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Small Modular Reactors and Perspectives for their Application in Brazil

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1. Introduction

Nuclear energy is a source of high energy density, very efficient, reliable, and has extraordinary advantages compared to other resources for energy generation, mainly because it is recognized as being clean energy due to its low levels of carbon gas emissions. Given the growing demand for electricity and the latent concern about the environmental impacts generated by large energy generating plants, new possibilities for the development and construction of nuclear facilities are emerging all over the world.

Within this scope, Small Modular Reactors (SMRs), previously used only as a prototype for larger reactors, appear as an option for compact, safe, flexible, and easy-to-build nuclear reactors, thus enabling not only an option to ensure national energy security, as well as used in other functions such as desalination of seawater. This article aims to make a literature review about SMRs, such as their definition, the concepts of the main types of reactors understudy and construction, advantages, disadvantages of their development, and possibilities and challenges of their implementation in Brazil.

2. Small Modular Reactors

SMRs are defined as new generation reactors designed to generate electrical energy up to 300 MWe. An important feature is their concept of modularity, whose components and systems can be manufactured in separate locations and then transported as modules to the installation locations, with a significant time reduction [1]. Each module is independent and can be turned off without affecting other ones. The independence also enables the formation of multiple modules and, consequently, increasing the power of the plant according to the required demand. The modules can share the secondary system, including the steam turbine, as well as essential equipment, such as diesel generators [2]. Moreover, due to the small size, reaching 1/3 to 1/4 the size of a traditional nuclear power plant, the transport of modules can be carried out by truck, rail, even small boats, and their installation may be nearby to users, such as in residential areas, hospitals, military bases, large industrial complexes, and remote locations [3].

SMRs offer important design simplifications through the standardization of installation construction and of their components and modules, which allows them to be manufactured in industrial conventional facilities, considerably increasing the number of suppliers and competitiveness, and reducing the inherent economic risks of time. Furthermore, the lower initial capital investment and financial risk allow emergent countries, with reduced investment, to initiate or amplify their nuclear program. Another important factor is that they are designed with improved safety systems, which maximize the use of passive safety features and incorporate the concept of defence in depth for accident prevention. As a result, most small reactor designs can easily remove decay heat using passive systems such as natural convection, even allowing to eliminate the need for on-site emergency electrical supply, supplied by batteries or diesel generators [4]. Additionally, the lower operating power leads to lower fuel consumption and, consequently, less generation of radioactive waste. The operating power levels also lead to low demand for cooling water, which is essential for remote regions and specific applications. Finally, the units can be installed in underground or underwater levels, providing greater protection against natural or man-made hazards [5].

The real attractiveness of SMR is their flexibility to enter traditionally non-nuclear energy markets, for example: water desalination and purification; advanced oil recovery process from oil shale and tar sands; advanced energy conversion processes such as coal-to-liquids and liquid biofuel production; general process heat for chemical or manufacturing processes and co-generation, and district heating in places with a high demand.

However, according to [6], SMRs still have some challenges to be overcome before their implementation, such as:

- Nuclear fuel spent from small reactors may be located in remote areas, which could create problems of transport and stocking;
- The development of new methodologies that prove the safety of modular units is necessary, since this is a reactor with different specifies;
- A concrete analysis on the cost-benefit relation of SMRs shall be performed; and
- Obtaining project certification and licensing, which currently faces several regulatory barriers.

The Generation III+ technology of SMRs (SMR GEN III+) are reactors based on the same physical principles as the current large reactors under construction, with the basic premise of scale reduction. Nevertheless, advances in the development of PWR-type SMRs led to two types of project design: (1) Loop Type, which consists of cooling circuits connected to the reactor pressure vessel and inside the reactor containment, as the current PWRs, and (2) Integral Type, also called iPWR, where there is the integration of the entire steam generation system inside the reactor pressure vessel and, therefore, there is no need for a pump in the primary circuit, since it occurs by the phenomenon of natural circulation, which decreases the number of equipment needed and increases passive safety features [3].

3. Perspectives for Application of Small Modular Reactors in Brazil

With the depletion of the national hydroelectric potential and high cost of maintaining conventional thermoelectric plants in operation, national studies are also being carried out with the aim of increasing the contribution of nuclear power to Brazil's electrical power generation mix, in addition to the already planned conclusion of Angra 3. Besides the resumption of Angra 3 construction, the national focus is on completing the works of the LABGENE project. A SMR of loop PWR-type, the LABGENE will have the capacity to produce an estimated power of 48 MWt, approximately 11 MWe. It is important to emphasize that, due to its dual usage characteristics (propulsion and energy generation), LABGENE will serve as a base and laboratory for others power reactor projects [8]. This will bring an opportunity hitherto unique in Brazil and will assist in the preparation of strategic research for development of new projects.

Based on the knowledge obtained with the LABGENE project, some possible applications can be projected, as:

- Energy generation: due to their operational flexibility, SMRs can be employed to supply electricity from remote regions to large urban areas. The modular concept of SMRs would be beneficial to adapt, without great efforts, to the energy demand of each Brazilian region. Another interesting point is that, with the worldwide trend of increasing insertion of intermittent renewable sources connected to the electricity grid, SMRs can always supply the demand of consumers, regardless of external climatic factors. By their connection to the power grid by synchronous generators, SMRs contribute to greater grid stability, especially in unusual operating events, such as short circuits and suddenly increased consumption [9].

- Water desalination: water security in Brazil has been a huge concern. As a result of this scenario, in 2016 CNEN has already started a conceptual project for seawater desalination through nuclear energy. A possible application of the SMRs is their construction within an industrial site [10]. The site would be supplied by the electric power production, and the heat generation from nuclear power plants (NPPs) could be used as cogeneration to water desalination.

- Floating nuclear power plant: an offshore floating SMR is designed for multipurpose use, as a combined energy supply for an offshore oil platform. This conception could play an important role in the national reality of oil exploration in the pre-salt region, which demands a high electrical power consumption [1, 11].

4. Nuclear Implementation Challenges in Brazil

Worldwide, one of the main obstacles to the development of nuclear power generation has been of an economic nature. The construction and financial costs are the major components of the NPP's total cost and, therefore, the commissioning involves high financial risks that restrict their competitiveness. Thus, as one of the biggest problems in the Brazilian nuclear program is the high costs arising from constant delays due to inefficient management, and the inherent advantages of SMRs technology could directly decrease those costs [3,11].

In order to consolidate a nuclear industry in Brazil, and to benefit from a clean, safe, and reliable energy source, the Brazilian energy policy must be based on a medium and long-term strategy, with well-defined objectives and a business model that integrate criteria such as: i.) plant standardization; ii.) new policies ad guidelines to speed up licensing for new projects and long term; iii.) commissioning time schedule reduction, and iv.) participation of private investors to raise financial resources, reducing uncertainties and economical risks.

5. Conclusions

The SMRs concept innovates by incorporating modularization in their architecture. This leads to standardization of the manufacturing, transport, and construction, enabling reduction of their total cost and raise de requirements of practicality, safety, and quality standards. The flexibility of the technological application of SMRs takes nuclear energy to a competitive economic level when compared to the highly overestimated renewable sources, such as wind and solar, since these are intermittent generators and of low energy density. Additionally, it enables the opening of new markets, both for countries that seek to expand and for those that aspire to start their nuclear program.

The SMRs have project characteristics that meet the Brazilian reality, mainly due to their wide applicability and the country's economic instability. Furthermore, the projects under development already have two important points as a premise: they are small reactors and PWR type, which already gives the country a certain advantage. Another interesting factor is the possibility of its insertion in the conventional industrial sector, and in oil extraction projects in the pre-salt, providing operational support and optimization in the process.

Even though Brazil has a well-structured nuclear organizational chart, the lack of management of financial resources, training skilled labour, and no medium and long-term perspectives of investment led to non-sustained nuclear industry development. In order to be competitive, a future perspective of expansion of SMRs application requires an assessment of the current Brazilian nuclear policies and regulation, aiming to achieve a new renaissance of the Brazilian nuclear industry.

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