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INAC 2024

debates the role of nuclear energy in the energy transition

LONG LIVE ANGRA 1

The plant is set to operate for another 20 years

Summary

Brasil Nuclear is a publication of the Brazilin Association of Nuclear Energy - ABEN
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There can be no energy transition **without nuclear power**

Despite Brazil having one of the cleanest energy matrices in the world, primarily relying on hydroelectric power, the country needs to engage in a serious debate about the energy transition to preserve the environment. This is an issue that has dominated the global agenda for some time and was also widely debated at the XI International Nuclear Atlantic Conference - INAC 2024, held in May in Rio de Janeiro. With contemporary society shaped by a current electro-intensive lifestyle, which will increase even further in the coming decades with areas such as Artificial Intelligence (AI), data centres and crypto-assets expanding rapidly, it is impossible to implement the energy transition without significantly expanding nuclear generation, which not only guarantees steady, constant and baseload electricity, but is also safe, clean (it emits practically no greenhouse gases) and has well-established technology.

> With areas such as Artificial Intelligence, data centres and crypto-assets rapidly expanding, it is impossible to implement the energy transition without significantly expanding nuclear generation

From an economic perspective, a study presented in February this year by the Getúlio Vargas Foundation (FGV) reveals the positive economic effects generated by investments in nuclear energy in Brazil. The study points out that for every R$1 billion invested in nuclear power, 22,500 jobs are created in the country, most of them high-level jobs, with an increase of R$2 billion in GDP, as well as an increase of R$3.1 billion in the country's output. It should be emphasised that nuclear energy is not subsidised in the same way as other energy sources, especially renewable ones.

It is also worth noting that nuclear power stations are factors in socio-economic development, as they drive the local, regional and national economies. Using the Angra 3 nuclear power station as an example, there is no other development of this magnitude in the state of Rio de Janeiro today. With an installed capacity of 1,405 MW, the plant will be able to produce around 12 million MWh/year, enough to serve 4.5 million people while occupying an area of just 0.08 km^2. This can be compared with the area occupied by other sources for generating 1,405 MW such as 40 km^2 (solar photovoltaic), 125 km^2 (hydroelectric) and 400 km^2 (wind).

This edition of **Brasil Nuclear** presents the debates that took place at INAC 2024, not only on the energy transition, but also on the central theme "Nuclear Energy: Guaranteeing Energy, Health and Food" as well as the challenge of developing a State Programme for nuclear activities in Brazil, innovation, international cooperation, advanced nuclear reactors, small modular reactors (SMRs) and the peaceful application of nuclear energy across a wide variety of fields. The reader will also find an overview of the Conference together with a brief history of INAC since it was established 22 years ago.

In an exclusive interview, executives from the China National Nuclear Corporation (CNNC) reveal their medium- and long-term vision for the Latin American nuclear sector, as well as regulatory matters and public concerns. China, it should be noted, is the country that is currently building the greatest number of nuclear power stations in the world, with a total of 29 under construction, according to the International Atomic Energy Agency - IAEA. They also comment on advanced nuclear technologies, such as SMRs, a topic intensely debated at a recent workshop held in partnership between Casa Viva Eventos, ABEN, AMAZUL and the Brazilian Navy - the second edition is already scheduled to take place on 25 and 26 November in Rio de Janeiro.

In this **Brasil Nuclear**, we also feature articles by experts on the safe and reliable extension of the useful life of the Angra 1 power plant; the natural occurrence of radioactive materials in the field of oil exploration; the importance of science and technology for the development of society and, given the world's current geopolitical situation, the urgent need to expand Brazil's nuclear sector.

Happy reading, everyone!

Carlos Freire
President Brazilian Association of
Nuclear Energy (ABEN)

CNNC could invest in nuclear energy and other projects in Latin America

CNNC is open to investing in Latin American countries. In addition to direct investment, the Chinese company offers EPC services, including financing, through partner banks, which can cover up to 85 per cent of the total cost. According to the company's executives, this collaboration could extend to various fields within the nuclear sector, including energy, non-energy applications, the nuclear fuel cycle, radioactive waste management and radiation safety, as well as equipment manufacturing. In a wide-ranging interview with **Brasil Nuclear**, executives Ma Ran, CNNC's general representative for the Americas, Song Danrong, chief engineer of the ACP100 SMR project, and Deng Huidong, uranium processing expert and director of the International Cooperation Centre, addressed topics such as fourth generation reactors and new sustainable practices for uranium mining and processing. They also anticipated that the ACP100 SMR, the world's first small modular multipurpose reactor under construction, will enter commercial operation in 2025.

What is CNNC's vision for the development of the nuclear sector in Latin America over the next ten or twenty years?

Ma Ran - The China National Nuclear Corporation (CNNC) is the backbone of China's nuclear science and technology industry, the main force in nuclear power development and construction, and the only Fortune 500 enterprise with a complete nuclear industry chain. CNNC places great importance on cooperation with Latin American partners and has been deeply engaged in the region for many years. In the spirit of mutual respect and win-win cooperation, CNNC is willing to join hands with Latin American partners to carry out full-industry chain collaboration across various fields of the nuclear industry, including nuclear energy, non-power applications, uranium resource development, nuclear fuel cycle, radioactive waste management and radiation safety, as well as equipment manufacturing.

CNNC is committed to sharing experiences and best practices in these areas and contributing more Chinese technology, products, and solutions to assisting countries in the region in transitioning towards clean energy, addressing climate change, pursuing industrial development, and creating more job opportunities.

Nuclear power, as a scalable clean energy source, is a key tool for China's transition towards a cleaner, low-carbon energy mix.

Ma Ran

Are there any plans by CNNC to invest in new nuclear power plants or small projects, such as Small Modular Reactors (SMRs), in Latin America?

Ma Ran - CNNC stays open toward investing in nuclear power and other projects in Latin American countries. However, given the significant scale of nuclear power investment, a stable political and economic environment in the partner country is a prerequisite. In addition, strong policy support is required in areas such as exchange rate stability, foreign exchange management, sovereign guarantees, and power purchase agreements (PPA).

Besides direct investment, CNNC can offer EPC services along with corresponding financing solutions for project owners. Based on the policies of our partner banks, financing can cover up to 85% of the total investment, meaning the project owner would provide only 15% of the initial capital.

How does CNNC view the role of nuclear energy in the energy transition and the reduction of carbon emissions?

Ma Ran - From a global perspective, the energy transition and carbon neutrality process in all countries still have a long way to go. Due to the intermittent and unstable nature of clean energy sources such as wind, solar, and hydropower, they cannot yet fully replace fossil fuels. Nuclear energy, as a safe and efficient base-load power source, offers stable and reliable operation with long refueling cycles, making it well-suited to handle the base load of the power grid and provide necessary load-following capabilities. It can significantly replace fossil fuels as a base-load power source. Increasing the proportion of nuclear power in the energy mix is beneficial for the security of the power grid and enhancing the grid's capacity to accommodate a large proportion of intermittent renewable energy like wind and solar power. As a result, nuclear energy will play a crucial role in the energy transition and de-carbonization efforts in both China and the world.

China has set national goals to peak carbon emissions before 2030 and achieve carbon neutrality before 2060. Nuclear power, as a scalable clean energy source, is a key tool for China's transition towards a cleaner, low-carbon energy mix. For example, the HPR1000 nuclear technology, with an installed capacity of 1160 MWe, generates nearly 10 billion kW·h of clean electricity annually, meeting the annual electricity needs of 1 million people in a moderately developed country. At the same time, it reduces the consumption of 3.12 million tons of standard coal and cuts carbon dioxide emissions by 8.16 million tons, equivalent to planting 70 million trees. Over its full project cycle, it can create more than 30,000 local jobs. This demonstrates that the large-scale development of nuclear power is of great significance for driving global energy transformation and achieving carbon neutrality goals.

How is CNNC working to overcome public and regulatory concerns about nuclear power in Latin America?

Ma Ran - Fear stems from the unknown, and the public's concerns and fears about nuclear power are understandable. China faced similar opposition when it began developing nuclear energy. To address public concerns and promote the development of nuclear power, CNNC has undertaken efforts in the following areas:

1. Strengthening Public Education: To counter misunderstandings and lack of knowledge about nuclear technology, CNNC has launched extensive educational campaigns. These include using media outlets, newspapers, and nuclear industry exhibitions to promote understanding. CNNC organizes nuclear power plant open days, industrial tours, and other activities to explain to the public how nuclear power works, its safety, environmental benefits, and comparisons with other energy forms.
2. Enhancing Public Participation: In the planning and implementation of nuclear power projects, CNNC fully considers public opinions and concerns. It gathers public input through hearings, surveys, and other means, and reflects these opinions in project decisions to increase public recognition and support for nuclear projects.
3. Strengthening Safety Regulations: Both the Chinese government and nuclear enterprises place great emphasis on nuclear safety regulations. They ensure that the design, construction, and operation of nuclear power projects meet or exceed international standards and safety requirements. The goal is to reduce the risk of nuclear incidents through stringent safety oversight and boost public confidence in nuclear power's safety.
4. Increasing International Cooperation: CNNC strengthens exchanges and cooperation with international nuclear organizations and other countries. On the one hand, by learning from international advanced experiences and technologies, CNNC enhances its nuclear technology and management capabilities. On the other hand, CNNC also demonstrates China's nuclear power achievements to the global community in an open and transparent manner.

Do you think the SMRs will substitute the large nuclear reactors in the world?

Song Danrong - Regarding the possibility for Small Modular Reactors (SMRs) to replace large reactors, it depends on several factors:

1. Economy: SMRs tend to cost more per unit than large reactors, but they may present economic advantages in some cases when their flexible deploy-

SMRs are unlikely to completely replace large reactors, but they can significantly complement the energy mix in specific scenarios.

Song Danrong

ment capabilities and lower initial investment are taken into account.

2. Flexibility: SMRs can be built in a smaller geographical area, suitable for areas with small populations or low power demand. They can also add modules as needed to expand capacity, providing better flexibility.
3. Safety: SMR designs incorporate inherent safety features, such as passive safety systems, which reduce the risk of human errors and accidents.
4. Policy Support: The extent to which governments support SMRs also affects their prospects. Some countries are actively developing and planning to deploy SMRs as part of clean energy.
5. Public Acceptance: SMRs are more likely to gain support from local communities than large nuclear facilities because of their smaller scale and limited potential impact.
6. Technical Readiness: SMR designs currently on the market are at different stages of development, but further technical validation and regulatory approvals are needed to achieve large-scale commercial applications.

In general, SMRs are unlikely to completely replace large reactors, but they can significantly complement the energy mix in specific scenarios. Future nuclear power sector is very likely to see large and small reactors coexist.

How does CNNC view the role of Small Modular Reactors (SMRs) in diversifying the global energy mix? Additionally, what are the main challenges for the commercialization and widespread adoption of these reactors?

Song Danrong - The ACP100 SMR technology, developed by CNNC, is the world's first commercial land-based modular, multipurpose small reactor under construction. The demonstration project in Hainan is expected to begin commercial operation in 2025, leading the world in progress. With an installed capacity of 125 MWe, the unit can generate up to 1 billion kW·h of clean electricity annually, sufficient to meet the production and living needs of 520,000 households in moderately developed countries. This is equivalent to reducing the consumption of 350,000 tons of standard coal and cutting carbon dioxide emissions by 880,000 tons, which is comparable to planting 7.5 million trees. Additionally, it is expected to create around 10,000 direct and indirect jobs.

CNNC believes that SMRs play an important role in energy diversification. Here are several key roles SMRs serve in energy diversification:

1. Enhanced Flexibility: SMRs are designed to be assembled like building blocks, which mean they can be easily added or removed depending on energy needs.
2. Rapid Deployment: Due to their small size and prefabrication, SMRs can be installed and put into service in a short time, playing its role in responding quickly to the changing energy demand.
3. Support for Renewable Energy Integration: SMRs can compensate for intermittent renewable energy sources such as wind and solar power to ensure a stable operation of the grid.
4. Thermal Energy Storage: Some SMR designs enable the energy storage of the heat generated, further enhancing their capacity as a renewable energy source.
5. Carbon Emission Reduction: SMRs, as a clean source of base load electricity, can help reduce reliance on fossil fuels and lower greenhouse gas emissions.
6. Strengthened Energy Security: SMRs can be deployed domestically, reducing the need for imported energy, thereby enhancing energy independence.

7. Reduced Risk Concentration: SMRs can be deployed in a distributed manner compared to large nuclear power plants, reducing the impact of a single point of failure.
8. Remote Power Supply: SMRs are suitable for providing a stable power supply to remote areas or small communities, especially in regions with underdeveloped infrastructure.
9. Others: In addition to power generation, SMRs can also be used for sea water desalination, industrial heating and other civil purposes.

In summary, thanks to the flexibility, adaptability, safety and reliability, SMRs have significant advantages in energy diversification and can promote the sustainability and resilience of energy system at multiple levels. However, challenges also exist for the development of SMRs:

1) Economy

- Unit cost: SMRs may cost more per unit of capacity than larger reactors, mainly because of the lack of economies of scale.
- Financing difficulties: Despite a smaller initial investment for a SMR project compared with traditional large nuclear power plants, financing difficulties still present, especially for startups.

2) Technical Readiness

- Validation cycle: New SMR designs require lengthy safety validation and testing before they are approved by regulatory authorities.

Does the operation of the Pebble Bed reactors confirm previous economic forecasts?

Ma Ran - Pebble Bed Modular High-Temperature Gas-Cooled Reactors (HTRs) offer significant advantages including inherent safety, advanced technology, flexible capacity, and environmental adaptability. With the advancement of commercial applications and the realization of modular and large-scale construction, the cost of HTRs is expected to decrease substantially, enhancing their economic viability. Additionally, HTRs can replace decommissioned coal-fired power plants, revitalizing industrial site resources and providing comprehensive clean energy services such as heating, steam supply, and industrial hydrogen production.

Based on the performance of the HTR demonstration project of CNNC in Shidao Bay, Shandong Province, HTRs have met the original economic forecasts. However, currently, when HTRs are used solely for electricity generation, their cost and economics are not advantageous compared to pressurized water reactors. Therefore, our future plans aim to further reduce costs, through large-scale and modular construction, and also by integration with industrial heat sources, hydrogen production and other applications, enabling large-scale commercial use.

Does the development of the fourth-generation reactor using thorium and liquid metal cooled aim to produce hydrogen by the high-temperature process?

Ma Ran - Fourth-generation nuclear reactors encompass technologies such as thorium-based molten salt reactors, liquid metal-cooled reactors, and pebble bed modular high-temperature gas-cooled reactors, all of which have the potential to produce hydrogen. One of the primary advantages of these advanced reactors is their ability to operate at higher temperatures than pressurized water reactors. This high-temperature feature is crucial for thermochemical hydrogen production methods, such as the "sulfur-iodine cycle," which requires temperatures above 800°C.

In China, the independently developed HTR was successfully commissioned and put to commercial operation in December 2023. Research on thorium-based molten salt reactors (TMSRs) and liquid metal-cooled reactors has advanced to the demonstration project stage. Take HTR as an example, it has features like inherent safety, high reactor outlet temperatures, high thermoelectric conversion efficiency, modular construction, adaptability to small and medium-sized grids, and broad application potential. These features ensure that core meltdowns will not occur under any accident conditions and can meet the heat source requirements for various applications, including ethanol purification, salt chemical processing, petrochemicals, coal chemicals, and hydrogen production. This demonstrates the efficient and versatile utilization of nuclear energy, underscoring the significance of fourth-generation reactors in future low-carbon energy systems.

Additionally, in mid-August 2024, the Chinese government approved the CNNC Xuwei project (Phase I), which includes two 1200 MWe HPR1000 reactors and one 600 MWe HTR. This will be the world's first nuclear power plant coupling HTRs with pressurized water reactors, innovatively adopting a collaborative operation model featuring "nuclear reactor - turbine-generator set - heating system". This Nuclear Power Plant (NPP) primarily focuses on providing industrial heating while generating electricity. Once completed, the plant will supply high-quality, low-carbon industrial steam on a large scale to the Lianyungang petrochemical base, one of China's major industrial hubs. The project is expected to deliver 32.5 million tons of industrial steam annually and achieve a maximum power generation capacity of over 11.5 billion kW·h.

> The National Uranium No. 1 Demonstration Project is a model for green and digital mining practices that undermine the conventional underground mining paradigm.
>
> Deng Huidong

Tell us about uranium mining and milling in China. What about your last and bigger project for uranium production. (Ordos Basin)?

Deng Huidong - On 12th July 2024, the construction of CNNC's National Uranium No. 1 Demonstration Project, China's largest natural uranium production capacity project, was commenced in Ordos City, Inner Mongolia Autonomous Region. Key indicators of the demonstration uranium project have ranked among the best in the world. Once completed, the project will be the country's largest producer of natural uranium, setting a new benchmark for construction excellence and embodying an environmentally friendly, cost-effective, intelligent, and highly efficient approach to uranium production.

The National Uranium No. 1 Demonstration Project is the culmination of more than three decades of China's pioneering spirit in in-situ leach uranium mining. It is a model for green and digital mining practices. The project uses an advanced CO2+O2 leach mining process that undermines the conventional underground mining paradigm by eliminating the need to bring the ore to the surface for processing, thereby increasing efficiency and reducing environmental impact. The leaching solution for uranium mining operates in a closed-loop system, and the hydrometallurgical production workshop operates in a silent, automated manner, creating a new method of uranium mining and milling that features zero waste emission, no ecological damage, and sustainable carbon reduction.

At the same time, the project will also integrate advanced technologies such as automation, remote centralized control and big data analysis, which can achieve "one-screen control and one-button uranium mining from thousands of miles away" and "visualization of resources, intelligent operation and analysis, and precise resource mining".

Would it be possible to establish a cooperation between CNNC and Aben to promote human resources in nuclear power, through courses, trainings, seminars, meetings and visits to nuclear power plants?

Ma Ran - Aben is a key partner for CNNC in the Latin American region, serving as a vital bridge between CNNC and the Brazilian nuclear industry. Aben has provided invaluable assistance in the development of CNNC's business in Brazil and in strengthening connections with the Brazilian nuclear sector. We have always valued our relationship with Aben and are eager to further enhance our comprehensive cooperation. As what you have mentioned, it's also our pleasure to promote the development of local human resources in Brazil's nuclear sector through various means, including courses, training programs, seminars, conferences, and visits to nuclear power plants.

INAC 2024 debates the role of nuclear energy **in the energy transition**

Bernardo Barata

With the theme "Nuclear Energy: Guaranteeing Energy, Health and Food", the XI International Nuclear Atlantic Conference - INAC 2024, the largest and most important event within the nuclear sector in the Southern Hemisphere, was held in Rio de Janeiro from 6 to 10 May.

Organised by the Brazilian Association of Nuclear Energy (ABEN), the conference was held at the Naval War College (EGN) except for the final day, when the event was relocated to the National Nuclear Energy Commission (CNEN). The opening ceremony featured a video in Portuguese, recorded by the director general of the International Atomic Energy Agency (IAEA), Rafael Grossi, praising the role of the young generation and women in the nuclear field, the success of cooperation with Brazil, the peaceful applications of nuclear energy and the importance of INAC.

The opening panel consisted of the following authorities: the president of ABEN, Carlos Freire Moreira; the chair of INAC, Maria de Lourdes Moreira; the president of CNEN, Francisco Rondinelli Junior; the director of EGN, Rear Admiral Gustavo Calero Garriga Pires; the CEO of Eletronuclear, Raul Lycurgo Leite; the director of the Naval Secretariat for Nuclear Safety and Quality (SecNSNQ), Admiral Petronio Augusto Siqueira de Aguiar, represented by Rear Admiral Humberto Moraes Ruivo; the director general of the Navy's Nuclear and Technological Development, Admiral Alexandre Rabello de Faria; the president of the Electric Energy Business Council of the Federation of Industries of the State of Rio de Janeiro (FIRJAN), Antônio Carlos Vilela, represented the president of FIRJAN, Eduardo Eugenio Gouvêa Vieira; the director of the Ministry of Science, Technology and Innovation (MCTI) Programme to Popularise Science, Technology and Scientific Education, Juana Nunes, also represented Inácio Arruda, the Secretary of Science and Technology for Social Development (SEDES/MCTI), and Reimont Santa Barbara, representative for the state of Rio de Janeiro in Brazil's House of Representatives.

The ceremony featured the signing of a Technical Cooperation Agreement between the Fluminense Federal University (UFF) and ABEN, with the aim of training and developing human resources and carrying out specific research. This was followed by the opening of the XI ExpoINAC, a showcase of products and services offered by domestic and international companies within the nuclear sector.

INAC 2024 also included the XXIII Meeting of Reactor Physics and Thermohydraulics (ENFIR), the XVI Meeting of Nuclear Applications (ENAN), the VIII Meeting of the Nuclear Industry (ENIN), the X Junior Poster Technical Sessions (poster session for undergraduate students) and the III ABEN Nuclear Ambassadors Award.

The central theme of INAC 2024, "Nuclear Energy: Guaranteeing Energy, Health and Food", was debated at a roundtable discussion coordinated by ABEN's first vice-president, Antônio Müller, with the participation of ENBPar's director of Energy Marketing, Strategic Projects and Market Studies, Wander Azevedo, CNEN's director of Radioprotection and Nuclear Safety, Alessandro Facure, AMAZUL's nuclear technical coordinator, Leonardo Dalaqua, the president of the Brazilian Society of Nuclear Medicine (SBMN), Rafael Lopes, and the consultant for the Brazilian Association for the Development of Nuclear Activities (ABDAN), Patricia Wieland. The panel broadly discussed the role that nuclear power can play in the fields of medicine/health, agriculture, power generation, industry and the environment, with a view to decarbonisation. Following the panel, a tribute was paid, including a video with old photos, to one of the pioneers in the construction of Angra 1, founder and first president of Eletronuclear, engineer Ronaldo Arthur Cruz Fabricio.

Challenges and opportunities

One of the highlights of the discussions held at INAC 2024 was the roundtable "Challenges and Opportunities for the Transition to Sustainable Energy: Exploring Nuclear Technologies", coordinated by Leonam dos Santos Guimarães, advisor to AMAZUL's Executive Board. The meeting brought together Francisco Rondinelli (CNEN), Bento Albuquerque (former Minister of Mines and Energy), Nel-

Bruno de Lima

son Leite (World Energy Council - WEC Brasil) Adriano Pires (CBIE), Giovani Machado (EPE), José Mauro Esteves (National Mining Agency - ANM) and Amilcar Guerreiro (CEPEL).

The president of CNEN, Francisco Rondinelli, expressed concern about the intense burning of fossil fuels, the predatory exploitation of natural resources and deforestation. He emphasised that he considers it a waste of public resources to interrupt the construction of Angra 3 and that nuclear energy in Brazil could expand so that it has the capacity to generate the same amount of energy as that of the Itaipu Binational Hydroelectric Plant - in his view, nuclear's share of the country's electricity matrix would ideally be in the range of 10% to 12%.

Economist Adriano Pires mentioned the various energy transitions that have taken place around the world, pointing out that the current one, unlike the previous ones – all motivated by the search for greater energy efficiency - is primarily due to environmental issues. In this respect, he clarified that "you can't look at the price of energy per se, but at the attribute of each source and the capacity factor" and emphasised the importance of seeking energy security linked to access to energy for low-income groups. This new cycle of nuclear energy expansion will provide innovations, bringing alternative solutions to traditional models of generation.

Giovani Machado, from EPE, spoke about the country's nuclear infrastructure and the challenges of escalating costs and missed deadlines, as well as the role of nuclear generation as described in the National Energy Plan - PNE 2050, drawn up by EPE. He spoke about nuclear generation in the context of energy security, system sustainability and decarbonisation and the possibility of it being used in other markets, notably carbon, industrial heating and hydrogen.

José Mauro Esteves dos Santos, former president of CNEN, pointed out that the energy transition offers the following opportunities for Brazil: use of Brazil's uranium reserves, improvements to the nuclear sector's supply chain, a return to training human resources and benefits for technical and scientific training within the nuclear sector. With regard to the challenges, he highlighted the creation of the business model; establishing partnerships - selecting partners; organising geological information (which is often incomplete); zoning of areas; very long timescales for developing greenfield sites, the establishment of partnerships and starting production.

Amilcar Guerreiro, from CEPEL, mentioned that concerns about rising electricity consumption and energy costs and the importance of energy security led to questions about whether sufficient energy resources are available, whether there are technological solutions available to guarantee accessibility and whether the reliability and resilience of the system can be guaranteed. Nuclear energy may therefore have a place in this context.

For his part, electrical and nuclear engineer Nelson Leite stressed that decarbonisation must be the means of achieving energy security anchored in electrification, and defended the pricing of the attributes of each energy source and emphasised three premises to be considered in the energy transition: energy security, environmental sustainability and accessibility.

The roundtable "The Current State of New Reactors in Latin America" discussed the Brazilian Multipurpose Reactor (RMB), the partnership between the Brazilian Navy and IPEN/CNEN for mastering nuclear propulsion technology and the Nuclear Power Generation Laboratory (LABGENE) - a full-scale, onshore prototype of the reactor that will be used in the first conventionally armed nuclear-powered submarine.

The roundtable "The Challenge of Developing a State Programme for Brazilian Nuclear Activities", moderated by Marcelo Gomes (Eletronuclear), included the participation of Francisco André Barros Conde (Office of Institutional Security of the Presidency of the Republic - GSI/PR), João Leal (State Secretary for Energy and the Economy of the Sea - SEENEMAR/RJ), Alessandro Facure (DRS/CNEN) and John Forman (consultant). This plenary session was marked by the obstacles and challenges to be overcome in order to create a Nuclear Programme, the history of the Brazilian Nuclear Programme (PNB), the current activities conducted by the Brazilian Nuclear Programme Development Committee (CDPNB), and the actions carried out by the Government of Rio de Janeiro to promote the nuclear sector, since the state is a hub of activities and companies from the sector.

The closing session of INAC 2024 was held in the CNEN auditorium. In total, there were eight presentations, two for each of the following thematic blocks: Innovation (Daniela Archila, from the Research and Development Directorate - DPD/CNEN, and Luciana Carvalheira, from the Nuclear Engineering Institute - IEN/CNEN), International Cooperation (Joana Azambuja, from DPD/CNEN, and Niklaus Wetter, from the Nuclear Energy Research Institute - IPEN/CNEN), Knowledge Management (Daniele Monegalha, from the Institute of Radioprotection and Dosimetry - IRD/CNEN, and Daniela Villa Flor Montes Rey Silva, from the Poços de Caldas Laboratory - LAPOC/CNEN) and Young Scientists/Leadership (Giovanna Machado, from the Centre for Strategic Technologies for the Northeast - CETENE, and Gabryele Moreira, from Women in Nuclear - WiN Brasil).

The closing roundtable was composed of the chair of INAC, Maria de Lourdes Moreira; the president of ABEN, Carlos Freire; the president of CNEN, Francisco Rondinelli; and the director of Research and Development at CNEN, Wilson Calvo. The chair of INAC, who was presented with a plaque of gratitude by ABEN's president, commented that the four main topics of the Conference were the importance of resuming construction work on Angra 3, technology transfer,

personnel training and employability and the replacement of human resources within the nuclear sector.

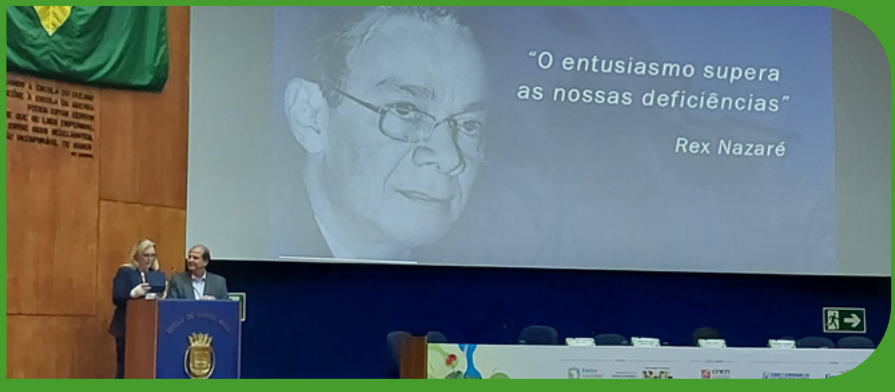
Awards

The third edition of ABEN's Nuclear Ambassadors Project elected the following winning teams: undergraduate category - Nuclear Monitors, formed by João Vitor Cavalcanti da Silva, Luís Augusto Costa de Lira Carvalho and Mariana Nunes Wanderley Braga; postgraduate category - Nuclear Minute, formed by Cássio Feitosa Trajano da Silva, Rafael Fernandes Rodrigues and Vinícius Cardoso Brum; and teacher category - Atomic, formed by Wallace Vallory Nunes (teacher), Joana Batista Soares and Karine Lima de Carvalho.

The tenth INAC Scientific Initiation Exhibition approved 87 extended abstracts, 66 from the ENAN area, 15 from the ENFIR area and six from the ENIN area, which were presented in e-poster format.

CNNC event

Hours before the opening ceremony of INAC 2024, the side event "Nuclear for a Better Life" took place, organised jointly by platinum sponsor China National Nuclear Corporation (CNNC) and ABEN. With the aim of promoting the exchange of technological information within the nuclear sector and experiences in industrial development, the seminar featured talks on the panorama of nuclear activities in China and Brazil, Small Modular Reactors (SMRs), Research & Development (R&D), the nuclear fuel cycle and the production of fuel elements, uranium mining and metallurgy, yellowcake production, nuclear applications and irradiation in the health sector, among other topics.



Cláudio Braz

Moments of emotion

Two tributes provided moments of great emotion for the participants at INAC 2024. The first was the tribute paid via videoconference to Rex Nazaré Alves, a Brazilian professor, nuclear physicist and former president of CNEN, who masterfully led the National Nuclear Energy Commission's efforts during the caesium-137 radiological accident in Goiânia in 1987.

Another emotional moment took place during the tribute to IPEN/CNEN researcher and professor Margarida Mizue Hamada, who passed away on 24 June 2023 at the age of 68. A great enthusiast in the nuclear area and with a significant teaching career, notably on the Nuclear Technology Postgraduate Programme at the Nuclear Energy Research Institute, with a PhD and as an industrial chemist, she held the position of chair of ENAN on several occasions, which has always been part of the Conference's scope, as well as helping to organise editions of INAC and serving on ABEN's board. A video was shown with testimonies from friends, colleagues from IPEN and her niece, who considered her as her second mother.

XI INAC had broad participation **from international experts**

Bernardo Barata

Living up to its name, INAC 2024 brought together prominent international experts and authorities among the speakers, paper presenters and sponsors. The participation of international speakers has been built up over the 22 years of the event's existence. Some experts are invited by the coordinators as part of the programme, but there is also voluntary participation by international registrants. The idea that international nuclear companies only had representatives in Brazil or Latin America is a thing of the past. These companies now have a team of experts in the nuclear field who travel to give presentations or for specific discussions and exhibitions at major congresses, as happened at INAC 2024.

Among the international institutions, INAC 2024 included the Idaho National Laboratory (INL), one of the US's major national laboratories, which stands out for its focus on research and testing of advanced reactors, among other activities. The chief scientist of INL's Materials and Fuels Complex, Abdul R. Dulloo, gave a lecture on the panorama of advanced nuclear reactors in the United States and the cost and timescale challenges for innovative systems. In his view, it is necessary to consider the installed capacity required to meet specific needs (micro, small or large nuclear reactors) and scale construction to reduce capital costs. He emphasised that the size of reactors is aligned with the needs of each application, citing industrial heat production, desalination and the generation of electricity and hydrogen.

The INL researcher also took part in the roundtable "SMR - Current Projects, Opportunities and Challenges for the Near Future", coordinated by Daniel Palma, from the Radioprotection and Nuclear Safety Directorate (DRS/CNEN). Abdul Dulloo spoke about the variety of SMR projects that exist in the US and emphasised that the country needs to intensify public-private partnerships and demonstrations, improve the licensing process, improve the supply and value chain and establish policies to enable a level playing field.

The manufacturing of nuclear fuel was addressed by another INL expert, metallurgical engineer Adrian R. Wagner. In his presentation, he covered the types of high-density uranium fuel opportunities for advanced manufacturing and techniques involving high energies and digital light processing.


Bruno de Lima

Professor Sheldon Landsberger from the University of Texas (USA), who is already well known at INAC, spoke about the "Natural occurrence of radioactive materials in oil exploration". Radioactivity in the oil and gas exploration sector and naturally occurring radioactive materials (NORM) are well known to everyone, but the effects of this radiation, whether on workers or through contamination of machinery due to the accumulation of sludge, are continually ignored.

Professor Sheldon emphasised that the chemistry and radiochemistry of radioactive species in petroleum waste products are very complex, unlike any other environmental matrices, and that typical assumptions about radioactive equilibrium are not valid, requiring reliable analytical methodologies to determine activity levels for disposal and radiological and environmental protection.

One organisation that is always present at INAC is the International Atomic Energy Agency (IAEA). This is due to the various agreements between Brazil and the IAEA in the areas of Technical Cooperation (Medicine, Agriculture, Industry and the Environment), Radiological Protection, Nuclear Safety, Safeguards and others. As well as the participation of the director-general Rafael Grossi, via video, in the opening session, there was a big turnout for the presentation by Danas Ridikas, who spoke about the Agency's activities in support of research with neutron sources, referring to both the latest research reactors and accelerators.

Lectures by researchers from Rosatom, Tecnatom/Westinghouse and CNNC, who gave an overview of the main projects and activities carried out by these companies, provoked great interest among the audience.

INAC gives a new dimension to the Brazilian nuclear sector

Vera Dantas

In August 2002, Brazil hosted a major international nuclear event for the first time, the International Nuclear Atlantic Conference (INAC). With the theme "The Return of the Nuclear Option", the conference, organised by the Brazilian Association of Nuclear Energy (ABEN), brought together renowned experts from Brazil and beyond, as well as authorities, politicians and opinion formers, for six days in Rio de Janeiro. To organise such a large-scale event, a committee was set up made up of luminaries such as: André Maisseau, President of the World Council of Nuclear Workers (WONUC); Ivan Chupilkin, Russian consul in Brazil; Roberto Hojman, President of the board of directors of the Chilean Nuclear Energy Commission, and Dario Jinchuk, Head of the Bilateral Relations Department of Argentina's National Atomic Energy Commission (CNEA).

The conference brought together other established events organised by ABEN, such as the IX General Congress on Nuclear Energy (CGEN), the XIII Meeting on Reactor Physics and Thermohydraulics (ENFIR) and the VI National Meeting on Nuclear Applications (ENAN). Another highlight of INAC 2002 was ExpoNUC, held at the Copacabana Fort and attended by companies and organisations from Brazil and abroad.

Tradition

ABEN has a tradition of organising congresses and meetings that examine the nuclear energy landscape, as well as technical issues and applications. One of the events that stood out in the pre-INAC period was the V CGEN, held in August 1994, whose central theme was the resumption of the Brazilian Nuclear Programme.

In 1997, the XII ENFIR and IV ENAN, held in the city of Poços de Caldas in Minas Gerais, were attended by experts from 20 countries, including the director of the Institute of Physical Chemistry of the Russian Academy of Sciences, Alexei Picaev, and from the USA, Glenn Knoll, one of the foremost authorities on radiation detectors.

In 2000, ABEN took an important step towards the creation of INAC two years later, bringing together CGEN, ENAN and ENFIR - these events, however, maintained their own identities and characteristics. Held in Rio de Janeiro and with the theme "Nuclear Future: Reflecting to Build", the event featured a ceremony in support of the resumption of the Angra 3 works, which was endorsed by various public authorities.

Success story

The second edition of INAC was held in September 2005 in Santos (SP). Despite the unfavourable economic climate, marked by the postponement of projects, the event was considered a success, with the presentation of more than 700 technical papers, the holding of three forums, the participation of international guests and a record number of registrations.

INAC 2007 had around 1,200 participants and the presentation of 800 scientific papers, out of a total of 1,200 registered. The theme "Nuclear energy and the energy challenges of the 21st century" sought to establish a dialogue between the different segments of the energy sector, such as hydroelectric, gas, coal and alternative sources.

A demonstration of INAC's importance to the international community was the coverage by the international journals Progress in Nuclear Energy, The International Journal of Nuclear Energy Science and Technology, and Science and Technology of Nuclear Installations. As well as planning a special edition for the XV ENFIR, the three journals invited authors to submit their work for publication.

The XV ENFIR was attended by international experts such as the Italian physicist Francesco D'Auria; Jonathan Schrag, consultant and former executive director of the Centre for Sustainable Energy at Columbia University; Professor Hiroshi Sekimoto, from the Tokyo Institute of Technology; engineer Jean François Babelot, from the Institute for Transuranium Elements, Karlsruhe, Germany and the president of Excel Services Corporation, Donald R. Hoffmann.

The VIII ENAN featured lectures by national and international researchers, such as Eric Marchioni, from the Université Louis Pasteur, in France; Olgun Güven, from Hacettepe University, in Turkey; and Geir Anton Johansen, from the University of Bergen, in Norway.

In a year marked by the Fukushima accident, the success of INAC 2011, held in Belo Horizonte, surprised the organisers: packed auditoriums, high-level lectures and debates, 1290 registered participants, 979 papers presented in lectures and posters and more than 8,000 visitors to the exhibitions marked a record attendance compared to the previous four editions.

With the theme "Nuclear Energy: New Jobs for a Better Life", INAC 2011 received technical papers from 22 countries and also included the participation of representatives from

The international speakers Peter Bode, John Bennett, Sheldon Landsberger and Bernard Faucher at INAC 2011

international research institutions, such as Peter Bode from the Netherlands, winner of the 2011 Hevezy Medal Award, the Australian John Bennett, from the Australian Nuclear Science and Technology Organisation, the Portuguese researcher Manoel Alonso, from the Euratom-IST Association, and the American, Shannon M. Bragg-Sitton, from the Idaho National Laboratory. Specialists from the world's leading companies in the nuclear sector, such as Areva, GDF Suez, GE Hitachi and Westinghouse, presented lectures at the II ENIN.

The theme of INAC 2015 was "The Brazilian Nuclear Programme: State Policy for Sustainable Development". ABEN brought delegations from countries with successful nuclear programmes, such as China, Korea, France and the United States, to the event to present to the academic community an account of their developments.

During INAC 2017, held in Belo Horizonte (MG), ABEN board member Alice Cunha da Silva launched "Nuclear Ambassadors", a communication project that forms part of ABEN's Public Acceptance Programme (APUB) and is aimed at undergraduate and postgraduate students interested in talking to the public about nuclear technology, increasing the reach of information about the sector throughout the country. The projects must be related to the United Nations global goals for sustainable development and should demonstrate how the use and development of nuclear technology helps to achieve these goals.

INAC 2019, held from 21 to 25 October 2019 in Santos (SP), had the theme "Nuclear New Horizons: Fuelling our Future" and discussed nuclear energy as a source of industrial and social development, employment, technology, strategic and economic growth, contributing to environmental goals in the countries and regions where it operates.

INAC 2021, whose theme was "Less Carbon Impact on Nature and More Quality of Life", was held using a virtual format due to the pandemic. However, the new format, according to researcher Margarida Hamada, coordinator of the XV ENAN, made it possible to increase the number of roundtable discussions and lectures with national and international experts. Among the participants were Anatoly Rosenfeld, from the University of Wollogong (Australia), Eduardo Yukihara, from the Paul Sherrer Institute (Switzerland) and Oswaldo Baffa, from the University of São Paulo (USP).

In 2024, INAC returned to an in-person format.

Review of the XI INAC

The largest nuclear sector conference in the Southern Hemisphere attracted 1,074 participants including registrants, guests, exhibitors and authorities and 530 academic papers (expanded abstracts) were submitted. Among the coordinators, supporters, sponsors and speakers, INAC 2024 brought together organisations such as: Idaho National Laboratory (USA); the University of Texas (USA); the International Atomic Energy Agency (IAEA); Eletronuclear; the National Nuclear Energy Commission (CNEN); China National Nuclear Corporation (CNNC); the Funding Agency for Studies and Projects (FINEP); Rosatom (Russian Federation's nuclear energy corporation); Amazônia Azul Tecnologias de Defesa S.A. (AMAZUL); Engenharia de Soluções (EBSE); Westinghouse; Sciofix - Instrumentação Científica; Diamante Energia; the Brazilian-Argentine Agency for Accounting and Control of Nuclear Material (ABACC); Holtec International; Helgeson Scientific Services; Empresa Brasileira de Participações em Energia Nuclear e Binacional S.A (ENBPar); GLP Laboratórios; Eckert & Ziegler; Centro Tecnológico da Marinha em São Paulo (CTMSP); Grupo O Dia Comunicação; Brazilian Institute of Nuclear Engineering (IEN/CNEN); Institute for Energy and Nuclear Research (IPEN/CNEN); Rio de Janeiro State University (UERJ); Indústrias Nucleares do Brasil (INB); National Council for Scientific and Technological Development (CNPq); São Paulo Research Foundation (FAPESP); Brazilian Navy; University of São Paulo (USP); Petrobras; the National Bank for Economic and Social Development (BNDES); and the Brazilian Society of Nuclear Medicine (SBMN).

The Conference coordinators were: Maria de Lourdes Moreira (INAC 2024), Frederico Antonio Genezini (XXIII ENFIR), Carmen Cecília Bueno (XVI ENAN), João da Silva Gonçalves (VIII ENIN), Marcelo Gomes da Silva (VIII ENIN co-chair), Graciete S. de Andrade e Silva (Junior Poster), Leonardo G. de Andrade e Silva (Junior Poster co-chair), Ricardo C. Barros (Junior Poster co-chair), Katia Lanes (ExpoINAC), Olga Y. Mafra (Nuclear Ambassadors), Márcia Flores (Logistics) and Ricardo Ferreira Ribeiro (Treasurer).

Angra 1 is set to operate safely **and reliably for another 20 years**

The continuous programme of technological improvement developed by Eletronuclear over the past few years has enabled the useful life of the plant to be extended

Marcelo Gomes

Nuclear power plants around the world are nearing the end of their initial useful life. The average age of North American reactors is over 40 years, and around 90 per cent of European reactors have been in operation for more than 30 years. As a result, the issue of extending the useful life of these plants has gained prominence in the strategies of operators of nuclear power plant.

Society's growing demand for clean energy has put nuclear power back at the centre of the energy transition. The International Energy Agency (IAEA), an organisation linked to the Organisation for Economic Co-operation and Development (OECD), sees nuclear energy as key to making this transition possible. Without the reliable, dispatchable energy of nuclear power plants, the integration of sources with high variability such as wind and solar is greatly jeopardised, even taking into account recent advances in energy storage. Thus, extending the life of plants in operation has taken on a prominent role in the transition to an emissions-free electricity matrix.

In business terms, extending the useful life makes perfect sense, as nuclear power plants are carefully maintained facilities with excellent operational performance, and the investment in construction is amortised after decades of operation. It is no wonder that more than 100 plants around the world have already had their initial licences extended, especially in the United States and Europe. In many cases, this extension is accompanied by an increase in installed capacity, obtained mainly by changing turbine sections.

The fundamental logic of the process of extending the useful life is that a nuclear power plant has few components that can effectively limit its useful life. Valves, pumps and control systems can be kept in optimum conditions, repaired or replaced with more modern components. Essentially, only the reactor pressure vessel and containment structure are irreplaceable, thus determining the life of the plant.

With so many processes to extend the useful life having been successfully completed, we can be assured that the nuclear industry has developed standards and procedures to guarantee the continuity of operations under full safety and performance conditions.

Here in Brazil, our first nuclear power plant, Angra 1, is coming to the end of its initial 40-year licence, which is due to expire in December 2024. Angra 1 was purchased from the US company Westinghouse on a turnkey basis as a complete package, with no transfer of technology from the suppliers. However, the experience accumulated by Eletronuclear in all of these years of commercial operation, with efficiency indicators that surpass those of many similar plants, means that the company is now able to carry out a continuous programme of technological improvement and integrate the latest advances in the nuclear industry.

Angra 1 has a capacity of 640 MW and entered commercial operation in 1985. After a troubled start, having experienced problems with some components, the plant has established itself among the best in its class, generating 4.78 million MWh in 2023, with a load factor of 88.24 per cent, equivalent to 322 days a year at full power.

In anticipation of the expiration of the plant's initial licence, Eletronuclear identified the renewal of Angra 1's licence—and, consequently, its operation for a further twenty years—as one of its main institutional projects. In the international nuclear industry, this process is called Long Term Operation (LTO).

Over the last few years, Eletronuclear has been developing studies and projects with the aim of making it possible to apply for an extension of Angra 1's operating licence for another 20 years. One of the highlights was the replacement of the plant's steam generators in 2009. It was a very complex operation, as these are large components, and lasted around five months. In addition to this replacement, a series of activities were carried out, such as applying a weld overlay to the pressuriser nozzles, replacing the reactor pressure vessel cover and substituting the main electrical transformers. Some programmes were also implemented, such as obsolescence management, as well as inspections and maintenance of concrete structures.

In 2019, Eletronuclear formalised its request for a useful life extension with the National Nuclear Energy Commission (CNEN) and has since been working with the nuclear regulator to ensure that the extension is granted. As agreed between the company and CNEN, the approach to the renewal of the licence is in accordance with the regulatory document 10 CFR 54 Requirements for Renewal of Operating Licenses for Nuclear Power Plants of the US Nuclear Regulatory Commission. In addition, the requirements set out in CNEN's Technical Notes NT-CGRC 007/18 - Regulatory Requirements for Long Term Operation for Nuclear Power Plants Rev. 0 and NT-CGRC 008/18 - Regulatory Requirements for Ageing Management in Nuclear Power Plants Rev. 0 were also met.

Eletronuclear contracted Westinghouse, the original designer of Angra 1, to develop the Integrated Plant Assessment (IPA) and the Time-Limited Ageing Analysis (TLAA), which form the backbone of the licence renewal process for nuclear power plants.

Projects are also being implemented to modernise and technically upgrade the systems, structures and components of Angra 1 that are required for it to operate during the long-term operation (LTO) period. The development and implementation of the projects associated with the extension of Angra 1's useful life are budgeted at approximately 400 million dollars. To obtain these funds, negotiations are underway with development banks and domestic banks to secure financing for short-term investments.

A fundamental step in enabling the plant to operate for this extended period was the development of the Dry Storage Unit (DSU), for storing irradiated fuel after it has been consumed in the reactor. This project included alterations to Angra 1 to allow the handling and removal of fuel from the spent fuel pools and its packaging in vessels suitable for transport to the DSU.

At the end of 2023, Eletronuclear submitted the plant's third Periodic Safety Reassessment to CNEN. This process is repeated every ten years of operation to demonstrate that the plant continues to operate safely and reliably.

Among the items analysed in this document are safety performance; emergency planning and radiological impact on the environment; management system and safety culture; equipment qualification, and the use of experience from other plants. This document is one of the bases for CNEN's licensing process.

Also in 2024, from 4 to 13 June, Angra 1 received the International Atomic Energy Agency's SALTO Mission (Safety Aspects of Long-Term Operation) to carry out a global safety assessment, which directly addressed the strategy and key elements for safe long-term operation (LTO) of nuclear power plants. Areas covered included the organisation of ageing management and LTO activities; definition of the scope; plant programmes and the corrective action programme; ageing management of mechanical, electrical, and I&C (Instrumentation and Control) ESCs and civil structures; and management of human resources, skills and knowledge for LTO. The SALTO Mission was preceded by three previous preparatory missions: the first in 2013, the second in 2018 and the third in 2022. The results obtained from the mission were highly positive, according to the IAEA's own assessment.

Throughout 2024, Eletronuclear has been actively engaging with CNEN, providing the necessary technical clarifications and complying with requirements, for which it has the benefit of AMAZUL's technical support.

With the conclusion of the licensing process, Angra 1 will be ready to operate for at least another 20 years, generating clean energy, free of greenhouse gas emissions.

Marcelo Gomes
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Naturally Occurring Radioactive Material in Oil Exploration: how Did This Happen?

Sheldon Landsberger

Introduction

Perhaps one of the first two papers on naturally occurring radioactive material (NORM) in the oil exploration sector were both published in 1904 and 1906, respectively. One was titled "A Radioactive Gas from Crude Petroleum" [1] and the other was titled "On Radioactivity of Mineral Oils and Natural Gases" [2].

There is a great deal of public misconception of the uses of oil. For instance, in the USA electricity production of oil is typically no more than a few percent. The distillation of crude oil which is approximately 40-45% per barrel allows to produce a host of gases for the manufacturing of thermoplastics in materials like Teflon, vinyl, and nylon, thermoset plastics in epoxy resin, volcanized rubber, and inflatable rafts, paraffin wax in crayons and candles, various pharmaceuticals, fertilizers, tires, and host of other commonly used household products. The other approximate 50% of the oil is used for transportation. In 2023 production of Brazil's oil, which is dominated by Petrobras, was 4.28 million barrels per day and ranked 7th in the world [3] with typically around 100 million barrels of daily world-wide extraction of oil from on-shore and offshore exploration. And thus, the production of oil in Brazil is a crucial component of its economy [4].

However, the extraction of oil has also led to the release very large amounts of radioactivity arising from the ^{238}U and ^{232}Th decay chains as can be seen in Figure 1 and Figure 2 [5]. Over the many millions of years, the ^{238}U and 232Th which are insoluble remain in place in the earth's formations, while ^{226}Ra ($t_{1/2}$ = 1630 y) and ^{228}Ra ($t_{1/2}$ = 5.8 y) are soluble and are attracted to oil and substantially increase in radioactivity concentrations.

While ^{226}Ra and ^{228}Ra are the main environmental and ecological concerns, all the daughter and subsequent grand-daughter products are also significantly elevated in radioactivity measurements.

Figure 1 - ^{238}U Decay Chain

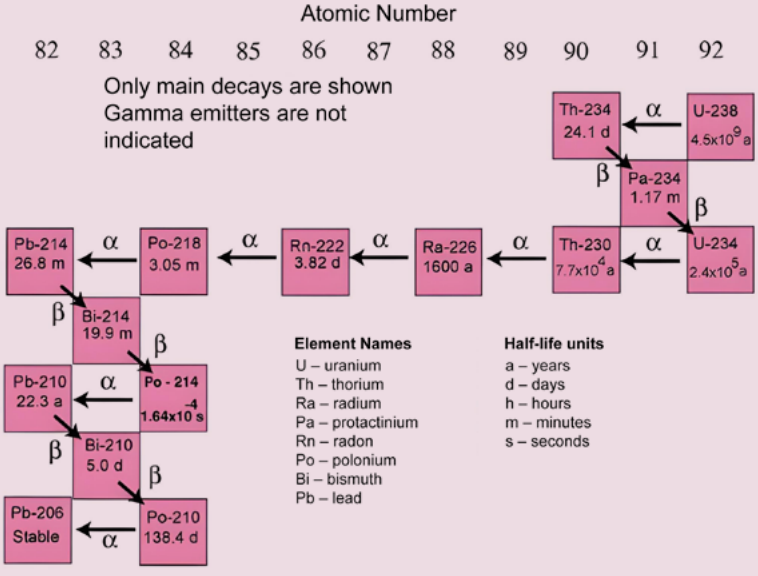

Figure - ^{232}Th Decay Chain

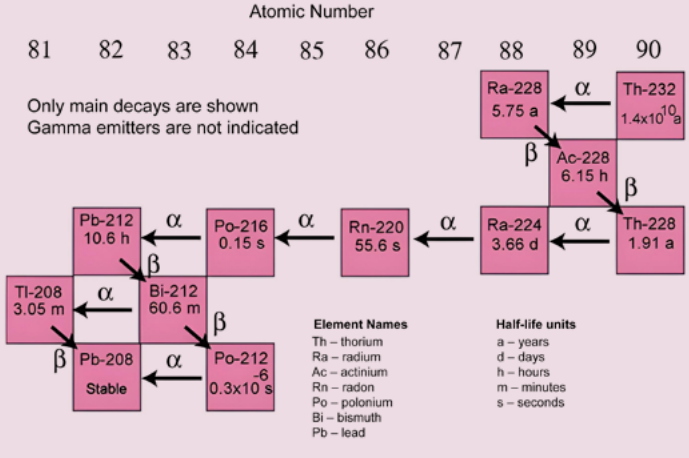

Figure 3 - Oil Pipe with NORM Scale

Figure 4 - Contaminated Oil Drill Pipe and Oilfield Waste

Radioactive waste from oil exploration can be found in the form hardened scale inside pipes (as seen in Figure 3) [6], sludge in oil separators or landfill waste [7] (as seen in Figure 4) and produced water. Off-shore oil exploration can lead to accumulation of radioactivity into the various areas of the marine environment [8].

Radioactivity concentrations given Bq/kg in the various oil waste products can vary by orders of magnitude for produced water, hard scale and sludge from for 226Ra, 228Ra, and 210 Pb, depending on geophysical characteristics of the formations and extraction processes. Monitoring for internal and external α, β, and γ radiation in air, water, scale, sludge and soil samples are key to providing good health physics practices. Several groups have modeled the dose rates from workers in the field (9-12). Radon gas, (222Rn) is also a concern, especially when workers are in closed structures.

Conclusions

The chemistry and radiochemistry of radioactive species in oil waste products is very complex unlike any other environmental matrix, with the added radiation. Typical assumptions on equilibrium are not valid and reliable analytical methodologies are needed to ascertain radioactivity activity levels for disposal and uphold health physics regulations.

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The importance of Science and Technology in the development of society

Helen J. Khoury

Science and technology play fundamental roles in the development of contemporary societies. They are cross-cutting activities that permeate all areas. Understanding their importance is essential for the sustainable growth and competitiveness of any nation.

Society demands solutions to problems related to improving quality of life, economic development, environmental challenges and security. The interaction between science and technology not only responds to these needs, but also promotes innovation and sustainable development. Scientific research provides the fundamental knowledge and theoretical understanding needed to develop new technologies that will contribute to solving problems. The practical application of technologies generates data and information that can lead to new questions and scientific research. This feedback loop between science and technology allows for the continuous improvement of existing solutions and the development of new approaches to tackling various challenges.

In Brazil, although there is significant potential for advances in science and technology, a number of challenges stand in the way of faster and more effective progress. This article explores some of the main obstacles facing the country on the road to more robust scientific and technological development.

Brazil's main challenge in the area of science, technology and innovation has been the lack of continuity in drawing up and implementing a long-term policy. What is needed is long-term planning and the definition of goals that make it possible to define priority research areas, allocate resources efficiently and create an environment that is favourable to innovation. Scientific activity in Brazil is marked by structural difficulties such as:

- Instability or lack of funding for research,
- Low pay for researchers
- Difficulties with infrastructure
- The population's lack of knowledge about how science is carried out in the country and the benefits of scientific activity for the country's development.

Insufficient funding

One of the main challenges for scientific and technological development in Brazil is economic instability and variations in the budget for science and technology, which contribute to an environment of uncertainty that makes it difficult to plan and execute quality projects. Investment in research and development (R&D) has historically been low compared to international standards. In Brazil, 1.2 per cent of GDP is invested in R&D, while this rate reaches 2.5 per cent among rich countries (OECD) and 4.6 per cent in South Korea, for example. Furthermore, the percentage of private sector investment in science and technology is very small. The lack of financial resources limits the ability of research institutions to acquire modern equipment, hire qualified staff and maintain long-term projects.

A strong STI system requires all of its components to be robust and interconnected:

i. public agents (with their incentives via programmes and regulations);
ii. knowledge agents (training people and developing technologies);
iii. funding agents (with resources for structuring the system);
iv. business agents (with investments, workforce absorption, technology adoption and development, and the provision of goods/services);

Training and retaining talent

Brazil faces difficulties in training and retaining scientific talent. Despite having a significant number of higher education institutions and research centres, there is a significant gap between the number of professionals graduating with master's and doctoral degrees and the number in formal employment. Figure 1 presents the result of a survey carried out by CAPES between 2009 and 2021, which shows the variation in the number of postgraduate graduates and those in formal employment. The graph shows a large gap between the number of graduates and the number with formal jobs. One of the causes of this gap is the lack of synergy between academia and the productive sector. Academic research is often not aligned with market needs, and technology transfer is limited. Establishing more effective partnerships between universities, research centres and companies can boost innovation and ensure that scientific advances have practical and commercial applications.

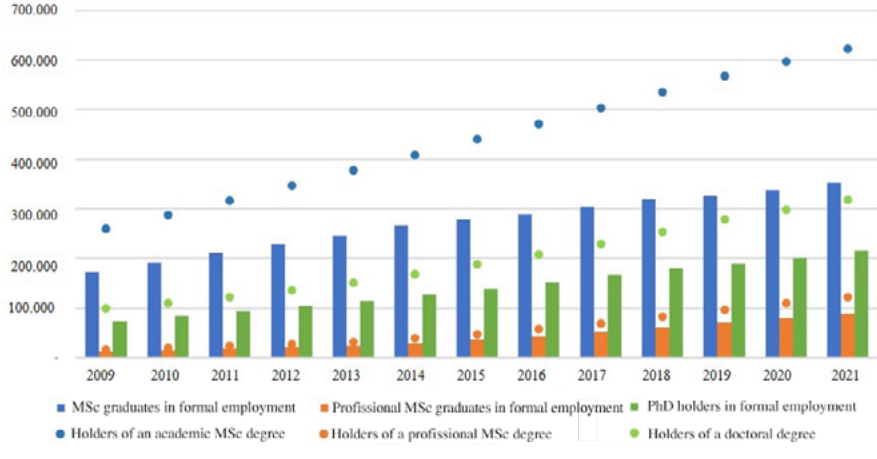
For young scientists, the academic path is full of challenges. Opportunities for postdoctoral fellowships are lim-

ited and fellowship amounts are outdated, as well as the lack of formal employment benefits. This is a point that is currently being discussed by funding bodies, but it is certainly not easy to resolve. Another point to highlight is the brain drain, where highly qualified researchers and professionals seek opportunities abroad, reducing the human capital available for scientific and technological development in the country.

We would like to highlight some proposals for consideration and to contribute to the training of qualified human resources in Brazil.

1. **Invest** in education and research, **update** the curriculum and promote continuing education programmes to **meet the demands of** the labour market. Postgraduate courses should include topics such as project management, entrepreneurship, etc. in order to prepare students for the labour market. The culture of innovation in Brazil is still at the development stage. Encouraging a mindset geared towards innovation and entrepreneurship is crucial to fostering a more dynamic and creative environment.
2. Stimulate **effective collaboration between academia, industry and companies.**
3. Value talent: **strategies to mitigate migration**.
4. Improve the business environment to stimulate **innovation**, reduce **bureaucracy** and promote investment in research and development.
5. Promote continuing education programmes following completion of higher education: Offering continuing education programmes is a valuable strategy for keeping professionals up to date with ever-changing scenarios and the new demands that arise.
6. Educate the general public about science and progress, starting from primary school: Public awareness of the importance of science and technology must be promoted in order to establish an informed and engaged society that understands the benefits of science for quality of life and social progress.
7. Scientific dissemination is fundamental for sharing scientific knowledge with society, motivating new students, improving the teaching and training of secondary school teachers and helping society to understand the importance of investing in research, science, technology and innovation.

Figure 1- Number of graduates and formally employed graduates with academic, professional master's and doctoral degrees, from 1996 to the reference year, 2009-2021. *Source: CAPES Coleta CAPES 1996-2012 and Sucupira Platform 2013-2021 (CAPES, MEC); and RAIS 2009-2021. Prepared by CGEE.*



Public policies and planning

The creation and implementation of effective public policies for science and technology are essential to meet the challenges mentioned. **Long-term** strategic planning is needed that includes **clear targets, performance evaluation and adjustment mechanisms.** Policies that promote international co-operation and participation in global research networks can also help overcome local limitations and broaden the impact of Brazilian research.

Conclusion

Science and technology are pillars for the development of society and essential for the country's economic and social development. Overcoming challenges related to funding, infrastructure, training talent, bureaucracy, partnership with the productive sector, innovation culture and public policies are fundamental for creating a more favourable environment for research and innovation. Adopting integrated strategies and promoting more effective collaboration between different sectors can help to tackle these challenges and boost scientific and technological development in Brazil. It is essential to publicise research activities and their impact on the daily lives of citizens. When people understand the benefits of scientific research, they are more likely to support initiatives that fund science and encourage innovation. Science communication not only informs, but also educates the population about the scientific method and the importance of critical thinking.

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Brazil's nuclear sector: **It's now or never!**

João da Silva Gonçalves

There is nothing more topical than talk of sustainable economies, energy transition, clean energy and/or a clean energy matrix, decarbonisation, the greenhouse effect and climate change. However, through all the current calamities taking place on all continents, we are seeing, in practice, the confirmation of predictions that the atmospheric temperature on Earth will increase by 3ºC. Floods, lack of rainfall, reduced river flow and/or depletion, melting glaciers and major fires have become part of the headlines and our daily lives, without any "effective" coordinated global action to try and reverse the situation. I use the word "effective" deliberately because, over the last 30 years, all the various COPs have still not managed to mobilise the signatory countries to take integrated and cooperative action, with proper consideration of sovereignties and international policies, with the urgency that the planet requires. What the reader may be wondering is what all this has to do with the Brazilian nuclear sector. And even more so, why is it "Now or Never"? I'll explain below.

Brazil has between the 6th and 8th largest uranium reserves in the world, with only a third of its territory adequately prospected. According to current reports from the Geological Survey of Brazil (SGB), prospecting data is completely out of date and more modern techniques and models could significantly change the scenario regarding the reserves of this mineral (Figure 1).

The energy equivalence of a single pellet of enriched uranium produced by Industrias Nucleares do Brasil S/A, the state-owned company responsible for exercising the monopoly established in our constitution regarding the industrial production activities of the nuclear fuel cycle, can be described as follows: a pellet of enriched uranium from the Angra 2 reactor, one centimetre in diameter and height (with a mass of approximately 7 g), contains the same amount of energy as 980 kilogrammes of coal or 461 litres (about three barrels) of oil or 16,800 cubic feet of natural gas. In other words, uranium-based nuclear fuels produce extremely high-density clean energy and, as Brazil could become the leader in uranium reserves if it resumes prospecting, our country is certainly part of the global solution for decarbonising economies, regardless of the fact that it has one of the

Figure 1 – Main areas of current uranium reserves

Source: INB

Table - Uranium reserves

Deposits	Reserves [t U_3O_8]		
	Measured & Indicated	Inferred	TOTAL
Caetité	51,520	35,569	87,089
Santa Quitéria	75,010	4,614	79,624
Others	39,500	26,600	66,100
TOTAL	166,030	66,783	232,818
Mineralization potential:		Pitinga/AM: 150,000 t U_3O_8	
		Rio Cristalino/PA: 150,000 t U_3O_8	

cleanest energy matrices on the planet (based on water, wind, biomass and, however timidly, nuclear).

On the other hand, we have industrialised the nuclear fuel cycle, and the only thing missing is the implementation of the second stage of production within the nuclear fuel cycle, which is the production of uranium hexafluoride gas. Both INB and the Brazilian Navy, through its USEXA demonstration plant, have the necessary technology to do this, and INB, according to the declarations and leadership of its president Adauto Seixas, has already restarted studies to resume this important strategic project, suspended in 2017, which could produce up to 4,000 tonnes of UF6. Another adjustment in INB›s industrial production capacities is the continuation of investments in the modular expansion of uranium enrichment activities through the project to implement the new commercial enrichment plant, UCEU, with the capacity to support the reactors of the Almirante Alvaro Alberto Nuclear Power Plant (Angra 1, 2 and, in the near future, Angra 3).

But for everything to happen, we need uranium, and now. Various actions have therefore been taken to revitalise and expand mineral production in Caetité, Bahia and to complete the initial nuclear and environmental licensing phase for the Santa Quitéria project in Fortaleza, Ceará, which has the potential to produce concentrate that could reach up to 2,300 tonnes of U3O8 per year. The current timetable indicates the start of production in 2028, provided that the INB/Fosnor consortium›s activities in uranium production, alongside the production of phosphate compounds for fertiliser production, progress as planned.

With the expansion of domestic production of nuclear fuels for the new Angra 3 reactor, global demand from the new market of small modular reactors (SMRs) and the implementation of the Brazilian Multipurpose Reactor (RMB), which is needed to mitigate the low level of domestic production of radiopharmaceuticals and the lack of support for the modern scientific development of nuclear applications, we have a gigantic, feasible and viable new nuclear programme, with huge challenges ahead. All of this, supported by the current increase in the international market price of the now commodity uranium and the conversion services for the production of uranium hexafluoride, needed to feed the enrichment plants which stand at US$ 164/kg for U3O8 and US$ 71/kg U as UF6 (as at October/2024).

There are more than 30 new large reactors along with the first SMRs that have been announced by various countries that have recognised their potential for supplying clean energy that only nuclear power can provide in the near future. This worldwide expansion in the reactor fleet, coupled with the life extension of those in operation, has put enormous pressure on market prices for uranium and conversion services. This situation is not expected to change in the next ten years, especially given the effects of the war between Russia and Ukraine, where the former has suffered various sanctions that could affect the logistics of supplying uranium and its services, since Russia is one of the major players in the nuclear market.

In summary, the Brazilian nuclear sector needs around R$40 billion in investments (author›s conclusion) over the next eight to ten years to consolidate the position across the various fronts mentioned above, both industrial and in the applications of nuclear technology, to provide baseload energy for Brazil, assist in the decarbonisation of the world›s economies, consolidate domestic mineral production of uranium including the supply of concentrate and/or conversion services, as well as to advance the development of nuclear applications (in medicine, agriculture, science and technology and industry).

The participation and leading role of Brazil›s nuclear sector in certain fields of this energy source and technologies will only take place if we can establish a state programme, with regulatory, business, commercial and long-term planning stability that is firm and predictable, so that the supply chain, logistics processes, training of human resources and consolidation of technological partnerships can take place very soon. It should be emphasised that the nuclear sector, by its very nature, is fully aligned with the current concept of ESG (Environmental, Social and Governance), increasing sustainability and generating benefits for society, the environment and for corporate governance in those locations where it is well established (see examples from countries such as France, USA, UAE, China, Japan, South Korea, among others); actually being the complete opposite of the prejudices of ill-informed people regarding the danger it poses and the pollution it generates.

Given this constellation of global factors, the confirmation of the worldwide environmental crisis, and the growing recognition of nuclear energy as a clean, safe, and perennial source of energy, necessary for the development, and dramatically increased sustainability of nations, as well as a major contributor to the environmental recovery of the planet, we can categorically state:

It›s now or never!

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[1] Mineral reserve: the economically and legally mineable part of a measured and/or indicated mineral resource, for which the technical and economic feasibility of mining has been demonstrated by means of appropriate technical studies that include the application of modifying factors (adapted from ANM resolution 94, 07/02/2022). Available at https://anttlegis.antt.gov.br/action/ActionDatalegis.php?acao=detalharAto&tipo=RES&numeroAto=00000094&seqAto=000&valorAno=2022&orgao=ANM/MME&nomeTitulo=codigos&desItem=&desItemFim=&cod_modulo=420&cod_menu=7145.

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