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Title

Rolls-Royce SMR Design Overview White Paper

Executive Summary

This Design Overview White Paper is produced for the Rolls-Royce SMR (RR SMR) Pre-Application activity under United States (US) Nuclear Regulatory Commission (NRC) Docket Number 99902143. This document is based on the United Kingdom (UK) Environment, Safety, Security, Safeguards (E3S) Case, Version 3 at UK Generic Design Assessment (GDA) Design Reference Point 4. It provides an overview of the general design of the Rolls-Royce SMR power station.

This White Paper describes the organizational arrangements for development of the RR SMR design in the UK by Rolls-Royce SMR Ltd. Deployment of the RR SMR in the United States of America (USA) will be undertaken by a different organization, although organizational arrangements for this company are expected to be similar to those presented in this document. Any differences in organizational or Quality Assurance (QA) arrangements between the two entities will be highlighted and reported at the appropriate future licensing stages.

The RR SMR utilizes System Internationale (SI) units of measurement and these are used throughout this White Paper. To aid the reader, imperial units are shown in brackets following the SI units for clarity; however, the value in SI units is and shall be taken as the design value.

The RR SMR power station base design utilizes a 50 Hz, 3,000 rpm turbine generating at 400 kV. For deployment in the USA, a 60 Hz, 3,600 rpm set generating at the required supergrid voltage will be utilized. Values for the base design are quoted in this White Paper.

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1 Introduction

1.1 The Rolls-Royce SMR

1.1.1 Rolls-Royce SMR (RR SMR) delivers a modular nuclear power station capable of generating up to 470 MW_e of low-carbon electricity for 60 years. Designed for resilience and sustainability, the RR SMR supports the transition to a cleaner energy future. By combining proven nuclear technology with innovative deployment methods, we offer a cost-effective and efficient approach to baseload power generation—ideal for both national grids and a wide range of industrial applications.

1.1.2 RR SMR builds on over 100 years of pioneering innovation in aerospace and more than six decades of nuclear expertise, developed through the delivery of a number of generations of Pressurized Water Reactors (PWR) for the UK Royal Navy's nuclear submarine programme.

1.1.3 The RR SMR programme is led by a team with deep experience in nuclear design, regulatory compliance, advanced manufacturing, and modular assembly. Our engineering capabilities are further reinforced by the strategic involvement of key shareholders, with whom we are collaboratively advancing the future of clean and reliable energy:

- Constellation Energy - operate 21 power stations in the U.S. which regularly achieve industry leading capacity factors and bring a wealth of experience in safe and efficient operations,
- ČEZ – the largest utility company in Central and Eastern Europe who operate two nuclear power plants in the Czech Republic, providing approximately one third of its electricity.

1.1.4 At its heart, the RR SMR utilizes proven PWR technology with an established track record for safety and reliability. This technology, used in over 70 % of nuclear power stations worldwide, together with our unique factory manufactured approach across the entire power station, provides a plant that is affordable, repeatable, investable and predictably deployable on sites around the World.

1.1.5 RR SMR can deliver private-wire high utilisation for baseload power and reliable thermal power for both district heating and industrial applications including hydrogen, sustainable fuel and ammonia production as well as supporting energy intense uses such as desalination.

2 What Differentiates Rolls-Royce SMR

2.1 Factory Manufactured Modular Approach

2.1.1 RR SMR maximizes modularization throughout the entire power station to enable standardized, factory-based and repeatable production. Our power station is unique to the extent to which this modular approach is being applied and utilizing proven nuclear technology to deliver reliable, always-on clean energy. Our factory-built, repeatable design, lowers capital costs, reduces project risk, and provides deployment certainty, making it an investable nuclear energy solution.

2.1.2 Road transportable modules are built and tested off-site and transferred to site for an efficient on-site assembly process within a covered facility (the Site Factory), minimizing construction time and weather-related delays.

2.1.3 The Reactor Island utilizes a raft foundation supported on aseismic bearings allowing the generic plant design above the aseismic bearings to be largely independent from the specific site location characteristics and facilitating the consistent and repeatable deployment of our generic power station design across different sites. Through this repeatable approach, site specific redesign of the generic plant for specific site conditions is reduced, driving a lower overall project cost and providing certainty in the deployment schedule.

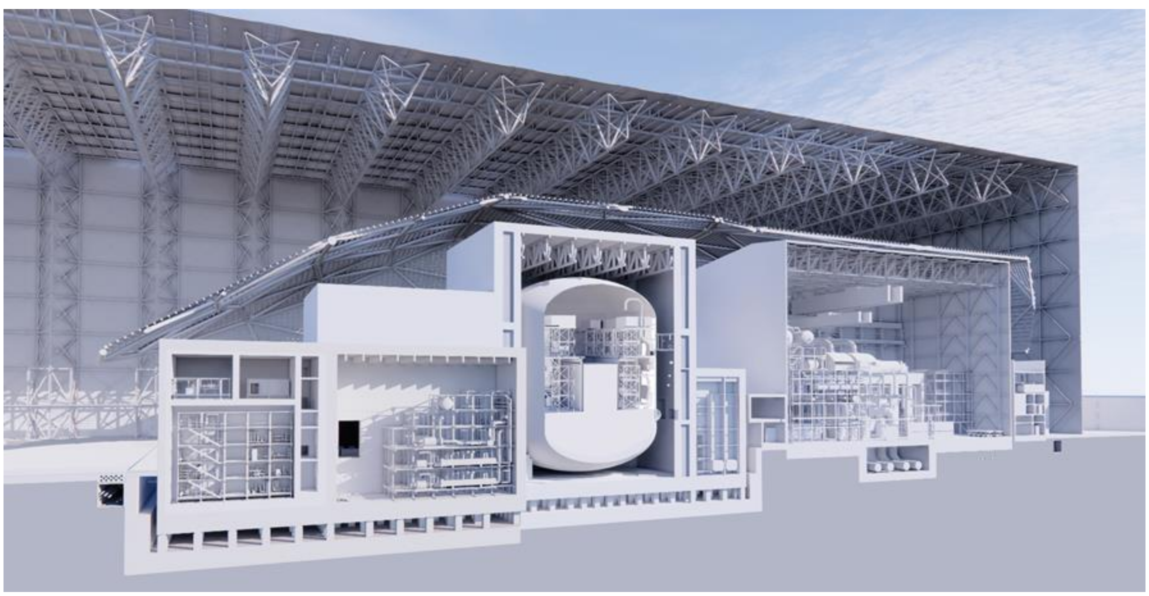

Figure 1 – Rolls-Royce SMR Side Profile

2.1.4 Our model is replicable across a fleet of global deployments, creating long-term skilled employment opportunities, and knowledge transfer through repeatable manufacturing and assembly processes.

2.2 Simplification of Project Delivery

2.2.1 RR SMR delivers a complete nuclear power station under a single, integrated Engineering, Manufacturing, and Assembly (EMA) contract. This approach contrasts with the traditional Engineering, Procurement, and Construction (EPC) model traditionally used for large nuclear projects, reducing the burden on customers by reducing contractual interfaces and parties reducing project complexity and risk.

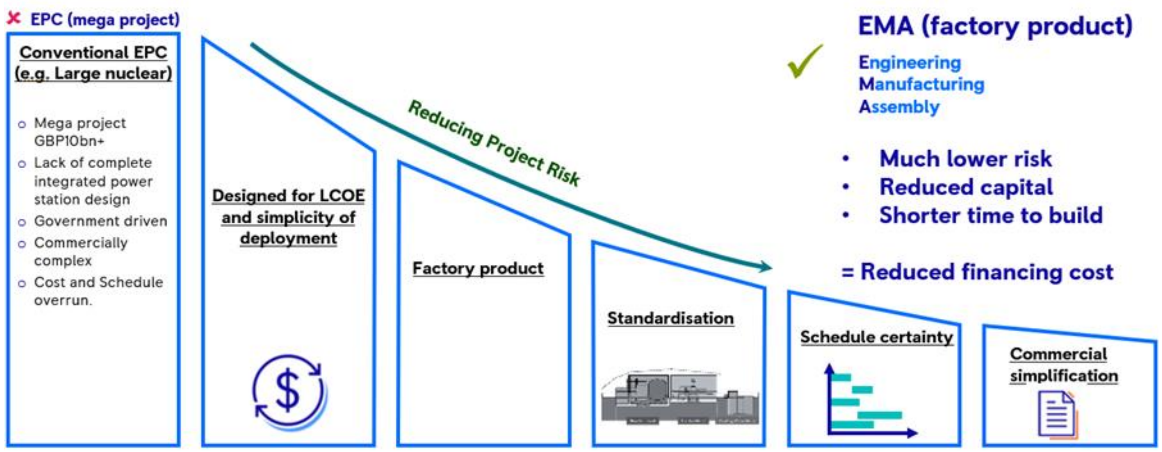

Figure 2 – EMA contract model

2.2.2 RR SMR stands out as the only Small Modular Reactor (SMR) provider offering a full nuclear power station solution under a single EMA contract. The EMA contracting model, hand-in-hand with our modular approach, treats nuclear power as a factory product, providing project repeatability and delivery certainty offering a lower overall project risk profile.

2.2.3 Our design and manufacturing strategy incorporates standardized components within factory assembled Mechanical, Electrical and Plumbing (MEP) modules. These modules are tested in a controlled factory environment before being transported to site, where they are stacked and connected through a streamlined assembly process. This eliminates the need for traditional stick-built construction. By shifting activity off-site, we gain greater control and consistency, which enhances overall quality. Additionally, with fewer on-site operations and personnel, this method significantly improves health and safety while reducing disruption to the local community.

2.2.4 This integrated and factory-based methodology promotes cost and schedule certainty. The flexibility of our approach supports centralized production while facilitating scalable, repeatable implementation on a global level.

2.3 Maximizing Power Output

2.3.1 The RR SMR has been engineered to maximize power output while retaining the logistical and quality advantages of off-site manufacturing. This design approach supports a low Levelized Cost of Electricity (LCOE) for customers. With a capacity of up to 470 MW_e, it ranks among the most powerful SMRs available and is capable of delivering reliable, low-carbon energy for up to 60 years.

2.3.2 This power level preserves the benefits of off-site production and EMA contracting, achieving the ideal balance between cost efficiency and delivery certainty. It represents the maximum power achievable while remaining within road transport limits – combining economic and logistical efficiencies of standardized, scalable production. This approach is fundamental in ensuring an investable product that minimizes LCOE.

2.3.3 The power station has also been designed with a focus on operational efficiency, helping to lower ongoing operational costs. This optimization has been supported by the expertise of our operator-shareholder.

2.4 Using Established PWR Technology

2.4.1 The RR SMR is a PWR and uses standard low enriched UO_2 fuel, technology which is familiar to global regulators and operators, providing an efficient and low-risk route to market.

2.4.2 RR SMR is now in the final Step of the UK's Generic Design Assessment (GDA) making it the most progressed SMR within a European licensing framework. Supporting this progress is our integrated Environment, Safety, Security, and Safeguards (E3S) Case, which aligns closely with IAEA SSG-61 and follows the structure of the US Nuclear Regulatory Commission's Regulatory Guides 1.70 and 1.206. This provides a standardized, internationally recognized format that supports efficient global regulatory engagement.

3 How a Rolls-Royce SMR is Delivered

3.1 Standardized Product

3.1.1 The RR SMR is delivered as a standard unit design with all of the equipment necessary (including its own turbine-generator package) for single unit operation or can be co-located with additional units to meet increased power demands.

3.1.2 The RR SMR is designed as a modular and standardized power station product, meaning that each unit is substantively the same as the others; so far as is possible, within the constraints of the site-specific environment.

3.1.3 Our design strategy to deliver this outcome considers the power station delivery in two parts:

- Groundworks and foundations and
- Standardized power station modules and buildings.

3.1.4 The groundworks and foundations for the power station are necessarily bespoke and matched to the local site ground conditions, and support the aseismic raft, upon which standard modules and buildings of the Reactor Island reside. The use of an aseismic bearing, assembled as a raft, significantly attenuates seismic ground motion, de-coupling the plant structures above – a key enabler for the repeatability of our standardized modular approach from site-to-site.

3.1.5 To provide an optimized power station for a given site, the RR SMR has the flexibility to incorporate different cooling water solutions such as indirect, direct and closed cooling.

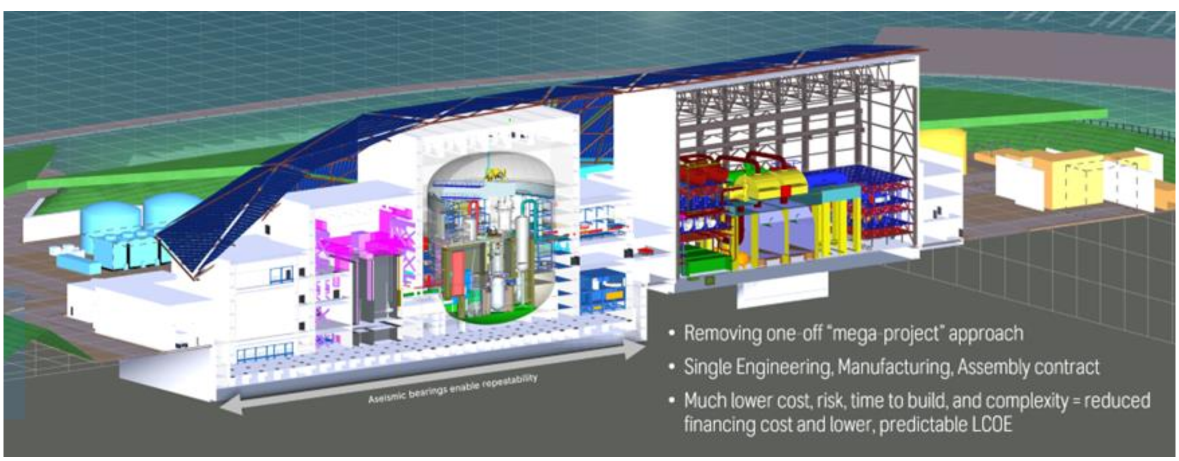

Figure 3 – Reactor and Turbine Island

3.2 Site Factory

3.2.1 On-site assembly of the power station modules and buildings is undertaken within an enclosed space via the implementation of a temporary construction shelter ('Site Factory' building). This has three main advantages:

- The site is isolated from the surrounding environment, practically eliminating the impact of adverse conditions such as wind, rain and snow,
- The local environment is isolated from the site construction, significantly reducing environmental impact, noise, and light pollution during construction and
- Facilities to support the construction workforce can be enhanced and security combined into a single physical structure. This may also allow for enhanced working hours (shift working, 24/7 working if desired).

4 Technical Overview

4.1 Power Station Overview

4.1.1 The RR SMR comprises a single unit, three-loop PWR which provides a power output of up to 470 MW_e (depending on site conditions) using industry standard UO_2 fuel. The design includes multiple active and passive safety systems, each with substantial internal redundancy.

4.1.2 The RR SMR consists of the following key areas:

- Reactor Island – includes the Structures, Systems and Components (SSC) that form the reactor, transfer and storage of new and used fuel, and any associated nuclear auxiliary systems. The purpose of the Reactor Island is to safely, and considering environmental impact, use the heat from a controlled nuclear fission reaction to generate steam, which is then passed to the Turbine Island,

- Turbine Island – takes the steam generated within the Reactor Island and using a steam turbine and generator, produces electricity, which is provided to the grid. There is capacity within the design for alternative combined heat and power application; in this scenario some of the steam is directed to secondary processes,

- Cooling Water Island – provides the primary means of removing heat from the power station, passing it to the external natural environment. It also provides auxiliary cooling to the Turbine Island systems,

- Balance of Plant – provides a range of ancillary functions to enable the rest of the power station to generate electricity.

4.2 Siting and Layout

4.2.1 Design features such as seismic isolation for safety related areas and road transportable modules ensure that the power station can be constructed on a wide range of site locations. In addition, the design baseline uses indirect cooling for the Cooling Water Island, which provides significant siting flexibility. This can be further adapted to meet local conditions (e.g. direct cooling or a dry cooling system) and facilitate installation on an even wider range of sites. The primary power station area: Reactor Island, Turbine Island, Balance of Plant (and outage laydown areas) is located within an earth berm and further areas containing, primary car parking area, grid connection area and waste stores sit outside this.

4.2.2 The main Cooling Water Island systems are located outside of the main site earth berm, within the Cooling Water Island satellite site (specific to indirect cooled plant variants). These are oriented to optimally meet the local site conditions.

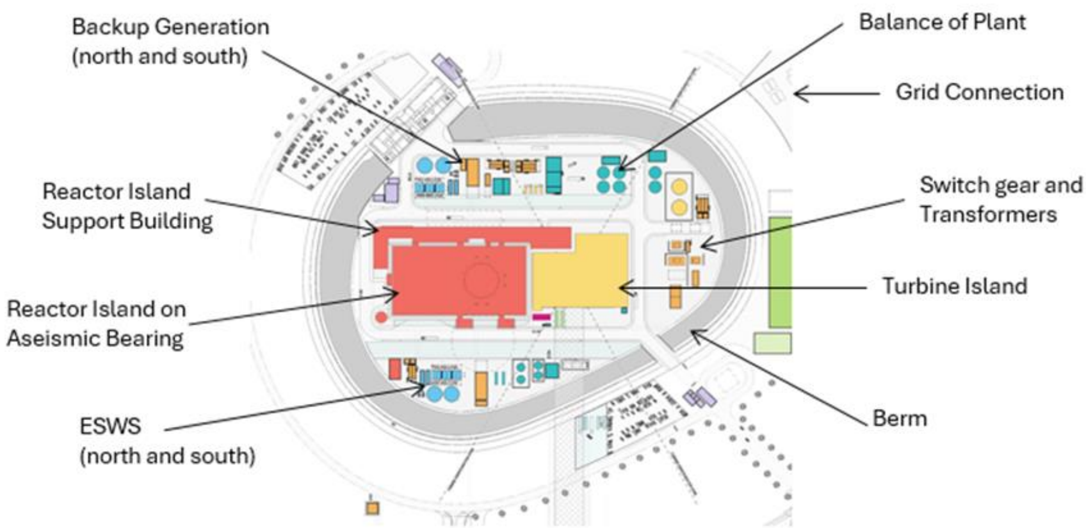

Figure 4 – Rolls-Royce SMR Site Layout

4.2.3 The Turbine Island has been located adjacent to the Reactor Island, to enable ease of connection and routing, particularly of the steam and the feedwater pipes, which run between Containment within the Reactor Island and Main Turbine Generator System within the Turbine Island. This is to minimize steam pressure losses and maximize electrical output.

4.2.4 New fuel import, fuel handling, fuel transfer channel, containment, steam and feedwater pipes, turbine hall and main generator, transmission area and main feed to the grid are all located along the central axis of the site.

4.2.5 The main transmission area, which contains the grid connection, has been positioned directly adjacent to the Turbine Island to minimize routing and power loss.

4.2.6 The primary access point to RR SMR has been positioned to the north-west of the Reactor Island so as to have a close relationship with the Reactor Island support building, which provides access to these critical areas. The support building is located directly north of the Reactor Island. However, the exact positions of access and support buildings can be tailored to site needs.

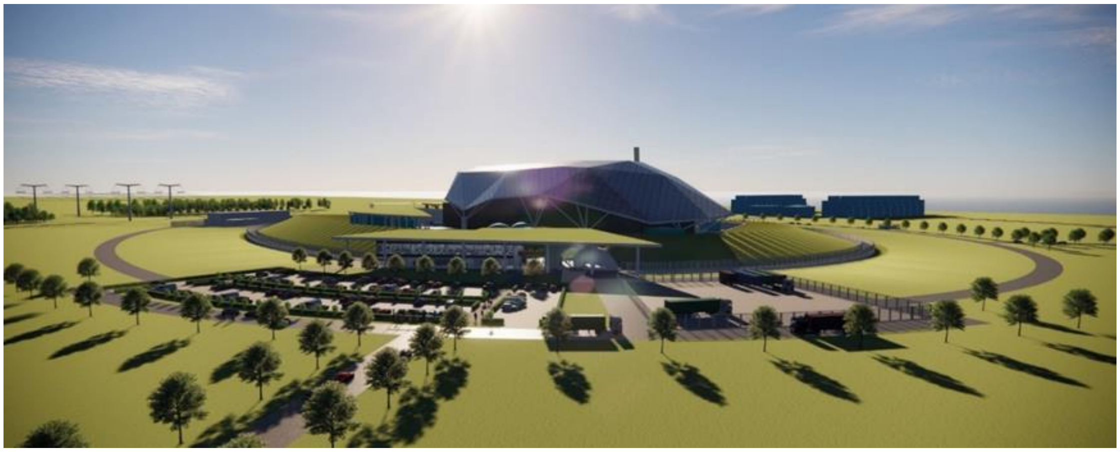

Figure 5 – Rolls-Royce SMR Earth Berm

4.2.7 Figure 4 shows the functional plant area is surrounded by an earth berm that obscures the day-to-day working heart of the power station from view with the folded tectonic shell structure accommodating a diversity of facilities that run the power station.

4.3 Power Station Area and Dimensions

4.3.1 The power station areas for a generic indirect cooled site are summarized in Table 1.

Table 1 – Power Station Areas Summary

Primary Plant Area inside Berm	Additional Functional Areas outside Berm	Cooling Water Island	Construction Footprint
100,000 m^2 (24.7 Acres)	47,728 m^2 (11.8 Acres)	68,266 m^2 (16.9 Acres)	450,000 m^2 (111.2 Acres)

4.3.2 The generic site areas outlined above need to be tested against site specific criteria such as topography, highways, watercourses prevailing wind etc. Further site-specific fit analysis is required to fully assess land area requirements and optimize the final site and construction layouts.

4.3.3 The site footprint of the berm site is 100,000 m^2 (24.7 acres). The maximum length of the berm is 410 m (1345 ft) with a maximum width of 340 m (1115.5 ft) and a maximum height of 11 m (36 ft). Figure 6 highlights the additional functional areas outside of the berm including the grid connection, entrances, parking and vehicle checking points and ILW and spent fuel stores. The areas of these are:

- Grid connection = 7,238 m^2 (1.8 Acres),
- Primary parking, and vehicle checking points = 16,5139 m^2 (40.8 Acres),
- Intermediate Level Waste (ILW) and Spent Fuel stores = 9,980 m^2 (2.5 Acres).

4.3.4 The Reactor Island and Turbine Island are enveloped with an architectural shell and are the largest structures on the power station site. The highest point of the shell is approximately 47 m (154 ft) above ground level. The combined footprint of the Turbine Island and Reactor Island is 19,189 m² (4.7 Acres).

4.3.5 The RR SMR will have the ability to be adapted to accommodate different cooling water systems (direct, dry etc.) to meet the siting requirements. Currently the RR SMR design baseline is for a standard indirect cooling system with Mechanical Draft Cooling Towers (MDCT).

4.3.6 The cooling tower modules, alongside other supporting systems such as the Forebay, Intake Tunnels and Pumphouse, are located outside of the main site earth bund, within the Cooling Water Island satellite site. These are oriented to optimally meet the local site conditions.

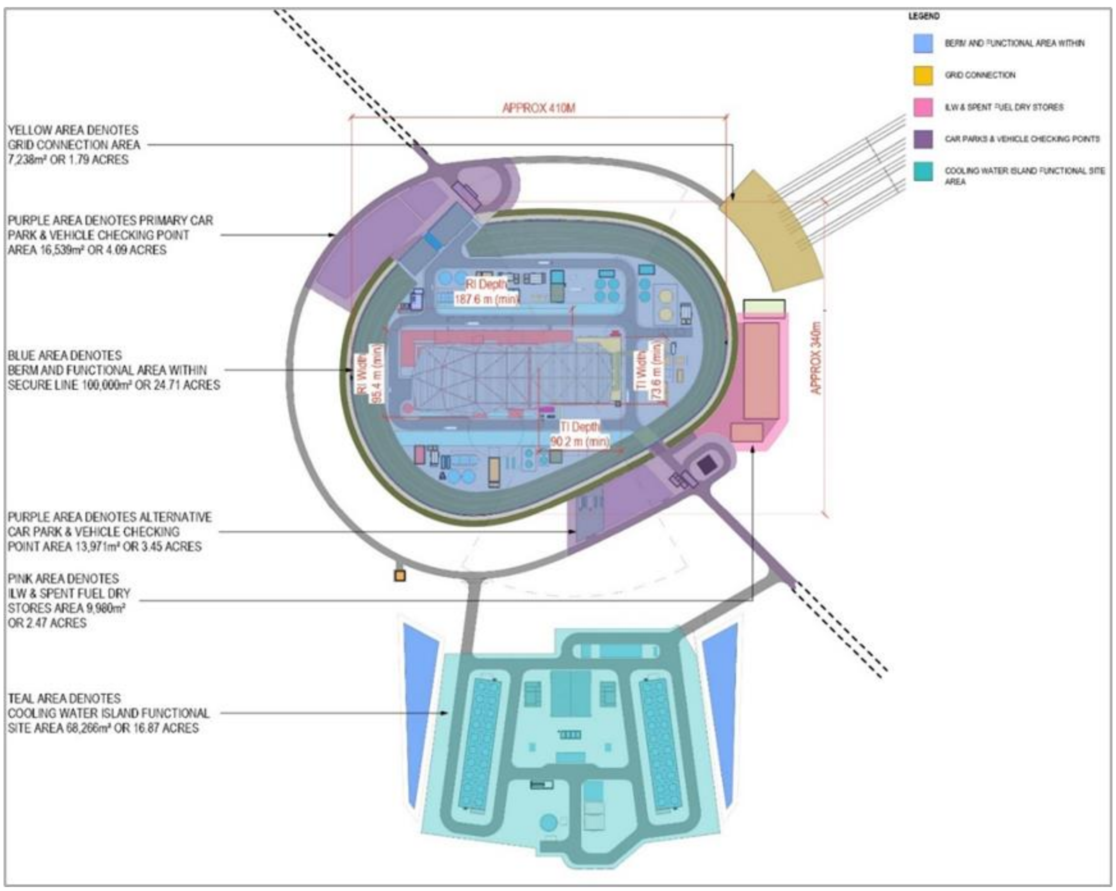

Figure 6 – Site Layout

4.3.7 Based on the current project assumptions, the total disturbed acreage during construction, including parking and laydown is up to approximately 450,000 m² (111.2 Acres) for the indirectly cooled design.

4.4 Power Station Design Basis

4.4.1 Table 2 presents the RR SMR design basis parameters including external hazards which are based upon a probability of exceedance of 10-4/year.

Table 2– Design Basis Parameters

Parameter	Value [1]
Earthquake (Peak Ground Acceleration)	0.3 g
Wind Speed – 10 Minute Mean	46.5 m/s (104 mph)
Tornado – Wind Speed	72 m/s (161 mph)
Tornado – Pressure Drop rate	13 mBar/s
Tornado – Max Pressure Drop	40 mBar/s
Missiles – Speed - Schedule 40 Pipe Automobile Solid Steel Sphere	24 m/s (53 mph) 24 m/s (53 mph) 6 m/s (13.4 mph)
Maximum Dry Bulb Air Temperature	49 °C (120.2 °F)
Maximum Wet Bulb Air Temperature	32.3 °C (90.1 °F)
Minimum Dry Bulb Air Temperature	-35 °C (-31 °F)
Maximum Air Humidity	100 %
Minimum Air Humidity	12 %
Rainfall	229 mm/hr (9 in/hr)
Rainfall	400 mm/24hr (15.7 in/24hr)
Lightning	300 kA
Snowfall	1.5 kPa (0.22 psi)

4.5 Seismic Design

4.5.1 The Rolls-Royce SMR design incorporates seismic isolation which reduces the susceptibility to seismic hazard for the Reactor Island. The Reactor Island basemat sits on top of aseismic bearings which decouple the superstructure from seismic ground motions limiting the peak

[1] These values correspond to the UK generic site envelope. Adjustments for international deployments will be made as appropriate.

acceleration transmitted to the structures above the isolation system. This allows the generic plant design above the aseismic bearings to be largely independent from the specific site location characteristics.

4.5.2 The current design input spectra for the Rolls-Royce SMR are anchored to 0.3 g Peak Ground Acceleration (PGA).

4.6 Emergency Planning Zone

4.6.1 The RR SMR design undergoing GDA is being developed in line with UK legislation for emergency preparedness. Under UK legislation, the Emergency Planning Zone (EPZ) is governed by the Radiation (Emergency Preparedness and Public Information) Regulations 2019 (REPPIR) (which implement the articles on emergency preparedness and response in the Basic Safety System Directive (BSSD) 20103/59/Euratom) and associated Approved Code of Practice and guidance. The EPZ for the Rolls-Royce SMR in the UK will be determined in conjunction with the UK regulator, combining technical assessment of the power station and its operating procedures, site specific factors, together with other factors including International Atomic Energy Agency (IAEA) guidance.

4.6.2 To support the derivation of a suitable EPZ in the UK, RR SMR has reviewed all possible events that could lead to the release of radiation and have determined possible dispersal routes and subsequent dose contours.

4.6.3 EPZs within the UK are not set at fixed, prescribed distances for all stations. In the UK, two geographical regions are defined around a nuclear power station for which emergency planning is required:

- Detailed EPZ (DEPZ),
- Outline Planning Zone (OPZ).

4.7 Detailed EPZ

4.7.1 This is a zone relatively close to the site for which detailed plans need to be in place to mitigate the dose consequences of a radiation emergency. Detailed planning ensures pre-determined response capabilities (and the necessary action to deploy them) can be implemented in a timely manner.

4.7.2 The boundary of this zone is enclosed by the contour for which a 100 mSv (10 Rem) dose is postulated for a reference accident without the mitigation provided by the emergency plan. The delivery of the emergency plan ensures doses within this region are below this threshold and As Low As Reasonably Practicable (ALARP). The Local Authority, in discussion with the UK regulator, may change the area to extend it because of local geographic, demographic and practical implementation issues, the need to avoid bisecting communities and/or to include vulnerable groups at the outer limit of the area.

4.7.3 The selected reference accident is one that bounds the radiological consequences of other postulated accidents and is calculated to occur with a frequency typically up to a 1 in 100,000 per year event.

4.7.4 The radioactive release associated with the bounding RR SMR event with a frequency in the range of 1 in 100,000 per year is anticipated to be substantially lower than that associated with current PWR power stations. This is primarily because the RR SMR is a Generation III+ design employing multiple diverse passive and active safety systems, and so the frequency of accidents causing radiation release are anticipated to be substantially below this frequency threshold. Furthermore, as the RR SMR comprises a physically smaller reactor, the inventory of fuel and other radioactive material is significantly reduced for a single unit and therefore the scope for radioactive release is additionally reduced.

4.8 Outline Planning Zone

4.8.1 In the UK, a default outline planning zone is defined as a circle of radius 30 km (18.6 m) around the site; however, this is subject to agreement, with the ability for the Local Authority or the regulator to propose an alternative zone.

4.8.2 Outline planning identifies, at a strategic level, the necessary response capabilities and actions, including where they would be obtained from and how they would be implemented. Response capabilities (and the necessary action to deploy them), should be available within longer timescales than would be expected for detailed planning and after the emergency is declared in most cases. Outline planning is proportionately less detailed and less onerous than detailed planning.

4.9 Assembly and Build Certainty

4.9.1 The RR SMR build certainty approach productionizes the build of nuclear power stations, addressing the fundamental challenges through the application of the following key principles:

- Maximize off-site build and assembly,
- Simplify logistics flow for on-site build,
- Minimize variation across all areas,
- Reduce and simplify interfaces (plug and play),
- Increase robustness to variation,
- Reduce human interaction.

4.9.2 These principles are embodied in the extensive modularization of the power station, across civil engineering, electrical systems and mechanical systems.

4.9.3 During assembly, the majority of RR SMR structures and equipment will be enclosed within a "Site Factory", which minimizes the impact of factors such as adverse weather conditions on programme schedules, whilst enabling 24/7 working. The Site Factory (Figure 7) provides both isolation of the site from the environment, and isolation of the environment from the site.

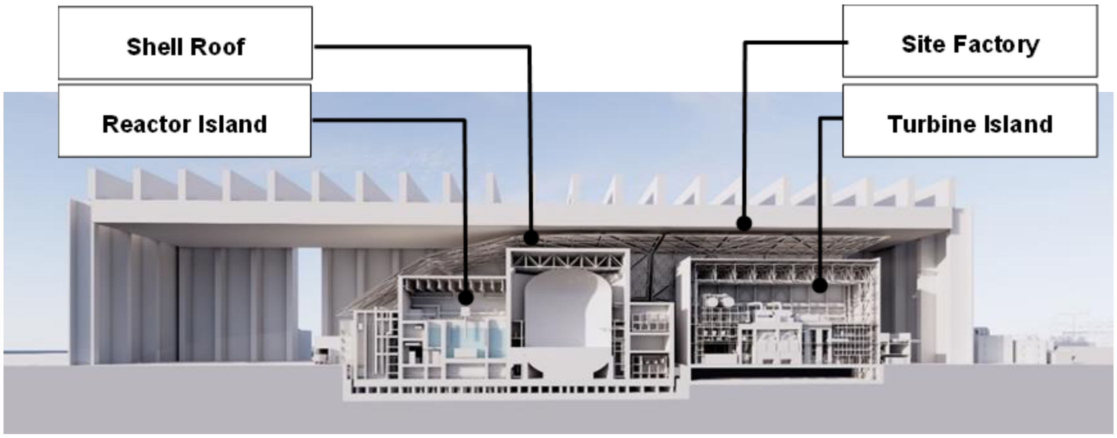

Figure 7 – Site Factory

4.9.4 Enhanced certainty of the assembly schedule and reduced capital costs provide a lower project risk, enabling lower financing costs resulting in a reduced LCOE.

4.10 Major Technical Parameters

4.10.1 A summary of the major technical parameters of the RR SMR is presented in Table 3.

Table 3 – Major Technical Parameters

Parameter	Value
Reactor Type	PWR
Electrical Capacity (MW_e)	Up to 470*
Thermal Capacity (MW_{th})	1358
Expected Design Availability (%)	Up to 95
Design Life (years)	60
Power Conversion Process	Rankine cycle
Passive Safety Features	Yes
Active Safety Features	Yes
Fuel Type / Assembly Array	Industry standard UO_2 fuel in 17 x 17 array, <4.95 % enriched
Manoeuvring Capability	3-5 % per minute between 50-100 % power (also operating less frequently down to 20 % power).
Fuel Cycle (months)	<18
Emergency Safety Systems	Active & Passive
Refuelling Outage (Days)	<18

Table 3 – Major Technical Parameters

Parameter	Value
Seismic Design (g)	0.3
Core Damage Frequency (per yr)	$<10^{-7}$

* Power output dependent upon configuration and siting environment, figure pertains to indirect cooled baseline.

4.11 Provision of Thermal Power

4.11.1 Each RR SMR has a thermal capacity of 1358 MW_{th} and is being designed with the potential for thermal offtake to support a wide range of applications. High temperature steam from the turbine cycle can be utilized to improve the efficiency of a range of industrial and non-electric applications including, but not limited to; industrial process heat, hydrogen production, cooling (e.g. for datacentres) via absorption chillers, and sustainable synthetic fuel production (see Figure 8).

4.11.2 Steam would not be directly extracted from the RR SMR system; a heat exchanger enables the safe extraction of thermal energy whilst ensuring isolation of systems and simplifying the safety case for industrial co-location.

4.11.3 The offtake of thermal power, in the form of steam, from the RR SMR can be managed dynamically during operations enabling a range of thermal offtakes from zero to approximately 400 MW_{th} of the thermal power from the core. A minimum level of steam is always required to be maintained to ensure there is sufficient energy to drive the turbine and feed the electrical load of the plant systems and to prevent deleterious effects within the steam turbine itself.

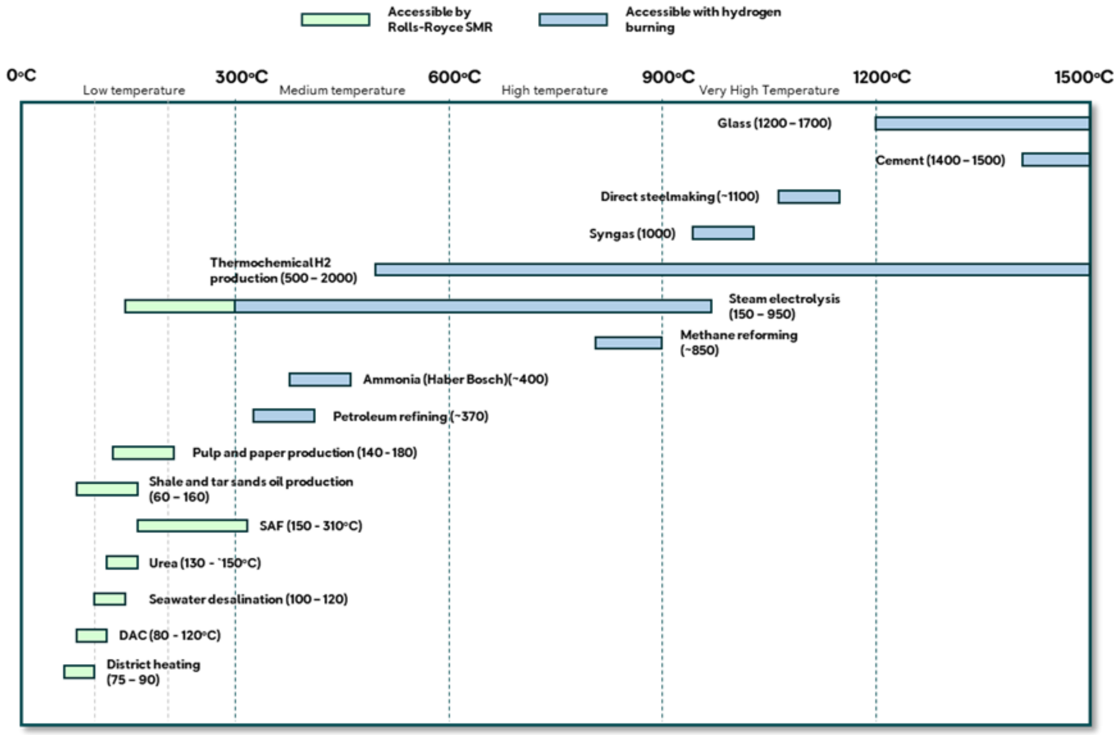

Figure 8 – Industrial Thermal Power Requirements

4.11.4 This flexibility enables the plant to support its customers as their power demand changes, either due to, short term cycles, seasonal changes or to wider market forces. This flexibility enables the RR SMR power station to provide large amounts of thermal power in the winter to support district heating systems and in the summer this power can pivot to boost electrical output to support increased demands from air conditioning or the production of hydrogen for long term energy storage.

4.11.5 Another advantage of this flexibility lies in the thermal inertia present in large scale heating systems. During periods of insufficient electrical supply to the grid, plant thermal output can be diverted to electrical to provide a short-term supply boost, ensuring continuation of supply. Once grid supply and demand are rebalanced, plant output can shift back to thermal power to recover lost temperature. This flexibility could provision for many hours or even days depending on the size and usage of the thermal system in question.

4.11.6 The use of thermal power increases the total useable energy that can be extracted from the RR SMR over and above its baseline configuration. The higher the ratio of thermal to electrical output the greater the benefit, up to a maximum limit of 400 MW_{th} where approximately 315 MW_e of net electrical output will still be produced.

4.11.7 For industries which require thermal power at temperatures over 300 °C (572 °F), the power station can be combined with electrolyzers to produce hydrogen allowing access to affordable and carbon-free heat. The RR SMR is capable of producing 270 tonnes of hydrogen a day, whilst achieving a competitive Levelized Cost of Hydrogen (LCOH) when combined with a Solid Oxide Electrolysis Cell (SOEC) system.

5 Reactor Island

5.1 Overview

5.1.1 In-line with existing PWRs, the RR SMR is comprised of a primary circuit, containing the fuel and coolant, and a secondary circuit that produces steam for the generation of electricity. The Reactor Island includes the Systems, Structures and Components (SSC) that form and support the primary circuit. The secondary circuit SSCs mostly comprise the Turbine Island, presented separately in Section 6. The secondary circuit that supplies the generated steam from the reactor, up to and including the Main Steam Isolation Valves (MSIVs), are considered as part of the Reactor Island.

5.1.2 A high-level Reactor Island layout can be seen below in Figure 9, where some of the main areas and features of Reactor Island are highlighted.

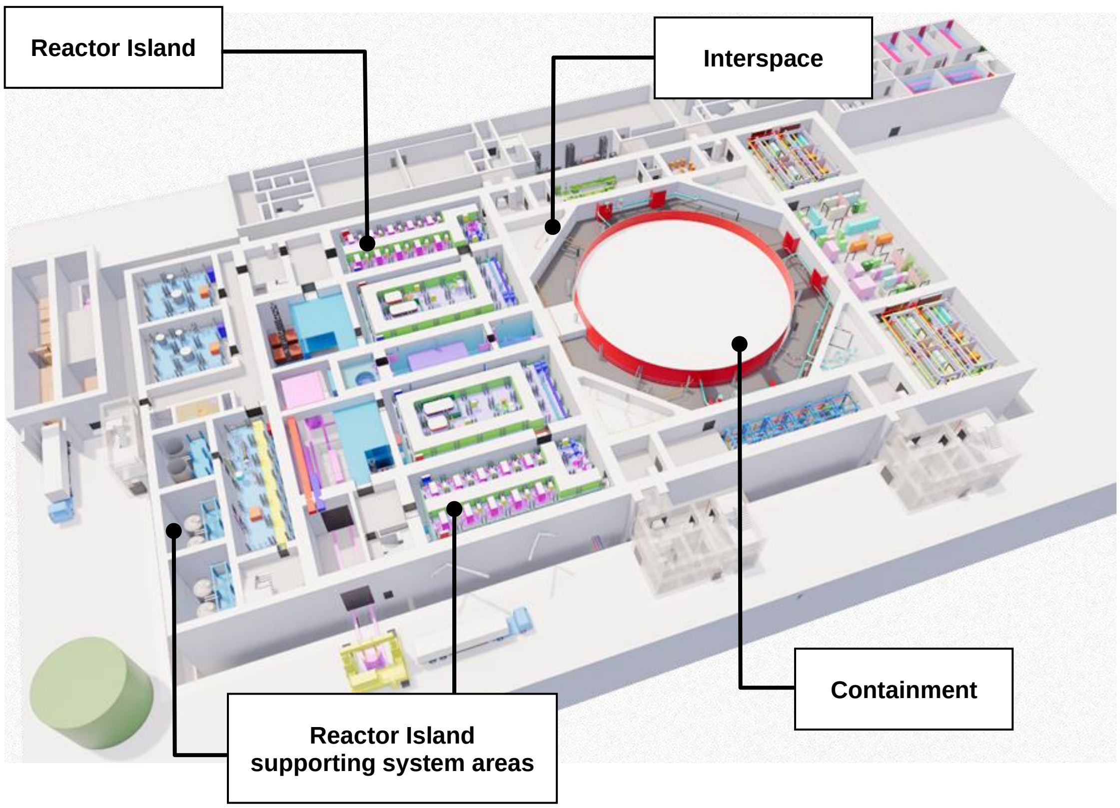

Figure 9 – Reactor Island Layout

5.2 Design and Nuclear Fuel System Design

5.2.1 Fuel assembly designs are based on existing concepts with large amounts of operational experience and proven reliabilities. The features for enhancing fuel reliability will be vendor specific and will reduce known fuel failure mechanisms such as grid-to-rod fretting and pellet clad interactions.

5.2.2 The RR SMR fuel system is tolerant to operating transients with load following and smart grid operations in mind. The power station is designed to deliver a ramp rate of 3-5 % rated power per minute and operate between 50-100 % power, with the expectation of also operating less frequently down to 20 % power. The minimum power has been assessed to be capable of supporting limited transients down to 75 % core power, with the Conventional Island supporting the remaining transients, to ensure safety margins to fuel failure mechanisms. The core design can be optimized to support larger core power transients as per any site-specific requirements.

5.2.3 The RR SMR uses industry standard nuclear fuel: UO_2 pellets enriched up to 4.95 % U-235, clad with a zirconium alloy and arranged in a 17 x 17 assembly. The core contains 121 fuel assemblies and has an active fuelled length of 2.8 m (9 ft), delivering a thermal power of 1,358 MW_{th}.

5.2.4 Each fuel assembly contains a significant number of fuel pins poisoned with gadolinia, with the remaining fuel pins being unpoisoned. The poison content in the fuel assemblies is varied to offset the excess reactivity associated with boron free operations as well as to minimize variations in axial offset and power peaking.

5.2.5 All aspects of the fuel and associated systems are based on existing conventional technology with proven operational experience. Fuel assemblies are based on existing designs and will not limit a utility to a single design. Minor modification will be made to the fuel assembly to accommodate the shortened fuelled length compared to GW scale reactors. In addition, minor changes to the layout of spacer and intermediate flow grids will be required; however, these changes are expected to be within the validation envelope of existing designs and empirical correlations.

5.2.6 Core reactivity is controlled through the insertion and removal of control rods, for both normal duty control, load following operations and rapid shutdown. The reactor core has 89 control rods which will be operated as a set of banked control groups. This allows for fine reactivity control when required, as well as rapid shutdown through scram. The high number of control rods allows full shutdown of the reactor in all modes of operation using control rod insertion only, thus removing the requirement for soluble boron even at limiting temperatures and in the event of a stuck or ejected rod. The core design also utilizes high levels of gadolinia poison distributed in the fuel to suppress start of cycle reactivity, manage the local power distribution and to limit axial offset.

5.2.7 Core control is achieved through the movement of control rods and through the placement of burnable poisons in the fuel. By careful placement of gadolinia in the core, through-cycle axial offset and power peaking factors are reduced to values comparable to other large nuclear projects which utilize soluble boron. The absence of soluble boron means the reactor system is not subject to boron dilution accidents and can also respond faster to power reduction transients. Normal duty reactivity control is conducted through control rod movement and moderator temperature feedback effects. This includes duty control, compensating for fuel depletion effects, load following and full shutdown. Automated control of moderator temperature provides a diverse means of reactivity control to assist management of xenon transients and Pellet-Cladding Interaction limits.

5.2.8 Unlike other designs, no concentration of soluble boron is maintained in the primary coolant for duty reactivity control. Duty reactivity control is provided through movement of control rods and use of the negative moderator temperature coefficient inherent to PWRs. Long term shutdown is also achieved through the insertion of the control rods. No addition of soluble boron is required to maintain a suitable subcritical margin at any temperature or level of burnup. An independent Emergency Boron Injection (EBI) system is also available to provide additional shutdown margin if required. The EBI system is diverse from the control rod scram function, allowing defense in depth in the event of scram failure.

5.3 Reactor Assembly

5.3.1 The Reactor Pressure Vessel (RPV) body forms the external vessel for housing the RPV Internals (RPVI) and interfacing with the Reactor Coolant System (RCS) loops, thereby allowing cold coolant to flow into the core and hot coolant to flow out to the steam generators. The RPV body forms the main mechanical support structure for the RPVI, RPV Closure Head (CH) and Integrated Head Package (IHP), together forming the reactor assembly.

5.3.2 The upper shell forms the upper end of the RPV body and consists of the upper flange region, the leak detection features, Reactor Coolant Loop (RCL) nozzles, Direct Vessel Injection (DVI) nozzles, reactor assembly support and the reactor pressure vessel internals alignment features. The upper shell features three pairs of reactor coolant loop nozzles, one pair per coolant loop. The external diameter of the upper shell features a support flange for mounting the RPV onto the RPV support structure.

5.3.3 The lower shell forms the mid-section of the RPV body and consists of a forged body with the upper and lower circumferential welds on each end for joining to the upper shell and lower head. The lower head features a pattern of core support features for axially supporting the core, as well as transmitting operational loads of the core barrel into the RPV body.

5.3.4 The CH is positioned on top of the RPV body, RPVI and reactor core and provides mechanical support for the CRDMs and IHP. It provides structural support and alignment for the CRDMs, In-Core Instrumentation (ICI), IHP lifting points and main closure bolting assembly. The CH also accommodates the final seal between the head and body and provides a pressure boundary for the coolant around the reactor core and internals.

5.3.5 To allow for core load, the RPV incorporates a removable CH. When in place, this completes the pressure boundary for the RCS. The CH is part of the IHP which performs several functions including housing the CRDMs and passing services to the top of the RPV.

5.3.6 The CH consists of a single forging which is formed of a torispherical dome with penetrations in for CRDMs and ICI; an outer flange for closure studs, nuts and washers; and a RPV seating face which contains two circumferential grooves for the sealing arrangement.

5.3.7 The design has an integral flange to remove the weld between the head profile and flange present in other plant designs. The wetted inside surface of the closure head is weld overlay clad for corrosion resistance.

5.3.8 The RPV CH which supports CRDMs, ICI assemblies, vent line, and an array of head area structures and supports, together make up the IHP. The IHP is made up of the following key head area components:

- IHP lifting assembly,
- Shroud,
- CRDM cooling assembly,
- Seismic supports,
- Missile shield,
- Integration of the CH components and associated cabling,
- Stud lifting and tensioning integration.

5.3.9 The IHP brings together the key head area components to reduce the duration of head area disassembly, removal and reassembly activities during an outage, and in turn reducing personnel dose and outage critical path time.

5.3.10 The movement of the control rods is provided by CRDMs. The CRDMs are mounted vertically to the top of the RPV closure head to adaptor tubes that penetrate through the CH. A drive rod extends down through this penetration to connect the CRDM to an individual control rod located in the reactor core. There are a total 89 CRDMs fitted to the plant. The CRDMs are enclosed in and form part of the IHP, which provides structural support, cooling and cabling to the CRDMs.

5.3.11 Each CRDM can raise, lower and hold its respective control rod, as well as rapidly insert the control rod back into the core (i.e. scram the reactor). This is achieved through a linear magnetic jacking mechanism where latches can grab the drive rod and step the rod up and down as demanded or hold its relative position. If electrical power is lost to the CRDM, the mechanism will passively release the drive rod allowing the drive rod and attached control rod to drop back into the core under gravity.

5.3.12 The linear magnetic jack mechanism consists of two latch assemblies (a stationary gripper and a movable gripper) which are actuated via three electromagnetic coils (a stationary gripper coil, a movable gripper coil and a lift coil). Energising the stationary gripper coil causes the stationary gripper to close and engage with the drive rod, energising the movable gripper coil causes the movable gripper to close and engage with the drive rod, and energising the lift coil causes the movable gripper to move vertically upwards one 'step'. The size of this step movement is based on the tooth pitch of the drive rod.

5.3.13 The RPVI is a collection of structural components that are contained within the RPV to form the main mechanical support structure for the fuel assemblies and the control rods to enable safe and reliable operation of the core. The RPVI are supported from the core support ledge in the RPV body, which the core barrel upper flange seats on. The RPVI also provides the main mechanical support to the In-Core Monitoring (ICM) assemblies.

5.3.14 The RPVI consists of two major subassemblies - the upper internals and the lower internals. The lower internals are the main structural part of the RPVI and includes the interface to the core support ledge on the RPV to position and support the fuel assemblies. The upper internals contain all the components that are positioned directly above the fuel assemblies and is designed to enable it to be removed and installed as a single unit to help minimize the number of operations during refuelling outages.

5.3.15 The RPVI control the direction of reactor coolant flow inside the RPV body to ensure adequate heat transfer from the fuelled region. It also aids core performance by providing reflection of neutrons at the core extremities and by providing radiation shielding protection through the presence of a heavy reflector.

5.3.16 The core barrel is the primary structural component within the RPVI and provides the structural connection between the RPV body and the major core components such as the fuel assemblies. It consists of an upper flange; a cylindrical shell and lower section termed the Lower Core Support Plate. The cylindrical shell is separated into two sections, the upper shell and the lower shell, based on the limitations of forging and manufacturing capabilities.

5.3.17 The neutron reflector is a subassembly of components that is fitted inside of the core barrel and extends the full length of the core's fuelled region to shroud the fuel assemblies once they are installed. This provides reflection of neutrons around the extremities of the core to optimize core performance, while also attenuating fast neutrons and gamma radiation to provide radiation shielding to the RPV body and reduce dose rates outside of the RPV.

5.3.18 The flow distribution device is a component that is fitted underneath the core barrel within the lower plenum region in order to provide the necessary control over the inlet coolant behaviour before it enters the fuel assemblies to achieve the desired heat transfer within the fuelled region and to ensure that the integrity of the fuel assemblies is maintained.

5.3.19 The RPV surveillance capsule is a sealed capsule that contains material test specimens taken from the RPV body. These capsules are fitted into the RPVI to support the RPV surveillance programme, which is required to monitor changes in the RPV body's material properties caused by irradiation embrittlement.

5.4 Fuel Cycle Characteristics

5.4.1 The RR SMR core design is based around industry standard UO_2 fuel with enrichments up to 4.95 %. Current designs do not utilize MOX or RepU, but assessments are underway to understand if these fuel types could be employed if required.

5.4.2 The core has been designed to achieve a minimum cycle length of 18 months at constant full power operations. If load following strategies were utilized the cycle length could be extended significantly. Flexibility on the cycle length can be achieved through operations at lower powers; however, if core power is not modified, refuel periods can still be scheduled within a window of several months. Higher degrees of flexibility can also be achieved if planned for in advance and new fuel assembly designs can be manufactured.

5.4.3 The current core design is based on an 18-month full-power cycle with flexibility to allow for load following operations. Once an equilibrium cycle is established, a transition to alternative cycle lengths (up to 24 months) will be possible if the plant is operated at lower powers.

5.4.4 The RR SMR is intended to operate with an open fuel cycle. The core design or the fuel handling facilities do not preclude the use of reprocessed fuel, but this has not been designed to facilitate this explicitly.

5.5 Spent Fuel Pool

5.5.1 The Spent Fuel Pool (SFP) is located outside of containment in the Fuelling Block of the Reactor Island. The SFP has capacity to enable the import and storage of fuel for up to nine cycles of operation without cask loading. This permits spent fuel to be cooled for more than 10 years prior to cask loading, though shorter cooling times are not precluded. The SFP facilitates storage of new fuel prior to a refuelling outage and provides capacity such that a full core offload can take place at any time. There is also additional capacity for damaged and failed fuel as well as non-fuel items. The SFP is permanently flooded.

5.5.2 The SFP has gates to separate the Upender Pit (UP) and Cask Loading Pit (CLP) from the fuel storage area of the SFP. The UP and CLP are drained and decontaminated when not in use. The SFP is connected to the in-containment Refuelling Pool during refuelling via a fuel transfer channel.

5.5.3 In the SFP, reactivity is controlled through geometrical spacing and in-built solid neutron absorbers in the storage racks. The design is such that subcriticality is maintained regardless of fuel state or location; no credit is taken for burnup, control rods or burnable absorbers. All of the fuel rack spaces are suitable for fresh fuel; there is no separate spent fuel region.

5.6 Reactor Coolant System

5.6.1 The primary function of the RCS is to utilize heated coolant from the reactor system to generate steam which is transferred to the steam systems to facilitate the generation of electricity. The system has a number of supporting functions to facilitate this objective (e.g. overpressure protection) and supports safety functions required by the reactor reactivity control systems and reactor heat removal systems.

5.6.2 The baseline architecture for the RCS consists of three vertical u-tube SGs with associated pipework loops and a single pump in each loop, mounted directly to the SG outlet nozzle. The configuration of the RCS is illustrated in Figure 10. The configuration of the SG, pipework and pump layout in each loop ensures a robust thermal driving head for natural circulation flow in faulted operation. In addition, the system includes a pressurising system, and associated overpressure protection equipment. The design includes multiple active and passive safety systems, each with substantial internal redundancy.

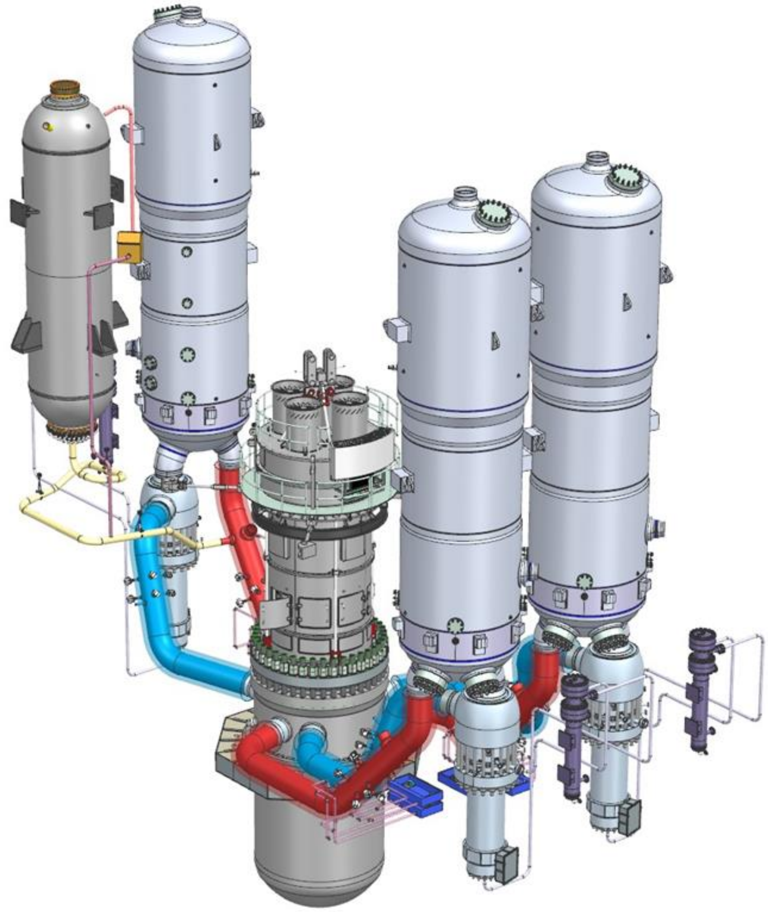

Figure 10 – Overview of RCS

5.6.3 The reactor core produces 1,358 MW_{th} and has been sized to maximize power output within an RPV that is road transportable. The arrangement has also been influenced by the desire to minimize containment size and reduce the water volume required for the purposes of plant protection.

5.6.4 The primary function of the Reactor Coolant Pressurizing System is to provide pressure control for the RCS and the reactor system, and to limit pressure changes during transients (both normal duty and faulted). In addition, the system provides interfaces for the reactor coolant pressure relief and automatic depressurization systems to the RCS, as well as housing instrumentation which supports the Reactor Island C&I systems.

5.6.5 Key components include a pressurizer vessel (including spray head and electrical heaters), as well as the surge and spray lines. The system also includes pressure, level, and temperature measurement equipment to facilitate pressure control, as well as supporting the initiation of various safety measures.

5.6.6 The Pressurizer is a vertical cylindrical vessel with hemispherical ends, which operates with a mixture of steam and water in equilibrium to provide the necessary overpressure to prevent boiling of the fluid in the RCS. To increase plant pressure, steam is generated by electrical heaters contained within the lower section of the vessel.

5.6.7 To reduce plant pressure, the Reactor Coolant Pressurizing System uses a pump induced spray system. The system contains two main spray lines and an auxiliary spray line. Each main spray line is fed via a Reactor Coolant Pump (RCP) whilst the auxiliary spray is fed via a Chemical Volume and Control System (CVCS) make-up pump.

5.6.8 As well as providing RCS overpressure, fluctuations in reactor coolant volume resulting from power changes or routine make-up and let-down are accommodated. Contractions in reactor coolant volume are accommodated through the supply of coolant from the Pressurizer to the RCS Pipework via the Surge Line (and vice versa for reactor coolant expansion). The Pressurizer is sized to provide robust and passive fault response for bounding faults, with accidents causing either rapid and significant cooldown or heat-up accommodated.

5.6.9 The RR SMR SG is a traditional recirculating SG with an integral preheater. The hot reactor coolant enters the SG through the primary inlet nozzle. It then enters the channel head inlet plenum before passing through the vertical U-tube bundle. It exits the bundle into the channel head outlet plenum and exits the SG via the primary outlet nozzle.

5.6.10 Secondary coolant enters the SG via the feedwater nozzle located in the lower part of the vessel on the outlet or “cold leg” side of the tube bundle, near the tube sheet. The pre-heated feedwater is fed directly into the preheater whilst the downcomer flow is directed to the non-preheater region of the bundle. The secondary coolant flows up through the tube bundle where a portion of it is heated to steam. The wet steam is passed through a series of moisture separators. The resulting dry steam exits the SG through the steam outlet nozzle whilst the separated water is recirculated.

5.6.11 The SGs also includes the provision of wide band, narrow band and cold calibrated level measurement, which facilitates the level control of the SG during both powered and shutdown operations, as well as supporting fault responses including the initiation of the Passive Decay Heat Removal (PDHR) and Scram safety measures.

5.6.12 The Reactor Coolant Pumps (RCPs) generate sufficient coolant flow to support the safe and efficient removal of heat from the core, and to facilitate the generation of steam in the SGs. The RCPs also provide a thermal duty to warm the reactor coolant during start-up.

5.6.13 The RCP System includes:

- The nozzles which connect to the reactor coolant pipework on the discharge side and the SG on the suction side,
- Pump casing and hydraulic components,
- Pump motor,
- Variable frequency drive to start and operate the motor during warm-up,
- Heat exchanger required for cooling the pump,

- Instrumentation which feeds the reactor protection and control systems.

5.6.14 The RCP is a single stage centrifugal pump with an overhung impeller, vertically orientated, and driven by a wet-wound induction motor located beneath the hydraulics and is welded directly to the SG Cold Leg. This simplifies the RCS and RCP design integration and provides an optimized and safe operating environment for the motor unit.

5.6.15 The RCP and motor are combined in a seal-less design, which removes additional ancillary equipment associated with a mechanical seal system. This avoids potential issues with seals which have been a cause of leaks in previous RCP designs and improves reliability and availability.

5.6.16 The primary function of the Reactor Coolant Pressure Relief System is to provide overpressure protection to the RCS and RPV during powered and shutdown operations using pilot operated Safety Relief Valves (SRVs).

5.6.17 The Reactor Coolant Pressure Relief System is comprised of two subsystems, delivering High-Temperature Overpressure Protection (HTOP) and Low-Temperature Overpressure Protection (LTOP) respectively. Relief from the HTOP subsystem is routed to the In-containment Water Storage System (IWSS) via the Automatic Depressurization System (ADS) discharge line and spargers, whereas discharge from the LTOP subsystem is routed directly to the refuelling pool via dedicated sparges.

5.6.18 Each subsystem is comprised of two SRVs, each sized to accommodate 100 % of the relief case flow rate to ensure that overpressure protection is provided with n+1 redundancy.

5.7 Reactor Island Auxiliary Systems

5.7.1 There are several auxiliary systems that support the Reactor Island:

- CVCS,
- Sampling systems,
- Laboratories,
- Cold Shutdown Cooling System (CSCS),
- Component Cooling System (CCS),
- Essential Service Water System (ESWS),
- Chilled Water System,
- Heating Ventilation and Air Conditioning (HVAC),
- Spent fuel pool support systems.

5.7.2 The primary purpose of the CVCS is to control the chemistry and the inventory of reactor coolant within the RCS. The CVCS consists of three subsystems to achieve these functions: the Level and Volume Control System, the Coolant Purification System, and the Chemistry Control System.

5.7.3 Inventory control is achieved by removal and addition of primary coolant by the Level and Volume Control System which is connected to the RCS. Level and pressure instrumentation within the RCS sub-systems is used as inputs for the Level and Volume Control System to achieve the target pressure or level depending on mode and operating sequence.

5.7.4 Chemistry is maintained within the defined parameters by a combination of high purity water supply, purification, and chemical dosing. High purity make-up is drawn from the Liquid Radioactive Effluent Treatment System (LRETS) and pumped into the RCS by the Level and Volume Control System. Purification is achieved by continuously passing a percentage of the RCS coolant inventory through the Coolant Purification System. Chemicals are dosed by the Chemistry Control System into the Level and Volume Control System return leg which subsequently flows into the RCS pipework.

5.7.5 Reactor Island sampling is performed to underpin safe and efficient operation by monitoring the chemistry parameters of systems within the Reactor Island. The Reactor Island Sampling System is split into three sub-systems: the Nuclear Sampling System (NSS) for the primary circuit and connected systems, the Auxiliary Sampling System (AxSS) for Steam Generator Purification System and Waste Systems, and the Process and Emissions Radiation Monitoring System (PERMS) for the main ventilation stack and reactor island system radiation monitoring.

5.7.6 There will be a single on-site ‘hot’ laboratory for analysis of radioactive samples on the RR SMR site, with a combination of ‘cold’ laboratories and online instrumentation panels utilized for analysis of inactive samples. The combination of online instrumentation, centralized external laboratories and dedicated on-site laboratory equipment will be optimized to support robust and efficient analyses, whilst minimizing staffing burden.

5.7.7 The primary function of the CSCS is to provide normal duty decay heat removal at low plant temperatures and pressures. During cool-down, both CSCS trains are operated to minimize the cooling duration. Once a sufficiently low temperature for refuelling operations is achieved, the function of the CSCS is to hold temperature fixed until such a time that decay heat removal can be handed over to the Fuel Pool Cooling System (FPCS) or the reactor is restarted.

5.7.8 While both trains may be used concurrently to increase RCS cooling rate, both trains are individually rated to hold-down the coolant temperature during refuel operations. This is to ensure a sufficient reliability of cooling for the safety category of the CSCS, and to provide tolerance to all frequent faults and hazards that may result in the failure of a single CSCS train.

5.7.9 During shutdown modes the CSCS also provides flow to the CPS and, via the CPS, to the Pressurizing System to support coolant purification and plant depressurization. Additional supply and return connections to the FPCS are also provided within each of the CSCS cooling trains to allow the CSCS to provide backup cooling to the fuel pools during FPCS maintenance periods, and to allow the CSCS to support other safety functions, including boron injection and containment cooling.

5.7.10 The primary function of the CCS is to circulate coolant to transfer waste heat from consumer reactor island fluid systems and components to the ESWS cooling towers during all modes of plant operation.

5.7.11 The architecture for the CCS consists of two independent cross-connected cooling trains, each containing an expansion tank and associated pipework and valves, which are connected to corresponding Essential Service Water System (ESWS) cooling towers.

5.7.12 Both trains include a centrifugal pump to circulate coolant to the consumer heat exchangers. Heated coolant is returned and circulated to the ESWS cooling towers where waste heat is rejected to the atmosphere.

5.7.13 The ESWS is the heat sink for the Reactor Island CCS which is responsible for cooling nuclear safety equipment within the reactor building. The ESWS has two independent and separated trains, with one redundant for safety related operations. Each train consists of multiple independent mechanical draft closed cooling towers cells, with at least one redundant cooling tower in each train.

5.7.14 The primary function of the Chilled Water System is to provide a source of cooling water for auxiliary plant and Heating, Ventilation and Air Conditioning (HVAC) at temperatures lower than can be achieved by the CCS. The Low Temperature Chilled Water systems operate at temperatures as low as approximately 6 °C (42.8 °F), and charge/discharge chilled water tanks which can be used to provide cooling to key safety systems during the endurance period should power be unavailable.

5.7.15 The primary function of the HVAC systems serving the controlled and uncontrolled areas is to provide ventilation to all areas of Reactor Island. In addition, the Heat Recovery System collects waste heat from the CCS to heat air within the HVAC systems Air Handling Units (AHUs); this is done by water source heat pumps.

5.7.16 The key components vary for each of the HVAC sub-systems depending on the requirements of the areas being served by those systems. The components will also vary depending on the build location of the power station. This will affect the intake air requirements e.g. Additional filtration may be required for dry, desert locations, and also impact the size/quantity of frost, cooling and heating coils and the requirement for the humidifier.

5.7.17 The spent fuel pool support systems include the following:

- Fuel Pool Cooling System – Removes decay heat from the coolant used in the wet storage of spent fuel,
- Fuel Pool Purification System – purifies the coolant used to remove decay heat from the wet storage of spent fuel,

- Fuel Pool Supply System – maintains the level in the pools used in the wet storage of spent fuel. The system also contains the Refuelling Water Storage Tank (RWST) which can store and supply coolant when needed during refuelling operations.

5.8 Radioactive Waste Management

5.8.1 The waste treatment systems provide for the collection and processing for disposition and discharge of gaseous, liquid and solid radioactive wastes generated within the power station. They are formed from the Gaseous Radioactive Effluent Treatment System (GRETS), LRETS and the solid radioactive waste storage and processing system, which are located in the radioactive auxiliary and waste areas.

5.8.2 The RR SMR design includes protection of the public, workers and environment to minimize risk to So Far As Is Reasonably Practicable (SFAIRP). This involves ensuring radiological doses are ALARP and ensuring all discharges, waste arisings and environmental impacts are As Low As Reasonably Achievable (ALARA) through the application of Best Available Tools/Techniques (BAT) and use of the waste hierarchy.

5.8.3 The waste treatment system technologies use proven technology and comparable use in similar modern PWRs. The waste treatment system suite is therefore considered to provide waste management consistent with the BAT approach. However, waste management will be continually reviewed, and waste will preferentially be eliminated at source where possible.

5.8.4 Treated gaseous and liquid effluents will be discharged to atmosphere and appropriate water course or sewer drain respectively to meet the discharge authorisations set by the local regulator.

5.8.5 RR SMR substitution of the standard PWR chemistry (boron and lithium hydroxide based) with a potassium hydroxide-based (soluble boron-free) chemistry will result in significant reduction in the inventory of tritium in the primary coolant, as neutron activation of dissolved boron and lithium in primary coolant accounts for the bulk (>90 %) of tritium produced in PWRs under normal operating conditions. The level of boron in primary coolant is a key driver for the bleeding and discharge of aqueous radioactive effluent; the elimination of soluble boron will therefore minimize the need to bleed primary coolant, resulting in minimal discharge of liquid radioactive effluent.

5.8.6 As such, the RR SMR eliminates the need for routine discharge of aqueous effluent to the environment under normal operating conditions – although very small amounts of liquid may require discharge for water balance, tritium management (if required to meet derived air concentration limits for refuelling options) or following an anticipated operational occurrence. In these rare cases, effluent to be discharged will be collected at the LRETS effluent monitoring tanks, where it will be monitored and sampled for confirmatory analysis to check that the water meets relevant quality criteria and regulatory limits. Any effluent that doesn’t meet these criteria is returned to the LRETS treatment train. Effluent that meets the discharge criteria will be released to the receiving environment through a single discharge line fitted with flow metering and flow proportional sampling equipment.

5.8.7 The quantities and volumes of aqueous and gaseous radioactive effluent discharged from the RR SMR to the environment (per unit MW generated) are therefore expected to be comparable to or less than discharges from existing PWRs, under both normal operations and accident conditions.

5.9 Safety Systems

5.9.1 Multiple layers of fault prevention and protection are provided on the power station through a range of active and passive systems, comprehensively ensuring safety for Design Basis (DB) and Design Extension Conditions (DEC), for all modes of operation and during all lifecycle stages. Safety measures are grouped into the following Fundamental Safety Functions (FSFs):

Control of Reactivity (CoR),

Control of Fuel Temperature (CoFT),

Confinement of Radiological Material (CoRM),

Control of Radiation Exposure (CoRE).

5.9.2 The safety measures are designed to minimize the burden on operators; following an automated one-time alignment of valves for safety measure actuation, no human intervention is required for at least 72 hours following a plant fault which requires the initiation of one of the safety functions.

5.9.3 Safety analysis of the power station indicates that a Core Damage Frequency (CDF) of <10-7/yr is achieved.

5.9.4 Table 4 below shows an illustration of the main safety functions at each level. Only the functions related to Intact Circuit Faults (ICF) and Loss of Coolant Accidents (LOCAs) are listed.

Table 4 – Main Safety Functions

DiD Level	CoR	CoFT	CoRM
Defense in Depth (DiD) Level 2– Preventative Safety Functions	Duty control rod insertion Rapid Power Reduction	High Temperature Heat Removal (HTHR) Low Temperature Decay Heat Removal (LTDHR)	RCS
DiD Level 3 – First Protective Safety Functions	Scram	Passive Decay Heat Removal (PDHR)	Faulted Containment
DiD Level 3 – Second Protective Safety Functions	Alternative Shutdown Function (ASF)	Emergency Core Cooling (ECC)	Faulted Containment
DiD level 4 – Mitigative Safety	Not required	Not required	Severe Accident Containment

5.9.5 CoR is provided by the reactor reactivity control systems which is comprised of duty control rod movements, Rapid Power Reduction, Scram and ASF.

5.9.6 Duty control rod movements can be made by the automatic control system or by the operator, in order to control the reactor within the temperature deadband and ensure that a margin to various fuel limits is maintained.

5.9.7 The Rapid Power Reduction measure provides a house-load capability and preventative response to certain faults which involved reducing the reactor power very quickly by dropping certain control rods into the reactor. Rapid Power Reduction is used to maintain the reactor critical in some loss of offsite power and turbine trip scenarios, preventing reactor shutdown where practicable.

5.9.8 The objective of the Scram function is to provide the principal means of CoR during faulted operation by inserting control rods into the reactor fuel thereby shutting down the reactor. Scram is triggered by the Reactor Control and Protection System (RCPS) and is the preferred shutdown method due to the clean-up required after initiation of ASF.

5.9.9 ASF provides a secondary means of CoR during faulted operation by inserting negative reactivity into the core in the form of soluble potassium tetraborate. Potassium tetraborate is injected into the core and Refuelling Pool via the Emergency Boron Injection System (which consists of boron storage tanks), as well as the High Pressure (HP) Injection System (which consists of high head pumps and associated pipework to deliver boron into the Reactor System) and the Fuel Pool Cooling System (which consists of pumps and associated pipework to deliver boron into the Refuelling Pool). ASF is initiated by the RCPS; however, the trips and equipment used are independent and diverse from those used to initiate Scram.

5.9.10 A number of distinct measures are included to support the CoFT safety function during shutdown and faulted operations:

- High-Temperature Heat Removal (HTHR),
- Low Temperature Decay Heat Removal (LTDHR),
- Passive Decay Heat Removal (PDHR),
- Emergency Core Cooling (ECC).

5.9.11 HTHR is the preferred heat removal measure following a fault that causes the reactor to shutdown. HTHR is also used to maintain the reactor critical in some loss of offsite power and turbine trip scenarios, preventing reactor shutdown where practicable.

5.9.12 There are two main routes through which HTHR removes heat from the reactor plant to atmosphere: Condenser Decay Heat Removal (CDHR) and Atmospheric Steam Dump (ASD).

5.9.13 CDHR uses the RCS, including the reactor vessel, SGs and RCPs, to remove heat from the core to the Main Steam System. The heat is then rejected to the Main Condensers, via a turbine bypass, and then to the natural environment by the main cooling water system. The main feed and auxiliary feed pumps are available to provide feed to the SGs. CDHR can provide long-term cooling, removing heat on a closed loop basis.

5.9.14 ASD can be used where CDHR is unavailable e.g. loss of Main Cooling Water System and involves the use of power operated steam relief valves in the ASD system to reject steam from the SGs to atmosphere. The auxiliary feed pumps provide feedwater to the SG from condensate storage tanks within Turbine Island. Once the feed water stores are exhausted, PDHR will be initiated to provide long-term cooling.

5.9.15 The primary function of the Low Temperature Decay Heat Removal (LTDHR) safety measure is to remove decay heat from the core during where the plant is at low temperatures and as such heat removal via the SGs (either using PDHR or HTHR) is no longer available.

5.9.16 Reactor coolant is circulated between the RCS and the CSCS, which transfers decay heat to the CCS; subsequently, coolant is transferred to the ESWS, which rejects decay heat to the atmosphere via the ESWS cooling towers.

5.9.17 PDHR primarily removes decay heat from the reactor core during faulted operation and transfers the heat to atmosphere. It is the preferred means of providing CoFT following design basis faults that render HTHR unavailable whilst the RCS structural integrity is maintained. In the event of failure of PDHR, ECC is capable of providing an independent means of Decay Heat Removal (DHR).

5.9.18 PDHR heat transfer from the reactor system to atmosphere is provided by three independent cooling trains each aligned to a separate RCS cooling loop. Each cooling train is sized to provide heat removal with 1 out of 3 redundancy. Each Local Ultimate Heat Sink (LUHS) train has sufficient stored water to provide 24 hours of heat removal; 2 out of 3 LUHS trains are sufficient to provide 72 hours of heat removal and 3 out of 3 LUHS trains are sufficient to provide at least 120 hours of heat removal.

5.9.19 ECC is designed to provide DHR without reliance on the structural integrity of the RCS. It is the principal means of controlling core temperature following intermediate and large LOCA events, where rejection of heat using the SGs is unavailable.

5.9.20 In the event of an accident where the RCS is depressurised, coolant is injected into the core via the Low Pressure Injection System (LPIS). The LPIS operates in three phases: an initial phase where coolant is driven by compressed gas into the RPV from the accumulators, a second phase where coolant is driven by gravity flow from the refuelling pool into the RPV, and a third phase where coolant is recirculated between the RPV and the Containment Sump. Together, the three phases ensure rapid initial injection followed by continuous recirculation of coolant. The LUHS removes heat from the containment atmosphere using a heat exchanger. The condensed steam drains to the sump screens, to the core, to provide continued cooling for the duration of the 72 hours.

5.9.21 The LUHS consists of three identical interconnected trains, each comprising a large, elevated tank containing demineralized water, as well as various supporting sub-systems. Heat is transferred to the coolant in the tank via the set of heat exchangers; the coolant subsequently boils, transferring decay heat to the environment. 2 out of 3 trains are sufficient to provide 72 hours of cooling without operator intervention.

5.9.22 The Containment Safety Measures function during all operational states and accident conditions to deliver the CoRM fundamental safety function. Successive barriers to confine radioactive material are provided by the fuel pellets and cladding, the RCS and the Containment Vessel.

5.9.23 The Faulted Containment Safety Measure operates during faults within Design Basis Conditions, where the fuel is fully or largely intact, primarily by retaining coolant within the remaining barriers including by isolating fluid systems connected to the RCS. During faults where coolant is leaking into the containment, the accumulation of hydrogen is limited by passive design features including Passive Autocatalytic Recombiners to prevent an explosion.

5.9.24 The Severe Accident Containment Safety Measure operates during Design Extension Conditions during which the fuel cladding and RCS have failed. Several functions may combine to deliver the safety functionality including containment isolation, passive heat removal via the LUHS, active heat removal via the Fuel Pool Cooling System, Severe Accident Depressurization, In-Vessel Retention, hydrogen recombination and ignition, and Containment Spray.

5.9.25 The principal component of the Containment System is the Containment Vessel, which is a large steel pressure vessel, with a cylindrical shell and ellipsoidal dome profiles. The Containment Vessel forms a leak tight pressure retaining structure surrounding the RCS.

5.9.26 The Containment Support Structure comprises a central reinforced concrete plinth and three large monolithic reinforced concrete blocks positioned at the outer regions of the lower dome (see Figure 11). This means that the lower dome of the containment vessel and part of the lower cylindrical shell is embedded in concrete internally and externally. The support structure transfers load to the base mat which in turn transfers loads through aseismic bearings to the raft foundation.

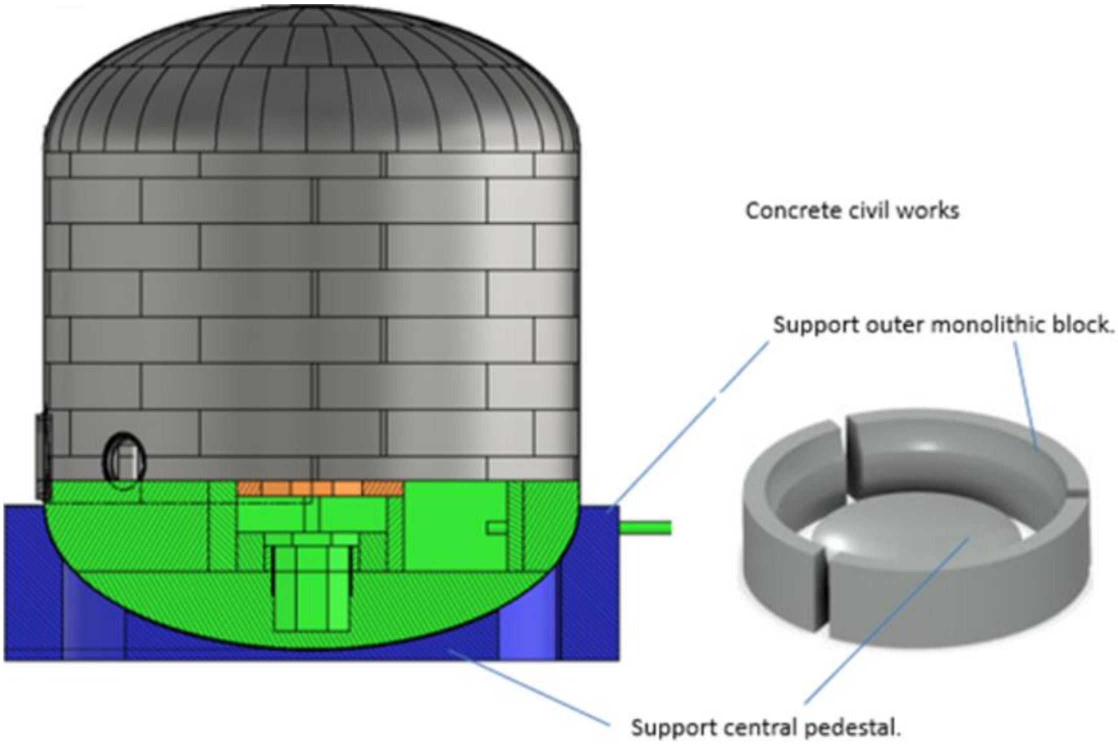

Figure 11 – Containment Vessel and Containment Support Structure

6 Turbine Island

6.1 Overview

Figure 12 – Turbine Island

6.1.1 The Turbine Island receives steam from the Reactor Island, generating electrical energy using the Main Turbine Generator System (MTGS), and supplies Feedwater back to the Reactor Island for the continued generation of steam. A schematic diagram of the major Turbine Island equipment is presented in Figure 13.

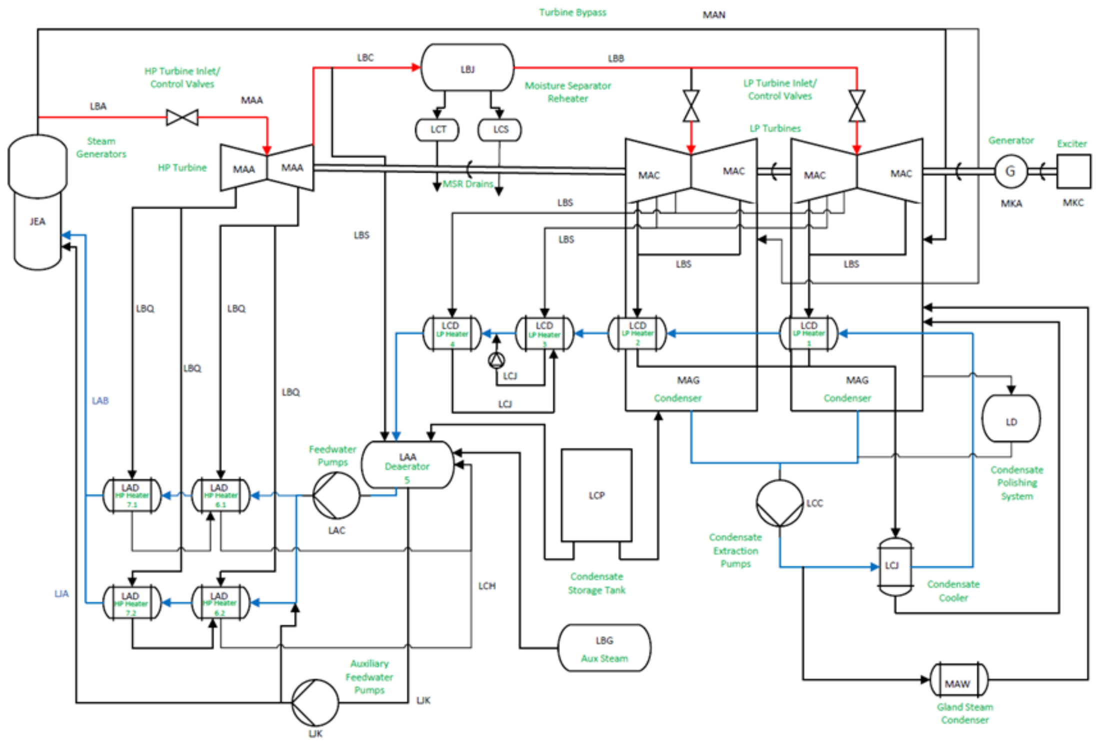

Figure 13 – High Level Turbine Island Schematic

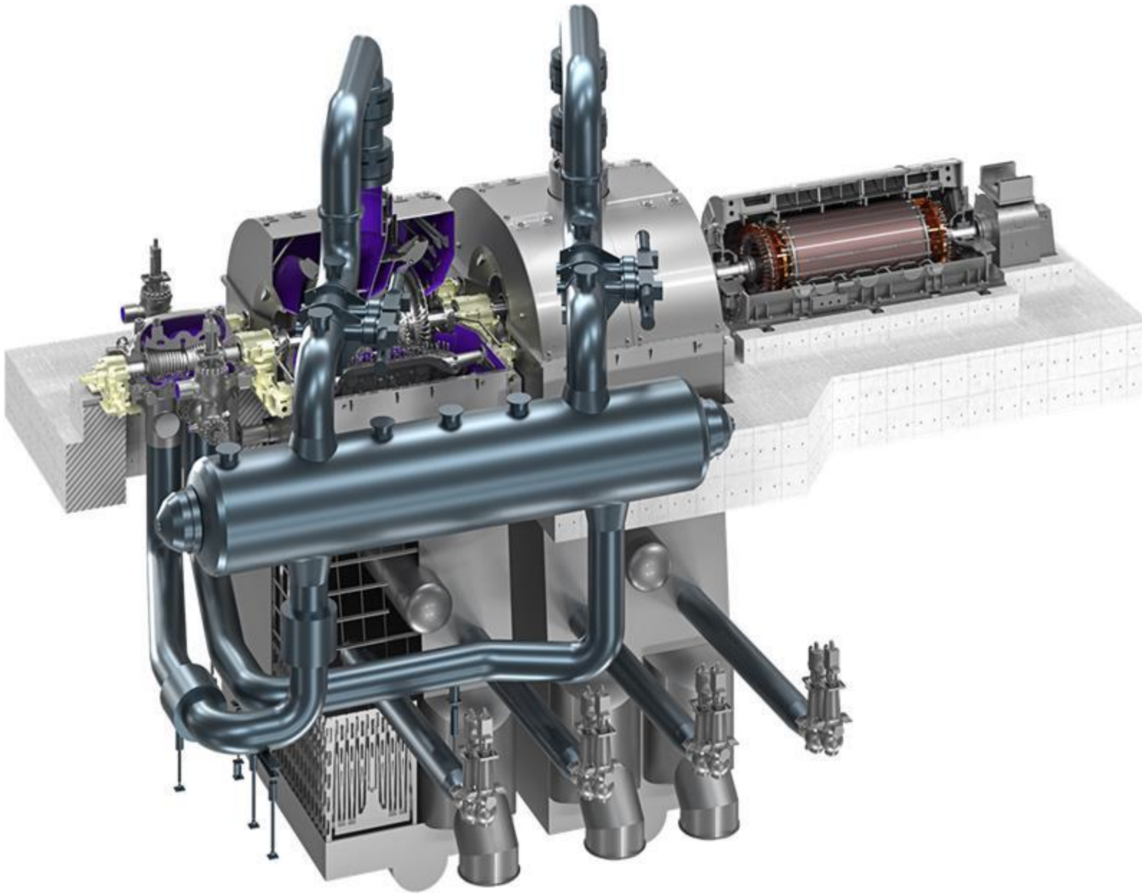

Figure 14 – Turbine Generator Condenser Arrangement

6.1.2 Each Rolls-Royce SMR unit employs a full speed wet steam turbine which comprises of one High Pressure (HP) turbine section and two Low Pressure (LP) turbine sections. Steam is extracted at seven points across the turbine system for feedwater heating to improve plant efficiency.

Primary Functions of the Steam Turbine:

- Convert thermal energy from steam into mechanical rotational energy via a multistage expansion process,
- Supply extraction steam for condensate and feedwater preheating via seven extraction steam points across the turbine sections.

High Pressure Turbine

6.1.3 Main steam enters the system through two combined HP steam stop and control valves, following filtration by steam strainers. Upstream of the HP stop and control valves, the steam is at saturated conditions and is throttled to the required parameters at the HP turbine inlet.

Within the HP turbine, steam expands through the blading, converting thermal energy into mechanical energy.

6.1.4 The HP turbine includes two extraction points, A7 and A6, which supply steam to the HP feedwater heaters. After expansion, the steam exits the HP turbine via bottom exhaust branches at Cold Re-Heat (CRH) conditions and flows into the CRH piping system, leading to the Moisture Separator Reheater (MSR).

Low Pressure Turbine

6.1.5 The LP turbines expand the reheated steam down to condenser pressure, expanding the steam through the blading and converting the thermal energy into mechanical energy. The HP turbine and LP turbine are connected on a single shaft which rotates the generator. The first LP turbine includes two extraction points, while the second includes a further two. These extractions serve both feedwater heating and turbine drainage functions. Specifically:

6.1.6 Extractions A1 and A2 are located in the condenser neck and do not require non-return valves due to the low pressure environment.

6.1.7 Extractions A3 and A4 are equipped with non-return valves and drains and are connected to the LP feedwater heaters.

6.1.8 Steam flow through the LP turbines decreases progressively due to these extractions. After final expansion in the LP blading, the remaining steam exits through the LP exhaust into the condenser. Each LP turbine inlet contains a combined butterfly stop and control valve. These valves immediately stop the steam flow into the LP turbines during a turbine trip, limit steam mass flow into the turbines on load rejection and maintain condenser vacuum during turbine bypass operation.

Turbine Bearings and Gland Seals

6.1.9 Bearings are mounted between the shaft and the casings of both the HP and LP turbines. The bearings are supplied with cooled oil for both bearing jacking and rotation. To assist in mitigating faults in the turbine and auxiliary systems, the bearings and oil are monitored for vibration, temperature, pressure and volumetric flow.

6.1.10 Both HP and LP turbine shafts have gland seals located at either end of their respective cases. The main functions of the gland seals are:

- Prevent steam exiting the HP turbine due to the differential pressures,
- Prevent air ingress into the LP turbine due to the differential pressures,
- Protect the bearings from hot steam and oil contamination,
- Pre-heat the shaft on startup.

6.1.11 Sealing steam is supplied from the auxiliary steam system on startup and the leak off steam system during normal operation. The leak off steam is obtained from the spindles of the HP turbine and LP turbine combined stop and control valves. To improve plant efficiency, heat is recovered from the used gland sealing steam through the gland steam condenser. This recovered heat is used to pre-heat the condensate.

Turbine Bypass Station

6.1.12 During normal shutdown, startup or faulted shutdown, and load rejection, steam cannot be directed from the SGs to the turbine path, as steam admission to the turbines is isolated. The function of the bypass station is to route the steam directly to the condensers. There are four bypass lines and valves, two per condenser. Each bypass line contains a bypass valve which includes a water injection spray mechanism, designed such that steam conditions are reduced to the required enthalpy to protect the condenser. The water used in the water injection spray is extracted after the condensate extraction pumps. The bypass station is a critical system for turbine control and protection during faulted conditions.

Generator

6.1.13 The generator is the key component for electrical generation of the Rolls-Royce SMR power station. The selected generator is a synchronous machine which is water and hydrogen cooled and consists of two primary parts, the stator and the rotor.

Primary Functions of the Generator:

- Converting rotational energy into electrical energy,
- Regulation of voltage level for correct distribution of power,
- Grid frequency synchronisation.

Stator

6.1.14 The stator is the stationary part of the generator responsible for producing electrical power. It consists of a core made from laminated steel and a series of copper windings arranged in slots around the inner circumference. The stator of the generator is designed for high thermal and mechanical stability. It uses direct water cooling for the stator bars, which allows for efficient heat removal and supports high power density. The stator core is built with insulation which enhances electrical endurance and reduces the risk of thermal degradation. Resistance Temperature Detectors (RTDs) are positioned in the stator slots where the highest temperature is anticipated.

Rotor

6.1.15 The rotor is the rotating component that creates the magnetic field necessary for electrical generation. It is mounted on the steam turbine shaft with the HP and LP turbines and spins inside the generator stator. The rotor is hydrogen cooled, which improves thermal conductivity and reduces frictional losses compared to air cooled designs. Cooling is achieved through axial hydrogen flow directly through each rotor winding turn, ensuring uniform temperature distribution. RTDs are positioned to monitor the gas temperatures upstream and downstream of the gas coolers. The rotor is engineered for continuous operation without requiring removal for service, and it incorporates pre-stressed, non-magnetic through bolts to maintain core integrity and minimize maintenance.

Generator Bearings and Seals

6.1.16 On either end of the generator, bearings are used to support the rotor against the casing. To assist in mitigating faults in the generator and auxiliary systems, the bearings and oil are monitored for vibrations, temperature, pressure and volumetric flow.

6.1.17 To maintain a seal within the generator, ensuring the hydrogen gas does not leak out and air does not ingress, gas tight and pressure resistant oil seals are used. The seals are located on the rotor shaft at either end of the generator casing. For an optimized design architecture, the seal oil is supplied from the same oil used for lubricating the turbine generator bearings. The oil is cooled by the closed cooling water system to reject heat from the sealed and lubricated components.

Condenser

6.1.18 The condenser is a critical component in the steam cycle, designed to condense exhaust steam from the LP turbines and other auxiliary sources. Its primary function is to maintain a vacuum environment for condensation while removing non-condensable gases, thereby maximizing the enthalpy drop across the turbines and improving overall thermal efficiency. A multi pressure condenser arrangement has been selected to maximize cycle efficiency and unit power when combined with the generic cooling water indirect architecture. The type of condenser would be revisited on a site basis to ensure maximum efficiency and optimization for power output.

Primary Functions of the Condenser:

- Condense exhaust steam from LP turbines during normal operation,
- Condense steam from the bypass system during bypass operation,
- Evacuation of non-condensable gases,
- Drainage and venting of steam turbine systems,
- Recovery of condensate to maintain a closed loop steam and water cycle.

Standpipe System

6.1.19 Drains from turbine systems operating at higher pressure and enthalpy than the condenser are routed through standpipes. These standpipes facilitate phase separation, allowing steam to be cooled via continuous water injection. The gaseous phase enters the condenser through the neck, while the liquid phase is directed to the hotwell via a siphon, which prevents steam flashing. Water injection coolers assist in reducing the thermal load on the condenser by partially condensing the steam within the standpipes.

Vacuum Breaker

6.1.20 The vacuum breaker system is designed to rapidly terminate vacuum conditions during turbine generator coast down following a trip. This mitigates potential damage during faulted scenarios. Automatic activation is linked to the turbine oil supply system under faulted operation, with manual initiation also available post trip.

Condenser Pressure Protection

6.1.21 The condenser pressure protection system provides two key functions:

- LP Turbine Blade Protection prevents excessive vibration and windage in the final stages of LP turbine blading due to elevated back pressure. The protection setpoint is dynamic, based on LP turbine inlet pressure, and triggers a turbine trip with a time delay,
- Overpressure Protection safeguards the condenser and LP turbine casings against overpressure. Fixed setpoints initiate turbine and bypass trips independently.

6.1.22 Each condenser steam space is equipped with dedicated pressure monitoring and protection. Pressure signals are processed using a 2 out of 3 logic configuration to ensure reliability.

Condenser Level Protection

6.1.23 Condensate levels within the condenser are regulated by condensate pumps. Faults such as pump failure can lead to unacceptable operating conditions due to condenser high/low level, including:

- Increased condenser pressure,
- Excessive structural loading on turbine foundations and condenser supports,
- Flooding of standpipes and direct drains (risk of steam hammer),
- Risk of vacuum pump damage due to suction nozzle flooding,
- LP turbine blade damage from contact with elevated condensate levels,
- Dry running of condensate pumps.

6.1.24 To mitigate these risks, condenser level protection is implemented using a 2 out of 3 logic system. If the condensate level exceeds allowable limits, the system initiates a turbine trip and disables demineralized water injection.

7 Cooling Water Island

7.1 Overview

7.1.1 The Cooling Water Island transfers waste heat from the Turbine Island to the environment. The RR SMR will have the ability to be adapted to accommodate different Cooling Water Systems to meet the siting requirements. Currently the RR SMR design basis is for an indirect cooling system but can be adapted to accommodate alternative solutions such as direct cooling, dry cooling towers and closed cooling.

7.1.2 The cooling tower modules, alongside other supporting systems such as the Forebay, Intake Tunnels, water filtration and Pumphouse, are located outside of the main site earth bund, within the Cooling Water Island satellite site. These are oriented to optimally meet the local site conditions.

7.2 Main Circulating Water System

7.2.1 The Main Circulating Water System (MCWS) transfers heat from the turbine condenser to the heat sink (the atmosphere via evaporative mechanical draft cooling towers (MDCT) for the indirect cooling baseline). The MCWS fundamentally enables optimum operation of the Steam Turbine and the subsequent generation of electricity.

7.2.2 Water is circulated from the cooling tower basin to the Main Circulation Pumps (MCP), which is downstream of the cooling tower basin. The water is then pumped through the turbine condenser and then back to the MDCT. The water enters the MDCT where it is sprayed out passing the airflow, driven by fans, which cools the water as it falls into the cooling tower basin. The use of MDCT versus natural draft cooling towers reduces the visual impact of the cooling towers while providing a standardized design.

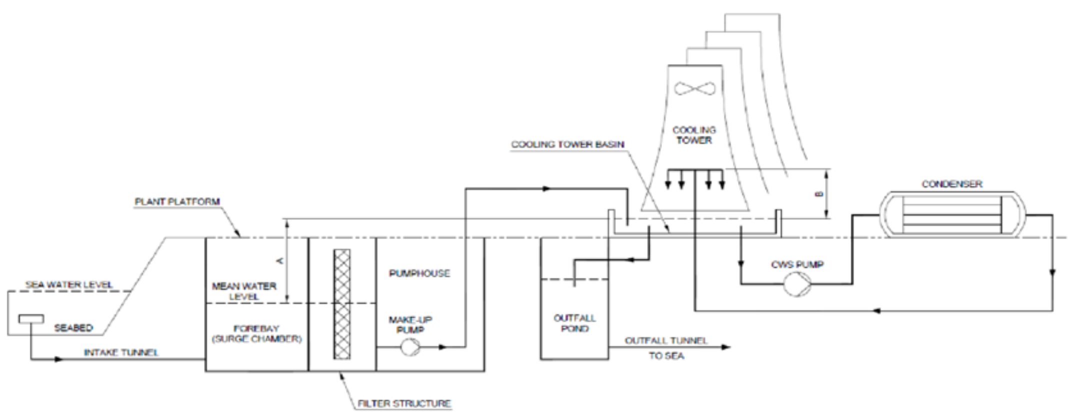

Figure 14 – Schematic of Indirect Cooling Regime

7.2.3 The cooling tower design basis uses a plume abatement system to abate the visible plume; however, this feature can be removed if not required for the site. The towers are a cellular structure and so the number of cells can be adapted based on the site's requirements. The baseline design has 40 cells, each with a footprint of 14 m x 14 m (46 ft). The total heat removal capacity of the MCWS is approximately 860 MW_{th} when the plant is operating at full power.

7.2.4 Approximately 2 to 3 % of the water within the MCWS closed circulation circuit is evaporated within the cooling towers during operation. This loss of cooling water is compensated for by the make-up water provided by the Auxiliary Cooling and Make-Up System (ACMS).

7.3 Auxiliary Cooling and Make-Up System

7.3.1 The Auxiliary Cooling Water and Make-Up System (ACMS) is responsible for providing make-up water to the MCWS, in addition to providing Auxiliary Cooling Water for Turbine Island systems and facilitating MCWS blowdown.

7.3.2 The ACMS provides make-up water to the MCWS which is supplied into the cooling tower basins. The make-up water supply provides a constant source of make-up water to replace water lost through evaporation, drift and blowdown from the cooling tower. Blowdown water is discharged back to the ACMS via connections to the cooling tower basins.

7.3.3 The blowdown system extracts water at a constant rate, driven by passive means, from the cooling tower basin and discharges this water back to the environment. This is critical to maintain adequate water quality within the MCWS. The ACMS blowdown system also receives discharges from surface water and treated wastewater systems across the plant.

7.3.4 The ACMS is configured as shown in Figure 15 for coastal applications, which uses sea water as the cooling fluid. It is recognized that the ACMS is a site-specific design that will be tailored to meet the specific needs of the site and customer.

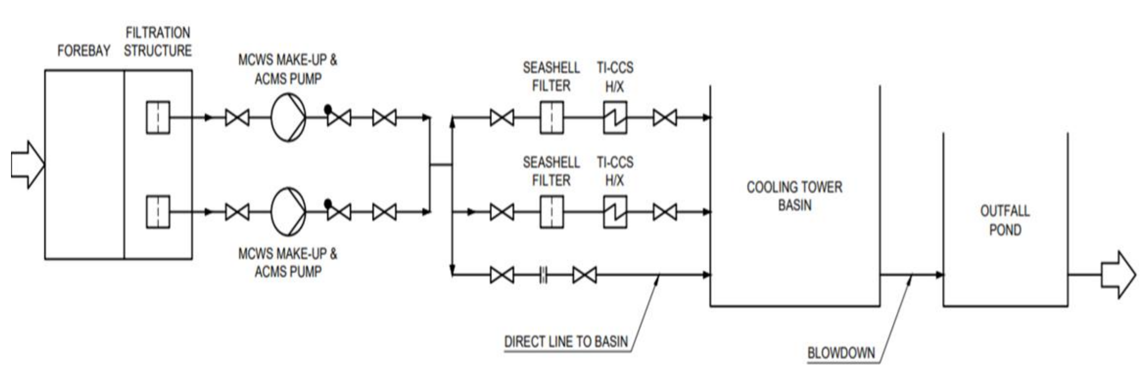

Figure 15 – Schematic of Auxiliary Cooling Water and Make-Up Water System

8 Electrical, Controls and Instrumentation

8.1 Control and Instrumentation Systems

8.1.1 Control and Instrumentation (C&I) systems monitor, control and protect the plant in both normal operations and faulted conditions. These systems are designed to provide a safe, secure, robust, and reliable solution, which is in line with recognized and endorsed best practices, such as defense in depth, provision of adequate and reliable engineering solutions, minimization of design complexity, provision of diversity, redundancy, segregation and separation.

8.1.2 This is further guided by a number of common principles:

- Standardization of equipment across all C&I systems covering not only equipment type but configuration, diagnostics, software development processes and communication,
- Distribution of C&I devices to support build certainty for installation. This maximizes, where appropriate, the use of fieldbus systems to reduce cabling and expand scope of data available,
- Network connection of all C&I systems (for diagnostics and monitoring), with due consideration for cyber security.

8.1.3 C&I systems are allocated to functions at the different DiD levels. The allocation of key C&I systems DiD levels are summarized in Table 5.

Table 5 – Allocation of C&I Systems to DiD Levels

DiD level	1	2	3	4	5
C&I System(s)	Reactor Plant Control System	Reactor Limitation & Preventive Protection System (RLPPS)	Reactor Protection System (RPS)	Severe Accident Management Systems (SAMS)	Human-Machine Interface (HMI) in the Emergency Control Centre
	Control Rod Control Systems (CRCS)	CRCS	Diverse Protection System (DPS)		
	Nuclear HVAC Supervisory Control System		Post Accident Management Systems (PAMS)		
	Reactor Plant Monitoring System				
	Fuel Route C&I	Fuel Route C&I			
	Radioactive Waste Management System C&I				

Note: The CRCS is likely to deliver DiD1 and DiD 2 functions (the CRCS controller will perform prioritisation of rod control between DiD1 and DiD 2 PLCs inputs).

8.1.4 The primary role of the DPS is to implement automatic functions responding to DB faults. These functions are assigned to both the DPS and the RPS with one means of detection assigned to the DPS, while another is assigned to the RPS (as far as is practicable) to ensure signal diversity between DPS and RPS. The DPS forms part of DiD level 3 along with the RPS, noting that the DPS and RPS needs to be independent from each other.

8.1.5 A secondary role of the DPS is to respond to design basis faults which occur simultaneously with a Common Cause Failure (CCF) of the RPS and will be sufficiently diverse and independent from the RPS. The DPS will be implemented in a hardwired technology, with no programmable devices in the path of the safety function.

8.1.6 The RPS fulfils two main roles:

- Secondary means of implementing functions alongside the DPS to provide signal diversity between RPS and DPS,
- Implementation of DiD level 3 functions.

8.1.7 The first role is fulfilled by the dedicated RPS 1 C&I system and the second role by the dedicated RPS 2 C&I system. The RPS will use programmable logic as a diverse technology system compared to the DPS. This allows complex functionality to be implemented in the RPS.

8.1.8 The AMS supports on-site staff in making decisions for the management of design basis accidents, design extension conditions, and severe accidents. The role of the AMS is to provide monitoring instrumentation and systems for preventive and mitigative accident management. The AMS is made up of two systems, namely, PAMS and SAMS.

8.1.9 The role of the PAMS is to provide monitoring instrumentation and systems for preventive and mitigative accident management during DBAs. It forms part of the DiD level 3. The PAMS displays information for monitoring accident conditions in the Main Control Room (MCR) and Supplementary Control Room (SCR).

8.1.10 The PAMS uses software based programmable technology similar to the platform used in the RPS allowing complex functionality to be more easily implemented. The SAMS provides C&I functionality dedicated to the management of severe accidents in DiD level 4. C&I functions which mitigate design extension conditions or severe accidents are assigned to the SAMS. Lower classification SAMS will be implemented in two redundancies as the underlying controlled system consists of two redundant trains. Operator commands for both the safe and the un-safe direction shall be given at the HMI of the SAMS.

8.1.11 A hardwired platform is used so that the SAMS can utilize the same type of platform as the DPS. Even though the DPS and the SAMS use the same technology, the systems will be independent from each other.

8.1.12 The RPCMS is made up of two systems, the RPCS and the Reactor Plant Monitoring System (RPMS). The RPCMS makes use of Commercial off The Shelf (COTS) solutions, which can be sourced widely in the supply chain.

8.1.13 The RPCS consists of the following sub-systems:

- RCS,
- RLPPS,
- CRCS,
- Nuclear HVAC Supervisory Control System,
- RPMS System Overview.

8.1.14 The RPMS monitors the non-safety critical parameters of the reactor to provide condition monitoring and consists of the following sub-systems:

In-core flux monitoring,

Loose-parts detection system,

Rotary equipment vibration monitoring and diagnostics systems,

Fatigue monitoring system,

Neutron noise monitoring system,

Primary circuit leak detection system,

Valve monitoring system,

Seismic monitoring system,

Reactor Island sampling system C&I.

8.1.15 The high-level role of the Fuel Route C&I System is to provide control, protection and monitoring of the Fuel Route SSCs. The Fuel Route C&I System (and its subsystems) forms part of DiD levels 1 and 2.

8.1.16 Some fuel route SSCs utilize Programmable Logic Controllers (PLCs) connected to the DPCS via a networked connection and local HMIs / operator panels connected to their local PLC. This is separate to any HMI functionality provided by the Distributed Control System (DCS).

8.2 Electrical Power Systems

8.2.1 The Electrical Power System (EPS) transmits electrical power from the Main Generator to the grid connection point, and to supply electrical power to site loads. Electrical power is generated using the steam turbine driven Main Generator described above, which produces electricity at a nominal frequency of 50 Hz and a voltage of approximately 20 kV. A generator transformer subsequently “steps up” the voltage for connection to the grid. A single unit transformer provides the normal source of power to site loads from the Main Generator and Main Grid Connection.

8.2.2 The grid interface of the RR SMR will be tailored to meet local requirements and avoid significant infrastructure development where possible. The preferred interface includes one or more main connections for power export; and an auxiliary connection. The main power export connections should be at 400 kV (or similar) to minimize transmission losses and fault levels. The auxiliary connection may be at the same voltage or at a lower voltage e.g. 132 kV.

8.2.3 The RR SMR is designed with the capability to 'trip to house load' in the event of a grid disturbance, rather than shutting down. This allows for a rapid reconnection to the Grid after the disturbance, contributing to the reliability and robustness of the grid, and providing defense in depth for the RR SMR's electrical supplies.

8.2.4 A single station transformer provides an alternative grid supply via the Auxiliary Grid Connection in case of unavailability of the main connection. The RR SMR's passive fault protection philosophy means that grid supplies are not required to deliver headline safety measure functionality.

8.2.5 The switchboard voltage levels have been selected from IEC 60038. The following system voltage levels are used in the electrical architecture:

- Offsite transmission connections – 400 kV,
- High Voltage Main AC Supply System – 11 kV,
- Low Voltage Main AC Supply System – at 400 V (230 V single phase),
- Low voltage uninterruptible 220 V DC and 110 V.

8.2.6 This list is focused on the voltages used for power distribution. Other voltages will be present in some locations and within some equipment, for example 6.6 kV for the reactor coolant pump motors and 48 V DC for a number of C&I systems and relay supplies.

8.2.7 The design of the safety-related power supplies includes the following power sources:

- Standby AC – two redundant divisions, providing power to the HP injection pumps, emergency boron injection pumps, battery chargers, and selected other loads where justified based on their importance to defense-in-depth or investment protection,
- Alternate AC – static or mobile power sources, providing a diverse supply of power in a Station Black Out (SBO) fault (unavailability of Grid, Main Generator and standby AC sources). This is to provide power to battery chargers and certain safety functions,
- Uninterruptible power supplies – multiple systems provided by onsite battery systems to match the independence and diversity requirements of the plant safety systems (such as actuators) and C&I systems. For selected loads, uninterruptible AC/DC will be provided for 24 hours for the protection systems and 72 hours for the accident management systems.

8.2.8 On-site supplies (AC or DC, depending on the load) are provided where required for investment protection or to provide immunity to supply interruptions e.g. for C&I, fire protection, telecommunications, security systems, turbo-generator seal oil / lube oil, and rod control system supplies.

8.2.9 On-site DC supplies are provided where required for investment protection or to provide immunity to supply interruptions e.g. for C&I, fire protection, telecommunications, security systems, turbo-generator seal oil / lubricating oil.

9 Balance Of Plant

9.1 Overview

9.1.1 Balance of Plant refers to a collection of systems that support the operation of the power station through all operating modes, such as the supply of coolant, gases and chemicals to Reactor Island, Turbine Island and Cooling Water Island. Balance of Plant systems are important to maximizing output and plant efficiency.

9.1.2 The location of key Balance of Plant equipment can be seen below in Figure 16. It should be noted that due to the nature of the Balance of Plant systems, equipment will be present throughout the power station.

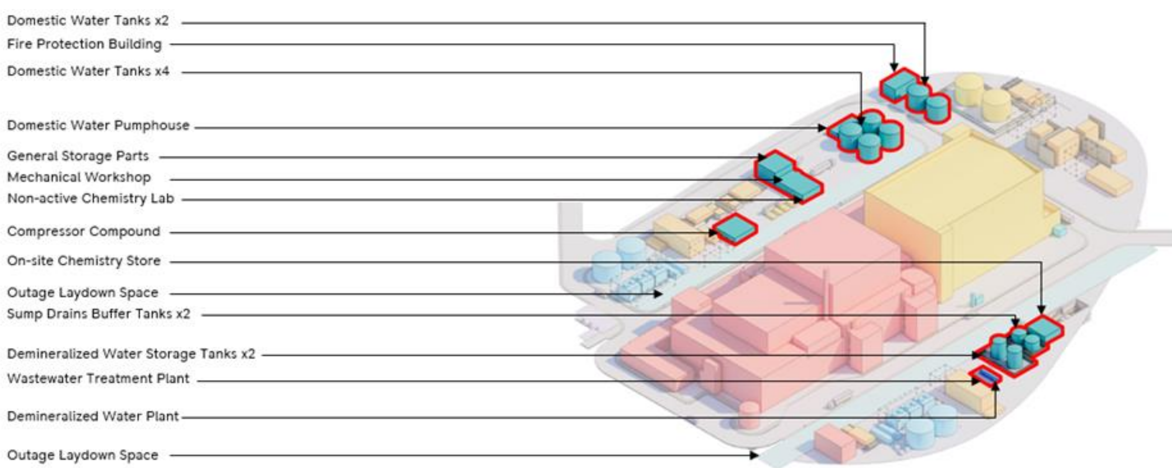

Figure 16 – Location of Balance of Plant Systems

9.2 Water Supply, Disposal and Treatment

9.2.1 The RR SMR water supply system architecture utilizes potable quality water drawn from city mains network as plant make-up water. Therefore, on site water treatment to meet plant make up water (i.e. raw water) quality is not required for sites with a suitable supply. However, there is flexibility in the design to incorporate modular, containerised treatment systems to utilize other water sources as necessary to meet the siting constraints.

9.2.2 Where an alternative supply exists on site, such as river water, this will be assessed for its technical and commercial viability with a view to implementing into the design where feasible.

9.2.3 This water is primarily used for the production of demineralized water, as make-up to the ESW cooling towers and for welfare services. For redundancy purposes, this system stores approximately 72 hours of raw water which equates to approximately 4500 m^3 (1,188,774 USG) of raw water. This will be stored across several large storage tanks.

9.2.4 The main raw water supply and distribution network is established early in the site construction to facilitate its early use.

9.2.5 The RR SMR demineralized water system produces, stores and distributes demineralized water. The system comprises of two x 100 % treatment trains, both housed in a single Commercially available Off The Shelf (COTS) shipping container. Each treatment train uses a Reverse Osmosis (RO) module followed by an Electro-DeIonization (EDI) module. Demineralized water is then fed into two 500 m^3 (132,086 USG) storage tanks, before being pumped to Reactor Island, Turbine Island or Balance of Plant systems via a duty/standby pumping arrangement.

9.2.6 During start-up procedures, the demineralized water demand increases significantly. During these instances, a mobile unit is brought to site specifically sized to cover scheduled peak demands that would occur infrequently during planned events.

9.2.7 A demineralized water distribution network is provided which ensures that each SSC receives demineralized water at the required flow and pressure.

9.2.8 The wastewater drainage and treatment system provides collection, treatment, and disposal for all non-active trade effluents produced across the RR SMR. The overarching philosophy of the system applies the waste minimisation hierarchy to reduce waste, maximize recycling and only discharges to the environment when necessary.

9.2.9 The wastewater drainage and treatment system collects non-active trade effluent from across the power station, including Turbine Island, Balance of Plant, Cooling Water Island and Reactor Island.

9.2.10 Effluents are processed based upon the waste minimization hierarchy, incorporating anticipated characteristics such as quality, flowrate and frequency.

9.2.11 Volumetrically, the largest operational sources of effluent are the ESWS cooling tower blowdown and the effluent produced during the demineralized water production process. Conversely, the largest operational water demands are make-up to the ESWS cooling towers, and make-up to the demineralized water production plant. As such, a containerized wastewater treatment plant is utilized to recycle the ESWS cooling tower blowdown and effluent produced during the demineralized water production process to be used as make-up to the ESWS cooling tower and the demineralized water production process.

9.2.12 This configuration has a dual benefit of reducing the RR SMR potable water demand, whilst also reducing the waste produced.

9.2.13 To support the maintenance drainage demand anticipated during an outage period, the throughput of the wastewater treatment plant will be bolstered through the utilization of additional, mobile wastewater treatment plants.

9.3 Auxiliary Systems

9.3.1 The central chemicals supply system receives, stores and supplies chemicals to be used across the RR SMR.

9.3.2 The central chemical supply system will store certain chemicals in a central chemical storage building, whereas some chemicals will be stored locally to the end user. As a general philosophy, chemicals will be stored to maximize inherent safety. This will consider, but not be limited to:

- Minimizing the quantities of chemicals stored on-site,
- Using less hazardous materials where possible,
- Reducing the strength of hazardous chemicals,
- Ensuring that potentially dangerous chemicals are located to minimize the "domino effect" (for example locating dangerous materials away from the Reactor Island where possible).

9.3.3 The chemicals used on the RR SMR, and the respective chemical supply system architectures, are typical for a PWR. Each chemical is stored and supplied in line with Operational Experience (OpEx), RGP and legislative requirements. Chemicals are stored in bulk tanks, Intermediate Bulk Containers (IBCs) and smaller containers, depending upon the usage rate and associated hazards.

9.3.4 The central gas supply system receives, stores, and supplies all gases, such as Hydrogen, Nitrogen and Argon, which are used across the RR SMR.

9.3.5 The Hydrogen supply system is to primarily supply hydrogen from a tube trailer system, accompanied with high-flow vents and pressure letdown equipment. Hydrogen cylinders will also be provided as back-up for safety critical applications.

9.3.6 The Nitrogen and Argon supply systems utilize bulk storage in cryogenic tanks accompanied by vaporizers in COTS packages. For high-pressure Nitrogen applications, a Nitrogen compressor is employed. Both Nitrogen and Argon will also be stored in gas cylinders.

9.3.7 All systems are housed in secure, clearly labelled and segregated areas across the site.

9.3.8 The central control air supply system generates, stores and supplies clean, dry, oil free compressed air. This is supplied to SSCs across the RR SMR at approximately 10 bar(a) for valve actuation, operation of pneumatic tools, cleaning, and other typical applications.

9.3.9 The central control air production system comprises of two x 100 % trains utilising COTS equipment, housed in two 40ft containers.

9.3.10 The primary function of the auxiliary steam generating and supply system is to generate and supply saturated steam for use in Turbine Island systems during plant start-up or fault conditions.

9.3.11 The system includes a permanent electric steam boiler that will quickly provide steam to the turbine gland seals during a fault that leads to the loss of the main steam supply.

9.3.12 The system also requires the use of a mobile, containerised, fired steam boiler that will be brought onto the RR SMR site to support start-up of the turbine following an outage. More specifically, this system will provide saturated steam for turbine gland sealing and de-aeration during start-up.

9.3.13 The ancillary sampling and monitoring system provides two overarching functions:

- In-process sampling and monitoring (excluding Reactor Island). This may be used, for example, to inform the operator of the chemistry specification of a certain system,
- Sampling and monitoring for final discharge accountancy / reporting to ensure permit compliance.

9.3.14 The ancillary sampling and monitoring system will use a variety of monitoring techniques. In some instances, discrete samples will be obtained and taken to a laboratory for analysis. In other instances, online monitoring techniques will be used to provide live feedback of a specific parameter.

9.4 Ancillary Systems

9.4.1 The fire extinguishing system provides all fire extinguishing services across the RR SMR, ranging from fixed water-based systems through to handheld fire extinguishers. All fire suppression systems are designed to adhere to national and / or international standards such as British Standards, EN fire standards and the National Fire Protection Association (NFPA) standards.

9.4.2 The RR SMR has a fire water ring main system that is designed in accordance with NFPA 24 which feeds a network of fire hydrants and water based fixed fire suppression systems. The system is fed from two tanks, each sized to hold enough water to supply the maximum system demand for 2 hours, via a pump house, designed in accordance with NFPA 20. The firewater pump house contains two electric driven pumps and one diesel driven pump, again, sized to deliver the systems maximum demand. A small jockey pump is also provided to maintain the system pressure when the system is not in use. All fixed gaseous fire suppression systems use inert gas.

9.4.3 The primary function of the conventional island heating, ventilation and air conditioning (CI-HVAC) system is to maintain ambient environmental conditions within conventional island systems, supporting both personnel comfort and equipment operability by supplying conditioned air and extracting non-nuclear contaminated air to the environment. The system includes the main CI-HVAC infrastructure responsible for regulating space temperature, humidity, and air quality through a variety of configurations, including ventilation-only, low-temperature, medium-temperature, and direct outside air systems. Space heating is provided through a dedicated heating system integrated into the main CI-HVAC framework. Cooling is delivered via a chilled water system that supports selected CI-HVAC units in areas requiring close temperature control.

9.4.4 The CI-HVAC system employs both recirculatory and non-recirculatory arrangements, with system selection driven by room occupancy and temperature control requirements. Recirculatory systems are used where extracted air is clean and can be reused to improve energy efficiency, while non-recirculatory systems are applied in areas where cross-contamination risks exist, particularly in occupied spaces served by shared ventilation. This configuration ensures environmental conditions are maintained in line with operational, safety, and human factors requirements.

9.4.5 The primary function of the mechanical handling system for the Turbine Island is to provide permanent mechanical lifting and handling capability for equipment installation, removal, and maintenance activities within the Turbine Building. It is designed to support the safe, efficient, and reliable handling of large or heavy equipment across all phases of the power station lifecycle, including construction, commissioning, operation, and decommissioning.

9.4.6 The system provides mechanical handling coverage throughout the Turbine Island Hall, supporting lifts, relocations, and maintenance activities involving plant components such as turbines, generators, condensers, pumps, and associated auxiliaries. It is specifically intended to maximize the use of permanent crane infrastructure, reducing reliance on mobile or temporary lifting equipment in order to improve safety, reduce setup time, and enable repeatable operations. The lifting system is integrated into the plant layout to allow access to major components without dismantling adjacent structures, thereby supporting maintainability and minimizing disruption during outages. It also provides the lifting capacity required for major installation and replacement activities during early project stages. The specific equipment to be handled will be defined in alignment with the selected turbine supplier's layout and handling requirements. The system is being developed with the flexibility to accommodate all foreseeable heavy lifts within the Turbine Island Hall, ensuring compatibility with the final OEM scope and supporting long-term operability consistent with best practice in turbine hall design.

9.5 Overview of Plant Water Requirements

9.5.1 Estimates of water usage for different cooling water solutions and water source types are summarized in Table 6.

Table 6 – Water Usage Summary

		Sea		Fresh		Potable Water	
		Abstraction	Discharge	Abstraction	Discharge	Abstraction	Trade Effluent Discharge
Sea Water site	Direct	50,440m^3/hr (13,324,838 USG/hr)	47,925m^3/hr (12,604,445 USG/hr)			50m^3/hr (13,208 USG/hr)	50m^3/hr (13,208 UG/hr)
	In-direct	5,760m^3/hr (1,521,631 USG/hr)	4,320m^3/hr (1,141,223 USG/hr)			50m^3/hr (13,208 USG/hr)	50m^3/hr (13,208 UG/hr)
	Closed Air Cooling	0* to ~480 m^3/hr (126,803 USG/hr)	0* to ~480 m^3/hr (126,803 USG/hr)			1 - 50m^3/hr (13,208 USG/hr)	1 -50m^3/hr (264 UG/hr)
Fresh Water site	Direct			49,200m^3/hr (12,363,252 USG/hr)	46,170m^3/hr (12,363,252 USG/hr)	50m^3/hr (13,208 USG/hr)	50m^3/hr (13,208 UG/hr)

Table 6 – Water Usage Summary

		Sea		Fresh		Potable Water	
	In-direct			5,615m^3/hr (1,483,326 USG/hr)	4,210m^3/hr (1,112,164 USG/hr)	50m^3/hr (13,208 USG/hr)	50m^3/hr (13,208 UG/hr)
	Closed Air Cooling			0* to ~480 m^3/hr (126,803 USG/hr)	0* to ~480 m^3/hr (126,803 USG/hr)	1-50m^3/hr (13,208 USG/hr)	1 -50m^3/hr (264 UG/hr)

Note: “Trade Effluent Discharge” incorporates continuous treated sewage discharges, wastewater treatment concentrates and other batch trade effluent discharges. The water usage (and discharges) is based on worst case temperature and water losses via evaporation. This is based on normal operation.

* Variation in Closed water usage is attributed to potential for additional zero liquid discharge equipment, deployed using plant powered by house loads to recycle the already low levels of effluent from closed air cooling.

10 Acronyms and Abbreviations

ACMS	Auxiliary Coolant and Make-Up System
ALARP	As Low As Reasonably Practicable
ASD	Atmospheric Steam Dump
ASF	Alternative Shutdown Function
AxSS	Auxiliary Sampling System
BAT	Best Available Tools/Techniques
BSSD	Basic Safety System Directive
C&I	Controls and Instrumentation
CCF	Common Cause Failure
CCS	Component Cooling System
CDF	Core Damage Frequency
CDHR	Condenser Decay Heat Removal
CLP	Cask Loading Pit
CoFT	Control of Fuel Temperature
CoR	Control of Radioactivity
CoRM	Confinement of Radiological Material
COTS	Commercial Off The Shelf
CPS	Coolant Purification System
CRCS	Control Rod Control System
CRDM	Control Rod Drive Mechanism
CRH	Cold Re-Heat
CSCS	Cols Shutdown Cooling System
CVCS	Chemistry and Volume Control System
DA	DeAerator
DB	Design Basis
DCS	Distributed Control System
DEC	Design Extension Condition
DEPZ	Detailed Emergency Planning Zone
DHR	Decay Heat Removal
DiD	Defense in Depth

DPS	Diverse Protection System
DVI	Direct Vessel Injection
E3S	Environment, Safety, Security and Safety
EA	Environment Agency
EBI	Emergency Boron Injection
EC&I	Electrical, Control and Instrumentation
ECC	Emergency Core Cooling
EDI	ElectroDelonization
EMA	Engineering, Manufacture, Assembly
EPC	Engineering, Procurement, Construction
EPS	Electrical Power System
EPZ	Emergency Planning Zone
ESWS	Essential Service Water System
EUR	European Utility Requirements
FPCS	Fuel Pool Cooling System
FSF	Fundamental Safety Functions
FWCV	Feedwater Control Valve
GDA	Generic Design Assessment
GRETS	Gaseous Radioactive Effluent Treatment System
GWTS	Gaseous Waste Treatment System
HMI	Human Machine Interface
HP	High Pressure
HRH	Hot Re-Heat
HTHR	High Temperature Heat Removal
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
ICF	Intact Circuit Faults
ICI	In-Core Instrumentation
ICM	In-Core Monitoring
IHP	Integrated Head Package
IVR	In-Vessel Retention
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Hydrogen

LOCA	Loss Of Coolant Accident
LP	Low Pressure
LPIS	Low Pressure Injection System
LRETS	Liquid Radioactive Effluent Treatment System
LTDHR	Low Temperature Decay Heat Removal
LUHS	Local Ultimate Heatsink System
MCP	Main Circulation Pump
MCR	Main Control Room
MCWS	Main Circulating Water System
MDCT	Mechanical Draft Cooling Towers
MSR	Moisture Separator Reheater
MTGS	Main Turbine Generator System
NSS	Nuclear Sampling System
OECD	Organization for Economic Co-operation and Development
ONR	Office for Nuclear Regulation
OPZ	Outline Planning Zone
PAMS	Post Accident Management System
PERMS	Process and Emissions Radiation Monitoring System
PDHR	Passive Decay Heat Removal
PGA	Peak Ground Acceleration
PLC	Programmable Logic Controllers
PWR	Pressurized Water Reactor
RCL	Reactor Coolant Loop
RCP	Reactor Coolant Pump
RCPS	Reactor Control and Protection System
RCS	Reactor Coolant System
REPPIR	Radiation (Emergency Preparedness and Public Information) Regulations
RLPPS	Reactor Limitation & Preventive Protection System
RO	Reverse Osmosis
RPCMS	Reactor Plant Control & Monitoring System
RPMS	Reactor Plant Monitoring System
RPS	Reactor Protection System

RPV	Reactor Pressure Vessel
RPVI	Reactor Pressure Vessel Internals
SAMS	Severe Accident Management System
SBO	Station Black Out
SCR	Supplementary Control Room
SFAIRP	So Far As Is Reasonably Practicable
SFP	Spent Fuel Pool
SG	Steam Generator
SOEC	Solid Oxide Electrolysis Cell
SRV	Safety Relief Valve
SSC	Structures, Systems and Components
SSE	Safe Shutdown Earthquake
UKEF	United Kingdom Export Finance
UP	Upender Pit