ABEN

ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR

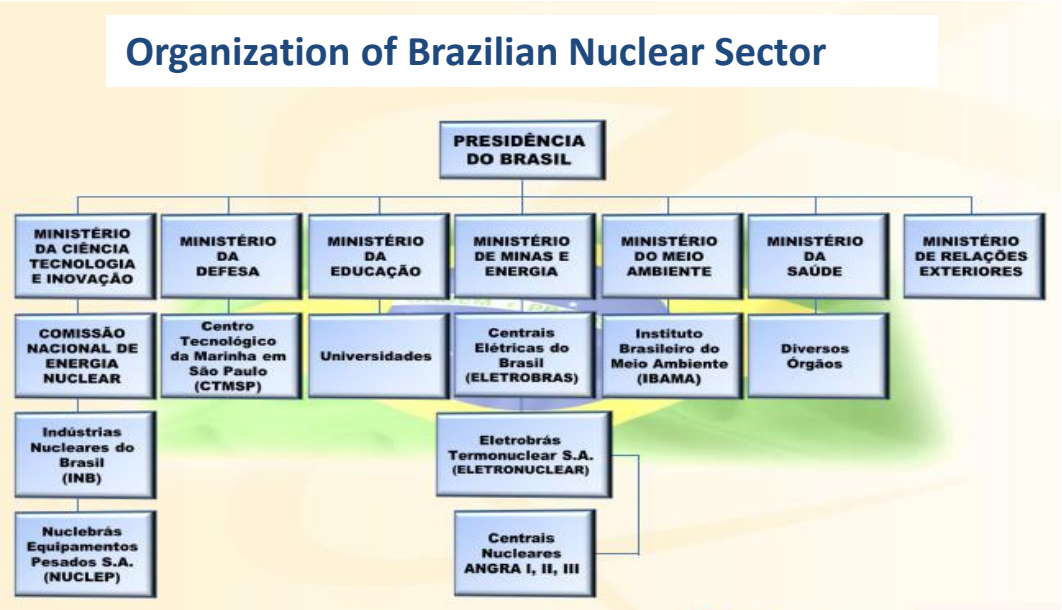
An Overview of the Brazilian Nuclear Activities

Annual Symposium on "New Technologies for Nuclear Power expansion Program"
Sociedad Nuclear Mexicana – Mexico, June 2017

Olga Simbalista – President of ABEN

Brazilian Nuclear Energy Association

Founded in 1982 and with its headquarters in Rio de Janeiro, Brazil, ABEN is an independent non profit organization responsible for the promotion of the pacific uses of nuclear energy in all its different fields, as well as for acting as an information channel on nuclear issues for the Brazilian society in general. Among its members, research scientists, qualified technicians, strategy and defense specialists give advises on: **Power production; Naval propulsion; Research, development, application and education; Safeguards; Quality assurance and control; Nuclear and environment licensing, among others.**



Brazilian Nuclear Sector
Main Institutions

Brazilian Nuclear Program is not a big one, as compared internationally, but it is diversified covering every single steps of the open fuel cycle and under safeguards unique in the world

Power production: National Commission of Nuclear Energy – CNEN (licensing, safety and safeguards), Eletrobrás Termonuclear - Eletronuclear (power production), Indústrias Nucleares do Brasil – INB (mining and fuel cycle) and Nuclebrás Equipamentos Pesados – NUCLEP (heavy components fabrication), IBQN – Institute for Nuclear Quality Assurance (independent technical surveillance organization) and Sipron (emergency plan and physical safety of public and installations)

Naval propulsion and strategic technology: Brazilian Navy (politics and strategies), CTMSP (R&D in sensitive technologies), Prosub (shipyard and , structures and naval bases), Amazul (development of sensitive technologies to the Brazilian Nuclear Program), and NUCLEP (heavy components fabrication)

Research. development, applications and education: CNEN and its institutes (IPEN, CDTN, IEN, IRD , RECIFE, Goiania) , Militaries Institutes and Brazilian public universities (UFRJ, Coppe/UFRJ, Uerj, UFF, USP, Unicamp, UFMG)

Nuclear Safeguards: .CNEN, Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials ABACC and International Atomic Energy Agency – IAEA

Nuclear and environment licensing: .CNEN and IBAMA (Brazilian Institute for Environment Protection)

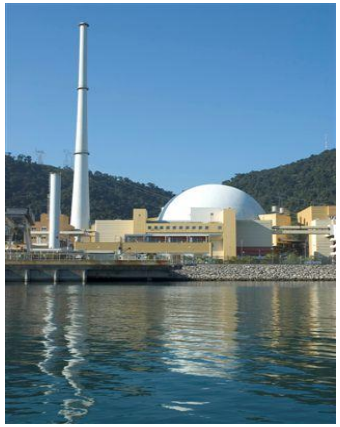
Nuclear Power Production Eletronuclear

Eletrobrás Termonuclear S/A - Eletronuclear is a government-controlled company, that accounts for the generation of approximately 3% of electric power consumed in Brazil.
At present, Angra 1 (657 MW) and Angra 2 (1350 MW) are in operation and Angra 3 (1405 Mw) is under construction.

Angra 1: operation since the 1980s

The first Brazilian nuclear power plant operates with a PWR, since 1985. It was procured on a turn-key basis as part of a package sale including no technology transfer. Still, the experience accumulated by Eletronuclear in all these years of commercial operation, with efficiency indicators surpassing those of many similar plants, leads the company to currently have the ability to carry out a continuous technology improvement program and incorporate the nuclear industry's most recent advances into plants like Angra 1. This enables Angra 1 to make the replacement of two steam generators. With this new equipment capability, Angra 1's commercial life will be extended and the plant will be capable of generating more power for Brazil.

The second Brazilian Power plant was contracted on behalf of the Brazil-Germany nuclear agreement, and its construction and operation occurred in conjunction with the transfer of technology to Brazil that led a technological development program, culminating in the mastering of practically all steps of nuclear fuel fabrication, except uranium enrichment. Due to its large electric generator, the largest in the South Hemisphere, Angra 2 decisively contributes decisively to maintain the hydro power plants' reservoirs at such levels as not to compromise electricity supply to Brazil's most economically important region, the Southeast.



Angra 2 is the 2nd Brazilian NPP

Nuclear Power Production Eletronuclear

Angra 3: about 70% of the design work completed

Angra 3 is practically be a replica of Angra 2, (incorporating the technological advances made since the construction of the latter) is under constrution and is planned to generate 1405 megawatts. Following a corruption probe in mid-2015, Eletrobras suspended civil construction and erecting contracts. In mid-2016 the corruption investigations involved Eletronuclear, and then funding ran out, halting the work and taking the construction schedule significantly beyond 2018. In January 2017 Eletronuclear formally annulled the electro-mechanical contract, having rejected appeals by companies Andrade Gutierrez, Camargo Correa, Queiroz Galvão, UTC, Techint, Odebrecht and EBE. The plant is about half completed. In March 2017 the government announced that it planned to sell Angra 3 by 2018. The deputy energy minister said that Russian and Chinese investors had expressed interest, though Eletronuclear would be the operator. ANGRA 3 has about 70 per cent of the design work completed and 70 per cent of the imported major equipment already manufactured and stored on site.

Central Nuclear Almirante Álvaro Alberto (CNAAA): site view

Nuclear Power Production Eletronuclear

A modern training center installed at Mambucaba (Municipality of Paraty) is provided with suitable places for the practical teaching of maintenance tasks, and with simulators that reproduce Angra 1 and Angra 2 control rooms, where foreign plants' operators are also trained.

There exists an emergency plan covering an area with a radius of fifteen kilometers around the CNAAA. Such plan, involving different organizations, even contemplates the need for orderly evacuation; for that reason, drills are periodically conducted in order to test the functioning of the plan.

Eletronuclear has a structure close to the nuclear power station that allows operator training, emergency plan exercises and waste storage

Radioactive substances resulting from nuclear energy generated at Angra plants are suitably stored in facilities owned by CNAAA itself. The low and medium range wastes are storage in buildings near the plants and the high level as the nuclear fuel itself used in reactors are stored inside the plants.

Nuclear Power Production
INB (Nuclear Fuel)

Indústrias Nucleares do Brasil (INB) operates in the field of uranium production - mining, processing ,enrichment, UF6 to UO2 conversion and fabrication of fuel that assemblies for Brazilian nuclear power plants ,using facilities located in Resende (RJ), Buena (RJ), Caetité (Bahia), Santa Quitéria (Ceará), Caldas (Minas Gerais) and São Paulo. The company has its headquarters in Rio de Janeiro.

Location of Uranium Geological Reserves in Brazil

Brazil has significant reserves of uranium, which leads the country to occupy the seventh position in the world rankings: 309,000 tonnes of ore are distributed among the states of Bahia and Ceará, Paraná and Minas Gerais.

But it is estimated that the Brazilian reserves are even bigger, since less than a third of the Brazilian territory was the subject of research in pursuit of the ore. Experts estimate that only the north of the country has the potential to house more than 300 million pounds of uranium.

Deposits have already been identified in Pitinga (Amazonas), where uranium is associated with other minerals, and Pará.

The Brazilian production of uranium began in 1982 in the town of Caldas / Minas Gerais. The mine supplied for 13 years the nuclear power plant Angra 1 and in 1995 the facility closed its production. The only uranium mine currently operating is located in Caetité / Bahia, where there are estimated reserves of 100,000 tonnes . The uranium concentrate Unit - INB Caetité is capable of producing about 400 tonnes / year.

To increase uranium production the INB formed in partnership with the Consortium Santa Quiteria to explore the field of Itatiaia, in Ceará, where the ore is associated with phosphate. There, reserves are estimated at 80,000 tonnes; When in operation, the mine will produce annually 1,600 tonnes of uranium concentrate.

Nuclear Power Production
INB (Fuel Cycle)

Nuclear Fuel Production

U3O8 - uranium concentrate Unit - INB Caetité is capable of producing about 400 tones / year

Conversion into UF6 – Is not done in Brazil in industrial scale (a plant located at CTMSP for its fuel cycle under tests)

Enrichment - INB produces uranium enriched to 4% for the production of fuels that feed the plants Angra 1 and Angra 2 and that will also feed Angra 3 in the future.
The enrichment process used by the company is the ultracentrifugation developed in Brazil by the Navy Technological Center in São Paulo (CTMSP), in partnership with the Institute of Energy and Nuclear Research (IPEN / CNEN). The enrichment facility is being implemented in stages in the Nuclear Fuel Factory (FCN), located in Resende, Rio de Janeiro. Part of the enriched uranium is still imported. In October, 2015, the FCN Enrichment Plant reached the capacity to produce about 14% of the annual average amount of enriched uranium needed to fuel the reactor Angra 1 and Angra 2. Uranium enrichment in Brazil is supervised by three institutions: International Atomic Energy Agency (AIEA), National Nuclear Energy Commission (CNEN) and Agency Brazil - Argentine Agency for Accounting and Control of Nuclear Materials (ABACC).

The state-owned INB also operates in the area of uranium mining, which exists in large quantities in Brazil

Nuclear Power Production
INB (Fuel Cycle)

Nuclear Fuel Production

Reconversion into Uo2 and Pellets fabrication and Fuel Assemblies

The production of pellets and fuel assembling are performed at INB's Nuclear Fuel Factory in Resende/RJ.

Angra 1 and Angra 2 plants are fed with two different fuels, both of them manufactured by INB. The Angra 1 Plant (Westinghouse technology) uses 121 4-meter long fuel assemblies, each containing 235
rods rigidly positioned in a metal frame formed by 10 spacer grids, one protective grid, 20 guide tubes and 1 instrumentation tube; and two nozzles, one bottom and one top.
The Angra 2 Plant (Siemens technology) uses 193 5-meter long fuel assemblies, each containing 236 rods rigidly positioned in a metal frame
formed by 9 spacer grids, one protective grid, 20 guide tubes and two nozzles, one bottom and one top.

Brasil já produz urânio enriquecido para a Argentina para abastecer uma usina nuclear na cidade de Lima, ao norte da capital Buenos Aires / **Crédito: Ascom/MCTIC**

Brazil sold enriched uranium to Argentina in 2016

Nuclear Power Production
NUCLEP (Heavy Components)

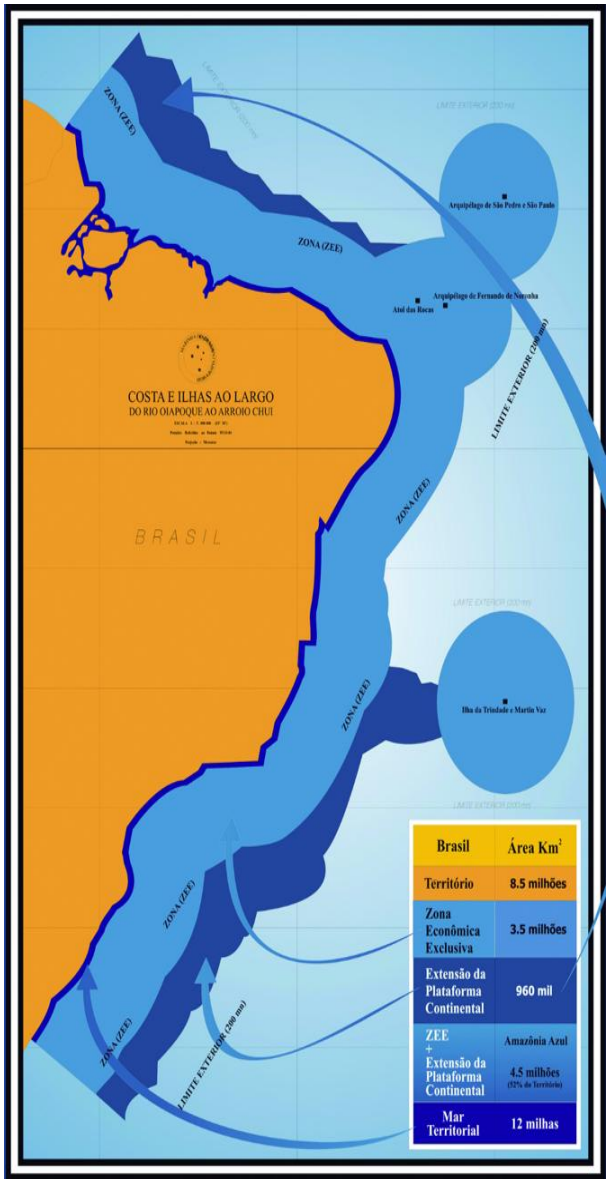
Heavy equipment manufacturing remains the responsibility of former Nuclebrás subsidiary *Nuclebrás Equipamentos Pesados S.A.* (Nuclear Heavy Equipment, NUCLEP) created in 1975 on behalf of the Brazilian German Agreement. Nowadays NUCLEP is a subsidiary of – but administratively independent of CNEN, and report directly to the Ministry of Science and Technology. NUCLEP was established to design and fabricate heavy nuclear power plant components, especially those used in the reactor primary circuit. NUCLEP is specialized in fabrication of large components made from steel, nickel, and titanium alloys. It maintains modern quality control laboratories, outfitted with precision instruments, qualified and certified according to international standards, for mechanical, chemical and metallurgical testing

Nuclep built Angra 1 nuclear power plant steam generator

Nuclep industrial site is located in Itaguaí, Rio de Janeiro State

NUCLEP assembled the new Steam Generators for Angra 1 and was responsible for the supply of three condensers, eight accumulators and super compact racks for Angra 2. Concerning Angra 3, it is going to supply the pressurizer, condensers and accumulators. NUCLEP was also the manufacture of the lower part of the pressure vasel of the Argentinean NPP Atucha 2, as well as for the WHOLE Body Unit counter for the Brazilian and Cuban governments.

Naval Propulsion



Brazilian coast is known as the Blue Amazon

In the early 1980's, the Brazilian Navy started a nuclear propulsion program. The Navy's main activity has been the development of uranium enrichment by using the ultracentrifuge process. Success was achieved by the end of the decade.

Brazil is the only non-nuclear-weapon state in which the military leases uranium enrichment technology to the civilian nuclear program, and the navy drives technological advances in the nuclear field. Also Brazil is the only non-nuclear-weapon state developing a nuclear-powered submarine.
Due to its continental coastal area (8.5 thousand kilometers) and its importance on Brazilian economy (95% of all imports and exports , and 90% of oil reserves), the Brazilian coast has been called Amazônia Azul (Blue Amazon), covering an area of 3.5 million square kilometers.

To protect that area, the Estratégia de Defesa Nacional (National Defense Strategy), in 2008, defined the necessity of having a strong naval force, including a nuclear submarine. In the same year, an agreement between Brazil and France was established for technology transfer for the production of four conventional submarines.
On behalf of the National Defense Strategy there are three main projects:

- The PROSUB (submarines development)
- CTMSP (nuclear reactor and its fuel cycle for the nuclear submarine)
- AMAZUL (engineering support for naval projects)

Naval Propulsion - NUCLEP

NUCLEP also has some activities concerning the fabrication of the pressure vessel of the submarine nuclear reactor prototype, as well as tanks, two steam generators and rings for conventional submarines.

Nuclep operates in areas such as nuclear power, defense, oil and gas and industrial projects

Naval Propulsion - Prosub

The Prosub will provide the Brazilian Defense Industry of all required technological support to achieve its goals, using as much as possible components fabricated in Brazil.
In addition to the five submarines under way (four conventional and one nuclear), Prosub is encharged of industrial infraestruture and operational support for Brazilian submarines' industry using two main installations:

- Estaleiros e Base Naval – EBV (Shipyard and Naval Base), main buildings in operation;
- Unidade de Fabricação de Estruturas Metálicas – UFEM (Metallic Structure Fabrication Unit), in operation in Itaguai (close to NUCLEP)

Naval complex of Itaguaí contains shipyard, naval base and UFEM

Naval Propulsion - CTMSP

At CTMSP (*Centro Tecnológico da Marinha em São Paulo*) – the Navy's Aramar Technology Center at São Paulo – a prototype reactor for naval propulsion and its nuclear fuel are being developed, in two technological units:

- Headquarter, located at São Paulo University's campus, where technical activities, engineering, project management are underway;
- Centro Experimental de Aramar (Research Center) – CEA, in Iperó City, São Paulo State, concentrating all laboratories, prototypes and installations covering the complete open fuel cycle for the nuclear submarine.

CTMSP units: headquarter and Centro Experimental Aramar

Nuclear submarine maquette

In 2009, the Navy proposal was that an 11 MW prototype reactor should be constructed and operated for about eight years, with a view to a full-sized (70 MW) version using low-enriched uranium .

In 2012 the government set up Blue Amazon Defense Technologies to develop nuclear submarines, with reactor prototype PWR using low-enriched uranium fuel (<20%) t and the first submarine commissioned in the 2020s.

The International Atomic Energy Agency (IAEA) and the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) apply safeguards to the prototype

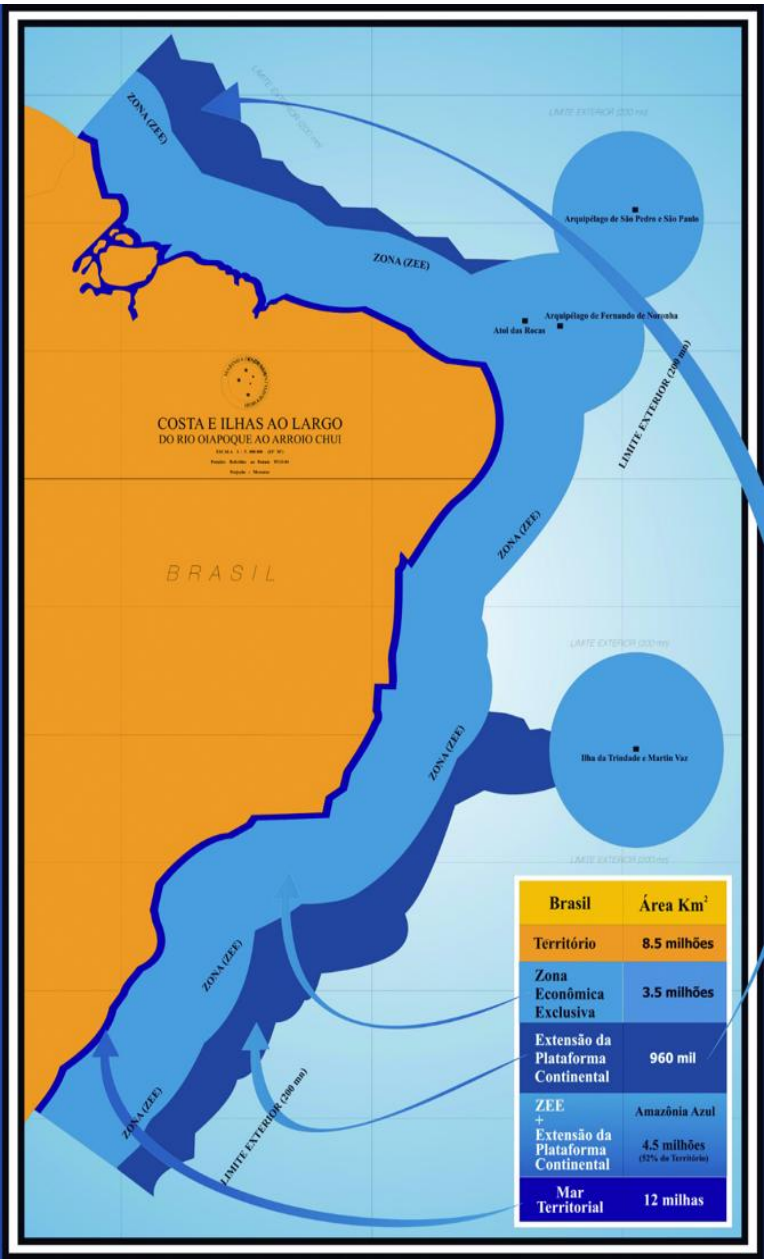
Naval Propulsion - CTMSP

CEA

Reactor vessel of nuclear submarine

At the CEA , there are many laboratories supporting CTMSP activities such as Radioecological Laboratory for the control of efluents emissions and environment, and the Laboratório de Geração de Energia Nucleoelétrica – LABGENE (Nuclear Energy Generation Laboratory), a Research Center responsible for validating all the operational conditions for the nuclear propulsion plant and for the fabrication of its nuclear fuel. In its area there will be construted 11 buildings, including the reactor and turbine ones, already under way.

Naval Propulsion - Amazul



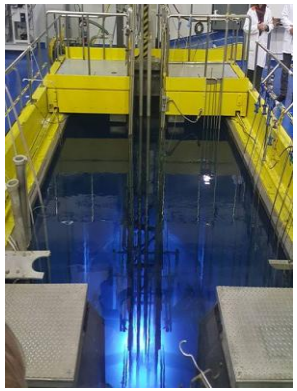
Amazônia Azul Tecnologias de Defesa S.A. – Amazul (Blue Amazon Defense Technologies) is a state owned company created in 2013 in order to promote, develop, transfer e maintain sensitive technologies for the Navy Nuclear Program, in particularly concerning the nuclear submarine, due to its strategic role on the protection of immense Brazilian coast.

Its staff congregates about 1.800 highly qualified employees, who are dedicated to the Brazilian nuclear technology autonomy, through project management, new technologies development, know how management, nuclear licensing, installation management, products commercialization, technical services, among others.

Research and Development

In Brazil, all nuclear R&D activities are developed by government institutions. They are carried out mainly by CNEN's six R&D Institutes, which are under the Ministry of Science and Technology and Innovation, and by military technology institutes, which are under the Ministry of Defense. These ministries are responsible for the establishment of the country nuclear R&D policies and strategies, as well as for the provision of the necessary budget and financing mechanisms to make the corresponding R&D projects feasible.

Six nuclear research centers have been established for carrying out R&D in nuclear sciences, and engineering. Research reactors, accelerators and several R&D laboratories, including pilot plant facilities, were progressively set up in these centers. These research centers belong to the Directorate of Research and Development (DPD) of the CNEN and are presented as follows.



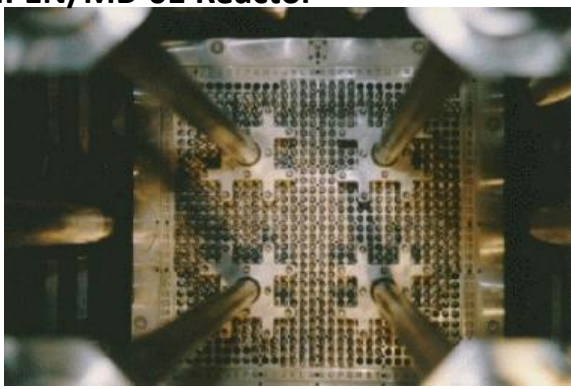
Reactor IEA-R1

IPEN

Plate fuel element fabricated at IPEN

IPEN (São Paulo/SP) - Institute for Energy and Nuclear Research has two Research Reactors (one 5 MW/pool type and one 100 W reactor/pool type),one Cyclotron Radioisotopes Production (^{99m}Tc; ^{131}I; ^{123}I; ^{18}F, etc.)
Among its activities are research on fuel cycle and materials; reactor technology; safety; fundamentals; radiation and radioisotope applications; biotechnology; environmental and waste technologies.

IPEN/MB-01 Reactor



Research and Development

In its Nuclear Fuel Center (CCN), IPEN produces nuclear fuel for the continuous operation of the IEA-R1 research reactor of IPEN. The serial production started in 1988, when the first nuclear fuel element was delivered for IEA-R1. In 2011, CCN proudly presents the 100th nuclear fuel element produced. Besides routine production, development of new technologies is also a permanent concern at CCN. In 2005, U O were replaced by U Si -based fuels, and the research of 3 8 3 2 UMo is currently under investigation

IPEN also supports the development of the Brazilian Multipurpose Research Reactor (RMB), whose project will rely on the CCN for supplying fuel and uranium targets. Due to the experience obtained during decades in research and technological development at Brazilian Nuclear Program, personnel has been trained and started to actively participate in design of the main system that will compose the Brazilian Multipurpose Reactor (RMB) which will make Brazil self-sufficient in production of radiopharmaceuticals.

CDTN

The Centro de Desenvolvimento da Tecnologia Nuclear (CDTN) is located in the campus of the Federal University of Minas Gerais State and acts in the research and development, education (post-graduation) and services provision in the nuclear field, research on mining, reactor technology, materials, safety, chemistry, environment and waste technologies.

CDTN has a TRIGA nuclear research reactor a Research and Radiopharmaceuticals Production Unit and a Gamma Irradiation Laboratory, Pilot Facilities for Mineral Goods Processing, besides a laboratory park with about 50 laboratories for physics and chemistry tests.

Trigga Reactor

Research and Development

IEN

(Rio de Janeiro/RJ) - Institute for Nuclear Engineering Research has a Research Reactor (100 kW, ARGONAUTA), conceived and constructed with Brazilian technology, and a Cyclotron Radioisotopes production (^{123}I, ^{18}F, etc.). Additionally, it develops research on instrumentation, control and man machine interfaces; chemistry and materials; safety; reactor technology.

CNRC-NE

CRCN-NE (Recife/PE) is a Nuclear Sciences Regional Centre located in the Northeast region and develops R&D activities on radiation protection, dosimetry, metrology and reactors technology.

CNRC-CO

CRCN-CO (Goiânia/GO) is a Nuclear Sciences Regional Centre of the Centre-west, responsible for R&D activities on underground water and environmental technologies.
Its location in Goiania city is due to the radioactive accident involving a Cesium capsule occurred in 1986 and considered one of the most relevant in the world, and where CNEN has constructed a sarcophagi deposit in constant monitoring, together with an Public Information Center

Research and Development

IRD

IRD (Rio de Janeiro/RJ)

Institute for Radiation Protection and Dosimetry Research

The institute is the Brazil´s center of expertise in radiation protection, dosimetry and metrology of ionizing radiation, and its activities cover all the areas in which man and the environment can be exposed to radiation, giving technical support to Brazilian Government Agencies and private Industries, Companies, Hospitals to carry out independent verification activities
IRD also offers services that are preferentially not provided by private companies: dose assessment, equipment calibrations, radioactive sources, analysis of environmental samples and dosimetryc films.

IRD is home to the laboratory designated by INMETRO as the Brazilian reference in the field of ionizing radiation, the National Metrology Laboratory of Ionizing Radiation (LNMRI).
LNMRI acts through the standardization, conservation and dissemination of ionizing radiation quantities in Brazil, which are applied in occupational and environmental radioprotection, nuclear safety, radiodiagnostyc, radiotherapy and nuclear medicine.

Research and Development

RMB

The Brazilian Multipurpose Reactor (RMB) Project is an action of the Federal Government, through the Ministry of Science Technology and Innovation (MCTI) and has its execution under the responsibility of CNEN.

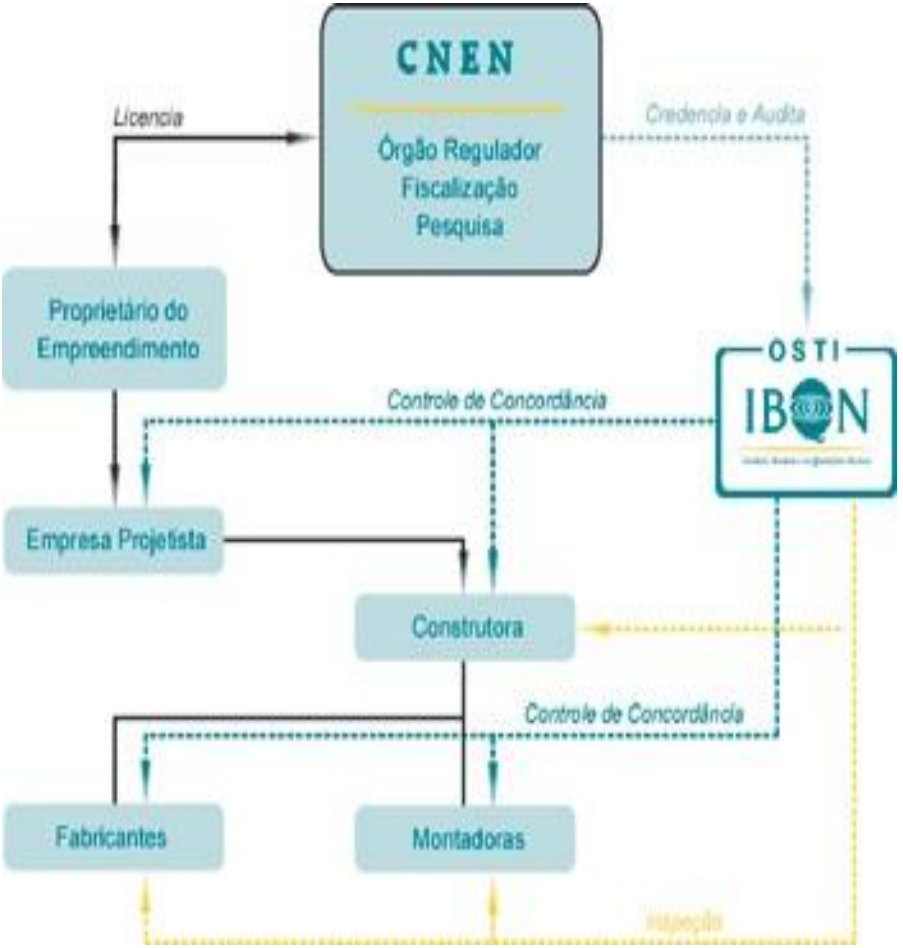
Multipurpose Reactor (RMB) has Australia's OPAL reactor being the reference design. The reactor will be used for the production of medical radioisotopes, as well as irradiation tests of advanced nuclear fuel and materials, and neutron beam research. Under a related contract signed in January 2012 with Argentinean INVAP, Brazil's Intertechne is developing the conceptual and basic design of buildings, systems and infrastructure for the RMB. It will be built in the municipality of Ipero The Nuclear Reactor RMB will be a open pool type reactor with maximum power of 30 MW and its reactor core will have a 5x5 3 configuration, consisting of 23 elements fuels (EC) of U Si dispersion-type Al having a density of up to 3.5 gU/cm and 3 2 235 enrichment of 19.75% by weight of U. Two positions will be available in the core for materials irradiation devices.

All facilities and associated infrastructure to the RMB Project are located in an area of about 200 hectares at 580 meters above sea level, in the city of Iperó, state of São Paulo, distant about 125 km from the city center of Sao Paulo. This area is adjacent to the Aramar Experimental Center (CEA), where is developed part of the Nuclear Propulsion Development Program, operated by the CTMSP. Although in the same place, the RMP Project has an exclusive access and full control of CNEN. The conceptual design of nuclear and conventional RMB systems and associated facilities are being developed by IPEN, which brings national experience in nuclear project (Nuclear Reactor IPEN/MB-01), operation and renovation of research reactor (IEA-R1 nuclear reactor of 5 MW), development and manufacture of fuel elements (100% of the fuel to operate the IEA-R1 is manufactured at IPEN), and national leadership in the production of radioisotopes

Nuclear Quality Control IBQN

The Instituto Brasileiro da Qualidade Nuclear – IBQN (Brazilian Institute for Nuclear Quality) is an organization created in 1978 to introduce the best practices on Quality Assurance for all Brazilian organizations involved on nuclear activities.

IBQN is an Independent Technical Organization responsible for the Quality Assurance in nuclear area, doing services for others sectors with its focus on quality, in order to increase competitiveness, social responsibility and environment protection.



Safeguards

Agência Brasileiro-Argentina de Contabilidade e Controle de Materiais Nucleares - ABACC

ABACC

All Brazilian nuclear activities are under safeguard control of CNEN, IAEA and ABACC the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials, created on July 18, 1991, with the signing of the Agreement between Argentina and Brazil for the Exclusively Peaceful Use of Nuclear Energy, henceforth named the Bilateral Agreement. After having been approved by the Congresses of the two countries, the Bilateral Agreement entered into force in December 1991.

The principal mission of ABACC is to guarantee Argentina, Brazil, and the international community that all the existing nuclear materials and facilities in the two countries are being used for exclusively peaceful purposes. The objective of ABACC is to administer and apply the Common System of Accounting and Control of Nuclear Materials (SCCC), whose aim is to verify that the nuclear materials in all the nuclear activities of the two countries are not deviated towards nuclear weapons.

The existence of ABACC is a clear demonstration of the political willingness of the two countries to provide transparency in their nuclear programs, creating an environment of mutual trust, and contributing to an increase in regional and international security.

The two countries provide the financial resources required for the operation of ABACC and must guarantee its institutional independence.

Other factors that determine the success of ABACC are the technical staff, the use of state of the art equipment and the permanent coordination with the national authorities of Brazil and Argentina and with the International Atomic Energy Agency.

Nuclear Forecasts in Brazil

- The nuclear future, as well as the country's future depends on the range of institutional, political, economic and social crisis underway in Brazil.
- In the near term, the most sensitive issue is the recovery of Angra 3, because the Brazilian main contractors are out of the game and, probably, it would be necessary to contract a foreign company to complete the plant and find new loans with consequences on time schedule and budget.
- New nuclear power plants, for sure are necessary, in medium and long terms, due to the end of hydraulic potential and the fast increase new renewables (wind and solar), which have intermittent behavior, asking for a base load source and also due to environment politics concerning clean energy sources.
- The research and development activities would also be maintained with high priority given to RMB by different ministries.
- The naval propulsion program would also be maintained due to its strategic importance.

Final Consideration: INAC 2017

We kindly would like to invite you to schedule 8th International Nuclear Atlantic Conference – INAC 2017, next October, 22 to 27, to be held in Belo Horizonte, Minas Gerais State, Brazil.
Its theme is "Nuclear Energy for National Projects".

More information can be obtained in our site **- www.inac2017.org.br**

Many Thanks

Olga Simbalista
aben@aben.com.br
olgasimbalista@gmail.com