



Conexão  
Nuclear

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## **Sustainable Taxonomy**

We Must Learn from  
International Examples

## **Use of SMRs in the Oil Industry**

A Solution for Remote Areas  
with Limited Infrastructure

## **Keeping an Eye on Finland**

Geological Discovery Could Transform  
the Global Energy Landscape

## **Total Cost of Electricity Provision**

Myths and Facts

# **Interview with Mikhail Chudakov**

IAEA Executive Shares Perspectives on the Challenges  
and Opportunities in the Nuclear Sector

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SUGGESTIONS AND QUESTIONS

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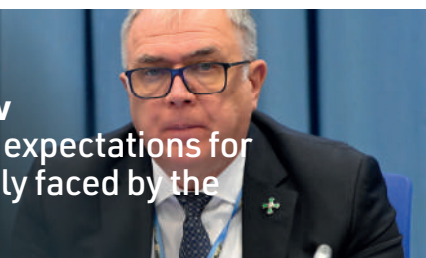


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# THE INCLUSION OF NUCLEAR ENERGY IN BRAZIL'S SUSTAINABLE TAXONOMY



As the world grapples with the challenges of climate change and the energy transition, nuclear energy and uranium are emerging as fundamental pillars in building a sustainable future. Across the globe, the importance of these resources is being recognized not only as a means to mitigate the impacts of climate change but also to ensure energy security. In Brazil, a country with vast uranium

reserves, it is imperative that we consider the inclusion of nuclear energy and uranium in our sustainable taxonomy, to fully leverage their potential and strengthen our position on the global stage.

However, in Brazil, the inclusion of nuclear energy in the Brazilian Sustainable Taxonomy (BST) remains a subject of debate, despite the precedent set by the European Union. The absence of nuclear energy in the BST represents a regulatory gap that could hinder essential investments in the country's energy security.

International experience highlights the value of a taxonomy that recognizes nuclear energy as a sustainable activity. In the European Union, for instance, nuclear energy is regarded as a key transitional technology for mitigating climate change. Although uranium is not explicitly listed, it is essential for the functioning of this energy system. China, on the other hand, classifies nuclear energy as a green technology, thereby promoting its adoption and implicitly recognizing uranium as a strategic resource for the nation's energy future. These approaches illustrate a global trend of including nuclear energy in sustainable taxonomies, generating both environmental and economic benefits.

The recent inclusion of nuclear energy in Law No. 14.766, sanctioned in 2024 as part of the Energy Transition Acceleration Program (PATEN), reinforces the importance of this resource in Brazil's strategy for decarbonization and energy security. This measure formally acknowledges

the role of nuclear energy as a sustainable source, paving the way for investments and financing in the sector. It also aligns Brazil with international best practices, ensuring more resilient and efficient energy planning.

However, the exclusion of nuclear energy from the BST undermines the coherence of Brazil's climate policy and limits the ability to attract investment in the nuclear sector. Without this recognition, funding earmarked for sustainable projects may be directed to technologies that, while renewable, do not offer the same generation stability as nuclear energy. Brazil holds significant uranium reserves and possesses full control of the nuclear fuel cycle, enabling the strategic development of this energy source within a model of energy self-sufficiency.

Moreover, nuclear energy plays a key role in decarbonizing hard-to-electrify industrial sectors, such as steel-making and clean hydrogen production. Brazil, which aims to establish itself as a global leader in the green hydrogen market, stands to benefit greatly from nuclear energy to ensure sustainable and competitive hydrogen production.

In this context, it is imperative that nuclear energy be included in the Brazilian Sustainable Taxonomy. Its exclusion disregards scientific evidence and reflects an unjustified bias against a technology that is essential to the energy transition. Inclusion will enable Brazil to attract investments, solidify its low-carbon power mix, and ensure energy security for future generations. It is now up to policymakers to make a decision grounded in science and national interest.

In this issue, we present a detailed article on this subject. We also explore, in the following pages, the use of SMRs and microreactors in the oil industry, the life extension of Angra 1, nuclear medicine, the cost of electricity provision, and the regulatory framework.

The nuclear sector stands at a turning point, and we are excited to share with you, our reader, this journey of transformation, innovation, and optimism.

Enjoy your reading! ■

*Celso Cunha, President of ABDAN*

*Leonam Guimarães, Technical Director of ABDAN*



# REGULATORY CHALLENGES IN BRAZIL'S NUCLEAR SECTOR: OPPORTUNITIES AND OBSTACLES

## CONEXÃO NUCLEAR BRINGS TO DISCUSSION SOME OF THE MAIN DIFFICULTIES CURRENTLY FACED BY THE NUCLEAR SECTOR

Brazil's nuclear industry faces a series of regulatory and infrastructure challenges that directly impact its ability to grow and operate efficiently. Despite the significant potential of nuclear energy for the country, barriers such as the complexity of the regulatory framework, the lack of investment in infrastructure, and ongoing environmental and safety concerns remain considerable obstacles.

In particular, the use of uranium—from mining through processing to its use in nuclear power plants—requires robust and appropriate regulation to mitigate risks and ensure public and environmental safety. Conexão Nuclear spoke with Felipe Tavares, Manager of Uranium Minerals at Indústria e Nucleares do Brasil (INB), and Sanzio Soares, Superintendent of New Business, to analyze the main regulatory and infrastructure difficulties currently faced by the nuclear sector and discuss how improving the regulatory framework could not only reduce these barriers but also contribute to more efficient and safer uranium management, aligning with international best practices and promoting the sustainable development of nuclear energy in Brazil.

### BRAZIL: IN THE RIGHT PLACE AT THE RIGHT TIME?

At a time when global uranium demand is about to exceed supply, Brazil finds itself in a strategic position to expand its production by leveraging its reserves and the potential for new mining business opportunities. However, this process is hindered by regulatory and infrastructure challenges that require careful analysis, particularly in regard to safety, sustainability, and governance.

In a recent lecture, Felipe highlighted the global scenario in which uranium demand is projected to

outpace supply within the next decade if no robust investments are made in the exploration of new deposits. In Brazil's case, this dynamic presents both a risk—since the country's current production does not meet the full demand of the Angra I and II nuclear power plants—and an opportunity for the development of new ventures. “We still have deposits with high exploratory potential and low production costs, which are rare assets in the world today,” he stated. Brazil therefore has a favorable outlook for investments in uranium mining, provided that the regulatory framework is strengthened and infrastructure is improved.

With the launch of the Uranium Prospecting and Mining Partnership Program (PPLU), INB is seeking to integrate the private sector into uranium exploration—an essential step to boost domestic production and reduce dependence on imports. “Our partnership model foresees the selection of qualified companies to make feasible the resumption of exploration projects that were halted over 40 years ago, with a commitment to adopt best environmental, social, and governance practices,” Felipe explained. However, he emphasized that the success of this model depends on adjustments to the regulatory framework.

Law No. 14.514/2022, which allows the establishment of partnerships for uranium exploration and mining, already lays the foundation for new business. Sanzio Soares, INB's Superintendent of New Business, points out that it is clear several aspects of the regulation of the nuclear-mining sector still require clearer definitions from regulatory agencies and the Federal Government itself, in order to provide greater predictability for contracts and greater legal certainty for potential investors in this activity. “But we understand that the cur-

rent legal framework already allows for the development of partnerships, and that is why we are investing in the Pró-Urânio program. The main adjustments needed depend on the regulation of Law No. 14.514/2022 through a decree. Certainly, a new legal framework would open greater opportunities for partnerships, but it would delay the entry of the private sector into uranium mining by many months or even years. The main challenges we are facing relate to the transition from the system that existed before the enactment of the Law to the current partnership framework,” he said.

From the infrastructure perspective, they warn that the main bottleneck is the limited number of trained professionals in the country for the prospecting and mining of radioactive materials. In geology and mining engineering schools, there are not many groups dedicated to training specialists in this area. These capabilities must be developed through specific support programs that enable the sector to resurge. Another limiting factor is radiological protection. For example, most commercial laboratories providing geochemical support to the mining sector are not prepared to handle radioactive samples.

Felipe pointed out the shortage of trained personnel as one of the main bottlenecks for the development of the sector. “In geology and mining engineering schools, there is a significant gap in the training of specialists in radioactive materials,” he noted. Moreover, the lack of laboratories specialized in radiological protection and geosciences related to the nuclear sector is also a barrier to the safe prospecting and mining of uranium in Brazil.

The discussion surrounding the regulatory framework is not limited to mineral production but also includes environmental safety and public health. According to the executives, the key to the success of uranium mining in Brazil lies in adopting best practices to mitigate social and environmental impacts. “There is no energy transition without the participation of nuclear energy,” they affirm. INB, with its commitment to the highest quality standards, plays a central role in this process, ensuring that uranium production in Brazil is safe and efficient.

In summary, Brazil faces a complex scenario: taking advantage of its mineral potential with the entry of the private sector, without compromising safety and sustainability. Improving the regulatory framework will be essential to ensure that uranium mining is not only profitable but also aligned with the best environmental and governance practices. The future of Brazil’s nuclear sector depends on these decisions, which—if well guided—can position the country at the forefront of clean and sustainable energy production. ■

## **“BRAZIL HAS A FAVORABLE ENVIRONMENT FOR URANIUM MINING INVESTMENTS, PROVIDED THAT THE REGULATORY FRAMEWORK IS STRENGTHENED AND INFRASTRUCTURE IS IMPROVED.”**

### **URANIUM PROSPECTING AND MINING PARTNERSHIP PROGRAM (PPLU)**

Pró-Urânio, or the Uranium Prospecting and Mining Partnership Program, is an initiative aimed at building partnerships between INB and the mining sector in order to make feasible the domestic production of this important mineral resource, eliminating dependence on imports and even enabling its export—adding another product to INB’s portfolio and increasing cash generation. There are various uranium-related mining assets across the country; however, INB does not currently have the operational capacity to develop them.

The proposal is to select qualified partners through a public bidding process that will consider operational and investment capacity, along with other aspects aligned with INB’s corporate principles, such as ensuring the adoption of best environmental, social, and governance (ESG) practices in project development. The partnership model will take the form of a consortium, in which INB provides the mining asset—which has already received significant public investment—and assumes the responsibilities defined by the state monopoly, such as the export of uranium concentrate not destined for domestic consumption. INB also grants the partner the right to explore and produce substances associated with uranium, which adds value to the project, and for which INB receives only a small royalty. On the other hand, the partner assumes the implementation and operational costs. The return is shared between the parties, based on terms established in the contract.

# NUCLEAR MEDICINE SUPPORTS THE ANALYSIS AND TREATMENT OF NEURODEGENERATIVE DISEASES

## TECHNOLOGICAL ADVANCEMENTS OFFER NEW PATHWAYS FOR EARLY DIAGNOSIS AND MORE EFFECTIVE TREATMENTS

In recent years, nuclear medicine has established itself as a promising tool in the fight against neurodegenerative diseases such as Alzheimer's and Parkinson's. Technological advancements, especially the use of methods like positron emission tomography (PET), have enabled a new approach to diagnosing—and potentially treating—these debilitating conditions. We spoke with Professor Carlos Alberto Buchpiguel, Director of the Division of Nuclear Medicine and Molecular Imaging at the Hospital das Clínicas Complex of the University of São Paulo's Medical School (FM-USP), who shared his insights on these advances and future perspectives.

### TECHNOLOGICAL ADVANCEMENTS AND THE DIAGNOSIS OF NEURODEGENERATIVE DISEASES

According to Professor Carlos Alberto Buchpiguel, the main evolution in recent decades has been the improvement in our understanding of the molecular mechanisms that lead to the development of neurodegenerative diseases. In the past, the main difficulty was the lack of tools to identify these molecular changes at the subcellular level. "Many physiopathological models were based on theories without solid diagnostic evidence," he explains.

With technological advances, it has become possible to identify anomalies in the production or deposition of abnormal proteins in the brain. In the case of Alzheimer's disease, for example, proteins such as beta-amyloid accumulate pathologically, forming neurofibrillary tangles that damage nerve cells. These changes trigger inflammatory and im-

mune-mediated responses that result in neuronal loss, a typical process of neurodegeneration.

These discoveries have enabled the development of new diagnostic and treatment methods. Imaging technologies such as PET have played a fundamental role in detecting these alterations non-invasively and early on. "Today, we can visualize these abnormal proteins in the brain even before the appearance of more severe clinical symptoms, which opens the door to faster and more effective diagnoses," says the professor.

### THE CONTRIBUTION OF PET TO EARLY DIAGNOSIS

Positron emission tomography (PET) stands out for its ability to detect molecular changes in the brain, such as the early deposition of beta-amyloid proteins. "Previously, these deposits could only be confirmed through autopsies, which made early diagnosis very difficult," Buchpiguel explains. Today, biomarkers used in PET scans allow these deposits

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**"IF WE CAN CONCENTRATE OUR EFFORTS, WE CAN REACH A LEVEL OF DEVELOPMENT SIMILAR TO THAT OF THE WORLD'S LEADING CENTERS."**

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to be detected non-invasively and in the early stages of the disease.

Early diagnosis has direct implications for treatment. Although new antibodies that block the formation of abnormal protein deposits have shown modest results, there is growing hope that such therapies may slow down or even halt the progression of the disease. “While these treatments still don’t provide a definitive cure, they represent a significant advance compared to what we had just a few decades ago,” the expert says.

Identifying these anomalies through PET also allows physicians to select the most appropriate patients for these innovative treatments, increasing the chances of success. “This is one of the greatest advances in the field of neurodegenerative diseases. We can now identify those who may benefit from therapies based on new medications,” says Buchpiguel.

## CHALLENGES AND LIMITATIONS OF NUCLEAR MEDICINE

Despite the advances, there are significant challenges on the path of nuclear medicine, both from a technological standpoint and in terms of public access to these therapies. Cutting-edge imaging technology and the use of new radiopharmaceuticals come at a high cost, limiting access—especially for lower-income patients. “The cost of incorporating these new treatments is high and they are often not available in the public health system,” the professor points out.

Furthermore, nuclear medicine research in Brazil faces an additional obstacle: international patents that protect these new treatments. The development of national alternatives and the creation of generic drugs still require time and investment, although the qualification of the Brazilian scientific community is a positive point. “What we lack is more focus and investment. If we can concentrate our efforts, we can reach a level of development similar to that of the world’s leading centers,” says Buchpiguel.

## THE FUTURE OF THERAPIES BASED ON NUCLEAR MEDICINE

Regarding the future of nuclear therapies for neurodegenerative diseases, the professor notes that although the use of radioactive agents to directly destroy proteins has not yet been validated, the concept of “theranostics” is already being explored.

“The term ‘theranostics’ refers to the combination of diagnosis and therapy based on the same molecular target. We are already seeing this with PET, which uses therapeutic agents to block the formation of abnormal proteins—this represents a form of theranostics,” he explains.

However, using radiation directly to treat neurodegenerative diseases—aiming to destroy harmful proteins in the brain—still faces serious limitations. “The challenge is to ensure that radiation does not affect surrounding healthy tissue, which could cause more damage than the protein deposits themselves,” he warns. For now, this type of therapy remains in the research stage, but it opens new perspectives for the future of nuclear medicine in this field. ■

### CARLOS BUCHPIGUEL EXPLAINS THAT THESE EXAMS CAN ALSO BE USED TO DIAGNOSE EPILEPSY AND STROKES

Positron emission tomography (PET-CT) is an advanced imaging exam that uses radiopharmaceuticals and biomarkers to identify brain abnormalities, such as the presence of amyloid proteins—typical in diseases like Alzheimer’s. This exam not only detects pathological changes but also helps assess synaptic dysfunction, enabling a more precise and earlier diagnosis. It is also useful in other neurological conditions, such as epilepsy—by locating abnormal brain activity—and in the diagnosis of strokes (cerebrovascular accidents), by assessing cerebral blood flow faster and more effectively than conventional imaging techniques like MRI.

Despite its advancements, this technology is still limited to centers of excellence, such as the Hospital das Clínicas at USP, which is developing a radiopharmaceutical production unit to serve patients within the Unified Health System (SUS). This allows the most vulnerable populations to access advanced diagnostic exams, although this kind of technology is still not widely available in other public institutions. In the private sector, these exams are more readily available in several Brazilian cities, highlighting the disparity in access to innovation across the country.



# SMRS IN THE OIL INDUSTRY AND ENERGY SUSTAINABILITY

## SMALL MODULAR REACTORS EMERGE AS AN ALTERNATIVE TO DECARBONIZE OIL PRODUCTION IN REMOTE AREAS WITH LIMITED INFRASTRUCTURE

In recent years, the world has witnessed increasing pressure to decarbonize global industry, particularly in the oil and gas sector. While the energy transition is a complex process, new technologies are emerging as viable alternatives to ensure continued production while aiming to reduce greenhouse gas emissions.

Among the most noteworthy innovations are Small Modular Reactors (SMRs), which are being evaluated by companies in the sector as a potentially revolutionary solution. To better understand how these reactors can be applied in the oil industry, we spoke with Professor Aquilino Senra, from the Nuclear Engineering Program at COPPE/UFRJ, a specialist in nuclear energy and its industrial applications.

### SMRS: FLEXIBILITY IN POWER SUPPLY FOR REMOTE REGIONS

Professor Aquilino explains that SMRs represent an emerging class of nuclear reactors, smaller and more flexible than conventional ones. “Initial analyses of SMRs show that these reactors are well-suited to the energy demand profile of oil processing, offering a viable and carbon-free supply of heat and electricity.”

This feature is especially relevant in remote regions or areas with limited infrastructure, where energy supply is a constant challenge. “SMRs can be installed on-site at an oil production facility, providing a reliable and continuous source of electricity and heat. Continuous full-power operation of SMRs can be maintained for periods ranging from 36 to 120 months, which enables stable and uninterrupted operations,” explains the professor.

The major advantage here, according to Aquilino, is that after this period, the reactor can be quickly replaced without significantly impacting the oil plant’s operations. “The SMR alternative eliminates

dependence on fossil fuels transported to the site, which not only reduces logistical costs but also removes vulnerabilities associated with fuel supply disruptions.”

### TECHNICAL ADVANTAGES AND CHALLENGES

One of the greatest advantages of SMRs compared to traditional energy sources like diesel generators is their ability to operate continuously and reliably for years. “SMRs provide stable baseload energy, which is essential for energy-intensive industries such as oil. Additionally, they are scalable and can be installed according to the growing needs of production,” details Professor Aquilino.

The flexibility of SMRs is another highlight. The compact size of these reactors allows them to be transported to remote locations—by land or sea—and installed quickly. For the oil industry, this is crucial, as many operations are located in hard-to-reach areas. “The modularity of SMRs is a major advantage. They are small and can be scaled according to the specific needs of each facility. This avoids the overuse of power, which could render larger reactors economically unviable,” says Aquilino.

Moreover, SMRs can supply process heat, which is used in various functions of the oil industry, such as refining, fertilizer production, and even hydrogen generation. “The hybrid production of electricity and high-quality process heat is a great benefit. Output temperatures between 250°C and 500°C are ideal for processes like heavy oil desulfurization and methanol production,” adds the expert.

However, despite their many advantages, the use of SMRs presents technical challenges. The management of nuclear waste is one of the main concerns. “The waste generated by nuclear reactors requires safe storage for extended periods, which demands adequate infrastructure,” explains Professor Aquilino.

## **"SMRS DO NOT COMPETE WITH CONVENTIONAL NUCLEAR POWER PLANTS, BUT RATHER EXPAND THE USE AND POTENTIAL OF NUCLEAR TECHNOLOGY FOR THE DECARBONIZATION OF OFFSHORE OIL PRODUCTION."**

lino. He also points to public resistance toward nuclear technology, often associated with safety risks and nuclear accidents.

### **SAFETY AND SUSTAINABILITY: THE FUTURE OF SMRS**

In terms of safety, SMRs offer significant advantages compared to traditional energy sources. Professor Aquilino explains that due to their modular design, these reactors can be installed in more protected locations, such as underground structures, making them less vulnerable to external events and potential failures. "The use of passive and innovative safety systems that rely on natural forces like gravity and convection makes SMR-type reactors more reliable. Furthermore, many models use intrinsically safer fuels, such as TRISO pellets, which have triple-layer protection and can withstand extremely high temperatures."

When it comes to sustainability, SMRs stand out for their lack of carbon dioxide (CO<sub>2</sub>) or other greenhouse gas emissions during operation. "Using SMRs to generate electricity and heat without burning fossil fuels is a significant contribution to climate change mitigation," Aquilino points out.

### **REGULATORY CHALLENGES AND THE POTENTIAL FOR LARGE-SCALE ADOPTION**

Despite promising advances, Professor Aquilino highlights that there are significant challenges to the broader adoption of SMRs in the oil industry.

"There are legal and regulatory issues that need to be addressed. Licensing the installation and operation of SMRs is a complex process that requires a solid legal framework to ensure safety and the effectiveness of the technology."

He also points out that, despite their great utility for decarbonizing the sector, SMRs do not compete directly with conventional nuclear power plants but rather expand the potential of nuclear energy. "SMRs are a viable solution for producing electricity and heat in offshore oil operations—something conventional nuclear plants cannot offer due to their scale and more complex infrastructure."

### **THE ENERGY TRANSITION OF THE OIL INDUSTRY**

The adoption of SMRs in the oil industry could represent a quiet revolution, especially when it comes to reducing dependence on fossil fuels and achieving global carbon emission reduction targets. However, as Professor Aquilino notes, there are still legal and technical challenges to overcome before SMRs can be widely deployed. The good news is that interest in this technology is growing, and over time, it may become a central pillar in the quest for a cleaner and more sustainable oil industry. ■



Photo: Oregon State University

# MIKHAIL CHUDAKOV, DEPUTY DIRECTOR GENERAL AND HEAD OF THE NUCLEAR ENERGY DEPARTMENT AT THE IAEA

In an exclusive interview with Conexão Nuclear, Mikhail Chudakov, Deputy Director General and Head of the Department of Nuclear Energy at the International Atomic Energy Agency (IAEA), shared his perspectives on the challenges and opportunities in the nuclear sector and detailed how international collaboration—especially with the IAEA—can strengthen Brazil’s nuclear initiatives. Read the full interview below.

**1 – Mr. Chudakov, it is a great privilege to have your participation in NT2E in Brazil. What are your main expectations for this event, particularly regarding the strengthening of international cooperation in the nuclear sector?**

International cooperation is vital for the long-term success of the nuclear sector. The Nuclear Trade & Technology Exchange fair has played an important role in promoting the nuclear sector in Latin America for over three decades, and I hope that this year’s edition will once again serve as a dynamic platform to reinforce existing cooperation agreements and highlight new collaboration opportunities.

**2 – The IAEA has played a key role in supporting countries on their energy transition journey. How can Brazil, with its nuclear projects under development, benefit from collaboration with the IAEA and other countries in the region?**

Brazil is already actively engaged with the IAEA, which serves as the main platform for international dialogue and knowledge exchange in fields related to nuclear energy. It offers a wide range of support services for countries both at the beginning of their nuclear energy journey and those with well-established programs. This includes peer review missions to assess practices in nuclear energy, safety, and security, as well as training courses, workshops, and other activities. Brazil, of course, falls into the latter category,



Photo: Dean Calma / IAEA

with operational experience in nuclear energy dating back to the early 1980s. But the nuclear energy sector is constantly evolving—with the introduction of new technologies and optimization of operational practices. There is always more to learn. Even the most experienced operators can—and should—strive to improve. In addition to engaging with the IAEA, Brazil can also consult with other countries operating nuclear programs in the region and around the world to benefit from lessons learned in their projects.

### **3 – With increasing focus on sustainability and energy security, what are the most critical challenges facing the global nuclear community today, and how is the IAEA addressing them?**

Although nuclear energy has gained momentum in recent years and continues to grow, several challenges must be overcome to ensure its long-term sustainability. Ensuring adequate financing is one of them. In 2024, the IAEA raised its annual projections for nuclear energy expansion for the fourth consecutive year. For that scenario to become a reality, a substantial increase in global investment is needed—at least US\$125 billion per year, up from the approximately US\$50 billion spent annually between 2017 and 2023. The IAEA is helping countries analyze how they can obtain additional financing for nuclear energy, including from the private sector. The latest edition of our report *Climate Change and Nuclear Power*, focused on finance, outlines ways to achieve this goal—such as adopting measures to build investor confidence through construction guarantees and cost predictability, as well as commitments to build multiple reactor units.

Capacity building and workforce development are also essential. Proactively developing talent is crucial to meet the growing needs of the nuclear sector. The IAEA projects that more than 4 million people will be working in the nuclear energy sector by 2050. It is expected that one-third of the current workforce will retire by 2030, and more than one million new professionals will be needed to fill the gaps left by retirements and support the significant expansion of nuclear energy. Solid knowledge management practices and human resource development are required. IAEA support in this area includes the International Nuclear Management Academy (INMA), which helps universities create master's programs in nuclear technology management, and the Nuclear Knowledge Management Schools, which provide education and training to young professionals on the development and implementation of nuclear knowledge management programs in nuclear science and technology organizations.

### **4 – Nuclear energy has played a key role in the debate over decarbonizing the energy matrix. What is your view on the future role of nuclear energy in global energy policy, especially in developing countries like Brazil?**

The decision to introduce or expand a nuclear en-

ergy program rests solely with the countries considering their various energy options. It is a long and potentially complex process that reflects the importance of committing to the long-term effort required for a successful nuclear energy program. We are pleased to see so many countries enthusiastic about nuclear energy, and indeed, all signs point toward an expansion of nuclear capacity in the coming years. There is now a global consensus—established at COP28 in Dubai—that the clean energy transition needs nuclear energy. Nuclear energy was included in the Global Stocktake during that pivotal meeting, with the 198 countries party to the United Nations Framework Convention on Climate Change calling for the accelerated deployment of clean energy technologies, including nuclear. At the same event, 22 countries committed to working toward tripling nuclear capacity by 2050—a number that has since increased to 31. It is clear that nuclear energy has a role to play in both developed and developing countries—not only in electricity generation, but also in a variety of non-electric applications, including seawater desalination, hydrogen production, and district heating.

The future of nuclear energy looks promising, but much remains to be done to ensure it reaches the levels we know it is capable of achieving.

### **5 – Brazil has major nuclear projects underway, such as the construction of new power plants. What are the IAEA's main recommendations to ensure that these projects meet the highest safety and operational efficiency standards?**

Safety is absolutely paramount at all nuclear facilities—including, of course, nuclear power plants. Nuclear safety is the responsibility of each individual country. The IAEA provides guidance on best practices through its Safety Standards and international reviews, as well as by organizing workshops, training courses, technical publications like our Nuclear Energy Series, and other capacity-building activities.

Operational efficiency is also essential for the sustainability of nuclear energy. Nuclear power plants can provide baseload energy or operate in “load-following” mode, adjusting their output in real time to match changes in electricity demand. Strong training practices can also enhance plant efficiency. Well-trained operators are efficient operators. ■



# LIFE EXTENSION OF ANGRA 1 WITH SAFETY AND EFFICIENCY

**ELETRONUCLEAR PREPARES TO ENSURE THE PLANT'S OPERATION UNTIL 2044 WITH A ROBUST MODERNIZATION PROGRAM AND INVESTMENTS IN SAFETY**

Angra 1 Nuclear Power Plant, one of Brazil's most important energy sources, is undergoing a life extension process that will allow it to remain in operation until 2044. This initiative has posed a major challenge for Eletronuclear, the company responsible for managing the plant, which is investing substantial resources and implementing significant changes to ensure safety and efficiency over the next 20 years.

In an exclusive interview with Conexão Nuclear, Sinval Gama, Technical Director at Eletronuclear,

detailed the main difficulties the company has faced during this process and the investments required to ensure the continued operation of Angra 1.

## TECHNICAL AND OPERATIONAL CHALLENGES

"The Angra 1 life extension program involves a set of technical and operational projects to ensure the preservation of safety levels and improve the plant's performance," Gama explains. According to the director, the program's activities include aging man-



Photo: Rodrigo Saldon



agement, system modernization, and the implementation of new requirements to meet the standards of regulatory agencies such as the National Nuclear Energy Commission (CNEN) and the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA).

The process, which has already been underway for more than 20 years, included a rigorous analysis of all technical, operational, and financial aspects of the plant, resulting in a series of modernizations and replacements of critical equipment. “The license renewal was requested in 2019, after a detailed evaluation and based on lessons learned from nuclear plants around the world. This led to the decision to extend the plant’s operation until 2044, which was approved in December 2024,” stated Gama.

### **SIGNIFICANT INVESTMENTS TO ENSURE SAFETY AND EFFICIENCY**

The Angra 1 life extension program requires a significant investment, estimated at around R\$ 3.2 billion. These resources will be applied to various projects, from control system modernization to the replacement of essential components for the plant’s safety and performance. Gama outlines some of the key projects: “We are investing in the replacement of sensors, safety valves, monitoring systems, and the modernization of electrical and instrumentation systems, as well as upgrades to turbines and cooling systems.”

According to him, these investments are aimed not only at ensuring the safe operation of the plant but also at promoting economic and social benefits for the surrounding region. “These projects are generating jobs and income for local communities while also ensuring the continued operation of the plant, which is fundamental for the country’s energy supply,” the director emphasized.

### **IMPACT ON BRAZIL'S ENERGY MATRIX**

Keeping Angra 1 in operation until 2044 has a direct impact on Brazil’s energy matrix, contributing 640 MW of firm power generation, which is essential for the National Interconnected System. “The plant will continue to provide stable, baseload energy, without the need for additional reinforcements in the transmission system,” stated Gama. He emphasized that, with the necessary investment for the life extension, the plant will be essential to meet Brazil’s growing energy demand.

### **COMMITMENT TO ENVIRONMENTAL AND COMMUNITY SAFETY**

One of the most critical aspects of the Angra 1 life extension process was meeting environmental and safety requirements. Environmental preservation and the safety of local communities are ensured through a comprehensive and exhaustive monitoring program that covers the entire surrounding area to verify, record, and guarantee that no environmental impacts are caused by the plant’s operation. “We strictly comply with all requirements from regulatory bodies such as CNEN and IBAMA to ensure that the plant’s operation is safe and responsible,” said Gama.

### **LESSONS FOR THE FUTURE**

With the experience gained from the operation of Angra 1, Eletronuclear plans to apply the lessons learned to the modernization and operation of other plants, such as Angra 2 and Angra 3. “We are constantly improving our processes based on the lessons learned from Angra 1 to ensure that future operations are even safer and more efficient,” says Gama. The life extension program for Angra 2, for example, is already being planned, with studies beginning now to ensure that the unit can also operate for an additional 20 years.

The decision to extend the life of Angra 1 is a key step toward ensuring the continuity of energy production in Brazil, supporting a safer and more sustainable energy future. Eletronuclear continues to invest in modernizing its facilities, maintaining a strong commitment to safety, efficiency, and sustainability—fundamental elements for the long-term operation of the plant. ■

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**“THE PROJECTS ARE GENERATING JOBS AND INCOME FOR LOCAL COMMUNITIES WHILE ENSURING THE CONTINUITY OF THE PLANT'S OPERATION, WHICH IS ESSENTIAL FOR BRAZIL'S ENERGY SUPPLY.”**

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# SUSTAINABLE TAXONOMY: THE ROLE OF NUCLEAR ENERGY IN BRAZIL

## IT'S TIME TO LEARN FROM THE EXAMPLE OF OTHER COUNTRIES

In recent years, the discussion around sustainable taxonomies has gained global relevance as an essential tool to guide investments and business initiatives aligned with the Sustainable Development Goals. These classifications define which economic activities can be considered sustainable, promoting a greener and more resilient future. In this context, nuclear energy stands out as a strategic solution for decarbonization, energy security, and global economic development.

Countries such as China and members of the European Union have already recognized nuclear energy as an activity that contributes significantly to the energy transition. In the European Union, it was included in the Sustainable Taxonomy as a “transitional activity,” provided it meets strict criteria such as the safe management of radioactive waste and financial guarantees for decommissioning. In China, the nuclear sector has been classified as a green technology, encouraging investment in advanced reactors...

In Brazil, however, nuclear energy has not yet been included in the Brazilian Sustainable Taxonomy (BST), a point that has raised concern among experts and stakeholders in the sector. This omission is seen as a critical gap, considering the role of nuclear energy in the national energy matrix and its contribution to global climate goals.

## NUCLEAR ENERGY IS ESSENTIAL FOR BRAZIL

According to Eliene Silva, from the Brazilian Taxonomy Coordination at ABDAN's Sustainability Committee, “excluding nuclear energy from the Brazilian Sustainable Taxonomy does not reflect the strategic role this source plays for the country and the world. While Brazil hesitates to recognize it, other nations are already reaping the benefits of its inclusion in their local taxonomies.” For Silva, including nuclear energy in the BST would not only attract new investments but also strengthen Brazil's position...

Leonardo Paredes, Technical Consultant at ABDAN, emphasizes that “nuclear energy is widely recognized as clean and safe, and its exclusion from the BST goes against inter-

national best practices.” He notes that nuclear energy is not only a solution for decarbonization, but also a cornerstone for ensuring energy security and promoting socio-economic development in several regions of Brazil.

## URANIUM AS A STRATEGIC RESOURCE

Including uranium in the taxonomy is also of great importance. Brazil has the seventh-largest uranium reserve in the world, and this strategic resource can be developed in a modern and responsible way. “Uranium mining has evolved with more sustainable technologies, reducing environmental impacts and offering regional development opportunities,” explains Leonam dos Santos Guimarães, Technical Director at ABDAN.

Leonam also reinforces that Brazil has the potential to become a major uranium exporter, contributing not only to the national economy but also to global energy security. “Uranium is fundamental for the self-sufficiency of the Brazilian Nuclear Program, enabling the country to meet its internal needs and expand its presence in the international market,” he states.

## A FUTURE WITH CLEAN AND SAFE ENERGY

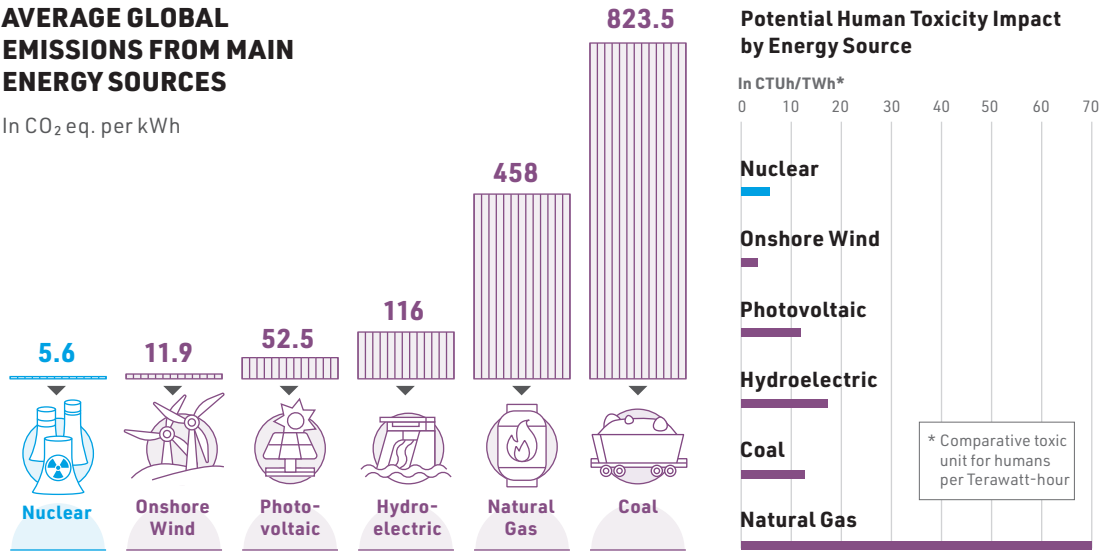
The consensus among experts is clear: nuclear energy and uranium are fundamental for Brazil's energy future and for meeting global sustainability targets. The exclusion of this source from the Brazilian Sustainable Taxonomy represents a setback at a time when the world is recognizing nuclear energy as an indispensable solution for the energy transition.

“Following the example of China and the European Union is an opportunity for Brazil to reaffirm its commitment to the Paris Agreement and attract the investments needed to expand its nuclear energy matrix,” concludes Leonardo Paredes. Moreover, including nuclear energy in the BST would allow Brazil to strengthen international cooperation, stimulate technological innovation, and create a cleaner, safer, and more competitive energy matrix.

Therefore, embracing nuclear energy and uranium as sustainable solutions is more than strategic: it is essential to ensure Brazil plays a leading role in the global energy transition.

**AVERAGE GLOBAL EMISSIONS FROM MAIN ENERGY SOURCES**

In CO<sub>2</sub> eq. per kWh



Source: UNECE, 2022

**TAXONOMIES**

**1. EUROPEAN UNION**

Nuclear energy is recognized in the European Union Taxonomy as a transitional activity within the context of climate change mitigation, subject to strict technical criteria to ensure its sustainability. Among the requirements are the safe management of nuclear waste, assurance that it does not cause significant harm to other environmental objectives, and financial security for decommissioning and waste management. Although uranium is not explicitly listed as a critical material, it is essential for the operation of nuclear reactors that fall under the sustainable criteria of the EU Taxonomy.

**2. CHINA (GREEN TAXONOMY)**

In China, nuclear energy is classified as a green technology, with significant incentives for investment in new nuclear projects and the development of advanced reactors. Uranium, although not explicitly detailed, is implicitly recognized due to its crucial importance for China's nuclear program, one of the most ambitious in the world, which plans to build 158 more nuclear reactors [1]. Therefore, uranium is essential to the country's energy strategy.

**3. UNITED STATES**

The United States currently has 95 nuclear reactors in operation and plans to build 13 more [1] and [3]. Although the country does not have a formal taxonomy,

the U.S. government considers nuclear energy a clean source and encourages it through policies such as the Inflation Reduction Act, which supports the transition to low-carbon energy sources. Uranium is listed as a critical material by the U.S. Geological Survey due to its strategic importance for energy security and for supplying the country's nuclear reactors.

**4. CANADA**

With 17 reactors in operation and 9 proposed [1], nuclear energy is a key part of Canada's energy transition strategies. It is included in sustainable finance criteria due to its role in reducing carbon emissions. Uranium, although not explicitly detailed in the country's taxonomy, is implicitly considered due to Canada's position as one of the world's largest uranium producers [2], reinforcing its relevance to the nuclear sector.

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# WHY DOES BRAZIL INSIST ON IGNORING THE REAL COST OF ENERGY?

## HOW DISTORTIONS IN ENERGY SOURCE COMPARISONS IMPACT THE COUNTRY'S ENERGY FUTURE

The debate on energy transition in Brazil has been marked by a partial—and often mistaken—view of the real costs of electricity generation. The simplistic comparison between the levelized cost of energy (LCOE) of nuclear energy and variable renewable sources, such as solar and wind, ignores essential factors such as system costs, backup needs, and grid stability. This distortion comes at a high price for consumers and for the country's energy security.

ABDAN and other entities and companies in the sector have repeatedly brought this issue to light, but face resistance from some stakeholders who insist on erroneous and incomplete comparisons. The cost discussion cannot be limited to plant-level analysis because, contrary to what is being marketed, the electricity generated is not always available at times of highest demand. What happens when intermittent sources fail to supply the required load? Who pays the price for system instability?

The fastest and most natural solution is to turn to gas-fired thermal power plants, but this option also incurs additional costs—especially in a scenario where the carbon price is expected to reach USD 100 per ton after 2030, which coincides with the scheduled operation of Angra 3, according to the main international publications. In the U.S. and Europe, this discussion is already a reality, while in Brazil the choice to ignore this factor continues to benefit only those who refuse to face the future.

Another overlooked issue is the dependence on hydropower as a backup for intermittent sources. Brazil faces growing challenges from droughts, wildfires, and the multiple use of water for agriculture, human consumption, and navigation. When there is not enough water, thermal plants remain the only alternative—along with the high costs they impose on consumers.

Even alternatives like the adoption of batteries to complement solar and wind intermittency

face economic limitations. Currently, the levelized cost of battery energy is around USD 200 per megawatt-hour—a prohibitive cost that few are willing to include in comparisons.

Meanwhile, nuclear energy remains marginalized in the debate, despite being a reliable solution with predictable costs and low carbon emissions. In developed countries, this scenario is already consolidated, with 28 nations committed to tripling their nuclear capacity by 2050, as agreed at COP28 and COP29. Why is Brazil going against this global trend?



### WHAT DOES THE WORLD SAY?

To deepen this discussion and bring an international perspective to the debate, ABDAN considered studies by experts from the world's leading institutions in the field: NEA (Nuclear Energy Agency), IAEA (International Atomic Energy Agency), WNA (World Nuclear Association), and IEA (International Energy Agency). These studies clarify why the costs of electricity generation must be analyzed broadly and realistically, taking into account not only plant-level costs, but also systemic impacts and environmental and economic externalities.

The truth is that Brazil can no longer afford to ignore this reality. Persisting in distorted comparisons between energy sources is to insist on a mistake that proves costly to consumers and undermines the country's energy security. The debate must be technical and well-founded—not manipulated by interests that perpetuate a flawed view of the Brazilian electricity sector.

**"COMPARING ONLY THE GENERATION COST AT THE PLANT LEVEL, WITHOUT CONSIDERING SYSTEM COSTS AND EXTERNALITIES, LEADS TO MISGUIDED DECISIONS THAT CAN COMPROMISE THE COUNTRY'S ENERGY SECURITY."**



## THE HELIOCENTRIC PARADIGM

For centuries, human knowledge about nature was shaped by direct—and often superficial—observation. A classic example is the belief in geocentrism: when looking at the sky, it seemed obvious that the Sun revolved around the Earth. This idea prevailed for a long time, despite the proposal of Aristarchus of Samos in the 3rd century BC, who had already suggested that the Sun—not the Earth—was the center of the Universe. It was only many centuries later, in the 17th century, that Nicolaus Copernicus organized and formalized the heliocentric model, paving the way for scientists like Kepler, Galileo, and Newton to consolidate the scientific consensus we hold today.

A similar mistake occurs in the energy debate—especially in Brazil. Many analysts—and even so-called experts—compare generation costs across

different energy sources without considering the appropriate criteria. A simple LCOE (Levelized Cost of Electricity) analysis at the plant level does not reflect the complexity of the electricity system, as each technology has specific attributes and additional costs, such as backup and grid stability. Since 2015, the OECD/NEA-IEA has warned that such comparisons should include system costs and externalities, such as carbon pricing. However, those who point this out are often treated as dissidents, disregarding the importance of a deeper and more grounded debate. Just like Galileo, who reaffirmed his findings before the Inquisition with “E pur si muove,” mathematics and set theory teach us that before adding numbers, we must understand the categories involved—otherwise, we are mixing apples and oranges in the same equation. ■



# NUCLEAR ENERGY AT SEA: THE FUTURE OF SUSTAINABILITY AND ENERGY SECURITY

## SHIP PROPULSION, POWER GENERATION IN PORTS, OR ENERGY SUPPLY FOR OFFSHORE OPERATIONS

The pursuit of clean and sustainable energy solutions has driven the development of nuclear energy for maritime applications. Whether for ship propulsion, energy generation in ports, or energy supply for offshore operations, nuclear power emerges as a viable alternative for decarbonizing the maritime sector.

### THE ORIGIN OF MARITIME NUCLEAR ENERGY

“Nuclear power generation was born at sea,” says Leonam Guimarães, Technical Director at ABDAN. Nuclear propulsion began in the 1950s with nuclear-powered submarines enabling autonomous, long-duration operations without the need for refueling. Since then, several countries—including the United States, Russia, France, and China—have expanded the use of nuclear energy for non-military purposes, including commercial vessels and floating power plants.

Renato Cotta, Technical Consultant at the General Directorate of Nuclear and Technological Development of the Brazilian Navy, reinforces the historical importance of this technology: “Offshore nuclear generation has been used in military naval environments since the 1950s, enabling long-term operations without the need for refueling.”

### THE ROLE OF SMALL MODULAR REACTORS (SMRS)

Small Modular Reactors (SMRs) are revolutionizing the nuclear sector, with at least 81 SMR projects under development worldwide—at least 10 of them focused on maritime applications. “China, Denmark, Russia, South Korea, Canada, and the USA are heavily investing in SMRs for nautical use, promising to transform maritime transportation and port infrastructure,” explains Guimarães.

Renato Cotta, who is also a full professor at POLI & COPPE – UFRJ, adds: “Offshore nuclear power plants

are being presented as safer, lower-cost solutions with less complex deployment. There are also submarine nuclear generation projects, like France’s FlexBlue, which can meet electricity needs in coastal and island regions.”

Cotta highlights a specific potential for Brazil: “Petrobras is already studying offshore nuclear generation for pre-salt oil exploration, due to the high CO<sub>2</sub> content of these fields and the need to reinject the gas.”

### BENEFITS OF NUCLEAR ENERGY AT SEA

Nuclear energy offers numerous possibilities for the energy transition of the maritime sector. Some of the main applications include:

- Nuclear propulsion for ships: vessels powered by nuclear energy can operate for long periods without refueling and significantly reduce greenhouse gas emissions.
- Power for port operations: SMRs can provide reliable and clean electricity to ports and coastal industrial complexes.
- Low-carbon fuel production: nuclear energy can be used to produce hydrogen and ammonia—promising alternatives for the maritime sector.
- Power supply for offshore oil and gas operations: extraction platforms demand large amounts of energy, and SMRs can ensure a stable and sustainable supply.
- Submarine reactors: projects like France’s FLEXBLUE propose the deployment of submerged nuclear reactors to supply offshore platforms, ensuring efficiency and energy security.

## INTERNATIONAL REGULATION AND CHALLENGES

Despite its potential, the adoption of nuclear energy at sea faces challenges. “Safety, regulation, and public acceptance are barriers to be overcome,” warns Guimarães.

Renato Cotta emphasizes that regulatory safety is essential for the advancement of the technology: “The Naval Nuclear Safety and Quality Department of the Brazilian Navy has been preparing for the licensing of civilian floating nuclear plants, in partnership with CNEN and the IAEA.”

### MAIN CHALLENGES:

- Safety and environmental protection: operating reactors in maritime environments requires strict protocols to prevent leaks and incidents.
- International regulation: the absence of a global regulatory framework for maritime reactors hinders the expansion of the technology. Organizations such as the International Maritime Organization (IMO) and the International Atomic Energy Agency (IAEA) are working to establish standards.
- Public acceptance: the perceived risk associated with nuclear energy still generates resistance in some sectors.
- High investment costs: the initial cost of implementing SMRs for maritime applications remains high and demands incentives and strategic partnerships.

## PROSPECTS FOR BRAZIL

Brazil holds a privileged position for the development of nuclear energy at sea. “We have consolidated expertise in the construction of the Brazilian Multipurpose Reactor (RMB) and in the Navy’s nuclear propulsion program,” notes Guimarães. This places the country in a strategic position to advance in the sector.

Cotta emphasizes: “Brazil’s experience with the development of LABGENE and the RMB gives us a solid foundation to move forward with the implementation of naval and offshore SMRs.”

### MAIN OPPORTUNITIES FOR BRAZIL:

- Development of commercial and military nuclear-powered vessels.
- Use of nuclear reactors to supply electricity to oil and gas platforms.
- Deployment of SMRs to supply coastal and riverside communities.
- Partnerships between the Navy, Petrobras, Amazul, and CNEN to strengthen the use of nuclear energy in the maritime sector.



Nuclear energy at sea represents a crucial step toward global sustainability and energy security. With the advancements of Small Modular Reactors (SMRs) and the growing need for decarbonization, this technology becomes an indispensable alternative for the future of the maritime sector.

“Brazil has a unique opportunity to consolidate its leadership in nuclear technology and promote a cleaner and more efficient maritime sector,” concludes Guimarães.

Cotta reinforces the strategic vision: “The integration of nuclear energy into Brazil’s maritime sector could represent a global competitive advantage, ensuring energy independence and sustainability.”

The implementation of nuclear energy at sea is not just a solution for the present—it is a strategic investment in the future of the global energy transition. ■

# FINLAND DISCOVERS MASSIVE THORIUM DEPOSIT WITH POTENTIAL TO POWER THE WORLD

**NEW REPOSITORY OPENS PERSPECTIVES FOR ENERGY SECURITY AND BOOSTS DEBATE ON THE FUTURE OF NUCLEAR ENERGY**



A recent geological discovery in Finland may transform the global energy landscape. Researchers have identified a vast thorium reserve in the central region of the country, estimated to be capable of powering nuclear energy production for millions of years.

Thorium is a radioactive chemical element that stands out as a promising alternative to uranium in nuclear energy generation. Reactors powered by thorium produce less radioactive waste and do not generate plutonium, reducing the risks of nuclear proliferation. Additionally, thorium is more abundant in nature, making it an attractive option to diversify the energy matrix.

The strategic location of the deposit in Finland—a country with advanced mining infrastructure—facilitates the ex-

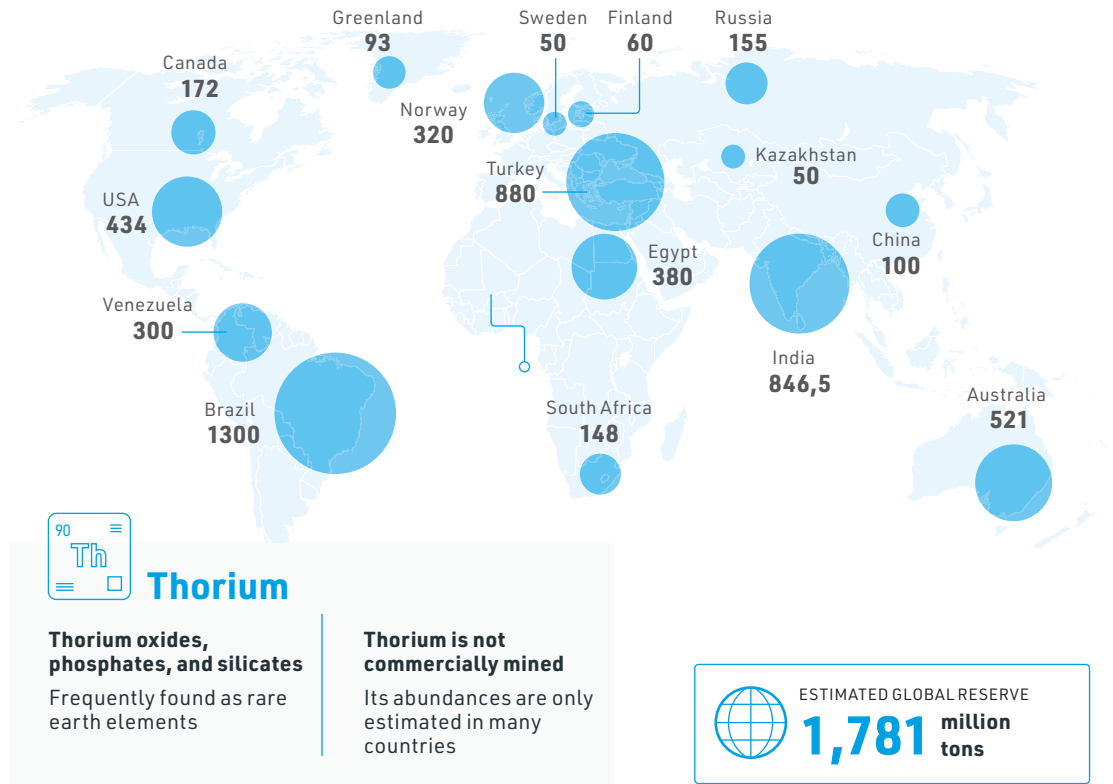
ploration and processing of thorium. However, significant challenges must still be overcome for thorium to become a commercial reality. Most current nuclear reactors are designed to use uranium, requiring substantial investments to adapt existing infrastructure. In addition, strict regulations for thorium use would need to be reviewed.

The discovery may also help reduce the West's dependence on uranium, whose production is concentrated in a few countries, contributing to the diversification of the global energy mix. The international community is closely watching the upcoming developments related to this finding, which has the potential to redefine the energy outlook in the coming decades:

“The recent discovery of a massive thorium deposit in

## THORIUM GLOBAL RESERVES

In thousands of tons



Source: Feasibility to convert an advanced PWR from UO<sub>2</sub> to a mixed (U,Th)O<sub>2</sub> core

Finland highlights the untapped potential of this element as a viable alternative to uranium in nuclear energy generation. Thorium offers significant advantages, such as lower production of radioactive waste and greater natural abundance. However, to fully harness this resource, a joint effort is needed to adapt our nuclear infrastructure and revise current regulations,” says Celso Cunha, President of ABDAN.

### GLOBAL OUTLOOK

The global map of thorium reserves shows a wide distribution of this element across the planet, with notable deposits in Brazil, Turkey, India, and Australia—countries that hold some of the largest known reserves. It is estimated that global reserves total approximately 1.781 million tons, although thorium is not yet mined commercially, and abundance figures remain only approximate. The discovery of the massive Finnish deposit adds a new strategic point to the global energy scenario, reinforcing thorium’s potential as a sustainable alternative to uranium in nuclear energy production.

### DEPOSITS IN BRAZIL

After four decades without conducting exploration studies, Brazil’s Nuclear Industries (INB) resumed mapping uranium deposits in August 2024. Through the Uranium Prospecting and Mining Partnership Program, INB aims to collaborate with mining companies to identify and explore new reserves of this strategic mineral. The initiative seeks not only to meet the domestic demand of Angra 1 and 2 nuclear power plants, but also to prepare for the expected increase in demand with the completion of Angra 3.

Brazil stands out for its significant uranium reserves, ranking sixth in the world, with approximately 309,000 tons of U<sub>3</sub>O<sub>8</sub>. The main uranium deposits are located in Caetité, in the state of Bahia, and in Santa Quitéria, in the state of Ceará.

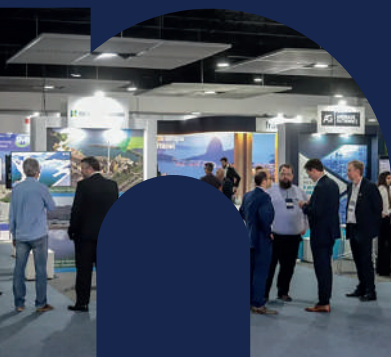
Harnessing these uranium reserves is essential for the development and expansion of the Brazilian nuclear program, contributing to the diversification of the country’s energy matrix and to national energy security. ■



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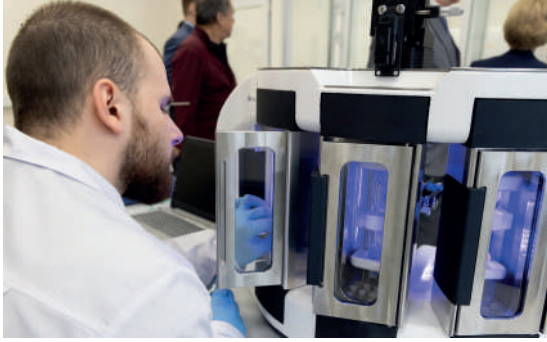
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# FUTURE TECHNOLOGIES FORUM: HOW ROSATOM SHAPES GLOBAL TRENDS



Rosatom continues to push the boundaries of technology, combining nuclear energy with emerging fields to drive innovation. At the Future Technologies Forum, the corporation presented cutting-edge advancements ranging from biocompatible tissue manufacturing to quantum computing and the development of new materials with specific properties.

## BIOFABRICATION: A NEW STAGE IN REGENERATIVE MEDICINE

One of Rosatom's highlights at the forum was its biofabricator—a revolutionary technology that allows for the cultivation of biocompatible equivalents of blood vessels. Unlike traditional bioprinting, this method uses an ultrasonic acoustic field to generate structures from living cells. Vascular equivalents of up to 10 cm have already been developed and are undergoing tests to assess their compatibility and integration into animal organisms.

A month ago, scientists implanted a blood vessel grown in the biofabricator into a rabbit. The operation was successful, and the animal remains healthy. In the future, this innovation is expected to enable not only the creation of blood vessels but also more complex tissues and organs, expanding possibilities for medicine.

According to Alexey Likhachev, Director General of Rosatom, this research lies at the intersection of physics, biology, and information technologies, underscoring its relevance for life quality and expectancy. "Soon, doctors will be able to use pre-prepared donor stem cells to restore damaged tissues and organs, study diseases, and test new drugs," he said.

In addition to meeting the growing demand for biocompatible materials for patients with varicose veins, thrombo-



sis, and coronary artery disease, the technology may also be applied in the regeneration of other damaged tissues and organs.

## MATERIALS OF THE FUTURE: DIGITAL MATERIALS ENGINEERING

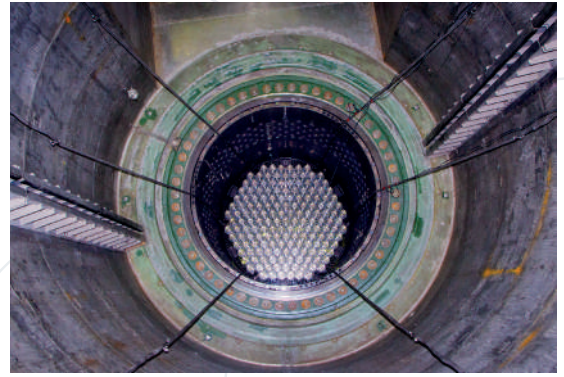
In addition to advances in biotechnology, Rosatom showcased cutting-edge solutions in the field of new materials. The corporation demonstrated an automated system for creating materials with specific properties, using artificial intelligence and digital modeling. This method enables the development of up to ten new material compositions per day, significantly reducing research and testing time.

"These materials can be compared to extreme sports athletes. They withstand temperatures above 1,300 °C, severe mechanical loads, and intense radiation. Our materials are the heart of the newest and most exclusive high-temperature nuclear propulsion units," said Nadezhda Potechina, Head of the Laboratory of Materials Science and Property Studies at the Luch Scientific Research and Production Institute.

One of the most important developments is a new high-strength alloy for the fourth-generation VVER-SKD reactors, designed for 80 years of operation. A metal-ceramic composite was also introduced for the fuel element cladding of the BREST-OD-300 reactor, ensuring greater durability and safety in the use of next-generation nuclear fuel.

## QUANTUM TECHNOLOGIES: FROM THEORY TO INDUSTRIAL APPLICATION

Another key research area involves quantum technologies, essential for the future of materials science and industry.



During the forum, Rosatom organized a debate on the practical application of quantum computing, highlighting the importance of creating an integrated platform for its industrial implementation. Russian scientists have already made significant advances: the country is among the six that possess quantum computers with a capacity exceeding 50 qubits.

According to Rosatom's Director of Quantum Technologies, Ekaterina Solntseva, the nuclear sector is an ideal testing ground for these solutions. In the future, quantum computing could be used to model new materials, develop drugs, and solve complex engineering challenges. An integrated platform is currently under development to enable industrial partners to incorporate these technologies into their processes.

Additionally, Rosatom announced the opening of a quantum laboratory and plans to host an international conference in July this year to drive the growth of the quantum industry. These initiatives will help accelerate the adoption of technologies that may become essential for scientific and technological progress in the coming decades.

### **CLOSED NUCLEAR FUEL CYCLE: THE FUTURE OF NUCLEAR ENERGY**

Rosatom also presented the development of a closed nuclear fuel cycle. Under the "Proryv" (Breakthrough) project, Rosatom scientists showcased innovative solutions for the creation of automated plants capable of operating without human intervention to reprocess used nuclear fuel, operating entirely autonomously with support from the latest robotics advancements. According to Alexander Zherebtsov, Head of the Department for the Development of Nuclear Fuel Cycle Technologies and Materials at "Proryv", in addition to safety, the competitiveness of this new model will extend to all stages of the cycle, directly impacting the adopted technological solutions.

This unprecedented approach is based on automated pyrochemical reprocessing technologies. A promising method for laser cutting of used nuclear fuel is also being

studied, which would make the process more efficient and sustainable.

Closing the nuclear fuel cycle will significantly reduce the volume of radioactive waste and make nuclear energy even more sustainable. This is a major step not only for Russia but for the global nuclear sector, as this technology could form the foundation for safer and more efficient nuclear energy development.

### **ENERGY STORAGE TECHNOLOGIES: THE FUTURE OF ELECTRIC TRANSPORTATION**

Another highlight of the forum was the development of energy storage technologies. During the event, a lithium-ion cell was presented, which will be produced at Rosatom's gigafactory in Krasnaya Pakhra. The factory's production capacity will allow for the manufacturing of up to 50,000 batteries per year, meeting the demand for electric vehicles not only in Moscow but throughout Russia's central region.

The development of energy storage systems is a strategic priority for the corporation. Rosatom is actively working on modern battery solutions that will improve the efficiency and sustainability of electric transport, as well as contribute to energy system stability amid the transition to renewable energy sources.

### **TRENDS AND PROSPECTS**

The Future Technologies Forum reaffirmed Rosatom's status as a global leader in nuclear energy, while also driving the development of innovative technologies in biomedicine, materials science, and energy. The solutions presented reflect the corporation's strategic approach to creating technological ecosystems capable of transforming essential industrial sectors.

For Latin America, this experience is particularly valuable, as Rosatom's integrated technological solutions can be applied in medicine, energy, and advanced manufacturing. Collaboration in these areas opens new opportunities for the region's sustainable development. ■



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