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Brazil's Uranium Mining Evolution: Domestic Developments and International Dynamics

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Abstract: This article provides an exploration of the historical trajectory of uranium mining in Brazil, providing insight into its emergence, development, and current status within the global nuclear landscape. From its early days, characterized by sporadic mining ventures to the establishment of strategic uranium reserves, Brazil's journey mirrors a complex interplay of domestic imperatives and international dynamics. However, despite Brazil's significant uranium resources and advances in nuclear technology, its narrative often remains overshadowed by other global nuclear actors. Thus, by delving into Brazil's historical engagement with uranium mining, this paper seeks to illuminate its evolving role and contributions to the nuclear domain. Furthermore, this study examines the impact of external influences, such as geopolitical pressures, the international price of uranium, and technological advancements, on Brazil's nuclear ambitions. Ultimately, it aims to enrich our understanding of Brazil's past, present, and future in the global nuclear area.

Keywords: Uranium Mining, Brazil, nuclear, history, management, future.

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A Evolução da Mineração de Urânio no Brasil: Desenvolvimentos Domésticos e Dinâmicas Internacionais

Resumo: Este artigo oferece uma exploração da trajetória histórica da mineração de urânio no Brasil, fornecendo uma visão sobre seu surgimento, desenvolvimento e status atual dentro do panorama nuclear global. Desde seus primeiros dias, caracterizados por empreendimentos de mineração esporádicos até o estabelecimento de reservas estratégicas de urânio, a jornada do Brasil reflete uma complexa interação de necessidades internas e dinâmicas internacionais. No entanto, apesar dos significativos recursos de urânio do Brasil e dos avanços na tecnologia nuclear, sua narrativa frequentemente permanece ofuscada por outros atores nucleares globais. Ao mergulhar no engajamento histórico do Brasil com a mineração de urânio, este artigo busca iluminar seu papel e contribuições em evolução no domínio nuclear. Além disso, examina o impacto das influências externas, como pressões geopolíticas, o preço internacional do urânio e avanços tecnológicos, nas ambições nucleares do Brasil. Em última análise, visa enriquecer nossa compreensão do passado, presente e futuro do Brasil na arena nuclear global.

Palavras-chave: mineração de uranio, Brasil, nuclear, história, gestão, futuro.

1. INTRODUCTION

Nuclear research in Brazil has a rich history dating back to the mid-19th century, characterized by early investigations into fission and uranium exploration. These endeavors culminated in Brazil's inaugural agreement with the United States in 1940, marking a foundational moment in the country's nuclear trajectory. The subsequent decades witnessed the establishment of key institutions such as the National Research Council (CNPq) in 1950 and the National Commission f or Nuclear Energy (CNEN) in 1956, signaling Brazil's commitment to advancing nuclear capabilities. Despite concerted investments by successive governments in nuclear capacity development, Brazil's nuclear policy encountered multifaceted challenges stemming from diverse stakeholder interests: academic, technical, military, commercial, and diplomatic, reflecting the country's evolving international aspirations and strategic imperatives [1].

Throughout the years, Brazil has demonstrated determined efforts in systematic prospecting for radioactive minerals, spearheaded by the CNPq in the early 1950s. Collaborative ventures with foreign partners, exemplified by technical cooperation agreements with the United States in 1955 and engagements with the French Center d'Etudes Nucléaires (CEA) in 1962, underpinned Brazil's uranium exploration endeavors [2], [3]. The establishment of the Nuclear Technology Development Center for Brazil (NUCLEBRAS) in 1974, bolstered by the landmark Agreement for Cooperation in the Field of Peaceful Uses for Nuclear Energy with Germany in 1975, marked significant milestones in Brazil's uranium mining trajectory. These initiatives identified uranium reserves across various regions, laying the groundwork for subsequent industry expansion.

The reorganization of Brazil's nuclear program in 1988 heralded a new phase, with uranium activities entrusted to Urânio do Brasil S.A., a subsidiary of Industrias Nucleares do

Brasil (INB). Despite occasional interruptions, uranium mining resumed in the early 1990s, underscoring Brazil's sustained commitment to nuclear energy development. Notably, ongoing projects like the Lagoa Real project in Bahia represent contemporary efforts to enhance Brazil's uranium mining sector, with innovative techniques poised to improve production efficiencies [2], [4].

In Brazil, uranium extraction from open-pit deposits, known as mining, is a crucial step in this cycle. The uranium ore undergoes processing to obtain a concentrate, which is then treated to produce yellowcake (U3O8). Subsequently, this yellowcake is refined and gasified to yield uranium hexafluoride (UF6). The enrichment stage follows, increasing the proportion of the fissile isotope uranium-235 [5]. The enriched uranium is processed into pellets and assembled into nuclear fuel rods for insertion into reactors, ultimately generating heat through the fission of uranium-235 to produce steam and electricity [6].

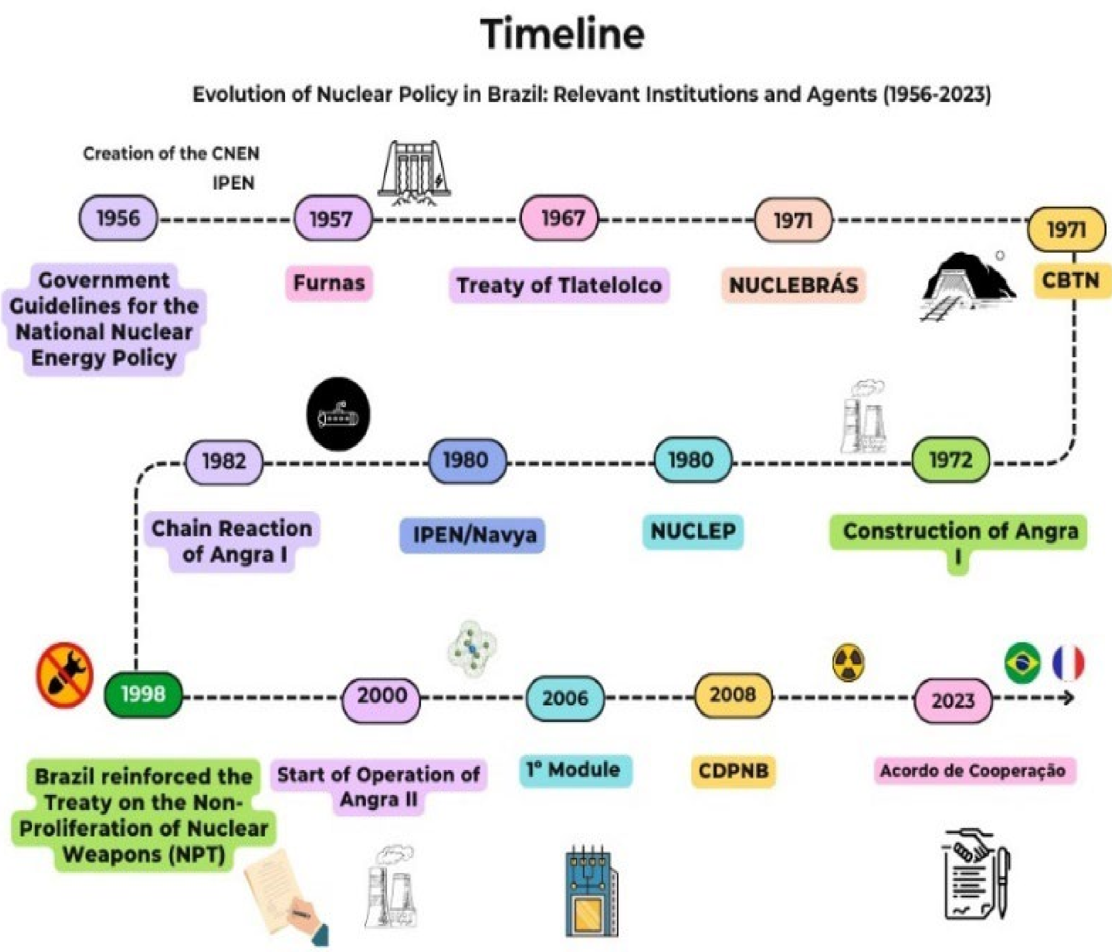
Additionally, the challenge of human resources poses a critical consideration for Brazil's nuclear endeavors. Quantifiable and precise goals regarding workforce development are essential for achieving technological autonomy and economic-scientific independence in the nuclear sector. Addressing this issue is vital for sustaining Brazil's nuclear capabilities and ensuring a skilled workforce capable of driving innovation and maintaining the country's nuclear technology dominance.

The scope of this paper is to deepen our understanding of Brazil's uranium prospecting and management and its interplay with nuclear activities. To achieve this goal, the article provides a comprehensive re-examination of Brazil's nuclear policy evolution and offers a concise overview of uranium mining, contextualizing its historical trajectory within broader national, regional, and international dynamics.

2. BRAZIL'S NUCLEAR POLICY EVOLUTION

In Figure 1, a detailed timeline illustrates the evolution of nuclear policy in Brazil, highlighting the most important milestones and the key bodies and agents involved from 1956 to 2023 [7].

Figure 1. Timeline of the Evolution of Brazil's Nuclear Policy from 1956 to 2023.



The key stages depicted in the timeline are summarized below:

- **1956: Foundations of Nuclear Policy:** During the administration of Juscelino Kubitschek, the Governmental guidelines for the National Nuclear Energy Policy were approv ed, marking the formal beginning of nuclear policy in Brazil. Two key institutions were established: the National Nuclear Energy Commission (CNEN) and the Institute for Energy and Nuclear Research (IPEN), the latter to conduct research in the field of nuclear energy. Furthermore, a Special Commission for the Study of Atomic Energy in Brazil was established [8].

- **1957: Birth of Furnas Centrais Elétricas:** On February 28, 1957, Furnas Centrais Elétricas was established as a state-owned company initially tasked with building and operating large hydroelectric plants. Later, Furnas would also become involved in nuclear energy projects, solidifying its role in the country's energy infrastructure.

- **1967: Treaty of Tlatelolco:** Brazil signed the Treaty of Tlatelolco, which established Latin America as a nuclear-weapon-free zone. This treaty reflects Brazil's commitment to peaceful use of nuclear energy, aligned with international nuclear non-proliferation policies [9].

- **1971: Creation of NUCLEBRÁS and the Companhia Brasileira de Tecnologia Nuclear**: The state-owned company NUCLEBRÁS was established to facilitate nuclear energy cooperation with the American company Westinghouse, and the Companhia Brasileira de Tecnologia Nuclear (CBTN) was created to conduct nuclear research and mining operations.

- **1972: Construction of Angra I**: Construction of Brazil's first nuclear power plant, Angra I, began as part of an agreement with the United States. This agreement included the supply of enriched uranium in exchange for Brazilian natural uranium [10].

- **1980s: Expansion and Nationalization:** During the 1980s, the binational company Nuclebrás Equipamentos Pesados (NUCLEP) was founded as part of the Brazil-Germany agreement. NUCLEP became fully nationalized during this decade. Meanwhile, IPEN and the Brazilian Navy developed nuclear propulsion technology for submarines, expanding the applications of nuclear energy in the military sector.

-**1982: Angra I and Poços de Caldas Industrial Complex:** Brazil achieved the chain reaction at Angra I and inaugurated the Fuel Element Factory (FEC) and the Poços de Caldas Industrial Complex. This advancement centralized state control over all nuclear research, ensuring a more integrated and regulated management of the sector [10].

-**1998: Brazil reinforced the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)**: Negotiated in July 1968, this commitment was later reinforced by Decree No. 2.864/1998, which established regulations for cooperation and the application of safeguards on peaceful nuclear activities under the supervision of the International Atomic Energy Agency (IAEA).

-2000: Start operation of Angra II

-2002: Oversaw the Construction of a Commercial-Scale Gas Centrifuge Uranium Enrichment Plant in Resende: The government expanded the nuclear program and oversaw the construction of a commercial-scale gas centrifuge uranium enrichment plant in Resende, which has been operational since May 2006. During the period from 2003 to 2011, the administration insisted on restricting visual access to the centrifuges to protect patented technology from industrial espionage, leading to negotiations with the IAEA. Brazil resisted signing the IAEA Additional Protocol, citing intrusion and commercial disadvantages imposed by advanced nuclear states.

-**2006: Technological Independence:** The first module of the uranium enrichment centrifuge cascade was inaugurated at the Resende Industrial Complex.

-**2008: Brazilian Nuclear Program Development Committee (CDPNB):** The CDPNB was established [11].

-2023: Cooperation Agreement with France: Brazil signed a cooperation agreement with France for the development of peaceful applications of nuclear energy.

The Brazilian Nuclear Program is fundamental for Brazil's sovereignty and plays a crucial role in scientific, technological, industrial, economic, and psychosocial development. It aims to ensure national defense, security, and energy needs. In the 2000s, Brazil quietly reviewed plans for uranium enrichment and deliberated on nuclear propulsion for submarines, involving the production of enriched uranium outside of NPT safeguards. However, despite reactivating these plans, they remained in the planning stage due to financial instability and slow economic growth [3], [7], [12].

Brazil aims to continue improving its nuclear energy plans, supported by various international agreements and national policies. Thus, on January 18, 2001, Brazil entered into an agreement with the Republic of South Korea for the civil use of atomic energy. Later, on October 25, 2002, Brazil signed an agreement with the French Republic for the peaceful use of nuclear energy, further expanding its network of international cooperation in this specific field. The guidelines related to the Brazilian Nuclear Policy were consolidated with Decree 9600, issued on December 5, 2018, establishing a clear and precise regulatory framework for the sector. On September 27, 2019, the CDPNB formed a technical group aimed at streamlining the regulation of the Brazilian nuclear sector. Shortly thereafter, on October 4, 2019, the Management Committee was established, tasked with restructuring CNEN and creating a competent authority for nuclear safety. Subsequently, on January 7, 2020, responsibility for the licensing and inspection of vessels using nuclear propulsion or transporting nuclear fuel was transferred to the Navy Command. Finally, Law 14.222 established the National Nuclear Safety Authority (ANSN) to ensure the safe use of nuclear energy.

These developments highlight Brazil's significant steps toward technological independence in nuclear fuel production over the past 68 years. They also reaffirm the country's commitment to advancing its nuclear program and consolidating long-term strategies for the sector. Brazil's ongoing focus on international cooperation and the peaceful use of nuclear energy aligns its policies with global standards of safety and sustainability.

Thus, Brazil's efforts to enhance its nuclear energy resources have been significantly supported through international cooperation, consistently within the framework of international treaties. Perhaps the most notable example of this international cooperation is the relationship between Brazil and Argentina. In the following section, we will highlight the most interesting points of this international cooperation between the two countries for benefit of the reader.

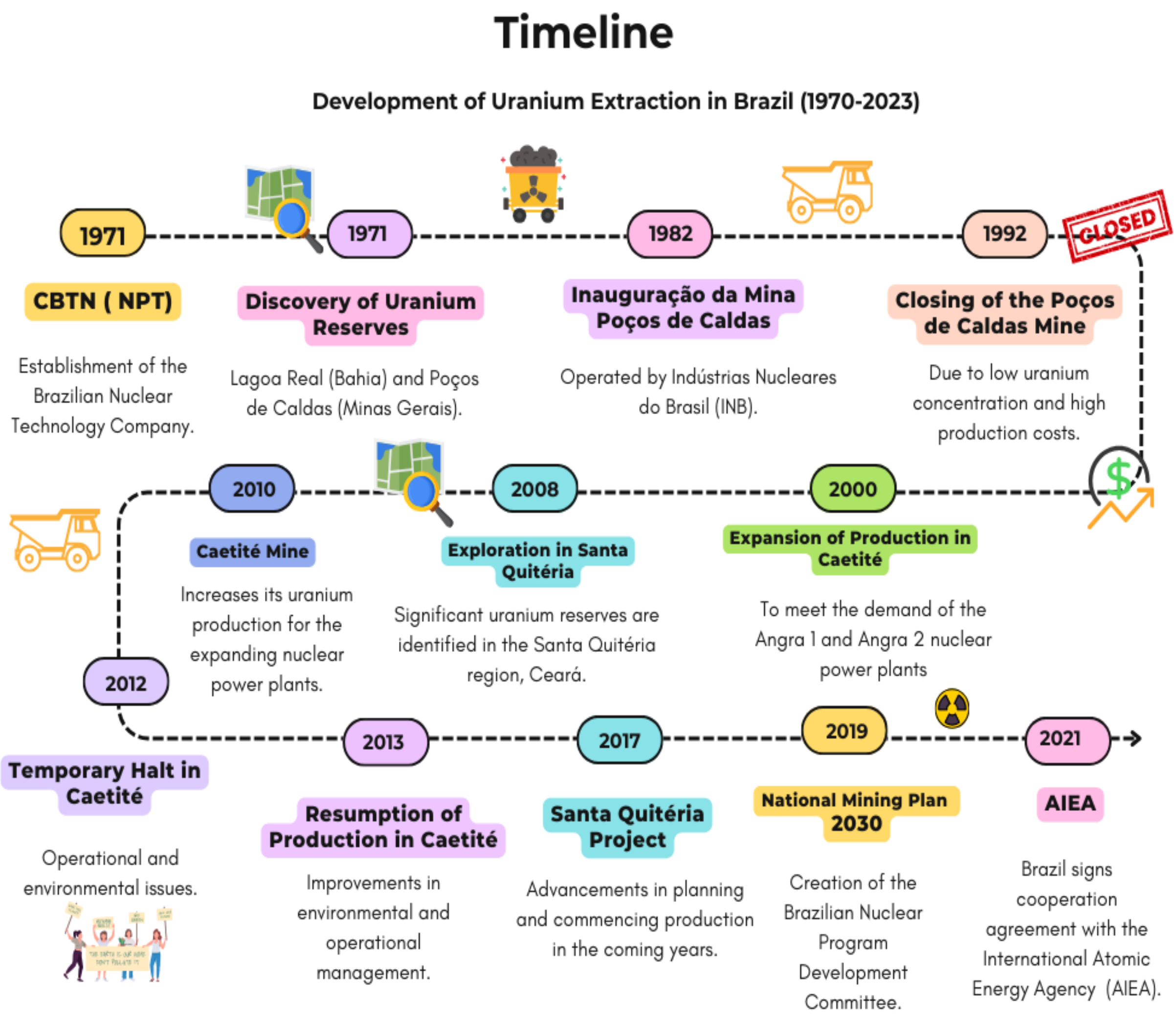
Brazil and Argentina have a history of nuclear cooperation that has developed over several decades, fostering mutual trust and advancing their nuclear capabilities. Here are some key points and dates related to this cooperation [2].

In the 1980s, Brazil and Argentina began building a framework for nuclear cooperation to ensure the peaceful use of nuclear energy, as part of broader efforts to reduce regional tensions and build trust. A significant milestone was the signing of the Guadalajara Agreement on November 28, 1991, which established the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC). The ABACC oversees nuclear materials to ensure their use for peaceful purposes, marking a significant step in transparency and mutual verification. In 1994, Brazil and Argentina, along with ABACC and the IAEA, signed the Quadripartite Agreement. This agreement reinforced non-proliferation commitments and allowed comprehensive safeguards on nuclear activities in both countries. In 2008, the two nations agreed to establish the Binational Nuclear Energy Committee, with the aim of jointly enriching uranium, producing radiological medical supplies, developing nuclear applications for agriculture, and designing and building research reactors. This cooperation represents a significant effort to improve their nuclear energy sectors through collaboration [2].

3. LANDSCAPE OF URANIUM MINES IN OPERATION IN BRAZIL: LOCATIONS, PRODUCTION, AND PROSPECTS

In Figure 2, a historical context is provided for uranium extraction from its inception in Brazil up to the year 2023.

Figure 2. Timeline showcasing the development of uranium extraction in Brazil from 1970 to 2023.



Uranium exploration in Brazil began in the 1980s with the operationalization of the Poços de Caldas mine in Minas Gerais, managed by Industrias Nucleares do Brasil (INB). The chronology begins in 1971 with the establishment of the Companhia Brasileira de

Tecnologia Nuclear (CBTN), the precursor to the present-day INB, marking the formal inception of nuclear activities in the country. At the same time, significant uranium reserves were identified in the regions of Lagoa Real, Bahia, Itataia and Poços de Caldas, Minas Gerais, laying the groundwork for future mineral exploration.

In 1982, the Poços de Caldas mine, Brazil's first uranium mine operated by INB, was inaugurated. However, in 1992, this mine was deactivated due to low uranium concentration and high production costs, prompting a period of reflection and reevaluation in the industry [13].

The year 2000 marked a milestone with the expansion of production at the Cachoeira mine in Caetité, Bahia, significantly increasing the extraction of uranium to meet the demands of the Angra 1 and Angra 2 nuclear power plants. In 2008, new reserves were discovered in Santa Quitéria, Ceará, setting the stage for a new mining venture.

In October 2009, the Santa Quitéria Consortium was established, comprising Galvani Fertilizantes and INB, with the objective of implementing a joint mining project in Santa Quitéria (CE). The venture encompasses the production of high-grade fertilizers for agriculture, dicalcium phosphate for animal feed supplementation, and uranium concentrate for electricity generation [14].

In 2010, production at the Cachoeira mine in Caetité increased, solidifying its status as a crucial uranium source for the country. However, in 2012, the mine was temporarily halted due to operational and environmental issues [15]. Production resumed in 2013 after improvements in environmental and operational management. In 2017, the Santa Quitéria project was conceived, which envisages the long-term exploration of uranium reserves in Ceará [16].

Today, INB holds exclusive responsibility for uranium extraction in Brazil, focusing on the Cachoeira mine, the country's sole active mine. However, Brazil's Strategic Plan, as outlined by the Brazilian Geological Survey (SGB/CPRM) for 2021-2025, presents optimistic projections for uranium exploration in the country. This plan includes the identification of new exploration sites and economic feasibility analyses. The Program for the Evaluation of Radioactive Mineral Potential integrates long-term geological exploration strategies, with a particular emphasis on the Uraniferous region of Lagoa Real in the municipality of Caetité, expected to commence in 2027, as well as the Carajás Province. Expansion plans aim to extend uranium exploitation to areas such as Itataia in Ceará, Rio Cristalino in Pará, Faixa Araguaia in Tocantins, and the eastern and southwestern zones of the Parnaíba Basin [10], [17], [18].

The project at Uraniferous Province of Lagoa Real in the municipality of Caetité, which is currently undergoing expansion to increase its annual production capacity to 670 tons of uranium. Production resumption is expected to occur in 2027, with expansion plans encompassing the development of both underground and open-pit mines. The integrated report for the Lagoa Real area in 2023 highlights the emphasis on mineral exploration for uranium extraction and processing to produce uranium concentrate (yellowcake, U3O8) [19]. The operation spans 17 natural deposits distributed throughout the region, with an estimated reserve of approximately 99.1 thousand metric tons of U3O8. With reserves totaling 100,770 tons of uranium, Lagoa Real uranium province is positioned to meet the demands of the Angra 1 and Angra 2 nuclear power plants, with the potential to support the development of two new plants in Rio de Janeiro (RJ) [19].

Among these planned expansions, Itataia, located in Ceará, possesses uranium resources totaling approximately 142.5 thousand tons associated with phosphate (P205). The defined mineral reserves consist of 79.5 million tons of ore with average grades of around 11% P205 and 998 ppm of U3O8, as well as P205 grades of 8.9 million tons and 79.3 thousand tons of U3O8. Despite not being the largest uranium reserve in the country, uranium production in Itataia remains economically viable primarily due to the presence of associated phosphate. [19].

Currently the mining of uranium in Brazil has emerged as a critical component of the nation's energy and technological development, underscored by the country's vast uranium reserves estimated at around 280,000 tU, positioning Brazil as the eighth-largest uranium holder globally [10]. Beyond its economic significance, uranium mining plays a pivotal role in Brazil's infrastructure and social development [18]. For instance, in the municipality of Caetité according to data from the Brazilian Institute of Geography and Statistics (IBGE) in 2021, the average monthly salary in this region is approximately double the minimum wage, highlighting the economic significance of uranium mining for the local community [20].

Then as mentioned earlier, in the late 19th century Brazil embarked on a series of geological studies and political strategies focused on uranium exploration, particularly in the northeastern states of Bahia, Ceará, as well as Paraná and Minas Gerais. These initiatives have been instrumental in Brazil's energy and technological advancement, solidifying the nation's pivotal role in these sectors regionally and internationally [17].

4. NAVIGATING GLOBAL FLUCTUATIONS: BRAZIL'S ROLE IN THE URANIUM MARKET

Brazil, capitalizing on the growing global interest in low carbon electricity generation, such as nuclear energy, has the potential to strategically position its uranium market to optimize future cash flow. In 2012, Brazil's uranium reserves were 309,000 tons. However, due to the vast territorial extension of the country, it is estimated that this number could increase to 800,000 tons, considering that 75% of Brazilian territory has yet to be geologically explored [21]. Furthermore, with the increase in global demand for clean energy, the country has the potential to become one of the top three key players in the international uranium market.

Uranium is in high demand to meet market needs, especially in energy generation. There are 440 nuclear power plants worldwide, and uranium also contributes to the production of medical isotopes (used in medical treatments and imaging diagnostics), agronomy (biological pest control in agricultural production), where it can contribute to advanced fertilization and pest control techniques and maritime propulsion [5]. With the introduction of small modular reactors (SMR) and particularly the commitment of 22 countries at the United Nations Climate Change Conference (COP28) in 2023 to triple nuclear energy capacity by 2050, uranium use has increased. Therefore, uranium has become a commodity of great strategic importance [22].

Taking into account the demand described earlier, factors such as the war between Russia and Ukraine, anti-government protests in Kazakhstan, and environmental considerations in uranium extraction must be taken into account, as they cause fluctuations in the price of this mineral. Specific events, such as the situation in Kazakhstan, illustrate these variations. In 2020, Kazakhstan supplied 40% of the world's uranium. When they decided to abolish the maximum price system, the price of liquefied gas soared. The unrest in Kazakhstan lasted nine days, but significantly affected uranium prices. The initial price of uranium in 2022 was 42 USD / lb of U3O8, but the spot price skyrocketed. Another notable example was the start of the war between Russia and Ukraine. Uranium prices rose from $30.35 per pound in January 2021 to $45 per pound on February 28, 2022 (four days after the invasion began) and $52.35 per pound on March 8. The price continued to rise even after April, reaching $63.75 on April 13 [23]. Moreover, events such as the Fukushima disaster and the geopolitics involved influence the extraction process and uranium prices, highlighting the need for a continuous analysis of price fluctuations to assess the economic viability of nuclear energy.

To maximize the potential of the entire uranium chain, Brazil must meticulously plan to identify and mitigate the risks associated with this sector, including environmental and regulatory challenges. Additionally, it is prudent to consider establishing public-private partnerships with experienced companies in the uranium sector, adapting processes to achieve a superior position in the global market. It is important to note that uranium would not only be valuable in the energy sector but also in health and agriculture, as previously mentioned. This facet would ensure a solid economic return, strengthen the country's energy independence and profile in sustainable energy, and increase innovation in vital sectors of the Brazilian economy [24].

Also, it is important to define quantifiable and precise goals and indicators for all activities and actions regarding the human resources necessary to achieve Brazil's technological autonomy in terms of economic and scientific independence in the nuclear sector. As seen in other countries, there has been talk recently about the idea that the Brazilian nuclear sector's production chain can be developed quickly and sustainably with objective infra-legal measures allowing the flexibility of the Union's monopoly through a constitutional amendment. It is noteworthy that this process of flexibility occurred in countries where the nuclear sector's production chain is already well-structured and plays an active role in global markets. Thus, with the flexibility of the monopoly, the possibility of attracting private investors while maintaining the state producer model can be achieved. The impossibility of this change is due to the global financing standard for infrastructure sectors, given the debt constraints of the state, especially for developing countries like Brazil. In summary, a new paradigm can be seen as the regulatory state. In this context, the international experiences accumulated by the United States, the United Kingdom, and Canada deserve the analytical attention of Brazil regarding this flexibility. Of course, when discussing the flexibility of the monopoly, the exploitation of nuclear minerals or the enhancement to ensure private sector participation in the uranium enrichment process, guarantees that do not compromise the security, protection, or nonproliferation objectives adopted by Brazil must be considered, *i.e.,* national sovereignty must be maintained. It is important to not forget that, through human resource development, research can be conducted that disseminates scientific and technological knowledge, promoting improvements in the production and supply of the nuclear sector. Another important example that must be carefully observed is that of the United States, where investments in human resources in nuclear science infrastructure and engineering fields occur through scholarships and visiting scientist programs, as well as student training programs. When observing the budgetary value allocated to human resource training in the nuclear area within the execution of the PPA (Pluriannual Plans) budgets of the nuclear programs, it is evident that these values are completely below Brazil's real needs. Therefore, without proper management of budget execution for human resource training in the nuclear area, the problem of intellectual capital leaving the country and the lack of sufficient personnel to occupy positions in the Brazilian nuclear sector will persist. Therefore, human and financial resources within the scope of Brazil's nuclear plan must be guaranteed to preserve the country's nuclear technology mastery.

Uranium mining and milling have undergone significant evolution over the years. By comparing modern approaches with outdated practices, it becomes evident how uranium mining can be conducted in a way that protects workers, the public, and the environment. Although this article did not directly address the environmental issues related to uranium mining, both in Brazil and other countries, it is essential to consider the environmental impact of this activity and seek sustainable alternatives, such as reprocessing and recycling.

While Brazil needs to face this reality to ensure the future of nuclear energy, other nations are already implementing strategies to mitigate the potential environmental damage caused by mining. Innovative and modern mining practices, combined with strictly enforced regulatory standards, aim to avoid past mistakes, particularly those made during the early history of the industry when maximizing uranium production was the main priority. Current leading practices in uranium mining strive to produce uranium efficiently and safely, limiting environmental impacts to acceptable levels. The collection of baseline environmental data, continuous monitoring, and public consultation throughout the mine's life cycle are essential to ensure that the operation proceeds as planned, providing early warnings of any adverse impacts, and keeping stakeholders informed [25].

Best practices also involve planning for mine closure before production begins, ensuring that the area is returned to an environmentally acceptable condition. It is crucial for mine workers to be well-trained and equipped, and for the work environment to be well-ventilated to minimize exposure to radiation and hazardous materials, thus reducing health impacts.

The adoption of these sustainable and innovative practices is crucial to ensure long-term sustainability, as well as the economic and environmental viability of nuclear energy.

5. CONCLUSIONS

Brazil's nuclear policy evolution during the 2000s reflects a complex interplay of domestic priorities, international dynamics, and strategic considerations. The revival of nuclear plans and their expansion during the current administration underscore Brazil's aspirations for technological autonomy and strategic influence on the global stage. However, the ambivalence toward the nonproliferation regime, coupled with disagreements over safeguards and access to nuclear technology, highlights Brazil's cautious approach to international norms and its determination to safeguard its technological advancements.

Moreover, Brazil's nuclear diplomacy efforts, including its leadership roles in disarmament conferences and bilateral cooperation with Argentina, demonstrate its commitment to shaping global nuclear governance while safeguarding its national interests. As Brazil navigates its nuclear trajectory, it faces the challenge of balancing its pursuit of technological advancement with its obligations under international agreements and the imperative of regional stability. Ultimately, Brazil's nuclear policy in the 2000s reflects its quest for strategic autonomy, technological prowess, and a nuanced approach to global nuclear governance.

Large economies such as China, India, Japan, Europe and the United States adopting nuclear energy and expanding their nuclear energy production capabilities have caused uranium prices to increase. However, the growing demand for this type of energy has raised concerns related to the global uranium supply chain. Brazil is one of the few countries in the world that, in addition to having the 6th largest uranium supply on the planet, has knowledge about all stages of the fuel cycle, being capable not only of mining, but also of enriching and producing pellets. All the factors presented and discussed here point to a favorable scenario for Brazil's leadership in the world uranium market, with INB's unconditional participation and search for partners, so that together with it can expand uranium exploration both in deep mining and in expansion of already installed production capacity.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest to disclose or personal relationships that could have appeared to influence the work reported in this paper.

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