spray pressurising system with associated pressure relief system.

The key design and performance parameters summarised in Table 5.3-4. A simplified schematic of the RCS [JE] is presented in Figure 5.3-1.

Table 5.3-4: Key Design and Performance Parameters for RCS [JE] at 100 % of Full Power

Parameter	Value	Units
Core Thermal Duty (total)	1358.0	MW_{th}
RCP Thermal Duty (per pump (3 off))	{REDACTED}	MW_{th}
Total Thermal Duty (including thermal losses)	{REDACTED}	MW_{th}
Primary		
Mass Flow Rate (total)	Thermal-Hydraulic flow (TH): {REDACTED} Best Estimate flow (BE): {REDACTED} Mechanical flow (ME): {REDACTED}	kg/s
Mass Flow Rate (per loop)	TH: {REDACTED} BE: {REDACTED} ME: {REDACTED}	kg/s
Reactor Pressure Vessel (RPV) Inlet Temperature (RCP Outlet Temperature)	TH: {REDACTED} BE: {REDACTED} ME: {REDACTED}	°C
RPV Outlet Temperature (SG Inlet Temperature)	TH: {REDACTED} BE: {REDACTED} ME: {REDACTED}	°C
Average Temperature	TH: {REDACTED} BE: {REDACTED} ME: {REDACTED}	°C
Core Outlet Temperature	TH: {REDACTED} BE: {REDACTED} ME: {REDACTED}	°C
Primary Operating Pressure	{REDACTED}	MPa(a)
Primary Design Pressure	{REDACTED}	MPa(a)
Primary Design Temperature	{REDACTED}	°C
Secondary (at the Thermal-Hydraulic design point)		
Steam Outlet Mass Flow Rate (total) (BoL)	{REDACTED}	kg/s

Parameter	Value	Units
Steam Outlet Mass Flow Rate (total) (EoL)	{REDACTED}	kg/s
Steam Outlet Pressure (BoL)	{REDACTED}	MPa(a)
Steam Outlet Pressure (EoL)	{REDACTED}	MPa(a)
Feedwater Mass Flow Rate (total) (BoL)	{REDACTED}	kg/s
Feedwater Mass Flow Rate (total) (EoL)	{REDACTED}	kg/s
Feedwater Temperature	{REDACTED}	°C
Secondary Design Pressure	{REDACTED}	MPa(a)
Secondary Design Temperature	{REDACTED}	°C

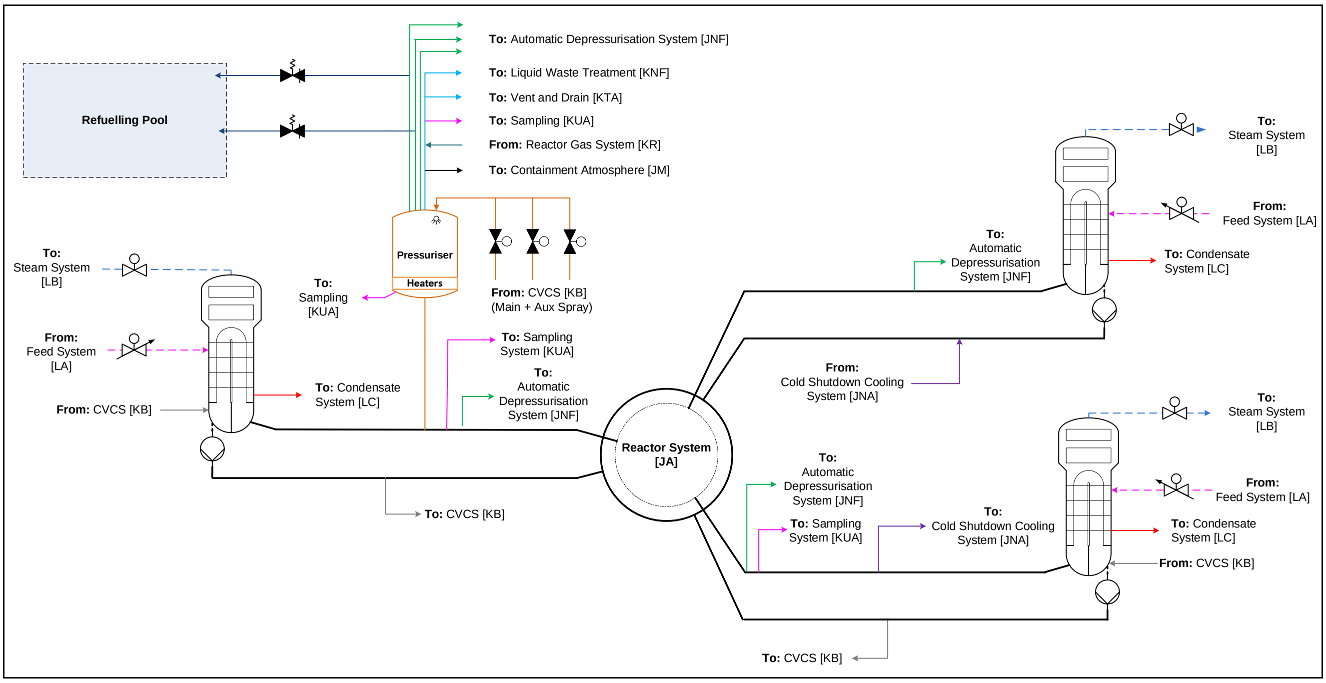

Figure 5.3-1: Simplified Schematic of the RCS [JE]

The developing layout of SSC supporting the RCS [JE] operation is summarised in [11]. The RCS [JE] is located within the hazard shield and on the aseismic bearing to provide protection against external hazards. Furthermore, each SG is elevated above the Reactor System [JA] to ensure that a sufficient thermal driving head is available for NC flow for plant protection in fault conditions.

Further description of the RCS [JE] is provided in the RCS System Design Description (SDD) [10]. Sub-systems and components of the RCS [JE] are also described in more detail in subsequent sections of this chapter.

5.3.4 Materials

The description of materials used for the RCS [JE] components are described in [10], with justification of structural integrity presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.3.5 Interfaces with Supporting Systems

The RCS [JE] is controlled by the Control and Instrumentation (C&I) system, specifically the Reactor Control and Protection System [JY], see section 5.3.7.

The RCS [JE] components requiring power are connected to the electrical power systems described in E3S Case Version 2, Tier 1, Chapter 8: Electrical Power System [12].

5.3.6 System Operation

Normal Operation

The Reactor Island Operating Philosophy [13] 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 Version 2, Tier 1, Chapter 13: Conduct of Operations [14].

During operating mode 1 (power operation), the RCS [JE] will transfer heated coolant from the Reactor System [JA] to the Steam Generating System [JEA], to facilitate the generation of steam. The Reactor Coolant Pump System [JEB] is used to return coolant to the Reactor System [JA] via the Reactor Coolant Pipework System [JEC] at a flow rate that remains constant during power operation.

During operating mode 2 (low power), for cooldown the turbine is tripped and thermal power is gradually decreased while continuing to control reactivity, until the reactor power is zero. During warm-up, following pre-critical checks and warming of the steam lines (mode 3), the secondary steam pressure and temperature is gradually increased by withdrawing control rods until the 'power range' is reached.

During operating mode 3 (hot standby), for warm-up coolant is heated to normal operating temperature. The Main Steam Isolation Valve (MSIV) bypass valves are opened to allow warming of the steam lines to prevent thermal shock prior to opening of the MSIVs.

During operating mode 4a (hot shutdown – steaming), for cooldown decay heat is removed from the Reactor System [JA] via the SGs whilst utilising HTHR [JN03]. As temperature is reduced, reactor coolant will contract causing a net reduction in pressuriser level. Pressure reduction is achieved through switching off the pressuriser heaters and inducing spray where necessary. For warm-up, the reactor coolant temperature is increased using the RCPs. Pressuriser heaters are switched on to raise the temperature of pressuriser contents, the level is slowly reduced via continued discharge through the CVCS [KB] allowing a steam bubble to form, following which cooling is aligned to SGs from the CSCS [JNA].

During operating mode 4b (hot shutdown – non-steaming), once the plant has been cooled to ~120 °C, the CSCS [JNA] is aligned as the duty heat sink to continue plant cooldown.

During operating mode 5a (cold shutdown – pressurised), for cooldown spray is continued into the pressuriser head whilst the CVCS [KB] provides make-up to fill the pressuriser and collapses the steam bubble further reducing pressure. For warm-up, the vent lines at the top of the pressuriser will be isolated and pressure will be increased by running the CVCS [KB] charging pumps to increase system pressure. The RCPs are switched on to provide additional heat input to the reactor coolant.

During operating mode 5b (cold shutdown – depressurised), for cooldown the RCS [JE] is vented via the Pressurising System [JEF] vent line to Containment [JMA] to facilitate drain down of the coolant. The coolant is drained to the required level via the interfaces with Coolant Purification System [KBE]. For a refuelling outage, the RPV closure head will also be drained via the CVCS [KB] let-down line, with atmospheric venting carried out by a dedicated RPV head venting subsystem in the Reactor System [JA]. Following confirmation that the pressuriser and RPV level are at the desired level the vent lines will be isolated. For warm-up, following core load the water level will be reduced via discharge from the refuelling cavity until the head can be replaced and the RCS [JE] refilled. All vent lines are isolated, and the top of the pressuriser and RPV head is connected to the Liquid Waste Treatment System [KNF], which draws a vacuum in the system to minimise the quantity of any trapped non-condensable gases. The CVCS [KB] make-up function is used to fill the plant until water solid.

During operating mode 6a (refuelling with reduced water level above fuel) and 6b (refuelling with reduced water level above fuel at nominal full), the RCS [JE] is drained in preparation for removal of the Reactor System [JA] Integrated Head Package (IHP).

Further details and the component configuration for all RCS [JE] normal operating modes are listed in [10].

5.3.6.1 Operation during Faults

The safety categorised functional requirements placed on the RCS [JE] during operation of Scram [JD01] or the ASF [JD02] to provide sufficient flow for controlled plant shutdown is facilitated through the provision of a flywheel within each RCP.

The safety categorised functional requirements placed on the RCS [JE] during operation of Passive Decay Heat Removal Safety Measure (PDHR) [JN02] rely on the thermal driving head provided by the RCS layout arrangement (with SGs elevated above the core) to provide heat removal by natural circulation between the Reactor System [JA] and the Steam Generation System [JEA]. Pressure and inventory control is achieved through injection via CVCS [KB] make-up pumps (when available) or High-Pressure Injection System (HPIS) [JND] pumps (or Low Pressure Injection System (LPIS) [JNG] accumulators for Station Blackout faults).

Specific operational responses to fault conditions are described in [10].

5.3.7 Instrumentation and Control

The RCS [JE] allocates functions onto the Reactor Control and Protection System [JY], which will monitor a range of key systems parameters and provide indication of these to the operator in the main control room (MCR) and in the emergency control centre.

It will also provide alarms to indicate that key system parameters are outside of the defined performance bands and/or safety limits. The control logic and envisaged requirements for monitoring, indication, alarms, and warnings are specified in the RCS SDD [10].

The Reactor Control and Protection System [JY] and allocation of safety categorised functional requirements from the RCS [JE] is presented in the C&I Engineering Schedule is described further in E3S Case Version 2, Tier 1, Chapter 7: Instrumentation and Control [15].

5.3.8 Monitoring, Inspection, Testing and Maintenance

The Examination, Maintenance, Inspection and Testing (EMIT) activities for the RCS [JE] are defined as through-life activities (TLA) within the RR SMR requirements management database, and cover safety derived tasks (in-service inspection (ISI)), reliability derived tasks (reliability centred maintenance (RCM)/preventative maintenance), and industry best practice/operational experience (OPEX) (Electrical Power Research Institute (EPRI) Preventative Maintenance Basis Database (PMBD)).

5.3.9 Radiological Aspects

The RCS [JE] is located within containment and is an access-controlled area, access is prohibited whilst the reactor is critical. The layout design of the RR SMR means there are systems/components that are near the reactor core, resulting in higher radiation dose rates and potential for increased operator exposure during EMIT activities.

Layout development is ongoing to include reduction of operator exposures (alongside other factors such as internal hazards), and the design excludes the use of high activation materials. Shielding assessments and provisions for containment are reported in E3S Case Version 2, Tier 1, Chapter 12: Radiation Protection [16]. The distance between the SGs and the core has been increased from previous reference design baselines to significantly reduce the risk of radiation embrittlement of components.

5.3.10 Performance and Safety Evaluation

5.3.10.1 Compliance with Safety Categorised Functional Requirements

Verification strategies are in development for the RCS [JE] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements, including RELAP thermal hydraulic performance analysis using RELAP5-3D and GOTHIC codes, structural integrity assessments, and rig tests.

At RD7/DRP1, performance analysis is used to develop the key system performance requirements for the RCS [JE], with the suite of performance analysis for bounding fault conditions that place safety categorised functional requirements on the RCS [JE] presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [3].

5.3.10.2 Compliance with Non-Functional System Requirements

A summary of the compliance for non-functional system requirements allocated to the RCS [JE] are summarised in Table 5.3-5. Further details are provided in [8] and [10].

Table 5.3-5: RCS [JE] Non-Functional System Requirements Compliance

Requirement ID	Non-Functional System Requirement	Summary of Compliance
JE-R-1918	Where the design baseline for redundancy requires redundancy in capacity through increased number of trains, the designer shall ensure the trains are sufficiently diverse, so as to not undermine the redundant capacity upon failure of operating train.	Compliant to redundancy requirements.
JE-R-1837	SMR systems that contain radioactive material shall be designed to prevent spread of that radioactive material beyond their boundary.	RCS [JE] design is informed by E3S design principles, performance analysis to confirm achievement of CoRM FSF
JE-R-2075	SMR systems shall not contain more nuclear inventory than is required to fulfil their requirements.	RCS [JE] is subject to chemistry sampling and monitoring through the Reactor Plant Sampling Systems [KU], which will detect any fuel failure and the presence of radioactive material within the RCS [JE] above specified limits.
JE-R-2078	Fluid systems that contain radioactive material shall not feature dead legs or crud traps.	No dead legs or traps are specified within the design.

5.3.10.3 ALARP, BAT, Secure by Design and Safeguards by Design

Key RCS [JE] design decisions made with respect to ensuring overall risks are reduced to ALARP, BAT, secure by design and safeguards by design include:

- Performance analysis has informed the design development of the RCP [JEB], resulting in the inclusion of a flywheel to provide an elongated coast-down following a loss of primary flow fault, which ensures sufficient cooling flow is maintained through the reactor to maintain the core within specified limits whilst providing time for safe shutdown by reactivity control systems.

- A pump induced (RCP) spray system design, with connections from two of the cold legs converging into a spray nozzle, has been selected for the pressuriser (described further in Section 5.8). Optioneering against other mechanisms (such as surge induced spray) concluded that the pump induced spray represents RGP in comparison with other pressurised water reactor (PWR) designs, it provides a passive response with no reliance on moving parts such as non-return valves, and performance giving increased margins to core saturation acceptance criteria.

5.4 Reactor Vessel

5.4.1 System and Equipment Functions

The primary function of the RPV [JAA] is to provide a pressure boundary for the primary coolant within the Reactor System [JA] (described within E3S Case Version 2, Tier 1, Chapter 4: Reactor (Fuel and Core) [17]), along with facilitating coolant flow and supporting the reactor core and RPV internal components.

The system contributes to the achievement of FSFs of CoR, CoFT and CoRM during normal operation and fault conditions.

5.4.2 Design Basis

5.4.2.1 Functional Requirements

Safety categorised functional requirements are specified for the RPV [JAA] flowed down from the Reactor System [JA], presented in Table 5.4-1 based on [18].

Table 5.4-1: RPV [JAA] Safety Categorised Functional Requirements

Requirement ID	Functional Requirements	Plant State(s)	Mode(s) of Operation	Safety Category
PT108-R-1316	The RPV [JAA] shall direct coolant through the Reactor Assembly from the Reactor Coolant System	DBC-1 DBC-2 DBC-3 DBC-4	All	A
PT108-R-1324	The RPV Body shall facilitate direct coolant injection from Engineered Safety Systems to the RPV Internals	DBC-3 DBC-4	All	A
PT108-R-1331	The RPV shall retain the PRV Internals in their specified position	DBC-3 DBC-4	All	A
PT108-R-1352	The RPV Body shall contain and confine coolant	DBC-1 DBC-2 DBC-3 DBC-4	All	A
PT108-R-1762	During a core melt event, the RPV Body shall maintain structural integrity	DEC-B	All	A
PT108-R-2029	During a core melt event, the RPV Body shall transfer heat from the corium to coolant.	DEC-B	All	A

Non-functional performance requirements associated with safety categorised functional requirements are allocated in [18].

No environment, security or safeguards functional requirements are assigned at RD7/DRP1.

5.4.2.2 Non-Functional System Requirements

Non-functional system requirements are allocated to the RPV [JAA] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [18].

5.4.2.3 E3S Classification

Safety Classification

The safety classification of the RPV [JAA] is undertaken in accordance with the methodology outlined in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules [2].

Gross failure of the RPV is postulated to be a highly energetic event which renders all levels of defence in depth failed including protection and mitigation safety systems; the core would melt, and radioactive material would be released to the environment. Therefore, the RPV [JAA] is nominally designed to be, and subsequently classified as, a VHR component.

Some components of the RPV are assigned a HR or Class 1 safety classification, as failure of these individual regions is not postulated to result in gross failure of the RPV and levels of protection and mitigation remain functional. The full breakdown of components classification is provided in the RPV Component Substantiation Report (CSR) [19].

Environment, Security and Safeguards Classification

No environment, security, or safeguards classification is assigned at RD7/DRP1.

Seismic Performance Classification

The seismic classification will principally be SPC1 in accordance with E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2].

5.4.3 Description

The RPV body [JAA] consists of three major vessel forgings:

- The upper shell which contains the reactor coolant loop (RCL) nozzles and Emergency Core Cooling (ECC) [JN01] direct vessel injection (DVI) nozzles; and interfaces with the RPV closure head (CH) and RPV internals supports, and leak paths for the seals between CH and RPV [JAA]
- The lower shell consisting of a single piece ring forging with no longitudinal welds, no penetrations/nozzles and uniform thickness across its length
- The lower head consisting of a single piece torispherical forging providing a converging profile with the RPV internal flow distribution device (FDD)

The RPV body interfaces with the RPV CH, which supports the Control Rod Drive Mechanisms (CRDMs) and In-Core-Instrumentation (ICI) amongst other functions. The CH seats on a sealing face on the RPV body with two off seal rings encapsulated in the CH seal grooves.

A total of 89 CRDMs are mounted vertically to the top of the RPV CH to adaptor tubes that penetrate the CH. A drive rod extends through these adaptor tubes to connect each CRDM to its corresponding control rod located in the reactor core. The CRDMs are enclosed within the Integrated Head Package which provides structural support, cooling and cabling to the CRDMs, with the IHP structure mounted on top of the CH.

The RPV body interfaces with the RPV internals, which are split into two main regions, the upper and lower internals. The lower internals include the neutron reflector, the core barrel, and the FDD. The upper internals include the upper support structures and the Control Rod Housing Columns (CRHCs).

The RPV body contains two leak detection lines which join to the plant drainage systems and provide a means of capturing and confining any leakage from the closure assembly seals between the RPV body and CH. It also has three penetrations to allow for the addition of soluble boron via the ASF [JN02].

Key RPV [JAA] attributes are presented in Table 5.4-2 and a diagram is presented in Figure 5.4-1.

Table 5.4-2: Key Attributes of the RPV [JAA]

Parameter	**Value**
Flange Diameter	4.20 m
Overall RPV Body Length	8.00 m
CH Height	1.20 m
RCS Nozzle Diameter	{REDACTED}

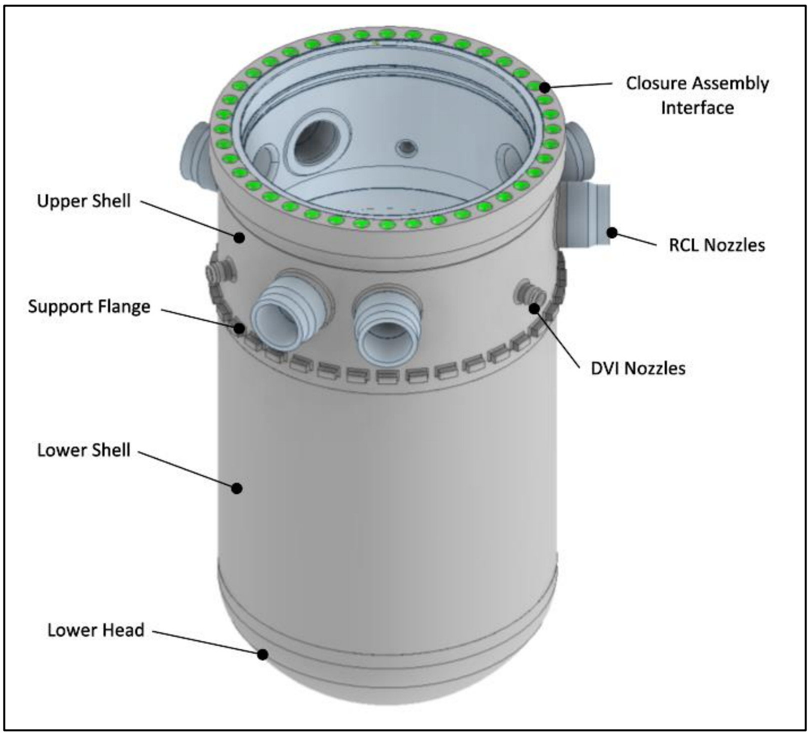

Figure 5.4-1: Diagram of the RPV [JAA]

Further details of the RPV components are described within the Reactor System SDD [20] and RPV CSR [19].

5.4.4 Materials

The RPV [JAA] forgings are made from SA508 Grade 3 Class 1 material with an enhanced chemistry specification to improve mechanical properties, weldability, and resistance to degradation mechanisms such as irradiation embrittlement. The RPV [JAA] safe ends are made from 316LN to match the RCL pipework material.

To provide corrosion protection, the internal wetted surfaces of the RPV are all covered with an austenitic stainless steel weld overlay. Nominally the cladding material includes a base layer of the higher alloyed 309L with subsequent layers being 308L.

The justification of structural integrity for VHR SSCs is presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.4.5 Interfaces with Supporting Systems

As described in section 5.4.3.

5.4.6 Performance and Safety Evaluation

Verification strategies for the RPV [JAA] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements primarily include computational fluid dynamics (CFD) and thermal hydraulic analyses, and core flow rig testing to validate analysis.

Performance analysis at RD7/DRP1 demonstrates that the RPV [JAA] flow performance requirements can be achieved.

Functional requirements to contain and confine coolant an maintain integrity during core melt are related directly to the structural integrity of the RPV pressure boundary. The structural integrity claims for VHR SSCs are described in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

At RD7/DRP1 no major shortfalls in the design and substantiation of the RPV [JAA] have been identified, providing confidence that the RPV [JAA] can reduce risks to ALARP as further evidence is developed. Full details of the verification activities at RD7/DRP1 for all E3S requirements assigned to the RPV [JAA] are presented in the RPV CSR [19].

5.5 Reactor Coolant Pumps

5.5.1 System and Equipment Functions

The primary function of the Reactor Coolant Pump System [JEB] is to generate coolant flow to support heat transfer for both the Steam Generation System [JEA] and the Reactor System [JA]. The system contributes to the achievement of FSFs of CoFT and CoRM.

5.5.2 Design Basis

5.5.2.1 Functional Requirements

Safety categorised functional requirements are specified for the Reactor Coolant Pump System [JEB] flowed down from the RCS [JE] and the HLSFs they deliver, presented in Table 5.5-1 based on [21].

Table 5.5-1: Reactor Coolant Pump System [JEB] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEB-R-1286	The Reactor Coolant Pump System [JEB] shall contain and confine reactor coolant	DBC-1 DBC-2 DBC-3 DBC-4	All	A
JEB-R-1251	While in Powered and Shutdown Operation, the Reactor Coolant Pump System [JEB] shall provide motive force for the flow of reactor coolant	DBC-1 DBC-2	1 to 5a	C
JEB-R-1259	While in Condenser DHR, Alternative Shutdown or SCRAM, and when de-energised, the Reactor Coolant Pump System [JEB] shall coast down safely	DBC-1 DBC-2 DBC-3 DBC-4	1 to 5a	A
JEB-R-1261	The Reactor Coolant Pump System [JEB] shall transfer heat to the reactor coolant during startup	DBC-1	2	C

Non-functional performance requirements associated with safety categorised functional requirements are allocated in [21].

No environment, security or safeguards functional requirements are assigned at RD7/DRP1.

5.5.2.2 Non-Functional System Requirements

Applied at system level in section 5.3.2.

5.5.2.3 E3S Classification

As specified in section 5.3.2.

5.5.3 Description

The Reactor Coolant Pump System [JEB] includes the nozzles which connect to the Reactor Coolant Pipework System [JEC], the pump hydraulic casing and impeller, the pump motor, the variable frequency drive (VFD) used for start-up and cooldown, electrical switchgear and transformer, the heat exchanger (HX) required for cooling the pump and the instrumentation which feeds the Reactor Control and Protection Systems [JY].

The RCPs are positioned underneath the SGs through mounting the RCPs to the SG outlet nozzle, illustrated in Figure 5.5-1. Each pump includes a flywheel, which provides an elongated coast-down following a loss of primary flow fault.

Figure 5.5-1: Orientation of the RCP

A summary of the key Reactor Coolant Pump System [JEB] design attributes is presented in Table 5.5-2.

Table 5.5-2: Key Reactor Coolant Pump System [JEB] Design Attributes

Parameter	Value
Pump Type	Hermetically sealed
Hydraulic Casing	SA-508 Grade 3 Class 2
Motor Casing	Martensitic Stainless Steel
Flywheel	Martensitic Stainless Steel
No. of speeds	Single Speed (VFD used for start-up and shutdown)
Total Length	{REDACTED}
Total Diameter	{REDACTED}
Internal Volume (hydraulic casing)	{REDACTED}
Total Weight	{REDACTED}
Design Temperature	{REDACTED}
Design Pressure	{REDACTED}

5.5.4 Materials

Materials are listed in Table 5.5-2.

The description and justification of materials used for VHR, safety class 1 and 2 SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.5.5 Interfaces with Supporting Systems

As outlined in for the RCS [JE] in section 5.3.5.

5.5.6 System and Equipment Operation

During operating mode 1 (power operations), the RCPs operate in a single speed configuration, with electrical power being directly supplied by the power station electrical distribution systems. During operating mode 2 (low power), the VFD is used to vary pump power as required, prior to transitioning to direct drive.

5.5.7 Instrumentation and Control

As outlined for the RCS [JE] in section 5.3.7.

5.5.8 Monitoring, Inspection, Testing and Maintenance

As outlined for the RCS [JE] in section 5.3.8.

5.5.9 Radiological Aspects

There is no irradiation activation of the RCP.

Low activation materials are used in the design of the Reactor Coolant Pump System [JEB].

5.5.10 Performance and Safety Evaluation

Verification strategies for the Reactor Coolant Pump System [JEB] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements include comparison against RGP, as well as additional analyses for hydraulic design, bearing design, motor design and selection of materials. Demonstration rigs will be constructed for hydrostatic testing. Other activities will include structural analysis, including ASME code compliance.

Full details of verification strategies at RD7/DRP1 are provided in the RCP verification strategy [22].

5.6 Steam Generation System

5.6.1 System and Equipment Functions

The primary function of the Steam Generation System [JEA] is to utilise heated coolant from the Reactor Coolant System Pipework [JEC] to generate steam which can be transferred to the Turbine Island via the Main Steam System [LBA]. The system contributes to the achievement of FSFs of CoFT and CoRM.

5.6.2 Design Basis

5.6.2.1 Functional Requirements

Safety categorised functional requirements are specified for the Steam Generation System [JEA] flowed down from the RCS [JE] and the HLSFs they deliver, presented in Table 5.6-1 based on [23].

Table 5.6-1: Steam Generation System [JEA] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEA-R-1827	The Steam Generation System [JEA] shall contain and confine Reactor Coolant at the system's specified design pressure and temperature	DBC-1 DBC-2 DBC-3 DBC-4	All	A
JEA-R-1791	While in All modes of operation, the Steam Generation System [JEA] shall contain and confine secondary coolant at the system design pressure and temperature	DBC-1 DBC-2 DBC-3 DBC-4	All	A
JEA-R-1674	While in Mode 1, the Steam Generation System [JEA] shall generate steam	DBC-1 DBC-2 DBC-3 DBC-4	1	C
JEA-R-1738	While in Modes 1, 2, 3, 4a, 4b or 5a, While in Condenser decay heat removal, the Steam Generation System [JEA] shall sense steam generator level	DBC-1 DBC-2	1 to 5a	C
JEA-R-1882	While in Passive Decay Heat Removal at Maximum PDHR Power, the Steam Generation System [JEA] shall generate steam.	DBC-3 DBC-4	All	B

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEA-R-1883	While in HTHR [JN03], the Steam Generation System [JEA] shall generate steam.	DBC-1 DBC-2 DBC-3 DBC-4	All	C
JEA-R-1956	While in Passive Decay Heat Removal at Minimum PDHR Power, the Steam Generation System [JEA] shall generate steam.	DBC-3 DBC-4	All	B
JEA-R-1889	The Steam Generation System [JEA] shall generate heated steam during PDHR operation.	DBC-3 DBC-4	All	B
JEA-R-1895	The Steam Generating System [JEA] shall sense steam generator level. ** Supports PDHR [JN02]*	DBC-3 DBC-4	All	B
JEA-R-1888	While in All modes of operation, When at All Modes, the Steam Generation System [JEA] shall sense SG level. ** Supports Scram [JD01]*	DBC-3 DBC-4	All	B

The safety categorised functional requirements for the Steam Generation System [JEA] are flowed down and allocated to relevant components in [24]. Non-functional performance requirements associated with safety categorised functional requirements are allocated in [23].

5.6.2.2 Non-Functional System Requirements

Non-functional system requirements are allocated to the Steam Generation System [JEA] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [23].

5.6.2.3 E3S Classification

Specified in section 5.3.2.

5.6.3 Description

The baseline architecture for the Steam Generation System [JEA] consists of three vertical u-tube, shell and tube SGs, each including equipment required for level measurement of the secondary side. The three SGs are located within the containment vessel in an elevated position relative to the RPV [JAA] to provide a robust thermal driving head for NC flow in faulted operation and to allow access to the RCP for maintenance and inspection.

The SG uses centrifugal separators to dry the steam, which is subsequently transferred to the Main Steam Piping System [LBA] for onward distribution to the Turbine Island [T01]. Reactor coolant is returned to the RCS pipework [JEC] via the RCPs [JEB] which is mounted directly to the SG outlet nozzle.

The SG includes an integral crossflow preheater, which works by preferentially directing feedwater to the cold side of the tube bundle. The system also includes the provision of both wide and narrow band level measurement, which facilitates the level control of the SG during both powered and shutdown operations, as well as supporting the initiation of the PDHR [JN02] and Scram [JD01] safety measures.

The Steam Generation System [JEA] includes the primary side of the SG, up to and including the primary nozzles. It also includes secondary side level measurement functionality which supports the control and protection of the RCS [JE].

A simplified schematic is illustrated in Figure 5.6-1, and a summary of the key physical and mechanical attributes for the system are presented in Table 5.6-2.

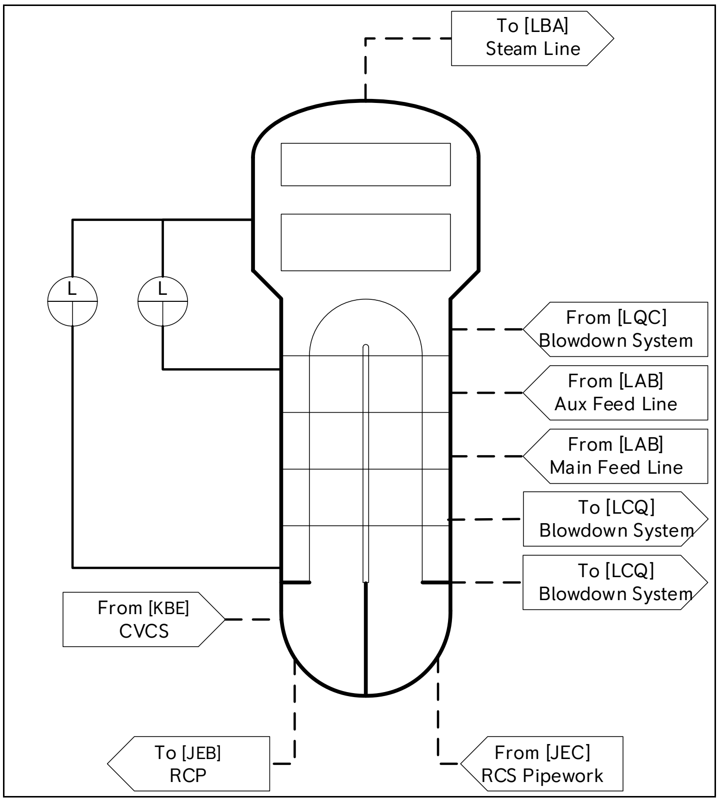

Figure 5.6-1: Simplified Schematic of the Steam Generation System [JEA]

Table 5.6-2: Design Attributes for the Steam Generation System [JEA]

Parameter	Value
Steam Generator Type	Vertical u-tube
Preheater Type	Integral crossflow
Tube Support Type	Lattice Grids
Dry Mass	{REDACTED}
Height	{REDACTED}
Tube Material	{REDACTED}
Major Forging Material	{REDACTED}
Primary Nozzle Safe Ends Material	{REDACTED}
Primary	
Number of Tubes	{REDACTED}
Tube Outer Diameter	{REDACTED}
Heat Transfer Area	{REDACTED}
Primary Internal Volume	{REDACTED}
Primary Design Pressure	{REDACTED}
Primary Design Temperature	{REDACTED}
Secondary	
Feed Configuration	{REDACTED}
Secondary Design Pressure	{REDACTED}
Secondary Design Temperature	{REDACTED}
Secondary Internal Volume	{REDACTED}
Upper Shell Diameter	{REDACTED}
Lower Shell Diameter	{REDACTED}

Further details of the Steam Generation System [JEA] are provided in the Steam Generator SDD [25].

5.6.4 Materials

Materials are listed in Table 5.6-2. The description and justification of materials used for VHR and safety class 1 SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.6.5 Interfaces with Supporting Systems

As outlined in for the RCS [JE] in section 5.3.5.

5.6.6 System and Equipment Operation

The operating philosophy for the RCS [JE] is summarised in section 5.3.6. Further details specific to the operation of the Steam Generation System [JEA] are provided in [25].

5.6.7 Instrumentation and Control

As outlined in for the RCS [JE] in section 5.3.7. Specific alarms and warnings for the Steam Generation System [JEA] are summarised in [25].

5.6.8 Monitoring, Inspection, Testing and Maintenance

As outlined in for the RCS [JE] in section 5.3.8.

5.6.9 Radiological Aspects

The design decision to incorporate an integral crossflow preheater into the design of the SG has considered potential radiological impacts. The design permits a reduction in heat transfer area, which can reduce the quantity of Nickel-58 released from the SG tubes into the reactor coolant due to corrosion, in turn reducing the quantity of Cobalt-58 generated due to activation. This is deemed to reduce the overall plant dose rates, even considering additional complexities associated with inspection of the feedwater distributor, which will be mitigated through use of remote inspection techniques.

More detailed information on design decisions is presented in the Steam Generation System SDD [25] and associated design decision files.

5.6.10 Performance and Safety Evaluation

Verification strategies for the Steam Generation System [JEA] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements primarily includes rig testing to demonstration corrosion resistance, structural Integrity assessments for confinement and resistance to hazards, and thermal hydraulic performance analysis using RELAP5-3D and GOTHIC codes.

At RD7/DRP1, performance analysis of expected bounding postulated events has identified no areas of non-compliance against acceptance criteria. The suite of performance analysis for bounding fault conditions that place safety categorised functional requirements on the Steam Generation System [JEA] is presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [3].

5.7 Reactor Coolant Piping

5.7.1 System and Equipment Functions

The primary function of the Reactor Coolant Pipework System [JEC] is the transfer of heated coolant between the Reactor System [JA] to the Steam Generation System [JEA] and back again (via the Reactor Coolant Pumps [JEB]) to support the generation of steam.

The Reactor Coolant Pipework System [JEC] also provides a route for the transfer of heated coolant between the Reactor System [JA] and Steam Generating System [JEA] to support the PDHR [JN02] and HTHR [JN03] safety measures, including under NC conditions.

The system also interfaces with several systems that support and protect the Reactor Plant [J] during powered, shutdown and faulted modes of operation, including the Reactor Coolant Pressurising System [JEF] and the Reactor Pressure Relief System [JEG].

The system therefore contributes to the achievement of FSFs of CoR, CoFT, and CoRM.

5.7.2 Design Basis

5.7.2.1 Functional Requirements

Safety categorised functional requirements specified for the Reactor Coolant Pipework System [JEC] flowed down from the RCS [JE] and the HLSFs they deliver, are presented in Table 5.7-1 based on [26].

Table 5.7-1: Reactor Coolant Pipework System [JEC] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEC-R-1383	The Reactor Coolant Pipework System [JEC] shall contain and confine Reactor Coolant at the system's specified design pressure and temperature	DBC-1 DBC-2 DBC-3 DBC-4	All	A
JEC-R-1286	While in Modes 1, 2, 3, 4a, 4b or 5a the Reactor Coolant Pipework System [JEC] shall transfer coolant from the Reactor System [JA] to the Steam Generation System [JEA].	DBC-1 DBC-2	1 to 5a	C
JEC-R-1630	While PDHR operation the Reactor Coolant Pipework System [JEC] shall transfer coolant from the Reactor System [JA] to the Steam Generation System [JEA].	DBC-3 DBC-4	All	B

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEC-R-1308	While in Modes 1, 2, 3, 4a or 5a the Reactor Coolant Pipework System [JEC] shall transfer coolant from the Reactor Coolant Pump System [JEB] to the Reactor System [JA].	DBC-1 DBC-2	1 to 5a	C
JEC-R-1634	While in PDHR operation the Reactor Coolant Pipework System [JEC] shall transfer coolant from the Reactor Coolant Pump System [JEB] to the Reactor System [JA].	DBC-3 DBC-4	All	B
JEC-R-1665	The Reactor Coolant Pipework System [JEC] shall transfer Coolant from the Reactor Coolant Pump System [JEB] to the Reactor System [JA] prior to reactor shutdown on loss of powered pump flow (during RCP coastdown) in the range {REDACTED}.	DBC-1 DBC-2 DBC-3 DBC-4	All	A
JEC-R-1319	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant hot leg temperature.	DBC-1 DBC-2	All	C
JEC-R-1323	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant cold leg temperature.	DBC-1 DBC-2	All	C
JEC-R-1334	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant level.	DBC-1 DBC-2	All	B
JEC-R-1341	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant flow rate.	DBC-1 DBC-2	All	C
JEC-R-1638	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense RCS loop pressure.	DBC-1 DBC-2	All	C
JEC-R-1365	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant hot leg temperature.	DBC-3 DBC-4	All	A
JEC-R-1422	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant cold leg temperature.	DBC-3 DBC-4	All	B

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEC-R-1373	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant pressure.	DBC-3 DBC-4	All	A
JEC-R-1378	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant flow rate.	DBC-3 DBC-4	All	A
JEC-R-1646	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense hot leg temperature.	DBC-3 DBC-4	All	A
JEC-R-1369	While in all modes of operation, the Reactor Coolant Pipework System [JEC] shall sense reactor coolant cold leg temperature.	DBC-3 DBC-4	All	B
JEC-R-1660	While the RCS is pressurised and in support of Low Temperature DHR V1 (duty DHR - cool down and hold down), the Reactor Coolant Pipework System [JEC] shall control flow of primary coolant around the Cold Shutdown Cooling System [JNA].	DBC-3 DBC-4	All	C
JEC-R-1663	While the RCS is pressurised and in support of Low Temperature DHR V2 (faulted - pressurised), the Reactor Coolant Pipework System [JEC] shall control flow of primary coolant around the Cold Shutdown Cooling System [JNA].	DBC-3 DBC-4	All	B
JEC-R-1664	While the RCS is de-pressurised and open to atmosphere and in support of LTDHR V3 (faulted - depressurised/open), the Reactor Coolant Pipework System [JEC] shall control flow of primary coolant around the Cold Shutdown Cooling System [JNA].	DBC-3 DBC-4	All	B

The safety categorised functional requirements for the Reactor Coolant Pipework System [JEC] are flowed down and allocated to relevant components in [27]. Non-functional performance requirements associated with safety categorised functional requirements are allocated in [26].

5.7.2.2 Non-Functional System Requirements

Non-functional system requirements are allocated to the Reactor Coolant Pipework System [JEC] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [26].

5.7.2.3 E3S Classification

As specified in section 5.3.2.

5.7.3 Description

The baseline architecture for the Reactor Coolant Pipework System [JEC] consists of three trains, each comprised of a hot and cold leg, as well as associated measurement equipment.

It also provides the tie in for interfaces with systems that support the Reactor System [JA] indirectly (Reactor Heat Removal Systems [JN] and Reactor Reactivity Control Systems [JD]) the Reactor Coolant Sampling Systems [KU] and the Chemical and Volume Control System [KB], as well as housing instrumentation which support the Reactor Control and Protection Systems [JY].

A simplified schematic is illustrated in Figure 5.7-1.

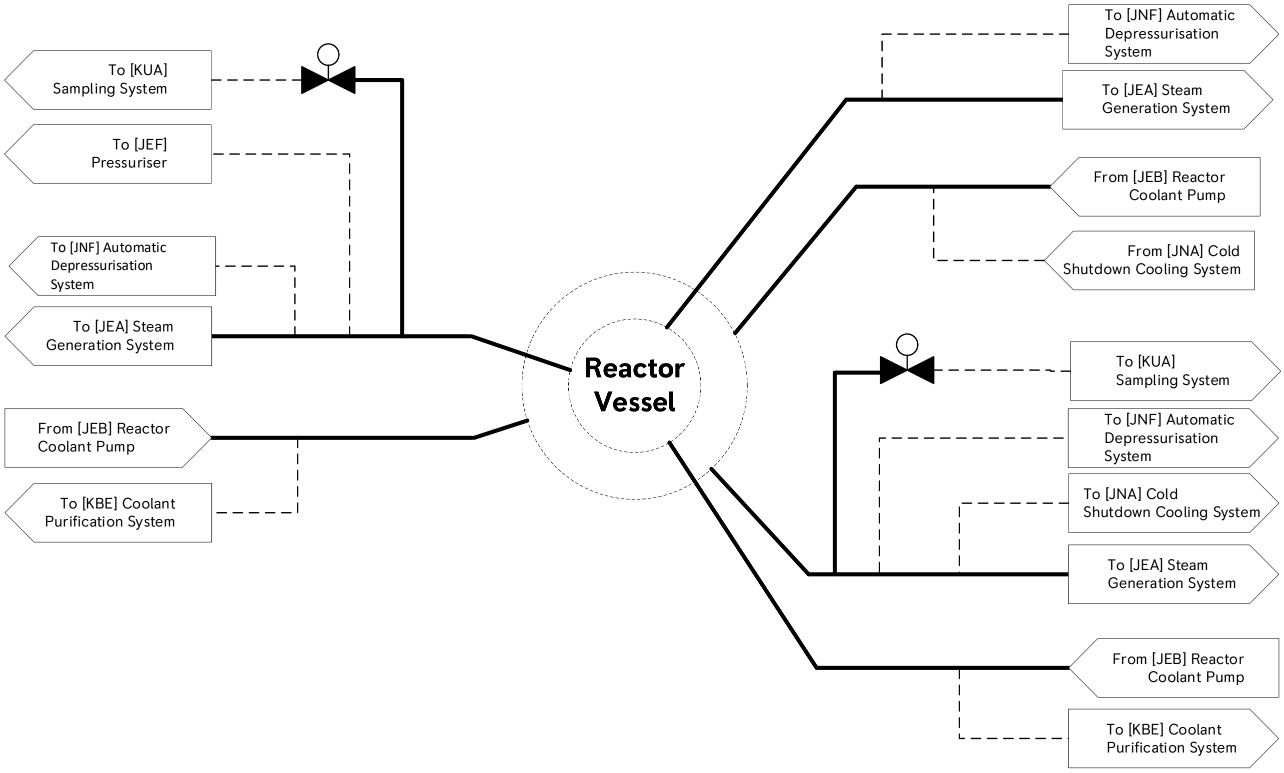

Figure 5.7-1: Simplified Schematic of the Reactor Coolant Pipework System [JEC]

A summary of the key Reactor Coolant Pipework System [JEC] design attributes is presented in is presented in.

Table 5.7-2: Key Reactor Coolant Pipework System [JEC] Design Attributes

Parameter	Value
Design Pressure	{REDACTED}
Design Temperature	{REDACTED}

Parameter	Value
Swept Length (hot leg)	JEA13: {REDACTED} JEA23: {REDACTED} JEA33: {REDACTED}
Swept Length (cold leg)	JEA11: {REDACTED} JEA21: {REDACTED} JEA31: {REDACTED}
Total Internal Volume (per loop)	JEC10: {REDACTED} JEC20: {REDACTED} JEC30: {REDACTED}
Outer Diameter	{REDACTED}
Inner Diameter	{REDACTED}
Material	{REDACTED}

Further details of the Reactor Coolant Pipework System [JEC] are provided in the RCS Pipework SDD [28].

5.7.4 Materials

The description and justification of materials used for VHR SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.7.5 Interfaces with Supporting Systems

As outlined in for the RCS [JE] in section 5.3.5.

5.7.6 System and Equipment Operation

The operating philosophy for the RCS [JE] is summarised in section 5.3.6. Further details specific to the operation of the Reactor Coolant Pipework System [JEC] are provided in [28].

5.7.7 Instrumentation and Control

As outlined in for the RCS [JE] in section 5.3.7. Specific alarms and warnings for the Steam Generation are summarised in [28].

5.7.8 Monitoring, Inspection, Testing and Maintenance

As outlined in for the RCS [JE] in section 5.3.8.

5.7.9 Radiological Aspects

No significant radiological aspects associated with the Reactor Coolant Pipework System [JEC] operation have been identified during design decisions at RD7/DRP1. Low activation materials are used in the design of Reactor Coolant Pipework System [JEC].

5.7.10 Performance and Safety Evaluation

Verification strategies for the Reactor Coolant Pipework System [JEC] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements primarily include structural integrity assessments to demonstrate the confinement function, and inspections to ensure the installation supports the transfer of reactor coolant.

At RD7/DRP1, performance analysis is used to develop the key system performance requirements at the RCS [JE] level, see section 5.3.10. This analysis provides confidence that the pipework layout is elevated to maintain sufficient flow via NC during faulted operation, subject to further confirmatory analysis.

5.8 Reactor Pressure Control System

5.8.1 System and Equipment Functions

The primary function of the Reactor Coolant Pressurising System [JEF] is to provide pressure control for the RCS [JE] and the Reactor System [JA], and to limit pressure changes during transients (both normal duty and faulted).

In addition, the system provides interfaces for the Reactor Coolant Pressure Relief [JEG] and Automatic Depressurisation System [JNF] to the Reactor Coolant System [JE], as well as housing instrumentation which supports the Reactor Control and Protection Systems [JY]. The system contributes to the achievement of FSFs of CoR, CoFT and CoRM.

5.8.2 Design Basis

5.8.2.1 Functional Requirements

Safety categorised functional requirements are specified for the Reactor Coolant Pressurising System [JEF] flowed down from the RCS [JE] and the HLSFs they deliver, presented in Table 5.8-1 based on [29].

Table 5.8-1: Reactor Coolant Pressurising System [JEF] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEF-R-1334	The Reactor Coolant Pressurising System [JEF] shall contain Reactor Coolant at the system's specified design pressure and temperature.	DBC-1 DBC-2 DBC-3 DBC-4	All	A
JEF-R-1305	While in Modes 1, 2, 3, 4a, 4b or 5a, the Reactor Coolant Pressurising System [JEF] shall pressurise reactor coolant.	DBC-1 DBC-2	All	C
JEF-R-1307	While in Mode 5b, the Reactor Coolant Pressurising System [JEF] shall vent the Reactor Coolant System [JE] to atmosphere.	DBC-1 DBC-2	All	C
JEF-R-1297	While in all modes of operation, the Reactor Coolant Pressurising System [JEF] shall sense pressuriser pressure.	DBC-1 DBC-2	All	C
JEF-R-1296	While in all modes of operation, the Reactor Coolant Pressurising System [JEF] shall sense pressuriser level.	DBC-1 DBC-2	All	C

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEF-R-1289	In all modes of operation, the Reactor Coolant Pressurising System [JEF] shall sense pressuriser pressure. **Supports Scram [JD01]*	DBC-3 DBC-4	All	A
JEF-R-1284	In all modes of operation, the Reactor Coolant Pressurising System [JEF] shall sense pressuriser level. **Supports Scram [JD01]*	DBC-3 DBC-4	All	A
JEF-R-1401	In all modes of operation, the Reactor Coolant Pressurising System [JEF] shall sense pressuriser pressure. **Supports ASF [JD02]*	DBC-3 DBC-4	All	B
JEF-R-1371	The Reactor Coolant Pressurising System [JEF] shall sense pressuriser pressure. **Supports ECC [JN01]*	DBC-3 DBC-4	All	A
JEF-R-1422	The Pressurising System [JEF] shall sense pressuriser level. **Supports PDHR [JN02]*	DBC-3 DBC-4	All	B
JEF-R-1415	The Pressurising System [JEF] shall sense pressuriser pressure. **Supports PDHR [JN02]*	DBC-3 DBC-4	All	B
JEF-R-1424	While in Passive Decay Heat Removal [JN02], the Pressurising System [JEF] shall isolate pressuriser heaters on demand. **Supports PDHR [JN02]*	DBC-3 DBC-4	All	B

The safety categorised functional requirements for the Reactor Coolant Pressurising System [JEF] are flowed down and allocated to relevant components in [30]. Non-functional performance requirements associated with safety categorised functional requirements are allocated in [29].

5.8.2.2 Non-Functional System Requirements

Non-functional system requirements are allocated to the Reactor Coolant Pressurising System [JEF] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [29].

5.8.2.3 E3S Classification

Specified in section 5.3.2.

5.8.3 Description

The principal component of the Reactor Coolant Pressurising System [JEF] is the pressuriser, which is connected to the RCS [JE] via spray and surge lines.

The pressuriser operates with a mixture of steam and water in equilibrium to provide the necessary overpressure to prevent bulk boiling of the fluid in the RCS [JE]. To increase plant pressure steam is generated by electrical heaters contained within the lower section of the pressuriser.

To reduce plant pressure, the Reactor Coolant Pressurising System [JEF] uses a pump induced spray system; when demanded by the Reactor Control and Protection System [JY], a spray initiation valve in the spray line opens, which allows coolant to enter the top of the pressuriser via a single spray nozzle to condense steam in the vessel, reducing pressure to the required level. The motive force for spray is provided by one of the RCPs whilst plant pressure is maintained above 2.0 MPa(a) and by the CSCS [JNA] during low pressure operations. If main spray is unavailable, the motive force for auxiliary spray is provided by one of the CVCS [KB] make-up pumps.

A simplified schematic is illustrated in Figure 5.8-1, and a summary of the key performance and design parameters for the system are presented in Table 5.8-2.

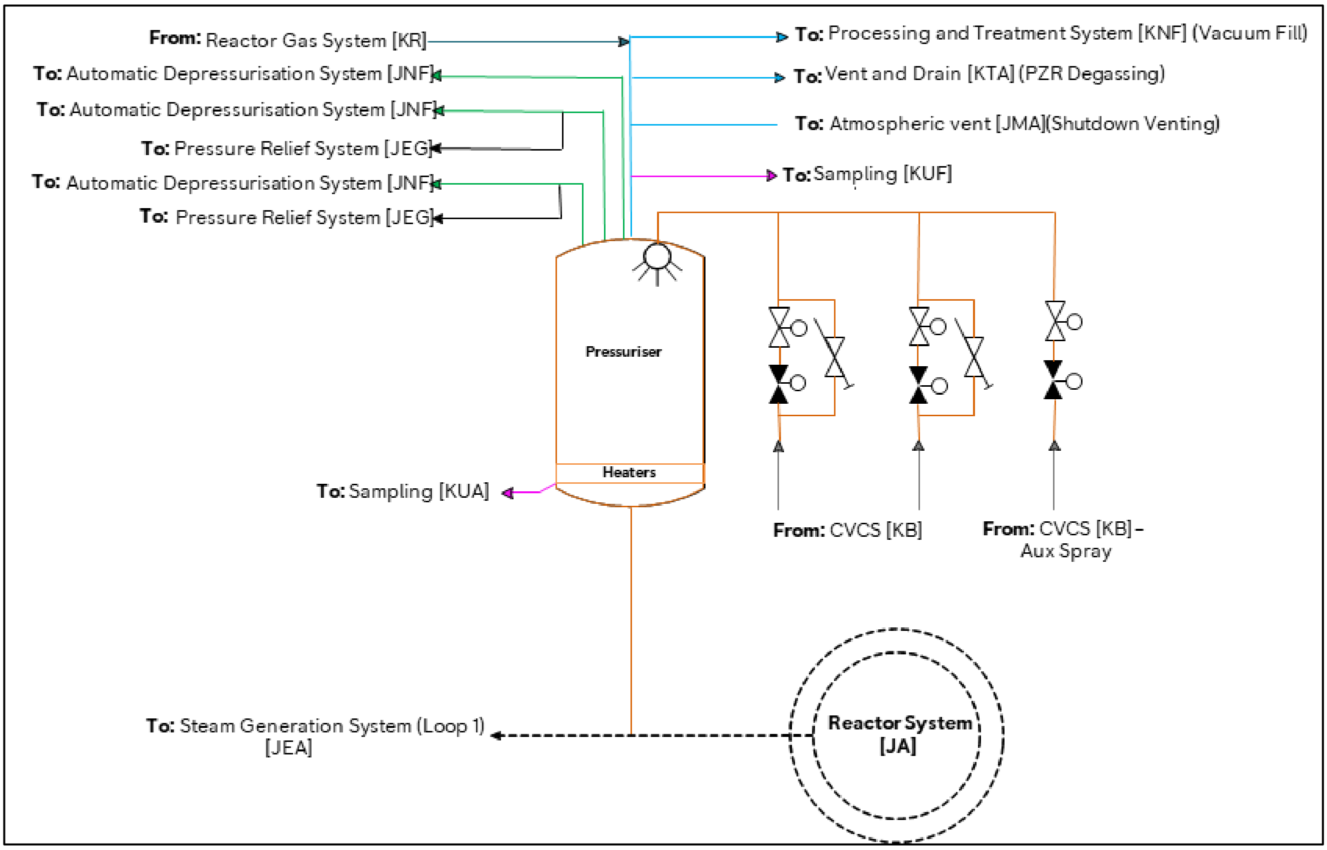

Figure 5.8-1: Simplified Schematic of the Reactor Coolant Pressurising System [JEF]

Table 5.8-2: Key Performance and Design Parameters for the Reactor Coolant Pressurising System [JEF]

Parameter	Value
Design Temperature	{REDACTED}
Design Pressure	{REDACTED}
Operating Temperature	{REDACTED}
Operating Pressure	{REDACTED}
Pressuriser Internal Volume	{REDACTED}
Pressuriser Water Volume at 100 % Full Power	{REDACTED}
Pressuriser Heater Power	{REDACTED}
Surge Line Nominal Diameter	{REDACTED}
Spray Line Nominal Diameter	{REDACTED}

Further details of the Reactor Coolant Pressurising System [JEF], including the pressuriser vessel, heaters, surge line, and spray line, are provided in the Reactor Coolant Pressurising SDD [31].

5.8.4 Materials

The pressuriser is manufactured from ASME SA 508 Grade 3 Class 1 steel, and internally clad with stainless steel (309L/308L) for corrosion resistance. The justification of materials used for VHR SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.8.5 Interfaces with Supporting Systems

As outlined in for the RCS [JE] in section 5.3.5.

5.8.6 System and Equipment Operation

The operating philosophy for the RCS [JE] is summarised in section 5.3.6. Further details specific to the operation of the Reactor Coolant Pressurising System [JEF] are provided in [31].

5.8.7 Instrumentation and Control

As outlined in for the RCS [JE] in section 5.3.7. Specific alarms and warnings for the Reactor Coolant Pressurising System [JEF] are summarised in [31].

5.8.8 Monitoring, Inspection, Testing and Maintenance

As outlined in for the RCS [JE] in section 5.3.8.

5.8.9 Radiological Aspects

No significant radiological aspects associated with the Reactor Coolant Pressurising System [JEF] operation have been identified during design decisions up to RD7/DRP1. Low activation materials are used in the design, for example, stainless steel cladding of the pressuriser helps to minimise the build-up of corrosion products in the RCS coolant.

5.8.10 Performance and Safety Evaluation

Verification strategies for the Reactor Coolant Pressurising System [JEF] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements are under development for the system level RCS [JE], described in section 5.3.10.

5.9 Heading Number Not Used

This section is reserved for boiling water reactors in the International Atomic Energy Agency (IAEA) safety report format [32] and is not used by RR SMR.

5.10 Reactor Coolant System Component Supports and Restraints

The description of the supports and restraints as well as justification of their structural adequacy and integrity will be reported in future revisions to the E3S Case.

5.11 Reactor Coolant Pressure Relief System

5.11.1 System and Equipment Functions

The primary function of the Reactor Coolant Pressure Relief System [JEG] is to provide overpressure protection to the RCS [JE] in the event of reactor or system faults, providing the FSF of CoFT. Overpressure protection for operating modes 1 – 4a is provided via the High Temperature Overpressure Protection (HTOP) sub-system and operating modes 4b – 5a is protected by the Low Temperature Overpressure Protection (LTOP) sub-system.

5.11.2 Design Basis

5.11.2.1 Functional Requirements

Safety categorised functional requirements are specified for the Reactor Coolant Pressure Relief System [JEG] flowed down from the RCS [JE] and the HLSFs they deliver, presented in Table 5.11-1 based on [33].

Table 5.11-1: [JEG] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JEG-R-1478	While in modes 1-4a JEG shall provide overpressure relief to the RCS	DBC-3 DBC-4	1-4a	A
JEG-R-1484	While in modes 4b-5a, JEG shall provide overpressure relief to the RCS and CSCS	DBC-3 DBC-4	4b-5a	A
JEG-R-1474	JEG shall contain and confine primary coolant in all modes of operation	DBC-3 DBC-4	All	A
JEG-R-1491	[JEG] SHALL sense HTOP primary relief flow	DBC-3 DBC-4	All	A
JEG-R-1498	JEG] SHALL sense HTOP primary relief temperature	DBC-3 DBC-4	All	A
JEG-R-1506	[JEG] SHALL sense LTOP relief temperature	DBC-3 DBC-4	All	A
JEG-R-1513	[JEG] SHALL sense LTOP relief temperature	DBC-3 DBC-4	All	A

The safety categorised functional requirements for the Reactor Coolant Pressure Relief System [JEG] are flowed down and allocated to relevant sub-systems and/or components in [34]. Non-functional performance requirements associated with the safety categorised functional requirements are allocated in [33].

No environment, security or safeguards functional requirements are assigned at RD7/DRP1.

5.11.2.2 Non-Functional System Requirements

Non-functional system requirements are allocated to the Reactor Coolant Pressure Relief System [JEG] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [33].

5.11.2.3 E3S Classification

Specified in section 5.3.2.

5.11.3 Description

The Reactor Coolant Pressure Relief System [JEG] comprises of the following two sub-systems:

- HTOP, providing overpressure protection during power operations (operating modes 1 – 4a), comprising two steam safety relief (SRVs) located on top of the pressuriser, each 100 % capable of achieving the safety function in a 1 out of 2 (1oo2) configuration.

- LTOP, providing overpressure protection during cold shutdown (operating modes 4b – 5a), comprising two water SRVs located on the RCS [JE]/CSCS [JNA] interface, each 100 % capable of achieving the safety function (1oo2).

Each of the HTOP and LTOP SRVs are protected against backflow by a non-return valve located in the discharge line. Each sub-system is provided with a means of air admission consisting of a non-return valve and a short section of pipework. This ensures that a vacuum does not form in the discharge lines due to steam condensing after a relief event.

The SRVs discharge into the Refuelling Pool [FAF] via spargers. The HTOP subsystem shares spargers with the Automatic Depressurisation System [JNF] whereas LTOP discharges via is own dedicated sparger.

A simplified schematic of both the HTOP and LTOP sub-systems is illustrated in Figure 5.11-1 and Figure 5.11-2. Key performance and design parameters for the system are presented in

Table 5.11-2.

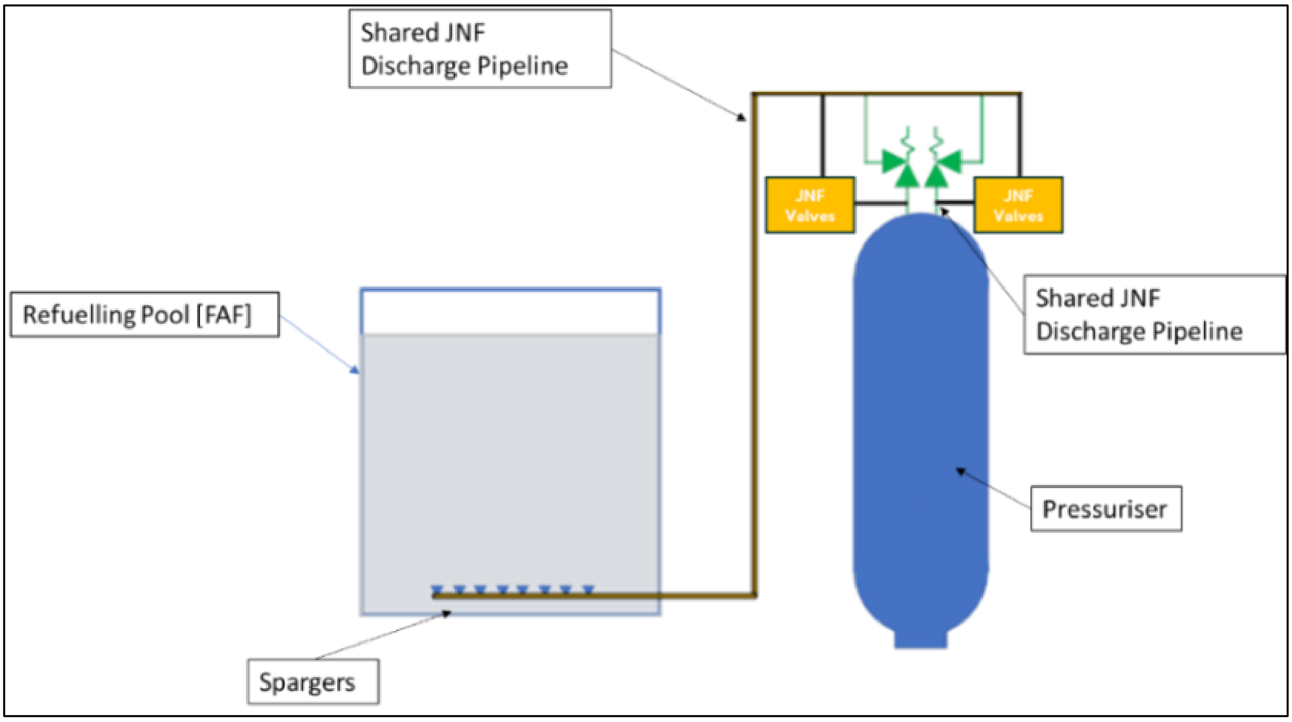

Figure 5.11-1: Simplified Schematic for the HTOP for the Reactor Coolant Pressure Relief System [JEG]

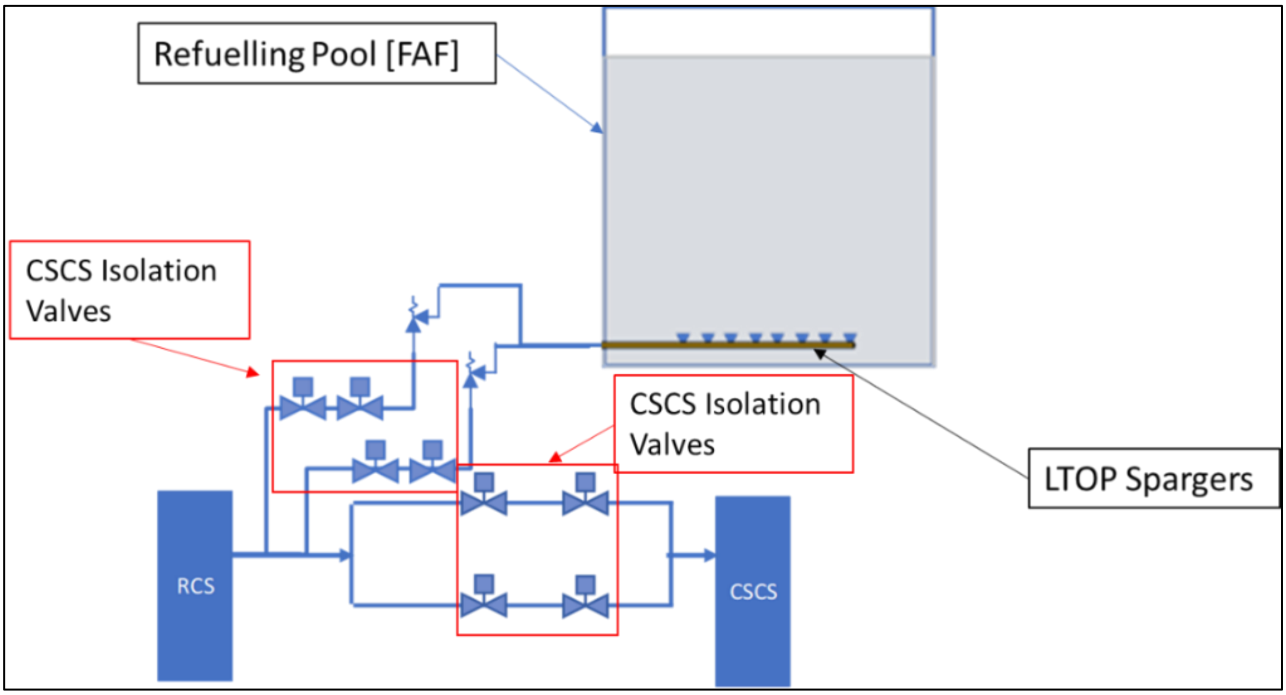

Figure 5.11-2: Simplified Schematic for the LTOP for the Reactor Coolant Pressure Relief System [JEG]

Table 5.11-2: Key Performance and Design Parameters for the Reactor Coolant Pressure Relief System [JEG]

Parameter	Value
HTOP	
Design Temperature	{REDACTED}
Design Pressure	{REDACTED}
Operating Temperature	{REDACTED}
Operating Pressure	{REDACTED}
HTOP SRV 1 Set Pressure	{REDACTED}
HTOP SRV 2 Set Pressure	{REDACTED}
LTOP	
Design Temperature	{REDACTED}
Design Pressure	{REDACTED}
Operating Temperature	{REDACTED}
Operating Pressure	{REDACTED}
LTOP SRV 1 Set Pressure	{REDACTED}
LTOP SRV 2 Set Pressure	{REDACTED}

Further details of the Reactor Coolant Pressure Relief System [JEG] are provided in the Reactor Coolant Pressure Relief SDD [35].

5.11.4 Materials

The valves and pipework are manufactured from austenitic stainless steel. The justification of materials used for Class 1 SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.11.5 Interfaces with Supporting Systems

As outlined in for the RCS [JE] in section 5.3.5.

5.11.6 System Operation

The operating philosophy for the RCS [JE] is summarised in section 5.3.6. Further details specific to the operation of the Reactor Coolant Pressure Relief System [JEG] are provided in [35].

5.11.7 Instrumentation and Control

As outlined in for the RCS [JE] in section 5.3.7. Specific alarms and warnings for the Reactor Coolant Pressure Relief System [JEG] are summarised in [35].

5.11.8 Monitoring, Inspection, Testing and Maintenance

As outlined in for the RCS [JE] in section 5.3.8.

5.11.9 Radiological Aspects

HTOP SRVs are in close proximity to the pressuriser with the potential for high dose rates, therefore EMIT arrangements will be developed to minimise operator exposure to ALARP, with the use of local shielding where necessary.

5.11.10 Performance and Safety Evaluation

Verification strategies for the Reactor Coolant Pressure Relief System [JEG] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements primarily include thermal hydraulic performance analysis using RELAP5-3D.

At RD7/DRP1, performance analysis of expected bounding postulated events for the Reactor Coolant Pressure Relief System [JEG], including loss of heatsink which is expected to produce the highest discharge rate for HTOP relief, demonstrate that relevant acceptance criteria can be achieved. The suite of performance analysis for bounding fault conditions that place safety categorised functional requirements on the Reactor Coolant Pressure Relief System [JEG] presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [3].

Key Reactor Coolant Pressure Relief System [JEG] design decisions made with respect to ensuring overall risks are reduced to ALARP include:

- A 1oo2 arrangement for HTOPs and LTOP SRVs follows RGP from other PWR designs and is deemed to provide suitable defence in depth against PIEs, with the benefits associated with further redundancy offset by increased vulnerabilities due to the potential for spurious lifts.

- SRV automated isolation to protect against spurious lift is not incorporated, which is consistent with RGP. The provision of SRV isolation could reduce the level of defence in depth in the design should it mistakenly actuate during power operation, with a loss of the pressure relief safety function. IAEA does not permit isolation, and no such isolation is found on other PWR designs in the UK. Furthermore, sufficient protection against a spurious lift fault is provided by the ECC [JN01] safety measure.

- Passive valve actuation of LTOP SRVs is selected over more complex options such as remotely actuated valves, to provide a simplified system that can likely meet safety criteria without the need for C&I or electrical input, which may introduce new vulnerabilities.

More detailed information on design decisions is presented in the Reactor Coolant Pressure Relief SDD [35] and associated design decision files.

5.12 Access and Equipment Requirements for In-Service Inspection and Maintenance

The EMIT activities for the RCS [JE] and associated systems are defined as TLA within the RR SMR requirements management database, and cover safety derived tasks including ISI, reliability derived tasks (RCM/preventative maintenance), and relevant good practice/ OPEX including the EPRI PMBD. EMIT programmes will continue to be developed and reported in the E3S Case as the design matures (see also E3S Case Version 2, Tier 1, Chapter 13: Conduct of Operations [14]).

5.13 Reactor Auxiliary Systems

5.13.1 Chemical and Volume Control System

5.13.1.1 System and Equipment Functions

The primary function of the CVCS [KB] is to control the chemistry and volume of the reactor coolant inventory within the RCS [JE]. The system maintains reactor coolant chemistry within specification and maintains pressuriser level within a required operating band. It comprises of three sub-systems: the Level and Volume Control System (LVCS) [KBA], the Chemistry Control System [KBD] and the Coolant Purification System (CPS) [KBE].

The CVCS [KB] contributes to the achievement of FSFs of CoR, CoFT, and CoRM during normal duty operations, and the CPS [KBE] provides isolation functions to achieve CoRM during fault and accident conditions.

5.13.1.2 Design Basis

Functional Requirements

Safety categorised functional requirements specified for each of the sub-systems of the CVCS [KB] based on the HLSFs they deliver are presented in Table 5.13-1, based on [36], [37], and [38].

Table 5.13-1: CVCS [KB] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
Level and Volume Control System [KBA]				
KBA-R-2859	While in Modes 1, 2, 3, 4a, 4b, 5a, 5b or 6a, the Level and Volume Control System [KBA] shall control coolant.	DBC-1 DBC-2	1 to 6a	C
KBA-R-2892	While in Modes 1, 2, 3, 4a or 4b with RCPs unavailable, the Level and Volume Control System [KBA] shall transfer coolant for spray.	DBC-1 DBC-2	1 to 4b	C
KBA-R-2878	While in Modes 1, 2, 3, 4a, or 4b, the Level and Volume Control System [KBA] shall provide the motive force for auxiliary spray on receipt of the Reactor Coolant Pump System [JEB] pump trip signal.	DBC-1 DBC-2	1 to 4b	C
Chemistry Control System [KBD]				
KBD-R-1800	While in Modes 1, 2, 3, 4a, 4b, 5a, 5b or 6a, the Chemistry Control System [KBD] shall control RCS hydrogen	DBC-1 DBC-2	1 to 6a	C

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
KBD-R-1802	While in Modes 1, 2, 3, 4a, 4b or 5a, the Chemistry Control System [KBD] shall store liquid dosing chemicals.	DBC-1 DBC-2	1 to 5a	C
KBD-R-1796	While in Modes 1, 2, 3, 4a, 4b, 5a, 5b or 6a, the Chemistry Control System [KBD] shall transfer liquid dosing chemicals.	DBC-1 DBC-2	1 to 6a	C
Coolant Purification System [KBE]				
KBE-R-1842	While in Modes 1, 2, 3, 4a, 4b or 5a, the Coolant Purification System [KBE] shall control coolant.	DBC-1 DBC-2	1 to 5a	C
KBE-R-1840	While in Modes 1, 2, 3, 4a, 4b or 5a, the Coolant Purification System [KBE] shall cool coolant.	DBC-1 DBC-2	1 to 5a	C
KBE-R-1846	While in All modes of operation, the Coolant Purification System [KBE] shall purify coolant [JE].	DBC-1 DBC-2	All	C
KBE-R-1863	While in Modes 1, 2, 3, 4a, 4b, 5a, 5b or 6a, the Coolant Purification System [KBE] shall filter coolant.	DBC-1 DBC-2	1 to 6a	C
KBE-R-1857	While in Modes 1, 2, 3, 4a, 4b or 5a, the Coolant Purification System [KBE] shall heat coolant.	DBC-1 DBC-2	1 to 5a	C
KBE-R-1871	While in Modes 1, 2, 3, 4a or 5a, the Coolant Purification System [KBE] shall receive dosing chemicals.	DBC-1 DBC-2	1 to 5a	C
KBE-R-1962	While in Modes 1, 2, 3, 4a, 4b or 5a, the Coolant Purification System [KBE] shall supply coolant to the pressuriser.	DBC-1 DBC-2	1 to 5a	C
KBE-R-1878	On receipt of the Emergency Core Cooling Safety Measure [JN01] phase 1 signal, the Coolant Purification System [KBE] shall isolate the Coolant Purification System [KBE] from the Reactor Coolant System [JE].	DBC-3 DBC-4	All	A
KBE-R-1879	On receipt of the PDHR [JN02] signal, the Coolant Purification System [KBE] shall isolate the Coolant Purification System [KBE] from the Reactor Coolant System [JE].	DBC-3 DBC-4	All	B

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
KBE-R-1880	On receipt of Containment [JM01] Isolation (Severe Accident) signal, the Coolant Purification System [KBE] shall isolate the Coolant Purification System [KBE] from the Containment Structure [JMA].	DEC-B	All	C
KBE-R-1881	While in Modes 1, 2, 3, 4a, 4b, 5a, 5b or 6a, on receipt of Alternative Shutdown Function [JD02], the Coolant Purification System [KBE] shall isolate the Coolant Purification System [KBE] from the Reactor Coolant System [JE].	DBC-3 DBC-4	All	B

Non-functional performance requirements associated with the safety categorised functional requirements are allocated in [36], [37], and [38].

No environment, security, or safeguards functional requirements are assigned at DRP1.

Non-Functional System Requirements

Non-functional system requirements are allocated to the CVCS [KB] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [39].

E3S Classification

The safety classification of the CVCS [KB] is undertaken in accordance with the methodology outlined in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules [2].

The LVCS [KBA] system fulfils safety category C safety functions, as such the highest classification of components safety class 3.

The Chemistry Control System [KBD] fulfils safety category C safety functions, as such the highest classification of components safety class 3.

The CPS [KBE] highest containment isolation function safety category is safety category A, as such the containment isolation valves and non-return valves at the containment penetrations are safety class 1 components. The CPS [KBE] purification function and structural integrity functions are safety category C functions, as such all other CPS [KBE] components are safety class 3.

No environment, security or safeguards classification is assigned at RD7/DRP1.

No seismic performance classification is assigned at RD7/DRP1.

5.13.1.3 Description

Level and Volume Control System [KBA]

The LVCS [KBA] contains a make-up line and a let-down line to support maintaining pressuriser level within a required band. The LVCS is connected to the CPS [KBE] and provides inventory management of the reactor coolant.

The LVCS [KBA] flow architecture is designed to run simultaneous makeup and letdown when the system is demanded to provide net RCS [JE] makeup or letdown, ensuring sufficient flow through both sides of the CPS [KBE] regenerative HX and enabling the required heat transfer.

Make-up reactor coolant is provided by the Liquid Radioactive Effluent Treatment System (LRETS) [KNF] and is injected via the LVCS [KBA] into the CPS [KBE] return leg. Two parallel high pressure charging pumps (1 duty, 1 standby) provide the motive force to inject the coolant. There is also a pressure relief valve upstream of each pump that is used to relieve overpressure until the pumps have spooled down following an over-pressure trip. Makeup is injected downstream of the CPS [KBE] regenerative HX to ensure it is pre-heated prior to reaching the RCS cold leg.

Let-down is fed from the CPS [KBE] return leg, and transfers coolant to the LRETS [KNF]. Letdown is taken from downstream of the CPS [KBE] ion-exchange columns (IXCs) and backwashable filters to ensure that it has been cooled and purified to meet the water chemistry specifications. Key components include an orifice plate to reduce the pressure and restrict the letdown flow rate. Downstream of the orifice plate is a control valve to throttle the flow rate using the feedback from the letdown line flow sensor.

A simplified schematic of the LVCS [KBA] is illustrated in Figure 5.13-1.

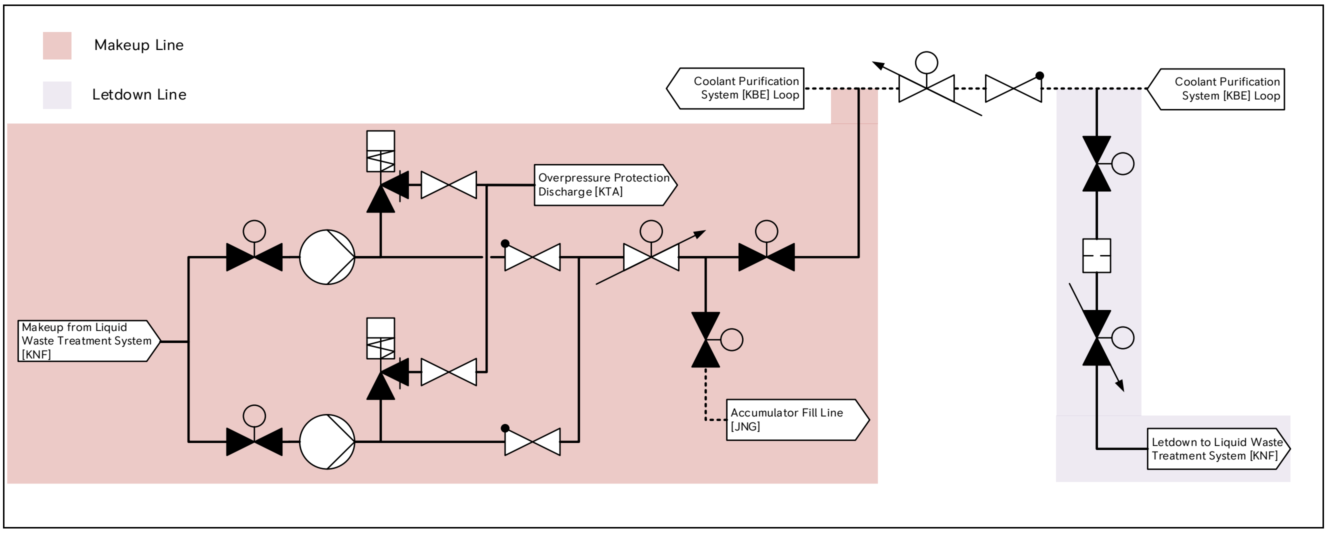

Figure 5.13-1: Simplified Schematic of LVCS [KBA]

Further description of the LVCS [KBA] is provided in the LVCS SDD [40].

Chemistry Control System [KBD]

The Chemistry Control System [KBD] controls the reactor coolant chemistry to ensure it is within the water chemistry specifications, providing zinc dosing, hydrogen addition and other chemical additions.

The baseline architecture for the Chemistry Control System [KBD] includes three chemical dosing lines that dose chemicals to the return line of the CPS [KBE], which in turn returns the dosed primary coolant to the RCS [JE]. The lines include a hydrogen dosing line, a zinc dosing line, and a chemical dosing line.

The hydrogen dosing line receives hydrogen from the Hydrogen Gas Supply Distribution System [QJC20], which provides hydrogen gas flow at the required pressure and transports it to the CPS [KBE] for onward transfer to the RCS [JE]. Key components on the hydrogen dosing line are a control valve and flow sensor for throttling the hydrogen gas flow depending on the demand from the RCS [JE] which varies with operating mode. A pressure sensor provides live hydrogen injection pressures prior to dissolution into the CPS [KBE] return leg.

The zinc dosing architecture includes a zinc addition tank, which is used to add the zinc acetate solution and store it as it is gradually dosed to the CPS [KBE] return leg using the zinc dosing pump. Due to the low flow rate required for zinc addition, there is a recirculation line and control valve that tees to the zinc dosing pump suction and discharge, which is used to run the pump at a higher flow duty point, while maintaining the low flow rate of zinc addition into the CPS [KBE]. A filter is located upstream of the zinc dosing pump to prevent any debris reaching the RCS [JE]. The zinc addition tank is equipped with level instrumentation.

The chemical dosing line includes a chemical addition tank, which is used to add different chemicals individually into the CPS [KBE], depending on the stage in the operating cycle. The chemicals are pumped using the chemical addition pump, which has an upstream filter to prevent any debris reaching the RCS [JE]. The chemical addition tank is equipped with level instrumentation.

A simplified schematic of the Chemistry Control System [KBD] is illustrated in Figure 5.13-2. Further description of the Chemistry Control System [KBD] is provided in the SDD [41].

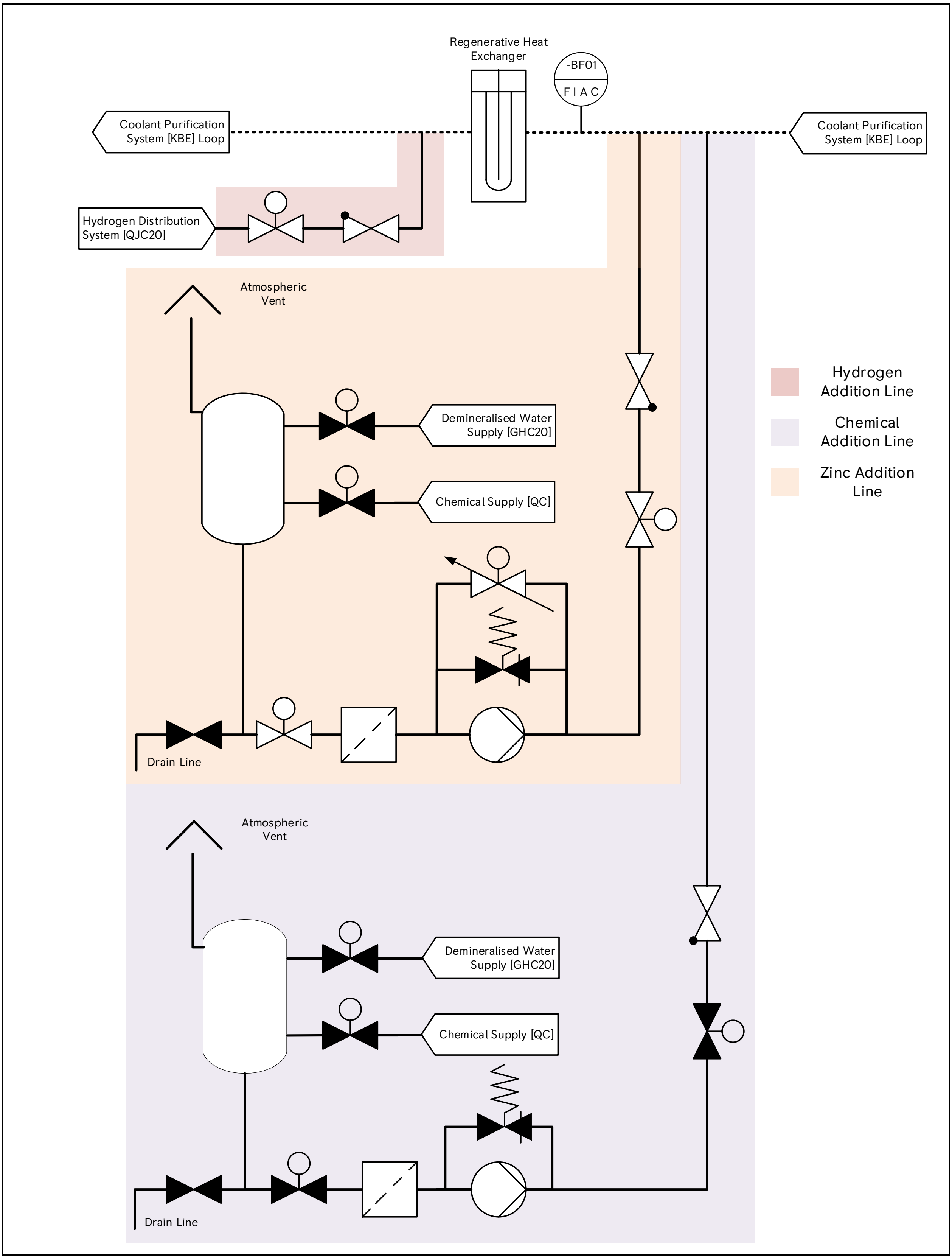

Figure 5.13-2: Simplified Schematic of the Chemistry Control System [KBD]

Coolant Purification System [KBE]

The CPS [KBE] purifies the reactor coolant to ensure it remains within the water chemistry specifications. A continuous flow of coolant is circulated through is a series loop that is fed and returned from the RCS [JE] in normal operation to purify the coolant and help maintain coolant activity within specified limits. It also provides a main flow to the pressuriser spray line (via the spray line parallel isolation valves).

- A header for receipt of coolant for purification, containing two connections to the RCS pipework [JEC] cold legs and a single connection to the CSCS [JNA] supply line. In addition, the header contains interfaces to supply coolant to the Reactor Coolant Pressurising System [JEF] spray lines to support RCS [JE] pressure control.
- A regenerative HX that cools reactor coolant on entry to the system and heats it on exit.
- A non-regenerative HX that further cools the influent reactor coolant so the temperature is low enough for it to pass through the IXCs.
- Two parallel mixed bed IXCs and a downstream fuel cladding failure cleanup (FCFC) IXC.
- Two parallel backwashable filters downstream of the IXCs.
- Prior to the CPS [KBE] loop return, there are feeds from the Chemistry Control System [KBD] and the makeup and letdown connections from the LVCS [KBA].
- A throttle valve for controlling the flow rate around the CPS [KBE] loop is located between the makeup and letdown interfaces.
- A header for return of purified coolant, containing two connections to the Steam Generation System [JEA] primary headers, and a single connection to the CSCS [JNA] return line. In addition, the header contains a connection to the Reactor Coolant Pressurising System [JEF] auxiliary spray lines to support pressure control in the event that the RCPs [JEB] are not functioning.

A simplified schematic of the CPS [KBE] is illustrated in Figure 5.13-3. Further description of the CPS [KBE] is provided in the SDD [42].

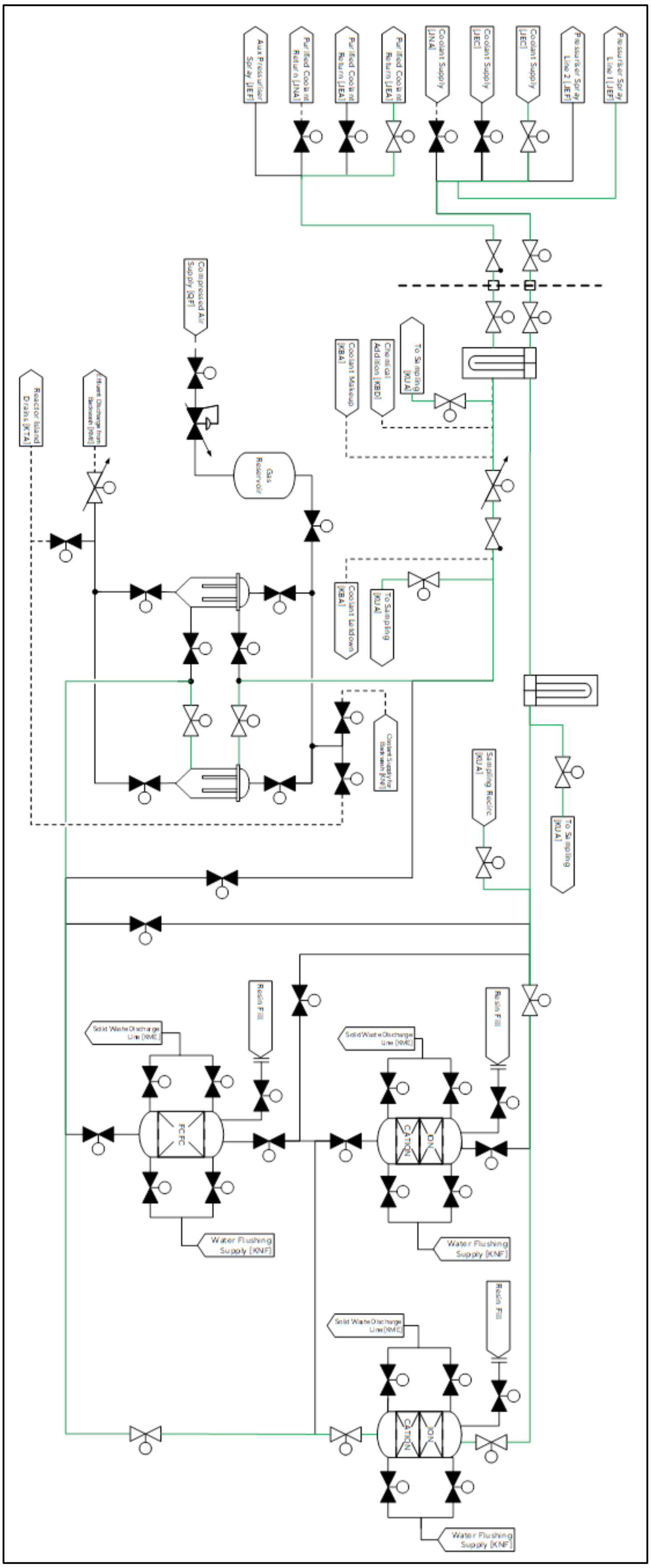

Figure 5.13-3: Simplified Schematic of the CPS [KBE]

5.13.1.4 Materials

The justification of materials used for safety class 1 and 3 SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.13.1.5 Interfaces with Supporting Systems

The functional and physical interfaces for the CVCS [KB] are described in section 5.13.2.3.

5.13.1.6 System Operation

Level and Volume Control System [KBA]

During operating mode 1 (power operations), automatic level control will manage the assumed let-down rate by starting the charging pumps when the bottom of the pressuriser level operating band is reached.

During operating modes 2 (low power), 3 (hot standby), 4a (hot shutdown – steaming) and 4b (hot shutdown – non-steaming), automatic level control will initiate to maintain water level appropriately during expansions and contractions in the RCS [JE].

During operating mode 5a (cold shutdown pressurised), in shutdown make-up is required due to coolant contracting as temperature decreases and for raising the pressuriser level to collapse the steam bubble and facilitate the depressurisation of the plant. In start-up, the plant is operating water solid with pressure control provided by the charging pumps prior to starting the RCPs.

During operating mode 5b (cold shutdown depressurised), for shutdown the plant is drained for refuelling through the let-down line, and for start-up filled with coolant to the top of the pressuriser through the make-up line.

During operating mode 6a (refuelling with reduced water level above fuel), the LVCS [KBA] will letdown and drain the RCS [JE] to under the RPV closure head level, to enable to RPV head to be refitted. The LVCS [KBA] does not provide any function during operating mode 6b.

Chemistry Control System [KBD]

During operating modes 1 (power operations) and 2 (start-up), oxygen is kept to within its low-level range by providing a small flow of hydrogen into the reactor coolant to replenish losses. Zinc is kept to within its low-level range by zinc acetate dosing, and coolant pH is kept within its specification by potassium hydroxide dosing. During operating modes 3 (hot standby) and 4a (hot shutdown – steaming), zinc is kept to within its mid-level range.

During operating mode 4b (hot shutdown – non-steaming), at start-up oxygen levels are rapidly reduced by hydrazine injection and mechanical degassing. At shutdown, hydrogen levels are reduced by mechanical degassing, and oxygen levels are increased by opening vents in the RPV and the pressuriser to aerate the reactor primary coolant and injecting hydrogen peroxide.

During operating mode 5a (cold shutdown pressurised) and 5b (cold shutdown depressurised), rapid oxygenation is achieved by injecting hydrogen peroxide into the RCS [JE].

Coolant Purification System [KBE]

During operating modes 1 (power operations), 2 (start-up), 3 (hot standby), and 4a (hot shutdown – steaming), the continuous flow rate through the loop is controlled using the throttle valve, with driving head provided by the RCPs [JEB]. The mixed bed IXCs can be used to reduce coolant zinc levels and purify coolant impurities where required. In the event of fuel failure, the Cation Bed IXC will perform failed fuel clean-up. Backwashable filters will filter suspended solids and any resin fines released from the IXCs.

During operating modes 4b (hot shutdown – non-steaming), 5a (cold shutdown pressurised), 5b (cold shutdown depressurised), 6a (refuelling with reduced water level above fuel), and 6b (refuelling with water level at nominal), driving head can also be provided through alignment to the CSCS [JNA] pumps. Should it be required, the mixed bed IXCs and backwashable filters can perform coolant clean-up following CRUD burst.

During faulted operations, in the event of a LOCA within the CVCS [KB], the containment isolation valves will close to isolate it.

5.13.1.7 Instrumentation and Control

Level and Volume Control System [KBA]

The Level and Volume Control System [KBA] places requirements on the Reactor Control and Protection System [JY] to monitor and indicate a range of key systems parameters and provide indication of these to the operator in the control room and in the emergency control centre, including the let-down flow rate and pressure, and charging pump status, inlet/outlet pressure, and flow rate.

It will also provide alarms to indicate that key system parameters are outside of the defined performance bands and/or safety limits. The requirements for monitoring, indication, alarms, and warnings are specified in the LVCS SDD [40].

Chemistry Control System [KBD]

The Chemistry Control System [KBD] places requirements on the Reactor Control and Protection System [JY] to provide control functions for control of the zinc dosing pump and automation of dosing, control of the hydrogen addition control valves and automation of continuous hydrogen injection, and control of the chemical dosing pump and automation of potassium hydroxide dosing.

It also places requirements to monitor, indicate and alarm on a range of key systems parameters and provide indication of these to the operator in the control room and in the emergency control centre, including the chemical and zinc tank level/filter differential pressure/pump status, and the hydrogen gas bottle manifold pressure, and line flow rate/outlet pressure.

Coolant Purification System [KBE]

The CPS [KBE] places requirements on the Reactor Control and Protection System [JY] to provide control functions for opening/shutting containment isolation valves.

It also places requirements to monitor, indicate and alarm on a range of key systems parameters and provide indication of these to the operator in the control room and in the emergency control centre, including the pre-cooler and cooler outlet temperature, inlet and return line flow rate, and downstream filter differential pressure.

The allocation of safety categorised functional requirements from the CVCS [KB] to the Reactor Control and Protection System [JY] is presented in the C&I Engineering Schedule, described further in E3S Case Version 2, Tier 1, Chapter 7: Instrumentation and Control [15].

5.13.1.8 Monitoring, Inspection, Testing and Maintenance

The EMIT activities for the CVCS [KB] are defined as TLAs within the RR SMR requirements management database, and cover safety derived tasks (ISI, reliability derived tasks (RCM/preventative maintenance), and industry best practice/OPEX including the EPRI PMBD).

5.13.1.9 Radiological Aspects

Backwashable filters are selected that enables automation of filter regeneration and remote cleaning, which significantly reduces the need for filter changes compared to traditional PWR filtering methods, in turn reducing operator dose uptake during EMIT.

5.13.1.10 Performance and Safety Evaluation

Verification strategies for the CVCS [KB] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements include mechanical flow and thermal hydraulic performance analysis. The suite of performance analysis for bounding fault conditions that place safety categorised functional requirements on the CVCS [KB] are presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [3].

Details of the key decisions taken in support of developing the CVCS [KB] system design are presented are presented in the SDDs [40] [41] [42] and associated decision records.

5.13.2 Residual Heat Removal System

5.13.2.1 System and Equipment Function

The residual heat removal for the RR SMR is carried out by the CSCS [JNA]. The primary function of the CSCS [JNA] is to provide low temperature decay heat removal at temperatures below {REDACTED} and plant pressures below {REDACTED}.

The CSCS [JNA] contributes to the achievement of FSFs of CoFT and CoRM for duty operation.

The CSCS [JNA] also supports the Low Temperature Decay Heat Removal (LTDHR) [JN04] safety measure to achieve temperature hold down during fault conditions; this E3S requirements and design definition for this safety measure is described in the E3S Case Version 2, Tier 1, Chapter 6: Engineered Safety Features [7].

5.13.2.2 Design Basis

Functional Requirements

Safety categorised functional requirements specified for the CSCS [JNA], based on the HLSFs they deliver, are presented in Table 5.13-2 based on [43].

Table 5.13-2: CSCS [JNA] Safety Categorised Functional Requirements

Requirement ID	Functional Requirement	Plant State(s)	Mode(s) of Operation	Safety Category
JNA-R-1386	While in normal shutdown, the Cold Shutdown Cooling System [JNA] shall transport primary fluid to the Reactor Coolant Pressurizing System [JEF] to reduce the plant pressure.	DBC-1 DBC-2	4b – 5b	C
JNA-R-1394	While in normal shutdown, the Cold Shutdown Cooling System [JNA] shall circulate primary fluid between the Reactor Coolant Pipework System [JEC] and the Coolant Purification System [KBE].	DBC-1 DBC-2	4b – 6b	C
JNA-R-1370	While the RCS is pressurised, and in faulted operation, the Cold Shutdown Cooling System [JNA] shall actively transfer heat, from the Reactor Coolant Pipework System [JEC] to the Component Cooling System [KAA].	DBC-3 DBC-4	4b	B
JNA-R-1379	While the RCS is de-pressurised and open to atmosphere, and in faulted operation, the Cold Shutdown Cooling System [JNA] shall actively transfer heat, from the Reactor Coolant Pipework System [JEC] to the Component Cooling System [KAA].	DBC-3 DBC-4	6a	B
JNA-R-1380	While in Power Operations, when at FPCS cooling train outage, and in faulted operation, the (JNA) Cold Shutdown Cooling System shall remove heat from the Spent Fuel Pool [FAB10].	DBC-3 DBC-4	1	B
JNA-R-1592	When demanded, the Cold Shutdown Cooling System [JNA] shall isolate the containment boundary.	DBC-3 DBC-4	All	A

The safety categorised functional requirements for the CSCS [JNA] are flowed down and allocated to relevant sub-systems and/or components in [44]. Non-functional performance requirements associated with the safety categorised functional requirements are presented in [43].

No environment, security or safeguards functional requirements are assigned at RD7/DRP1.

Non-Functional System Requirements

Non-functional system requirements are allocated to the CSCS [JNA] based on the E3S design principles as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2], listed in [43].

E3S Classification

Safety Classification

The safety classification of the CSCS [JNA] is undertaken in accordance with the methodology outlined in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules [2].

For duty operation, the CSCS [JNA] delivers safety category C functions. However, the safety classification for the majority of the CSCS [JNA] is driven by the safety category of the function to remove decay heat during faulted operation, which is safety category B and hence are a assigned a safety class 2.

Isolation valves within CSCS [JNA] boundary support the safety category A function to isolate containment in support of ECC [JN01] operation and are assigned a safety class 1.

Environment, Security and Safeguards Classification

No environment, security or safeguards classification is assigned at RD7/DRP1.

Seismic Performance Classification

The seismic classification is SPC1 in accordance with E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2].

5.13.2.3 Description

At RCS [JE] temperatures above 120 °C the Turbine Island steam and feed systems are used to remove heat from the RCS [JE]; however, at temperatures below 120 °C heat transfer in the SGs will be ineffective. Therefore, when the plant needs to be cooled below 120 °C (such as during refuelling operations) the CSCS [JNA] is used for reactor plant temperature control.

During cool-down, both CSCS [JNA] trains are operated to reduce RCS [JE] temperature. Once a sufficiently low temperature for refuelling operations is achieved (55 °C or below), the function of the CSCS [JNA] is to hold temperature at this value (or below) until such a time that decay heat removal can be handed over to the Fuel Pool Cooling System (FPCS) [FAK] or the reactor is restarted.

Heated primary coolant is drawn from a single RCS [JE] hot leg connection and is split into two parallel cooling trains. Each train contains a low-pressure pump and a shell and tube HX. Hot coolant is circulated by the pump through the hot side of the HX with flow through the cold side provided by the Component Cooling System (CCS) [KAA]. The cold coolant exiting the HX is pumped through the core via a CSCS [JNA] connection to an RCS [JE] cold leg connection.

During shutdown modes the CSCS [JNA] also provides flow to the CPS [KBE] and, via the CPS [KBE], to the Pressurising System [JEF]. These supply and return connections are attached to the common RCS supply and return lines located inside containment. This arrangement places the CPS [KBE] and Pressurising System [JEF] pipework in parallel with the RCS [JE] system, with the CSCS [JNA] pumps circulating coolant.

Additional supply and return connections to the FPCS [FAK] are also provided within each of the CSCS [JNA] cooling trains to allow the CSCS [JNA] to provide backup cooling to the Spent Fuel Pool (SFP) [FAB10], should the FPCS become faulted, in support of Fuel Pool Cooling Safety Measures.

Each train is aligned for cooling through operation of remotely controlled valves downstream of the HX and opening of the containment isolation valves, with the manual maintenance isolation valves upstream and downstream of the pumps already open. Within each cooling train, a recirculation line containing an inline control valve is provided from the outlet of the HX to the CSCS [JNA] pump suction to regulate flowrate.

The system has connections to the Reactor Coolant Pressure Relief System [JEG] on the common suction line from the RCS [JE] for LTOP during shutdown. Pressure relief within the CSCS [JNA] cooling trains is provided by low-capacity pressure or thermal relief valves on each cooling train. Interlocks are in place to prevent initiation of the CSCS [JNA] before the primary circuit pressure and temperature are within operating limits.

A simplified schematic of the system is illustrated in Figure 5.13-4.

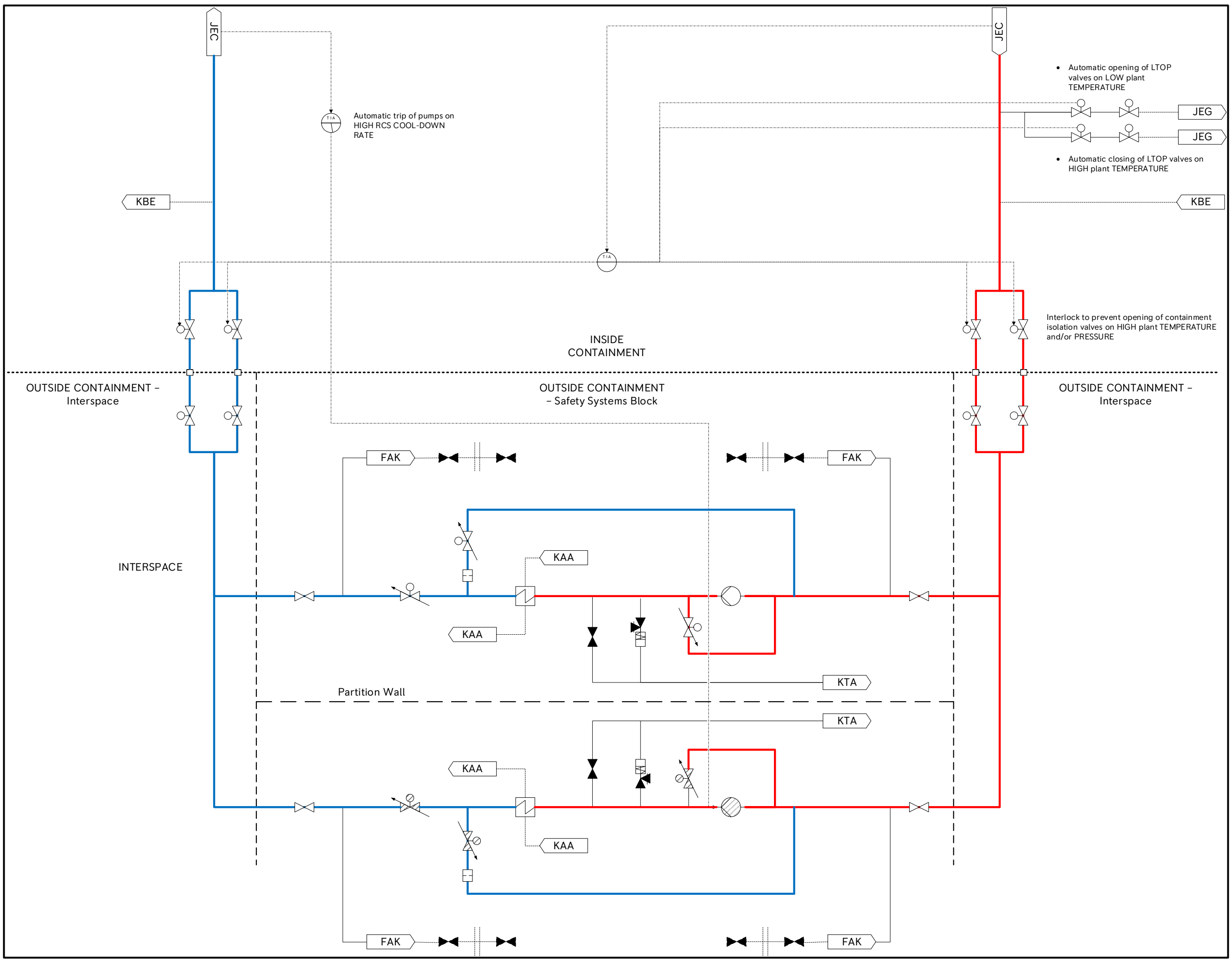

Figure 5.13-4: Simplified Schematic of the CSCS [JNA]

Further description of the CSCS [JNA] is provided in the CSCS SDD [45].

5.13.2.4 Materials

Most of the material used in CSCS [JNA] will be stainless steel. This is used to construct the pipework for the cooling trains, supply and return pipework to the RCS [JEC], and the key components, such as valves, heat exchangers and pumps. The justification of materials used for safety class 2 SSCs are presented in E3S Case Version 2, Tier 1, Chapter 23: Structural Integrity [1].

5.13.2.5 Interfaces with Supporting Systems

The functional and physical interfaces for the CSCS [JNA] are described in section 5.13.2.3.

5.13.2.6 System Operation

During operating modes 1 (power operations), 2 (start-up), 3 (hot standby), and 4a (hot shutdown – steaming), both containment isolation valves and the remote system isolation valves are closed.

During operating modes 4b (hot shutdown – non-steaming) and 5a (cold shutdown pressurised), both trains are operated. Both containment isolation valves and the remote system isolation valve are opened to align the CSCS coolant pumps to provide spray flow to the top of the pressuriser. Manual maintenance isolation valves and remote cooling train control valves will also be opened. A constant flow of coolant is allowed to circulate through the CPS [KBE] to replicate the primary coolant purification process during normal power operations.

During operating mode 5b (cold shutdown depressurised), the CSCS [JNA] is now required to hold the reactor plant temperature below {REDACTED} at atmospheric pressure. Both cooling trains remain operational throughout the mode.

During operating modes 6a (refuelling with reduced water level above fuel) and 6b (refuelling with water level at nominal), both trains will continue to operate, however should it be necessary under faulted conditions, a single train may provide sufficient cooling to maintain the {REDACTED} (maximum) hold-down temperature of the RCS [JEC].

Operations during faulted operation will be described as part of the LTDHR [JN04] safety measure in E3S Case Version 2, Tier 1, Chapter 6: Engineered Safety Features [7].

5.13.2.7 Instrumentation and Control

The CSCS [JNA] places requirements on the Reactor Control and Protection System [JY] to provide control functions, including control of pumps, alignment of remote isolation valves, and control of remotely operated valves. It also places requirements to monitor, indicate and alarm on a range of key systems parameters and provide indication of these to the operator in the control room and in the emergency control centre, including pump state, valve state and position, cooling train mass flow rates, heat exchanger inlet/outlet temperature, and pump bearing/winding temperature. These are described in the CSCS SDD [45].

The allocation of safety categorised functional requirements from the CSCS [JNA] to the Reactor Control and Protection System [JY] is presented in the C&I Engineering Schedule, described further in E3S Case Version 2, Tier 1, Chapter 7: Instrumentation and Control [15].

5.13.2.8 Monitoring, Inspection, Testing and Maintenance

The EMIT activities for the CSCS [JNA] are defined as TLAs within the RR SMR requirements management database, and cover safety derived tasks (ISI, reliability derived tasks (RCM/preventative maintenance), and industry best practice/OPEX including the EPRI PMBD).

It is expected that CSCS [JNA] EMIT will be performed during powered operations (operating mode 1) when fully isolated. Additionally, maintenance will be scheduled to avoid times when parts of the FPCS [FAK] are unavailable due to maintenance, so as not to undermine its reliability for providing back-up cooling to the FPCS [FAK].

5.13.2.9 Radiological Aspects

As the CSCS [JNA] handles primary circuit quality water, in general, subsystems and components will use low activation synthetic materials, rather than organic ones, in oils, insulation and lagging etc.

5.13.2.10 Performance and Safety Evaluation

Verification strategies for the CSCS [JNA] to demonstrate compliance with its safety categorised functional requirements and associated non-functional performance requirements primarily include thermal hydraulic performance analysis. At RD7/DRP1, analysis supports design optimisation as presented in the CSCS SDD [45]. The suite of performance analysis for bounding fault conditions that place safety categorised functional requirements on the CSCS [JNA] are presented in E3S Case Version 2, Tier 1, Chapter 15: Safety Analysis [3].

Key CSCS [JNA] design decisions made with respect to ensuring overall risks are reduced to ALARP include:

- The CSCS [JNA] comprises a two-train architecture that operates on a 1oo2 basis to achieve hold-down and two trains used to achieve cool-down. This is selected on the basis that it achieves the required reliability and presents the optimised position with respect to through-life EMIT and capital costs. One and three train architectures were considered as part of the optioneering assessment, which concluded that a single train would be unlikely to meet reliability targets, and whilst a three-train system would increase the level of redundancy and reliability, this would be of limited safety benefit due to potential for common cause failures whilst introducing the potential for additional leak paths. A review of RGP also showed that other PWR designs for residual heat removal systems generally incorporate N+1 redundancy.

- The design solution for a single set of supply and return connections to the RCS [JE] has been assessed against options incorporating additional redundancy. A single connection can meet all deterministic expectations for DiD and redundancy (as a safety class 2 system it is not subject to single failure criterion), and evaluation of failure frequencies demonstrates that it can meet probabilistic risk targets by several orders of magnitude. An increased level of redundancy would increase the reliability of the system, though this would be marginal given the increased risk of a LOCA. A review of RGP shows that higher levels of redundancy are incorporated in other PWR designs, however these systems are generally part of safety systems that support delivery of a safety category A safety function, which is not representative of the RR SMR CSCS [JNA]

More detailed information on design decisions is presented in the CSCS [JNA] SDD [45] and associated design decision files.

5.14 Conclusions

5.14.1 ALARP, BAT, Secure by Design, Safeguards by Design

The design of all SSCs presented in this chapter are developed in accordance with the systems engineering design process. This 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 criteria that ensure risks are reduced to ALARP, apply BAT, and are secure by design and safeguards by design, as described in E3S Case Version 2, Tier 1, Chapter 3: E3S Objectives and Design Rules for SSCs [2]. This provides confidence that claims can be met when the full suite of arguments and evidence is developed.

A summary of key design decisions made with respect to ensuring overall risks are reduced to ALARP, BAT, secure by design and safeguards by design is provided, where applicable based on design decisions up to RD7/DRP1, in respective sections of this chapter. The overall demonstration of ALARP, BAT, secure by design and safeguards by design at RD7/DRP1 is presented in E3S Case Version 2, Tier 1, Chapters 24, 27, 32 and 33 respectively.

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

None identified in this revision.

5.14.3 Conclusions and Forward Look

The generic E3S Case is developed to meet its objective 'to provide confidence that the RR SMR design will be capable of delivering the E3S fundamental objective as it developed from a concept design into a detailed design' [4]. This confidence is built through development and underpinning of top-level claims across each chapter of the E3S Case, through supporting arguments and evidence. The top-level claim for chapter 5 is '*the RR SMR Reactor Coolant System and Associated Systems are designed and substantiated to achieve functional and non-functional safety requirements through the lifecycle and reduce risks to ALARP*'.

The arguments and evidence presented to meet the generic E3S Case objective at Version 2 include the selection of appropriate codes and standards that follow RGP. Safety functions are identified aligned to the FSFs, which are categorised in accordance with the E3S categorisation and classification methodology, with SSCs assigned both a safety and seismic classification.

The design and layout of SSCs at RD7/DRP1 are also developed and evaluated in accordance with the E3S design principles through the integrated E3S and engineering processes [2], including design optioneering, to drive risk reduction to ALARP, and to demonstrate BAT, secure by design and safeguards by design. This provides confidence that E3S functions can be achieved by the design as functional requirements are derived through ongoing and iterative E3S analyses.

Further arguments and evidence to underpin the claim will be developed in line with the E3S Case Route Map [5] and reported in future revisions of the generic E3S Case, which will further build confidence that the RR SMR can deliver its fundamental E3S objective. This broadly includes continued iterative E3S analysis and finalisation of E3S requirements including environment, security and safeguards, detailed design development of all SSCs, and verification and validation of E3S requirements.

5.15 References

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[17] Rolls-Royce SMR Limited, SMR0004210 Issue 3, "Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 4: Reactor (Fuel and Core)," May 2024.

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5.16 Appendix A: Claims, Arguments, Evidence

Table 5.16-1 provides a mapping of the claims to the corresponding sections of the chapter that summarise the arguments and /or evidence. The full decomposition of claims and link to underpinning Tier 2 and Tier 3 information containing the detailed arguments and evidence is presented in the E3S Case Route Map [5]. The route map includes the trajectory of Tier 2 and Tier 3 information as the generic E3S Case develops, which will be incorporated into Tier 1 chapters as it becomes available and in line with generic E3S Case issues described in [4].

Table 5.16-1: Mapping of Claims to Chapter Sections

Claim	Section of Chapter 5 containing arguments / evidence summary
The Reactor Pressure Vessel [JAA] Non-Functional System Requirements are complete	Section 5.4.2.2
The Reactor Pressure Vessel [JAA] Non-Functional System Requirements are correctly assigned	Section 5.4.2.2
The Reactor Pressure Vessel [JAA] codes and standards are correctly assigned	Section 5.0.4
Safety Requirements for the Reactor Pressure Vessel [JAA] are complete	Section 5.4.2.1
Environmental Functional Requirements for the Reactor Pressure Vessel [JAA] are complete	None at this revision
Security Functional Requirements for the Reactor Pressure Vessel [JAA] are complete	None at this revision
Safeguards Functional Requirements for the Reactor Pressure Vessel [JAA] are complete	None at this revision
The Reactor Pressure Vessel [JAA] is classified correctly	Section 5.4.2.3
The Reactor Pressure Vessel [JAA] design achieves its E3S functional requirements	Section 5.4.6
The Reactor Pressure Vessel [JAA] design achieves its E3S non-functional system requirements	Section 5.4.6
Structural integrity is substantiated commensurate with the SSC classification	Covered in E3S Case Chapter 23
The Reactor Pressure Vessel [JAA] design definition is verified to meet its requirements	Section 5.4.6
The Reactor Pressure Vessel [JAA] system is validated to meet its E3S functions	Not covered in this revision
Verification of the Reactor Pressure Vessel [JAA] system is preserved through its operational life	Not covered in this revision
Reactor Coolant System [JE]	Section 5.3

Claim	**Section of Chapter 5 containing arguments / evidence summary**
claims structure as The Reactor Pressure Vessel [JAA] system	
Steam Generation System [JEA] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.6
Reactor Coolant Pump System [JEB] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.5
Reactor Coolant Pipework System [JEC] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.7
Reactor Coolant Pressurising System [JEF] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.8
Reactor Coolant Pressure Relief System [JEG] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.11
Cold Shutdown Cooling System [JNA] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.13
Chemical and Volume Control System [KB] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.13
Level and Volume Control System [KBA] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.13
Chemistry Control System [KBD] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.13
Coolant Purification System [KBE] *claims structure as The Reactor Pressure Vessel [JAA] system*	Section 5.13

5.17 Appendix B: SSCs in Scope of Chapter 5

Table 5.17-1 lists those SSCs that are within the scope of Chapter 5, and the section of the chapter they are addressed.

Table 5.17-1: SSCs in Scope of Chapter 5

RDS-PP®	SSC	Section in Chapter 5
JAA	Reactor Pressure Vessel	5.4
JE	Reactor Coolant System	5.3
JEA	Steam Generation System	5.6
JEB	Reactor Coolant Pump System	5.5
JEC	Reactor Coolant Pipework System	5.7
JEF	Reactor Coolant Pressurising System	5.8
JEG	Reactor Coolant Pressure Relief System	5.11
JNA	Cold Shutdown Cooling System	5.13.2
KB	Chemistry and Volume Control System	5.13.1
KBA	Level and Volume Control System	
KBD	Chemistry Control System	
KBE	Coolant Purification System	

5.18 Abbreviations

1oo2	1 out of 2
ADS	Automatic Depressurisation System
ALARP	As Low As Reasonably Practicable
ASF	Automatic Shutdown Function
ASME	American Society of Mechanical Engineers
BAT	Best Available Techniques
BE	Best Estimate flow
BoL	Beginning of Life
BS	British Standard
BWR	Boiling Water Reactor
C&I	Control and Instrumentation
CAE	Controls, Arguments and Evidence
CCS	Cooling Component System
CFD	Computational Fluid Dynamics
CH	Closure Head
CHDR	Condenser Decay Heat Removal
CoFT	Control of Fuel Temperature
CoR	Control of Radioactivity
CoRM	Control of Radioactive Material
CPS	Coolant Purification System
CRDM	Control Rod Drive Mechanism
CRHC	Closure Rod Housing Column
CRUD	Chalk River Unidentified Deposits
CSR	Component Substantiation Report
CSCS	Cold Shutdown Cooling System
CVCS	Chemistry and Volume Control System
DBC	Design Basis Condition
DHR	Decay Heat Removal
DiD	Defence in Depth

DR	Definition Review
DRP	Design Reference Point
DVI	Direct Vessel Injection
E3S	Environment, Safety, Security and Safeguards
EBI	Emergency Boron Injection
ECC	Emergency Core Cooling
EMIT	Examination, Maintenance, Inspection and Testing
EoL	End of Life
EUR	European Utility Requirements
FPCS	Fuel Pool Cooling System
FSF	Fundamental Safety Functions
GDA	Generic Design Assessment
GER	Generic Environment Report
GSR	Generic Safety Report
HLSF	High Level Safety Function
HPIS	High Pressure Injection System
HR	High Reliability
HTHR	High Temperature Heat Removal
HTOP	High Temperature Overpressure Protection
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
ICI	In Core Instrumentation
IHP	Integrated Head Package
ISI	In-service Inspection
IVR	In-Vessel Retention
IXC	Ion Exchange Column
LOCA	Loss of Coolant Accident
LPIS	Low Pressure Injection System
LRETS	Liquid Radioactive Effluent Treatment System

LTOP	Low Temperature Overpressure Protection
LVCS	Level and Volume Control System
ME	Mechanical flow
MSIV	Main Steam Isolation Valve
NC	Natural circulation
OD	Outer Diameter
OPEX	Operating Experience
PCSR	Pre-Construction Safety Report
PDHR	Passive Decay Heat Removal
PIEs	Postulated Initiating Events
PMBD	Preventative Maintenance Basis Database
PWR	Pressurised Water Reactor
RCL	Reactor Coolant Loop
RCM	Reliability Centred Maintenance
RCP	Reactor Coolant Pump
RCS	Reactor Cooling System
RD	Reference Design
RDS-PP	Reference Designation System for Power Plants
RGP	Relevant Good Practice
RPV	Reactor Pressure Vessel
RR	Rolls-Royce
TE	Thermal-Hydraulic flow
TLA	Through-Life Activities
SDD	System Design Description
SG	Steam Generator
SGRV	Steam Generator Relief Valves
SMR	Small Modular Reactor
SRV	Safety Relief Valve

SSC	Structure, System and Component
UK	United Kingdom
UT	Ultrasonic Testing
VCT	Volume Control Tank
VFD	Variable Frequency Drive
VHR	Very High Reliability