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THE BRAZILIAN NAVY NUCLEAR PROGRAM: APPLICABILITY, VIABILITY AND RELEVANCE

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ABSTRACT

One of the cleanest energy sources on the planet, nuclear energy is recognized for its great potential as a dual-use technology (with both civil and military application). The complexity of nuclear development also results in an intense spin-off process, generating benefits in the social, scientific, and industrial fields and contributing to projects in different sectors. The objective of this paper is to present the Brazilian Navy's Nuclear Program, its history and its main aspects. Moreover, it aims to outline the relevance of the program to the Brazilian nuclear sector and to the national defense industrial base. For this purpose, the text is mostly based on official data and literature review, focusing especially on nuclear development since the 1940s. Its results allow us to conclude, in particular, that the development of this technology would also enable Brazil to remain in the group of countries with high nuclear capacity as well as, in the future, to become an exporter of nuclear fuel. Finally, it is important to understand it as a long-term state program and to ensure its maintenance and continuity, given its current advanced stage and its effects on Brazil's development.

Keywords: Brazilian Navy's Nuclear Program. Nuclear energy. National defense. Technology spillover. Brazilian Navy. Public policies. Defense industry. Defense Industrial Base (DIB).

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INTRODUCTION

Considered one of the cleanest energy options on the planet, nuclear energy requires knowledge and technologies of a high degree of complexity in its generation process. The great interest in its development is especially justified by the versatility of its applications, with particular emphasis on electric power generation, its most popular application. Possessing a dual-use nature – deployed in both civil and military sectors – nuclear technology is employed in areas such as medicine, industry and agriculture, to name a few examples. In addition, it creates strong bonds of dependence between those who produce it and those who use it.

The complexity regarding nuclear development often results in the association between the domain of this technology and national scientific and technological progress. Furthermore, Brazil's use of nuclear energy exclusively for peaceful purposes demonstrates the country's responsibility to comply with international norms on the subject - in broad terms and more specifically in relation to its neighbors, given the historical success of the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), created in 1991, which will be further discussed.

From the 1950s on, Brazil dedicated itself to the search for autonomy in what concerns nuclear development, and established its first agency focused on this type of energy in 1956 – the National Nuclear Energy Commission (CNEN). In this regard, the Brazilian Navy Nuclear Program (PNM) was created in 1979, with the purpose of achieving control of the nuclear fuel cycle and building a propulsion plant through the nuclear reactor – which would be a prototype on land of the propulsion system to be used in the first national nuclear-powered submarine.

In 1987, representing one of the first effects of the PNM, Brazil announced the domain of the technology of enrichment of uranium for ultracentrifugation. Currently, the country possesses technological autonomy in all the stages of production of the nuclear fuel. The prototype in land of the system of nuclear propulsion is under construction, with its commissioning foreseen for 2021. This step constitutes one of the most significant in what it refers to the development and building of the first Brazilian submarine with nuclear propulsion.

Nuclear development stimulates the national industry and brings advances in science, technology and innovation. Furthermore, the domain of nuclear capacities has raised Brazil to the select group of countries that have the potential and credibility to develop such technology for peaceful purposes.[4] Therefore, the PNM – as well as the Submarine Development Program (PROSUB) – consists not only of a strategic program of the Brazilian Navy, but also of a State program, being fundamental for the Brazilian nuclear sector and, ultimately, for the country's technological development.[5]

Research and processes related to nuclear development also bring several direct and indirect benefits – such as technological externalities. One of the projects that directly benefits from the technology developed under the PNM is the Brazilian Multipurpose Reactor (RMB), which will be presented and discussed throughout the text, as well as other important projects carried out in Brazil. Within this framework, the main objective of this paper is to demonstrate the relevance of the PNM for national defense and for the development of the country. Besides the progress directly related to the nuclear fuel cycle domain, this paper also intends to point out the gains provided by the use of nuclear technology in different sectors.

In order to meet the objective stated above, this text is mostly based on official data and literature review and has four sections, in addition to this introduction. The first section presents the history of nuclear development in Brazil, from institutionalization to the most recent advances in the sector. The second section focuses on the PNM itself, presenting its main aspects and its current perspectives. The third section, in turn, highlights the positive externalities caused by the technologies developed within the PNM when applied in projects that directly benefit society and different civil sectors. Finally, the last section compiles the collected information and provides final considerations on the subject.

NUCLEAR DEVELOPMENT IN BRAZIL

The first experiences concerning the development of nuclear technology worldwide originated from the perspective of achieving a new

[4] Nuclear verifications have been made available by different institutions such as the Nuclear Futures Lab at Princeton University, and Arms Control Association (PRINCETON NUCLEAR FUTURES LAB, 2020; ACA, 2017).

[5] Brazilian Navy Nuclear Program (PNM) and Brazilian Navy Submarine Development Program (PROSUB) are two different and distinct programs carried out by the Brazilian Navy. Despite their very close and interconnected relationship, each one has its own objectives, actions and budgets.

source of energy – by exposing uranium to specific chemical conditions (TEIXEIRA, 2007). Still in the 1930s, several studies were carried out by scientists from different universities around the globe, culminating in the creation of the Uranium Commission (1939) and the National Defense Research Committee (1940), both in the United States (US) and composed of physicists – Americans and foreigners – and military personnel from that country (CNEN, 2017).

In December 1942, as a result of the efforts of the newly created institutions, the first nuclear reactor, built at the University of Chicago by a group of scientists led by the Italian Enrico Fermi, came into operation. The reactor was based on the fission of enriched uranium, a process that releases a large amount of energy, and still being used in current reactors. Its design allowed the generation of a self-sustaining chain reaction - making nuclear energy one of the cleanest, since it produces little waste and does not emit greenhouse gases (CNEN, 2017).

In addition to the development of the nuclear reactor, the scientists had already identified that the amount of energy released by fission of enriched uranium could allow the construction of extremely powerful bombs. The American participation in World War II (1939-1945) resulted in the application of the nuclear field discoveries for military and non-peaceful purposes – in 1945, the first explosion of a nuclear artifact was carried out in the US, and a few days later two nuclear bombs were dropped on the Japanese cities of Hiroshima and Nagasaki (CNEN, 2017; LEITE; ASSIS; CORRÊA, 2016).

In 1954, the US launched the submarine Nautilus into the sea, being the first one with nuclear propulsion (WADE, 2018). The incorporation of a nuclear reactor into a naval environment represented a new military employment for nuclear technology, reinforcing its great potential for applicability. Today it is estimated that there are about 160 of them, most being submarines, but also including military vessels such as aircraft carriers and icebreakers (WORLD NUCLEAR ASSOCIATION, 2020).

The beginnings of nuclear development in Brazil also date back to the 1930s, when research on cosmic radiation and radioactivity began at the University of São Paulo (USP). However, only in the following decades the country began to seek partnerships that would enable the acquisition and development of nuclear technology, as will be further detailed.

INSTITUTIONALIZATION OF THE NUCLEAR SECTOR IN BRAZIL

The high degree of technological complexity and the need to comply with the strict standards of the international regime have led the states to be the main players in nuclear development. To these factors should be added elements such as the dual-use nature of nuclear technology and the sensitive knowledge required to generate this type of energy (LEITE; ASSIS; CORRÊA, 2016; PATTI; SPEKTOR, 2020). It is therefore important that states have an institutional structure for the development and promotion of the nuclear sector, comprising its own bodies, legislation and policies. Accordingly, Brazil has sought to establish such framework since the 1940s, thus reaching its current stage.

The 1940s and 1950s were marked in Brazil by the signature of bilateral cooperation agreements in the nuclear agenda. In 1940, the country signed an agreement with the US for the prospection of radioactive minerals. In 1951, the National Research Council (CNPq) was created – currently called the National Council for Scientific and Technological Development – having Admiral Álvaro Alberto as its idealizer and first director (PATTI, 2012; CNEN, 2017).

In the following years, during Getúlio Vargas' government, Brazil sought to acquire nuclear technology and equipment by signing cooperation agreements with developed countries, such as West Germany – for centrifuges for uranium enrichment; France – for uranium dioxide; the United Kingdom (UK) – for uranium hexafluoride; and the US – for research reactors (CNEN, 2017). With the exception of the agreement signed with the US, all of the others were frustrated by the death of Vargas in 1954 and the rise of Café Filho as president, who decided Brazil should be only aligned to Washington.

In 1956, after Juscelino Kubitschek took office as president, the Atomic Energy Institute (IEA) was created, with the specific purposes of conducting research in the nuclear field and leading to the installation of the first research reactor in the country. In the following year, Brazil signed an agreement to join the North-American program "Atoms for Peace". As part of the program, Brazil inaugurated its first nuclear research reactor – and the first in Latin America – the IEA-R1 (CNEN, 2017).

As observed, during the Kubitschek government, Brazilian nuclear policy took on more assertive contours. At that time, the National

Nuclear Energy Commission (CNEN) was created, being established in 1956. In the 1960s, the first research reactor built in Brazil (Argonauta) was inaugurated, containing 93% of national components (IEN, 2019). It particularly confirmed Brazil's interest in developing nuclear technologies.

ADVANCEMENTS OF NUCLEAR TECHNOLOGY IN BRAZIL

During the military regime, the Brazilian nuclear program acquired a more strategic orientation and experienced years of constancy in both investments and objectives. Under president Costa e Silva's rule, a plan was drawn up for the complete and autonomous development of nuclear energy in Brazil (PAUL, 2000, p. 110). However, the choices made over this period would lead Brazil to maintain a relationship of dependence with the US. As Patti (2012) notes, the Brazilian effort at the time was to obtain, through international agreements, the necessary infrastructure to develop the national nuclear industry core in a short period.

In this context, between 1971 and 1972, CNEN and Eletrobrás led negotiations for a nuclear agreement with the US that would allow Brazil to build its first thermonuclear plant. Installed in Angra dos Reis, in the city of Rio de Janeiro, the plant (Angra I) would be supplied with enriched uranium, although the agreement did not contemplate the transfer of any technologies to Brazil: neither that of the reactors, nor that of uranium enrichment. Thus, in the short and medium term, the deal kept Brazil dependent on enriched uranium imported from the US (KURAMOTO; APPOLONI, 2002). As will be detailed below, the rupture of this dependence started around the mid-1970s, with an agreement signed with Western Germany, and reached an important milestone in the following decade, after the endogenous development of nuclear enrichment technology by Brazil (NEDAL; COUTO, 2013).

Still in the 1960s and 1970s, the Brazilian nuclear policy would start to adopt a more assertive profile on the international level. Brazil's engagement with non-proliferation had its first landmark in the regional sphere, with the signature of the 1967 Tlatelolco Treaty, which prohibited nuclear weapons in the Latin American and Caribbean region. It is interesting to note that Brazil ratified it the following year, which is rather unusual in the Brazilian ratification process. In order to ensure compliance with its obligations, the treaty created the Organization for the Proscription of Nuclear Weapons in Latin America and the Caribbean (OPANAL).

As of 1970, in turn, the newly established Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was open for signature. Under the argument that the treaty was discriminatory and promoted a freeze of world power, creating a class of countries with the most advanced technologies in the nuclear area and another category of nations without the right to develop them, Brazil refused to join it, a position that would only be revised in the 1990s (CASTRO, 1971).

With the first oil shock in 1973 and the first Indian test with nuclear explosives in 1974, Brazil felt the impacts of its choice for continued nuclear dependence. At that time, and especially because of the mentioned events, the U.S. Atomic Energy Commission announced that it would not comply with the agreements with Brazil for the supply of enriched uranium necessary for the operation of the research and energy reactors (COSTA, 2000). This context prompted Brazil, under the Ernesto Geisel administration, to resume the path of seeking autonomy in the nuclear area, leading to the signature of the nuclear agreement with West Germany in 1975 (LOHBAUER, 2000).

In order to implement the agreement, the state-owned company Nuclebrás Equipamentos Pesados S/A (Nuclep) was created on the Brazilian side. According to Kuramoto and Apolloni (2002), the endeavor was an attempt by the military government to provide Brazil with advancements equivalent to those of countries then considered modern. Also, nuclear energy would be the most viable solution to the problem of dependence on electric power, since the exhaustion of the hydroelectric potential in Brazil was already calculated at that time (CARPES, 2006). Furthermore, nuclear energy would relativize the Brazilian dependence on coal and oil imports in the long term.

The agreement with West Germany foresaw the construction of eight thermonuclear power plants and the transfer of technologies to Brazil, including that of uranium enrichment (LOHBAUER, 2000; ADLER, 1987). In the years following the agreement signature, both Brazil and Germany underwent international pressure to undo it – mainly from the US. Although Brazil and Germany maintained the agreed commitment, the terms of the agreement suffered significant changes, driving Brazil in the direction of an independent search for nuclear autonomy.

In 1979, Brazil opted for the development of an autonomous nuclear program, under which the desired uranium enrichment technology could be developed without external interference (PATTI, 2012). The first stage of the program involved the three branches of the Armed Forces in a scientific effort to obtain its own nuclear technology. The Navy carried out studies regarding ultracentrifugation; the Army, regarding graphite; and the Air Force, regarding laser technologies. The attempts of the Navy on ultracentrifugation were the most successful and the one that originated the Brazilian technology of uranium enrichment. Beyond the development of uranium enrichment technology, the program also included investigations on electric energy generation, as well as it foresaw the construction of nuclear reactors for submarine propulsion and for thermonuclear power plants (CARPES, 2015).

An important step for the development of these technologies was the accomplishment of the first experiences with an ultracentrifuge capable of providing the isotope separation of uranium (process of enrichment), in 1982, and the acquisition of several mini cascades for centrifugation, put in operation in 1984. In the following years, until 1989, there were many delays due to problems related to the operation of the new ultracentrifuges. In this period, it was possible to reach up to 5% of uranium enrichment (BARLETTA, 1997), which was enabled from efforts of recently created specialized bodies, such as the Special Projects Coordination (Copesp), and the Aramar Experimental Center (CEA), in Iperó, São Paulo.

During the 1990s, there was a discontinuity in the pursuit of the general objectives regarding nuclear technologies development, including the construction of the nuclear-powered submarine within the Navy. In this period, occurs what Batista (2000) considers a dismantling of the national nuclear program, in the administrations of Fernando Collor de Mello and, especially, Fernando Henrique Cardoso (CARPES, 2006).

At the regional level, there have been significant advances in the nuclear area. In 1991, Brazil and Argentina signed a deal that would allow the creation of the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC). In the same year, Brazil, Argentina, ABACC, and the International Atomic Energy Agency (IAEA) signed a quadripartite agreement that would bring both Brazil's and Argentina's nuclear programs under international safeguards (ABACC, 1991). It is worth mentioning that the ABACC is not just the only agency of its kind in the world, but it has also become an international model of bilateral nuclear confidence building.

The NPT was signed and ratified by Brazil in 1998, which contributed to the adoption of policies to reduce public spending on nuclear issues. Within this context, Brazilian investments in nuclear development began to be more constrained, at the national and international levels, after the country entered the treaty (CORRÊA, 2010). Therefore, such budget restrictions made it difficult for the Navy to continue prioritizing the PNM and the nuclear-powered submarine project, thereby focusing on maintaining human resources and the means of operation already in place.

Throughout the 2000s, there was renewed focus on the Brazilian Nuclear Program (PNB), which began with the revision of its current aspects and the reinforcements of its original objectives, namely the construction of the nuclear-powered submarine and the inauguration of the uranium enrichment facility. In this context, the PNB was put back into the condition of a State policy precisely to guarantee its continuity and budget.

At the domestic level, the arguments for the resumption of the program included, in particular, the importance of diversifying energy sources, increasing the use of an energy considered clean rather than those that result in CO^2 emissions. In the scope of strategic interests regarding foreign policy, it is worth noting that the motivations for the renewal of the program were based on autonomy in science, technology and innovation in key areas that could give the country international prestige and demonstrate its maturity in highly complex areas (CARPES, 2006).

Internationally, Brazil is recognized for its trajectory on the subject, for its political decisions regarding nuclear issues and for its respect for international nuclear disarmament obligations and regime – being for example the only BRICS country that has never developed nuclear weapons. Furthermore, the acknowledgement extends to the fact that the country is a signatory to nearly all regional and multilateral agreements prohibiting the development, storage, or use of nuclear weapons – with the only exception of the Additional Protocol to the NPT. Brazil has therefore proved to be a responsible country, without geopolitical motivations to proliferate nuclear technology and committed to both non-proliferation and disarmament international efforts (SPEKTOR, 2017). More recently, it has strengthened its engagement by taking a leading role in the negotiations of the Treaty on the Prohibition of Nuclear Weapons (TPNW), which the Brazilian president was the first to sign (BRAZIL, 2017).

Alongside these commitments, the country has pledged the legitimate right to develop nuclear technology for peaceful purposes, which is guaranteed by the NPT. In this regard, the next section intends to examine and discuss the main elements that constitute the Navy Nuclear

Program (PNM), as well as its relevance to National Defense and to the country's development.

THE BRAZILIAN NAVY NUCLEAR PROGRAM AS A NATIONAL STRATEGIC COMPONENT

The resumption of the Brazilian nuclear program in the early 2000s focused on four major technological efforts set out in the 2008 National Defense Strategy (END): i) concerning the nuclear-powered submarine program, to achieve the complete nationalization of core technologies and the development of the nuclear fuel cycle on an industrial scale, including reactor manufacturing; ii) to accelerate the mapping, prospecting and exploitation of uranium deposits; iii) to develop the capacity to design and build nuclear thermal power plants, with technologies and capabilities that lie under national domain, even if developed through partnerships with states and foreign companies, thus contributing to supply the demand for renewable energy; iv) to increase the capabilities to use nuclear energy in a broad spectrum of activities (BRAZIL, 2008).

In summary, the current panorama of the Brazilian Nuclear Program presents two main dimensions: a strategic one, based on the construction of the nuclear-powered submarine, and a commercial one, with the possible participation of Brazil in the international market of enriched uranium (LEITE; ASSIS; CORRÊA, 2016). As for the former, it is worth mentioning that only few countries in the world currently have technologies for the construction of this class of submarines – China, United States, France, India, United Kingdom and Russia.

In general, Brazilian interests in the nuclear-powered submarine is guided by the primary objective of protecting the Blue Amazon, reaching even other regions of interest in the future – thus serving as a political and strategic instrument of deterrence and sea denial, as well as being a source of prestige and projection of power. The achievement of this advanced capacity, also supported by the partnership with France in the scope of PROSUB, represents a significant step towards the recognition of Brazil as an important player in discussions and decisions regarding nuclear energy.[6] Considering the aforementioned context,

[6] It is worth noting that the agreement with the French company Naval Group does not encompass the transfer of nuclear technology, which is an autonomous national development (NAVAL GROUP, 2015).

this section intends to elaborate on the specific elements of the Brazilian Navy Nuclear Program (PNM).

Another relevant defense-related instrument, the Brazilian Defense White Paper (LBDN) defines the key features of the PNM, implemented since 1979. Its main purposes are to achieve complete and autonomous control of the nuclear fuel cycle, and building a nuclear power generation plant – the Nucleo-Electric Power Generation Laboratory (LABGENE), which would serve as a prototype for the reactor of the country's first nuclear-powered submarine (BRAZIL, 2012a; 2012b; BRAZILIAN NAVY, 2017; 2018a).

Strongly connected, although distinct, PNM and PROSUB are programs subordinated to the recently created Directorate General of Nuclear and Technological Development of the Navy (DGDNTM), which also incorporated the Navy Technological Center in São Paulo. The 2016 restructuration led to the establishment of the new Directorate General, aiming at the rationalization of resources allocation and the execution of the main project of Brazilian Navy at present, the deployment of the nuclear-powered submarine (BRAZILIAN NAVY, 2017; ANDRADE et al., 2018). The DGDNTM is then the central executive body of the Brazilian Navy's Science and Technology System, being responsible for the coordination of research and development, and science, technology and innovation activities (BRAZILIAN NAVY, 2017a).

The development of the nuclear-powered submarine is also closely associated with the Brazilian National Defense Strategy (END) with respect to the three sectors defined as strategic and essential for national defense: space, cybernetics and nuclear. The most recent edition of the document reinforces that the nuclear area transcends the division between development and defense and corroborates the importance of complete nationalization on an industrial scale of the nuclear fuel cycle technologies, as well as of reactor construction process (BRAZIL, 2018). It is especially important to emphasize that states in general do not transfer this type of technology. In 1978, Brazilian Navy thus stated that it was essential to build nuclear-powered submarines, but pointed out that it would first be necessary to pursue complete control of the nuclear fuel cycle and only then develop an autonomous nuclear propulsion system, using exclusively national effort (LANA, 2014; ANDRADE; CARPES; LEITE, 2018).

Specific research object of this article, the PNM is coordinated by the Navy Technological Center in São Paulo (CTMSP), being developed mainly at the Aramar Experimental Center (CEA). The program targets the establishment of endogenous technical competence to design, build, commission, operate and maintain Pressurized Water Reactor (PWR) type nuclear reactors, as well as to produce their fuel. As previously mentioned, the PNM also has the construction of a nuclear power generation plant as its objective, in addition to the goal of achieving the complete control of the nuclear fuel cycle (BRAZILIAN NAVY, 2007; LANA, 2014).

In September 1987, Brazil announced the domain of the technology of uranium enrichment by ultracentrifugation, which represented a fundamental step in its nuclear research efforts. Following that, the country thus possesses the technological control of all the stages of the nuclear fuel cycle (LANA, 2014; CNEN, 2016a). Regarding the other front of the PNM – the installation of a nuclear power generation plant, the Brazilian Navy is building, at CEA, the LABGENE. As previously stated, it is an onshore prototype of what will constitute the first Brazilian nuclear-powered submarine propulsion system, simulating the conditions that will be found within the submarine operation (LANA, 2014; KASSENOVA, FLORENTINO, SPEKTOR, 2020).

In an interview given in 2017, the Director General of DGDNTM pointed out that the Brazilian Navy is the only military branch in the world whose nuclear program is under the safeguard of the International Atomic Energy Agency (IAEA) – as well as the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) (ALBUQUERQUE JÚNIOR, 2017a).

In 2013, the PNM – as well as the PROSUB – was included in the federal government's Growth Acceleration Program (PAC),[7] reinforcing its strategic importance for Brazil. The integration of PROSUB into the PAC is justified by the many benefits the program brings to the State and to Brazilian society. Based on the triad of technology transfer, nationalization and personnel training, the program is deeply connected to science, technology and innovation, providing in all its stages considerable returns and positive externalities for society and for national development (BRAZILIAN NAVY, 2014).

[7] See more information on this program at: <http://pac.gov.br/>.

DIRECT BENEFITS AND EXTERNALITIES: PNM AS A DRIVER FOR NATIONAL DEVELOPMENT

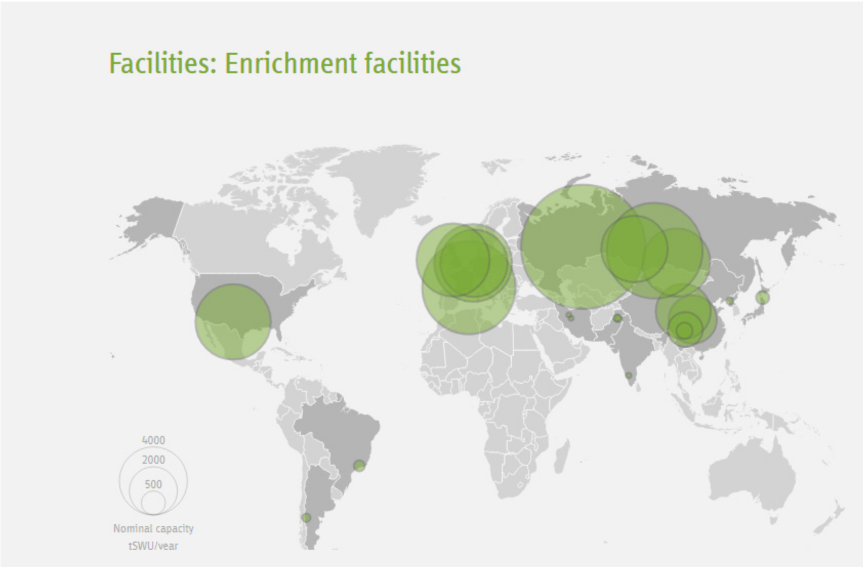
The nationalization of components and technologies driven by autonomous development or technology transfer generates opportunities for a significant spillover process across national industries. This particularly results in the diffusion of specialized knowledge by different productive chains, in benefit of the Brazilian society. When it comes to military technologies this process is especially intensified. The dual-use nature is a common feature in the defense industry, contributing significantly to the development of different sectors and of science, technology and innovation endeavors.

The concept of spillover is deeply related to innovation and consists precisely in the overflowing of a technology to different civilian sectors. Traditionally recognized for its dual nature, the defense industry thus constitutes an important agent of scientific and technological generation, promoting various other industrial areas. In that sense, we may observe that technological knowledge is considered an influential component of geopolitics, increasing the dissuasive power of a country in the international landscape (TILL, 2009; ANDRADE; FRANCO; HILLEBRAND, 2019).

In general, the PNM has the potential to produce relevant impact in the technological and productive areas in Brazil. Among its positive externalities, we can highlight the development of several systems and their employment in the national industry, such as special alloy steels, polymeric materials and digital control systems, increasing the qualification of Brazilian companies. Moreover, LABGENE itself is an example of a project based on dual-use technology, since it may serve as a model for reactors to be installed in isolated locations for electricity generation and for water desalination.

As far as the international nuclear scenario is concerned, it is interesting to note that the Brazilian nuclear plants are some of the very few enrichment plants in the Southern Hemisphere, according to the International Panel on Fissile Material at Princeton, which reports the location estimates of enrichment plants and several other data. The figure 1 shows all known uranium enrichment facilities worldwide as of the end of 2019.

Figure 1 – Uranium enrichment facilities worldwide (2019)



Source: IPFM, 2020.

From a historical perspective, it is also interesting to point out that some of the main defense companies currently operating are those that benefited from major military projects in the 1980s – period when Brazilian Defense Industrial Base reached its peak (CONCA, 1997; PIM, 2007). Thus, the large size and scope of PNM also allows us to imply that the participating companies will benefit from substantial positive effects. These outcomes derive in particular from the program's nationalization component, which will secure their development and the expansion of their business in the medium and long term.

One of the central features of the Brazilian Navy's Science and Technology System, the PNM is closely articulated with the Brazilian Nuclear Program. By maintaining important partnerships with agencies such as the Nuclear Industries of Brazil (INB) and the Institute for Energy and Nuclear Research (IPEN), the Brazilian Navy performs all its activities in accordance with the guidelines of the National Nuclear Energy Commission (CNEN), including those related to licensing, inspection and control issues. Currently, the Brazilian Navy also supports the installation of isotopic separation systems (ultracentrifuge cascades) in the INB, through a signed agreement, by supplying ultracentrifuge cascades for uranium enrichment. It is important to note that the Brazilian Navy is the only provider of ultracentrifuges in the country (NAVY OF BRAZIL, 2018b; KASSENOVA, FLORENTINO, SPEKTOR, 2020).[8]

Advantages for Brazilian foreign trade can also be credited to PNM. In 2016, Brazil started to export enriched uranium to Argentina, through the Brazilian Nuclear Industries (INB) and with the Brazilian Navy technology (DRUMMOND, 2017). Therefore, the country, which previously sold only crude ore, becomes an important player in the nuclear fuel market, being able to supply a product of high added value to other countries. There is also the major asset of being the only country in Latin America and the Southern Hemisphere that dominates the technology necessary for its production (LANA, 2014; DRUMMOND, 2017).

The export of enriched uranium changes Brazil's status at international level, no longer seen only as an ore reservoir. The country thus acquire the recognition that it has the capacity and expertise to produce and sell nuclear fuel on the international market (FERREIRA MARQUES, 2017). Furthermore, in the future, it is expected that Brazil will also be able to export submarine equipment and systems, and even the vessels themselves, as a direct result of the PROSUB. Hence, it is noticeable that the PNM alongside with the PROSUB represent a major step in strengthening the national Defense Industrial Base (LANA, 2014; DRUMMOND, 2017).

In addition to the PNM's relevance in terms of Brazil's national defense, deterrent capacity, and Defense Industrial Base enhancement, the program will also directly contribute in different productive sectors of the country. The highly advanced industrial and nuclear technologies developed in the program will enable important advances in areas such as nuclear medicine, agriculture, environment and the chemical industry. One of the main applications of the developed technologies will occur within the Brazilian Multipurpose Reactor (RMB).

The RMB has as its main objectives i) the production of radioisotopes and radiopharmaceuticals; ii) the irradiation and testing of nuclear fuels and structural materials; and iii) the development of scientific and technological research using neutron beams.[9] It is also important to emphasize the qualification of the national industry that will result from the project,

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[8] It should also be noted that part of the fuel used in the Angra plants is enriched through the technology developed by the Brazilian Navy in Aramar.

[9] More information on this subject is available on the website of the Institute for Energy and Nuclear Research (IPEN). See at: <https://goo.gl/Kb9DQE>.

especially in the testing and qualification of nuclear materials and fuels, a fundamental step to ensure safety in the development of this technological cycle and in the manufacture of these products (CNEN, 2016b).

The execution of the entire RMB project is under the responsibility of the National Nuclear Energy Commission (CNEN) and is supported by the *Financiadora de Estudos e Projetos* (Finep), which signed an agreement worth R$ 150 million – in total, the project's budget is estimated at approximately US$ 500 million (R$ 2.65 billion).[10] *Amazônia Azul Tecnologias de Defesa S.A.* (Amazul), a Brazilian state-owned company that supports the development of different national programs, is co-executing the detailed project of RMB. The building will be located on a 2 million m^2 site in Iperó (SP), contiguous to CEA. Its operation, however, will be performed by CNEN (IPEN, 2020).

In the area of medicine, for instance, the development of RMB will make Brazil self-sufficient in the production of radioisotopes, elements used in the manufacture of radiopharmaceuticals that serve for the diagnosis and treatment of diseases such as cancer. Currently, Brazil imports about R$ 48 million of these supplies every year from Argentina, Russia and South Africa, providing them more than four hundred hospitals and clinics. It is also worth noting that demand for radiopharmaceuticals for hospital use is increasing rapidly while supply is declining (BRAZIL, 2018b; IPEN, 2019).

According to Admiral Bento Albuquerque Junior, current Brazilian Minister of Mines and Energy and former General Director of Nuclear and Technological Development of the Navy, the per capita use of nuclear medicine procedures in Brazil (which total approximately R$ 2 million annually) is twice as low as in Argentina and six times less than in the US. There is also a repressed demand in the sector, and the RMB will allow it to be met as well as to expand the amount of radiopharmaceuticals offered to society. The shift will therefore allow Brazil to optimize health resources and even become an exporter of the produced asset (ALBUQUERQUE JÚNIOR, 2017b).

In the agriculture, industry and environmental areas, the application of RMB will be focused on developing technologies that enable the use of radioactive tracers in different activities. Some examples of deployment are the testing of materials such as inertial sensors of oil platforms, the tracking of fissures in surfaces such as aircraft wings, and the verification of the amount of pesticides in food (DRUMMOND, 2017).

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[10] Exchange values for 01 July 2020.

It is clear from the externalities and actions mentioned above that the PNM, in addition to its primary objective, represents a program with impact in different areas. Besides the core improvements in national defense, the execution of the program also means the autonomous control of advanced technologies and the achievement of relevant progress in science, technology, and innovation, generating benefits to society and to the country's development.

FINAL REMARKS

The Brazilian Navy Nuclear Program (PNM) is shown to be significant in terms of national autonomy and technological achievements. From the elements presented throughout this paper, it can be stated that the PNM should be considered not only a strategic program of the Naval Force, but also an important program of State.

The development of nuclear technology provokes an extensive spillover process, leading to autonomy in terms of important technological applications, to the qualification of labor in a higher level, and to the endogenous manufacture of machines and industrial components. Such aspects, among others aforementioned, therefore justify the importance of the continuity of public investments in PNM. In addition, beyond the continuity in the allocation of resources to the program, it is essential to maintain the predictability in the application of these resources, allowing long-term planning and optimizing technological and scientific developments. The current stage and the achievements already accomplished by PNM corroborate the relevance of its continuation and improvement.

The intense articulation between PNM and Brazilian Nuclear Program is particularly important. In this sense, the Brazilian Navy's partnerships with key bodies in the sector, such as the INB and IPEN, stand out. It was observed that all the activities developed within the scope of the PNM are carried out in accordance with the CNEN guidelines. Moreover, the program is under safeguard of the International Atomic Energy Agency (IAEA) and the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC).

In general, the PNM causes impacts in different productive sectors, in addition to strengthening national defense capabilities. In this regard, among its positive externalities, the development of several items and employment systems in the national industry should be highlighted, increasing the qualification of Brazilian companies. In addition, the Laboratory of Generation of Nuclear Power (LABGENE) itself, as presented, consists of a significant example of dual-use technology application.

Through the assessment performed in this paper, it is possible to observe several positive results from the Brazilian Navy's efforts in the development of nuclear technology, specifically by means of the PNM. As one of the three strategic segments addressed by the National Defense Strategy, the nuclear sector has achieved important recent advancements and provided relevant progress in science, technology and innovation in Brazil.

The complete control of the nuclear fuel cycle, the autonomous development of advanced technologies and the training of highly qualified labor are combined with the achievement of international prestige, as results derived from the PNM. The construction of the Brazilian first nuclear-powered submarine and the possibilities of nuclear fuel exports also joins the direct benefits of the program. Therefore, it is recommended that efforts be maintained to ensure the necessary resources and investments, guaranteeing the PNM continuation and thus its positive effects on the productive and industrial sectors and ultimately on the development of the country.

O PROGRAMA NUCLEAR DA MARINHA: APLICABILIDADE, VIABILIDADE E RELEVÂNCIA

RESUMO

Uma das opções energéticas mais limpas do planeta, a energia nuclear é reconhecida pelo seu grande potencial de aplicabilidade dual (uso civil e militar). A complexidade inerente ao desenvolvimento nuclear resulta em um intenso processo de arrasto tecnológico, gerando benefícios nos âmbitos social, científico e industrial e contribuindo para projetos em diferentes setores. O objetivo deste artigo é apresentar o Programa Nuclear da Marinha do Brasil, seu histórico e seus principais aspectos. Além disso, pretende-se retratar a relevância do programa para o setor nuclear brasileiro e para a Base Industrial de Defesa do país. Para tanto, o texto estrutura-se a partir de informações oficiais e revisão de literatura, tendo como foco especialmente o desenvolvimento nuclear desde a década de 1940. Constata-se, em particular, que o domínio dessa tecnologia também permitiria ao Brasil permanecer no grupo de países com alta capacidade nuclear, bem como, no futuro, tornar-se um exportador de combustível nuclear. Finalmente, mostra-se importante compreendê-lo como um programa de Estado de longo prazo e assegurar sua manutenção e continuidade, tendo em vista seu estágio avançado atual e seus efeitos sobre o desenvolvimento nacional.

Keywords: Programa Nuclear da Marinha. Energia nuclear. Defesa nacional. Arrasto tecnológico. Marinha do Brasil. Políticas públicas. Indústria de defesa. Base Industrial de Defesa (BID).

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