Activities in the Field of SMRs in Slovenia

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ABSTRACT

Development of commercial nuclear reactors was proceeding in direction of increasing their power. However, a large Nuclear Power Plant (NPP) is not a solution for every investor and every location. Another option was therefore developed with concepts of different Small Modular Reactors (SMRs) that gained a lot of attention. Their power is typically defined to be from low power of few MWe up to 300 MWe and is relatively small in comparison with the large 1,6 GWe units. The SMRs are modular because they are designed for modular manufacturing in factories and transportation as modular units to the location for installation. Strong motivation for installation of a SMR is the versatile design with possibility of load following operation. Different applications of SMRs are: production of electric energy for the grid or for big local users, energy (heat) production for industrial usage and district heating by cogeneration. More special applications are Hydrogen production or desalination of sea water.

There is growing interest for SMRs in Slovenia. The first step in possible deployment of SMRs in Slovenia is to assess options for SMRs installation, both for different locations and various SMR designs. Adequacy of some potential SMR locations depends on factors like availability of connection to power grid, provision of backup power sources and the heat sink, natural hazards such as flooding and seismic events, transport routes and generally on economics of investment. A tentative list of SMR designs covers a range from small PWRs to advanced reactor designs. A potential SMR installation needs preparation of an initiative for the project. This is followed by the process of national spatial plan preparation and environmental impact assessment.

In order to improve its readiness for demanding SMR licensing, the Slovenian Nuclear Safety Administration (SNSA) gathers international experience related to SMRs. The SNSA is active within the Regulatory Track of the IAEA initiative NHSI which aims to increase regulatory collaboration among Member States. Also, the SNSA participates in the Phoenix project in Slovenia which has a goal to conduct a pre-feasibility study for the potential deployment of SMRs in the country.

Keywords: *Small Modular Reactors, site assessment, project Phoenix, regulatory review of SMR*

1 INTRODUCTION

Slovenia has acquired significant experience with nuclear energy, primarily through the operation of the Krško NPP, which has been in operation for over 40 years. This plant has played a crucial role in providing stable electricity supply and reducing greenhouse gas emissions. The TRIGA Mark II research reactor, operated by the "Jožef Stefan" Institute since 1966, has supported nuclear research, education, and training. The country emphasizes the peaceful and sustainable use of nuclear energy, integrating it into national energy strategies alongside renewable sources. Recent geopolitical events and the energy crisis have underscored the importance of reliable energy supply, further supporting nuclear energy's role in Slovenia. The National Assembly of Slovenia has adopted a resolution [1] to promote the long-term peaceful use of nuclear energy, advocating for transparent and inclusive legislative processes. This resolution also calls for modernizing the nuclear program, involving stakeholders from education, research, regulatory bodies, investors, and the public. Furthermore, aiming for long-term energy independence and low-carbon transition, Slovenia supports the expansion of its nuclear program through projects like a new NPP (JEK2) and deployment of SMRs, if this will prove feasible, economically justified and environmentally acceptable.

2 CHARACTERISTICS OF SMALL MODULAR REACTORS

The SMRs are gaining considerable traction in the energy sector, emerging as a promising solution for addressing the world's growing energy needs while mitigating environmental impact. These reactors, which are typically defined to have electrical power up to 300 MWe, are significantly smaller than traditional nuclear power plants, offering a range of advantages:

1. One of the primary benefits of SMRs is their modularity. Unlike conventional reactors, which require substantial time and financial investment for construction, the SMRs are factory-built and can be assembled on-site in a relatively short period. This modular approach reduces the initial capital costs and allows for incremental capacity addition, making them an attractive option for both developed and developing nations.
2. Safety is another critical factor contributing to the appeal of SMRs. These reactors incorporate advanced safety features, such as passive cooling systems that can operate without human intervention or reliance on external power sources. The smaller size and advanced design of SMRs also limit the potential consequences of any nuclear incident, thereby enhancing public confidence in nuclear energy.
3. Environmental considerations are also driving the adoption of SMRs. As the world strives to reduce greenhouse gas emissions and transition to cleaner energy sources, SMRs offer a low-carbon alternative to fossil fuels. They produce minimal waste and can be integrated with renewable energy systems to provide a stable and reliable energy supply, essential for achieving sustainability goals.
4. Moreover, SMRs are versatile and can be deployed in a variety of settings. Their compact size makes them suitable for remote locations and small grids, where traditional nuclear power plants would be impractical. This flexibility extends their applicability beyond large urban centers to rural and isolated areas, contributing to energy security and economic development in undersupplied regions.

Governments and private companies worldwide are recognizing the potential of SMRs. Countries like the United States, Canada, and the United Kingdom, as well as countries in EU and Asia, are investing in SMR research and development, aiming to lead the next wave of nuclear innovation. Partnerships between public and private sectors are accelerating the commercialization of SMR technologies, with several projects already underway.

The SNSA actively follows advances concerning SMR regulation and in this way raises its readiness to provide capability for timely licensing of eventual SMR projects in Slovenia. It is active within the IAEA NHSI where it is collaborating in the Regulatory Track of the NHSI. The SNSA is also a part of the Phoenix partnership in Slovenia. The Phoenix project prepares a pre-feasibility study for possible deployment of SMRs in Slovenia.

3 NUCLEAR HARMONIZATION AND STANDARDIZATION INIATIVE

Various designs of SMRs are being considered for deployment by countries around the world. Having approximately standardized design is a condition for serial production. When deploying a SMR design to several Member States, it is advantageous if the design changes arising from differences among Member States' regulations are minimized. This may be facilitated by collaborative reviews in which regulators from different Member States work together and by leveraging (making best use of) reviews previously performed by other regulators. The ability to collaborate and leverage information has the potential to allow for easier international deployment of SMRs to both experienced and embarking nuclear nations – without compromising safety.

The Nuclear Harmonization and Standardization Initiative (NHSI) was introduced by the IAEA Director General in early 2022 in response to growing interest in advanced reactors, including SMR. Under the NHSI process, governments, regulators, designers, technology holders, operators and other international organizations come together in a collaborative effort, consistent with their national roles and responsibilities, to harmonize and standardize regulatory and industrial approaches in support of the global deployment of safe and secure SMRs. The NHSI is divided into two main tracks: the Regulatory Track and the Industry Track.

The approaches developed by the Regulatory Track track are meant to enhance national reviews, enabling regulators to take maximum advantage of international work and efforts by other regulators. This track focuses on enhancing regulatory collaboration among member states, reducing redundant efforts, increasing efficiency, and developing common regulatory positions while maintaining nuclear safety and national sovereignty. This framework could be used as the basis for future regulatory harmonization in the licensing of new technologies. The Regulatory Track is organized (see Table 1) into three Working Groups (WGs).

Table 1: Working Groups

Working Group	Description of activity
WG1	Establishes a framework for sharing information on SMR technology among regulators, addressing issues related to classified information.
WG2	Implements a multinational pre-licensing process for SMR designs to identify potential issues early, minimizing the need for design modifications during national licensing processes.
WG3	Leverages reviews from other regulators and facilitates collaboration during ongoing national regulatory reviews of SMR designs, utilizing experiences from previous international regulatory collaborations.

The Industry Track aims to standardize industrial practices for SMR development, manufacturing, construction and operations. It is organized (see Table 2) into four Topical Groups (TGs).

Table 2: Topical Groups

Topical Group	Description of activity
TG1	Harmonizes high-level user requirements for SMR designs and documents these requirements for designers.
TG2	Develops a platform for comparing national standards and codes related to SMR technology, including quality management and equipment qualification.
TG3	Establishes a global cooperation network, "NEXSHARE," for experimental testing and validation of design and safety analysis computer codes relevant to SMR technology.
TG4	Supports the development of infrastructure for recipient countries to significantly reduce plant development timelines.

Working Groups and Topical Groups are finishing drafts concerning results of their work. Slovenia is participating in the WG3 of the Regulatory Track. The WG3 was focused on planning organization of various modalities of collaboration among regulators. To this end, it is important to understand possible divergences among regulators. Divergences can have multiple sources. They can include but are not limited to:

- Divergences in regulatory frameworks that lead to country-specific design changes or country specific parts of safety demonstration. Also, the safety goals may differ, and there may be differences in assessment criteria,
- Divergences in licensing processes, like difference in the depth of the review at various licensing stages,
- Divergences in capacity and capability of included regulators because there can be considerable differences in experience, etc,
- Divergences in the time schedules of included regulators.

Also, a quality assessment of the information received from other regulators has to be assessed. The organization of collaboration among regulatory bodies is presented and explained in detail in [2].

4 PROJECT PHOENIX

Project Phoenix is focused on transition from coal-fired power plants to SMRs, leveraging nuclear energy to meet global energy demands while minimizing environmental impact [3]. In response to an invitation from the US Department of State, the Slovenian Ministry of the Environment, Climate, and Energy (MOPE) successfully applied to join the Project Phoenix [4]. The partnership is lead by MOPE and it includes GEN energija, the Šoštanj Thermal Power Plant, Holding Slovenske elektrarne, ELES, TALUM, "Jožef Stefan" Institute, and the SNSA as the nuclear regulator. The technical advisory services are provided by Sargent & Lundy, a leading global energy services company. The objective of the Phoenix project in Slovenia is to conduct a pre-feasibility study for the potential deployment of SMRs in the country. Six potential locations for SMR deployment have been identified across Slovenia. The study aims to evaluate the suitability of these sites and assess the feasibility of installing an appropriate SMR on these sites. The study will outline the main advantages and disadvantages of each site and identify the key infrastructure developments necessary for SMR deployment. The findings of the study will be purely informative and will not result in any final decisions on SMR installation.

4.1 Contents of the pre-feasibility study

The pre-feasibility study will address several key areas:

1. Applicable Laws and Standards: A comprehensive list of IAEA standards and relevant Slovenian laws, codes, and standards will be included.

2. Electrical System Analysis: This section will describe the current state of Slovenia's electricity grid system and future demand forecasts.

3. Site Evaluation: Information about potential sites, including existing layout, transportation routes, infrastructure status, construction feasibility, cooling water sources, geotechnical and seismic conditions, electrical interconnections, and environmental considerations, will be collected and analyzed.

4. SMR Design Criteria: Publicly available information on mature SMR technologies, including two micro-reactor technologies, will be gathered and compared in the report.

5. Licensing Processes: An overview of international and Slovenian licensing processes for SMRs, including timelines and regulatory requirements, will be presented.

6. Economic Analysis: This will include estimates of capital costs, operating expenses, and levelized cost of electricity for SMRs, as well as funding and financing options.

Regular meetings between Slovenian and US partners are ongoing, with the pre-feasibility study expected to be completed by mid-2025.

5 CONCLUSION

Slovenia is a country with a well-developed and operational nuclear program. Nuclear energy is a strategic energy source that has the potential to produce large amounts of electricity while achieving climate change mitigation goals. Good experience with operation of the Krško NPP and need for more energy production in the future is the reason why Slovenia considers possibility of new nuclear builds. The SNSA as the nuclear regulator is involved in the licensing processes from the start according to the Ionising Radiation Protection and Nuclear Safety Act. The SNSA approach is based on NOAK principle (Non-first Of A Kind) and favours already proven designs with constructional and operational experience. The SMRs are currently not ready yet, but a few countries are already starting first SMR projects now. The SNSA is actively monitoring developments in SMR regulatives to enhance its preparedness for possibility of licensing the SMR projects in Slovenia. It is engaged within the IAEA NHSI, contributing to the Regulatory Track of the initiative. Additionally, the SNSA is involved in the Phoenix partnership in Slovenia, which aims to conduct a pre-feasibility study for the potential deployment of SMRs in the country.

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