



About us

Based in Wilmington, North Carolina, GE Hitachi Nuclear Energy (GEH) is a world-leading provider of advanced reactors, fuel and nuclear services. Established in 2007, GEH is a joint venture between GE and Hitachi to serve the global nuclear industry. The alliance combines GE's design expertise and history delivering reactors, fuels and services globally with Hitachi's proven experience in advanced modular construction, to offer customers the technological leadership required to effectively enhance reactor performance, power output and safety. The company operates facilities in Wilmington, San Jose, California, Vallecitos, California and Morris, Illinois.

Global Nuclear Fuel (GNF), a GE-led joint venture, operates fuel manufacturing facilities in Wilmington and Kurihama, Japan. GNF, through a joint venture with ENUSA, markets fuel for plants in Europe that is manufactured at a site in Juzbado, Spain.

GE was one of the first reactor Original Equipment Manufacturers (OEMs), and GEH, through its GE legacy, has the benefit of more than 60 years of global nuclear project experience. GE was instrumental in engineering, designing, procuring, manufacturing and constructing over 80 nuclear power plants globally. Combined, these plants provide more than 70 GW of electricity. GE first built the 30 MWe Boiling Water Reactor (BWR) in Vallecitos, California as a prototype in only two years, receiving the first atomic power license from the U.S. Atomic Energy Commission. In 1957, this reactor became the first privately owned and operated nuclear power plant to deliver electricity to the grid. After that, GE built the 180 MWe Dresden 1 BWR for Commonwealth Edison, the first private commercial nuclear power plant.

GEH Nuclear Plant Products ... Proven Technology

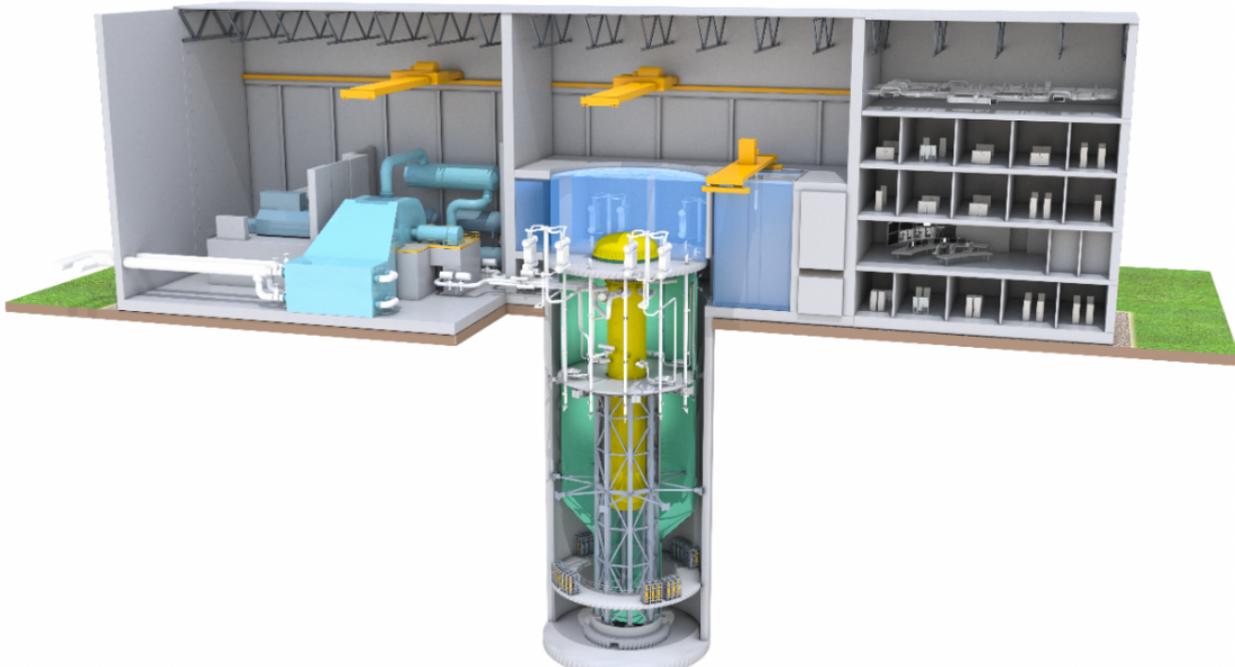
GEH offers various nuclear technologies including gigawatt scale BWRs, (the ABWR and ESBWR). Our recent focus has been on innovating potentially disruptive Small Modular Reactors (SMRs), including the BWRX-300 and the Sodium Fast Advanced reactor, PRISM. In addition to these reactor design offerings, GEH has been offering and providing a full range of engineering, services and infrastructure expertise to start-up reactor vendors.

BWRX-300: A Game Changing SMR

The BWRX-300 is a 300 MWe water-cooled, natural circulation SMR design with passive safety systems. It is the tenth evolution of the BWR and represents the simplest, yet most innovative design since GE began commercializing nuclear reactors in 1955.

A Dramatic Reduction in Scale and Complexity

The BWRX-300 leverages the development and design certification of the U.S. NRC-licensed, 1,520 MWe ESBWR to help future plants operate smarter, faster and on a less costly basis. Compared to the ESBWR, the BWRX-300 is designed to achieve about a 90 percent volume reduction in plant layout, concrete and other costly materials. Notably, the innovative SMR is designed to reduce building volume by about 50 percent per MW, which should account for approximately 50 percent less concrete per MW. The ESBWR has approximately 160,000 m³ of safety related concrete while the BWRX-300 utilizes less than one tenth of that amount. The BWRX-300 will significantly improve the next generation of reactors due to its affordability, greater flexibility, and enhanced safety. The BWRX-300 uses natural circulation and passive cooling isolation condenser systems to promote simple and safe operating rhythms. In the global race for advanced nuclear, the BWRX-300 sets itself apart with its proven, simpler processes and systems.



BWRX-300: A Game Changing SMR

Features and Benefits:

- **Cost competitive:** projected to have significantly less capital cost per MW when compared with a typical water-cooled SMR
- **World class safety:** designed to mitigate loss-of-coolant accidents (LOCA) enabling simpler passive safety
- **Innovative cost-competitive design:** designed to allow the Nth-of-a-kind (NOAK) BWRX-300 to be competitive with the levelized cost of electricity of natural gas and renewables
- **Passive cooling:** designed to allow steam condensation and gravity to cool the reactor for a minimum of seven days without power or operator action
- **Quick Deployment:** Deployable as early as 2027, thanks to proven know-how, supply chain, components, certified fuel and simpler construction techniques

Cost Competitive

The BWRX-300 is designed to provide clean, flexible, baseload electricity generation that is competitive with the levelized cost of electricity of natural gas fired plants and renewables. The BWRX-300 NOAK is projected to require up to 60 percent less capital cost per MW when compared with other typical water-cooled SMR and large nuclear designs in the market and is designed for significant reductions in operating, staff, maintenance cost and security requirements. The mitigation of a LOCAs enables simpler passive safety systems and a more compact reactor building compared to prior Light Water Reactor (LWR) designs. A strong focus on design-to-cost has resulted in an innovative solution that limits plant volume, concrete and steel, while utilizing the ESBWR's design and licensing basis to the fullest extent.

Regulatory Approval

GEH is leveraging the licensing work from the ESBWR in our licensing efforts for the BWRX-300, which is currently undergoing pre-licensing activities with the US and Canadian regulators.

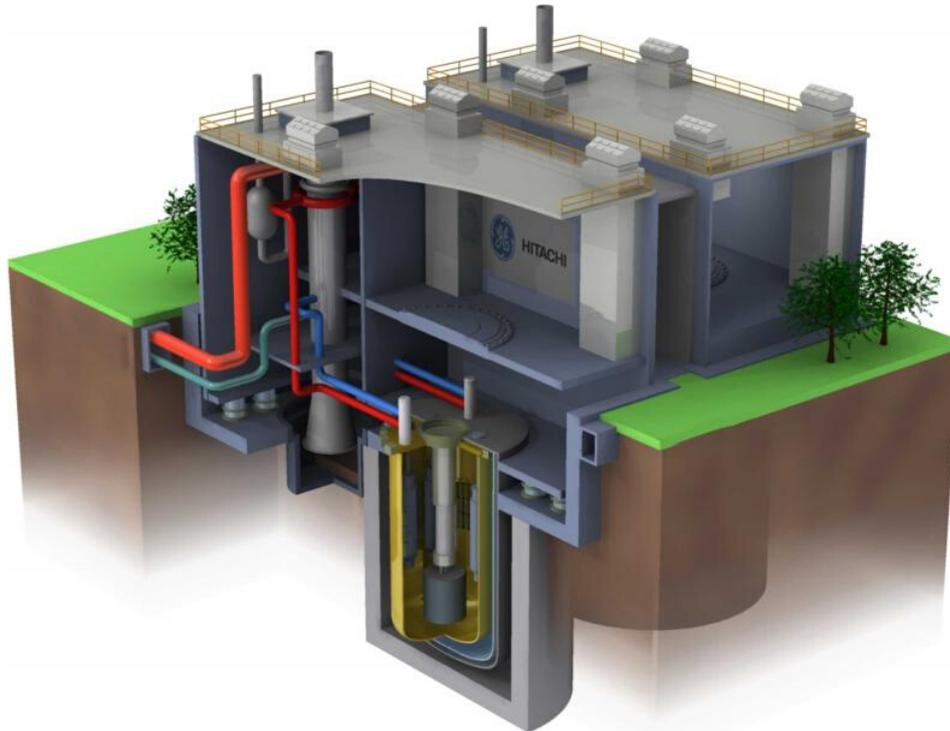
Global Interest in the BWRX-300

There continues to be growing interest in the BWRX-300 technology and design. Below are a few highlights demonstrating the level of interest.

- Most recently, the U.S. Department of Energy (DOE) announced awards to develop tools around Artificial Intelligence-enabled digital twins using the BWRX-300 small modular reactor as a reference design.
- There continues to be considerable interest in SMRs in Europe. To date, we have signed Memorandums of Understanding with Synthos, S.A. in Poland, Fermi Energia in Estonia and CEZ in the Czech Republic.
- Additionally, we are in conversations with several stakeholders and interested parties in both developed and emerging countries who are working toward carbon reduction targets.

Advanced Reactors: PRISM

Our portfolio of nuclear reactor products also includes PRISM, a sodium-cooled fast reactor.



PRISM is based on the EBR-II reactor which had 30 years of successful operating experience at Argonne National Lab - West (today known as Idaho National Lab) PRISM has a long development history and can be utilized for power generation and high temperature heat applications. Additionally, when combined with electrometallurgical processing, PRISM can recycle LWR used nuclear fuel, changing it from a liability into an asset generating emissions-free power.

In November 2018, the U.S. DOE awarded GEH a contract to utilize PRISM as a basis to support the conceptual design, cost/schedule estimate and safety framework activities for a proposed fast spectrum Versatile Test Reactor (VTR). According to the U.S DOE, the VTR will help accelerate the testing of advanced nuclear fuels, materials, instrumentation and sensors and could be completed as early as 2026. In 2020, GEH announced a partnership with TerraPower to further develop the VTR as part of the Phase II program. Our multigenerational reactor product approach aims to support our customers and the industry for decades to come.

Key Advantages:

- Sodium-cooled fast reactor ... Generation IV
- 165 and 311 MWe options ... flexible
- Compact pool-type ... atmospheric, eliminates LOCA
- Passive safety ... air cooling
- Proven metal fuel ... inherently safe
- Superheated steam ... plant efficiency
- Modular design ... quality and efficiency
- High temp ... industrial process heat applications
- Fuel recycling application ... 99% fuel utilization



NUSCALE

Let's change the power that changes the world

NuScale Power has developed game-changing small modular reactor (SMR) nuclear technology. At the heart of this technology is the fully factory-fabricated NuScale Power Module™ (NPM) which produces electricity and process heat for a variety of industrial applications, including desalination for clean drinking water, to improve the quality of life for all humankind.

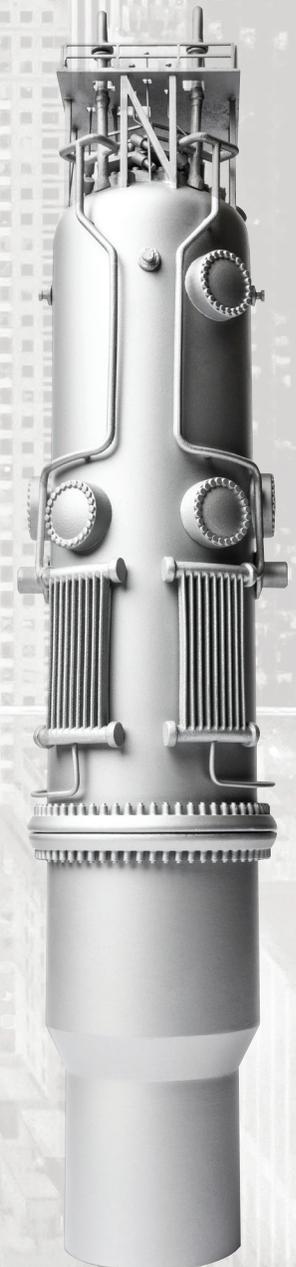
SMARTER

NuScale is not nuclear as the world knows it. Building on proven nuclear technology with a focus on integration and simplification, we created a smarter design that offers an economic and carbon-free power solution with unparalleled safety, flexibility, reliability, and resiliency. The NPM brings together traditional components – the reactor vessel, steam generator, and containment – into a single, simplified module. Each module can produce 60 megawatts of electricity (MWe), and a NuScale power plant can house up to 12 NPMs for a total output of 720 MWe (gross). This scalability feature is unique to NuScale and allows for customization of facility output to match demand.

CLEANER

The NPM produces clean energy that is 100% carbon-free. In addition to producing reliable always-on baseload power no matter the time of day, weather, or season, the NuScale plant can load follow to complement intermittent power generation sources such as wind, solar, and hydropower.

The 60 MW of carbon-free electricity that one NPM produces can power 45,000 homes in the U.S. The 720 MW of carbon-free electricity that a 12-module NuScale plant produces is enough to power nearly 540,000 homes. The NPM also has the unique ability to tailor electric and steam power outputs and can provide process heat for desalination, hydrogen production, and oil refining applications to decarbonize the industrial sector.



SAFER

NuScale's power plant design incorporates several simple, redundant, and independent safety features—setting a new standard for nuclear safety performance and offering unparalleled system resilience. NuScale's Triple Crown for Nuclear Plant Safety™ design ensures that the NuScale Power Module safely shuts down and self-cools, indefinitely with no need for operator or computer action, AC or DC power, or additional water. Our groundbreaking SMR technology is invulnerable to cyber-attacks, geomagnetic disturbances, and electromagnetic pulse attacks. The NPM has Black Start capability to start up from cold conditions without the aid of external grid power, and can also serve as a First Responder power source after a grid-loss event—providing power in 60 MWe increments once the grid is restored.

COST COMPETITIVE

NuScale's smarter plant design is efficient, scalable, and cost-competitive. The NuScale plant has a 36 month construction schedule that is significantly shorter in comparison to large gigawatt-sized nuclear power plants. The option to add modules incrementally reduces initial capital costs, and the very first NPM generates power and revenue immediately. This scalability and shorter construction schedule offers an unprecedented cost-effective and flexible energy option with lower financial risks. Cost savings are also realized through repetitive manufacturing. Safety-related fabrication work is taken out of the field since modules are both produced and tested in a factory. This standardizes the manufacturing process, increases efficiency, improves quality, and lowers cost.

With these smarter, cleaner, safer, and cost-competitive features, NuScale is changing the power that changes the world through its mission to improve the quality of life for all humankind by continuously improving nuclear power.



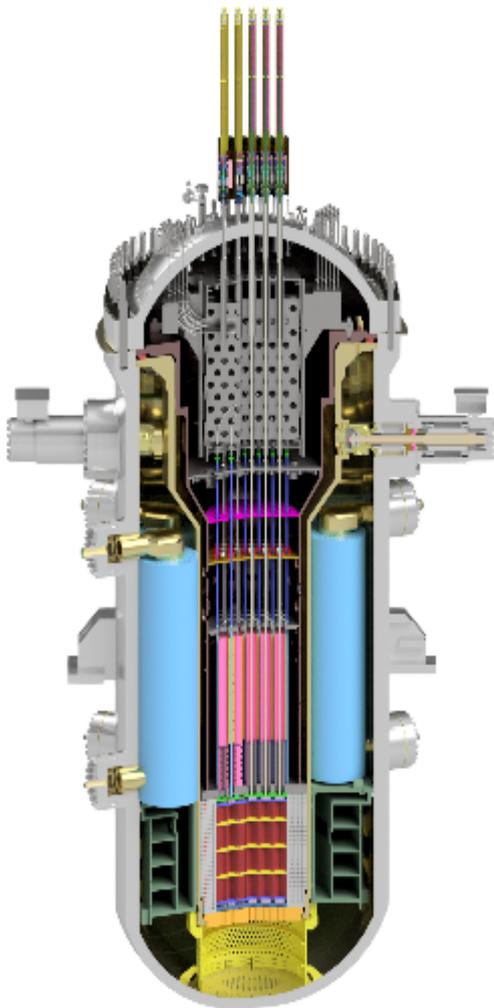
Artist's conception of NuScale Power's proposed SMR plant



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SMART (System-integrated modular advanced reactor)



MAJOR TECHNICAL PARAMETERS

Parameter	Value
Technology developer, country of origin	KAERI (Republic of Korea) and K.A.CARE (Kingdom of Saudi Arabia)
Reactor type	Integral PWR
Coolant/moderator	Light water / light water
Thermal/electrical capacity, MW(t)/MW(e)	365/ 107
Primary circulation	Forced circulation
NSSS Operating Pressure (primary/secondary), MPa	15 / 5.8
Core Inlet/Outlet Coolant Temperature (°C)	296 / 322
Fuel type/assembly array	UO ₂ pellet/17x17 square
Number of fuel assemblies in the core	57
Fuel enrichment (%)	< 5
Core Discharge Burnup (GWd/ton)	< 54
Refuelling Cycle (months)	30
Reactivity control mechanism	Control rod driving mechanisms and soluble boron
Approach to safety systems	Passive
Design life (years)	60
Plant footprint (m ²)	90,000
RPV height/diameter (m)	18.5/6.5
RPV weight (metric ton)	1070 (including coolant)
Seismic Design (SSE)	> 0.3g with 0.18g of automatic shutdown
Fuel cycle requirements / Approach	Conventional LWR requirements applied (spent fuel capacity: 30 years)
Distinguishing features	Coupling with desalination and process heat application, integrated primary system
Design status	Licensed/certified (standard design approval)

1. Introduction

The System-integrated modular advanced reactor (SMART) is an integral PWR with a rated electrical power of 107 MW(e) from 365 MW(t). SMART adopts advanced design features to enhance safety, reliability and economics. The advanced design features and technologies implemented in SMART were verified and validated during the standard design approval review. To enhance safety and reliability, the design configuration incorporates inherent safety features and passive safety systems. The design aim is to achieve improvement in economics through system simplification, component modularization, reduction of construction time and high plant availability.

2. Target Application

SMART is a multi-purpose application reactor for electricity production, sea water desalination, district heating, process heat for industries and suitable for small or isolated grids. SMART has a unit output large enough to meet the demands of electricity and fresh water for a city population of 100,000.

3. Main Design Features

(a) Design Philosophy

The SMART design adopts an integrated primary system, modularization and advanced passive safety systems to improve the safety, reliability and economics. Safety performance of SMART is assured by adopting passive safety systems together with severe accident mitigation features. The passive safety features rely on gravity and natural circulation and require no active controls neither operator intervention to cope with malfunctions and safety-related events. Improvement in economics is achieved through system simplification, in-factory fabrication, reduction of construction time and high plant availability.

(b) Nuclear Steam Supply System

SMART has an integral reactor coolant system configuration that enables the elimination of large bore pipe connections resulting in the removal of the large break loss of coolant accident (LB-LOCA) from the design bases events. The nuclear steam supply system (NSSS) consists of the reactor core, steam generators, reactor coolant pumps, control rod drive mechanisms, and reactor internals in the reactor pressure vessel (RPV) and the reactor closure head. The primary cooling system is based on forced circulation by the reactor coolant pumps during normal operation. The system has natural circulation capability for use in emergency conditions.

(c) Engineered Safety System and Configuration

Safety systems of SMART are designed to function automatically on demand. These consist of a reactor shutdown system, a passive safety injection system, a passive residual heat removal system, and containment pressure and radioactivity suppression system. Additional safety systems include reactor overpressure protection system such as an automatic depressurization system (ADS) and pressurizer safety valves, and a severe accident mitigation system. As a result, reactor safety is enhanced substantially and the core damage frequency is reduced.

(d) Plant Safety and Operational Performances

The load following operation of SMART is simpler than that of large PWR because only a single bank movement and small insertion limit is required. SMART is suitable for load following operation because of the small reactivity change for the power change due to the minimized coolant temperature change, relatively high lead bank worth due to a small number of fuel assemblies and the short effective core height leading to rapid damping of xenon oscillation. The daily load following performance of SMART core shows that radial peaking factor, 3-dimensional peaking factor and the axial offset were satisfied within design limit.

4. Design and Licensing Status

Korea Atomic Energy Research Institute (KAERI) received the standard design approval from Korean Nuclear Safety and Security Commission (NSSC) in July 2012. A safety enhancement program to adopt passive safety system in SMART began in March 2012, and the testing and verification of the PRHRS and PSIS were completed in the end of 2015. In September 2015, a pre-project engineering agreement was signed between the Republic of Korea and the Kingdom of Saudi Arabia for deployment of SMART. This PPE project was successfully completed in February 2019 and First-of-a-Kind (FOAK) plant construction in Saudi Arabia will be followed soon.

5. Development Milestones

March 1999	Conceptual design development
March 2002	Basic design development
June 2007	SMART-PPS (Pre-Project Service)
July 2012	Technology verification, Standard Design Approval (SDA)
March 2012	First step of Post-Fukushima corrections and commercialization
September 2015	Pre-project engineering agreement signed between Republic of Korea and Kingdom of Saudi Arabia for the deployment of SMART in the Gulf country
November 2015	Pre-Project Engineering started.
February 2019	The Pre-Project Engineering completed.
January 2020	SMART100 Standard Design Approval Applied.



RITM-200 (JSC “Afrikantov OKBM”, Russian Federation)

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RITM-200 Reactor

MAJOR TECHNICAL PARAMETERS	
Parameter	Value
Technology developer, country of origin	Afrikantov OKBM, Russian Federation
Reactor type	Integral PWR
Coolant/moderator	Light water / light water
Thermal/electrical capacity, MW(t)/MW(e)	165/53
Primary circulation	Forced circulation
System pressure (MPa)	15.7
Core inlet/outlet temperatures (°C)	277/313
Fuel type/assembly array	UO ₂ pellet/hexagonal
Fuel type/assembly array	199
Fuel enrichment (%)	<20
Fuel burnup (GWd/ton)	-
Fuel cycle (years)	6-7
Main reactivity control mechanism	Control rod driving mechanism
Approach to engineered safety systems	Combined active and passive systems
Design life (years)	60 with possible extension
Plant footprint (m ²)	60,000 – NPP with 2 reactors 89,000 – NPP with 4 reactors
RPV height/diameter (m)	7.5 / 3.4
Seismic design	0.3 g
Distinguishing features	Integral reactor, in-vessel corium retention, double containment
Design status	Six RITM-200 reactors are installed on icebreakers Arktika, Sibir and Ural Land-based NPP under development

1. Introduction

RITM series reactor RITM-200 is the latest development in III+ generation SMR line designed by JSC “Afrikantov OKBM”. It has incorporated all the best features from its predecessors and is based on time proved pressurized water reactor (PWR) technology and 400 reactor-years of Rosatom experience in operation of small reactors in icebreakers. Six RITM-200 reactors are successfully installed on icebreakers Arktika, Sibir and Ural. Two reactors of Arktika icebreaker successfully passed all power up tests during dock-side trials.

Scalable modular design is what makes Rosatom SMR a suitable solution for local energy needs. The capacity of land-based NPP can be easily expanded from 106 MW and higher by building additional main building and cooling towers. Auxiliary buildings can be shared to reduce the land use. Safety is enhanced by deliberate design choices such as combination of active and passive systems, inherent safety features, defense-in-depth principle. These systems eliminate as many potential risks as possible, reduce the chance of accidents, and ensure that if an accident does occur, the consequences are minimal. All post-Fukushima requirements such as a 72-hour grace period in case of the loss of coolant accident are implemented. Uranium core with under 20%

enrichment level and fuel cycle of 6-7 years ensure long time operation and meets international non-proliferation requirements.

2. Target Application

RITM series reactors can be used for multiple applications including electrical power generation, water desalination, and cogeneration.

3. Specific Design Features

(a) Design Philosophy

RITM series reactors are the evolutionary development of the reactors (OK-150, OK-900, KLT-40 series) for Russian nuclear icebreakers with a total operating experience of more than 50 years (more than 400 reactor years). Incorporation of the steam generators into the reactor pressure vessel has made the reactor system and containment very compact as compared to the KLT-40S. RITM design makes it possible to increase electric output (40% more) and reduces the dimensions (45% less) and the mass (35% less) in contrast to KLT-40S. While integral reactor configuration almost eliminates the classic large loss-of-coolant accident (LOCA) and the other inherent features and active and passive safety systems apply concepts of diversity, redundancy, physical separation, and functional independence to achieve the necessary safety level and reliability.

(b) Nuclear Steam Supply System

RITM nuclear steam supply system consists of the reactor core, four steam generators integrated in the reactor pressure vessel, four canned main circulation pumps, and two pressurizers. The primary cooling system is based on forced circulation during normal operation and allows natural circulation for emergency condition.

(c) Reactor Core

RITM reactor core accommodates low enriched fuel assemblies similar to KLT-40S that ensures long time operation without refueling and meets international non-proliferation requirements. The height of the core is 1,650 mm. The core consists of 199 fuel assemblies with uranium-intensive cermet fuel. Corrosion-resistant alloy is used for fuel cladding. The core has the assigned service life of 8 TWh. The design of the fuel rods is resistant to power changes with a design rate of $0.1\% P_{\text{rated}}/s$.

(d) Reactivity Control

Control rods are used for reactivity control. A group of control rods drive mechanisms is intended to compensate for the excessive reactivity at start up, power operation and reactor trip. A group of safety rods is designed to scram the reactor and to maintain it in the subcritical condition in case of accident. The design of control and safety rods is based on the drives used in KLT-40S reactor.

(e) Reactor Coolant System

The reactor pressure vessel is thick-walled cylindrical pressure vessel with an integrally welded bottom head and a removable top head. The reactor is designed as an integral vessel with the main circulation pumps located in separate external hydraulic chambers with side horizontal sockets for steam generator cassette nozzles. The steam generators provide steam of 295°C at 3.82 MPa and capacity of 261 t/h. Four pumps are installed in the cold legs of the primary circulation loop. The pumps are vaned, single-stage, and have a canned asynchronous electric motor with single winding.

(f) Steam Generator

The RITM-200 uses once-through (straight tube) steam generators. The configuration of the steam generating cassettes makes it possible to compactly install them in the reactor pressure vessel. The RITM-200 steam generator is divided into four primary circuit loops. Each loop consists of three once-through cassettes (12 in total) with a common feed water and common steam manifolds. Each

cassette consists of 7 modules. There is a specially designed system for steam generator leakage detection, based on the pressure difference, temperature, and radioactivity sensor data. In case a leak is detected, it is possible to find out and shut down the leaking module individually without opening the reactor.

(g) Pressurizer

The design adopts pressure compensation gas system well-proven in the Russian ship power engineering. It is characterized by a simple design, which increases reliability, compactness, and requires no electric power. The compensation system is divided into two independent ones to reduce the pipe diameter in the compensatory nozzles of the steam generating unit and to decrease a coolant leakage rate in large break LOCA. It makes possible to use one of pressurizers as a hydraulic accumulator, increasing reactor plant reliability considerably in potential LOCA.

4. Safety Features

The safety concept of the RITM-200 is based on the defence-in-depth principle combined with the inherent safety features and use of passive systems. Properties of inherent safety features are intended for automatic control of power density and reactor scram, limitation of primary coolant pressure and temperature, heating rate, primary circuit depressurization scope and outflow rate, fuel damage scope, maintaining of reactor vessel integrity in severe accidents. RITM-200 optimally combines passive and active safety systems to cope with abnormal operating occurrences and design basis accidents.

- Passive pressure reduction and cooling systems reliability is confirmed by test bench.
- Pressurizer is divided into two independent ones to minimize size of potential coolant leakage rate.
- Main circulation loop of the primary circuit is located in a single vessel.

The exposure dose for the staff in normal operation and design basis accidents does not exceed 0.01% of the natural radiation limit. The public exposure dose in case of severe accidents is below the value requiring protective measures.

(a) Engineered Safety System Approach and Configuration

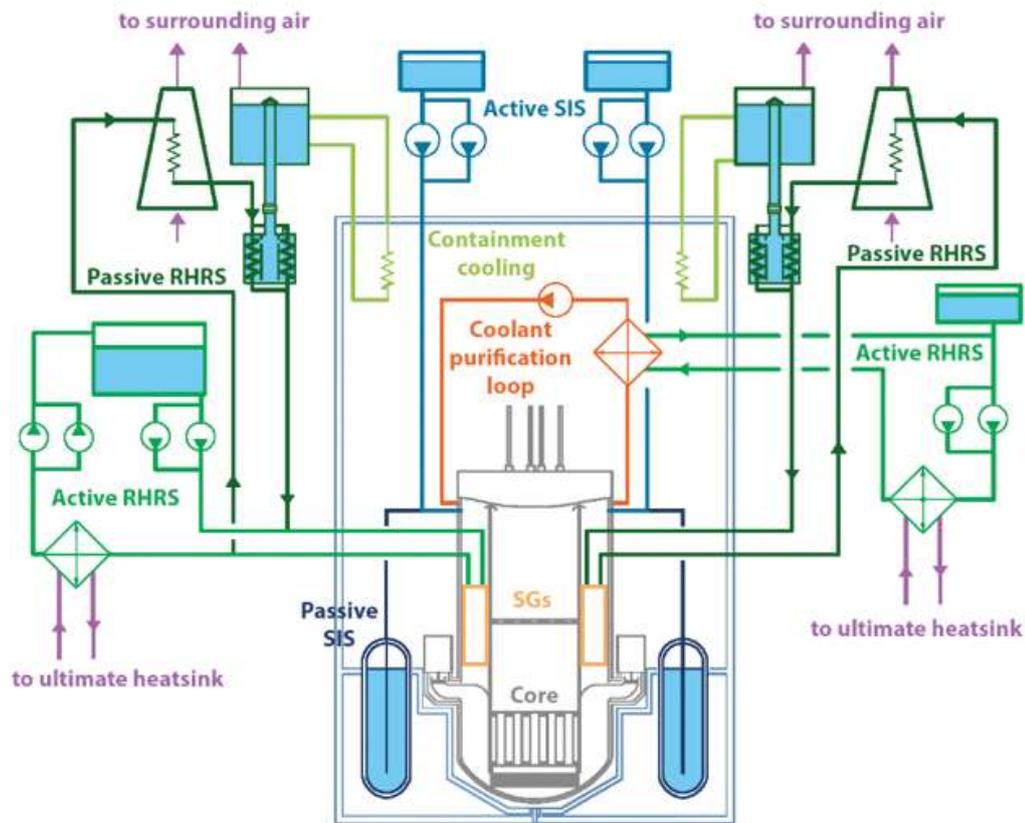
The high safety level of RITM series reactors is achieved both by inherent safety features and a combination of passive and active safety systems. Moreover, redundancy of safety system equipment and channels and their functional and/or physical separation are provided to ensure high reliability. Safety systems are driven automatically by the control system, when controlled parameters achieve appropriate set points. In case of automated systems failure, self-actuating devices will actuate directly under the primary circuit pressure to ensure reactor trip and initiate the safety systems. Safety rods drop into the core by gravity with spring assist when power is removed from electromagnetic couplings consequently ensure reactor shutdown even in case of total station blackout.

(b) Residual Heat Removal System

The residual heat removal system (RHRS) consists of four safety trains:

- Active safety loop with forced circulation through steam generator.
- Active safety loop with forced circulation through the heat exchanger of primary-third circuits of primary circuit coolant purification loop.
- Two passive safety loops with natural coolant circulation from water tanks through steam generators. Evaporated in steam generators water condenses in air-cooled heat exchangers and flow back to tanks with water heat exchangers. After complete water evaporation from the tanks, the air-cooled exchangers continue provide cooling for unlimited time. Combination of air and water heat exchangers allows to minimize dimensions of the heat exchangers and water tanks.

All safety train are connected to different steam generators and provide residual heat removal in compliance with the single failure criterion. Active safety trains consist of a water tank, pumps, and a heat exchanger to ultimate heatsink.



(c) Emergency Core Cooling System

The emergency core cooling system consists of safety injection system (SIS) for water injection in primary circuit to mitigate the consequences of a break loss-of-coolant accident. The system is based on active and passive principles with redundancy of active elements in each channel and consists of:

- Two passive pressurized hydraulic accumulators;
- Two active channels with water tanks and two make-up pumps in each channel.

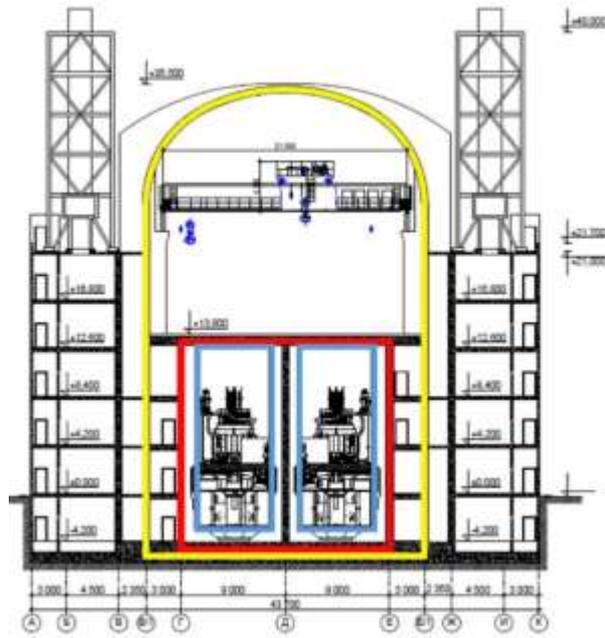
In combination with the residual heat removal system the passive safety trains anticipate a post-accident grace period of 72 hours without operator action or power in case of combination of LOCA and total station blackout.

(d) Containment System

The containment consists of three levels:

- Primary containment (shown in blue) designed for internal pressure of 0.5 MPa (abs) with dimensions of 6 m × 6 m × 15.5 m around the reactor vessel to localize possible radioactive releases (~300 m³ of free space).
- Secondary containment (shown in red) is a solid building core made of thick reinforced concrete walls (800 mm thick) to protect primary containment from external impact.
- Third level of containment (shown in yellow) is a collapsible building structure of thin reinforced concrete walls to dissipate most of the energy of external impact and minimize influence to secondary containment.

The design of solid core and collapsible structures takes into consideration the maximum potential external impacts including large commercial aircraft crash.



5. Instrumentation and Control Systems

An automated control system is provided in the RITM-200 based nuclear power plant to monitor and control plant processes. This system possesses necessary redundancy with regard to safety function fulfilment and allows both automated and remote control of the power plant.

6. Plant Arrangement

The land-based small NPP consists of two RITM-200 reactors with a specified electrical capacity of 106 MW. Buildings are arranged to optimize interconnections and interfaces between buildings and to minimize unused areas. An aerial view of small NPP and the plant layout are presented below.



106 MWe



- ① Reactor building
- ② Turbine building
- ③ Radwaste building
- ④ Indoor switchgear
- ⑤ Cooling towers
- ⑥ Cooling water pumps
- ⑦ Backup generators
- ⑧ Security gates
- ⑨ Administration building
- ⑩ Water treatment building
- ⑪ Fire station
- ⑫ Sewage works

Small NPP layout is sectioned in two areas:

- Secured area related to power generation systems itself, including reactor and turbine buildings and cooling towers. It also includes the building for nuclear material management (radwaste building).



Small NPP secured area

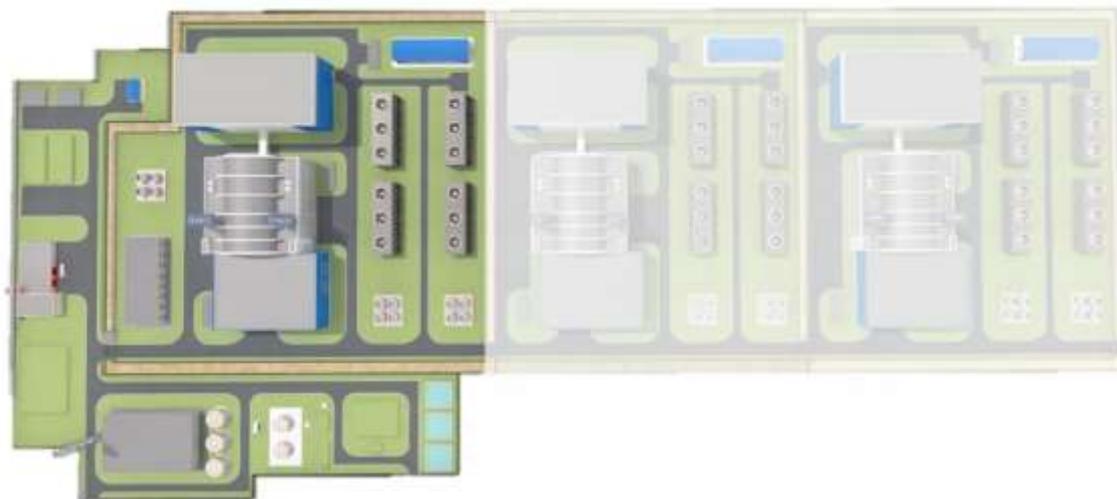
- Auxiliary system area consists of water treatment building, fire station, administration building, etc.



Small NPP auxiliary area

Small NPP site segmentation allows utilizing modular approach for simplification of possible future plant electrical capacity growth. Construction of additional areas with reactor and turbine buildings allows increasing power generation incrementally by step of 106 MW. While the auxiliary building systems stay in shared use for all nuclear units.

Small NPP site area for 106 MW is 14.8 acres (59,894 m²), 212 MW – 22.2 acres (89,840 m²), and 318 MW – 29.7 acres (120,192 m²).



Scalability of small NPP based on RITM-200 reactors

Main building

The optimized design of small NPP consists of one reactor building with two RITM-200 reactors. It is assumed that the two reactors will be commissioned simultaneously.

The main building actually consists of three buildings:

- Reactor building footprint is 45x44 m and 35 m of height.
- Turbine building footprint is 30x63 m and 31 m of height.
- Nuclear material management building (radwaste building) footprint is 36x48 m and 19 m of height.

7. Design and Licensing Status

The RITM-200 design is developed in conformity with Russian law, codes and standards for nuclear power plants and safety principles developed by the world community and IAEA requirements.

8. Development Milestones

2012	Detailed design of RITM-200
2018	Land-based NPP conceptual design

2023		Site license
2024		License for construction, first concrete
2027		License for operation, NPP commissioning

Terrestrial Energy Technology Summary

Conventional Nuclear power plants have used the same technology for over 60 years. As energy markets have evolved and regulatory standards increased, Conventional Nuclear power plants have become too costly to remain commercially relevant for private enterprise – new nuclear power plants today are government sponsored projects. While this commercial position severely limits the role that nuclear power could play in the clean energy mix, it has also opened the door for transformative nuclear innovation and the commercialization of Generation IV technologies.

Terrestrial Energy aims to deliver that transformative nuclear innovation and provide a solution to the affordability and cost problem of Conventional Nuclear power with its Generation IV Integral Molten Salt Reactor (IMSR[®]) power plant. This commercially transformative capability is achieved with the use of Generation IV technology in an innovative market-focused design for a 195-megawatt power plant that is affordable, cost-competitive, and a clean and resilient alternative to fossil fuels.

Using a molten salt coolant, which has high thermal stability, the IMSR[®] operates at 700 °C permitting superior thermodynamic efficiency compared to Generation III technologies for electric power generation – a step improvement from 30% to 47% thermal efficiency. Further gains in capital efficiency are achieved with low-pressure operation and the extensive incorporation of passive and inherent safety that is only possible with molten salt, liquid-fueled reactors. The IMSR[®] is fueled with standard civil power reactor fuel, standard assay (<5%) LEU.

The IMSR[®] innovation consists of a sealed integral Core-unit housing the liquid fuel, moderator, pumps, primary heat exchangers and shutdown rods. The entire Core-unit is replaced at the end of its 7-year life eliminating the need to open the reactor vessel for maintenance. A non-fueled liquid fluoride salt loop transfers heat from the Core-unit to a third solar nitrate salt loop. This loop transfers heat to a separate building for generating superheated steam for electric power generation or for direct industrial process heat applications.

The naturally strong negative reactivity coefficient of temperature of the liquid fuel provides a self-governing, stable temperature regime, and establishes an inherently safe operating profile in which reactor power is inherently controlled to demanded power without the need for manipulating any reactivity control device. There are no restrictive neutron flux limits such as those for traditional water-cooled reactors. Hence, neutron flux can transiently increase by a significant amount without any negative effects on core integrity. For these reasons, the IMSR[®] does not require any control rods nor automatic flux control algorithms for reactor power control. The rapid response characteristic, and low fission product poison density enables load-following capability facilitating backing-up variable wind and solar power generation; a capability that supports electric grid reliability and wind and solar deployments. The liquid fueled IMSR[®] allows significant simplification of the power plant design, which eases construction and commissioning capital cost burdens and improves overall operating cost performance.

The IMSR400 is a high temperature, graphite moderated, liquid fueled, pool-type Advanced Small Modular Reactor with the fuel, primary pumps, heat exchangers, shutdown rods and graphite moderator integrated into a compact, sealed, and replaceable Reactor Vessel Core-unit. The plant operates at near atmospheric pressure (hydrostatic) and provides 195 MWe (net) in electrical power as well as 600°C deliverable heat for a broad range of commercial and industrial needs.

The IMSR400 passive cooling systems are comprised of two separate systems: The Internal Reactor Vessel Auxiliary Cooling System (IRVACS) and the Irradiated Fuel Cooling System (IFCS). These systems are seismically qualified, highly robust, and fail-safe passive shutdown cooling systems for the IMSR400.

Major advantages of this type of passive cooling are its simplicity, fault tolerance, and positioning outside containment (avoiding containment penetrations and allowing easier inspection and access). The IRVACS/IFCS are closed-loop systems, operating on ambient pressure nitrogen, rather than open cycle air. This enhances safety and provides a more inert and controlled environment for the Core-unit silo and guard vessel.

The IMSR400 fuel, in the form of uranium tetrafluoride (UF₄), is dissolved in a eutectic mixture of low-cost fluoride salts without the addition of either lithium or beryllium. The benefit of this eutectic is that it minimizes the production of tritium; tritium production is a challenge for any MSR design proposal that includes lithium fluoride (LiF) and/or beryllium difluoride (BeF₂) in its fuel salt mixture. The liquid Fuel Salt is an integral system – nuclear fuel, coolant, and heat transfer medium – which provides the basis for a less complex reactor configuration with many safety attributes. The utilization of less than 5% U235 provides a major commercial advantage due to its broad availability in existing supply chains, and the ability to meet technical requirements and nuclear policy and regulations in many countries that are currently utilizing or contemplating deploying nuclear power plants. This fuel is separately brought to the power plant site as a solid, where it is added to the IMSR Core-unit. This allows the IMSR to operate with online fueling. Additionally, and unlike solid-fuel reactors, there is no need to remove a proportion of used fuel during makeup fueling. All the fuel remains inside the closed IMSR Core-unit during the entire power operations period of the Core-unit. The small volume of additional makeup Fuel Salt added over the 7-year life to accommodate reactivity loss due to fuel burnup is simply accommodated in the upper gas plenum of the Core-unit. The fuel contained in the end-of-life Core-unit is discharged to storage casks located in containment. The used fuel remains in this storage configuration for the life of the plant.

The IMSR400 Containment is a passive, sealed, low-leakage envelope that houses all systems that may contain highly radioactive material, specifically the Core-unit (active reactor), the off-gas lines/storage, irradiated fuel tanks, and any pipe transferring irradiated liquid fuel. In the event of a leak in any of these systems, the Containment prevents the release of any radioactive materials. The Containment is designed to maintain integrity during all transients or design basis accidents, and it is noted that accidents identified to date do not cause any significant pressurization inside containment. The entire system is designed for seismic qualification for a Design Basis Earthquake. The envelope follows the strict rules of a containment, i.e. an essentially leak-tight structure with a defined design pressure and a defined maximum leak-rate at that pressure.

The IMSR400 inherently controls reactor power to demanded power in the short term, without the need for any automatic manipulation of a reactivity control device. This capability stems from the highly responsive negative core temperature coefficient of reactivity. In the long term, reactivity is controlled by routine manual additions of small amounts of Fuel Salt. Secondly, there are no restrictive neutron flux limits in the molten Fuel Salt core compared to limits in traditional water-cooled reactors related to fuel cladding integrity. Hence, neutron flux can be allowed to transiently increase by a significant amount without any negative effects on integrity of the core. For these reasons, the IMSR400 does not require any control rods nor automatic flux control algorithms for short term power control.

The IMSR400 is designed such that reactor shutdown (i.e., sub-criticality) of the reactor is not required to reach a safe end-state for any AOO or DBA. A safe end-state for IMSR400 is defined to be the reactor at a low power, the Reactor Vessel temperature within acceptable limits, and no fuel boiling. As a defense-in-depth safety measure, and for operational purposes, the IMSR400 design will include an independent means of shutting down the reactor with shutdown rods for bringing the reactor to a

shutdown sub-critical state which will eventually result in cooldown to a cold state as decay heat becomes negligible.

The secondary coolant salt flows in a closed loop from the primary heat exchangers in the Core-unit to secondary heat exchangers external to the Core-unit. Heat is then removed from the secondary heat exchangers by the nitrate Solar Salt Loop, a third molten salt loop using an inexpensive and common molten nitrate salt. This molten salt transfers the heat of the secondary coolant to the turbine building for electricity generation, industrial process-heat uses, or both. This method gives the IMSR400 the versatility to be a high-temperature industrial heat source that can provide electrical power as well as 600°C heat for a broad industrial process heat market.

For process heat applications, either a steam cycle or a direct use of the solar salt is possible. For power generation applications, the nitrate Solar Salt loop heats a pressurized water loop utilizing a steam generator; boiling water to steam under pressure. Additional superheating from the hot solar salt provides dry, high quality, superheated steam to a conventional industrial electrical generator system.

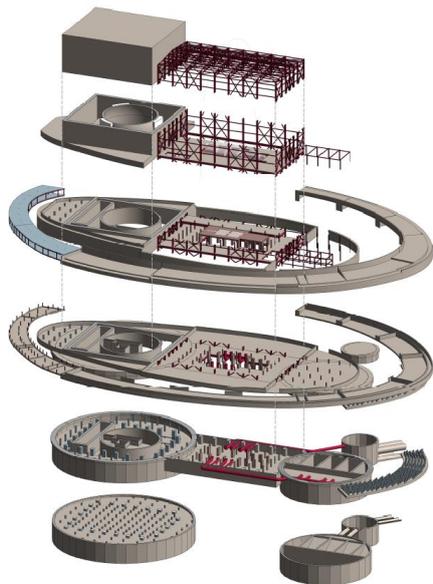
Neither AC nor DC electrical power is required to bring the IMSR400 Core-unit to a safe state, even indefinitely; although, a very limited capacity of electrical power is necessary to permit monitoring the state of the plant.

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UK SMR (Rolls-Royce and Partners, United Kingdom)

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MAJOR TECHNICAL PARAMETERS	
Parameter	Value
Technology developer, country of origin	Rolls-Royce and Partners, United Kingdom
Reactor type	3-loop PWR
Coolant/moderator	Light-water / Light-water
Thermal/electrical capacity, MW(t)/MW(e)	1276 / 443
Primary circulation	Forced (3 pumps)
Operating Pressure (primary/secondary), MPa	15.5 / 7.6
Core Inlet/Outlet Coolant Temperature (°C)	296 / 327
Fuel type/assembly array	UO ₂ / 17x17 Square
Number of fuel assemblies in the core	121
Fuel enrichment (%)	4.95 (max)
Core Discharge Burnup (GWd/ton)	55 – 60
Refuelling Cycle (months)	18 – 24
Reactivity control mechanism	Rods and Gd ₂ O ₃ solid burnable absorber
Approach to safety systems	Active and passive
Design life (years)	60
Plant footprint (m ²)	10,000
Site footprint (m ²)	40,000
RPV height/diameter (m)	11.3 / 4.5
RPV weight (metric tonnes)	220
Seismic Design (DBE)	> 0.3g
Fuel cycle requirements / Approach	Open cycle; Spent fuel transferred to a pool for storage prior to transfer to long term dry cask storage.
Distinguishing features	Modular approach facilitating rapid and cost-effective build.
Design status	Conceptual

1. Introduction

The UK SMR has been developed 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 of 443 MW(e) from 1276 MW(th) using industry standard UO₂ 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 build is enhanced through site layout optimisation and maximising modular build, standardisation and commoditisation.

2. Target Application

The UK SMR is primarily intended to supply baseload electricity for both coast and inland siting. The design can be configured to support other heat-requiring or cogeneration applications, as well as provide a primary, carbon free, power source for the production of e-fuels.

3. Main Design Features

(a) Design Philosophy

The design philosophy for the UK SMR is to optimise levelised cost of electricity against low capital cost. The power output is maximised whilst delivering robust economics for nuclear power plant investment and a plant size that enables modularisation and standardisation throughout.

(b) Reactor Core

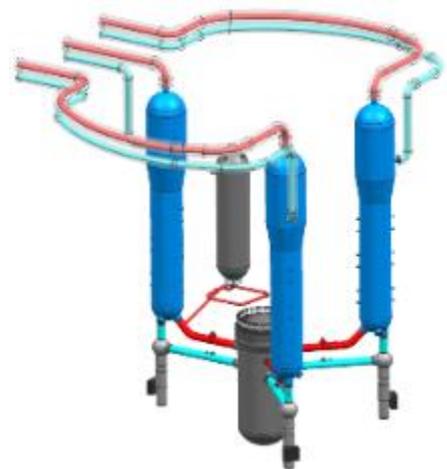
The nuclear fuel is industry standard UO_2 enriched up to 4.95%, clad with a zirconium alloy and arranged in a 17x17 assembly. The core contains 121 fuel assemblies and has an active fuelled length of 2.8 m, delivering a thermal power of 1276 MW(th). Each fuel assembly contains 40 poisoned fuel pins, with the remaining 224 fuel pins being unpoisoned. The poison used is distributed Gd_2O_3 (containing natural gadolinium) at 8 wt%.

(c) Reactivity Control

No concentration of soluble boron is maintained in the primary coolant for duty reactivity control, which facilitates a simplified plant design and eliminates risks associated with hazardous boric acid as well as the environmental impact of boron discharge. Duty reactivity control is instead provided through movement of control rods and use of the negative moderator temperature coefficient inherent to PWRs. It is a goal to achieve a zero-discharge plant.

(d) Reactor Coolant System

The RCS is a three loop, close-coupled configuration; Steam Generators 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 RCS pipework hot leg. A centrifugal Reactor Coolant Pump is mounted via a close-coupled nozzle, from the bottom of each SG outlet header.



(e) Reactor Pressure Vessel

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

(f) Steam Generator

A vertical u-tube SG design has been selected as a mature and readily deployable technology; other designs were considered but deemed insufficiently mature for commercial deployment in 2030.

(g) Pressuriser

The primary circuit pressure is controlled by electrical heaters located at the base of the pressuriser and spray from a nozzle located at the top. Steam and water are maintained in equilibrium to provide the necessary overpressure. The pressuriser is a vertical, cylindrical vessel constructed from low alloy steel, sized to provide passive fault response for bounding faults, with accidents causing either rapid and significant cooldown or heat-up accommodated.

4. Safety Features

(a) Safety System Approach

The UK SMR design has been developed through a combined system engineering and safety assessment approach. The safety informed design supports the process by which risks are demonstrated to be acceptable and As Low as Reasonably Practicable (ALARP).

Defence in depth is provided through the provision multiple layers of fault prevention and protection in the form of independent and diverse active and passive systems, with multiple trains per system. Passive safety systems are designed to deliver their safety functionality autonomously for 72 hours, minimising the demand on human actions and AC electrics.

(b) Engineered Safety Measures

In addition to duty 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.

Full bore RCS large 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.

The primary circuit and other key systems are located within a steel containment vessel to confine release of radiation sources during both normal and faulted operation. The UK SMR also adopts in-vessel retention (IVR) to confine the postulated melt in severe accidents.

5. Plant Safety and Operational Performances

The behaviour of the plant during normal and faulted conditions has been analysed and assessed using industry validated codes to demonstrate significant safety margin across the levels of defence in depth.

The Probabilistic Safety Assessment (PSA) calculates an overall core damage frequency from plant faults of $<10^{-7}$ per year of power operation, and that no single fault or class of faults makes a disproportionate contribution to risk, i.e. a balanced risk profile is achieved.

Internal and external hazard assessments have defined the design basis and informed the plant layout from a perspective of segregation and separation of safety related equipment. Key equipment is protected by the hazard barrier which is resilient against external hazards including aircraft impact and tsunamis.

6. Instrumentation and Control Systems

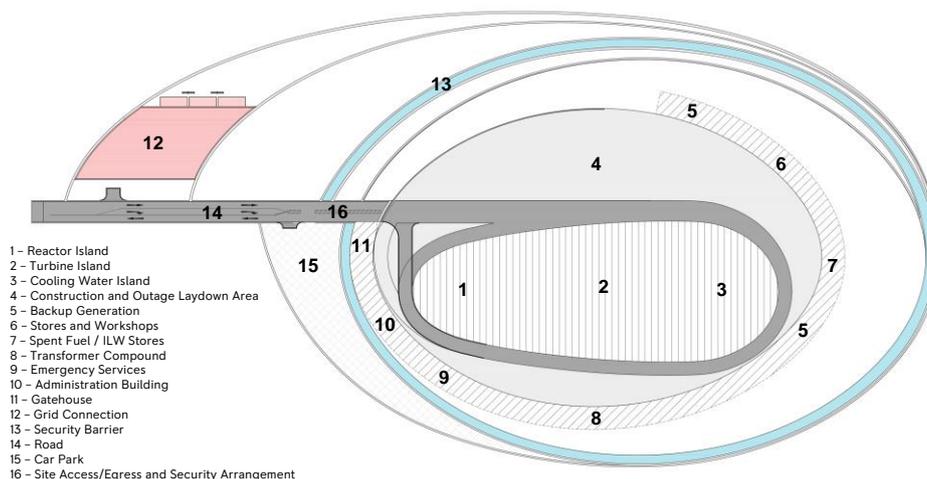
The UK SMR plant is controlled and protected by a number of control and instrumentation (C&I) systems. The reactor plant control system manages duty operations and uses an available in industry programmable logic controller (PLC) or distributed control system (DCS). It uses mixed analogue and nonprogrammable digital sensors and communicates on hardwired multichannel digital electrical networks. Opportunities to use smart devices and wireless technologies are being pursued.

The reactor protection system (RPS) provides shutdown in response to a fault. The RPS contains priority logic, which from the range of input signals received determines whether to initiate reactor shutdown. The hardwired diverse protection system (HDPS) uses non-programmable electronics and as such provides a diverse means to shut down the plant in response to fault conditions.

Post-Accident and Severe Accident Management Systems within the Nuclear C&I System provide clear plant status displays, over the days and months following a postulated accident.

7. Plant Layout

The power station is designed for installation on an extensive range of inland and coastal sites, across a wide range of soil and earth conditions, whilst maintaining a compact site footprint of approximately 40,000 m². This flexibility is enabled through design features such as seismic isolation for safety related areas. The three-loop PWR is located in the Reactor Island, adjacent to Turbine Island with the Cooling Water Island following. Support buildings and auxiliary services are situated within a berm that sweeps around the site and provides a layer of protection from external hazards such as tsunami or aircraft impact.



8. Design and Licensing Status

The project targets completion of the UK Office for Nuclear Regulation Generic Design Assessment process in time for construction of the first of a kind power station to commence in 2025. This timescale is considered achievable through the optimised use of proven technologies to minimise development time and regulatory risk. A consortium has been formed to deliver the UK SMR, with a wide range of additional UK based academic and industrial partners engaged to further develop capability. Design definition is at a mature design concept 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

9. Fuel Cycle Approach

The UK SMR operates on an 18-24-month fuel cycle, with a three-batch equilibrium core. The duration of refuelling outage is currently estimated at 18 days, with significant scope for further optimisation as the design progresses. Refuelling is managed through the provision of an in-containment refuelling pool which temporarily stores both new and spent fuel during a refuelling outage. Spent fuel is subsequently transferred to an external spent fuel pool for storage prior to transfer to long term dry cask storage.

10. Waste Management and Disposal Plan

The UK SMR waste treatment systems are based on use of proven technologies and best available techniques. Industry lessons learned and good practices have been used in the development of systems to minimise active and non-active wastes and discharges, through both design and operational practices adopted. Standardised waste treatment system components and modules are used to achieve the flexibility required for the waste informed design.

Operation without soluble boron in the primary coolant allows significant reduction in environmental discharges and concomitant simplification of the waste treatment systems. It is a design goal to achieve a zero discharge plant.

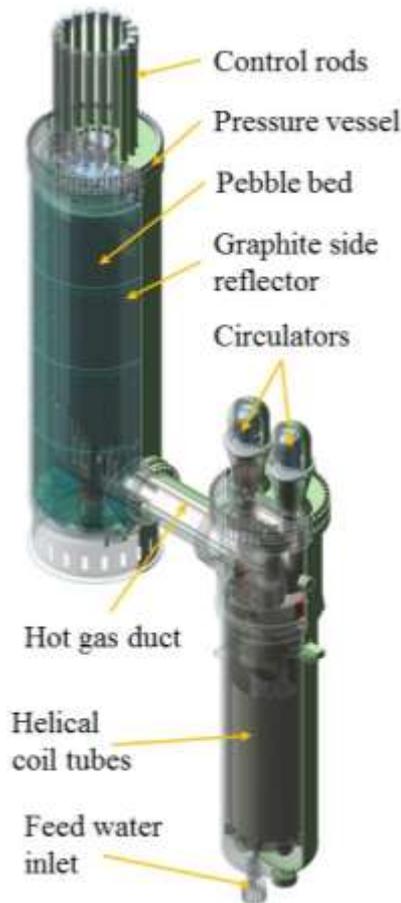
11. Development Milestones

2015	Rolls-Royce development of initial reference design
2016	Formation of consortium for design of whole power station concept
2017	Mature design concept developed
2025	Projected start of first of a kind construction
2030	Planned first of a kind commercial operation



Xe-100 (X Energy, LLC - USA)

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MAJOR TECHNICAL PARAMETERS	
Parameter	Value
Technology Developer, Country of origin	X Energy, LLC - USA
Reactor type	Modular HTGR
Coolant/moderator	Helium/Graphite
Thermal/Electrical capacity, MW(th)/MW(e)	200/75
Primary circulation	Forced helium circulation
System pressure (MPa)	16.5
Core inlet/exit temperatures (°C)	260/750
Fuel Type/Assembly Array	UCO TRISO / Pebbles
Number of Fuel Units	220,000 Pebbles per reactor
Fuel Enrichment (%)	14
Fuel Burnup (GWd/ton)	148
Fuel Cycle (months)	Online fuel loading
Main Reactivity Control Mechanism	Thermal feedback & Control Rods
Approach to Engineered Safety Systems	Passive
Design Life (years)	60
Plant Footprint (m ²)	216 m X 246 m (4 reactor modules with 4 turbines)
RPV Height/Diameter (m)	20m / 4.88m
Seismic design	0.3 g
Distinguishing features	Online refuelling, core cannot melt and fuel damage minimized by design, independent fission product barriers, potential for advanced fuel cycles
Design Status	Conceptual design development

Introduction

The Xe-100 is a pebble bed high-temperature gas-cooled reactor with continuous thermal rating of 200 MW. It features a continuous refuelling system with low enriched fuel spheres or pebbles of approximately 14 wt% entering the top of the reactor and passing through the core six (6) times to achieve a final average burnup of 148,000 MWd/tHM.

Target Application

Process heat applications, desalination, electricity and co-generation.

Specific Design Features

(a). Design Philosophy

A major aim of the Xe-100 design is to improve the economics through system simplification, component modularization, reduction of construction time and high plant availability.

(b). Reactor Core

The Xe-100 core comprises of approximately 220,000 graphite fuel elements (pebbles) each containing approximately 18,000 UCO TRISO coated particles. The core is graphite moderated with online refueling

capability. The advantage of online refueling is that the core excess reactivity is maintained at below 2% which means that no burnable poisons are needed to ensure that the reactor reactivity remains within safe shutdown limits at all times. This also improves the neutron economy of the core and helps the Xe-100 to achieve an average burnup of 148,000MWd/tHM. At full power approximately 193 fresh pebbles are added daily and a similar number are also removed as spent fuel.

The core geometry (i.e. aspect ratio), power density, heavy metal loading and enrichment level have been optimized to ensure that decay heat can be removed during even the most severe accident scenario such as a total loss of power along with the loss of the helium heat transfer fluid. During such an event, known as a Depressurized Loss of Forced Cooling (DLOFC), the decay heat is removed passively through making use of the thermal characteristics of the core and graphite core support structures.

(c). Fuel Characteristics

TRistructural ISOTropic (TRISO) particles are embedded in a graphite matrix pebble to form the fuel element. Particles contain coated uranium oxide and carbide (UCO) kernels enriched at 14 wt% and are slightly smaller in diameter (425 μm) than the usual UO_2 (500 μm) fuel kernels used in Germany and China. The optimized moderation ratio (NC/NA) yields a heavy metal loading of around 7 g/pebble. This enables the Xe-100, under worst case water ingress scenarios, to be shut down with its reactivity control and shutdown system (RCSS). Moreover, the graphite shell does not melt but sublimates (changes into vapor) at $> 3,920^\circ\text{C}$ (4,200 K) and fuel temperature never exceeds $1,100^\circ\text{C}$ during normal operation. Therefore, X-energy does not have to bear the same magnitude of costs related to the pressure vessel, containment building, or safety systems as those of a traditional nuclear plant.

(d). Fuel Handling System

The fuel handling system (FHS) moves fresh fuel pebbles, upon arrival at the plant, to the reactor where they remain until the fuel has been fully utilized. The pebbles are then removed from the reactor and transferred to the spent fuel storage system. The FHS is comprised of four main subsystems/components: New fuel loading system; Fuel unloading & recirculation system; Fuel burnup-measurement system; Spent fuel handling & storage system.

The FHS is a closed system which allows for 100% accountability of the fuel as it enters and exits the reactor. Each time the fuel passes through the reactor the burnup is measured to determine the amount of useful fuel available. If the fuel is not fully spent, it is recycled through the reactor and remains in the fuel handling system until spent and is then deposited into a spent fuel cask. These casks are stored onsite for the life of the plant.

(e). Reactivity Control

First and foremost the reactor relies on a strong negative temperature coefficient to ensure nuclear stability at all times. For operational reactivity control the reactor has a RCSS comprised of a bank of nine control rods with B_4C as the main control poison. A second bank of nine rods remains in the fully withdrawn position acting as reserve shutdown system primarily used for maintenance shutdown. The negative temperature coefficient alone will shut the reactor down to a safe shutdown condition without the need for active reactivity control systems. The control rod and shutdown rods can however individually shut down the reactor in a controlled shutdown operation. To achieve indefinite shutdown at temperatures of about 100°C for maintenance, both banks are inserted. Due to continuous fuelling, a minimum excess reactivity margin can be maintained. This margin is functionally selected to allow for start-up when performing load-follow operation (100%-40%-100%) and is sufficient to cover the effect of Xeon decay.

(f). Reactor Pressure Vessel and Internals

The reactor pressure vessel (RPV) and internal structures are designed for a 60-year life.

4. Safety Features

The intrinsic safety characteristic of the plant is guaranteed by a relatively low power density of 44.84 MW/m^3 , high thermal inertia of the graphitic internals and a strong negative temperature coefficient of reactivity over the total operational regime of the reactor. Also, the use of qualified UCO TRISO coated particle fuel provides excellent retention of fission products at the source. The pressure boundary provides a further independent physical barrier to retain the small amount of fission products that may end up circulating in the helium and in graphite dust particles. The reactor building venting route also minimizes the release of fission products by venting through filtered release vents.

(a). Engineered Safety System Approach and Configuration

The primary engineered safety systems are designed to be passive. Unintended plant transients are avoided due to the small excess reactivity resulting from continuous fuelling. The RCSS insertion depth during normal

operation binds around 1.4 Niles, allowing for load-follow operation within the range of 100% - 40% -100%. Any spurious signal that would cause full withdrawal of the RCSS would therefore only translate to a higher temperature and will not cause fuel damage.

(b). Decay Heat Removal/ Reactor Cooling Philosophy

Passive decay heat removal is possible, while the fuel temperature remains below admissible values. The radionuclides remain inside the fuel even throughout extreme upset events. If the active heat removal system is not available, then the core heat is removed passively through: Conduction between the pebbles and side reflector; Convection and thermal radiation to the core barrel, RPV; and, Reactor Cavity Cooling System (RCCS). Loss of the RCCS does not result in a safety concern as decay heat can be safely dissipated into the building structures and finally to the environment.

(c). Containment Function

Xe-100 “functional containment” is based on TRISO coated particles serving as the primary barrier to radionuclide release. The fuel element matrix contributes to additional resistance and adsorber surface in diffusing radionuclides. The helium pressure boundary (HPB) is the secondary independent barrier while the reactor building serves as final barrier. In the event of a break in the HPB a building flap will open, serving to let the helium escape to atmosphere through a filtered release vent to remove radionuclides.

Plant Safety and Operational Performances

10.1 What are the inherent safety features?

Non-metallic fuel elements – meltdown proof and efficient retention of radionuclides in the TRISO- coated particle fuel during normal operation allows for relatively clean helium circuits and plant operations with low contamination of cooling gas and radioactivity release.

Helium – Chemically and radiologically inert helium is an effective heat transport fluid. Moreover, it does not influence the neutron balance. Helium allows for very high coolant temperatures.

Graphite core structures – allows for high-temperature operations and provides high thermal inertia to the reactor resulting in slow transient response during a loss of active cooling.

10.2 What are the safety systems (active and passive)?

Fuel elements; Reactor protection system (RPS); Core support structures; RPV; Reactor building

10.3. Please describe Defense in Depth programme in design and multi-barrier approaches for operational transients and accidents, both with and without core damage, including:

10.3. a. Key safety features to limit plant transients;

RCSS insertion depth during normal operation binds around 1.4 delta k-eff. Any spurious signal that would cause full withdrawal of the RCSS would therefore only translate to a higher temperature that would remain below an allowable value shown experimentally not to cause any fuel damage. Furthermore, because the reactor core and its internals are mostly graphite, this provides a high thermal inertia that would cause any transient to be slow-acting.

10.3. b. Key safety features to avoid core damage;

Features include reactor core with low power density, which is very robust and has a high thermal capacity to make the reactor thermally stable during all operational and controlled procedures. Strong negative temperature coefficients also contributes to the excellent inherent safety characteristics.

10.3. c. Key safety features to contain core damage if it is possible;

Core meltdown proof – no Core Damage Frequency

10.3. d. Key safety features to reduce or eliminate large offsite release;

Multiple – independent fission product barriers: (1) Qualified UCO TRISO coated particle fuel provides retention of fission products at the source; (2) ASME designed pressure boundary provides a further reliable physical barrier to retain the small amount of fission products that may end up circulating in the helium and in graphite dust particles; (3) A filtered and vented reactor building.

10.3. e. Degree of diversity and redundancy in providing the above key safety features.

A series of independent fission product barriers provides redundancy and diversity. Failure of any one individual barrier will not impact the performance of another neighboring system/barrier.

10.4. What is the worst accident scenario, and what would be the release?

The Depressurized Loss of Forced Coolant (DLOFC) is the worst-case accident scenario. This assumes the RCSS has also failed to insert. Under this scenario no fuel damage will be experienced.

Instrumentation and Control System

10.6. a. Human-machine interface and instrumentation and control (I&C) design;

The I&C system consists of three layers: Distributed control system, investment protection system, and reactor protection system. The human machine interface is configured in such a way that no operator action is required to ensure safe shutdown of the reactor during all events.

Plant Arrangement

