

Small modular reactors

Rolls-Royce SMR and BWRX-300

Working paper

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1 Introduction

Small modular reactors (SMRs) are reactors that are designed to differ from conventional reactors in their smaller size and modular design. Each SMR unit typically has a rated power output of up to 300 MWe, which is about one-third of the power output of most nuclear power plants.

The term “small modular reactors” (SMRs) covers a large number of reactors of different technologies and sizes, so from a technical point of view, it is not a harmonized category. SMRs are usually defined as reactors with a capacity of 20-300 MW. However, some manufacturers are now also developing several reactors that they refer to as SMRs, with outputs well above 300 MW like the Rolls Royce SMR. Only a few SMRs are currently under construction worldwide, and none of these reactors are commercially available models.

The modular design of SMRs like the Rolls-Royce SMR is intended to allow their components to be manufactured off-site and assembled later on-site, making their deployment more flexible and less location dependent.

They also feature passive safety features such as gravity- and convection-driven cooling systems to eliminate the need for external energy or active human intervention for shutdown and cooling.

However, there are still many questions regarding the safety level and risks associated with SMRs. The following working paper focused on the two SMR types currently planned for the countries participating in the **Joint Project – Nuclear Risk & Public Control**, the BWRX-300 and the Rolls-Royce SMR. The two reactor types are described and discussed in Chapters 2 and 3 respectively. Chapter 4 then answers the questions previously submitted by the Joint Project about the reactors, as far as this is possible at the current stage of the project.

2 The BWRX-300

The Czech Republic is currently planning to deploy small modular reactors (SMRs), with the *GE Vernova Hitachi BWRX-300* being considered as one of the technologies. In 2020, GE Hitachi Nuclear Energy and Czech utility ČEZ have signed a Memorandum of Understanding on examining the economic and technical feasibility of potentially constructing a BWRX-300 in the Czech Republic.¹ Current information indicates that the Czech Republic has entered into a strategic partnership with Rolls-Royce SMR for its primary SMR project. (see Chapter 3) The BWRX-300 remains an important candidate for the Central and Eastern Europe region, as companies such as Orlen Synthos Green Energy (OSGE) are planning to use these reactors.

Poland's Orlen Synthos Green Energy (OSGE) is project developer for BWRX-300 small modular reactors (SMRs) in the region.² Poland's first BWRX-300 is to be built in Włocławek. Włocławek was one of six sites selected by OSGE in 2023 for further geological investigations with a view to constructing the BWRX-300 from GEVH.³

¹WNN: GEH promotes BWRX-300 design in Czech Republic; 4 February 2020; <https://www.world-nuclear-news.org/Articles/GEH-promotes-BWRX-300-design-in-Czech-Republic>

² WNN: Hungary looking at deployment of BWRX-300s, 1 August 2025; <https://www.world-nuclear-news.org/articles/hungary-looking-at-deployment-of-us-small-modular-reactors>

³ WNN: Site of Poland's first SMR selected; 28 August 2025
<https://www.world-nuclear-news.org/articles/site-of-polands-first-smr-selected>

In August 2025, Hungarian nuclear energy development firm Hunatom has signed a letter of intent with Synthos Green Energy to establish a pre-framework for joint activities relating to project development for up to 10 GE Vernova Hitachi Nuclear Energy (GEVH) BWRX-300 small modular reactors.

The BWRX-300 is a boiling water reactor (BWR) with natural coolant circulation and passive safety systems, and an electrical output of 300 MWe. The design is based on the Economic Simplified Boiling Water Reactor ESBWR, which has already been licensed by the U.S. NRC in 2014 and has an electrical output of 1,520 MWe.

The reactor building of the BWRX-300 contains the primary containment and the reactor pressure vessel (RPV) and extends below ground level. The reactor core is located inside the RPV. The operating pressure is 7.2 bar. The coolant inlet temperature is 270°C and the coolant outlet temperature is 287°C. The reactor is fueled by GNF2 fuel rods, which are used in many Pressurized Water Reactors (PWR).

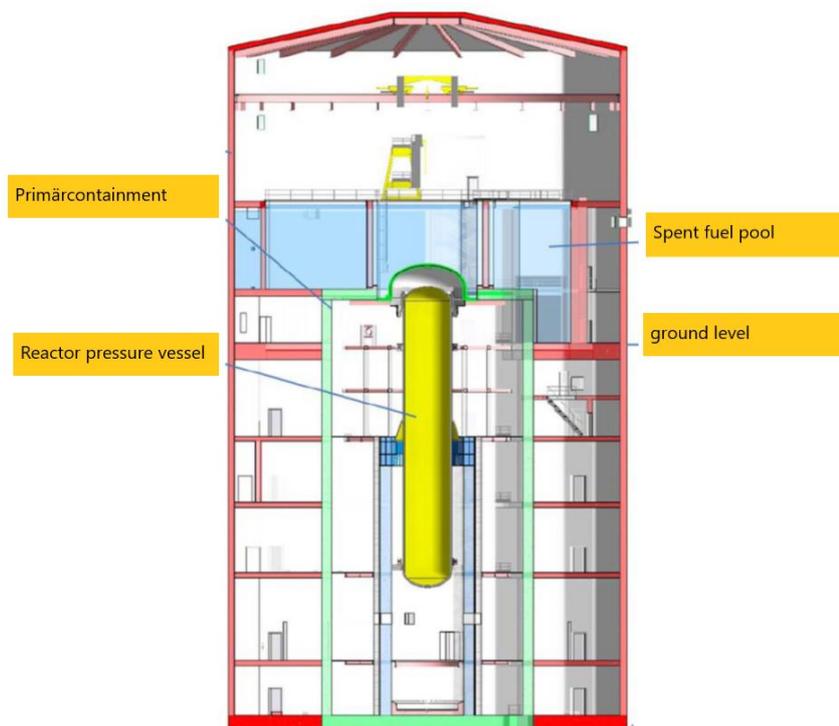


Figure 1: Schematic illustration of the BWRX-300 (OSGE 2023)

The containment encloses the RPV, the control rod drives, and the coolant pipes up to the isolation valves. These limit the pressure increase in the containment in the event of major coolant loss accidents. A dry containment is used. Inerting the containment with nitrogen minimizes the risk of hydrogen explosions. It should withstand an earthquake with a PGA of 0.3g (SSE).

The spent fuel pool is located at ground level in the reactor building and has sufficient capacity for eight years' worth of spent fuel elements and for complete unloading of the reactor core.

The operating life is at least 60 years. According to GEH, the service life of the BWRX-300 can be extended to 80 years, depending on operating history and system condition. (GEH 2023) The expected construction time is 30 to 36 months. The reactor has a modular design. The BWRX-300 is planned as a single unit.

The technology is still under development, so some challenges for the FOAK (=First-of-a-Kind) design are unavoidable.

2.1 Development history

The development history of the BWRX-300 is not a success story. The two previous reactor types (Simplified Boiling Water Reactor SBWR and ESBWR) were never built. Only four reactors of the last reactor type built (Advanced Boiling Water Reactor ABWR) were constructed in Japan, which have been out of operation for more than ten years. Among the predecessors was the reactor type (BWR-4), where the Fukushima accident occurred in 2011.

In 2017, development of the BWRX-300 was initiated based on the ESBWR design. The changes from the ESBWR to the BWRX-300 are primarily due to the desire to reduce costs. According to the manufacturer, the cost reduction from the ESBWR to the BWRX-300 is about 60% (ENCO 2022).

The most important design changes to the BWRX-300 relate to reducing the complexity of the safety systems. It is clear that reducing costs was a priority for the BWRX-300. Reducing the number of safety systems is not possible without reducing the level of safety. Whether the respective licensing authorities will accept these design changes in the licensing process and how great the actual reduction in the level of safety will be cannot be assessed at this stage.

It is also noteworthy that the BWRX-300 is the only BWR among the advanced SMRs. Apart from four ABWRs whose construction in Japan and Taiwan has been suspended, there are no other BWRs among the new construction projects. This is also due to the fact that the BWR concept has been rejected worldwide for safety reasons.

2.2 Licensing process

United States: In August 2022, the Tennessee Valley Authority (TVA) began planning for the possible deployment of a BWRX-300 at the Clinch River site. GEH submitted preliminary review documents of its BWRX-300 design to NRC. The review was initiated by the NRC in December 2019 but had not been completed by September 2025.⁴ In May 2025, the TVA has submitted an application to the US NRC to build a BWRX-300 at the Clinch River site. This makes the TVA the first utility in the USA to submit a construction permit application for the BWRX-300 technology.⁵

Canada: In January 2023, GEH announced that Ontario Power Generation (OPG) had placed an order for a BWRX-300 reactor, which is expected to be commissioned by 2029.⁶ In January 2025, GEH said that early site preparation work at Darlington had been completed with construction of the first unit expected to start in 2025, and commercial operations expected to commence by the end of 2029. In April 2025, the Canadian Nuclear Safety Commission (CNSC) has announced its decision to authorize OPG to construct a BWRX-300 reactor at the Darlington New Nuclear Project site in Clarington, Ontario.⁷

⁴ NRC: GEH BWRX-300, last update May 01, 2025. <https://www.nrc.gov/reactors/new-reactors/advanced/who-were-working-with/pre-application-activities/bwrx-300>

⁵ WNN: TVA submits first US BWRX-300 construction application; 20 May 2025. <https://world-nuclear-news.org/articles/tva-submits-first-us-bwrx-300-construction-application>

⁶ WNN: BWRX-300 completes Phases 1 & 2 of Canadian pre-licensing review; 15 March 2023. <https://world-nuclear-news.org/Articles/BWRX-300-completes-Phases-1-2-of-Canadian-pre-lice>

⁷ Canada: Commission authorizes Ontario Power Generation Inc. to construct 1 BWRX-300 reactor at the Darlington New Nuclear Project site; April 4, 2025. <https://www.canada.ca/en/nuclear-safety->

United Kingdom: GEH applied for a two-step GDA which is expected to complete in December 2025. At the end of Step 2, the regulators will publish Step 2 GDA Statements indicating their level of confidence in whether the design can potentially be operated in Great Britain. Should an organization wish to bring forward plans to deploy GEH’s BWRX-300 in Great Britain, a further period of detailed design assessment will need to be carried out by the regulators. This could be undertaken on a generic basis with GEH if it chooses to return to GDA to complete Step 3, or it could be done with a UK licensee/constructor as part of a site-specific development.⁸

2.3 Key safety features

The management of severe accidents for the BWRX-300 is based on passive heat removal (through natural circulation) via the isolation condenser system (ICS) or the containment cooling system (PCCS). According to the manufacturer, neither core injection nor emergency power is required in the event of a loss-of-coolant accident (LOCA).

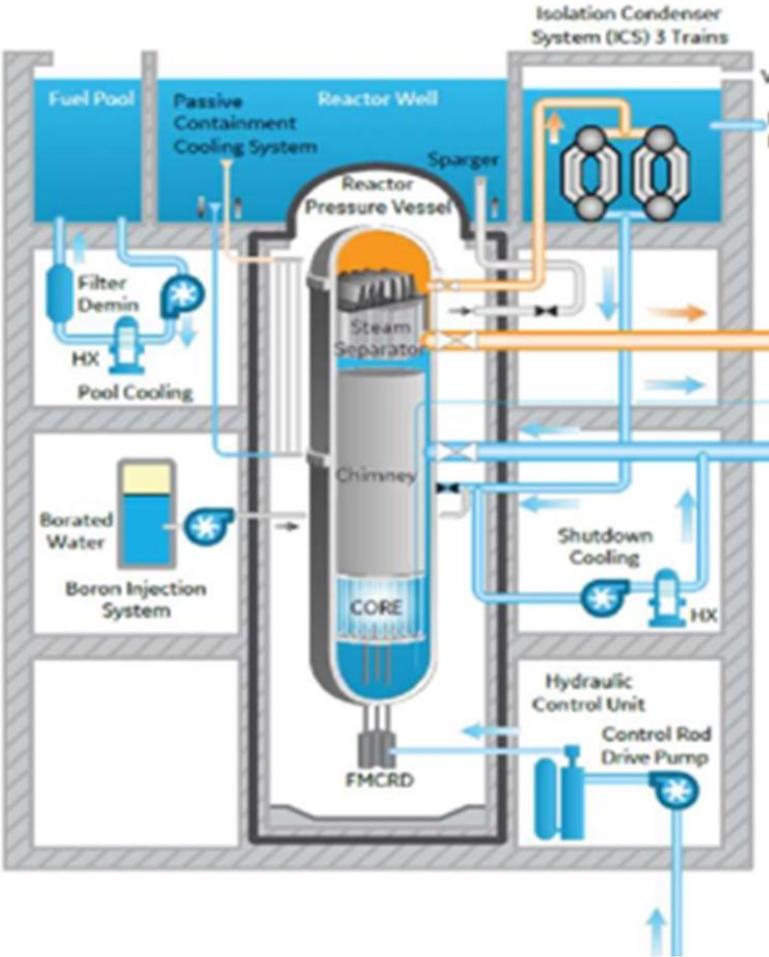


Figure 2: Major Systems of the BWRX-300 (GEH 2023)

The **Passive Containment Cooling System (PCCS)** uses natural circulation to transfer heat from the containment building to a pool in order to maintain the pressure and temperature of the containment

[commission/news/2025/04/commission-authorizes-ontario-power-generation-inc-to-construct-1-bwrx-300-reactor-at-the-darlington-new-nuclear-project-site.html](https://www.onr.org.uk/generic-design-assessment)

⁸ ONR: GE-Hitachi’s BWRX-300 completes the first step of generic design assessment December 2024; <https://www.onr.org.uk/generic-design-assessment>

building within design limits in the event of accidents or failure of the active containment cooling system. The PCCS consists of several heat exchangers in the containment building which, in the event of a LOCA, transfer heat from the containment building to the water-filled reactor pit above the reactor pressure vessel (RPV). This is intended to ensure cooling for 72 hours without the need for measures of the personnel or AC power.

PCCS operation does not require any sensors, controls, logic or electrically operated devices. Since there are no containment shut-off valves between the PCCS heat exchangers and the containment, the PCC is always in a 'standby' state.

Residual heat removal is ensured during primary circuit shutdown events via the **isolation condenser system (ICS)**. The heat is transferred to the IC pool, which is open to the atmosphere. The ICS is a natural circulation-driven safety system designed to provide emergency cooling of the reactor core, residual heat removal and overpressure protection of the RPV in the event of a loss of normal heat sink. Two ICS trains are required for LOCA mitigation (analysis assumes one ICS train has a single failure). With two ICS trains in service, decay heat removal is sustained for seven days without operator action. All three ICS trains are credited for beyond design basis events. The heat rejection process is continued beyond seven days if the IC pool inventory is replenished. The ICS pools are located above ground and are not pressurized. Clean makeup water can be added directly to the ICS pools using readily available transportable sources such as a fire truck.

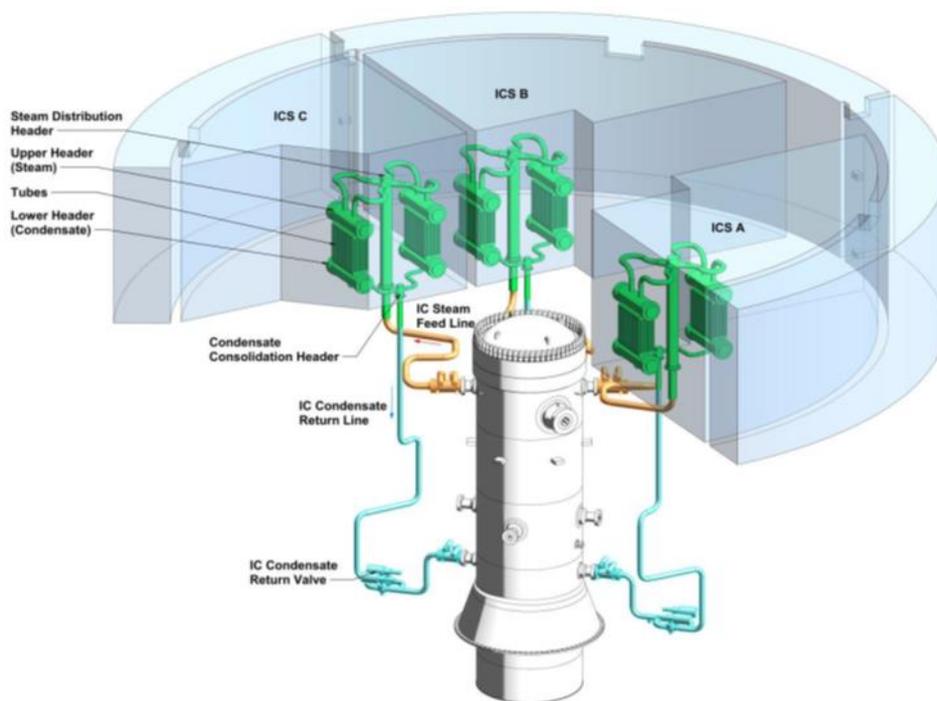


Figure 3: Schematic diagram of the isolation capacitor system (ICS) (GEH 2023)

The system consists of three identical and independent circuits, each consisting of: a pair of heat exchangers; an ICS pool above the containment in which the heat exchangers are immersed; steam supply and condensate return lines to/from the RPV, which supply both heat exchangers; for each supply/return line, a pair of RPV shut-off valves in series, which are integrated into the RPV, and a pair of parallel condensate return valves.

The ICS may be placed in service manually from the Main Control Room (MCR), automatically by the protection systems signal or by passive means if a loss of Direct Current (DC) power occurs (fail-safe). To place a train of the ICS in service, one of the parallel condensate return valves is opened (or fails open), allowing the standing condensate to drain to the RPV inlet in the chimney region.

In contrast to the ESBWR, the BWRX-300 is not equipped with a core catcher. It is assumed that the ICS provides sufficient cooling to make a core catcher unnecessary. Whether this assumption is justified cannot yet be conclusively assessed. In any case, the cost savings will lead to a reduction in safety.

2.4 Passive safety systems

A key feature of the BWRX-300 is the use of passive safety systems (the isolation condenser system (ICS) and the passive containment cooling system (PCCS)). It should be emphasised that the passive safety systems of the BWRX-300 have not yet been tested in operation.

Passive safety systems are being used more and more frequently in the design of nuclear power plants. It is generally assumed that they offer greater reliability at significantly lower construction and maintenance costs. Natural circulation may be more reliable than a pump, but it is less clear how to quantify its reliability. The forces that cause natural circulation depend on thermohydraulic factors that are poorly understood and can be subject to considerable uncertainty. There is greater uncertainty regarding its reliability.

Unlike active components, passive systems can have a large intermediate state between the simple states of ‘success’ or ‘failure,’ which makes it difficult to integrate them into traditional safety analyses.

Furthermore, a **passive safety system** may not be able to perform its assigned function even if there is no mechanical or electrical failure. This is because a passive safety system may rely on low-intensity phenomena (e.g. natural convection) which, under certain conditions, may not be sufficient to perform its function. Such failures could occur if the phenomena involved are sensitive to the system geometry (e.g. sensitivity to pressure losses), the environmental parameters and the discrepancy between the design expectations and the actual conditions, for example due to external influences (climate, earthquakes, etc.).

The multi-layered safety concept is also the fundamental safety principle for newer reactor designs, in which passive systems are used to a greater extent. The key to this safety concept is to achieve a sufficient degree of independence between the various levels. The BWRX-300 does not offer this independence between safety levels.

2.5 Probabilistic safety analyses (PSA)

According to the IAEA (2016), a situation can be considered practically impossible if the occurrence of the event is either physically impossible or if the event can be considered extremely unlikely with a high degree of confidence. The term ‘extremely unlikely’ is not defined in more detail by the IAEA, nor is there currently an internationally accepted numerical definition. For the frequencies of core damage and large releases (CDF and LERF), values are often given that represent the median of the calculated probability distribution.

Whether accidents involving large or early releases can be ruled out for the BWRX-300 cannot be assessed at this stage.

GEVH explained that the calculated core damage frequency (CDF) is smaller than 10^{-7} per year, the large release frequency (LRF) is smaller than 10^{-8} per year.

WENRA has published an analysis of the applicability of safety objectives for new reactors (WENRA 2013) to the safety assessment of SMRs (WENRA 2021b). It concludes that the safety objectives also apply to SMR concepts.

To demonstrate the practical exclusion of accident sequences that would lead to large early releases, GEH cites a general probabilistic parameter of less than 10^{-8} /year for the BWRX-300 reactor type. The basis on which the probabilistic parameter estimates are based is not specified. The probabilistic value

can only include probabilities of internal events leading to large or early releases. Site-specific events that could potentially lead to severe accidents cannot be included, as assessments of site-specific hazards (natural hazards and man-made hazards; e.g. earthquakes, floods, explosions, aircraft crashes) are apparently not yet available. The contribution of the hazards mentioned to the risk of early or large releases can only be determined on the basis of detailed hazard analyses as part of a probabilistic safety analysis (PSA). It is not possible to prove the practical exclusion of early and large releases solely by stating a probabilistic risk.

2.6 Load following

The BWRX-300 is primarily intended for **base load operation**. However, the BWRX-300 should also be capable of regulating the daily load to compensate for fluctuations in renewable energies. According to GEH, load following in the range of 50 to 100% of output should be possible, with an output change of 0.5% per minute.

In general, operating a reactor in load following mode has technical disadvantages, as the plant components are exposed to numerous thermal stress cycles. Continuous load fluctuations generally pose a challenge for the reactor core and other systems, as thermal cycles affect the fuel and cause thermal stress in the main components, leading to faster ageing. (OECD/NEA 2011) Whether the observed and expected problems are reduced by the design of the BWRX-300 has not yet been proven and will have to be demonstrated in practice. In addition, load following operation has an economic disadvantage when the plants are operated at reduced power.

2.7 Standardization

The delays and cost overruns in nuclear projects are partly attributed to the large scale of on-site assembly work, which is said to be more efficiently organized in a factory. However, reactors always require extensive work on site, such as the construction of foundations and power and water supply lines. For the BWRX-300, the ratio of factory to site activities is stated as 60 to 40. According to GEH, this is strongly influenced by the existence of a sea-based unloading facility at the site. The expected construction period is 30-36 months.

The main components of the BWRX-300 are to be manufactured in **specialized production facilities** and delivered to the site as prefabricated components ready for assembly. Above all, however, mass production would carry the risk of standardized errors. When manufacturing identical components, there is a risk that a design flaw will eventually occur in all plants whose components have passed through the production line in question. (THOMAS & SEQUENS 2023) This phenomenon was clearly evident in France in 2022, when a large number of reactors were shut down for safety reasons due to concerns about corrosion and cracking in stressed components. Although stress corrosion is a known phenomenon that had already occurred in other components of the French nuclear power plant fleet, this type of cracking was not expected in these plants. (ASN 2023; WNISR 2023)

Furthermore, even in industrial series production, there is a risk that components will not meet the required quality standards due to fraud and counterfeiting. (PISTNER et al. 2021) This has also already occurred on a large scale, e.g. in France. On 5 May 2016, the French Nuclear Safety Authority (ASN) stated that ‘irregularities’ had been found in the manufacturing control records for around 400 components manufactured since 1965 at the Areva forging plant in Le Creusot, France.⁹

⁹ NEI: Irregularities found at Areva’s Le Creusot forge; Nuclear Engineering International; 6 May 2016; <https://www.neimagazine.com/news/newsirregularities-found-at-arevas-le-creusot-forge-4885947> .

2.8 Terror attacks

Many facilities in a modern industrial society are vulnerable to sabotage and terrorist attacks. Third-party interference (terrorist attacks or acts of sabotage) can have a significant impact on nuclear facilities and thus also on the planned BWRX-300.

According to WENRA (2013), it is expected that a deliberate crash of a commercial aircraft will not lead to a core meltdown accident in new nuclear power plants and therefore, in accordance with WENRA safety objective (O2), should only have minor radiological consequences. In order to verify this, the effects of direct and secondary impacts of the aircraft accident must be considered (vibrations/shocks, burning and/or explosion of the aircraft fuel). In addition, buildings or parts of buildings containing nuclear fuel and safety-relevant safety equipment should be designed in such a way that no kerosene can penetrate them. (WENRA 2013) These requirements should also apply to an SMR.

It is likely that the design of a SMR will take a much more stringent approach to **cybersecurity** from the outset, which has tended to be retrofitted in nuclear power plants currently in operation. The plant's systems will probably be completely isolated, preventing cyber-attacks. (ENCO 2022)

In terms of safety issues, SMRs, including the BWRX-300, offer no advantages over conventional nuclear power plants. The same concepts as for all nuclear power plants are required for the security concept. According to GEH (2023), the **security concept** of the BWRX-300 is not disclosed to the public. The presentation in GEH (2023) therefore only contains general and partial information on the physical safety features.

- It is explained that all important facilities are located in areas where access is monitored and controlled. Most of the safety-relevant areas are located within the radiological control areas, which are not accessible during operation and are usually only entered during fuel element replacement.
- The safety concept and the physical separation of redundant systems, as well as simple passive safety systems, further support the physical safety of the facility, as several safety-relevant SSCs would have to be sabotaged in order to carry out effective radiological sabotage.
- Many components of safety-relevant systems are located below ground level, which reduces the risk of external threats.

Although part of the reactor is located below ground level (for cost reasons), the pools for the passive safety systems, which are essential for heat removal and the prevention of a serious accident, are located above ground level. The cooling pool for spent fuel elements is also located above ground level. The reduction in safety systems makes successful sabotage easier. This is further facilitated by the factory manufacture of many components

The information provided by GEH (2023) clearly shows that the new reactor's **physical protection** requirements are largely based on previous requirements.

However, an improvement of the previous physical protection system would be necessary for two reasons: Firstly, targeted terrorist attacks on nuclear facilities must also be considered possible in Europe. Secondly, it should be borne in mind in this context that drones are used in a military context for reconnaissance, i.e. to spy on a planned target.

Military actions against nuclear facilities, such as the Russian attacks on Ukrainian NPPs, pose a further danger that deserves special attention in the current global situation. Russia's attack on Ukraine has given rise to scenarios that were previously considered highly unlikely. The risk of catastrophic accidents has increased once again.

With the war in Ukraine, civilian nuclear facilities have become direct and indirect targets of armed conflict for the first time. Russia has made it clear that international rules prohibiting acts of war around nuclear power plants can only remain in force as long as all actors feel bound by them. In such cases, nuclear facilities become a particular threat. (BASE 2022)

It is more difficult to rule out armed conflict over a longer period of time. Even if the armed conflict does not take place on the current territory of Eastern Europe, the additional dangers must be taken into account, including: the use of remote-controlled drones loaded with explosives.

3 Rolls-Royce (RR) SMR

3.1 ČEZ and the Rolls-Royce SMR

On 17 July 2025, ČEZ and the British company Rolls-Royce SMR signed an early work agreement for the construction of the first small modular reactor (SMR) in Czechia. The aim is to obtain the necessary permits, support detailed planning and negotiations with the regulatory authorities so that the reactors can be commissioned on schedule. The cooperation also includes joint efforts in the development of modular nuclear reactor technologies.¹⁰

While initial deployment is planned for the Temelín site, ČEZ is also exploring opportunities to deploy SMRs at Tušimice in the Ústí nad Labem Region.¹¹ Construction of the SMR at the Temelin site is scheduled to begin in 2029 with completion planned in the mid-2030s.¹² ČEZ plans to build modular reactors with a total capacity of three gigawatts (3 GW) by 2050.¹³

Rolls-Royce's SMR strategy hinges on a public-private partnership (PPP) model, a structure designed to mitigate the financial risks inherent in nuclear projects. By July 2025, ČEZ had acquired a 20% stake in Rolls-Royce SMR for a total of 250 million.¹⁴ Furthermore, there is a multi-million-pound partnership with Curtiss-Wright for reactor protection systems and a

¹⁰ Czech energy group ČEZ completes entry into Rolls-Royce SMR; 08/07/2025; <https://english.radio.cz/czech-energy-group-cez-completes-entry-rolls-royce-smr-8859142>; ČEZ a Rolls-Royce SMR podepsaly dohodu o přípravných pracích na zavedení SMR v České republice; 17 July 2025; <https://www.cez.cz/nextcez/cs/pro-media/tiskove-zpravy/cez-a-rolls-royce-smr-podepsaly-dohodu-o-pripravnych-pracich-na-zavedeni-smr-v-ceske-republice-223216>

¹¹ Czech development just the latest news in a booming small modular (nuclear) reactor market, 30/7/2025; <https://knowledge.energyinst.org/new-energy-world/article?id=139752>

¹² Czech Company ČEZ Progresses with First SMR at Temelín; 06.08.2025; <https://www.czechtradeoffices.com/us/news/czech-company-cez-progresses-with-first-smr-at-temelin>

¹³ ČEZ schließt Einstieg bei Rolls-Royce SMR ab. Unternehmen wollen gemeinsam modulare Reaktoren in Großbritannien bauen ČTK; 7. August 2025; <https://www.e15.cz/byznys/prumysl-a-energetika/cez-dokoncil-vstup-do-rolls-royce-smr-firmy-spolu-stavi-modularni-reaktory-ve-velke-britanii-1426544>

¹⁴ ČEZ spent six billion crowns on a fifth stake in Rolls-Royce SMR; 7. August 2025; <https://www.novinky.cz/clanek/ekonomika-cez-s-rolls-royce-smr-pripravi-tri-modularni-reaktory-v-britanii-40533318>

collaboration with ŠKODA JS for component manufacturing.¹⁵ Rolls-Royce (RR) began design work on the SMR in 2015 with a team of about 150 people. In December 2017, the UK government provided funding of up to £56 million over three years to support SMR research and development.

Although the Rolls-Royce SMR is based on proven pressurized water reactor (PWR) technology, the overall modular concept and new production method are still new and therefore carry certain cost and schedule risks. ČEZ spokesperson Kříž explains: "*The first small modular reactor of its kind will not be built in the Czech Republic. Rolls-Royce SMR will build it in its home market in the UK. Czechia is therefore next in line. The risk of delays and cost overruns is already reduced thanks to the experience gained in the United Kingdom*".

On 10 June 2025, the British government announced that Rolls-Royce SMR had been selected as the UK's preferred bidder to build the country's first small modular reactors after a two-year competition. The British government pledged 2.5 billion pounds (\$3.4 billion) for the SMR programme over the next four years.¹⁶ Rolls-Royce SMR plans to build three small modular reactors with the state-owned company Great British Energy–Nuclear (GBE-N). The projects are scheduled to come online in the mid-2030s.

According to ČEZ, a comprehensive approval process has already been initiated in Temelín. The necessary update of the South Bohemia Region's spatial planning principles has been successfully completed, and the environmental impact assessment (EIA) is currently underway. The EIA documentation is to be submitted in 2026. The approval process has also already begun in Tušimice in the Ústí nad Labem region. There, ČEZ is now awaiting the results of the investigation process as part of the EIA review. Detailed geological surveys are currently being carried out.

ČEZ has completed nine geological drillings to a depth of between 50 metres and 200 metres near the Temelín NPP. The first survey related to the SMR project was carried out three years ago with four boreholes to a depth of 30 metres.¹⁷

3.2 Rolls-Royce (RR) SMR General Design

The Rolls-Royce (RR) SMR is a single-module unit with a thermal output of 1358 MWth and an electrical output of 470 MWe. The generic Rolls-Royce (RR) SMR design is a small three-loop Pressurised Water Reactor (PWR) with design life of 60 years for non-replaceable components. The intended fuel is uranium dioxide (UO₂). The reactor core consists of 121 fuel elements in a 17 x 17 configuration. The target burn-up is specified as 55-60 GWd/t, which is comparable to the values for large nuclear power plants.

¹⁵ Rolls-Royce's Strategic Pursuit of Funding for Small Modular Reactors: A Blueprint for Energy Transition Investment; 31.08.2025; <https://www.ainvest.com/news/rolls-royce-strategic-pursuit-funding-small-modular-reactors-blueprint-energy-transition-investment-2508/>

¹⁶ Reuters: Rolls-Royce denies report of IPO plans for small nuclear reactor unit; 30.08.2025; <https://www.reuters.com/business/energy/rolls-royce-denies-report-ipo-plans-small-nuclear-reactor-unit-2025-08-30/>

¹⁷ WNN: CEZ completing Temelin SMR boreholes survey; 6 August 2025; <https://www.world-nuclear-news.org/articles/cez-completing-temelin-smr-boreholes-survey>

The RR SMR design has been developed by the RR based upon established PWR technology, in use all over the world. Innovation comes in the form of its modular approach to construction which would see the majority of the power station built in factory conditions and assembled on site. The reactor itself is of a typical PWR design, including a steel Reactor Pressure Vessel (RPV) holding fuel assemblies, Steam Generators (SG), Reactor Coolant Pumps (RCP) and piping, all held within a steel containment vessel. The reactor is equipped with a number of supporting systems for normal operations and a range of safety measures are present in the design to provide cooling, control criticality and contain radioactivity under fault conditions. Passive safety features are preferred to active components, reflecting the RR's design philosophy.

The design has a **steel containment** that can reduce the release of fission products into the environment in the event of core damage accident.

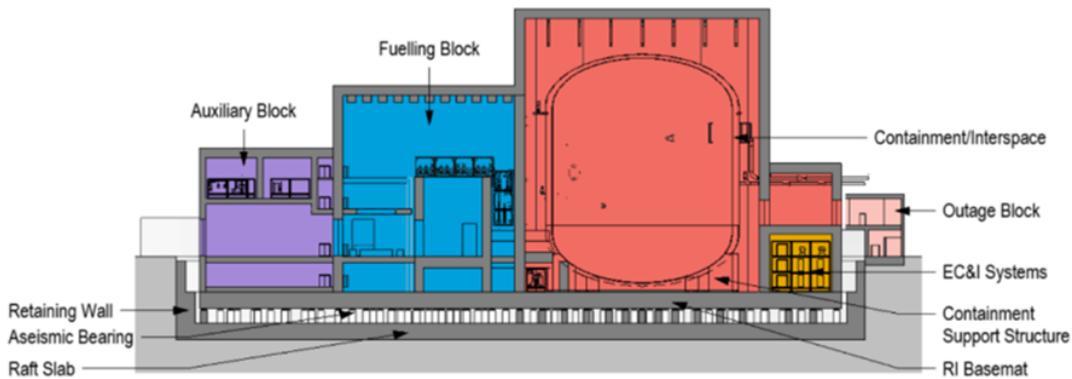


Figure 4: Indicative Section Through Reactor Island Structures of the RR SMR (ONR 2024c)

Power output was initially designed to be 440 MWe and subsequently increased to 470 MWe which is above the usual range considered to be a SMR. The EIA documents for the SMR for Temelín and Tušimice assume an output of 498 MWe.¹⁸ The RR SMR has a relatively high nominal output (470 MW) for an SMR. This corresponds, for example, to the output of the VVER-440 reactors in operation at the Dukovany and the Paks NPP. This reactor size may require difficult on-site assembly work. It seems highly impractical to assemble 90% of the plant in a factory.

The reactor is designed to be protected from **external hazards** and the effects of ground movement. The design should withstand an earthquake with a PGA of more than 0.3g (SSE).

One disadvantage of the RR SMR's design is that the **forced circulation of the coolant** requires the use of active elements and has a negative impact on the reliability of the system.

The design is based on a modular construction with a high proportion of factory-made components in order to reduce construction time and costs. On-site activities are primarily limited to the assembly of **prefabricated**, pre-tested modules. According to RR, this concept minimises the time required on site, as 90% of the manufacturing and assembly work is carried out under factory conditions.

¹⁸ Jacobs Clean Energy: Neues SMR Kernkraftwerk am Standort Tusimice, Bekanntmachung eines Vorhabens, Januar 2025; https://www.umweltbundesamt.at/fileadmin/site/themen/energie/kernenergie/verfahren/tschechien/smr_tusimice/de_smr_tusimice_scoping.pdf

The goal is an on-site construction time of around 500 days and a total construction time of four years, with two years for site preparation and another two years for construction and commissioning. The expected construction period of 24 months does not apply for FOAK plants. The design is 85% standardized and 15% site-specific. The design includes road-transportable modules. The RDB diameter must not exceed 4.5 m to ensure that the British road transport height limit of 4.95 m is not exceeded. The RR SMR requires a site area of approximately 40,000 m³. The plant area is 10,000 m³.

The RR SMR should operate in base load but **load following operation** in the range of 50–100% should also be possible (3–5% per min according to British grid code). This rate seems to be very fast compared to announced capability of other SMR designs. (see chapter 2.6)

An advantage of the RR SMR's design is that it uses PWR technology, the most widely used concept for nuclear power plants. While the basic elements of the RR SMR reactor are typical of most PWR in operation today, there are some state-of-the-art innovations.

The RR SMR uses a **boron-free primary circuit design**, in which toxic and corrosive boric acid has been removed from all operating systems. This reduces the power plant's overall water consumption and reduces wastewater generation. Boron-free operation also prevents dilution accidents. However, the boron-free operation has not yet been tested in operation.

The design of the RR SMR includes the following safety systems:

- ☐ Passive decay heat removal system (PDHRS)
- ☐ Passive containment cooling system (PCCS)
- ☐ Passive Emergency Core Cooling System (ECCS)
- ☐ Additional Small Leak Injection System (SLIS)

The design includes passive reactor shutdown systems and passive core spray systems with only two redundancies (N+1). Furthermore, the concept of passive safety systems has not yet been tested in operation.

The reactor can be brought to a safe state for up to three days (72 h) without operator intervention in a design basis accident (DBA). However, this only applies to DBAs.

According to RR, the calculated core damage frequency (CDF) and also the large release frequency (LRF) are smaller than 10⁻⁷ per year.

The basic design uses direct cooling and therefore cooling with sufficient cooling water access must be provided, also cooling tower can and will be used as a cooling system in Czech Republic.

The emergency planning zone (EPZ) for the RR SMR and the emergency preparedness measures will be determined later in the detailed design phase.

It is explained that security measures are integrated into the plant design, e.g. entry and exit points of the buildings and structural resilience. SMR security is designed in accordance with the Security Assessment Principles of the British ONR (SYAPS). According to ONR (2024f), the security features, by way of systems and components that will meet regulatory expectations for protection of the plant, are not part of the early design. Security risks from sabotage, of the plant and theft of nuclear material will only become apparent once the design has matured.

3.3 Generic Design Assessment (GDA)

The Environment Agency, the Office for Nuclear Regulation (ONR) and Natural Resources Wales (the regulators) have an assessment process - Generic Design Assessment (GDA) which enables them to scrutinize new nuclear power units designs before they are built in the UK. Step 1 of the Rolls-Royce SMR GDA formally began on 3 April 2022. The regulators completed Step 1 of the GDA (initiation), Step 2 of the GDA (fundamental assessment) began

on 3 April 2023. Step 3 (detailed assessment) is ongoing. Designer (requesting party) is Rolls-Royce SMR Limited. The assessment is likely to take about four years and is expected to be completed by 2026.

The GDA process focuses on the design of a generic nuclear power plant and is not site-specific. Due to its non-site-specific nature, the outcome of the GDA will be of limited use for the Czech Republic, but it will enable potential critical issues to be considered.

Some of the ONR's GDA assessments from Step 2 are briefly described in the following sections.

3.4 Management of Severe Accident

The Rolls-Royce SMR includes several design basis safety measures and severe accident safety features. The Rolls-Royce SMR design employs In-Vessel Retention (IVR) as its molten core (corium) cooling strategy. The corium is retained within the RPV and is cooled via ex-vessel cooling. Figure 5 shows a schematic diagram of the relevant SSCs that support IVR.

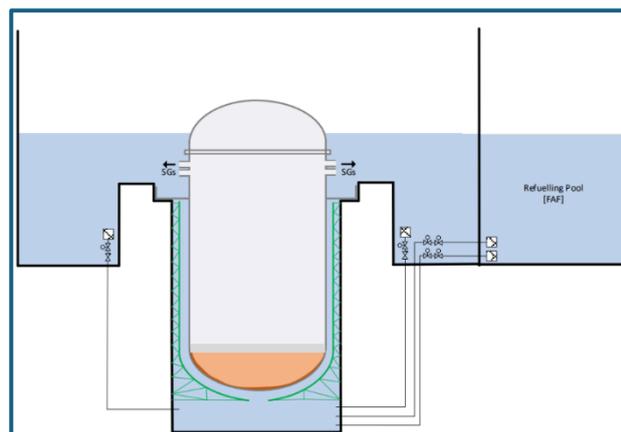


Figure 5: Schematic Diagram of In-Vessel Retention (ONR 2024a)

Steam generated from IVR and any released directly from the primary circuit is condensed by the Passive Containment Cooling (PCC) Heat Exchangers (HX) of the Local Ultimate Heat Sink (LUHS). The condensate then drains back into the Reactor Cavity via the containment sump. No containment spray is claimed during this mode. The containment sump is hydraulically connected to the Reactor Cavity during a severe accident, allowing the condensed water to be reused for IVR. The water which cools the containment atmosphere, which is on the inside of the PCC HX tubes, evaporates and exits the LUHS into the atmosphere.

Generally, during a severe accident in a PWR, there is potential for RPV failure whilst the reactor is still at high pressure. This can lead to high pressure melt ejection (HPME) of the corium from the RPV, which can challenge the containment. A decision has been made by the RR to include a severe accident depressurization function in order to avoid HPME. However, the design of this function is still in development.

Hydrogen generated during a severe accident also poses a threat to the containment. The Rolls-Royce SMR design includes a Hydrogen Reduction System (HRS), consisting of Passive Autocatalytic Recombiners (PARs), located inside the containment to prevent conditions which could challenge integrity of the containment.

ONR (2024a) concluded concerning severe accident management, that the RR has identified relevant severe accident phenomena that should be prevented/mitigated and appropriate safety features to provide for severe accident management. The selected severe accidents sequences

provide an adequate basis for the analysis provided during Step 2. Also, RR's proposed methodology for performing radiological consequence analysis is adequate, However, the analysis has not been presented for assessment in Step 2.

It is explained that ONR (2024a) has confidence that the RR has a valid approach to demonstrate in Step 3 that the design practically eliminates sequences with the potential to lead to large or early releases. But further work is required to demonstrate that the risks have been reduced ALARP. ONR highlighted that the justification of the exclusion of a filtered containment venting system and containment leakage filtration is missing. As the Level 2 and 3 probabilistic safety analysis (PSA) has not been completed, the full justification for this decision has not been submitted during step 2. ONR (2024e) concluded that there are limitations and gaps in various aspects of the PSA. For example, RR has not identified all potential initiating faults and their associated Initiating Event Frequencies (IEFs). Regarding the hazards PSA, the RR has presented insufficient detail to form a judgement on the adequacy of the internal hazards analyses. For external hazards, evidence will need to be provided during site specific activities.

3.5 Chemistry of primary circuit

The RR SMR design adopts a primary circuit operating chemistry regime that differs from that of other operating PWRs in that reactivity control is achieved using control rods rather than through the addition of soluble boron to the primary coolant in normal operations. Additionally, the RR has selected potassium hydroxide, rather than lithium hydroxide, as the alkalisng agent to achieve the desired pH in the primary circuit.¹⁹ Further work will need to be undertaken in Step 3 of GDA by the RR to develop the underlying evidence supporting the chemistry claims and arguments.

ONR (2024b) concluded the chemistry implications of adopting a boron-free potassium hydroxide primary circuit and SFP chemistry are well documented in the submissions, except for those aspects relating to shutdown chemistry. Relevant benefits, including a reduction in tritium production, are identified and initial evidence for these is presented. However, further justification is required to substantiate a number of related claims. Whilst key aspects of this substantiation are reliant on the results of a laboratory test programme which is not expected to yield results until Step 3 of GDA. Insufficient information was provided by the RR during Step 2 to form a judgement on the feasibility and implications of the shutdown chemistry approach.

3.6 External hazards

A hazard shield, with various structures, systems and components (SSCs) located within it, formed from reinforced concrete walls and slabs, with the primary function to protect safety critical SSCs from external hazards including accidental and malicious aircraft impact.

¹⁹ Whilst lithium hydroxide is the common choice amongst operating Western PWRs, a number of Eastern European VVERs operate successfully with potassium hydroxide conditioning

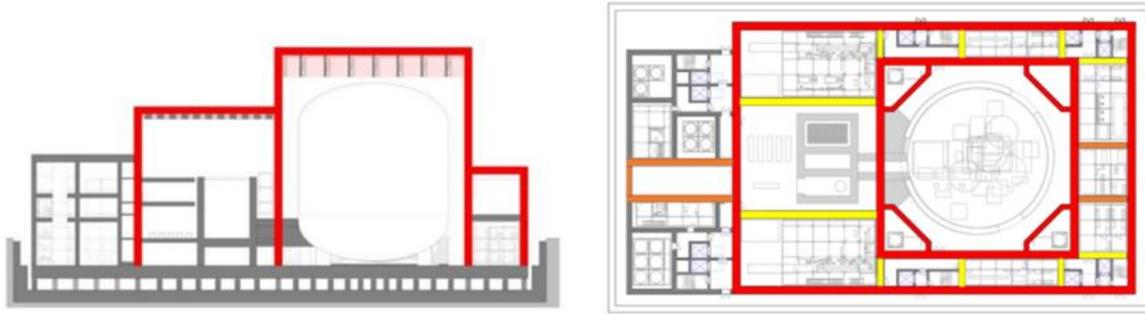


Figure 6: Extent of hazard shield shown in red (elevation on left (l), plan on right (r)) (ONR 2024c)

The hazard shield and reactor island rest on a basement, which is supported by a seismic isolation system. The function of the seismic isolation system is to reduce the seismic demand to the majority of reactor island superstructures, including the reactor and spent fuel pool. The design employs low damping rubber bearings and the proposals provide isolation in the horizontal direction only.

High Extreme Ambient Temperatures (EAT) have the potential to increase heat loadings on SSCs. Heating Ventilation and Air Conditioning (HVAC) and passive cooling systems have the function of protecting SSCs from excessive heating loadings, whether from internal or external sources. **The detailed design is ongoing.**

Several external hazards, e.g. extreme winds, lightning and geomagnetically Induced currents (GICs), have the potential to cause Loss Of Offsite Power (LOOP) and may also cause faults in electrical and C&I SSCs. Backup electrical supplies will be provided, including diesel generators. **Additional mitigations, such as diverse SSCs, may be provided but the detailed design for this is ongoing.**

The proximity and arrangement of SSCs affects the outcomes for various external hazards such as seismic events, aircraft crashes and high EAT. **Details of the layout are still being developed.**

According to ONR (2024d), the technical quality of the RR's submissions has been to some specific shortfalls, e.g. **cliff edge methology**. ONR has identified a number of challenges that the RR will need to address during Step 3, including the impact of the significant uncertainties that exist in estimating the effects of climate change.

3.7 Modular design

The RR SMR design proposes the use of 'system modules'. According to RR, the benefit of this approach is that the modules can be assembled off-site and transported and installed upon delivery. This is a key feature of the RR SMR design that is a novel approach. The steel modules are also referred to as 'Mechanical Kit of Parts' (MKoP).

The design description explains the design of the 'process clusters' within the seismically isolated reactor island. It defines a process cluster as, 'the conglomeration of 'system modules' into discrete structural framing systems.' Figure 7 shows the terminology used for module combinations. The process clusters are anchored into the concrete structure at the base of the cluster only. For each process cluster, segregation concrete walls (barriers) are provided.

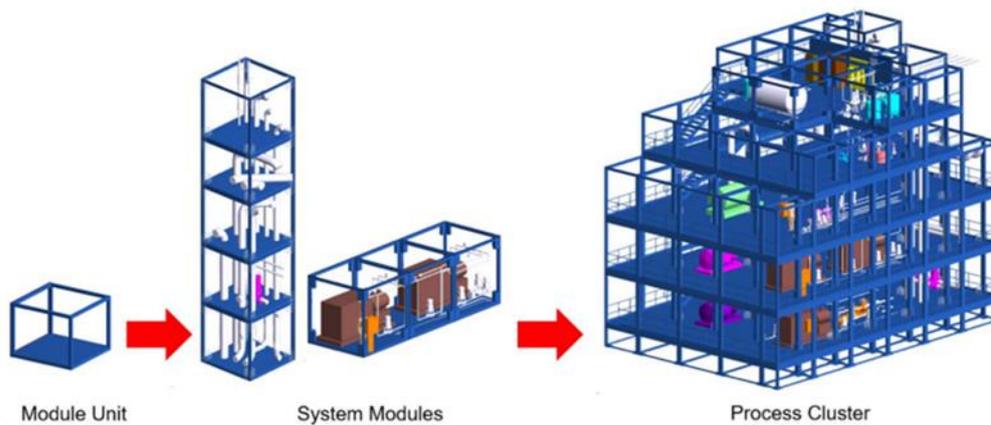


Figure 7: Assembly of Modules, System Modules and Process Clusters (ONR 2024c)

At the time of ONR’s assessment during Step 2, the design is still under development. The development of very important issues, for example, the seismic resistance system is still ongoing. Also, the selection and location of internal hazards barriers within the process clusters is not confirmed. No details are provided of the connection between the MKoP, which forms the process clusters and the concrete interface. Among others, ONR criticized the lack of any specific requirements for process clusters supporting the Main Control Room (MCR).

ONR (2024c) has concluded based on its assessment: Further work is required to present a fully developed safety case. The design principles and methodologies adopted require further development to demonstrate that they are sufficient to enable the design and substantiation of the civil structures.

In addition, the safety concerns mentioned by ONR, there are some general concerns based on previous experience with standardized factory-made components (see chapter 2.7).

4 Answers to the specific questions

Question 1

- ☐ It is said that the Rolls-Royce (RR) SMR is to be constructed using approximately 1,500 (!) standard portable modules manufactured and tested in off-site factories.²⁰ Can putting them together be done without compromising nuclear safety?

Answer to question 1:

Although RR has a plan and a preliminary concept for the modular construction method, according to the ONR there are still many questions and safety concerns regarding the assembly of the module on site. The necessary safety analyses have not been provided yet (see chapter 3.7).

In addition, there are some general concerns based on previous experience with standardized factory-made components (see chapter 2.7). Above all, however, mass production would carry the risk of standardized errors. When manufacturing identical components, there is a risk that a design flaw will eventually occur in all plants whose components have passed through the production line in question. Furthermore, even in industrial series production, there is a risk that components will not meet the required quality standards due to fraud and counterfeiting.

Question 2

- ☐ Rolls-Royce (RR) states that the reactor uses "passive and inherent safety features," but details about their concepts and scope have not been fully disclosed. If passive systems are not sufficiently robust or complete (e.g., against long-term power or cooling failures), they may be insufficient in the event of a serious accident. What are the strategies for managing severe accidents (e.g., core meltdown, core catcher)?

Answer to question 2:

The RR SMR intends to use in-vessel retention cooling (IVR) to prevent major radioactive releases in the event of a core meltdown accident. However, not all details have been worked out at this stage of the project. The safety concept cannot therefore be assessed as reliable at this stage, as it is still under development. It can only be conclusively evaluated once the concept has been finalised. (see chapter 3.4)

Question 3

- ☐ Given that the BWRX-300 is a boiling water reactor and that the Czech Republic has no experience with boiling water reactors, how difficult will it be for the regulator to assess safety issues?

Answer to question 3:

Both boiling water reactors (BWRs) and pressurised water reactors (PWRs) are light water reactors, but they differ in their design principles and systems. The main difference is that a PWR keeps the water under high pressure to prevent boiling and transfers the heat to a secondary circuit to generate steam, while a BWR allows the water to boil directly in the reactor core, generating steam that then drives the turbine. Consequently, BWRs are direct-cycle systems with radioactive steam in their turbine cycle, while PWRs are indirect-cycle systems in which the steam in the secondary circuit is not radioactive. For safety reasons, the pressurised water reactor is now the most commonly chosen technology for nuclear power plants. (see chapter 2.1)

Different design principles and safety systems require specific knowledge for the nuclear authorities. In addition to the new safety design of the SMR BWRX-300, there is also the fundamental design

²⁰ RR SMR: Our technology, 2025; <https://gda.rolls-royce-smr.com/our-technology>

difference of the BWR compared to the operating PWR in Czech Republic. It may be quite complex for the Czech nuclear authority (SUJB) to assess whether the reduction in safety systems has a negative impact on the safety level of the plant.

Question 4

- ☐ The BWRX-300 is said to have 100% passive core cooling for 7 days without human intervention. Is this possible? What are the risks?

Answer to question 4

It should also be emphasized that the passive safety systems of the BWRX-300 have not yet been tested in operation. A passive safety system may not be able to perform its assigned function because it relies on low-intensity phenomena, which can be sensitive to environmental parameters or external influences (climate, earthquakes, etc.). Since the magnitude of the natural forces driving the operation of passive systems is relatively small, counteracting forces (e.g. friction) can have a greater influence. The BWRX-300 does not have a core catcher or an explicit in-vessel concept. The severe accident management relies on the passive cooling systems (see chapter 2.3 and 2.4).

Question 5

- ☐ The presented plans for the implementation of these reactors in the Czech Republic, except for the pilot one in Temelin, are very close to large cities, refineries and chemical plants. Do they have a level of safety that will prevent contamination from in the event of a LOCA accident?

It is not possible to answer this question yet, because both the design and the safety case are still in the development. For the BWRX-300, it is envisaged that the Emergency Planning Zones (EPZ) sizes will be calculated using dose-based and consequence-oriented methods and, according to GE H, the TVA Clinch River Early Site Permit process is a representative estimate.

EPZs are Zones around a nuclear reactor that are prepared to respond to an emergency. EPZs allow to pre-define the protective actions to mitigate the most likely consequences of a radiation emergency. According to IAEA, there are two EPZs: the Precautionary Action Zone (PAZ) with a suggested Radius of 3 to 5 km and Urgent Protective action planning Zone (UPZ) with a suggested radius of 15 to 30 km.

No work has been done to date on defining the EPZ for the UK SMR. EPZs will be determined by the ONR judgement which combines technical assessment of the plant (e.g., source term) and its operating procedures, site specific factors, together with other factors considered by the ONR Emergency Preparedness and Response Team, including IAEA guidance.

Question 6

- ☐ What protection do these SMRs guarantee from external attack?

Answer to question 6

The RR SMR is said to have protection against external hazards. However, as the designs are not yet finalised, this cannot be assessed. In addition, the site assessment, which must be carried out, is also important for external hazards. For the BWRX-300, too, the level of protection against external hazards can only be assessed after site development.

References

- ASN (2023): ASN REPORT on the state of nuclear safety and radiation protection in France in 2022; May 2023.
- BASE – Bundesamt für Sicherheit der nuklearen Entsorgung (2022): Laufzeitverlängerung deutscher Kernkraftwerke? Stand 26.07.2022.
- ENCO (2022): Abschlussbericht ENCO-FR-(22)70 REV 5, Analyse von Konzepten von Small Modular Reactors (SMR); im Auftrag des Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technology; Stand 2022.
- GEH (2023): BWRX-300 General Description, General E005N9751 Revision F, December 2023.
- OECD/NEA (2011): Technical and Economic Aspects of Load Following with Nuclear Power Plants (2011)
- ONR (2024a): Generic Design Assessment of the Rolls-Royce SMR; Step 2 assessment of Severe Accident Analysis; ONR Assessment Report, Report Issue No: 1; ONRW-2126615823-2780; June 2024
- ONR (2024b): Generic Design Assessment of the Rolls-Royce SMR; Step 2 Assessment of Chemistry Report Issue No: 1; ONR Assessment Report ONRW-2126615823-2874; July-24
- ONR (2024c): Generic Design Assessment of the Rolls-Royce SMR; Step 2 Assessment of Civil Engineering; ONR Assessment Report; ONRW-2126615823-3203 Jun-24
- ONR (2024d): Generic Design Assessment of the Rolls-Royce SMR; Step 2 assessment of External Hazards; ONR Assessment Report; ONRW-2126615823-3584; June-24
- ONR (2024e): Generic Design Assessment of the Rolls-Royce SMR; 2 Assessment of Probabilistic Safety Analysis ONR Assessment Report; ONRW-2126615823-2692; June-24
- ONR (2024f): Generic Design Assessment of the Rolls-Royce SMR; Step 2 assessment of Security; ONR Assessment Report; ONRW-2126615823-3520; June-24
- OSGE (2023): Kleines Modulares Kernkraftwerk. Projektinformationsblatt. Bauträger: BWRX-300 Stawy Monowskie Sp. z o.o. mit Sitz in Warschau, al. Jana Pawła II 22, 00-133 Warschau. Auftragnehmer: Autorenteam ORLEN Synthos Green Energy Sp. z o.o., Teamleiter: Robert Truszkowski. Warschau, April 2023. Nicht öffentlich.
- PISTNER, C.; ENGLERT, M.; KÜPPERS, C.; VON HIRSCHHAUSEN, C.; WEALER, B.; STEIGERWALD, B.; DONDERER, R. (2021): Sicherheitstechnische Analyse und Risikobewertung einer Anwendung von SMR-Konzepten (Small Modular Reactors); Vorhaben 4720F50500; Öko-Institut e.V., Darmstadt; TU-Berlin; Fachgebiet Wirtschafts- und Infrastrukturpolitik (WIP); Physikerbüro Bremen; Bundesamt für die Sicherheit der nuklearen Entsorgung (BASE); Berlin, März 2021.
- THOMAS, S.; SEQUENS, E. (2023): Perspectives of small modular reactors in the Czech Republic: Stephen Thomas Professor Emeritus (University of Greenwich), Edvard Sequences, Energy consultant, Calla - Association for the protection of the environment; October 2023.
- WENRA (2013): Safety of New NPP Designs. A report by RHWG – Reactor Harmonization Working Group. March 2013. <https://www.wenra.eu/publications>.
- WNISR (2023): The World Nuclear Industry Status Report 2022; Mycle Schneider Consulting Project; Paris, October 2022; V3-02/2023.

WUA (2023): UVP-Verfahren zum geplanten Neubau von Small Modular Reactors (SMR) in Polen; Fachstellungnahme zum BWRX-300; Oda Becker, Kurt Decker, Manfred Mertins, Gabriele Mraz. Im Auftrag der Wiener Umweltschutzbehörde; November 2023.

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