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Floating NPP for co-generation of electricity and water desalination in Brazil

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Abstract: Climate change, population growth, urbanization, agriculture demand, water pollution and inefficient water management practices exacerbate the problem of water scarce particularly in the semi-arid Northeast. Additionally, long-term planning and investment are essential to mitigate future water scarcity challenges as the demand for water continues to rise with population growth and economic development. Desalination in Brazil is typically done through conventional methods, such as reverse osmosis, but not through nuclear source. While Brazil has a robust nuclear energy program, primarily for electricity generation, the country does not use nuclear reactors for desalination purposes. The objective of the present analysis of the inclusion of a project of a floating nuclear power plant (FNPP) in Brazil to co-generation of electricity and potable water by means of seawater desalination in residences and industries located in remote regions. This paper reviews recents works in the area of SMR and desalinization in Brazil. In addition, calls on investors, researchers, engineers, regulators, designers, stakeholders and decision-markets to open the debate about the the possibility of developing a national FNPP in the future.

Keywords: SMR, FNPP, desalination, co-generation.

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Usina nuclear flutuante para co-generação de eletricidade e dessalinização de água em Brasil

Resumo: As mudanças climáticas, o crescimento populacional, a urbanização, a demanda agrícola, a poluição da água e as práticas ineficientes de gestão da água agravam o problema da escassez de água principalmente no semiárido nordestino. Além disso, o planejamento e o investimento de longo prazo são essenciais para mitigar os desafios futuros de escassez de água, já que a demanda por água continua a aumentar com o crescimento populacional e o desenvolvimento econômico. A dessalinização no Brasil normalmente é feita através de métodos convencionais, como a osmose reversa, mas não através de fonte nuclear. Embora o Brasil tenha um programa robusto de energia nuclear, principalmente para geração de eletricidade, o país não utiliza reatores nucleares para fins de dessalinização. O objetivo da presente análise é a inclusão de um projeto de usina nuclear flutuante (FNPP) no Brasil para suprir a falta de energia elétrica em residências e indústrias localizadas em regiões remotas e para a produção de água potável por meio da dessalinização da água do mar. Este artigo revisa trabalhos recentes na área de SMR e dessalinização no Brasil. Além disso, apela a investidores, investigadores, engenheiros, reguladores, projetistas, partes interessadas e tomadores de decisão para abrirem o debate sobre a possibilidade de desenvolver um FNPP nacional no futuro.

Palavras-chave: SMR, usina nuclear flutuante, desalinização, co-generação.

1. INTRODUCTION

Floating Nuclear Power Plant (FNPP) named as Transportable Nuclear Power Plants (TNPP) by the International Atomic Energy Agency (IAEA) in 2013 is defined as a "transportable and/or relocatable nuclear power plant which, when fuelled, is capable of producing electricity, heat, and desalinated water" [1]. It is a combination of Small Modular Reactor (SMR) technology with ships and floating platform (i.e. barge) [2]. FNPP is designed to provide electricity to remote and isolated regions.

Offshore Floating Nuclear Plant (OFNP) concept is similar to those used in offshore oil/gas operations. It suggests that the nuclear power plant is installed in a fixed position (i.e. anchored to the seabed or the shore, and attached to shore by power lines) away from populated coastlines or in deep-sea locations [3].

Both types of NPP are built in a shipyard and transported to the site. Nuclear plants should be near the coast, but not necessarily on the coast.

FNPPs can be manufactured in a factory, assembled in a shipyard, and then transported to their final location. This process can potentially accelerate construction timelines and reduce costs. Countries like Canada, China, Denmark, South Korea, Russia, and the USA are actively developing designs for marine small modular reactors, with some projects already in advanced stages.

The IAEA is collaborating with its Member States to identify additional guidance and standards that may be required to ensure the safety of floating nuclear power plants [4].

Nuclear power plants can provide a clean energy source for desalination processes. Nuclear power plants generate heat through nuclear fission reactions, which can be used to produce steam. This steam can then drive turbines to generate electricity, but it can also be directly used in thermal desalination processes and hydrogen production.

Thermal desalination methods like multi-stage flash distillation (MSF) and multiple-effect distillation (MED) rely on heat to evaporate seawater and separate fresh water from salt. The heat required can be supplied by various sources, including fossil fuels, solar energy, geothermal energy, and nuclear energy [5].

Numerous studies can be found in the scientific literature about the NPP coupled to desalinization plants mainly in Kazakhstan, India, Japan and USA, but only few studies can be found about the SMR coupled to desalinization [6].

Several types of nuclear reactors can potentially be used to provide heat for desalination processes. The suitability of each type depends on factors such as the required temperature of the heat, efficiency, water quality, safety considerations, and regulatory requirements.

2. FLOATING NUCLEAR POWER PLANT

There is not a specific operational example of a FNPP with Pressurized Water Reactor (PWR)-type Small Modular Reactor (SMR) used for seawater desalination. However, the Akademik Lomonosov FNPP, wiich was connected to the grid in 2019 and started commercial operation in May 2020 [7], is expected to support seawater desalination, in regions where water is scarce [8]. It is expected to produce up to 240,000 cubic meters of fresh drinking water per day [7]. Additionally, the projects with concept of integrating PWR-type SMR with desalination processes are under consideration for example, by NuSCale [9]. Furthermore, Saudi Arabia (KSA) and Jordan also are exploring the possibility of using SMR for desalination in their regions [10].

China's ACPR50S is the second FNPP; currently under instalation which is a compact two-loop pressurized water reactor (PWR)-type SMR designed for both electricity generation and desalination purposes. It has a thermal output of approximately 200 MWt (megawatts thermal) and generates around 50 MWe (megawatts electrical). This modular reactor can be utilized for power generation, heating, and desalination of seawater, making it suitable for remote and hard-to-reach locations [11], [12].

The resulting SWOT analysis of a FNPP for electricity generation in Brazil [13] identified that, despite various challenges, the FNPP offers numerous benefits in the agricultural sector, industries, businesses, and homes for Brazil. In the Northeast region of Brazil, the application of a FNPP is justified not only by its potential to have many rivers, as referenced in [13], but also by its ability to mitigate deforestation in the area. By providing a sustainable and efficient energy source, an FNPP eliminates the need for deforestation normally associated with the establishment of infrastructure for conventional energy production, thus preserving critical ecosystems and biodiversity. The SWOT analysis made it possible to assess some strengths and weaknesses of FNPPs providing useful information for the developers of the technology and decision making.

2.1. Recents works about SMR + desalinization in Brazil

Brazil has expertise in Pressurized Water Reactor (PWR) technology, such as the Angra 1 and Angra 2 reactors, in fabrication of fuel elements, in enrichment of theses fuel elements and desalination.

While Brazil has the technical expertise in both PWR and desalination technologies, it has not yet combined them into a nuclear desalination project. The idea of using nuclear energy for desalination is technically feasible and could be explored in the future, particularly as the country continues to seek sustainable solutions to water scarcity in certain regions.

Small Modular Reactors (SMRs) of the Pressurized Water Reactor (PWR) type have been considered and researched for their potential use in desalination processes, including multi-stage flash (MSF) and other thermal desalination methods. In Brazil, three studies [14-16] examined the use of advanced nuclear reactors for electricity production and desalination and concluded that the excess heat produced during the nuclear power generation process can be utilized to drive thermal desalination (See Table 1).

The design and developmmment of FNPP for co-generation of seawater (See Table 2) from desalinitation should be aligned with the best practices of the four mature industries: maritime, nuclear, transporte and desalinization.

Table 1: SMR for co-generation of electricity and water desalination

COUNTRY	REACTOR DESIGN	POWER	STATUS
Brazil, Gonzalez R. D., et.al. 2019 [14]	Gas Turbine Modular Helium Reactor (GT-MHR)	600 MWth/288 MWe	Research
Brazil, Gonzalez R. D., et.al. 2023 [15]	High-Temperature gas-cooled Reactor Pebble bed Module (HTR-PM)	500 MWth/210 MWe	Research
Brazil, Gonzalez R. D., et.al. 2023 [16]	PWR	52 MWth/11 MWe	Research
KAERI, Republic of Korea [12] [17]	SMART (PWR)	365 MWt/107MWe	Licensed/certified
NIKIET, Russian Federation [12]	VK-300 (BWR)	750 MWt/ 250 MWe	Detailed / standard design
Holtec International, United States of America) [12]	SMR-160 (PWR)	525 MWth/160 MWe	Completed Phase 1 of vendor design review with CNSC

Table 2: FNPP with PWR-type SMR for co-generation of electricity and water desalination

DEVELOPER	REACTOR DESIGN	POWER	STATUS
Russian Federation OKBM Afrikantov OKBM [12]	RITM-200	175 MWth/50 MWe	Under construction
OKBM Afrikantov OKBM [12]	VBER-300	917 MWth/325 MWe	Licensing stage
OKBM Afrikantov OKBM [12]	ABV-6E	38 MWth/6-9 MWe	Licensing stage
China, CGNPC [12]	ACPR50S	200 MWth/50 MWe	Under installation

The use of PWR-type SMR for desalination in FNPPs or ONPPs is a promising technology, it is not yet widely implemented but is actively being explored and developed.

3. RESULTS AND DISCUSSIONS

Conventional desalination plants have been used in Brazil since 2004, when the Federal Government's Água Doce Program was launched, which is a well-developed technology in Brazil. The initiative, which implemented 240 desalination systems implemented in the Brazilian semi-arid region since the beginning of 2019, was highlighted in the publication of the International Desalination Association (IDA), the most important institution on the subject [18]. Similar equipaments used in traditional desalinization process can also be used in desalinization systems integrated with SMR, i.e., evaporators, deaerator, pumps, valves and condensers. In addition, commons equipaments used in industries such as wastewater treatment, food, petroleum, petrochemical, power generation (including nuclear), and pulp and paper can be used in desalinization systems integrated with SMR, i.e., flashing units, membrane separation, and chemical treatment.

Although the integration of SMR with desalinization process contributes to reduce the greenhouse gases (GHG) to atmosphere because remplace fossil power plant not compatible with sustainable development, however, the use of FNPPs for cogeneration of electricity and desalination in the Blue Amazon region may have environmental impacts (such as potential risks to marine ecosystems) and need for rigorous safety protocols.

The Blue Amazon is recognized for its exceptionally high or very high biological importance due to the vast diversity of species in its marine biome. Many areas outside the biome are insufficiently studied to determine their actual ecological importance [19]. Accidental or intentional releases of radioactive material from a FNPP could directly contaminate seawater, spreading quickly over large areas and cause long-term environmental damage [20]. Additionally, radionuclides released into the air can settle on the sea surface, remaining in the water and influencing atmospheric dispersion due to ocean absorption [21]. These risks, along with their implications for emergency planning and the marine biome, must be carefully analyzed, considering factors such as extensive contamination during transportation or operation.

Brazil is addressing the challenges associated with licensing SMRs for both marine and onshore applications. The country's maritime and nuclear regulations are developing to accommodate these technologies. Nevertheless, Brazil has neither developed nor acquired SMR technology, which remains a significant obstacle in establishing a cogeneration plant within a FNPP.

4. CONCLUSIONS

Brazil indeed has a robust nuclear energy program that includes several advanced projects and facilities, such as the development of nuclear submarines, the LABGENE (Laboratório de Geração Núcleo-Elétrica), and the RMB (Reator Multipropósito Brasileiro). In adition, Brazil has developed the capability to dominate the entire nuclear fuel cycle. This includes everything from uranium exploration, mining, and milling, to conversion, enrichment, and fuel fabrication, as well as reactor operation.

These projects reflect Brazil's strategic investments in nuclear energy however, despite these capabilities; Brazil has not yet combined them to create a nuclear desalination system, which remains a potential area for future development and descarbonization.

The study concludes that the FNPP in addition to contributing to the solution to supply a clean, reliable, and fexible energy source and drinking water for human consumption or agricultural purpose in remote regions, the implementation of this proposal could represent in the future a source of financial resources for the country and international collaboration.

This study will encourage investors, researchers, engineers, stakeholders and decision-makers to open the debate about the benefit of using an FNPP to cogeneration of electricity and fresh water in Brazil, taking into account the self development and capabilities reached in nuclear technology.

CONFLICT OF INTEREST

We have no conflicts of interest to disclose. All authors declare that they have no conflicts of interest.

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