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SMALL NUCLEAR REACTORS AS DRIVERS OF THE BRAZILIAN ENERGY TRANSITION

PEQUENOS REATORES NUCLEARES COMO INDUTORES DA TRANSIÇÃO ENERGÉTICA BRASILEIRA

PEQUEÑOS REACTORES NUCLEARES COMO IMPULSORES DE LA TRANSICIÓN ENERGÉTICA BRASILEÑA

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ABSTRACT

In this article, our analysis will focus on the possibility of acquiring or developing small modular nuclear reactors in Brazil. It offers an overview of the benefits and impacts of current energy sources for the population, supports the benefits of nuclear energy as a clean energy source, demystifying its military potential, and points to ways for the country to achieve a sustainable energy transition. The article is based on Jonathan Tennenbaum's theoretical framework regarding the history of nuclear technology consolidation. It recommends the completion of current projects and the development and construction of small modular nuclear reactors to drive Brazil's energy transition toward decarbonization.

Keywords: Nuclear Energy. Electric Power Generation. Small Modular Reactors. Nuclear Propulsion.

RESUMO

Neste artigo a nossa análise se concentrará na possibilidade de aquisição ou no desenvolvimento de pequenos reatores nucleares (small modular reactors) no âmbito Brasil. Oferece uma perspectiva dos benefícios e impactos das formas de energias atuais para a população, respalda os benefícios da energia nuclear como energia limpa desmistificando seu poder bélico e aponta caminhos para o País efetivar a transição energética de forma sustentável. O artigo se insere com base teórica em Jonathan Tennenbaum em relação ao histórico de consolidação da tecnologia nuclear. Recomenda-se a conclusão dos projetos atuais em andamento e o desenvolvimento e a construção de pequenos reatores nucleares modulares para induzirem a transição energética brasileira, na busca da descarbonização.

Palavras-chave: Energia Nuclear. Geração de Energia Elétrica. Pequenos Reatores Modulares. Propulsão Nuclear.

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RESUMEN
En este artículo, nuestro análisis se centrará en la posibilidad de adquirir o desarrollar pequeños reactores nucleares modulares en Brasil. Ofrece una visión general de los beneficios e impactos de las fuentes de energía actuales para la población, respalda los beneficios de la energía nuclear como fuente de energía limpia, desmitifica su potencial militar y señala las vías para que el país logre una transición energética sostenible. El artículo se basa en el marco teórico de Jonathan Tennenbaum sobre la historia de la consolidación de la tecnología nuclear. Recomienda la finalización de los proyectos actuales y el desarrollo y la construcción de pequeños reactores nucleares modulares para impulsar la transición energética de Brasil hacia la descarbonización.

Palabras clave: Energía Nuclear. Generación de Energía Eléctrica. Reactores Modulares Pequeños. Propulsión Nuclear.

1 INTRODUCTION

The improvement in the quality of life of the Brazilian population, the increase in the Human Development Index (HDI) and the expansion of the industrial park effectively involve the supply of electricity. To illustrate this statement, Figure 1 presents a night photo of Brazil, recorded from the International Space Station, where the Southeast Region stands out, illuminated, especially the State of São Paulo.

Figure 1

Image of Brazil from the International Space Station

Photo: International Space Station (ISS)

Thus, one of the objectives presented in this article was to understand the interaction of propagating the results of nuclear research studies of strategic importance for the country. To this end, the energy sources of the regions of Brazil, their natural and economic characteristics were investigated. Considering that Brazil diversifies its energy sources by region, in order to minimize natural and economic impacts. In this context, energy sources are present in Brazil in the form of solar energy, wind energy, hydroelectric energy and nuclear energy, exponential paths in the search for the country's energy balance, according to the social, economic and geographical characteristics of the regions in the country.

As specificities and social and environmental impacts of the energy used in different regions of Brazil, the following can be mentioned: the North Region (Hydroelectric Plant), Belo Monte Plant and Tucuruí Plant; deforestation, imbalance in the ecosystem and methane projection; social impact on the way of life when considering the construction of dams; the South Region (Hydroelectric / Wind / Biomass / Thermoelectric). Thermoelectric plants, when

using coal, generate environmental impacts with pollution and greenhouse gases. Regarding wind energy, even though it is a clean source, it has caused impacts on fauna; the Midwest Region (Hydroelectric / Thermoelectric (Biomass / Natural Gas) / Solar Energy), with impacts on the course of water and floods. The production of biomass, on the other hand, promotes deforestation and biodiversity loss; the Northeast Region (Wind / Solar Hydroelectric / Thermoelectric), with great wind and solar potential, contributes to the reduction of greenhouse gases, renewable wind energy can impact the fauna of the region. As for thermoelectric plants driven by biomass or natural gas, they may generate pollution on a smaller scale than those powered by coal or fuel; the Southeast Region (Hydroelectric / Thermoelectric / Nuclear Energy - Furnas Power Plant). When considering the industrialization of the Southeast Region in a combination of nuclear, hydroelectric and thermoelectric energy, natural gas has an environmental impact in terms of CO_2 emissions in contrast to coal and fuel oil. CO_2 emissions are considered low when it comes to nuclear energy, but with the challenges of waste storage and remote accidents.

We believe that all forms of electricity generation should be used judiciously to improve the quality of life of the Brazilian population. However, in this article, our analysis will focus on the production of electrical energy through nuclear reactors.

The motivation for carrying out this study was articles published on the internet, where one of them mentions the possible acquisition of a Russian Small Modular Reactor (SMR) that would meet the supply needs of remote regions.

It is intended in this article to list the pros and cons for the country in acquiring or developing small modular nuclear reactors to complement its energy park.

2 CURRENT ENERGY SCENARIO

According to the Sputnik Brasil channel, "With an eye on the energy transition, the federal government instituted, through the Ministry of Mines and Energy, the Amazon Energies program, which proposes to be the largest decarbonization program in the world" (Acácio, 2024, p.1). Stressing that "To solve the use of thermoelectric plants to serve isolated communities, should Brazil bet on the implementation of small modular reactors?" (Acácio, 2024, p.1).

Brazil, considered **the country with the most renewable energy matrix among the largest economies in the world,** makes the government work on reducing diesel fuel in energy production in the Amazon region, based on the Amazon Energies program.

By means of a decree, the government created the Amazon Energies Program "investments in actions and projects in the Isolated Systems located in the Legal Amazon

region aimed at reducing the generation of electricity through fossil fuels and contributing to the quality of electricity" (Acácio, 2024, p.2). In this scenario, the Minister of Mines and Energy, Alexandre Silveira, **defends the implementation of small modular reactors (SMR). Like this**

> Leading the energy transition in the world: the "mission" is desired by several actors at the top level of the federal government. The initiative has already been defended by the Vice President and Minister of Development, Industry, Commerce and Services, Geraldo Alckmin, and by the Minister of Science, Technology and Innovation, Luciana Santos, in addition to President Luiz Inácio Lula da Silva himself (Acácio, 2024, p.1).

According to Dr. Leonam Guimarães, technical director of the Brazilian Association for the Development of Nuclear Activities (ABDAN), SMRs represent an advantage due to their flexibility, safety, and lower initial investment cost (Acácio, 2024, p.1).

It is important to note that Brazil is among the countries that hold the uranium chain, denoting the importance of greater government investment positively in the country's economic production.

3 CHARACTERISTICS OF SMR

Our analysis focuses on the possibility of acquiring or developing small nuclear reactors as a possible solution to complement the energy grid or use in remote points in Brazil, to generate energy, heat oil transmission lines at the bottom of the ocean, to illuminate airstrips in remote regions such as the Amazon, or also feed the Comandante Ferraz base in Antarctica.

In this new political context of restructuring, Brazil is betting on small modular reactors (SMRs), with the proposal of decarbonizing the world and, in this context, creates the Amazon Energy Program. This Program marks a new development cycle as it seeks to implement the reactors. For the propagation of knowledge and studies of modular sciences, the reactor is present, focused on the energy transition. Compared to traditional reactors, SMRs are designed to generate electricity more flexibly and cost-effectively. Because they are small-scale nuclear reactors, they are characterized by their modularity. Considered sources of continuous energy for remote regions, they become a reliable source of energy when considering operational capacity, which is independent of extensive electrical networks.

Leading the energy transition in the world is present and necessary, considering that Brazil, according to Acácio (2024), during a narrative on the Sputnik News channel, says**:** **"**Brazil is **the country with the most renewable energy matrix among the largest economies in the world.** Through the Amazon Energies program, for example, the

government seeks to reduce the use of diesel fuel in energy production in the region" (Acácio, 2024, p.1).

Thus, we will make a brief overview of the advantages and uses of small nuclear reactors. Advantages: The modular structure provides savings in scale construction, increase in the generation of electricity according to local demand, in addition to the availability of energy in the continental dimensions of the country. Uses: small power plants in diverse locations, including remote or difficult to access; naval propulsion, submarine, production of radiopharmaceuticals, both for diagnosis and treatment of various diseases.

4 NUCLEAR PROJECTS UNDERWAY IN THE COUNTRY

The main projects underway in the nuclear area in the country are briefly presented below.

4.1 COVE 3

According to Eletro Nuclear_Energia Limpa

> Currently under construction, Angra 3 will be the third plant of the Almirante Álvaro Alberto Nuclear Power Plant (CNAAA). With a power of 1,405 megawatts, the new unit will be able to generate more than 12 million megawatt-hours per year, enough to serve 4.5 million people. In this way, nuclear energy will generate the equivalent of 60% of the consumption of the state of Rio de Janeiro and 3% of the consumption of Brazil (Eletro Nuclear, 2024, p.1).

According to Eletro Nuclear's explanation, Angra 3 expects to start operating in 2028, operating with reliability and guarantee in the supply of the Brazilian electricity system. Emphasizing that "nuclear power plants do not emit greenhouse gases, unlike fossil fuel-powered thermoelectric plants. Therefore, the plant will have minimal environmental impact and will generate clean energy" (Eletro Nuclear, 2024, p.2).

It is worth noting that the Angra 3 plant will promote the diversification of the electricity matrix and the reduction of costs of the National Interconnected System (SIN).

4.2 LABORATORY OF NUCLEOELECTRIC GENERATION (LABGENE)

According to the Navy Technological Center in São Paulo (CTMSP),

> For the operation of the nuclear submarine, the Brazilian Navy is building, at the Aramar Experimental Center, the Nucleoelectric Power Generation Laboratory (LABGENE), which will be used to validate the design conditions and test all possible operating conditions for a nuclear propulsion plant (Brazilian Navy, 2024, p.1).

4.3 BRAZILIAN MULTIPURPOSE REACTOR (RMB)

The RMB is a multipurpose nuclear research reactor whose main objective is the production of radioisotopes, which are the raw material for the production of radiopharmaceuticals used in Nuclear Medicine in the diagnosis and treatment of various diseases.

5 NUCLEAR FISSION IN DUALITY

For a better understanding of the subject, it is worth making some considerations about the generation of nuclear energy. Today the fission of the uranium atom is considered the main technique used to generate electricity in nuclear power plants, the atomic nucleus splits into two or more particles, taking advantage of the kinetic energy of these fragments to produce electricity. Thus, nuclear fission is pointed out as a clean and efficient alternative in promoting energy, preferably because it does not emit gases. Nuclear power plants are used today in Japan, France, Germany, the United States, China, Russia, India, South Korea, Canada, Argentina and Mexico. By considering the application of the fission process in the generation of electricity, they avoid its use in weapons of mass destruction.

Designing crucial roles in the development of Nuclear Energy today in Brazil is necessary with the utmost urgency. With the revolution in Nuclear Physics, research has been opening dual paths both for the use of radioactivity in medicine, for the diagnosis and treatment of cancer, including in food preservation in industry, in pest control, in archeology, that is, diversified segments. There are many benefits beyond the generation of electricity. Thinking about nuclear fission in the generation of electrical energy would become impossible without the pioneering discoveries of the uranium atom.

The uranium atom, isotope uranium-235 (U-235), is classified as the main element used in nuclear power plants. Relevant as a heavy element, U-235 is considered a fissile form and, consequently, rare, a fact that explains its ability to split into smaller parts, nuclear fission, when bombarded with neutrons. Released in fission, the kinetic energy transformed into heat generates steam that moves the turbines and generates electricity.

Used in nuclear power plants, uranium touted as a low-cost fuel is not a concern about the risk of shortages in the medium term. The replacement of thermal power plants by nuclear power plants is a relevant topic within the public debate on the energy transition and the environmental impact of different sources of energy generation.

The history of Nuclear Energy itself, the Brazilian nuclear concept, had its development between the 1950s and 1960s, when the uranium enrichment process began. Natural

uranium has about 0.7% U-235 and 99.3% U-238, a fertile isotope. To be used in nuclear power plants, uranium-235 needs to be enriched, increasing the concentration of U-235 to about 3% to 5%. "Among the countries that imported German technology was Brazil, which in 1975 would sign the controversial Nuclear Cooperation Agreement" (Brandão, 2008).

In this scenario, uranium-235 is essential for the operation of nuclear reactors when considering its ability to sustain nuclear reactions in a controlled chain. Self-sustaining nuclear fission chain reactions are limited to a few rare substances, isotopes of uranium or plutonium; they only occur under extraordinary conditions and are not transmitted to other substances.

In this context, Tennembaum addresses in his book "The Economics of Isotopes", the existence of elementary individuals that are still unknown. In a scenario of hundreds of isotopes, most of them artificially generated, commercial use is present in areas ranging from medicine to food preservation. Without the use of radioactive isotopes produced in nuclear reactors and particle accelerators, society would not benefit from the countless advances in knowledge of the processes that occur in the nucleus of the atom and in the technologies that nuclear fission and fusion promise, with prospects for the creation and use of new isotopes in holistic areas with new energy sources. water supply, among others. Referred to as a scientific, cultural, socioeconomic and technological revolution, with the potential to eliminate the mistaken concept of "LIMIT" for the development of humanity, Tennenbaum, guided "The Economics of Isotopes", based on the book.

> Man's incipient mastery of the power to transmute chemical elements and to create new states of matter that did not previously exist on Earth and perhaps not even in the universe, demonstrates once again that we live in Plato's universe and not in Aristotle's. It is a universe in which processes are primary, in which "nothing is permanent but transformation," in which when dealing with such things as atoms and so-called elementary particles, we have to speak, not about an "it," but about a "thus" (as Plato wrote in the Timaeus). More than in any previous "phase state" of the physical economy of humanity, the advent of what I call "Isotope Economy" means a situation in which social practice will necessarily have to be oriented to "true ideas," to the discoverable universal principles that govern the changes and evolution of the universe, and not primarily to sense objects. This means the end of empiricism and materialism. - Jonathan Tennenbaun – in the book: The Economics of Isotopes – Chapter 1, (Tennenbaum, Chapter 1, 2007).

From then on, one side occupies the history of Nuclear Energy itself, and the other that, placing us on a relational journey between quality of life and electricity consumption, takes us to the focal point of ideological, political and social issues, ardent in various societies around the contemporary world.

6 ACQUISITION X DEVELOPMENT OF SMR

Initially, before we begin to discuss the title of this section, it is necessary to conclude the nuclear projects in progress. Finalize Angra 3, which is a large reactor, and deliver it to the energy grid and accelerate the completion of the Nucleoelectric Generation Laboratory (LABGENE), a small reactor used for naval propulsion, in addition to the Brazilian Multipurpose Reactor (RMB), which is also a small reactor and whose main object will be the production of radiopharmaceuticals used in Nuclear Medicine.

When we use any product from another country, all the knowledge acquired and all the technology developed belong to the country of origin. Thus, we believe that after the conclusion of LABGENE and RMB we will have all the necessary expertise to propose and build an SMR perfectly suited to national needs.

7 FINAL CONSIDERATIONS

In this article, an analysis applied to the nuclear sector was discussed, which can help budget planning. It is believed that the completion of ongoing nuclear projects is the best strategy to be followed, rather than the acquisition of new nuclear reactors.

It is also expected that after the completion of these projects, the country will have the necessary expertise to design and build its own SMRs.

We foresee two ways for the country to carry out the energy transition in a sustainable way: the first is the implementation of the proposals presented in this work that may represent a rebirth of Nuclear Energy in Brazil, causing a drag in the entire production chain, from mining in Caetité in Bahia to the Universities spread throughout the country, passing through the industrial park; the second is that Nuclear Energy becomes a State project and not a government project.

The tireless search for understanding the benefits of Brazilian nuclear development focuses on the political, scientific and ideological issues of our time.

The article seeks to demystify the power of war by focusing on the peaceful use of nuclear energy, which led to the development of destructive weapons, carried out in wars that profoundly mark history even today. War scenarios, such as those we have witnessed between Ukraine and Russia, where countries such as North Korea often announce the potential use of nuclear weapons in political and strategic statements. They point to the devastating power of nuclear weapons for mass destruction and geopolitical coercion. It is important to note that the nuclear arms race has brought benefits in the increase of research related to the domain of the atom and, consequently, its use in other areas such as the energy matrix, medicine, etc. This period, however, proved to be one of the most expressive of the

bases of Nuclear Energy, related to history with effective aspects of science. However, today the focus of nuclear energy changes. Peace is sought in a Brazilian transitional race with an eye on decarbonization.

Demystifying nuclear energy by pointing out the replacement of thermal power plants by nuclear power plants can bring, especially in terms of reducing greenhouse gas emissions and air pollutants, significant environmental benefits. To this end, it is essential to consider the various challenges associated with nuclear waste management and the risks of accidents. Challenges also need to be solved, considering that abandoning the problem does not symbolize the best solution.

The replacement of thermal power plants by nuclear power plants is a relevant topic within the debate on the energy transition and the environmental impact of different sources of energy generation.

Awareness of the benefits and problems of Nuclear Energy plays a fundamental role in its acceptance by the population. Inform to demystify.

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