



Rolls-Royce

UK SMR





Introduction

The UK SMR has been derived to deliver a market driven, affordable, low carbon, energy generation capability. The developed design is based on optimised and enhanced use of proven technologies that presents a class leading safety outlook and attractive market offering with minimum regulatory risk.

A three loop, close-coupled, Pressurised Water Reactor (PWR) provides a power output at circa 400-450 MWe from 1200-1350 MWth using industry standard UO_2 fuel. Coolant is circulated via three centrifugal Reactor Coolant Pumps (RCPs) to three corresponding vertical u-tube Steam Generators (SGs). The design includes multiple active and passive safety systems, each with substantial internal redundancy.

Rapid, certain and repeatable reactor and overall power station build is enhanced through site layout and maximising modular build, standardisation and commoditisation. The UK SMR design is illustrated below. The three loop reactor (Figure 1) is located in Nuclear Island, shown in red, adjacent to Turbine Island, shown in yellow, with the Cooling Water Pump House following, shown in blue (Figure 2). These facilities are protected by a robust hazard shield. Support buildings and those containing auxiliary services are situated within a berm that sweeps around the site and provides further protection from external hazards, e.g. tsunami or aircraft impact.

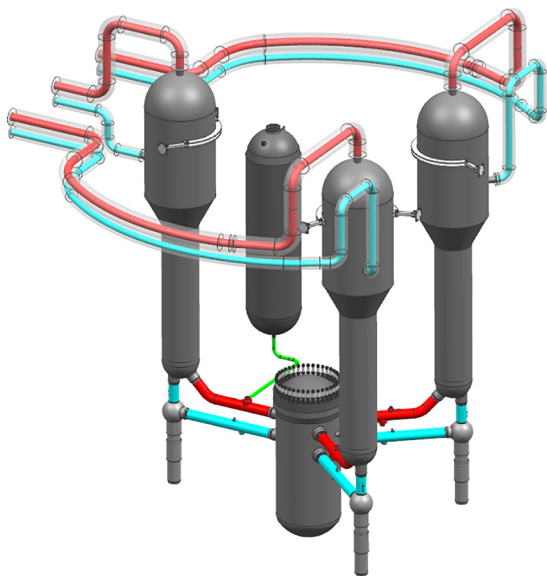


Figure 1 - Reactor Coolant System

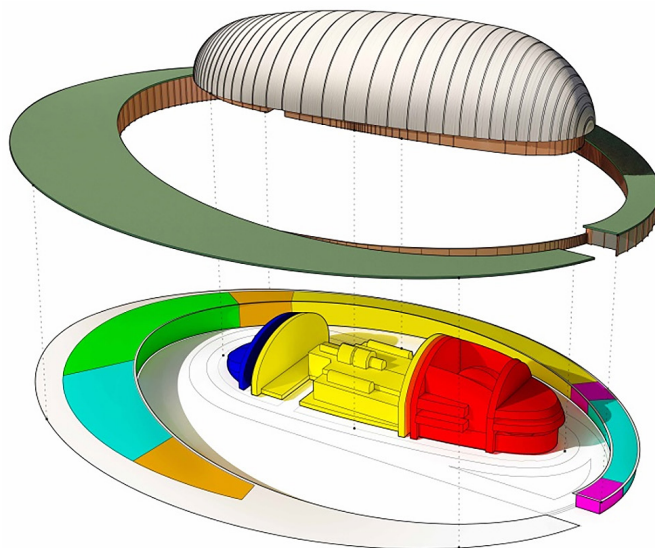


Figure 2 - Expanded Site View

Target application

The UK SMR is primarily intended for electricity production; however, the design can be configured to support other heat-requiring or cogeneration applications.



Development milestones

- 2015** Rolls-Royce development of initial reference design
- 2016** Formation of consortium for design of whole power station concept
- 2017** Mature design developed
- 2023** Planned achievement of regulatory Design Acceptance Confirmation (DAC) and Statement of Design Acceptability (SoDA)
- 2030** Planned first of a kind commercial operation

General Design Description

Design Philosophy

The UK SMR is designed to optimise Levelised Cost of Electricity (LCOE) against capital cost and therefore, the power output is maximised whilst delivering robust economics for Nuclear Power Plant investment and a power plant size that enables standardisation and modularisation across the entire power station.

To minimise the construction phase of the programme, the UK SMR is fully modularised to enable the plant to be transported by road, rail or sea. Targeting a 500 day modular build, this concept minimises the onsite time and effort required to construct and build the plant, allowing power generation to commence at the earliest possible point. The plant has been designed to optimise manufacture, inspection and maintenance with the intention to maximise through life plant availability.

Through a robust combination of active and passive safety measures, the UK SMR has been designed to present a class-leading safety outlook, driving radiological risk as low as reasonably practicable, surpassing internationally recognised numerical safety targets by significant margins.

Reactor Coolant System Layout

Three vertical u-tube SGs and the pressuriser are located around the circumference of the Reactor Pressure Vessel (RPV), with short close-coupled pipework connections between them. The pressuriser is connected to the reactor coolant system pipework hot leg. The SGs are located asymmetrically

around the RPV so that access is provided to support removal and movement of the RPV head and internals to storage locations within the containment boundary in support of refuelling operations.

The reactor coolant system uses pumped forced flow at power but is also configured to provide natural circulation flow for passive decay heat removal, by virtue of SG elevation above the RPV, which ensures a robust thermal driving head between the thermal centres of the core and the SGs. The RCPs are mounted, via close-coupled nozzles, from the bottom of the SG outlet header.

The tri-axial symmetry of the 3-loop design enables a compact configuration in tandem with the three lift elements that require movement (closure head, internals and fuel). This results in simplified linear lifts in 2-axes rather than complex 3-axis lifts requiring a polar crane. The elimination of a heavy lift polar crane (and associated mounting corbels) significantly reduces the effort required to ensure that the civil engineering design meets seismic requirements and in turn reduces cost by eliminating an expensive support structure.

Major Technical Parameters

Parameter	Value
Technology Developer	Rolls-Royce
Country of origin	United Kingdom
Reactor Type	PWR
Electrical Capacity (MWe)	400 – 450
Thermal Capacity (MWth)	1200 – 1350
Expected Capacity Factor (%)	>90
Design Life (years)	60
Plant Footprint (m ²)	TBC
Coolant/Moderator	Light Water
Primary Circulation	Forced circulation
System Pressure (MPa)	15.5
Main Reactivity Control Mechanism	Control rods
RPV Height (m)	11.3
RPV Diameter (m)	4.5
Configuration of Reactor Coolant System	Compact
Coolant Temperature, Core Outlet (°C)	327
Coolant Temperature, Core Inlet (°C)	296
Power Conversion Process	Rankine cycle
Cogeneration Capability	Possible configuration
Passive Safety Features	Yes
Active Safety Features	Yes
Fuel Type / Assembly Array	Industry standard UO ₂ fuel in 17x17 array
Fuel Active Length (m)	2.8
Number of Fuel Assemblies	121
Fuel Enrichment (%)	4.95
Fuel Burnup (GWd/Te)	55 – 60
Fuel Cycle (months)	18 – 24
Number of Safety Trains	3 diverse decay heat removal methods, each with multiple trains
Emergency Safety Systems	Passive
Refuelling Outage (Days)	18
Distinguishing Features	<ul style="list-style-type: none"> • Compact site footprint • Modular approach facilitating rapid and cost effective build • Larger power output than similar SMRs • Highly reliable passive safety systems • Attractive exterior that is robust to hazards
Modules per plant	1
Estimated Construction Schedule (days)	TBC
Seismic Design (g)	0.3
Core Damage Frequency (per reactor year)	<1E-07
Design Status	Mature Initial Concept (termed Basis of Design)

Reactor Core and Reactivity Control

The reactor core is the heart of the reactor design, providing the fuel for generation of nuclear heat for transfer to pressurised water flowing through the core and onward heat transfer to the secondary systems so that electrical power can be generated. The nuclear fuel is industry standard UO_2 enriched up to 4.95%, arranged in a 17x17 assembly. UO_2 pellets are contained in tubes made from zirconium alloys, which give good neutron economy, structural stability and corrosion resistance in the PWR environment.

The core contains 121 fuel assemblies and has an active fuelled length of 2.8 m. Each fuel assembly contains 40 poisoned fuel pins, with the remaining 224 fuel pins being unpoisoned. The poison used is distributed Gd_2O_3 (containing natural gadolinium) at 8 wt%.

The UK SMR Programme is pursuing accident tolerant fuel technology with a focus on silicon carbide cladding. This technology is considered insufficiently mature for commercial deployment in 2030 in the first of a kind plant, but will be brought online once available.

Unlike other designs, no concentration of soluble boron is maintained in the primary coolant for duty reactivity control. This affords a simplified design and eliminates risks associated with hazardous boric acid and environmental impact of boron discharge. It is a design goal to achieve a zero discharge plant. Duty reactivity control is provided through movement of control rods and use of the negative moderator temperature coefficient inherent to PWRs.

Reactor Pressure Vessel

The RPV assembly consists of an RPV body, a torispherical closure head assembly and a bolting arrangement comprising studs, nuts, spherical washers and mechanical seals. The RPV diameter is constrained to be less than 4.5m to ensure that the UK road transport height limit of 4.95m is not exceeded.

The close-coupled loops are connected to the RPV above the fuelled region with no connections or penetrations below this so that the Loss Of Coolant Accident (LOCA) risk is minimised.

Pressuriser

Primary circuit pressure is controlled by use of electrical heaters located at the base of the pressuriser and spray from a nozzle located at the top of the pressuriser. Steam and water are maintained in equilibrium to provide the necessary overpressure. The pressuriser is a vertical, cylindrical vessel with top and bottom heads constructed of low alloy steel.

The UK SMR employs surge induced spray whereby primary coolant passively expands into the spray line causing spray. This provides a simple and safe configuration.

The pressuriser is sized to provide robust and passive fault response for bounding faults, with accidents causing either rapid and significant cooldown or heat-up accommodated.

Steam Generators

A vertical u-tube SG design has been selected as a mature and readily deployable technology. Other designs have been considered but deemed insufficiently mature for commercial deployment in 2030 in the first of a kind plant.

Reactor Coolant Pumps

The pump and motor in the RCP will be combined in a sealless design; this avoids potential issues with seals which have been a cause of leaks in previous RCP designs.

The RCP design provides a flow rate of 3.95 m³/s and generates 56m of head (4 bar).

Control Rod Drive Mechanisms

The design is based on using an extant linear magnetic jack CRDM design in a diagonal 'checkerboard' pattern, which is modified accordingly to meet the UK SMR requirements.

Safety Features

The UK SMR design has been developed through a combined systems engineering and safety assessment approach. Based on compliance with relevant good practice and sound engineering, the safety informed design supports the process by which SMR risks are demonstrated to be tolerable and as low as reasonably practicable.

For all design basis faults, defence in depth is provided through the provision of robust safety measures, designed against conservative conditions, which meet the guidelines from the deterministic design basis analysis. Multiple layers of fault prevention and protection are provided through diverse and independent active and passive systems, comprehensively ensuring UK SMR safety for design basis and design extension conditions, for all modes of operation and during all lifecycle stages.

In addition to heat removal via the closed loop SG steam and feed cycle, the Passive Decay Heat Removal (PDHR) system and the Emergency Core Cooling System (ECCS) are passive, redundant, diverse and segregated protective safety measures that provide multiple means of decay heat removal in response to faults. All design basis LOCAs are protectable by ECCS, with diverse protection additionally available from the Small Leak Injection System (SLIS) for smaller leaks. Control Rods (scram) and Emergency Boron Injection provide two diverse and highly reliable means of reactor shutdown. Three Safety Relief Valves are provided to protect against over pressure hazards, each fully capable of providing relief. Robust containment is provided to mitigate the release of fission products to the environment in the unlikely event of core damage.

The safety benefits afforded by the design of UK SMR are reflected within the Probabilistic Safety Assessment (PSA) which calculates an overall core damage frequency from all plant hazards <1E-07 per year of power operation. PSA additionally identifies that the UK SMR presents a balanced design with no single initiating fault making a disproportionate core damage frequency contribution.

Reflecting the design philosophy which prioritises use of passive safety features, active components and supporting electrical supply, are identified as not significantly important to the UK SMR risk. As such, hazards which render active systems unavailable such as complete loss of electrical supplies (station blackout) present very low risk. Similarly, failures of operator actions in delivery of safety functions are also identified to not be significantly important, with automated delivery of one-time-movement valve alignment for safety measure actuation, such that the burden on the operator in delivering safety actions is extremely low.

Internal and external hazards assessment has defined the design basis and informed the site layout from the perspective of segregation and separation of safety related equipment. Key equipment is protected by a hazard shield, which is robust against external hazards including aircraft impact and tsunami.

Control and Instrumentation Systems

Control and Instrumentation (C&I) systems have been designed in line with recognised and endorsed best practices, e.g. provision of adequate and reliable engineering solutions, defence in depth, minimisation of design complexity, provision of diversity and redundancy, etc.

The Reactor Plant Control System will use an available in industry Programmable Logic Controller (PLC) or Distributed Control System (DCS). It will use mixed analogue and non-programmable digital sensors and will communicate on hardwired multichannel digital electrical networks. Opportunities to use smart devices and wireless technologies are being pursued.

The Reactor Protection System (RPS) provides safe shutdown in response to a fault. The RPS contains priority logic, which from the range of input signals received determines whether or not to initiate a reactor trip. The RPS will use digital systems, designed specifically for the nuclear industry. It will use mixed analogue/nonprogrammable digital sensors and communicate on hardwired multichannel digital electrical networks by preference.

Hardwired systems are systems which, ideally, do not use digital, software-based logic devices, sensors, displays or other components/sub-systems. The Hardwired Diverse Protection System (HDPS) will be diverse to the RPS and will therefore use non-programmable simple electronics.

The experience of Three Mile Island and other accidents has shown the need for clear plant status displays for long-term essential systems, over days and months, following an accident. This requirement is met by the inclusion of Post-Accident and Severe Accident Management Systems within the Nuclear C&I System.

Control Room Human Machine Interface is defined encompassing displays, alarms and manual controls. The Nuclear C&I definition also covers fuel route and hazardous material monitoring system.

Non-Nuclear C&I features include distributed control, networked communications and both traditional and 'smart' instruments/actuators.

Design and Licencing Status

Design definition is at a mature basis of design stage. A Rolls-Royce Design Certificate has been issued reflecting the product definition. This covers:

- Power Station Definition and Principles of Operation
- Reactor Island Systems Definition
- Turbine Island Systems Definition
- Civil Engineering Solution
- Site Layout
- Electrical Power System
- Safety Management Prospectus
- Preliminary Safety and Environmental Report
- Preliminary Security Solution

The UK SMR project aims to deploy the first of a kind SMR in the UK by 2030. Entry into the UK Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA) process is planned for 2019.

Power Station Arrangement

An aerial view of the UK SMR is presented in Figure 3 and the plant arrangement is presented in Figure 4.

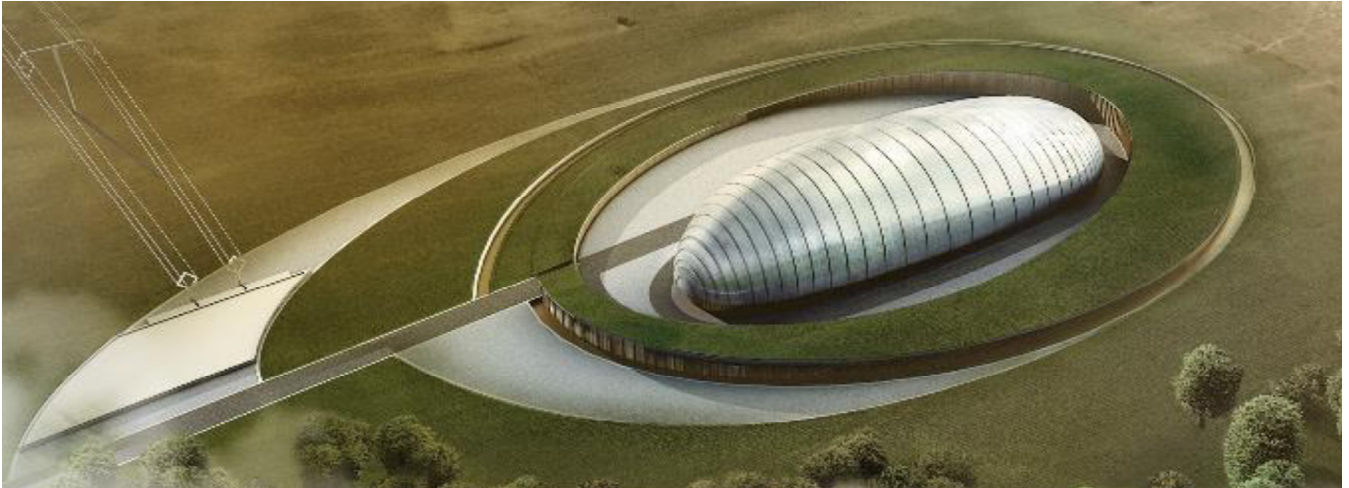


Figure 3 - UK SMR Aerial View

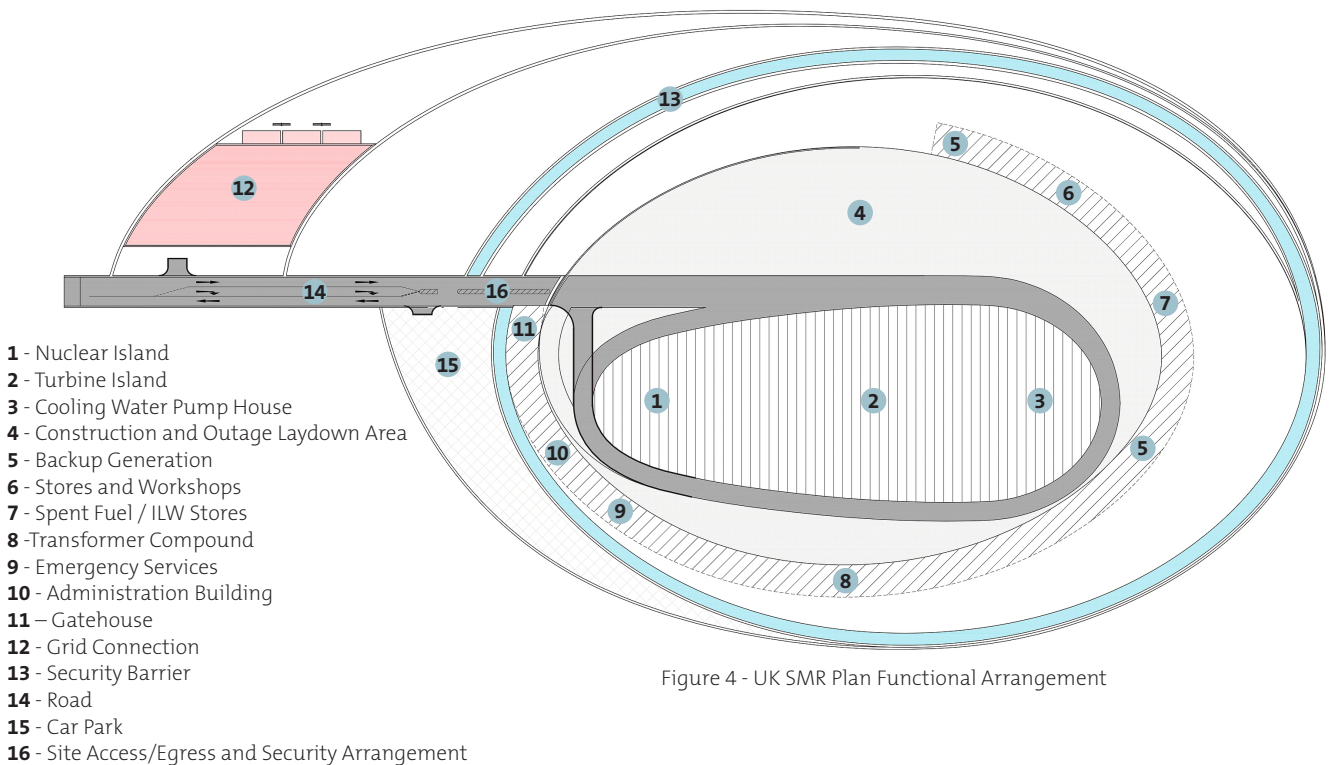


Figure 4 - UK SMR Plan Functional Arrangement

Plant Economics

Detailed and comprehensive cost analysis of the UK SMR, complemented through market demand analysis, has determined that the first of a kind plant is capable of delivering a Levelised Cost of Electricity of around £75/MWh

for the initial plant and levels of around £60-70/MWh for mature implementations of the design. This is in line with market expectations and confirms that the proposition is commercially viable.

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