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Small Modular Reactors in the Nuclear Energy Sector of the Republic of Bulgaria – Advantages in Implementation and Challenges in their Licensing

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***Abstract*— Over the past four to five years, intensive development has been observed in Central and Eastern Europe of the American nuclear company NuScale - a world leader in the design of small modular reactors. Initiatives to expand the use of nuclear energy and the advancement of technologies in this production are supported and led by the United States of America government. In the article, the author analyzes the prospects of small modular reactors as an eco-innovative technology in nuclear energy, which allows the construction of reliable, clean, safe and economically advantageous energy sources for future generations. Their place in the national energy policy of the Republic of Bulgaria is examined and to what extent the country is interested in their implementation. When compared, the progress in countries such as Romania and Poland is tangible and can be useful to the country. At this stage, the implementation of NuScale's small modular reactors technology in our country is still being studied and evaluated within the framework of the Memorandum of Understanding signed in 2020. It is known that nuclear projects are associated with radiation and environmental risks and the process of their licensing by the national nuclear regulatory authority - the Nuclear Energy Agency is complex and lengthy. The main points of licensing according to the Bulgarian nuclear legislation are presented and the changes that need to be made to the current licensing regimes in order to facilitate the introduction of small modular reactors into operation. The possibilities of international cooperation are also examined to help the process of their licensing.**

Keywords*— licensing, nuclear legislation, nuclear regulatory authorities, small modular reactors

I. Introduction

A small modular reactor (SMR) is a class of small nuclear fission reactors designed to be built in a factory, shipped to operational sites for installation, and then used to power buildings or other commercial operations. The term SMR refers to the size, capacity, and modular design. The reactor type and nuclear processes can vary. Of the many SMR designs, the pressurized water reactor (PWR) is the most common. However, recently proposed SMR designs include: Generation IV, thermal neutron reactors, fast neutron reactors, molten salt, and gas-cooled reactor designs.

After the Fukushima accident [1], the last ten years have seen increased interest in this class of nuclear reactors as an eco-innovative technology in energy production.

Modular reactors are expected to reduce on-site construction and increase containment efficiency. These reactors are also expected to improve safety by employing passive safety features that do not require human intervention, although this is not specific to SMRs, but rather a feature of most modern reactor designs. SMRs are also claimed to have lower plant personnel costs because their operation is relatively simple and they are claimed to have the ability to circumvent the financial and safety barriers that hinder the construction of conventional reactors.

Maximum safety [2] is one of the main characteristics of small modular reactors. They are fail-safe and self-sufficient with the passive mode of operation of the safety systems. They are protected from external influences by a

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strong hermetic core enclosure. They are designed to withstand extreme external influences. Defense in depth is provided by multiple levels of protection to reduce the impact of accidents. They are designed to shut down the reactor and maintain it in a safe state without any operator action, without the need for backup power or the operation of electric pumps.

They are easy to build. Many reactors with such technology are already in commercial operation or are in the process of being built. The modular design is simplified modular. The operation of those already in operation is reliable with shortened planned shutdowns for repairs and refueling with nuclear fuel. The target operational life of the reactors is over 80 years.

II. MATERIALS AND METHODS

The article analyzes international [3], [4] and national legislation, including strategic and guiding documents of state bodies.

In Bulgaria, scientific publications on the topic are scarce, and changes in state policy and regulations are frequent and inconsistent. A combination of different scientific research methods was used to obtain a more complete and objective picture of the problem under study, among which the following stand out: historical-chronological, comparative and systematic analysis.

III. RESULTS AND DISCUSSION

A. Opportunities for building small nuclear fission reactors in the Republic of Bulgaria

In the context of achieving the European Union's goals for climate neutrality by 2050 and diversification of energy resources, on October 14, 2020, the Council of Ministers of the Republic of Bulgaria decided to undertake preparatory actions and study the possibilities for building a new nuclear power plant on the site at Kozloduy NPP approved by order of the Chairman of the Nuclear Regulatory Agency. According to point two of this decision, the relevant Minister is assigned to take the necessary actions and authorize Bulgarian Energy Holding EAD to enter into negotiations with companies from the United States of America developing new nuclear technologies for peaceful purposes, including small modular reactors, in order to study the possibilities for building a new nuclear power plant on Site No. 2 at Kozloduy NPP.

An information release on the website of "Kozloduy NPP - New Builds" PLC regarding the meeting draws attention to the fact that the small modular reactors in question would have advantages in liberalized markets such as the European one, due to their ability to follow the load of the grid and support its sustainability, especially after the widespread penetration of unpredictable alternative energy sources.

The above expresses interest at the government level in the implementation of this new eco-innovative technology for our energy sector. It is known that in implementation of the decision taken, actions have been taken in an operational plan and at the end of 2020 a Memorandum of Understanding was signed to study the possibility of implementing nuclear technology based on small modular reactors in the Republic of Bulgaria between "Kozloduy NPP - New Builds" PLC and NuScale Power, LLC. This Memorandum strengthens bilateral strategic relations, while at the same time deepening cooperation in the field of energy security. Through the document, both parties are committed to the responsible use of nuclear energy and technologies with an emphasis on human capital and labor development, education, training, in order to maintain the highest standards and practices in the field of nuclear safety and security.

In the context of the Memorandum of Understanding, on December 4, 2020, the US Ambassador and her team visited Kozloduy NPP. The purpose of the visit was to familiarize themselves with the activities of Kozloduy NPP and its project company in order to explore the possibility of a partnership in developing a solution for the future energy needs of the Republic of Bulgaria. The Ambassador and the management of Kozloduy NPP discussed how Kozloduy NPP is leveraging its infrastructure and human capital advantages to make it the center of Bulgarian nuclear energy for generations to come.

In a February 17, 2021, statement, NuScale said that under the agreement it would support Kozloduy in conducting studies and analyses, including the development of a feasibility study schedule, project-specific cost estimates, and design, planning, and licensing activities. NuScale was created based on research funded by the United States Department of Energy (DOE) and conducted by a team of nuclear scientists at Oregon State University and Idaho National Laboratory. In the early 2000s, DOE funded the research from 2000 to 2003.

NuScale was founded in 2007, and certification with the US Nuclear Regulatory Commission (NRC) began in February 2008.

In 2020, the U.S. Nuclear Regulatory Commission (NRC) approved the design of a new type of reactor known as a small modular reactor (SMR). The design, by Portland, Oregon-based NuScale Power, aims to speed up construction, reduce costs, and improve safety compared to traditional nuclear reactors, which are typically many times larger. SMR proponents have long touted them as a way to help revive the nation’s nuclear industry and expand the reach of low-carbon electricity. But some experts have raised concerns about the potential costs and remaining safety issues the industry will need to address before such reactors are actually built.

B. Prospects for the construction of small nuclear fission reactors in the regions of Central and Eastern Europe

In March 2019, NuScale and Nuclearelectrica signed a Memorandum of Understanding covering the exchange of

business and technical information regarding NuScale's nuclear technology, with the aim of evaluating the development, licensing and construction of a NuScale SMR in Romania. Nuclearelectrica is the operator of Romania's only nuclear power plant, Cerna Voda, which currently provides approximately one-fifth of the country's electricity.

In November 2021, following a meeting between US Special Presidential Envoy for Climate John Kerry and Romanian President Klaus Iohannis at the Glasgow Climate Conference, NuScale announced its intention to build its first small modular reactor in Romania by 2028 with the Romanian national nuclear company Nuclearelectrica. The six-module nuclear power plant will have a gross installed capacity of 462 MWe and will make Romania the second country in the world after the United States to deploy NuScale's SMR technology.

Nuclearelectrica's participation in the project is carried out through the project company RoPower Nuclear, of which it owns 50%.

In January 2021, Nuclearelectrica received a non-repayable grant of 1.28 million USD from the United States Trade and Development Agency for use in identifying potential sites in Romania to host SMRs. The grant will be used to finance the costs of services required in connection with the provision of technical assistance for the preliminary assessment of new potential SMR-compatible nuclear sites in Romania, excluding the existing Cerna Voda site. The funds will also be used in the development of a roadmap for SMR licensing.

In January 2023, RoPower Nuclear received a $14 million grant from the U.S. Trade and Development Agency to build an SMR plant in Romania. RoPower and NuScale are currently conducting Phase 1 of the FEED Study, which consists of a series of engineering and design activities and surveys, a technical analysis of the preferred site, which is the former Doicesti power plant, a schedule and cost estimate.

The Small Modular Reactor (SMR) power plant project to be developed in Romania has received key approval from the National Nuclear Control Commission (CNCAN) in 2023, according to a statement from Romanian nuclear company Nuclearelectrica.

"The approval of the Licensing Base Document (LBD) represents a key milestone in the small modular reactor project, which will facilitate the implementation of the licensing process for all stages of the NuScale power plant in Romania," Nuclearelectrica said in a filing to the Bucharest Stock Exchange.

The LBD establishes the licensing requirements for the six-module power plant project, the applicable national and international regulatory documents, codes and standards, as well as the design characteristics that ensure the fulfillment of nuclear safety requirements and criteria.

In addition to Romania, NuScale and Polish mining conglomerate KGHM also announced a contract to build an SMR in Poland in February 2022.

The final commercial agreement with mining and processing company KGHM Polska Miedź SA is for the deployment of a VOYGR power plant with a capacity of up to 924 MWe as early as 2029 to support KGHM's copper and silver production in Poland.

The agreement, signed on February 14, 2022 in the presence of US and Polish government officials, will begin the preparation of the entire investment project, including site selection.

The deal adds another major perspective to NuScale's development of small modular reactors (SMRs) in Central and Eastern Europe, a region that has quickly become a hotspot for advanced nuclear projects due to a combination of factors. But it is also particularly noteworthy because it represents a deal with a large industrial energy user, a key decentralized energy market that could benefit from smaller baseload, flexible power plants. KGHM is the second largest industrial energy user in Poland.

This confirms the attractiveness of SMRs for large industry.

The commercial agreement follows a memorandum of understanding that the two companies and Poland-based business engineering consultancy Piela Business Engineering signed in September 2021 to collaborate on the development, licensing and construction of NuScale VOYGR in Poland. Under this memorandum of understanding, the companies worked to study the implementation of NuScale's SMR technology as a coal diversion/repurposing solution for existing coal-fired power plants as well as for energy to support industrial operations in Poland. The study included an analysis of technical, economic, legal, regulatory, financial and organizational factors.

NuScale's VOYGR SMR technology, first introduced in 2000 as a concept at Oregon State University, has evolved into a modular light water reactor (LWR) design that can deliver energy for power generation, district heating, desalination, hydrogen production, and other process heat applications. With flexibility as a key attribute, NuScale currently offers VOYGR power plants in scalable sizes, including as twelve 77-MWe modules and as four- and six-module facilities.

For KGHM, which owns Europe's largest copper ore deposit (located in southwestern Poland), the prospect offers a new path to decarbonizing its mining operations, as well as potential cost savings. SMR technology is expected to increase the company's cost efficiency and transform the Polish energy sector. SMRs can be used not only to generate power – they can be used to generate heat and also to produce hydrogen for various operations.

Poland has the largest coal reserves in Europe, generating 70% of its energy from coal in 2020. In November 2021, it committed to phasing out its coal-fired

power plants. It aims to do so by 2040. The country is steadily increasing its shares of gas and renewables to meet the European Union's strict climate targets and reach climate neutrality by 2050.

However, Poland has no nuclear power plants. Although this will require detailed planning, including the creation of a related regulatory framework, Poland's revised energy policy until 2040, adopted in February 2021, envisages commissioning its first nuclear power reactor in 2033, followed by subsequent units. The plan envisages an investment of PLN 140 billion (about $40 billion) in new facilities. The deployment of GE-Hitachi Nuclear Energy's BWRX-300 SMRs is also being explored.

NuScale is preparing for a major expansion in Poland. It is considering a 2027 delivery schedule for its first commercial offering, VOYGR, with the timing dependent on Poland's regulatory requirements. NuScale is preparing to meet the regulatory requirements of global customers like Poland. NuScale Power says its modular light water reactor can deliver "reliable and abundant" carbon-free nuclear power for power generation, district heating, desalination and other process heat applications. NuScale's SMR design includes a fully fabricated NuScale Power Module capable of generating 77 MWe using a "safer, smaller, scalable version" of pressurized water reactor technology.

C. Rules for licensing activities related to the use of nuclear energy in the Republic of Bulgaria

State regulation of the safe use of nuclear energy and ionizing radiation and of the safe management of radioactive waste and spent fuel in the Republic of Bulgaria is carried out by the Chairman of the Nuclear Regulatory Agency, which is an independent specialized body of the executive branch and has competence defined by the Act on the Safe Use of Nuclear Energy.

A significant part of the nuclear legislation and specifically in the Act on the Safe Use of Nuclear Energy is devoted to the regulation of activities, respectively, obtaining a permit or license to carry them out. In Chapter Three of the act entitled "Regulation of Activities", the legislator has provided for three sections, which set out the general conditions, fees and nuclear facilities for which the Chairman of the NRA issues permits or licenses, and in general terms present the requirements and the procedure for their issuance.

The issues relating to the procedure for issuing licenses and permits, the issuance procedure, the scope and content of licenses and permits, the conditions for their amendment, renewal, termination, revocation and control are regulated in detail in the Regulation on the Procedure for Issuing Licenses and Permits for the Safe Use of Nuclear Energy. The structure of the regulation is tailored to the specifics of the types of nuclear facilities and activities.

Nuclear power plants, as well as the approved sites for their construction, are objects of national importance [5]. According to the Act on the Safe Use of Nuclear Energy, a nuclear power plant is built by a decision of the Council of Ministers. The proposal for the construction of a nuclear power plant is submitted by the relevant minister. He organizes a discussion of the proposal for the construction of a nuclear power plant, in which state bodies and local government bodies, representatives of public organizations and interested individuals and legal entities participate. The use of a power unit of a nuclear power plant in accordance with its main purpose begins after the entry into force of an operating license issued in accordance with the law and in the presence of an effective license for the production of electricity and/or heat, issued in accordance with the Energy Act.

In accordance with the requirements of the Environmental Protection Act, actions should be taken to carry out a procedure for assessing the environmental impact of an investment proposal for the construction of a new nuclear power plant and obtaining an environmental license [6], [7].

A procedure for notifying the local population through the mass media is launched and, after receiving instructions from the Ministry of Environment and Water, a task for the scope and content of the Environmental Impact Assessment is developed. A report on the Assessment is prepared and submitted to the Ministry of Environment and Water, as the competent authority for assessing the quality of the report and the degree of impact of the investment proposal on the protected areas.

The activities related to the ongoing Environmental Impact Assessment procedure include responses to questions received in connection with the Assessment report from the competent authorities and the interested public. The Assessment procedure ends with a Decision of the Minister of Environment and Water, by which the competent authority approves the implementation of the investment proposal for the construction of a new nuclear power plant.

According to Section III of the Law on the Safe Use of Nuclear Energy, the licensing procedure for a new nuclear power plant includes the issuance by the Chairman of the Nuclear Regulatory Agency of individual administrative acts, through which compliance with the safety requirements of the nuclear facility is controlled.

After the Council of Ministers has taken a decision in principle to build a new nuclear power plant, the relevant Minister is given a mandate to submit a report under Art. 45, para. 2 of the Safe Use of Nuclear Energy Act for a decision on the merits. When implementing the investment proposal, the two-stage approach indicated by the International Atomic Energy Agency is followed, in which first a site assessment is carried out to identify possible locations for future NPPs (carried out by a ministry or national authority) and secondly - the licensee carries out the assessment of the proposed site.

Analyses and development of documents - annexes to the Minister's report follow. Preparations begin for the implementation of the first stage of the licensing regime for nuclear facilities - the so-called pre-project stage, in which, if the requirements of the Regulation on the procedure for issuing licenses and permits for the safe use of nuclear energy are met, the Chairman of the Nuclear Regulatory Agency issues a permit for site selection and subsequently an order for approval of the selected site. A process for licensing the new nuclear capacity is initiated. An application is submitted to the Nuclear Regulatory Agency for the issuance of a permit for determining the location of a new nuclear facility (site selection) within the meaning of Art. 15, para. 4, item 1 of the Act on the Safe Use of Nuclear Energy.

After issuing a permit for determining the location of a new nuclear facility (site selection) by the Nuclear Regulatory Agency, the activities related to "Investigation and determination of the location of the preferred site for the construction of a new nuclear power plant" have been finalized, an independent verification of the submitted project documents is carried out and a Preliminary Report for the analysis of the safety of the nuclear facility is developed. In connection with the preparation for construction, a Technical Terms of Reference for the design of a detailed development plan with a supporting plan included therein is developed, in accordance with Art. 125 of the Spatial Planning Act. The Technical Terms of Reference are coordinated with the Ministry of Environment and Water.

Then, documents are prepared and submitted to the Nuclear Regulatory Agency for issuing an Order for Approval of the Preferred Site by the Chairman of the Agency within the meaning of Article 33, Paragraph 4 of the Safe Use of Nuclear Energy Act.

The second stage of the permitting regime concerns the so-called Engineering. Design is carried out and, accordingly, preparation and submission to the Nuclear Regulatory Agency of the necessary documents for issuing a design permit, within the meaning of Art. 15, para. 4, item 2 of the Act on the Safe Use of Nuclear Energy. This is followed by a procedure for selecting a designer, preparation of a technical design and issuance of an order for approval of the technical design by the Chairman of the Nuclear Regulatory Agency. With the order for approval of the technical design, the Engineering stage is considered completed.

The third stage of the permitting regime under the Safe Use of Nuclear Energy Act – concerns Construction and commissioning and includes a Permit for the construction of a nuclear facility, within the meaning of Art. 15, para. 4, item 3 of the Act and a Permit for the commissioning of a nuclear facility, within the meaning of Art. 15, para. 4, item 4 of the Act. The same are issued before the license for the operation of the nuclear facility. For the issuance of both permits, the applicant must be a legal entity registered in the Republic of Bulgaria (Art. 33, para. 2) and must have financial, technical, material, human resources and an organizational structure to fulfill its obligations to ensure the requirements, norms and rules for nuclear safety, radiation protection and physical protection.

The application for a license to operate a nuclear facility shall be submitted after the conditions of the permit for commissioning the nuclear facility have been met. The compliance with the conditions of the permit for commissioning shall be established by a commission of inspectors of the Nuclear Regulatory Agency, appointed by order of the Chairman of the Agency, which shall verify the documents submitted by the applicant and carry out an on-site inspection.

D. Challenges in licensing small modular reactors and the role of regulatory authorities and international cooperation in this process

Small Modular Reactors business models require them to be manufactured in large numbers with the same design licensed in several countries without significant changes. As a result, regulators are encouraged by suppliers, licensees and some governments to increase the harmonisation of their regulatory requirements, streamline their licensing processes and promote mutual recognition of safety reviews carried out by their partners to facilitate the national licensing process for these designs [8].

The International Atomic Energy Agency plays a key role in international cooperation related to the use of nuclear energy [9]. It is an organization within the framework of the United Nations, without being a specialized agency within the meaning of Art. 57 of the Charter of the United Nations. Its statute was approved on 26 October 1956 in the form of a treaty that entered into force on 29 June 1957. It is a classic intergovernmental organization with a global focus on scientific and technical cooperation in the field of peaceful uses of nuclear technologies [10], [11].

During the period 2021-2022, the Chairman of the Nuclear Regulatory Agency of the Republic of Bulgaria and representatives of the agency took an active part, respectively, in the 65th and 66th regular sessions of the General Conference of the International Atomic Energy Agency.

During the sessions, the Chairman of the Nuclear Regulatory Agency, as the head of the Bulgarian delegation, exchanged information with the Deputy Director General of the International Atomic Energy Agency on the review of safety and security standards in relation to the proposed new technologies in the nuclear field, including small modular reactors. The events accompanying the General Conference included a forum for discussing the new platform on small modular reactors and a workshop dedicated to the challenges in their licensing, in which representatives of the Nuclear Regulatory Agency participated. Outside the plenary sessions, the Chairman of the Agency held bilateral meetings with high-ranking representatives of the International Atomic Energy Agency, the European Commission and similar regulatory bodies from other

countries. At the meeting with the Executive Director for Operations of the US Nuclear Regulatory Commission, among other issues, the American experience in the licensing process for small modular reactors was discussed.

The Chairman of the Nuclear Regulatory Agency also participated in the meetings of the Bulgarian delegation with the US Deputy Assistant Secretary of State for Non-Proliferation of Nuclear Weapons, with representatives of the US industry, led by the US Deputy Assistant Secretary of State for Commerce, with the Deputy Minister of Industry and Trade of the Czech Republic and with representatives of the French company EDF. At the meetings, the Bulgarian Deputy Minister of Energy presented the current status of the nuclear program of the Republic of Bulgaria, as well as the existing plans for its development at this stage. Issues related to the technologies for small modular reactors being developed by the US and French sides were also discussed, and with the US representatives, issues related to the diversification of nuclear fuel supplies.

The Spring Workshop of the Western European Nuclear Regulators Association (WENRA) was held in Helsinki, Finland on 5 and 6 April 2023. The Bulgarian Nuclear Regulatory Agency was represented by its Chairman.

During the meeting, WENRA issued a statement on the development of small modular reactors and innovative reactors, stating that more and more countries are supporting the development of small and innovative reactors to meet their decarbonized energy needs in the context of climate change, with a strong expectation from stakeholders that national licensing processes will be completed quickly.

Such processes allow each national regulator to gain an understanding of the acceptability of the plant safety case and, where applicable, the validity of the assessment already carried out by its counterparts. In particular, the assessment of site-specific aspects of the projects will remain the responsibility of the national regulatory authority.

WENRA members confirm their willingness to promote mutual cooperation in the safety assessment of reactor projects in this regard. To this end, they encourage their respective governments to provide the regulatory authorities with a mandate, if necessary, and sufficient resources.

On June 27, 2023, the Chairman of the Bulgarian Nuclear Regulatory Agency participated in the second plenary meeting of the Nuclear Harmonization and Standardization Initiative. The meeting is taking place in Vienna, Austria.

The Initiative was established by the Director General of the International Atomic Energy Agency, Raffaello Grossi, to support the harmonization and standardization of regulatory and industrial approaches to facilitate the safe and successful deployment of small modular reactors worldwide. This process brings together nuclear regulatory authorities and companies from the nuclear sector from around the world, as well as international organizations and industry associations. The second plenary meeting took stock of the work already done on the Initiative, and reported on the progress, as well as the difficulties in its implementation, discussed the outstanding issues and planned future actions, where necessary. The Republic of Bulgaria is an active participant in the Initiative, as a representative of the Nuclear Regulatory Agency is included in the working group for the "Pre-licensing Regulatory Review of Small Modular Reactors".

IV. CONCLUSIONS

Small modular reactors, as an eco-innovative technology in nuclear energy, allow for the construction of reliable, clean, safe and economically advantageous energy sources in the national energy policy of the Republic of Bulgaria.

With the Memorandum of Understanding signed at the end of 2020 to study the possibility of implementing nuclear technology based on small modular reactors in the Republic of Bulgaria between "Kozloduy NPP - New Builds" PLC and NuScale Power, LLC, both parties are committed to the responsible use of nuclear energy and technologies with an emphasis on human capital and labor development, education, training, in order to maintain the highest standards and practices in the field of nuclear safety and security.

The Memorandum of Understanding is a proven commercial practice through which the parties lay the foundations for the implementation of projects of mutual interest, while at the same time not requiring the assumption of a commitment to a future investment decision or the incurrence of related financial costs and to what extent the party is interested in their implementation. The comparison made for the implementation of similar projects in countries in Central and Eastern Europe and specifically in Romania and Poland shows that their experience can be studied and used in Bulgaria.

It should be noted that our country has well-established nuclear legislation and a well-structured national regulatory authority, which is a necessary starting point for licensing new nuclear capacities, but combined with the practical problems of a lack of information internationally regarding the appropriate method for licensing small modular reactors, this creates inconsistencies and deficiencies in the legal framework for their licensing.

Questions arise as to whether the current licensing regimes are appropriate? What changes should be made? Could increased international cooperation help speed up the licensing process and does this threaten national sovereignty?

These objective factors determine the need for legislative intervention to harmonize the legal framework for licensing small nuclear reactors.

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