Conexão Nuclear

Vol. No. **05**
Issue No. **20**
Sep. 2024

Licensing of New Reactors

Brazil has homework to do

For a More Sustainable World

Environmental Contributions of the Nuclear Sector

Supply of Radiopharmaceuticals

What are the challenges and opportunities for improvement?

Interview with Fatih Birol

Executive Director of the IEA

From energy transition to nuclear safety - in Brazil and globally

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DANCING WITH THE DEVIL

For several years, we have debated the extent of the participation of intermittent sources in the Brazilian electric grid. Academic studies had already shown that we would have inertia problems, particularly in the northeast of Brazil.

Adding to this fact, which imposes severe operating regimes on our hydroelectric plants—40% of which are approximately over 40 years old—the hydrological regimes of our rivers have been changing markedly, forcing us to review the hydrological cycles used in our electric planning.

The National Water Agency (ANA) just reinforced the situation of scarcity in the Madeira and Purus rivers in Amazonas, as well as their tributaries. The severe drought in the North has arrived. In 2023, the announcement was made in October.

The National System Operator (ONS), in July 2024, communicated to all companies to keep existing thermal plants fully available, indicating a high probability that we might need to activate them if it does not rain, leading consumers to pay high electric energy tariff rates.

The worst part of all this is that this scarcity scenario is not new. Since 2021, low rainfall has imposed much lower levels on hydroelectric reservoirs.

The need to ensure energy security makes it imperative that we change the way we plan our system—currently on a 10-year cycle, but 5 of these are already defined.

Another important issue is the multiple uses of water. An important discussion is knocking at our door about how much water we should keep stored at the end of a hydrological cycle in our dams, with the purpose of ensuring the supply for agriculture, human consumption, etc. Without a doubt, we will have to rethink the way to control all this intermittency that we are bringing into our system.

I must also remember here that 87% of energy generation in Brazil is renewable, and our sector accounts only for 2% of greenhouse gas emissions. In times of energy transition and climate programs, we need to accelerate investments in sources that take more than 10 years to come into operation, otherwise, we will continue to talk about the same problems and in a more catastrophic way than today.

In the past, we did a good job with the implementation of our hydroelectric and nuclear thermal plants. We created local supply chains, generated knowledge and technology. And now, with all this subsidy that we injected into intermittent sources, which exceeds 160%, it is worth evaluating how much content and knowledge actually remain in the country.

The whole world is rushing to advance with nuclear thermal plants. Brazil has the sixth-largest uranium reserve in the world and has only researched 1/3 of the national territory. We dominate the fuel cycle. I ask: What are we doing to participate in this select group of world suppliers?

In 2025, we will have COP 30 in Brazil, in the Amazon. And a good portion of the energy in the region is supplied by oil thermals. Let's dare, let's replace all with the new SMR technology!

What will our decision be: will we advance, or will we continue sitting idly by, always missing the opportunities that knock at our door? ▪

SMALL MODULAR REACTORS AND ISOLATED SYSTEMS: A LONG-TERM SOLUTION

U.S.-BRAZIL JOINT REPORT ON SMRS UNVEILS NEW OPPORTUNITIES AND CHALLENGES FOR THE BRAZILIAN ENERGY MATRIX

The Brazilian energy sector is at a pivotal moment, and new technologies are shaping its future. The recently released report "United States–Brazil Joint Study: A Preliminary Assessment of Opportunities and Challenges for Small Modular Reactors in Brazil" offers an in-depth analysis of the potential for Small Modular Reactors (SMRs) in Brazil. Among other possibilities, this technology emerges as a promising long-term solution suited for small capacities and isolated systems. This assessment, a collaboration between the U.S. Department of Energy (U.S. DOE) and the Idaho National Laboratory (INL) in partnership with the Energy Research Company (EPE), provides a detailed overview of how SMRs could impact the national energy matrix.

TECHNOLOGY AND POTENTIAL OF SMRS

The study reviewed over 80 global SMR projects, focusing on various technologies and concepts, including cooling and generation capacities. SMRs are touted as a flexible and scalable solution, with benefits such as lower initial costs and smaller spatial requirements compared to traditional nuclear reactors. However, the report clarifies that its purpose is not to assess the competitiveness of SMRs within the Brazilian energy matrix but to provide a basis for public policy formulation and regulation.

Thiago Ivanoski is the Director of Economic, Energy, and Environmental Studies at EPE, a state-owned company that provides services to the Ministry of Mines and Energy (MME) in the area of studies and research to subsidize the planning of the energy sector, covering electricity, oil and natural gas, and their derivatives, and biofuels. Among other activities, he works on the technical assessment of generation projects from all energy sources (hydropower, natural gas, wind, solar, biomass, nuclear, coal, etc.), including technical qualification and calculation of ceiling prices for electric energy auctions (including isolated systems), development of feasibility studies, inventory and optimization of hydroelectric plants, preparation of the Ten-Year Energy Expansion Plan – PDE, and the preparation of various technical studies aimed at subsidizing the planning of Brazil's energy sector.

Ivanoski highlights that "SMR technology is still in development, and the initial analysis done by the study focuses on assessing how these reactors can be integrated into the Brazilian market, considering data availability, costs, and regulatory issues."

INTERNATIONAL CONTRIBUTIONS AND DEEPENING

The study was conducted under the United States and Brazil Energy Forum (USBEF), a platform aimed at strengthening collaboration between Brazil and the USA in the energy sector. The expertise of the Idaho National Laboratory, one of the most respected nuclear research centers worldwide, was crucial for the project. INL, known for its excellence in nuclear research and housing over 6,000 researchers, brought refined technical vision and deep knowledge of emerging technologies.

According to Ivanoski, "Collaboration with INL and the U.S. DOE was essential for deepening the analysis of SMR technologies. They provided a technical and practical perspective that helped shape the understanding of the challenges and opportunities associated with these reactors in the Brazilian context."

CHALLENGES AND OPPORTUNITIES IN BRAZIL

The report does not recommend a specific technology or manufacturer but provides an overview of the opportunities and challenges associated with implementing SMRs in Brazil. Among the aspects covered are the adaptability

of technologies to the national energy market and the analysis of economic and regulatory factors. The flexibility of SMRs and their ability to operate at different scales are pointed out as significant advantages, especially in a country with a diverse energy market like Brazil.

The National Energy Plan 2050 (PNE 2050) already considers SMRs as a potential source of electric generation by mid-century, depending on factors such as cost reduction, technological advancement, and regulatory adaptation. EPE is closely monitoring the development of these reactors and the evolution of the global market, with the prospect that pilot projects could be carried out in the future to help assess the practical viability of these reactors in Brazil.

Ivanoski explains that "the effective integration of SMRs into the Brazilian energy matrix will depend on various factors, including technological progress, socio-environmental licensing, and the evolution of regulation. Pilot projects and demonstrations will be crucial to validate the technology and assess its suitability for our context."

"THE SCENARIO FOR SMRS IN BRAZIL IS PROMISING, BUT COMPLEX. IMPLEMENTING THIS TECHNOLOGY WILL REQUIRE SIGNIFICANT ADVANCES IN TERMS OF REGULATION, TECHNOLOGICAL DEVELOPMENT, AND SOCIAL ACCEPTANCE."

THE FUTURE OF SMRS IN BRAZIL

The scenario for SMRs in Brazil is promising but complex. Implementing this technology will require significant advances in terms of regulation, technological development, and social acceptance. The report provides a valuable starting point for understanding these challenges and opportunities, and international collaboration is a crucial aspect of the success of this endeavor.

As Ivanoski concludes, "the report provides a solid foundation for discussion and development of public policies and regulations that can support the integration of SMRs in Brazil. Although many steps remain to be taken, the potential for this technology is significant and deserves careful consideration.

" The future of Small Modular Reactors in Brazil is still being shaped, but ongoing analyses and collaborations offer a promising glimpse of what could become a crucial part of the Brazilian energy matrix in the coming decades.

EPE PUBLISHES COMPLETE VERSION OF PASI - PORTAL FOR MONITORING AND INFORMATION ON ISOLATED SYSTEMS

Isolated systems are areas that, for technical or economic reasons, are not connected to the National Interconnected System (SIN) and therefore receive electric energy services through local distributors and generation auctions, as per Decree No. 7.246/2010. The planning of these systems is done annually, taking into account specific characteristics of each locality, such as load, demand, and consumption profile, to define energy contracting needs. To improve economic and energy efficiency and promote the use of renewable resources, Ordinance Normative No. 59/GM/MME/2022 created PASI (Portal for Monitoring and Information on Isolated Systems). Developed by the Energy Research Company (EPE), PASI aims to centralize and disseminate important data on isolated systems, facilitating information exchange among responsible agencies. The complete version of PASI, published at the end of February 2024, gathers detailed data on consumer markets, load, demand, generation supply, plant costs, and other relevant aspects. The platform now includes information from ANEEL and CCEE, with new sections for data on plants, beneficiaries, and contracts, plus an updated glossary and explanations about the new features of the portal. Visit: https://pasi.epe.gov.br/ ▪

NUCLEAR ENERGY AND THE SUSTAINABLE DEVELOPMENT GOALS: A PARTNERSHIP FOR THE FUTURE

THE NUCLEAR SECTOR EMERGES AS A POWERFUL ALLY IN ACHIEVING VARIOUS GOALS.

In 2015, the UN General Assembly launched an ambitious global agenda for a sustainable future, marked by 17 Sustainable Development Goals (SDGs) to be achieved by 2030. These goals span a range of global challenges, from eradicating poverty and hunger to ensuring access to clean water and addressing climate change. For Clédola Tello, a researcher at the Center for the Development of Nuclear Technology (CDTN) of the National Nuclear Energy Commission (CNEN), the nuclear sector has proven to be a powerful ally in achieving several of these goals, offering innovative and sustainable solutions that extend across different critical areas. According to the International Atomic Energy Agency (IAEA), the use of these techniques directly contributes to nine of the 17 SDGs.

SDG 2: ZERO HUNGER AND FOOD SECURITY

Hunger and malnutrition remain persistent challenges in many parts of the world. However, nuclear technology plays a crucial role in combating these issues. Nuclear techniques, such as the use of stable isotopes, help study and understand the causes and consequences of malnutrition, from undernutrition to obesity. These technologies enable detailed analysis of diets and nutrient levels, assisting in the development of more effective food policies. Additionally, food irradiation, a safe nuclear technique, is used to prolong the shelf life of products and ensure that nutritious foods are available even in remote regions.

SDG 3: GOOD HEALTH AND WELL-BEING

In medicine, the contribution of nuclear energy is significant and diverse. For example, radiotherapy is a widely used technique for treating cancer, offering hope and healing to millions of patients worldwide. Additionally, imaging techniques such as Positron Emission Tomography (PET) are essential for the early diagnosis of diseases. Nuclear energy also supports the research and development of vaccines and medications, crucial for combating epidemics and infectious diseases, especially in developing countries. This technology is directly contributing to improving global health and enhancing quality of life.

SDG 6: CLEAN WATER AND SANITATION

Sustainable water management is essential for human survival and the preservation of ecosystems. Nuclear and isotopic techniques are employed to monitor and manage water resources, analyzing the quality and quantity of water in different regions. For instance, the tritium/helium-3 technique allows for studying the dynamics of water bodies and better understanding the impact of climate change on water availability. These insights are crucial

"NUCLEAR TECHNOLOGIES OFFER EFFECTIVE AND INNOVATIVE SOLUTIONS THAT DIRECTLY CONTRIBUTE TO THE ACHIEVEMENT OF THE SUSTAINABLE DEVELOPMENT GOALS."

for formulating water management strategies and ensuring that water resources are used efficiently and sustainably.

SDG 7: AFFORDABLE AND CLEAN ENERGY

Access to energy is a prerequisite for economic and social development. Nuclear energy stands out as a reliable and low-carbon solution for electricity generation. In a large country like Brazil, nuclear energy can provide a significant amount of electricity, contributing to energy security and regional development. With low environmental impacts and significant benefits in mitigating climate change, nuclear energy is increasingly considered in many energy matrices around the world.

SDG 9: INDUSTRY, INNOVATION, AND INFRASTRUCTURE

Innovation and sustainable industrialization are driven by advanced technologies, and nuclear energy significantly contributes to this. The use of radiations and isotopes in the industry allows for process enhancement, quality control, and automation. Additionally, nuclear techniques are applied in tracking sediments and identifying natural resources, promoting more efficient and sustainable industrialization.

SDG 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

Sustainability in food production and consumption is a growing concern. Nuclear technology can enhance crop resilience, as demonstrated in the treatment of rice with irradiated seaweed, which improves plant resilience to weather changes and climate shifts. This contributes to more sustainable and safe agricultural production, helping to ensure that foods are produced responsibly and efficiently.

SDG 13: CLIMATE ACTION

Monitoring and mitigating the impacts of climate change are essential for preserving our planet. Nuclear technologies play a crucial role in this effort, offering advanced methods for collecting data and monitoring environmental changes. Data collection on greenhouse gas emissions and the identification of pollution sources are facilitated by nuclear techniques, providing a solid scientific basis for policy decisions and the implementation of adaptation and mitigation measures.

SDG 14: LIFE BELOW WATER

Preserving oceans and marine resources is crucial for the health of aquatic ecosystems and human life. Nuclear and isotopic techniques are used to study and protect these resources, helping to understand the impact of climate change and monitor the quality of marine water. These techniques are essential for the conservation and sustainable management of oceans.

SDG 17: PARTNERSHIPS FOR THE GOALS

Collaboration across different sectors is crucial for the success of the SDGs. In Brazil, for example, collaboration between the Brazilian Association for the Development of Nuclear Activities (ABDAN), the National Nuclear Energy Commission (CNEN), universities, researchers, and the industry is vital for the effective implementation of the SDGs. This partnership strengthens sustainable development and ensures that the benefits of nuclear technologies are widely utilized.

"Nuclear energy has proven to be a valuable ally in the pursuit of a sustainable future. From health and food to energy and the environment, nuclear technologies offer effective and innovative solutions that directly contribute to the achievement of the Sustainable Development Goals. By integrating these technologies responsibly and collaboratively, we are taking significant steps toward a fairer, safer, and more sustainable world for all," states Clédola Tello. ▪

CONTRIBUTIONS OF THE NUCLEAR SECTOR TO ENVIRONMENTAL CONSERVATION

DISCOVER SUCCESSFUL PROJECTS IN ECOSYSTEM PRESERVATION

The Brazilian nuclear sector, often associated with energy generation, also plays a crucial role in environmental preservation. Eletronuclear, responsible for operating the Angra 1, 2, and 3 nuclear plants in the Costa Verde region of Rio de Janeiro, has been notable for its involvement in environmental projects that go beyond its legal obligations. Two examples are the "Tartaruga Viva" (Living Turtle) Program and the Wildlife Rehabilitation Center (CRAS), which demonstrate the company's commitment to biodiversity conservation and ecosystem recovery.

TARTARUGA VIVA PROGRAM: PROTECTING MARINE SPECIES IN ILHA GRANDE BAY

The Tartaruga Viva program, meaning "Living Turtle", was initiated as part of the environmental licensing for nuclear plants. Its scope surpasses mere compliance with legal requirements, reflecting a deep commitment to the protection of marine fauna. The program is aimed at monitoring and preserving sea turtles in Ilha Grande Bay, an area that hosts the Eletronuclear plants.

Since its inception, the program has been tracking the species of sea turtles present in the area, monitoring their health, growth, and development. From April 2018 to May 2024, 37 turtles were rescued alive, and 16 of them, after receiving necessary care, were rehabilitated and returned to the sea. This work is essential for the preservation of these species, many of which are endangered.

However, the program also highlights the challenges faced by marine fauna due to human activity. Tartaruga Viva received 190 dead animals, 84 of which underwent necropsies. From these analyses, it was found that 20% of the animals had garbage in their gastrointestinal tracts,

"ALL THESE PROJECTS HAVE A SIGNIFICANT ENVIRONMENTAL EDUCATION COMPONENT, POSITIVELY IMPACTING LOCAL CULTURE AND THE PRESERVATION OF FAUNA."

"TODAY, NO COMPANY CAN SURVIVE WITHOUT THIS CONNECTION TO THE ENVIRONMENT IN WHICH IT IS EMBEDDED."

while 30% of the deaths were caused by drowning, a result of improper disposal of fishing nets.

According to Marco Antonio Alves, Communication Coordinator at Eletronuclear, "all these projects have a significant educational component. Tartaruga Viva, for instance, has two main pillars: raising public awareness to contact the project when finding a debilitated turtle and, at the same time, changing the local culture where turtles were traditionally seen as a food source. This practice has nearly vanished, demonstrating the positive impact of the program."

The program has also invested heavily in environmental education, promoting awareness of the impacts of human activities on the environment. In 2023, the program's base welcomed over 4,000 visitors, including school and university students, and actively participated in events, conferences, and beach cleanup campaigns.

WILDLIFE REHABILITATION CENTER: CARE AND REINTEGRATION INTO NATURE

Another successful example is the Wildlife Rehabilitation Center (CRAS), a voluntary initiative by Eletronuclear reflecting its commitment to terrestrial fauna. The CRAS was established to meet the demand for a specialized facility to treat and rehabilitate debilitated wild animals found in the area of the Nuclear Central.

Since beginning its operations in 2021, the CRAS has attended to 928 animals from 138 different species, including mammals, birds, and reptiles. Of these, 378 were rehabilitated and reintroduced to their natural habitats. One of the most notable cases involved a jaguarundi (Leopardus pardalis), which arrived at the center with severe injuries, including skull fractures and a ballistic projectile lodged in its body. After thorough treatment, including surgery and rehabilitation, the animal was returned to the wild in full health.

"We have one project that addresses aquatic beings and another that cares for animals from the Atlantic Forest. This integrated approach is essential, and nowadays, no company can survive without this connection to the environment it inhabits. Moreover, these projects create local employment, contributing to the region's economy," comments Marco Antonio Alves.

The CRAS not only treats and rehabilitates animals but also contributes to scientific research and environmental education, raising awareness about the importance of conserving wildlife.

ENVIRONMENTAL COMMITMENT

The environmental projects of Eletronuclear exemplify how the Brazilian nuclear sector can significantly contribute to biodiversity preservation and ecosystem recovery. Both the Tartaruga Viva program and the CRAS demonstrate that environmental responsibility is an integral part of Eletronuclear's operations, extending beyond legal compliance and showing a genuine commitment to sustainability.

"These projects bring a significant return on image for the company, as society begins to see Eletronuclear as an entity committed not only to profit but also to the social and environmental issues of the region," concludes Marco Antonio Alves. ▪

FATIH BIROL, EXECUTIVE DIRECTOR OF THE INTERNATIONAL ENERGY AGENCY

Nuclear Connection interviewed Fatih Birol, Executive Director of the International Energy Agency, for this edition. From energy transition to nuclear safety, the conversation yielded several insights. Check it out!

1 – The transition to cleaner and more sustainable energy sources is a global priority. What role does nuclear energy play in this process, and how does the IEA see nuclear energy contributing to achieving climate and decarbonization goals in the coming years?

Nuclear energy is an important technology that can play a key role in helping the world meet its energy and climate objectives. While each country has different needs and circumstances and should develop its own decarbonization path, our analysis shows that, at the global level, any path to a net-zero energy sector involves an increase in nuclear energy.

In the IEA's Net Zero Roadmap, which outlines a path for the global energy sector that aligns with the goal of limiting global warming to 1.5°C, global nuclear capacity more than doubles by mid-century, reaching over 900 gigawatts. In this context, it is encouraging to see that the nuclear sector has made a strong comeback globally in recent years. Expanding the technology can simultaneously help countries reduce their dependence on fossil fuel imports and cut carbon dioxide (CO_2) emissions, and many governments have given it a new look, especially after the global energy crisis triggered by Russia's invasion of Ukraine in 2022.

Nuclear energy is especially important when thinking about decarbonizing our electricity system. Our analysis shows that electricity generated from nuclear energy is expected to reach an all-time high by 2025. While renewable energy sources—including solar photovoltaic, wind, and hydro—are vital to achieving our international energy and climate goals, we also need nuclear energy. This is particularly the case in countries that do not have strong renewable potential. Nuclear power plants can provide stable electricity to the grid, complementing renewable energies in reducing emissions from the energy sector, while also contributing to electrical security.

There has been a recent surge of interest in new nuclear technologies, such as Small Modular Reactors (SMRs) and nuclear fusion. What are the IEA's expectations regarding the advancement and commercialization of these technologies, and how might they impact the global energy market?

> **“FACILITATING INTERNATIONAL COOPERATION ON ENERGY ISSUES IS THE FOUNDATION OF THE IEA’S WORK.”**

2 – Technological innovation is essential for achieving the world’s energy and climate targets. This includes innovation in nuclear energy—which, despite its benefits, still faces challenges such as high financing costs and long construction times.
The IEA closely monitors advanced technologies, such as Small Modular Reactors, or SMRs. These technologies have the potential to bring major benefits—reducing costs and increasing flexibility in energy grids if the dynamics behind them continue to grow. Based on our analysis, SMRs could begin to play a significant role in energy transitions in the 2030s if regulatory and investment decisions are made quickly and if the technology proves commercially viable. The IEA does not currently consider nuclear fusion in its outlooks for the global energy sector for the coming decades due to significant uncertainty about its technical and economic viability. However, the IEA supports the work of independent international experts through some of our technology collaboration programmes that are working to advance research, development, and commercialization of nuclear fusion and related technologies.

3 – Nuclear safety and waste management are fundamental concerns for the industry. What are the main IEA initiatives to ensure safety at nuclear facilities and promote effective practices for managing radioactive waste?
Public concerns about safety and waste management are among the reasons why some countries have decided to phase out nuclear energy or halt new developments. It is crucial that governments and industry continue to work together to ensure nuclear safety through strong policies and rules—and robust, independent regulatory oversight. The IEA has called on governments to promote efficient and effective safety regulation and to implement solutions for the disposal of nuclear waste in consultation with citizens. Clear communication about these measures is essential. I would add that our colleagues at the International Atomic Energy Agency (IAEA) and the OECD’s Nuclear Energy Agency (NEA) do important work in promoting safety practices and waste management.

4 – International cooperation is crucial for the development and regulation of the nuclear sector. How is the IEA working to promote collaboration between countries, and what policies are being promoted to ensure a harmonized and safe approach to the expansion of nuclear energy worldwide?
Facilitating international cooperation on energy issues is the foundation of the IEA’s work. This includes encouraging greater collaboration on nuclear energy and technologies. In 2022, in the midst of a global energy crisis, we published a special report on Nuclear Power and Secure Energy Transitions. This report explored the role of nuclear energy in building a safer, cleaner, and more affordable energy system. It also presented a series of recommendations for policymakers in countries that see a future for nuclear energy. These included extending the lifetimes of power plants, ensuring that electricity markets properly value low-emission dispatchable capacity, creating financing frameworks to support new reactors, accelerating the development of SMRs, and reassessing nuclear power plants based on performance. And early next year, we will publish a new special report on financing new nuclear energy projects.

5 – How does the IEA view the role of entities like ABDAN in promoting nuclear activities in Brazil?
Given the complexity of the nuclear sector, it is essential that well-functioning organizations exist that can build bridges between the public and private sectors on fundamental issues. It is also important that countries have informed, fact-based discussions about the different energy options available. Each stakeholder can play a role in this. Organizations like ABDAN are well positioned to provide valuable information to policymakers about the latest challenges and opportunities. ▪

ENERGY TRANSITION: THE INDISPENSABLE ROLE OF THE NUCLEAR SECTOR

CLEAN HYDROGEN PRODUCTION IS ONE AREA WHERE NUCLEAR ENERGY CAN MAKE A SIGNIFICANT DIFFERENCE

In recent years, the energy transition has become a central topic in discussions about the future of the planet. With growing concerns about climate change and the need to reduce dependence on fossil fuels, various countries have been revising their energy matrices in search of more sustainable solutions. In Brazil, this movement gains even more relevance given the historically clean electric matrix, which faces new challenges with increasing demands and seasonal changes. In this scenario, nuclear energy emerges as a fundamental piece to ensure the resilience, reliability, and stability of the national energy system. Carlos Leipner, a nuclear energy expert, shared in an interview highlights about the role this energy source plays and can play in the energy transition, both in Brazil and globally.

BRAZILIAN ELECTRIC MATRIX: A CHALLENGING SCENARIO

Addressing the Energy Transition Leipner emphasizes the importance of understanding the Brazilian electric matrix, which is predominantly clean, thanks to hydroelectric energy. However, this dependence brings significant challenges. “In the last 10 to 20 years, our reliance on hydro sources has already begun to present some challenges,” states Leipner, noting how seasonal rainfall variations have affected the generation capacity of reservoirs, which often are not full enough to meet demand.

With the growing participation of renewable sources like wind and solar energy, Brazil has been seeking to diversify its electric matrix. However, these sources are intermittent by nature, which requires a complement that nuclear energy can provide. “Nuclear accounts for about 2% of Brazil’s electric matrix today, but it is poised to play a more significant role in the coming decades, especially to strengthen the resilience and reliability of the system,” highlights Leipner.

NUCLEAR BEYOND ELECTRICITY GENERATION

Leipner expands the vision of the role of nuclear energy, suggesting that it can go far beyond the electric matrix. He explains that globally, only 20% of consumed energy comes from electricity, while the other 80% depends on fossil fuels, especially in the transportation and industry sectors. “Segments such as the cement, steel, and even some modes of transportation, like maritime and air, are difficult to decarbonize,” observes Leipner. In this context, nuclear energy can be a protagonist in the production of clean fuels, such as hydrogen, which has gained prominence in decarbonization discussions.

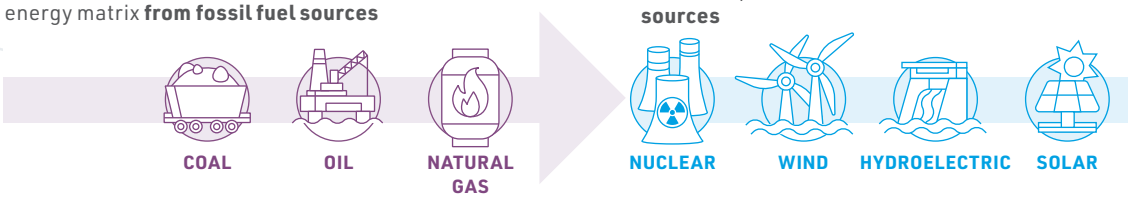
CLEAN HYDROGEN: A NEW FRONTIER

The production of clean hydrogen is one area where nuclear energy can make a significant difference. Leipner explains that currently, 95% of hydrogen is produced from fossil sources, which generates large amounts of CO_2. “The challenge is to increase hydrogen production in a way that

THE EXPANSION OF THE NUCLEAR PARK AND THE INCLUSION OF NUCLEAR IN NEW PUBLIC POLICIES WILL BE FUNDAMENTAL TO THE SUCCESS OF THIS ENERGY TRANSITION.

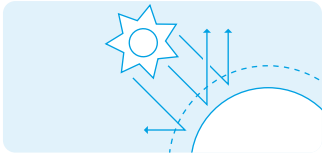
WHAT IS AN ENERGY TRANSITION?

An energy transition involves shifting the global energy matrix **from fossil fuel sources** to **cleaner, renewable sources**



OBJECTIVE OF THE ENERGY TRANSITION

To reduce greenhouse gas emissions to combat climate change.



Additionally, it aims to enhance energy security and diversify energy sources for greater stability.

HOW IS AN ENERGY TRANSITION ACHIEVED?

An energy transition is accomplished through:

Decarbonization: Replacing fossil fuels with renewable energies.

Energy Efficiency: Implementing technologies that reduce energy consumption.

Technological Innovation: Developing new technologies for energy storage and distribution.

Public Policies: Establishing regulations and incentives to promote clean energy usage.

IMPORTANCE OF THE ENERGY TRANSITION

Combating Climate Change: Reduces the amount of CO2 in the atmosphere.

Public Health: Decreases pollution, leading to better air quality and fewer respiratory diseases.

Energy Security: Lessens dependence on fossil fuels and oil-exporting countries.

Economic Benefits: Creates new jobs and opportunities in renewable energy sectors.

Source: ABDAN

is clean," he says. Nuclear energy can contribute to this, especially through low-temperature electrolysis, where electricity generated by nuclear is used to split water molecules into hydrogen and oxygen. Leipner also mentions the importance of focusing on developing technologies to capture and use the hydrogen produced by existing nuclear plants in Brazil, like those in Angra. "We are already producing hydrogen, but it's not being captured. Capturing it and using it would be an important step to demonstrate the role of nuclear in the clean hydrogen production chain," he suggests.

COMPARING WITH THE WORLD

Compared to other countries, Brazil is in a unique position, especially in terms of the electric matrix. However, Leipner warns that there is still much to be done, particularly in the decarbonization of industrial and transportation sectors. "Brazil is not yet at the forefront in focusing on these sectors. There is a lot of room for the country to develop in this direction," he says.

Leipner also highlights the increasing energy demand in emerging sectors, such as data centers, which require huge amounts of electricity and cooling. In the United States and Europe, there are already initiatives for these centers to be powered by nuclear energy, which could be a trend for Brazil as well.

THE FUTURE

The energy transition in Brazil is just beginning, and nuclear energy has a crucial role to play. With a forward-looking perspective, the country can leverage its natural and technological advantages to not only ensure a clean and resilient electric matrix but also lead in new fronts, such as clean hydrogen production and the decarbonization of hard-to-electrify sectors.

"We are at a decisive moment," concludes Leipner. "The expansion of the nuclear park and the inclusion of nuclear in new public policies will be fundamental to the success of this energy transition, not just in Brazil but globally." ▪

CRITICAL CHALLENGES IN RADIOPHARMACEUTICAL SUPPLY IN BRAZIL: AN ANALYSIS OF THE CURRENT AND FUTURE SCENARIO

TO FACE THE CHALLENGES AND ENSURE THE SUSTAINABILITY OF NUCLEAR MEDICINE, IT IS ESSENTIAL THAT THE STATE ACTS WITH SERIOUSNESS AND COMPETENCE.

Nuclear medicine is a fundamental area of modern medicine, enabling functional imaging of organs and tissues of the body, while providing precise information on the functioning of internal systems that cannot be visualized by conventional anatomical exams alone. Through the application of radioisotopes, nuclear medicine plays a crucial role in the early diagnosis of serious diseases, such as cancer, and in monitoring cardiac and metabolic conditions. Sibila Grallert, a pharmaceutical expert on the subject and director of the CMR (Center of Molecular Research), explains that the ability to visualize and treat diseases with high precision offers a significant advantage in preventive and therapeutic medicine, especially with the advancement of techniques such as SPECT, SPECT/CT, PET/CT, and PET/MRI.

RADIOISOTOPES: THE HEART OF NUCLEAR MEDICINE

Radioisotopes are radioactive substances used in various applications within nuclear medicine. They are fundamental to both diagnostic and therapeutic procedures. Key diagnostic methods include Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET), which provide detailed visualizations of organic and metabolic functions. In the therapeutic realm, the theranostics concept has revolutionized the field by combining diagnosis and treatment in a single approach, offering hope to many patients with complex conditions.

In Brazil, the production and distribution of these radioisotopes face significant challenges, especially after the discontinuation of production by the Institute of Energy and Nuclear Research (IPEN) in 2021. “The difficulty in maintaining a consistent and secure supply chain compromises the availability of radiopharmaceuticals and puts the continuity of essential treatments and diagnoses at risk,” warns Sibila.

THE IMPACT OF THE DISCONTINUATION OF PRODUCTION BY IPEN:

In 2021, IPEN halted the production of radiopharmaceuticals due to a lack of resources to import essential supplies and maintain operations. This decision revealed the fragility of Brazil’s healthcare system, especially in a country of its size. The production halt directly affected the availability of radioisotopes, undermining the quality of diagnostics and treatments. It highlighted Brazil’s critical dependence on foreign suppliers and underscored the urgent need for a strong national strategy for the production and distribution of these materials.

LOGISTICAL AND REGIONAL CHALLENGES IN DISTRIBUTION:

Brazil faces a complex dilemma when it comes to distributing radiopharmaceuticals. Given the country’s vast size, transporting radioactive materials poses significant logistical challenges. Distribution requires specialized equipment to ensure safety during transport, as well as an efficient

"THE DISCONTINUATION BY IPEN UNDERSCORED BRAZIL'S CRITICAL DEPENDENCE ON EXTERNAL SUPPLIERS."

network that can reach remote and hard-to-access regions. The lack of adequate infrastructure and the complexity of the logistical process lead to delays and limited access to treatments, further exacerbating regional inequalities within the healthcare system.

LEGAL ASPECTS AND THE FLEXIBILITY OF THE MONOPOLY:

Constitutional Amendments 49 (2006) and 118 (2022) were significant in attempting to flexibilize the Union's monopoly on the production and commercialization of radioisotopes. These amendments aimed to allow the private sector to enter the market, with promises of increased supply and regionalization. However, market response has fallen short of expectations.

A lack of regulatory clarity and challenges in adapting to the new legal framework have been major obstacles. The transition from a state monopoly to the private sector has not been accompanied by an effective reorganization of needs and operations, resulting in market concentration in a few companies and continued dependence on international suppliers for essential radioisotopes.

INVESTMENTS AND OBSTACLES TO PRIVATE INITIATIVES:

Despite the opportunities presented by the constitutional amendments, the radiopharmaceutical market still faces significant challenges in attracting private investment. The primary reasons include a lack of legal clarity, a slow product registration process, and high taxes. Additionally, the historical reliance on IPEN/CNEN and the complexity of the sector make it difficult for nuclear medicine services to quickly and effectively adapt to the new market realities.

THE ROLE OF RADIOPHARMACIES:

Commercial radiopharmacies have emerged as an alternative solution for the distribution of radiopharmaceuticals in Brazil. Currently, only two are operational in the country, located in São Paulo and Rio de Janeiro. These facilities play a vital role in distributing ready-to-use doses, particularly for smaller nuclear medicine services. Group-associated radiopharmacies, which serve multiple units within the same organization, have also proven to be an effective solution for minimizing waste and improving efficiency.

THE RESPONSIBILITY OF THE BRAZIIAN GOVERNMENT AND FUTURE PERSPECTIVES:

Sibila emphasizes that to address the current challenges and ensure a sustainable future for nuclear medicine in Brazil, the State must act with seriousness and competence. This includes revising the tax regime for nuclear medicine drugs and equipment, establishing clear medium- and long-term health policies, and creating a high-level commission to develop a national nuclear medicine project.

Creating a transparent regulatory environment and encouraging private sector involvement is crucial to ensuring the continuity and expansion of nuclear medicine services in Brazil. ▪

CRITICAL CHALLENGES IN THE TRANSPORT OF RADIOACTIVE MATERIALS

SPECIALISTS ASSURE THAT WHEN REQUIREMENTS ARE STRICTLY FOLLOWED, THIS OPERATION IS EXTREMELY SAFE.

Logistics and transport services for industries handling radioactive and other high-risk materials face several challenges in Brazil, which include regulations and compliance. The transport of hazardous materials is strictly regulated by bodies such as the National Nuclear Energy Commission (CNEN) and the National Land Transport Agency (ANTT). Complying with all the complex and frequently changing standards and regulations is a constant challenge.

Ensuring safety during transport is crucial to prevent accidents and protect public health and the environment. This involves the use of specialized vehicles, continuous staff training, and strict monitoring of transport conditions. Conexão Nuclear sought best practices from ABDAN-affiliated companies in this sector, such as TAM International, which specializes in radioactive material transport, and Edlow International Company, which handles the transport of nuclear materials, import/export licensing, and nuclear fuel cycle consultancy.

Nathalia Alba, Senior Project Manager at TAM International, highlighted relevant points regarding the challenges and importance of international logistics in this sector, such as the limited number of transportation companies with the necessary infrastructure (licenses, training, experience, insurance) and restrictions at ports around the world.

It is known within the sector that most ports

PROCESSES INVOLVED IN THE TRANSPORTATION OF RADIOACTIVE MATERIAL

The safe transportation of radioactive material requires strict regulation, careful planning, and continuous monitoring.

SAFETY AND PROTECTION

Includes measures to prevent radioactive material leaks and accidents. Packaging must be designed to withstand impacts, fires, and other adverse conditions.

REGULATION AND COMPLIANCE

At the international level, organizations like the IAEA set standards and guidelines. Each country may also have its own regulations that must be strictly followed.

ROUTING AND PLANNING

This involves considering population density, road conditions, and proximity to sensitive facilities. Routes and schedules are planned to minimize risk.

EMERGENCIES AND CRISIS MANAGEMENT

Includes regular training for response teams and the availability of contingency equipment to deal with possible incidents.

MONITORING AND TRACEABILITY

It's crucial to ensure that the material is not diverted or lost. Monitoring systems must be implemented to track the location and status of the material.

Source: ABDAN

have specific requirements according to the materials transported in their terminals, which vary by location and can change over time. All these elements limit the available options and routes, leading to increased logistics costs.

Regarding regulatory conditions, for example, cargo classified as IMO Class 7 must comply with numerous standards, from permits to packaging and labeling. This affects regulatory requirements at various levels, including the necessary transportation permits, the packaging used, how containers and packages are labeled and marked, and how the cargo is tied down and secured within the containers.

Moreover, shippers must be aware not only of international regulations but also local standards in each country, as they may differ. Therefore, it is essential that shippers understand and adapt to the specific requirements of each country through which the transportation will pass.

Jack Edlow, President of Edlow International Company, shared on NucleRCast during his visit to Brazil the complexity and inherent challenges in the transport of radioactive and nuclear materials. According to Edlow, the main difficulty in this sector lies in ensuring maximum safety during all phases of transport.

This involves robust packaging, meticulous documentation, coordination with regulatory authorities, and risk management. He emphasized that despite technological advances and strict safety practices, the transport of nuclear materials remains a highly sensitive and complex process, requiring constant commitment to excellence and compliance.

"The transport of radioactive material, when all requirements are strictly followed, is extremely safe. The packaging used is robust, certified, and undergoes rigorous testing to ensure leak prevention and contamination. Additionally, there are real-time monitoring systems to track the materials during transport," highlights the TAM International executive. Recently, the company joined ABDAN, which can contribute to aligning with international and national regulations and standards.

In addition to the logistical and regulatory challenges, Edlow emphasizes the importance of clear communication and transparency with the public and stakeholders. Public perception of radioactive material transport can be a significant obstacle, and the company works to educate and inform about the stringent measures taken to ensure safety.

"WE ARE VERY EXCITED ABOUT OUR PARTNERSHIP WITH ABDAN. THE COLLABORATION CAN CONTRIBUTE TO THE DISSEMINATION OF COMPLIANT TRANSPORT PRACTICES."

Transporting Radioactive Material is a Complex Task That Involves Several Significant Processes. Learn More:

- **Safety and Protection**: Ensuring safety during transport is crucial to protect both workers and the public. This includes measures to prevent leaks of radioactive material and accidents. Packaging must be designed to withstand impacts, fires, and other adverse conditions.
- **Regulation and Compliance**: The transport of radioactive material is highly regulated. Internationally, organizations like the International Atomic Energy Agency (IAEA) establish norms and guidelines. Each country may also have its own regulations that must be strictly followed.
- **Routing and Planning**: Choosing the safest transportation routes is challenging. This includes considering population density, road conditions, and proximity to sensitive facilities. Routes and schedules must be planned to minimize risk.
- **Emergency and Crisis Management**: Having well-defined emergency response plans is essential. This includes regular training for response teams and the presence of contingency equipment to deal with potential incidents.
- **Monitoring and Traceability**: Keeping strict track of the material during transport is crucial to ensure it is not diverted or lost. Monitoring systems must be in place to track the location and status of the material. ▪

THE PRIVATE SECTOR IN BRAZIL'S NUCLEAR PROGRAM: PATHS AND CHALLENGES

THE INVOLVEMENT OF PRIVATE COMPANIES IN COMPLETING ANGRA 3 PROMISES INVESTMENT AND INNOVATION BUT REQUIRES STRICT REGULATION AND TRANSPARENT MANAGEMENT.

The entry of private companies into Brazil's nuclear program, especially regarding the completion of Angra 3, is a topic of heated debate and various perspectives. Leonam Guimarães, Technical Director of the Brazilian Association for the Development of Nuclear Activities (ABDAN), highlights the key points involving this initiative, emphasizing both the benefits and the challenges to be faced.

INVESTMENTS AND RESOURCES

The participation of private companies in the Brazilian nuclear program brings with it the promise of new investments and financial resources, which are essential for completing Angra 3. «The plant has faced financial difficulties and delays for years. The private sector's involvement can not only accelerate the process but also ensure the project's completion,» says Guimarães. The additional financial contributions are seen as an opportunity to revitalize the timeline and ensure that the plant becomes operational as planned.

TECHNOLOGY AND EXPERTISE

Private companies, especially those with international experience, can introduce advanced technologies and specialized knowledge to the Brazilian nuclear sector. «The expertise brought by these companies has the potential to improve the efficiency, safety, and sustainability of nuclear projects in Brazil,» comments Guimarães. The incorporation of technological innovations is fundamental to advancing the sector and maintaining the highest operational standards.

REGULATION AND SAFETY

Safety is one of the pillars of the nuclear sector, and with the private sector's involvement, strict regulation becomes even more critical. «It is imperative that the Brazilian government and regulatory authorities, such as the National Nuclear Energy Commission (CNEN), ensure that all safety regulations are meticulously followed,» emphasizes the Technical Director of ABDAN. Constant oversight and compliance with regulations are essential to prevent incidents and ensure the safe operation of the facilities.

ECONOMIC IMPACT

The completion of Angra 3 has significant potential economic impacts at both local and national levels. Beyond generating direct and indirect jobs, the plant will help diversify Brazil's energy mix. «The plant will provide a stable and sustainable source of electricity, which is crucial for the country's economic development,» says Guimarães. The stability of energy supply is key to industrial growth and improving the population's quality of life.

POLITICAL AND SOCIAL CHALLENGES

Despite potential benefits, the entry of private companies into the nuclear sector faces political and social resistance. «Issues related to national sovereignty, energy security, and environmental impacts are often raised and must be carefully addressed,» Guimarães warns. Transparent dialogue and effective communication are essential for gaining support from the public and legislators, alleviating concerns, and building trust in the project.

TRANSPARENCY AND MANAGEMENT

For the success of the public-private partnership, transparency in project management is indispensable. «Well-drafted contracts and efficient oversight can minimize risks and ensure the objectives of Brazil's nuclear program are achieved,» Guimarães stresses. Clear responsibility allocation and transparent management are key elements to ensure operational efficiency and reliability.

STRENGTHENING THE REGULATORY BODY IS CRUCIAL TO ENSURING THAT THE OBJECTIVES OF NUCLEAR REGULATION ARE MET, WHETHER THE OPERATORS ARE STATE OR PRIVATE SECTOR.

In Guimarães' view, private company involvement in Brazil's nuclear program and the completion of Angra 3 can bring numerous benefits, such as investments, technology, and expertise. However, it is essential to have strict regulation and transparent management to ensure the project's safety and social acceptance. As he points out, «It is a unique opportunity for Brazil to advance in the nuclear sector, but it requires a firm commitment to safety and transparency.» The success of this initiative depends on close and effective collaboration among all parties involved, aiming for the sustainable and safe development of Brazil's nuclear sector.

RICARDO FRAGA GUTTERRES, FORMER DIRECTOR OF DRS/CNEN, TALKS ABOUT THE REGULATION OF STATE AND PRIVATE ACTIVITIES

Nuclear regulation in Brazil is currently the responsibility of the National Nuclear Energy Commission (CNEN), which has established a comprehensive set of standards and resolutions to ensure the safety of nuclear operations. According to Ricardo Fraga Gutterres, former director of DRS/CNEN, «This task will soon be transferred to the National Nuclear Safety Authority, a body already created by law.» The 67 standards and resolutions cover everything from facility licensing to radiation protection and the transport of radioactive materials.

These standards are developed consistently with legislation and international commitments, harmonized with the safety standards of the International Atomic Energy Agency (IAEA). Gutterres explains that «Conventions and treaties do not distinguish between state or private operators, ensuring that all are treated equally by regulation.» This generalist approach aims to ensure that all nuclear operations, regardless of the operator, meet the same rigorous safety standards.

Brazil's federal constitution establishes the union's monopoly over nuclear activities, but in the past two decades, legislation has introduced changes to ease this monopoly. Gutterres observes that «Although such changes alter the routine of regulatory activity, there has been no need identified for changes in regulation regarding the specific treatment of state or private actors.» The legislative changes aim to broaden access to the benefits of nuclear technology without compromising safety.

Gutterres emphasizes that «Safety and the peaceful use of nuclear technology are inseparable elements.» Strengthening the regulatory body is crucial to ensuring that the objectives of nuclear regulation are met, regardless of whether the operators are state-owned or private. Commitment to safety, transparency, and regulatory compliance is essential for the sustainable advancement of Brazil's nuclear program. ▪

THE RACE FOR SMRS: IS BRAZIL READY FOR LICENSING?

ONE OF THE MAIN CHALLENGES CURRENTLY FACED IN THE COUNTRY IS REGULATION

Licensing nuclear reactors in Brazil has been a key topic, especially with the growing popularity of small modular reactors (SMRs) and global interest in safer, more efficient technologies. These reactors, offering greater flexibility, are seen as a promising solution for energy generation in various regions. However, Brazil still faces significant regulatory challenges regarding these reactors.

SMRs are advanced reactors with a power capacity of up to 300 MW(e), whose components can be produced and transported as modules to installation sites. Most SMR designs incorporate advanced safety features, allowing for deployment as either a single-module or multi-module plant. These reactors are being developed for various technologies, including water-cooled reactors, high-temperature gas reactors, and others. A major challenge faced by these reactors is regulation.

Brazilian legislation regarding the criteria and requirements for selecting sites for nuclear plants still lacks technical definitions and specific regulations for SMR licensing. Talking about regulating these reactors under the current framework is considered imprudent and premature.

According to Leonardo Paredes, a nuclear reactor engineering researcher at ABDAN, the association is conducting a series of studies and dialogues with companies such as EDF, Rosatom, and Westinghouse. The technical data provided by these companies reinforce the idea that discussing SMR regulations in Brazil is imprudent and premature.

LICENSING AND SITE SELECTION

Unlike large power reactors, SMRs have new safety features that may render some traditional licensing criteria, such as the distance from urban centers, less relevant. However, the development of specific regulations, which are being discussed in global regulatory agencies such as the U.S. Nuclear Regulatory Commission (NRC), is essential to ensure the safety and feasibility of these installations. “Brazil is not yet ready to license an SMR, as our references are limited to Angra’s PWR reactors. We need to analyze the regulatory frameworks being developed abroad,” states Leonardo Paredes.

In Brazil, the constitution and regulations governing the selection of sites for reactor installation still need to be adapted to account for these new technologies. Specific regulations for SMRs are necessary to avoid future issues and ensure that the country is prepared for the new era of nuclear energy.

CHALLENGES:

- Development of specific regulations for SMRs.
- Analysis and adaptation of existing standards for new technologies.
- The need to harmonize the regulatory framework with existing legislation.
- Importance of regulatory foresight to address different dynamics.

THE IMPORTANCE OF INTERNATIONAL ANALYSIS

Before directly addressing SMR licensing and safety in Brazil, it’s crucial to analyze existing regulatory frameworks in other countries. International experience can provide valuable insights and help avoid pitfalls in regulating these reactors in Brazil. “In the United States, SMR studies are more advanced, especially with NuScale, which received 100% approval of the project’s safety de-

BRAZIL IS NOT YET READY TO LICENSE AN SMR, AS OUR REFERENCES ARE LIMITED TO ANGRA’S PWR REACTORS. WE NEED TO ANALYZE THE REGULATORY FRAMEWORKS BEING DEVELOPED ABROAD

tails by the Nuclear Regulatory Commission (NRC)," recognizes Paredes.

The race for SMRs is ongoing, but Brazil still needs to progress in creating a robust regulatory framework to ensure the safety and feasibility of these technologies. A careful analysis of international regulations and the adaptation of existing laws and standards will be crucial for the country to position itself as a leader in the use of innovative nuclear technologies. "Besides the U.S., there are some individual efforts in Europe, but we still lack enough information to move forward in Brazil," says the expert. "I believe we have many other challenges to overcome before focusing on SMRs. It won't be an easy process, and it will require much more preparation than we currently have."

CNEN

In an exclusive interview with ABDAN magazine, Anna Leticia Sousa, senior researcher at the National Nuclear Energy Commission (CNEN), discussed Brazil's challenges and initiatives in the field of licensing new nuclear technologies. "As always, a common theme with nuclear energy, nuclear licensing, and nuclear law, is that all these licensing issues undergo international harmonization," she explained. This need for harmonization stems from nuclear energy's history, especially in Europe, where proximity between borders necessitated alignment between nations.

Although Brazil does not yet have fully developed modular reactor technology, it has been prominent internationally due to its active participation in these forums. Anna Sousa revealed that even before the Brazilian government made an official decision regarding SMR deployment, CNEN had been participating in international discussions, creating a "focus group" that involves the Directorate of Radiation Protection and Safety (DRS) and the Directorate of Research and Development. "Our idea was to get ahead, because we estimated the amount of work that would come our way, and start studying for when the Brazilian government made that decision," she highlighted.

EXPECTATIONS FROM THE GOVERNMENT

Anna Sousa also shared her thoughts on the current government's relationship with the nuclear sector, noting an initial perception of distance. "At the beginning of this government, we felt a bit of distance from the nuclear sector," said Sousa, expressing an opinion shared by many of her colleagues. Despite this distance in early decisions, the researcher noted that the government has recently shown signs of greater involvement. "Nowadays, we see the government more inclined, getting closer, and talking," she observed. She mentioned the nuclear sector's participation in the 5th Science and Technology Conference as an example of this rapprochement.

As a regulator, Sousa believes it is crucial to maintain a healthy distance between promotion, financing, implementation, and political decision-making, especially in the early stages of projects. ▪

THESE REACTORS, OFFERING GREATER FLEXIBILITY, ARE SEEN AS A PROMISING SOLUTION FOR ENERGY GENERATION IN VARIOUS REGIONS. HOWEVER, REGULATING THESE REACTORS IN BRAZIL STILL FACES SIGNIFICANT CHALLENGES.

ALTHOUGH BRAZIL DOES NOT YET HAVE FULLY DEVELOPED MODULAR REACTOR TECHNOLOGY, IT HAS BEEN PROMINENT INTERNATIONALLY DUE TO ITS ACTIVE PARTICIPATION IN THESE FORUMS.

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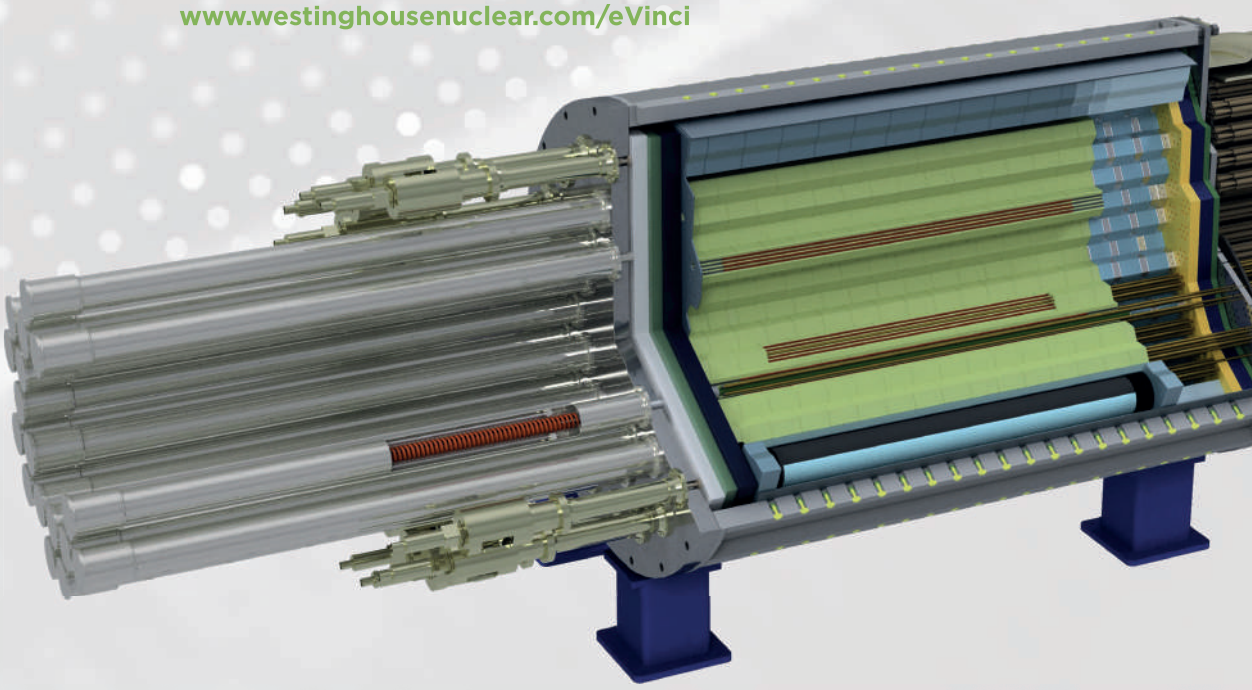

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FOUR STEPS TO A BALANCED NUCLEAR FUEL CYCLE

As Brazil progresses towards its goal of achieving carbon neutrality, the country needs to increase the share of nuclear energy in its energy matrix and build a large nuclear park based on both large and small reactors. The most important part of the large-scale development of Brazil's nuclear energy industry is the timely creation of a management system for irradiated nuclear fuel. In search of a sustainable, safe, and economical solution, Rosatom has developed a comprehensive product called the "Balanced Nuclear Fuel Cycle."

A presentation of innovative Russian technologies for managing irradiated nuclear fuel at the Latin American Section of the American Nuclear Society (LAS/ANS) symposium sparked active discussion. For countries with nuclear generation experience, Rosatom offers solutions to address accumulated obligations during industry operations. For newcomers, it provides an opportunity to establish a nuclear energy sector without deferred issues, ensuring future generations are not burdened with resolving them. Rosatom proposes organizing this work based on the "balanced nuclear fuel cycle" concept, which allows for the reuse of valuable resources, reduces the volume of waste, and decreases the radiotoxicity of the generated waste.

WHAT IS THE BALANCED NUCLEAR FUEL CYCLE?

The Balanced Nuclear Fuel Cycle is a suite of four services, including the reprocessing of irradiated fuel with the fractionation of high-activity radioactive waste, the production of uranium-plutonium fuel, the post-combustion of minor actinides in fast reactors, and the creation of long-term storage systems for irradiated fuel and high-activity waste. These services can be purchased separately or together. They can be utilized by owners of pressurized water reactors – various modifications of VVER, PWR, BWR reactors, etc. The specific design will be customized to the client's needs. These four products allow for the "turn-key" management of nuclear fuel, meaning once the irradiated fuel is taken from the owner, only the vitrified short-lived radioactive waste fraction, ready for safe storage, is returned. The remaining components of the irradiated fuel are effectively eliminated, making the nuclear fuel cycle balanced and sustainable overall.

REPROCESSING OF IRRADIATED NUCLEAR FUEL

The reprocessing of irradiated nuclear fuel with the fractionation of high-activity waste is a fundamental component of the closed nuclear fuel cycle. This process allows the recovery of useful materials from the fuel, minimizing radioactive waste volume and ensuring safe and efficient isolation. Rosatom's institutes have over a century of experience in applied radiochemistry development and five decades of commercial reprocessing of used nuclear fuel. This expertise has led to solutions that fully meet current environmental requirements, including minimizing the generation of secondary radioactive waste. The main value of the Balanced Nuclear Fuel Cycle for potential clients lies in eliminating the need to build deep geological repositories for the final isolation of irradiated nuclear fuel and high-activity waste in countries using nuclear energy (currently over 35). Geological conditions vary significantly between these countries, making the construction of such repositories extremely expensive and complex, especially considering the need to model and justify their safety for periods ranging from 10,000 to 100,000 years. Ensuring that all these facilities, built in diverse geological conditions and with distinct design solutions, maintain the same safety levels for millennia is a considerable theoretical challenge.

FUEL FABRICATION FROM RECOVERED NUCLEAR MATERIALS

The second important component of the Balanced Nuclear Fuel Cycle is the ability to use fuel made

THE "BALANCED NUCLEAR FUEL CYCLE" IS BASED ON CUTTING-EDGE TECHNOLOGIES, INCLUDING THE POSSIBILITY OF REPROCESSING AND SEPARATING USED NUCLEAR FUEL WASTE, UTILIZING PLUTONIUM-CONTAINING FUEL IN FAST REACTORS, AND CONDUCTING THE TRANSMUTATION OF MINOR ACTINIDES.

from recovered nuclear materials extracted from irradiated nuclear fuel. After cooling in a pool, the irradiated nuclear fuel is placed in special transport and transfer containers. Gradually, the irradiated nuclear fuel is transferred to higher-capacity storage assemblies. Once enough of these assemblies are collected for a shipment, they are sent to Rosatom's facilities for reprocessing. In the Balanced Nuclear Fuel Cycle, reprocessing involves separating the irradiated nuclear fuel into fractions. This separation involves the extraction of uranium (about 96% of the total fuel volume) and plutonium (approximately 1.2%), elements of great energy value. Efficient use of these elements is crucial for sustainable resource management and environmental safety. Fuel containing regenerated uranium and plutonium, or only regenerated uranium, offers clients the opportunity to use nuclear materials more efficiently and save on raw materials. Recycling nuclear materials, just as recycling other materials in various industrial sectors, represents a promising approach to sustainable development.

MORE EFFICIENT WASTE STORAGE

Minor actinides—americium (Am), neptunium (Np), and curium (Cm)—are by-products of uranium and plutonium fission. Although they represent less than 1% of irradiated nuclear fuel, their radioactivity makes them dangerous for hundreds of thousands of years. Rosatom has developed a technology to incorporate minor actinides like americium and neptunium into fuel for fast reactors, where, under the action of fast neutrons, they are transformed into stable fission products or much less dangerous transuranic elements. Rosatom's operational, under-construction, and planned reactors allow the transmutation (or incineration) of minor actinides on an industrial scale.

In the context of the Balanced Nuclear Fuel Cycle, after reprocessing the irradiated nuclear fuel, the client receives back a vitrified short-lived fraction. This fraction can be managed in conventional storage facilities. The main feature of this fraction is that it does not require deep geological storage because after 300 to 350 years, its radioactivity will be comparable to natural uranium ore. And after an additional 100 years, it will become as harmless as the sand on Copacabana beach. Therefore, for its storage, deep geological facilities (around 400-500 meters deep) like those required for irradiated nuclear fuel are not necessary. A simple borehole of 70-72 meters, slightly deeper than a metro station, is sufficient.

FEASIBILITY STUDY

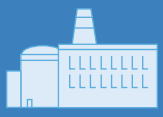
Currently, Rosatom offers its potential clients the opportunity to explore Balanced Nuclear Fuel Cycle technologies through a so-called Feasibility Study – a technical-economic study that assesses the compliance of various Balanced Nuclear Fuel Cycle options with the specific needs of each client, considering the capabilities of Russian facilities. Experience shows that this modeling allows for an objective evaluation of different alternatives, enabling an informed decision about the long-term Nuclear Fuel Cycle scenario and the necessary steps for its implementation, in line with the interests of a specific client. Given the diversity of stakeholders involved in decisions regarding the development of the Nuclear Fuel Cycle – nuclear plant operators, regulatory bodies, politicians, civil society, and environmentalists – these assessments are highly sought after and useful. ▪

Sustainable Nuclear Fuel Cycle

ROSATOM

The Sustainable Nuclear Fuel Cycle (Sustainable NFC) is an innovate product of ROSATOM State Corporation, which makes management of spent nuclear fuel (SNF) and its reprocessing products efficient and stable.

Customer's territory



Light-water reactor (LWR)

Long-term storage systems for SNF and HLW

SNF temporary storage HLW-SL* , long-term storage and/or final disposal on the territory of the customer's country

SNF transfer for reprocessing to the Russian Federation

Interim storage of SNF in the Russian Federation until its reprocessing and HLW-SL* until its return to the customer

Components performed by Rosatom on its territory

SNF reprocessing and HLW partitioning

Radiochemical reprocessing of SNF with reprocessed uranium and plutonium recovering

HLW partitioning with isolation of HLW-SL; returning HLW-SL to the customer

Interim storage of long-lived fractions of HLW and temporarily unclaimed regenerated nuclear materials with the possibility of its use and transmutation

Minor actinides burning in FRs

Separation of americium, neptunium, curium from HLW

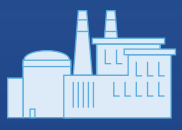
Fabrication of americium burnout elements (ABE) enabling placement of minor actinides in the reactor core

Irradiation of the ABEs in FRs
ABEs reprocessing with HLW conditioning

U-Pu fuel

Production and supply of fuel based on reprocessed uranium and plutonium

Ensuring maximum recycling of nuclear materials in existing reactors



Fast reactor NPP (FRs)

Sustainable NFC is chosen to:

MINIMIZE THE VOLUME AND RADIOACTIVITY OF WASTE
to be finally isolated at the deep geological repository and in some cases to exclude the need to construct such a facility

MAXIMIZE THE USE OF THE ENERGY POTENTIAL
of nuclear materials by its recycle

OPTIMIZE THE COSTS
of nuclear fuel cycle

PROVIDE A SUSTAINABLE MODEL
of production and consumption due to the ultimate solution for SNF disposed

* High-level waste (HLW) of SNF reprocessing may be separated into different fractions. Short-lived fraction (HLW-SL) consisted of cesium and strontium is to be vitrified and sent for final disposal.

ABDAN

ASSOCIATED COMPANIES OF ABDAN

01. AMAZUL – (AMAZÔNIA AZUL TECNOLOGIAS DE DEFESA S.A.)
02. ANDRADE GUTIERREZ – (ANDRADE E GUTIERREZ CONSTRUÇÕES E SERVIÇOS S/A)
03. ATECH – (ATECH NEGÓCIOS EM TECNOLOGIAS S.A.)
04. ÁUREA – (TRIFORCE BLINDAGENS E INSTALAÇÕES LTDA.)
05. BUTTING – (BUTTING TUBOS DE INOX LTDA.)
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11. EDF – (ÉLECTRICITÉ DE FRANCE)
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14. ELETROBRAS ELETRONUCLEAR – (ELETROBRAS TERMONUCLEAR S/A ELETRONUCLEAR)
15. ENBPAR – (EMPRESA BRASILEIRA DE PARTICIPAÇÕES EM ENERGIA NUCLEAR E BINACIONAL S.A.)
16. ENGETEC – (ENGETEC CONSTRUÇÕES E MONTAGENS S.A.)
17. FRAMATOME – (FRAMATOME ANP LTDA.)
18. HOLTEC – (HOLTEC DO BRASIL SERVIÇOS E EMPREENDIMENTOS LTDA.)
19. IDOM – (IDOM CONSULTING ENGINEERING ARCHITECTURE SAU)
20. INB – (INDÚSTRIAS NUCLEARES DO BRASIL S/A)
21. LZA ENGENHARIA – (LZA ENGENHARIA E GERENCIAMENTO LTDA.)
22. MPE – (MPE ENGENHARIA E SERVIÇOS S.A.)
23. NUCLEP – (NUCLEBRÁS EQUIPAMENTOS PESADOS S/A)
24. OEC – (OEC S.A.)
25. ROSATOM – (ROSATOM AMERICA LATINA LTDA.)
26. TAM INTERNATIONAL LP – (TAM INTERNATIONAL LP)
27. THEIA NUCLEAR – (THEIA NUCLEAR DISTRIBUIDORA DE RADIOFÁRMACOS EM MEDICINA NUCLEAR LTDA.)
28. TRACTEBEL ENGIE – (TRACTEBEL ENGINEERING LTDA.)
29. WESTINGHOUSE – (ELECTRIC DO BRASIL SERVIÇOS PARA CENTRAIS NUCLEARES LTDA.)

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