

Advanced Modular Reactor Development in the Slovak Republic

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ABSTRACT

Newvys is a joint venture between newcleo and JAVYS, established in June 2025, with the objective of deploying Generation IV nuclear reactors at the Jaslovské Bohunice site in Slovakia, specifically within the area of the V1 NPP under decommissioning phase. The project is based on the Advanced Modular Lead-cooled Fast Reactor (LFR-AS-200), a liquid lead-cooled system operating in a fast neutron spectrum. This technology enables the efficient re-use and potential reprocessing of spent nuclear fuel (SNF), supporting a closed fuel cycle approach. By utilizing fast reactor technology, the system offers significant potential for reducing both the volume of high-level radioactive waste and its long-term radiotoxicity. Furthermore, the strategic use of SNF as primary energy resource contributes to enhanced fuel sustainability and may reduce Slovakia's reliance on imported fresh nuclear fuel. The deployment of LFR technology therefore represents a promising pathway toward improved resource utilization, waste minimization and increased energy security.

Keywords: *Advanced Modular Reactors, MOX, spent nuclear fuel*

1 INTRODUCTION

Slovakia, known for its extensive experience in the operation of nuclear power plants, decommissioning, and the management of radioactive waste, stands as a formidable candidate for the further expansion of its nuclear energy portfolio. The country has developed significant technical expertise over decades of operating VVER-type reactors, as well as through its ongoing decommissioning activities.

A key milestone in Slovak nuclear sector was shutdown of two units at the Jaslovské Bohunice V1 NPP, mandated by Government Resolution No. 801/1999. Therefore, Slovakia has accumulated extensive practical experience in nuclear decommissioning and radioactive waste management. The decommissioning of the V1 NPP began in 2011 and is scheduled for completion in 2029, represents one of the most significant projects. This process has not only strengthened national capabilities but has also created opportunities for the future utilization of existing nuclear infrastructure.

In the context, the redevelopment of the V1 brownfield site offers a strategic opportunity for the deployment of the new nuclear technologies. Given its location within an established nuclear site, the are benefits from existing infrastructure, regulatory understanding and public acceptance, making it particularly suitable for the construction of new nuclear facilities. Furthermore, the existing regulatory maturity at Bohunice ensures that the licensing process for new technologies, such as SMRs or AMRs, can benefit from decades of environmental monitoring data and a localized supply chain already proficient in nuclear quality standards (QA/QC).

In Europe, a growing demand for decarbonization targets and reliable energy security has led to renewed interest in nuclear power, often referred to as nuclear renaissance. This trend is closely linked to the development of the Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs), which offer advantages such as reduced capital costs, modular construction, and enhanced passive safety systems, while conventional large-scale reactors remain the backbone of baseload power [1]. Supported by initiatives from the European Commission and the International Atomic Energy Agency, these technologies are expected to play a key role in future energy systems.

In addition, the AMR technology is one of the most promising pathways for such deployment, which offer enhanced safety features, greater flexibility and improved economic scalability compared to the conventional large-scale reactors. Advanced concepts such as lead-cooled fast reactors (LFRs) present an opportunity to integrate innovative fuel cycle solutions and contribute to the long-term sustainability of nuclear energy in Slovakia. Within this framework, LFRs represent a leap toward the "closed fuel cycle." Unlike traditional thermal reactors, LFRs can operate in a fast neutron spectrum, which allows for transmutation of minor actinides, ensuring reduction of the radiotoxicity and volume of high-level radioactive waste, enhanced passive safety by utilizing the high boiling point and thermal inertia of lead to prevent core meltdown without active operator intervention, high-temperature output, providing process heat for industrial applications or hydrogen production, moving beyond simple electricity generation [2].

Based on these technical, economic, and strategic considerations, the lead-cooled fast reactor (LFR) technology was selected during the pre-feasibility study as the preferred option for potential deployment at the Jaslovské Bohunice site.

The ongoing feasibility studies in Slovakia act as a critical bridge between theoretical potential and industrial reality. It will thoroughly evaluate site, technology, closed fuel cycle, construction and project management and financing models. This ensures that the deployment of AMRs is not only technically feasible but also economically competitive in the evolving gas and renewable energy markets.

The AMR project will generate significant employment opportunities during both construction and operation, complementing existing job creation associated with decommissioning and maintenance activities at the site. The co-existence of multiple nuclear-related projects will support the establishment of a stable, skilled workforce and long-term local employment. This will in turn stimulate the development of secondary economic activities such as construction services, technical maintenance, catering, and transportation. The project's implementation will also strengthen regional educational and research capacities through cooperation with universities, technical institutes, and training centers. The AMR's innovative technology will attract young professionals and researchers, positioning Jaslovské Bohunice as a center of excellence for advanced nuclear systems in Central Europe.

2 PROJECT DESCRIPTION

2.1 Locality

The Jaslovské Bohunice site, located in the Trnava Region of western Slovakia, is the most important nuclear energy complex in the country. The area covers approximately 300 ha and lies about 25 km north of Trnava and 80 km from Bratislava. Ownership and operational responsibilities are divided mainly between Slovenské elektrárne, a.s. (SE) for operating units and JAVYS, a.s. for decommissioning, waste management, and related activities.

There are currently three nuclear power plants in Jaslovské Bohunice - A1, V1 and V2 NPPs. However, only V2 NPP units are currently in operation. The A1 power plant was shut down in 1977, the first unit of the V1 NPP was shut down at the end of 2006 and the second unit at the end of 2008. Both the A1 and V1 nuclear power plants are currently being decommissioned. Nuclear facilities for the processing and treatment of radioactive waste, storage of solid radioactive waste

and storage of spent nuclear fuel are also operated at the Jaslovské Bohunice location - in principle also necessary for the operation of the future AMR.

The Jaslovské Bohunice site represents not only the history of nuclear energy production in Slovakia, but also a strategically positioned asset for future nuclear development. As the decommissioning of the A1 and V1 nuclear power plants progresses under the responsibility of JAVYS, a.s., a unique opportunity emerges to repurpose this established nuclear locality for the deployment of advanced reactor technologies, particularly Generation IV (Gen IV) systems.

Reusing the Bohunice site for new nuclear capacity could position Slovakia at the forefront of Gen IV technology implementation in Europe. Unlike greenfield projects, the Bohunice area already possesses nearly all critical prerequisites necessary for successful nuclear development. These include a well-established and licensed infrastructure, a robust connection to the national transmission grid, and sufficient and proven cooling water resources. Such advantages significantly reduce both project risk and capital costs while shortening deployment timelines.

Equally important is the presence of a highly skilled and experienced workforce. Personnel currently engaged in decommissioning activities can be gradually and sequentially transitioned to the construction and future operation of new nuclear units. This continuity ensures job stability, preserves valuable institutional knowledge, and facilitates the transfer of expertise across project phases. Moreover, it enables the development of advanced competencies required for next-generation nuclear technologies.

The Bohunice region also benefits from high public acceptance of nuclear energy, stemming from its long operational history and familiarity with nuclear facilities. This social factor is often a critical determinant in the successful siting and deployment of new nuclear projects.

2.2 Lead-cooled Fast Reactor

Lead-cooled fast reactors (LFRs) feature a fast neutron spectrum, high-temperature operation, and cooling with either molten lead or a lead-bismuth eutectic alloy, both of which support low-pressure operation, have very good thermodynamic properties, and are relatively inert to interaction with air or water. They enable multiple applications including the production of electricity, hydrogen and heat. The system concepts represented in the International Forum for Generation IV. Reactors are based on the European ELFR reactor, the Russian BREST-OD-300 [3] and the US-designed SSTAR [4] system concept. Numerous other LFR concepts are also in various stages of development in various countries including China, Russia, USA, Sweden, South Korea, Japan and also Europe [1].

The LFR has excellent nuclear material management capabilities as it operates in the fast neutron spectrum, enables efficient conversion of fissile uranium and provides a closed fuel cycle. It can also be used for minor actinides transmutation from the spent fuel of light water reactors. An important feature of LFR is the inherent safety that results from the choice of molten lead as a relatively inert and low-pressure coolant. From the point of view of sustainability, lead is abundant and thus available even if a large number of reactors are deployed. More importantly, as with other fast reactors, fuel sustainability is greatly enhanced by the conversion capabilities of the LFR fuel cycle. Because they use a liquid coolant with a high boiling margin, which does not react with air or water, LFR concepts offer considerable potential in terms of safety, simplification of construction and economic performance.

As it is a coolant operating at atmospheric pressure, a loss of coolant accident (LOCA) can be virtually eliminated by adapting a pool type reactor and appropriate reactor vessel design [5]. This is not only a safety advantage but also offers additional potential for simplifying the equipment and improving economic performance, as the complex process of simultaneously controlling temperature, pressure and coolant level (as in water-cooled reactors) is not required.

2.3 LFR Advantages

The use of lead as a coolant has the following advantages compared to other reactor cooling methods:

Liquid lead acts as a reflector for neutrons. Neutrons escaping from the reactor core are to some extent directed back into the core, allowing for better neutron economy. This in turn allows greater distance between the fuel rods in the reactor, allowing for better heat removal with the lead coolant. Lead undergoes almost no activation by neutrons. However given the high fluxes and the large coolant volume, the lead activation by neutrons needs to be considered [5].

Although lead practically does not absorb neutrons, its high density makes it very effective at absorbing gamma radiation. Unlike liquid sodium, which is also used in fast reactors, lead is not reactive with water or air and solidifies when it leaks.

The very wide temperature range over which lead remains in the liquid phase (over 1126 °C) means that any thermal fluctuations are absorbed without any significant pressure variations. In practice, the operating temperature will be kept at around 500 °C – 550 °C, mainly due to other material properties and physico-chemical limitations. Lead has higher thermal conductivity (35 W.m⁻¹.K⁻¹) compared to water (0.58 W.m⁻¹.K⁻¹), which means that heat transfer from the fuel to the coolant is very efficient [5].

As with all fast reactor designs, the high temperature and high thermal inertia allow for passive cooling enabling higher safety margin in emergency situations. All fast reactor designs operate at significantly higher core temperatures than water-cooled (and moderated) reactors. This enables significantly higher thermodynamic efficiency in steam generators. A larger part of the nuclear fission energy can thus be converted into electricity. Efficiencies of more than 40% are realistically achievable, compared to around 30% in water-cooled reactors [5].

2.4 Technical Challenges

As with all types of advanced generation IV. reactors, there are challenges with lead-cooled reactors:

The high density and correspondingly high weight of lead as a coolant leads to the need for careful design consideration to avoid seismic impacts on the reactor system. This problem is solved by innovative configurations of primary systems with a short reactor vessel in connection with the introduction of seismic isolators. The high melting point of pure lead (327°C) requires that the primary cooling system be maintained at temperatures that prevent solidification of the lead coolant or at least maintain recirculation at the core level to allow it to cool [1][2][5]. The use of a large lead pool type configuration and appropriate primary system design provides an effective and definitive solution to this problem.

The use of lead-bismuth alloy as the coolant produces a significant amount of the polonium isotope Po-210 from the neutron activation of the bismuth isotope Bi-209. This radioactive element dissolves in coolant and is an alpha emitter with a half-life of 138.38 days [2]. This can seriously complicate maintenance and pose a serious alpha-contamination problem for the power plant. The alpha particle emitted by Po-210 has high energy (~5.4 MeV) and is therefore highly radiotoxic in case of internal body contamination (inhalation and ingestion risks) [2]. Pure lead produces an order of magnitude less polonium and therefore has an advantage over lead-bismuth alloy in this respect.

The most challenging problem with liquid lead as a coolant is possible damage caused by erosion and corrosion of fuel rods and internal parts of the reactor. Surface erosion is aggravated by the high density and associated kinetic energy of liquid metal circulating at increased speed in the reactor, especially if it is contaminated with abrasive solids (oxides detached from metal surfaces)

or metal debris. Corrosion is promoted by the dissolution of metals present in the alloys (e.g. Ni, Cr, released from stainless steel) in the liquid metal cooling medium and embrittlement of the fuel coating and structural materials of the reactor internals [1][2]. As part of the development of materials resistant to lead corrosion at higher temperatures, surface treatment (e.g. aluminization) of austenitic steels is proposed as an effective way of protecting them from corrosion [5]. Likewise, relatively low operating temperatures reduce the potential impact of this problem.

The high density of lead means that the fuel rods, control rods and mobile components of the reactor float in the metallic coolant, seriously complicating the engineering systems needed to handle them and prevent debris from floating.

All metal coolants (both lead and sodium) are opaque to visible light. The opacity of lead, combined with its high melting point, presents challenges related to inspection and monitoring of components in the reactor core, as well as fuel handling. This problem can be countered by choosing suitable and specific design elements, such as innovative core configurations with fuel cells extended above the lead level, which are applied in the latest European projects, which mitigate this problem.

3 CONCLUSION

In conclusion, the future development of the Jaslovské Bohunice site depends on a thorough and well-structured evaluation of all key factors. The ongoing feasibility study plays a crucial role in this process, as it will provide comprehensive information about the site conditions, selected technology, advanced fuel cycle options, and overall system performance. It will also assess financial models, investment needs, construction planning, and project management approaches. Together, these analyses will help determine whether the project is not only technically feasible, but also economically viable and practically achievable.

Altogether, the combination of technical infrastructure, human capital, and societal acceptance creates a uniquely favourable environment. Leveraging these strengths, the redevelopment of the Jaslovské Bohunice site could serve as a flagship project—demonstrating Slovakia's capability to implement innovative nuclear solutions while simultaneously driving regional economic growth, fostering innovation, and strengthening long-term energy security.

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