BRASIL NUCLEAR

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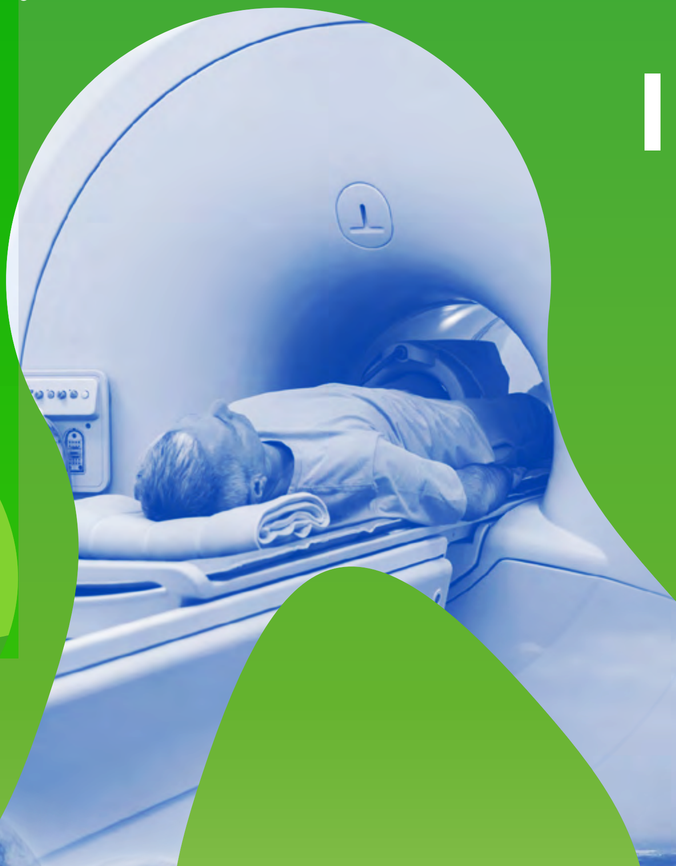

INAC 2024

Nuclear Energy:
Guaranteeing Energy,
Health and Food

BRASIL NUCLEAR

30 Years of
Communicating
with Society

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Aben President
Carlos Freire Moreira

Editorial Board
Carlos Henrique C. Mariz - Aben
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Márcia Flores - Aben
Paulo Ribas - Aben
Olga Mafra - Aben
Olga Simbalista – Aben

Publisher
Vera Dantas

Contributor
Bernardo Barata

Artwork
IG+ Comunicação Integrada

Brasil Nuclear is a publication of the Brazilin Association of Nuclear Energy - ABEN
Rua Candelária, 65 • 14º andar • Centro Rio de Janeiro • RJ • CEP: 20091-906
Tel: (55 21) 2266 0480 • 2588 7000 • Ramal 4721
aben@aben.org.br • www.aben.org.br

Brasil Nuclear is 30 Years old!

This year the magazine **Brasil Nuclear** celebrates its 30th anniversary. The magazine is a communication tool for disseminating to society at large current issues related to the nuclear sector, ranging from scientific research and development to information aimed at demystifying and challenging prejudices against nuclear energy. A little of this success story is retold in this issue, in an article by the journalist Vera Dantas, who also took part in the creation of the magazine. I would therefore like to congratulate all those at ABEN who had the vision of creating this very valuable tool.

Much has been said and written about the current state of nuclear energy, recognising its significance and even its fundamental importance for the future of the planet. This view was confirmed at the United Nations Conference on Climate Change, more commonly known as COP28, held in Dubai at the end of 2023, when 22 countries signed a declaration aimed at tripling nuclear power generation. In the document, they recognise the key role of nuclear energy in achieving net-zero emissions of greenhouse gases by 2050. In addition, there is society's perception of the widespread use of nuclear technology, particularly in medicine, in industry, in the preservation of foodstuffs and historical documents, and in combating environmental pollution. Some of these topics are covered in a very didactic way in the articles: "Decarbonisation and Sustainability of the Nuclear Energy Life Cycle", by Leonam dos Santos Guimarães; "Exploring the Current Scenario of Nuclear Medicine in Brazil", by the president of the Brazilian Society of Nuclear Medicine, Dr Rafael Willain Lopes and in the very timely article on "Application of Nuclear Energy in Agriculture and Food Irradiation in Brazil", by researchers Anna C. H. Villavicencio and Valter Arthur.

> The country, which is among the world's ten largest producers, with only a third of its territory prospected, cannot miss the opportunity to become an important player in this market

This issue's cover story is on the International Nuclear Atlantic Conference (INAC 2024), which will be held from 6 to 10 May. The challenges of organising it, the first in-person face event following the pandemic, are discussed by researcher and Professor Maria de Lourdes Moreira, chair of the event and an invaluable contributor to previous editions of INAC. Meanwhile, the journalist Bernardo Barata discusses the importance of the event, as well as looking back at its first edition in 2002.

Finally, it is important to reflect briefly, from a strategic point of view, on the current situation of nuclear energy around the world, and the direct impact on all the players within the nuclear fuel cycle chain, including Brazil. The war in Ukraine, coupled with the growing global demand for uranium, due to the construction of new nuclear power plants and the depletion of mines in many of the world's producers, has raised the price of uranium to levels rarely experienced before. Brazil, which is among the world's ten largest producers, with only a third of its territory prospected, cannot miss the opportunity to become an important player in this market. Add to this the fact that it has technological mastery of all the stages of the nuclear fuel cycle, which guarantees it a self-sufficiency that few countries in the world have. So what is missing for this to happen? Well, credibility, which necessarily involves completing Angra 3 and extending the life of Angra 1.

In addition, it is essential to have clear rules and legal certainty for fuel cycle activities, which are indispensable for attracting partners willing to invest in Brazil. To this end, it is necessary to regulate Law 14.514/2022 which established the ANSN (Agência Nacional de Segurança Nuclear [National Nuclear Safety Agency]), with the appointment of its president, and establish governance for the sector in order to structure, with the participation of all the stakeholders, a State Programme with objectives, goals and resources that will enable progress to be made in the nuclear sector in a continuous and harmonious way, generating wealth, employment and well-being for society.

Happy reading, everyone!

Carlos Freire Moreira
President of Aben

"INAC's key differentiator is its scientific and academic profile"

Maria de Lourdes Moreira, chair of INAC 2024

Chemical engineer Maria de Lourdes Moreira has extensive experience in organising technical events in the nuclear field. Since 1997 she has been involved in coordinating the National Meeting on Reactor Physics and Thermohydraulics (ENFIR), one of the most important events, on the subject, for the academic and scientific community. In the second semester of 2023, while in the middle of organising the 23rd edition of ENFIR, she was taken by surprise when the board of the Brazilian Association of Nuclear Energy (ABEN) invited her to take on the responsibility for the general coordination of the International Nuclear Atlantic Conference (INAC), which will be held from 6 to 10 May at the Naval War College in Rio de Janeiro. Although a little intimidated by the size and scope of INAC, she accepted this unexpected invitation, given that the then chair had to withdraw from the event due to personal reasons. A graduate of the School of Chemistry at Rio de Janeiro's Federal University (UFRJ), with a master's degree in nuclear energy and a doctorate in civil engineering, both from UFRJ's Coppe Institute, Maria de Lourdes has been Head of the Reactor Engineering Technology sector at the Nuclear Engineering Institute (IEN) of the National Nuclear Energy Commission (CNEN) since 2010, and is also founding professor of the master's degree of the Postgraduate Programme in Nuclear Sciences at the Institute. Her extensive involvement with INAC goes back to the second edition of the event, held in 2005 in Santos (SP). In this interview with Vera Dantas, from **Brasil Nuclear**, Malu, as she is known within the nuclear community, talks about the challenges, difficulties and the rewards of being in charge of INAC and anticipates some of the attractions of the event.

Before taking on the general coordination of INAC, you coordinated ENFIR several times. What are the main differences between the two roles?

The scope of the responsibilities. The greatest difficulties were always faced by INAC's general coordinator (chair), who took on the responsibility of organising, selecting and booking the venue, dealing with the authorities, hiring staff, security and securing sponsorship for the event. The individual coordinators responsible for each event, as was my case, just dealt with the academic side of things: choosing and inviting speakers from Brazil and abroad - in the latter case, this would involve taking care of flights, travel expenses, accommodation and personally welcoming the speakers to the event.

Are international guests receptive to be being invited to the INAC?

Yes, everyone has always been keen to take part in INAC and they have always enjoyed visiting Brazil. Our country has always been very attractive to foreigners. They were always delighted by Brazil, irrespective of whichever city hosted the event. An example is Professor Francesco D'Auria, from the University of Pisa in Italy, who has taken part in several editions of the ENFIR. He has been consistently present and is a guest who has always honoured us with his participation.

Although attracting sponsorship is a responsibility of both ABEN's board and the chair of INAC, do the coordinators take part in this process?

The coordinators have always participated directly in the process of attracting funding from organisations such as CNPq, CAPES and research institutions at a state level. This is because these institutions require that applications be submitted by researchers or professors with doctorates. We have always received support from CAPES, CNPq and agencies such as FAPESP (SP), FAPERJ (RJ), FAPEMIG (MG) and other state-level research foundations, depending on the state hosting the event. FAPESP and FAPEMIG supported INAC, even when the conference was held in Rio. FACEPE, from Pernambuco, supported the event when it was held in Recife.

Is it rewarding to organise an event as big as INAC? Do the rewards outweigh the challenges?

Yes, the rewards have always outweighed the challenges, especially when you see the positive impact that the congress has on the nuclear community in general, and more specifically on the academic community. In this regard, there is a great reward.

Can you name one of the biggest challenges you've faced?

Yes, and it was very recent. In 2021, due to the pandemic, ABEN faced the enormous challenge of holding INAC in a virtual format. It was something new, completely different from what we were used to. But fortunately everything worked out and the congress was a huge success.

INAC takes place every two years, which means it should have been held in 2023. What prompted the postponement to 2024?

When we started organising INAC in 2022, the pandemic was still not over, which led to doubts about the format of the event: should we repeat the virtual experience, return to the in-person format or even promote a hybrid event? This generated a lot of debate among the organisers and the ABEN board. We consulted researchers, lecturers, students and professionals from the nuclear community, who responded positively to the in-person format. We felt that people needed this physical contact; they were tired of sitting in front of a screen. What reinforced the in-person option was the fact that the Naval War College kindly provided space for the event to be held in 2024.

When did you take over the general coordination of INAC?

I was already involved in the general coordination working on specific issues, such as assessing the facilities of the Naval War College, but during this period the then chair had to leave INAC for personal reasons. ABEN's board of directors invited me to take on the coordination which I agreed to and in September 2023 I started working as the event coordinator.

What was it like taking on such a responsible role?

I didn't expect to face such financial difficulties with this edition. The reason being that our traditional partners are now limited in their ability to sponsor events, due to the restrictions imposed by the legislation which regulates public funding. Many of our sponsors are public entities, which face these restrictions.

Is this also due to the increase in the number of events in the sector?

Yes, today there are many events in the nuclear field. But none of them are as big as INAC. In addition, what is unique about INAC is its scientific and academic profile. The other events have lectures, but only INAC offers students the opportunity for active participation, through the presentation of master's, doctoral and undergraduate research projects. That's what sets INAC apart.

How many participants are expected??

So far, we have over 700 registrations and around 530 technical papers have been submitted. That's a lot!

How are the INAC organisers tackling this financial difficulty?

Part of the money we have raised is earmarked for expenses with international guests and some institutions are financing the costs of their speakers; for example, the Idaho National Laboratory and the University of Texas in the USA, as well as the International Atomic Energy Agency are bringing guests at their own expense. The Chinese company CNNC, for its part, is bringing renowned experts, such as the chief engineer of its modular reactor (SMR) project. This demonstrates INAC's great international prestige.

In addition to Rio de Janeiro, INAC has already been held in Santos (SP), Belo Horizonte (MG), Recife (PE) and São Paulo (SP). Is this rotation an advantage?

Yes, rotation is positive because it favours exchanges between institutions in different states and the participation of people from different regions.

What is the theme of INAC 2024?

The theme Nuclear Energy: Guaranteeing Energy, Health and Food encompasses the vision of nuclear energy playing an important role in the search for sustainable solutions in terms of the energy transition and climate change.

Our aim is to communicate to the general public the importance of nuclear energy within the context of sustainable solutions, which is central to current discussions. In addition, nuclear energy plays a fundamental role in energy and food security, guaranteeing a reliable supply of energy and contributing to increased food production.

Of the various applications of nuclear energy, which is the most visible?

Without a doubt, it's the health applications. People are more concerned about their health, and nuclear medicine plays a very important role in diagnosing and treating diseases. It has great social appeal. Our programme will cover all the societal applications of nuclear energy. There will be specific round table discussions covering nuclear medicine, agriculture, the treatment of radioactive waste, as well as discussions on energy.

How much space is there for the presentation of lectures and technical papers?

We will have three days for the presentation of technical papers. Lots of technical papers will be presented as e-posters. The papers will be available electronically during the entire congress.

Of those who have signed up so far, are most of them from the academic community?

Yes, most of the applicants are masters, doctoral and post-doctoral students, as well as university professors. But many researchers from the Navy and CNEN's research institutes as well as professionals from companies within the nuclear sector have also signed up.

Can you recall a special moment at INAC when the coming together of people resulted in an important project?

Meetings, which events like INAC really help facilitate, always bear fruit. It is very common for participants to get in touch with the speakers to exchange ideas or make further contact. Many of the people I know today were contacts I made at INAC. For example, there were professionals in the reactor area whose work I had already read, but with whom I had not yet had personal contact. In-person contact is fundamental for a deeper interaction and exchange of ideas, often resulting in collaborations and even concrete agreements.

How receptive and supportive is the government to INAC?

We are facing significant challenges, but we have already secured support from CNPq and FINEP. We are now waiting for responses from other projects that were submitted to different organisations and companies in order to secure additional financial support.

How important is INAC to the nuclear area?

Nuclear energy plays a fundamental role in the search for sustainable solutions, and INAC continues to be a key platform for this. Research that is currently being carried out in Brazil will be presented at INAC. INAC is an essential moment for driving forward innovation and promoting integration between researchers in the areas of energy, health and food for the sake of our future. It's no coincidence that we chose the theme Nuclear Energy: Guaranteeing Energy, Health and Food.

INAC 2024 will mobilise the domestic and international nuclear sectors

Bernardo Barata

The biggest and most important event for the nuclear sector in the Southern Hemisphere, the International Nuclear Atlantic Conference - INAC 2024 will be held in the city of Rio de Janeiro from 6th to 10th May, with the theme "Nuclear Energy: Guaranteeing Energy, Health and Food". The opening ceremony and the event itself will take place at the Naval War College, in the Urca neighbourhood; however, some lectures and the closing ceremony will take place in the auditorium of the National Nuclear Energy Commission (CNEN), in Botafogo, also on the south side of the city.

Organised by the Brazilian Association of Nuclear Energy (ABEN), the Conference, which is now in its 11th edition (the first took place in 2002), will bring together the XXIII Meeting on Reactor Physics and Thermohydraulics (ENFIR), the XVI Meeting on Nuclear Applications (ENAN), the VIII Nuclear Industry Meeting (ENIN), the X Junior Poster Technical Sessions (poster session for undergraduate students), the XI ExpoINAC (exhibition of the services and products of companies from the Brazilian and international nuclear sectors) and the III ABEN Nuclear Ambassadors Award.

Following the last edition, in 2021, which took place online due to the Covid-19 pandemic, the event, will return to the in-person format and is already generating significant interest, such as the 530 academic papers (expanded abstracts) already submitted, according to the chair of INAC 2024, Professor Maria de Lourdes Moreira.

INAC 2024 also includes among its coordinators, supporters, sponsors and speakers entities such as: Idaho National Laboratory (USA); University of Texas (USA); International Atomic Energy Agency (IAEA); Eletronuclear; National Nuclear Energy Commission (CNEN); China National Nuclear Corporation (CNNC); Funding Authority for Studies and Projects (FINEP); Rosatom - Russia's state nuclear energy corporation; Amazônia Azul Tecnologias de Defesa S.A. (AMAZUL); EBSE – Engenharia de Soluções; Westinghouse; Sciofix - Instrumentação Científica; Diamante Energia; Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (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; National Bank for Economic and Social Development (BNDES); and the Brazilian Society of Nuclear Medicine (SBMN).

Among the topics to be discussed at INAC 2024 are: the current panorama of nuclear reactors in Latin America; naturally occurring radioactive materials in oil exploration; the future destination of radioactive waste; fundamentals and applications in the field of dosimetry; how the application of nuclear technology improves quality of life; on-going projects and future opportunities and challenges for small modular reactors (SMRs); IAEA activities in support of research and applications with neutron sources; the challenges for promoting scientific and technological development in Brazil; new trends in theranostic radiopharmaceuticals applied in nuclear medicine; the uranium market; radiotherapy; obstacles and opportunities in the transition to sustainable energy - harnessing nuclear technologies; the challenge of creating a state programme for nuclear activities in Brazil; human resources; research & development funding in Brazil; the future of nuclear fuels; and food irradiation.

As is the tradition now at INAC, visitors to ExpoINAC will be able to learn about the countless benefits arising from the peaceful application of nuclear energy, in fields such as electricity generation, medicine, agriculture, the environment, industry, the preservation of cultural assets and collections, and propulsion for spacecraft and ships. The exposition brings together experts who will explain the uses of nuclear technology with the help of videos, materials, leaflets and models.

Sadly, this year's INAC will be the first without the important participation of our dear friend, researcher and professor at IPEN/CNEN, Margarida Mizue Hamada, who passed away on 24 June 2023 at the age of 68. She was a great enthusiast of the nuclear field and made a significant contribution to the area through her teaching career, especially on the postgraduate Nuclear Technology Programme at the Institute for Energy and Nuclear Research. With a doctorate in industrial chemistry she was, on several occasions, the chair of the ENAN, which has always formed part of the scope of INAC, indeed she helped to organise various editions of INAC and served on the ABEN board.

Visit the INAC 2024 website, register and find further information including the programme for the biggest event for the nuclear sector in the Southern Hemisphere: www.inac2024.com.br.

INAC, as seen by prominent figures within the nuclear sector

INAC 2024 is a conference that will debate the application and use of nuclear reactors, nuclear energy and the activities of the nuclear industry. I think this is a very important moment for our country, especially when we are trying to develop domestic industry and stimulate employment, and the world is discussing clean sources of energy. I would say that debating the application and use of nuclear reactors, and especially small reactors (SMRs), is extremely important so that society can learn more about the uses of nuclear energy.

Carlos Seixas, President of Nuclebrás Equipamentos Pesados S.A. (NUCLEP)

As AMAZUL's CEO, it is with great satisfaction that I reinforce our commitment to the advancement and development of the nuclear industry in Brazil. AMAZUL's participation at INAC 2024 is a clear reflection of this commitment.

INAC, organised by the Brazilian Association of Nuclear Energy (ABEN), is an extremely important event for the sector, bringing together experts, researchers, government authorities and people from the world of business to discuss key issues for the future of nuclear energy in the country. This year, with the theme "Nuclear Energy: Guaranteeing Energy, Health and Food", the conference will address crucial issues for sustainable development and energy security.

It is an honour for AMAZUL to have 18 technical papers approved for presentation at this edition of INAC, demonstrating our commitment to excellence and innovation in all the areas of our operations. In addition, our company's presence at ExpoINAC 2024 highlights our contribution to promoting business and initiatives within the nuclear sector, both domestically and internationally.

Newton de Almeida Costa Neto, CEO of Amazônia Azul Tecnologias de Defesa S.A. (AMAZUL)

I can state that INAC is the most significant event in the nuclear sector on our side of the American continent, because there is no other event of this size taking place in South, Central or North America. It's a forum that brings together participants from all over the world, from all the Brazilian institutions that work in the nuclear area or in sectors with nuclear applications. It's organised in five different areas of interest: nuclear applications, reactor physics, industry, training of human resources for the area and the trade exhibition. So, it's a very important event where there is a significant exchange of information about the situation within the nuclear sector, about what countries are doing, what Brazil is doing, and also to discuss ideas and proposals aimed at improving our activities within the sector.

Congratulations to ABEN for organising INAC, which is so important for the Brazilian nuclear sector.

Francisco Rondinelli Jr, President of the National Commission of Nuclear Energy (CNEN)

INAC 2024 is the largest international conference on nuclear energy along the Atlantic, bringing together themes such as: nuclear technology applications, nuclear reactors for power generation and research and specialised nuclear industries. It is a favourable ecosystem for integrating research, development, teaching and innovation in a collaborative way with the participation of universities, science and technology institutes, the public and private sectors and society. The essential technical-scientific sessions, together with the excellent participation of undergraduate students and the exhibition of companies, make this edition of INAC 2024 – "Nuclear Energy: Guaranteeing Energy, Health and Food", truly extraordinary.

Wilson Aparecido Parejo Calvo, Director of Research and Development at CNEN

INAC is extremely important for the nuclear sector, especially at a time when we are discussing the expansion of this activity in Brazil. It is an opportunity to bring together international companies and organisations to promote the exchange of experiences between participants. Eletronuclear is pleased to be sponsoring yet another edition of this event. This is a long-standing partnership and we are really looking forward to the five-day conference.

Raul Lycurgo Leite, CEO of Eletronuclear

I want to congratulate the organisers of the International Nuclear Atlantic Conference, an important meeting where a number of current issues on nuclear resources will be discussed with a view to benefiting society. This is particularly important now, when the need to produce carbon-free energy is one of the main international priorities, so I want to wish the conference every success.

Sylvio Canuto, member of the General Coordination Committee for Science, Humanities and Arts at FAPESP

INAC is a partner of CAPES in its mission to promote and value education and science which are the driving forces behind the country's development. Brazil has a scientific output of great significance and it needs to transform this knowledge to generate high technology, employment and income. This movement should be spearheaded by the doctoral graduates of our postgraduate programmes. In this respect, INAC has a lot to offer since it brings together academia and the productive sector, an essential combination for improving Brazil's socio-economic outlook.

The advancement of national science is indispensable in strategic areas such as health, climate emergencies, the production of food and the generation of clean energy. This will help to reduce inequalities, meet society's needs and showcase Brazilian research at an international level.

Events such as INAC and the role of ABEN are of the utmost importance for bringing specialists together, strengthening professional relations, stimulating scientific exchange and cooperation and promoting the use of nuclear technology as an instrument of peace and progress for humanity.

Denise Pires de Carvalho, President of the Agency for the Development of Higher Education (CAPES)

INAC 2024 is an important conference for the nuclear sector in our country as it reaffirms Brazil's commitment to developing and improving nuclear technology, as well as promoting international cooperation in this area.

The conference provides an opportunity for military personnel, specialists, researchers, academics and representatives from the nuclear industry to meet and share theoretical and practical knowledge as well as experiences. INAC 2024 contributes to the dissemination of up-to-date information on the latest technological advances, innovations and scientific research in the nuclear sector. This exchange of knowledge is fundamental for the development of safe, efficient and sustainable solutions that meet society's needs.

The conference further strengthens dialogue and cooperation between Brazil's Navy and players within the nuclear sector.

Admiral Alexandre Rabello de Faria, Director General of Nuclear and Technological Development of the Navy

It will be a great honour to take part in INAC 2024. I intend to show the enormous possibilities we have in relation to Brazil's large uranium reserves, their securitisation and the great possibility of financing a major nuclear programme based on these reserves and with these resources. I also want to deal with the subject of food irradiation and its importance for Brazilian agribusiness, the progress made and the maturity of this technology. I'm also going to discuss the issue of nuclear medicine in Brazil, which is so important and yet which is far behind that practised in Argentina or even Chile and the progress we still need to make. I think it will be a great opportunity for us to discuss various important areas and possibilities for the nuclear system and nuclear activities in Brazil.

Julio Lopes, member of the House of Representatives (PP/RJ) and President of the Joint Parliamentary Front for Nuclear Technology and Energy

30 years of Brasil Nuclear

Vera Dantas

At the beginning of 1994, a group of professionals linked to the Brazilian Association of Nuclear Energy (ABEN), led by Guilherme Camargo, Márcia Flores and Everton Carvalho, decided to create a communication channel between the nuclear sector and society, especially "opinion formers" – technical professionals, politicians, researchers, students, journalists and the military. The aim was to clarify for the general public the major issues surrounding the subject and to demystify and dispel the many prejudices about nuclear energy. The Nuclear Energy Public Acceptance Programme (**APUB**) was created, and its communication strategy included hiring a press officer to initiate dialogue with the media, taking part in debates and seminars, giving talks in schools and companies, and creating a vehicle that would provide readers with trustworthy and objective information about nuclear energy. The magazine **Brasil Nuclear** was born.

APUB included representatives from ABEN and professionals from other entities and organisations such as NUCLEP, CNEN, ABDAN, NUCLEN and FURNAS (the last two gave rise to Eletronuclear).

With the aim of winning over public opinion, which had been the target of anti-nuclear campaigns, **APUB's** immediate objective was to ensure the resumption of work on the Angra 2 nuclear power plant, which had been paralysed. The objective was achieved, as the following year the federal government released funds for the completion of Angra 2, which went into operation in March 2000. Another action of the programme was to counter the anti-nuclear campaign launched by the non-governmental organisation Greenpeace to prevent the construction of Angra 2 and to shut down Angra 1.

The first four editions of **Brasil Nuclear** were in the format of a newsletter, which, in the fifth edition in 1995, was replaced by the full-colour magazine. The new version received praise from entities as diverse as the Legislative Assembly of Rio de Janeiro and the War College. Gradually, the magazine gained influence and generated positive repercussions and stands out among the vehicles that disseminate science and technology. Today, the magazine has a digital format, with versions in Portuguese and English.

Pioneering

Over the course of 30 years, **Brasil Nuclear** anticipated many issues that would only, later on, gain prominence in the media, such as global warming and its consequences for the environment and the population. Another example were the warnings in various editions of the magazine about the need for investment to meet the demand for electricity and avoid a collapse of the national grid, which ended up happening with the rationing ("blackout") of 2001.

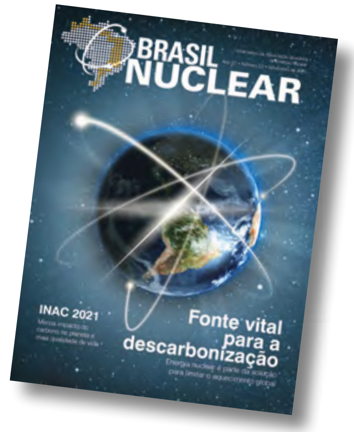
The risk of water scarcity in the world was anticipated by **Brasil Nuclear**. In 2002, issue 24, dedicated to the subject, showed the contribution of nuclear energy to preserving water resources, through solutions such as reactors for desalinising sea water and the use of irradiation to clean up rivers and lakes, degrade industrial effluents and disinfect domestic sewage.

Another example of **Brasil Nuclear's** pioneering approach has been its promotion of the health benefits of nuclear medicine. With articles in several editions, the magazine has reported on the growth in the use of radiopharmaceuticals for carrying out both diagnosis and the treatment of various diseases, as well as the evolution of their production, here in Brazil, through the research institutes of the National Nuclear Energy Commission (CNEN). In 1988, the magazine reported on the start of domestic production of Fluor-18FDG, a radioactive substance used in PET-CT scans, extremely precise imaging equipment used to investigate and diagnose neurological and cardiac diseases and to detect metastatic cancers.

Brasil Nuclear has also followed the evolution of the food irradiation sector, one of the most advanced processes for preserving and increasing the durability of agricultural products, contributing to an increase in exports. Another application of nuclear energy in agriculture, reported on by the magazine, is radioentomology, a technique that uses radioactively modified insects to control pests with high efficiency and without damaging the environment. Also in the area of agriculture, Brasil Nuclear presented solutions that use nuclear technology to improve soils used for growing soya, such as the technique of sterilising peat using radiation. Peat is a type of organic soil that is very fertile and used intensively in soya production in Brazil. Its sterilisation is necessary to enable bacteria to adapt in order to capture nitrogen, a gas that speeds up the plant's metabolism.

One of the issues of **Brasil Nuclear** that generated the greatest repercussions was the one dedicated to the participation of women in nuclear energy (issue 17, April-September 1998). Incidentally, the magazine was of historical importance as it retrieved and provided evidence of the visit made to Brazil by Marie Curie, the discoverer of radioactivity.

More than just providing information, **Brasil Nuclear** also encourages the development of national technologies within the sector, as in the case of the nuclear submarine project, currently being developed by the Brazilian Navy, and the Brazilian Multipurpose Reactor (RMB). In the case of the RMB, as well as publishing several articles, the magazine took part in a campaign to raise awareness among authorities and the population in general about the importance of the project, which aims to end external dependence on radioisotopes for medical treatment, the supply of which has been interrupted on several occasions due to problems with other countries' research reactors. In 2010, the then president of ABEN, Edson Kuramoto, contacted the then vice-president of the Republic, José Alencar, and presented the RMB project. Alencar, who was himself battling cancer and was a user of nuclear medicine procedures, "showed sensitivity in understanding the importance of the reactor for the country, enabling it to become self-sufficient in the production of radioisotopes, and he was very agile in promoting contacts with the ministers involved," recalls Kuramoto. "Later, he sent a letter detailing the actions he had taken to help with the authorisation."



According to Kuramoto, during these 30 years, **Brasil Nuclear** has played a fundamental role in expanding knowledge about nuclear energy and was very important for the resumption of work on the Angra 2 and Angra 3 plants. CNEN president, Francisco Rondinelli Jr., has congratulated the magazine and its professionals for their work down through the years. "**Brasil Nuclear** provides an invaluable service, which is to bring quality information and clarification to Brazilian society about the benefits of the nuclear sector's activities and projects," he said.

Decarbonisation and Sustainability of the Nuclear Energy Life Cycle

Leonam dos Santos Guimarães

Nuclear energy has been widely recognised as a low-carbon source, especially when compared to traditional energy sources based on fossil fuels. One of its main advantages is that it does not emit carbon dioxide or other greenhouse gases (GHG) nor other pollutant gases during operations. It also has the advantage that, unlike intermittent renewable sources such as solar and wind, it can supply a large amount of base-load energy (constant energy) continuously, which is crucial for meeting the energy demand of large urban and industrial areas. This is why nuclear energy is a crucial component in the transition to a low-carbon global energy system.

Although direct emissions are very low, within the complete life cycle of nuclear energy there are indirect emissions at the stages of fuel production, plant construction, operation, decommissioning and waste management. Although studies show that, even considering these stages, total emissions are still considerably lower than those from fossil energy sources, it is necessary to implement strategies to further reduce indirect emissions throughout the life cycle.

Comparison with other forms of energy

The GHG emissions associated with nuclear energy are predominantly indirect, originating in the construction and decommissioning of power plants, the mining and processing of uranium and the transportation of fuel. Studies indicate that these emissions are generally between 10 and 30 grams of CO2 equivalent per kilowatt-hour (g CO2e/kWh). Comparing them to energy sources that use fossil fuels and renewable energy sources, we have:

Coal: this is one of the most carbon-intensive ways of generating electricity, with emissions typically ranging from 800 to 1,000 g CO2e/kWh;

Natural gas: less carbon-intensive than coal, but still emits around 400 to 500 g CO2e/kWh;

Hydroelectric power: generally has low emissions, in the range of 1 to 20 g CO2e/kWh. However, there may be significant methane emissions in some cases, especially in tropical regions;

Wind Energy: The emissions associated with wind energy are also low, at around 4 to 12 g CO2e/kWh;

Photovoltaic Solar Energy: Life cycle emissions from solar energy vary between 20 and 50 g CO2e/kWh, depending on the technology and location;

Biomass: Emissions can vary widely depending on the source of the material and the conversion technology, but are generally in the range of 100 to 400 g CO2e/kWh.

In terms of lifecycle GHG emissions, the emissions produced by nuclear power are significantly lower than those of energy sources based on fossil fuels, and are often similar or slightly higher than wind power, but generally lower than solar power and significantly lower than biomass.

The Life cycle of a nuclear power plant

The life cycle of nuclear energy covers several stages, from the extraction of raw materials to waste management and the decommissioning of power plants. Each of these stages has environmental and safety implications, and is accompanied by varying levels of carbon emissions and management challenges. The life cycle analysis of nuclear energy considers all of these aspects in order to assess its total environmental impact.

Uranium is extracted through open-cast or underground mining, depending on the depth of the uranium deposit. The uranium ore is crushed and processed to extract uranium in the form of a powdered concentrate, known as yellow cake. It is then refined and converted into uranium hexafluoride (UF6), a salt that gasifies at a low temperature and which is necessary for the enrichment process.

Natural uranium contains around 0.7 per cent uranium-235 (U-235). Enrichment increases this concentration to around 3-5 per cent for use in today's large nuclear reactors or up to 20 per cent for use in advanced small reactors.

Subsequently the UF6 is reconverted into uranium dioxide (UO2), which is then pressed, sintered and ground into ceramic pellets. The pellets are mounted on fuel rods, which are grouped together to form mechanical assemblies called nuclear fuel elements.

In the operation stage, fuel elements are loaded into the core of nuclear reactors to generate energy through nuclear fission, without direct emissions. During operation, the heat generated by nuclear fission is used to produce steam, which in turn generates electricity. The generation of energy by the reactors generates low and medium level radioactive waste, which includes contaminated items used in the operation and maintenance of the plant. They are treated and stored in secure facilities.

Spent nuclear fuel discharged from the reactor core contains around 5 to 10 per cent high-level radioactive waste. The remaining 90-95% is made up of uranium, plutonium and metallic materials that can be reprocessed and recycled after a period of long-term storage, constituting what is known as the “closed fuel cycle”. However, it is possible to opt for the open fuel cycle, which requires final disposal of the spent elements in secure geological formations.

After completing its useful life, which can be up to 80 years, the plant is taken out of service and decommissioned. This includes the removal of any remaining spent nuclear fuel, the decontamination of equipment and structures, and the dismantling and demolition of the plant. After decommissioning, the site is cleaned up and returned to its natural state, as far as conditions allow. Alternatively, it is prepared for a new use.

Uranium mining and processing

These steps are energy-intensive and have a considerable carbon footprint, mainly due to the use of heavy machinery and energy-intensive processes. In these cases, we have the following possibilities for improvement:

- Implementation of energy efficiency technologies in the mining machinery;
- Use of renewable energy sources, such as hydroelectric, solar or wind power, or even nuclear power, for mining operations;
- Adoption of environmental recovery and reforestation programmes in mining areas.

The extracted ore is processed to remove impurities and increase the concentration of uranium. This usually involves a series of chemical and physical steps, which can be energy intensive. Possibilities for improvement are:

- Implement technologies that optimise the use of energy in the grinding, leaching and purification processes;
- Develop processes to recycle and reuse waste and by-products of the uranium processing;
- Explore technological innovations within uranium processing that reduce the carbon footprint;
- Implement more efficient separation methods that require less energy;
- Explore the use of biological processes for the extraction and purification of uranium, which may offer more sustainable alternatives.

Uranium conversion

The conversion of uranium concentrate (yellow cake) into uranium hexafluoride (UF6) is an energy-intensive process and uses hazardous chemicals. Proposals for improvement are:

- Implement more sophisticated process controls to maximise efficiency and minimise the consumption of chemicals;
- Integrate renewable energy sources, such as solar and wind power, or even nuclear power in the conversion facilities to supply part, or all, of the energy required for the process;
- Research and development into alternative, cleaner conversion methods that reduce the use of hazardous chemicals and emissions, as well as the development of catalysts that can convert at lower temperatures, thus reducing energy consumption;
- Improve effluent treatment methods to minimise environmental impact and implement processes to

> The implementation of these decarbonisation strategies has the potential to strengthen the position of nuclear energy as a low-carbon source, an unavoidable option in the fight against climate change

recycle by-products of the process, such as hydrofluoric acid, reducing the need for new inputs and minimising waste;
- Installation of advanced emissions monitoring systems;
- Continuous investment in research to constantly improve conversion processes in terms of efficiency and environmental impact.

Uranium enrichment

Conventional enrichment methods are energy intensive and contribute significantly to the carbon footprint of nuclear energy. The most widely used method today is ultracentrifugation, which relies on high-speed rotating centrifuges to separate uranium isotopes. Possibilities for improvement are:

- Optimisation of centrifuges, developing more efficient machines capable of achieving the degree of separation with a lower consumption of energy.
- Implementation of automated and optimised process control systems to reduce energy waste;
- Integration of renewable or nuclear energy sources to supply electricity to enrichment facilities;
- Exploration of laser-assisted uranium enrichment, which has the potential to be more efficient and less energy-intensive, and carry out research into new, more efficient materials for use in centrifuges and in separation processes;
- Implementation of techniques to recycle depleted uranium, a by-product of enrichment, reducing the need for additional enrichment. Improving UF6 handling processes to minimise losses and leakages;
- Implementation of advanced emissions monitoring systems to ensure operations have a low environmental impact.

Reconversion of uranium

Uranium reconversion is the process that turns uranium hexafluoride (UF6) back into uranium oxide (UO2) to produce the powder that is used in the manufacture of nuclear fuel pellets. This process involves high temperatures and the handling of reactive gases. Proposals for improvement are:

- Improving the efficiency of the furnaces used in calcination and in the chemical reaction, reducing energy consumption and implementing heat recovery systems to utilise waste heat in other stages of the process;
- Research and development of advanced catalysts that can carry out the conversion at lower temperatures, reducing energy consumption. Research into alternative conversion methods that are more efficient and generate less waste;
- Use of clean energy sources;
- Improvement of effluent treatment systems to reduce the release of harmful chemicals into the environment, and implementation of processes to recover and recycle materials and chemicals used in the process;
- Installation of advanced monitoring systems to ensure that operations have a low environmental impact.

Production of uranium oxide pellets

At this stage, uranium dioxide powder (UO2) is transformed into pellets that make up the fuel elements used in nuclear reactors. Possibilities for improvement are:

- Use of state-of-the-art, more energy-efficient sintering furnaces to reduce energy consumption and implementation of heat recovery systems to use residual heat in other operations, reducing the demand for additional energy;
- Development and use of more efficient pressing machines, which require less energy to operate, and optimisation of the granulometry of the UO2 powder to improve process efficiency and reduce waste;
- Use of clean energy sources;
- Research into the design of pellets that optimise fuel efficiency and reduce the need for material and energy during production;
- Implementation of processes to recover and reuse UO2 powder wasted during production and optimisation of the processes to minimise the generation of solid and liquid waste;
- Installation of advanced monitoring systems to ensure operations have a low environmental impact and carry out periodic assessments to identify and mitigate environmental impacts at all stages of the process.

Manufacture and assembly of combustible elements

In the conventional process of manufacturing and assembling fuel elements, the UO2 pellets are loaded into zirconium alloy tubes, known as fuel rods. After loading, the rods are sealed and assembled into groups called fuel elements, in accordance with the reactor's specifications. Possibilities for improvement are:

- Implementation of more efficient automated systems, which reduce energy consumption during manufacturing and assembly. Improved sealing processes to reduce the time and energy required;

- Implementation of processes to recover and reuse materials, such as zirconium and UO2, which are left over during manufacture. Reducing material waste through precision manufacturing techniques;
- Use of clean energy sources;
- Research and development into fuel rod and fuel element designs that maximise fuel efficiency;
- Installation of emissions monitoring systems to ensure operations have a low environmental impact.

Transportation and loading of fuels into the reactor

The fuel elements are transported from the factory to the nuclear power plant, usually by lorry and train, and in some cases by sea. Possibilities for improvement:

- Use of low-emission transport vehicles, such as electric or hybrid trucks, to reduce the carbon footprint of land transport and efficient logistics planning to minimise the distance travelled and maximise the load per trip, reducing the total number of trips required;
- Implementation of more energy-efficient fuel handling and loading systems within nuclear power plants and the use of automated fuel loading systems, increasing efficiency and reducing energy consumption;
- Use of clean energy sources;
- Implementation of monitoring systems to track and optimise greenhouse gas emissions associated with fuel transport;
- Investment in carbon offset projects to neutralise unavoidable emissions;
- Development of packaging for transporting fuel that is lighter, recyclable and/or made from sustainable materials and continuity of research and development into technologies to ensure maximum safety during transportation, avoiding accidents that could cause environmental damage.

Reactor operation

Energy generation in the core of a nuclear reactor is the heart of the nuclear energy production process, where nuclear fission of uranium takes place, releasing a large amount of heat. The heat generated is transferred to a water or other coolant circuit, which then generates steam that is used to drive turbines, which in turn drive generators to produce electricity. Possibilities for improvement are:

- Investment in new generation reactors such as SMRs or fourth generation reactors that are more efficient, safer and have less environmental impact. Development of advanced nuclear fuels that can operate at higher temperatures and with greater thermodynamic efficiency;
- Use of state-of-the-art monitoring and control systems to optimise reactor operation, increasing efficiency and reducing energy waste;
- Implementation of predictive maintenance systems to ensure efficient operation and extend the useful life of the reactor;
- Investment in research into nuclear fusion, which has the potential to be an even cleaner and more abundant source of energy.
- Development of technologies for recycling nuclear fuel, reducing the need for mining and processing new uranium;
- Exploration of hybrid systems that combine nuclear energy with renewable energy sources such as solar

and wind power to optimise energy production and reduce dependence on fossil fuels.

Construction of nuclear power plants

The construction of a nuclear power plant is a long and complex process that involves the implementation of a diverse infrastructure and advanced technological systems.

Indirect emissions during the construction of nuclear power plants are an important part of the life cycle emissions profile of nuclear energy. These emissions do not come directly from the production of nuclear energy, but rather from activities related to the construction of the plant. The principal contributing factors are:

- Steel and Concrete Production: Steel and concrete are used extensively in the construction of nuclear power plants. The production of these materials is energy-intensive and often relies on fossil fuel-based energy sources, resulting in significant CO_2 emissions. The transport of these heavy materials is usually done by lorries, trains or ships, which emit greenhouse gases.
- Construction and Site Infrastructure: Construction equipment such as excavators, cranes and trucks usually run on diesel, contributing to carbon emissions. The energy used within the construction site, whether for machinery, lighting or temporary installations, may come from non-renewable energy sources.
- Manufacturing and transportation of Nuclear Components: The manufacture of specialised components for nuclear reactors, such as pressure vessels, steam generators and control systems, is also energy intensive. Many of these components are produced at specialised sites and need to be transported long distances to the site of the power plant.
- Associated Indirect Activities: Construction of roads, bridges and other support infrastructures around the plant. The activities of suppliers and service providers involved in construction also contribute to indirect emissions.

When considering these factors, it is clear that although nuclear power plants do not emit CO_2 during operation, the indirect emissions associated with their construction are significant and should be considered when assessing the total carbon footprint of nuclear power. Implementing mitigation strategies can help reduce these emissions. Possibilities for improvement are:

- Use of construction materials with a lower carbon footprint, such as recycled steel and concrete with sustainable additives. Optimising the use of materials to minimise waste;
- Use of construction equipment that operates using alternative fuels or electrical technology in order to reduce emissions during construction. Implementation of renewable energy sources, such as temporary solar panels, to power construction operations;
- Use of integrated planning techniques to optimise logistics and reduce construction time. Adoption of modular and prefabricated components that can be built off-site and assembled on-site, reducing the time and resources needed for construction;
- Use of advanced technologies, such as robotics and automation, to increase efficiency and reduce energy consumption in construction. Implementation of sustainable construction practices, including efficient water management and pollution reduction;
- Continuous monitoring of environmental impact during construction and implementation of measures to mitigate negative impacts. Also investment in carbon offset projects to neutralise emissions generated during construction.

Decommissioning and dismantling

The decommissioning and dismantling process, which takes place at the end of the power plant's useful life, includes risk assessment, safety planning and logistical preparation. This is followed by decommissioning and clean-up, with the removal of spent nuclear fuel and decontamination of systems and structures. Next comes dismantling with the physical demolition of the plant's structures, including the reactor building and supporting installations. During these stages, radioactive and non-radioactive waste must be managed, categorised, treated and disposed of safely. In these cases, we put forward the following proposals for improvement:

- Use of advanced technologies for the decontamination of structures and equipment, reducing the volume of radioactive waste. Use of robots and automated systems to carry out dangerous or energy-intensive tasks, improving efficiency and safety;
- Recovery and recycling of non-contaminated materials, such as metals and concrete, to reduce the amount of waste generated. Adoption of strategies to minimise the generation of waste during decommissioning and dismantling;
- Selection of highly energy-efficient equipment and machinery for dismantling operations. Implementation of temporary clean energy sources to meet the energy needs of on-site operations;
- Continuous monitoring of environmental impact

- during decommissioning and dismantling. Carry out environmental impact assessments to identify and mitigate negative effects on the environment;
- Development of advanced methods for the safe storage and disposal of radioactive waste. Investment in research into the transmutation of nuclear waste to reduce radioactivity and the volume of waste.

Management of low and medium-level radioactive waste

The management of low- and medium-level radioactive waste includes its treatment and conditioning to ensure a reduction in the volume and the immobilisation and encapsulation of the waste to ensure safe handling, transport and storage. This is followed by initial storage of the residues in secure facilities until the radioactivity decreases significantly to allow for final disposal, which generally involves placing the residues in underground or surface facilities specially designed for this purpose. Possibilities for improvement are:

- Implementing processes to reduce the amount of waste generated during the operation of the plant, minimising it at source. Developing methods to recycle materials from the waste, hence reduce the volume of waste that needs to be treated and stored;
- Using energy-efficient waste treatment technologies and designing initial and intermediate storage systems that minimise energy use;
- Implementation of renewable energy sources, such as solar and wind power, and even nuclear power, to provide electricity for waste treatment and storage facilities;
- Improvements in waste disposal facilities through the development of new technologies and materials to improve the safety and efficiency of final disposal facilities;
- Investment in research into advanced disposal technologies in underground facilities that offer greater safety and long-term stability;
- Implementation of long-term monitoring systems to guarantee environmental safety and the effectiveness of waste disposal and regular environmental impact assessments to identify and mitigate negative effects on the environment.

Long-term management and final disposal of spent fuel

The long-term management and final disposal of spent fuel elements (SFEs) from a nuclear power plant represents a significant challenge, given the high radioactivity and long life of the waste. The aim is to store and dispose of these materials safely, avoiding environmental impacts and risks to human health.

The management of spent fuel elements involves initial and intermediate storage, followed by final disposal. After being removed from the reactor, the SFEs are generally stored initially in cooling pools within the plant itself. After a reasonable period of time cooling in the pool the SFEs are transferred to dry storage containers, which are placed in intermediate storage facilities. These containers have passive cooling systems that do not require active energy to keep the SFEs at a safe temperature. Possibilities for improvement are:

- Implementation of renewable or nuclear energy sources to supply electricity to intermediate storage facilities and monitoring operations;
- Investment in research to improve deep geological storage technologies, increasing safety and efficiency. Choice of final disposal sites based on sustainability criteria and minimal environmental impact, promoting public acceptance;
- Development of reprocessing technologies that allow the recovery of useful materials from SFEs, reducing the volume of waste. Research into closed nuclear fuel cycles, where reprocessed materials are reused as fuel;
- Implementation of sophisticated systems to provide continuous, long-term monitoring of the state of the SFEs and the environment surrounding the storage and disposal facilities;
- Carry out Regular impact assessments to identify and mitigate negative effects on the environment.

Conclusion

Implementing these decarbonisation strategies has the potential not only to make nuclear energy more sustainable, but also to strengthen its position as a low-carbon energy source, an inevitable option in combatting climate change. By minimising GHG emissions and maximising efficiency and safety, nuclear energy can play a crucial role in the global energy transition to a cleaner and more sustainable future.

The implementation of cleaner technologies, energy efficiency and careful consideration of the entire life cycle are fundamental steps towards achieving this goal. Nuclear energy can play a significant role in reducing carbon emissions and providing reliable, clean energy for the future.

Leonam Guimarães is Coordinator of AMAZUL's Science & Technology Committee

Exploring the current scenario of **Nuclear Medicine in Brazil**

Rafael Willain Lopes

Nuclear medicine is a speciality that corresponds to a field of knowledge related both to the acquisition of images of physiological and pathophysiological processes and to the treatment of diseases, playing an important role in clinical management in many cases. In Brazil, there are just over a thousand doctors working in the field of nuclear medicine, according to the most recent demographics, almost half of them are qualified and are members of the Brazilian Society of Nuclear Medicine (SBMN) - which will celebrate 63 years of existence on 14 September. The field has experienced progress and challenges, reflecting the health scenario and the technological capabilities of the country. Let's take a closer look at its current status in Brazil.

Technological progress

Over the last 15 years, Brazil has made remarkable advances in nuclear medicine technology. The acquisition of state-of-the-art imaging equipment, such as Single-Photon Emission Computed Tomography (SPECT), ultrafast cameras with Cadmium-Zinc-Tellurium (CZT) semiconductors and Positron Emission Tomography (PET) combined with Computed Tomography (CT), the PET-CTs, many of which already have several new technologies at their disposal, such as new crystals, time of flight, reconstruction algorithms, larger detectors and/or digital detectors, and even on-board artificial intelligence - has greatly improved the diagnostic capabilities of medical institutions throughout the country. In addition, in the last 10 years, nuclear medicine services that make use of both SPECT and PET-CT are present in most Brazilian state capitals and in many of its major cities. Today, there are more than 180 PET-CT scanners in Brazil, whereas in 2006 there were only five in the entire country. These advanced imaging technologies allow precise visualisation of physiological processes within the body thus aiding the detection and characterisation of diseases ranging from cancer to neurological disorders.

At the same time, the development of radiopharmaceuticals - radioactive drugs used in nuclear medicine procedures - has expanded the scope of the diagnostic and therapeutic options available to healthcare professionals in Brazil. As a result of collaboration involving the Nuclear Energy Research Institute (IPEN), the International Atomic Energy Agency (IAEA), and both domestic and international pharmaceutical companies, Brazilian researchers now have access to a diverse range of radiotracers, which allow more accurate diagnosis and customised treatment strategies.

It is true that Brazil still suffers from external dependence on the main raw material for conventional nuclear medicine examinations (SPECT) that is molybdenum, which is incorporated into molybdenum-technetium generators, currently produced in Brazil exclusively by IPEN and distributed to the more than 400 nuclear medicine services throughout Brazil on a weekly basis. The cost of importing this input is around 15 to 20 million dollars, in addition to all of the difficulties related to this logistical chain. Other important isotopes for the treatment of various types of cancer are also imported on a weekly basis, such as Iodine-131 and Lutetium-177, in varying and increasing quantities.

Clinical Applications

Nuclear medicine plays a crucial role in the diagnosis and management of various conditions prevalent in Brazil

Cancer imaging and therapy represent significant areas of application, with nuclear medicine techniques providing invaluable insights into tumour biology, staging and response to treatment. In addition, cardiac imaging using nuclear medicine technology provides assessments of myocardial perfusion, function and viability, aiding the diagnosis and management of cardiovascular diseases, which represent a substantial burden on Brazil's healthcare system.

Furthermore, nuclear medicine techniques are increasingly being used in neurology, endocrinology and rheumatology, offering non-invasive means of assessing organ function and identifying pathological abnormalities. From detecting neurodegenerative disorders to assessing thyroid function and diagnosing inflammatory joint diseases, nuclear medicine contributes to comprehensive patient care across various medical specialities.

Challenges and opportunities

Despite the progress made in Brazil, several challenges persist, hampering its widespread adoption and hence access to advanced technologies and services. Limited infrastructure and resources in certain regions represent barriers to the establishment of nuclear medicine facilities, particularly in remote areas where health disparities are prevalent. In addition, the high cost associated with acquiring and maintaining sophisticated imaging equipment together with all of the infrastructure and logistics related to the activity present financial challenges for healthcare institutions and hinder the expansion of services throughout the country. Regulatory and infrastructural problems, both operational and transportational, in a country as large as Brazil, combined with the high costs resulting from these difficulties, threaten the survival and promising future of this speciality in Brazil.

On the other hand, the shortage of professionals, such as nuclear doctors, biomedical doctors, radiopharmacists, medical physicists and technologists with specific training in nuclear medicine, represents a significant impediment to the growth of the field. It is essential that efforts be made to improve educational and training programmes for the area in order to address this shortage within the workforce and ensure the availability of qualified professionals capable of providing high-quality care to patients throughout the country.

However, in the midst of these challenges, there are opportunities for collaboration and innovation within Brazil's nuclear medicine community. Partnerships between academia, government agencies, health professionals and industry stakeholders can facilitate the exchange of knowledge, expertise and experience, driving advances in research, education and clinical practice. In addition, initiatives aimed at promoting public awareness and understanding of nuclear activity can help alleviate misconceptions and promote confidence in these advanced medical technologies.

Future directions

Looking to the future, we have immense potential for growth and development. By leveraging technological innovations, promoting interdisciplinary collaborations and investing in education and infrastructure, Brazil can increase its capabilities in the field and improve health outcomes for its population. Embracing emerging trends such as theranostics - the integration of diagnostic imaging and targeted therapy - can revolutionise disease management and usher in a new era of precision medicine in Brazil.

In conclusion, nuclear medicine occupies an important position in Brazil's healthcare landscape, offering advanced diagnostic and therapeutic solutions for a wide range of medical conditions. Although there are challenges, collaborations, institutional partnerships and concerted efforts to overcome barriers and capitalise on opportunities can propel the specialty forward into a bright future, always striving to ensure equitable access to quality services of nuclear medicine for all Brazilians. With continued investment and commitment, Brazil is poised to emerge as a leader in innovation and excellence in nuclear medicine.

President of the Brazilian Society of Nuclear Medicine

Application of Nuclear Energy in **Agriculture and Food Irradiation in Brazil**

Anna Lucia C. H. Villavicencio[1]
Valter Arthur[2]

The increase in the world's demand for food and the problems that arise from ensuring adequate storage and processing facilities have forced us to look for new methods of food preservation. In these times of great change, the application of ionising radiation to promote food safety by preserving, disinfecting and reducing microbial loads, among other applications, on grains, seasonings, herbs in general, fruit, vegetables, red/white meats (beef, pork), poultry, fish and seafood, among other products, is a practice used by many countries to extend shelf life and reduce losses during the storage of the product.

It is a process in which food products are exposed to ionising radiation (so called because it ionises the medium it passes through), including Y-rays, X-rays and accelerated electrons produced by machines known as electron accelerators. The process does not increase the level of natural radioactivity in food. Irradiated food does not become radioactive after this procedure. The overall average dose absorbed by food subjected to a process of irradiation should not exceed 10 kGy, in order to ensure that the irradiated food continues to be safe from a toxicological, nutritional and microbiological point of view.

Irradiation is used in several countries as a method of preserving food and food products, whether the food is in bulk or industrially packaged, following the recommendations of the joint committee between the United Nations Food and Agriculture Organisation (FAO), the International Atomic Energy Agency (IAEA), the World Health Organization (WHO) and the Codex Alimentarius, which continually strives to promote up-to-date standards, research and decision-making on this subject, due to the importance of staple food safety in many countries.

This technology is aimed at minimising the huge losses that occur due to contamination and decomposition caused by bacteria, as well as the growing concern about foodborne diseases (FBDs). The application of the irradiation process can reduce microbial loads to near-zero levels, such as, for example, *Escherichia coli* O157:H7, which is known to cause haemorrhagic colitis as a result of the consumption of undercooked or raw meat contaminated with this bacterium. The increase in international trade in food and the strict phytosanitary export standards, in terms of quality and quarantine, to which food is subject, add to the need for food irradiation.

Dosimetric systems are used for each type of radiation or equipment used during processing, in order to check that the correct dose has been applied to the product. These dosimeters are suitable for measuring doses ranging from 0.1 to 50kGy, are simple to use, have reproducibility and stability, are easy to calibrate and have traceability. The validation of the industrial process is carried out in accordance with the AAMI/ISO-11137 standard.

With regard to food safety in Brazil, government bodies such as the Ministry of Agriculture, Livestock and Supply and the Ministry of Health, through the National Health Surveillance Agency (ANVISA), control this process through labelling, to prevent fraud from occurring. The Radura symbol is used worldwide for labelling. In Brazil, however, although labelling is obligatory under ANVISA legislation, Radura is not used, but rather appropriate wording. Sometimes, in certain places where food is sold, the specification for radiation processing is printed on the product packaging, as defined by RDC 21 of 2001.

To obtain food that is ever safer and healthier, while at the same time maintaining its natural characteristics, scientists from different fields, in particular, the field of Food Science and Engineering, have applied themselves to study the safe application of this technology and the impact of the application of the technology on food quality.

Food irradiation is a growing technology in several countries and is applied to different types of food. Like other processes applied to foods, this technology cannot be applied indiscriminately to all foods, as some are not suitable and, in these cases, there are other more relevant processes. Foods in general respond better to low and medium doses of radiation, depending on their characteristics and nutritional properties. Although the irradiation process does not cook the food, as normally there should be no increase in temperature, it can eliminate different types of pathogens without damaging the food's natural characteristics.

It is well known and established by the Codex Alimentarius and approved by the American Food and Drug Administration (FDA) that irradiation in the doses used for food should not sterilise the food, because in the case of sterilisation, the application of high doses in certain foods would result in a significant loss of nutrients.

Generally, foods contain key components which, although they are present in very low concentrations, they regulate the flavour, appearance and nutritional value of the food. These components are very sensitive to irradiation and, if the dose is too high, it can cause harmful transformations in the taste, smell and colour of these foods. It should always be borne in mind that the aim of the irradiation process is to protect the food against deterioration, to reduce the load of potentially harmful bacteria and to make food healthy and as close as possible to its natural characteristics. An example of this application in sensitive samples is the case of edible flowers; after radiation processing, their shelf life is increased by up to 10 working days when stored in refrigerated environments, free from insect contamination, and without losing their natural properties.

As with any comestible product, food service workers and consumers must follow good manufacturing and handling practices to protect the food from cross-contamination. Irradiation, when used in conjunction with other conservation processes and preparation techniques, reduces the microbial load and other foodborne illnesses. In combination with processes such as heat, reduced humidity, pH, modified environment, salting, acidifiers, packaging, among others, irradiation can offer more stable products in tropical conditions. Chemical treatments combined with radiation offer advantages over stand-alone treatments. Currently, the following concepts are used: low doses of radiation between 0.01-1 kGy; medium doses, between 1.1 kGy-10kGy, and high doses above 10kGy.

The process of irradiating food, although it requires a relatively high investment initially, brings rapid returns for a continuous process. Estimated costs for food irradiation range from US$10 to US$15 per tonne for a low-dose application and from US$100 to US$250 per tonne for a high-dose application, depending on the type of machine used: 60Co, electron accelerator (Rhodotrons) or X-rays (modern, industry-specific machines).

There is great potential for commercialising irradiated foods, especially grains, which are important sources of protein for various consumer applications where the need for food safety applies. Every year, there are significant losses with each harvest, due to insect infestation during storage or fungal contamination. To combat these losses, radiation processing of the grains is an attractive and healthy alternative compared to chemical treatments.

The international market is playing a key role in the application of this technology, which is used by many food producers, exporters and distributors, meat processing plants and the food industry and is well accepted by the majority of the world's population. The trend is towards more widespread use, especially in countries with a large agrarian economy. As Brazil is now a major food producer and exporter, it must be prepared for the impacts of new technologies. If more investment were made in this technology, it would be possible to acquire safe, good quality food and reduce post-harvest losses and the problems that occur between harvests.

Due to the large amount of agro-industrial waste generated, irradiation can be beneficial to society and the economy as it allows greater reuse of inputs and hence results in a reduction in the amount of waste that requires treatment and disposal. The benefits of irradiation in agro-industrial residues include those of food, but when the aim is to produce flours and food additives, the depolymerisation process can be very beneficial and effective. In this process, molecules can be broken down, which improves properties such as extractability and the bioavailability of bioactive compounds and nutrients.

There is still a lot to be done in the field of food irradiation, such as dose optimisation, its application to new products and / or residues and, above all, greater support for disseminating information to the general public about the benefits to food safety. Public acceptance is a key factor in the evolution of the application of this technology in our daily lives. We need to demonstrate and publicise the advantages and versatility of food irradiation as an innovative technology for society and the world of business, as well as for agribusiness.

Final considerations

On 9 November 2018, the Committee for the Development of the Brazilian Nuclear Programme (CDPNB), coordinated by the Office of Institutional Security of the Presidency of the Republic (GSI/PR), set up the Technical Group (GT-7), which was coordinated by the Ministry of Agriculture, Livestock and Food Supply (MAPA), with the aim of promoting the application of nuclear technology in agriculture. The group finalised its activities on 14 October 2020, concluding that the construction of multipurpose irradiators is justified and that they will be a tool for boosting the national economy through exports and, at the same time, will reduce public expenditure on health.

On 23 November 2022, the launch of the business plan model for the installation of a multipurpose radiator in Brazil, took place. The document includes a description of the factors to be taken into account when setting up and operating an irradiator which will, as a matter of priority, be aimed at irradiating agribusiness products, with a special emphasis on fruit and vegetables. The document also mentions that the equipment could be used to treat meat, seasonings, nuts, herbal medicines, animal feed, packaging and other products. In addition, it is estimated that the technology could generate an annual turnover of R$261 million, with a return 3.9 years after the machine enters operation.

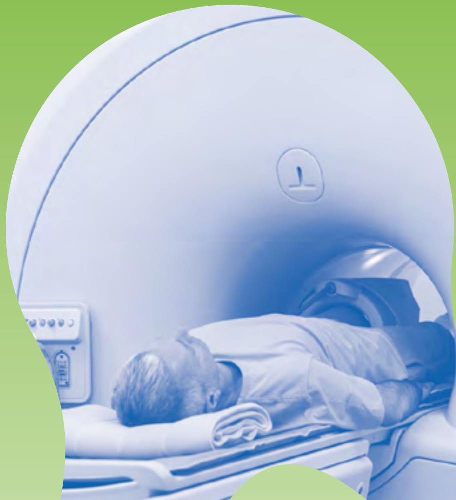
As part of the CDPNB's remit to monitor issues relevant to the nuclear sector, the GSI/PR organised a meeting with the Ministry of Agriculture, Livestock and Food Supply on 23 January 2024, with the aim of presenting the panorama of food irradiation and disseminating the actions carried out by GT-7 over recent years. Discussions took place on the possibility of initiating new actions and future negotiations in relation to the implementation of food irradiation facilities in Brazil. During the meeting the participants discussed issues relating to: Anvisa's health regulations on the subject; initiatives presented by the Federal Government of the USA, through the NGO CRDF Global, to promote actions and discuss challenges and opportunities for the inclusion of this technology on the federal administration's agenda; dissemination of the business plan drawn up by the independent consultancy.

As a result of this meeting, subsequent meetings will be structured with the aim of coming to a common understandings in order to take up the actions recommended by GT-7, as well as contacting and including renowned experts from institutions with expertise in the sector, such as EMBRAPA and IPEN, to take part in future discussions on the subject.

Finally, the Ministry of Agriculture, Livestock and Food Supply was included in the newly created Technical Group (GT-15), set up by Resolution CDPNB No. 29 of 14 December 2023, with the aim of updating and defining the activities and actions of the Nuclear Sector Social Communication Network over the next four years, in order to disseminate, among public servants and consumers, the benefits of irradiating food, agricultural inputs and products. It should be noted that the government will continue to work to attract investment for the construction of multipurpose irradiators, publicise the business plan among investors and entrepreneurs within the sector, and seek to update the regulations relating to the application of irradiation in the sanitary treatment of food.

1. Institute for Nuclear and Energy Research (IPEN-CNEN/SP), Centre for Radiation Technology (CETER).

2. Centre for Nuclear Energy in Agriculture (CENA)



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