INNOVATION AT BRAZIL'S NATIONAL NUCLEAR ENERGY COMMISSION (CNEN)

FAQs

CNEN's Innovation Management System

The Research and Development Directorate (DPD), at CNEN headquarters, is responsible for planning, fostering, coordinating and supervising research, technological development, technology transfer and innovation related to nuclear technology and ionizing radiation applications.

CNEN's Innovation Management System was established by DPD and its technical-scientific units in 2007, aiming at the implementation and operation of the incentives from the Brazilian Innovation Law, enacted in 2004, and the creation of the Technology Transfer Offices (TTOs). The Innovation Law was considered an important instrument for encouraging Science, Technology and Innovation (STI) in the country.

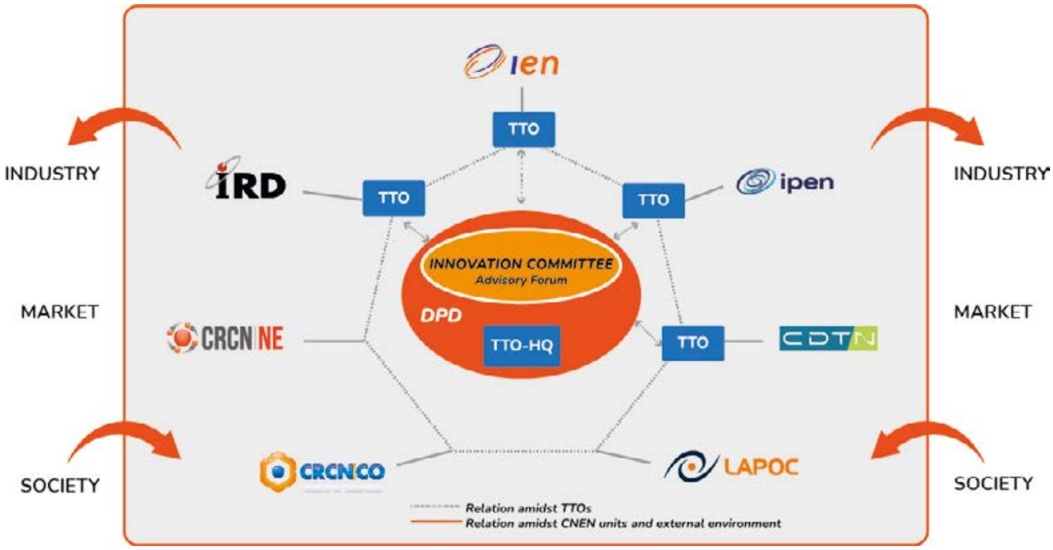
The Innovation Law was amended by the recent national STI legal framework from 2016 to 2018, playing a fundamental role in enhancing relations with industry, increasing the rate of knowledge transfer, leveraging economic and social development and strengthening the national innovation system. As well, the new National Strategy on STI (2023-2030) is an ongoing discussion that emphasizes the important drivers of the country's economic and social transformation and themes to be prioritized in face of global challenges and sustainable development, including nuclear energy.

In line with the guidelines of the new STI legal framework, CNEN established its Innovation Policy and the Innovation Management System's new structure in 2019 and 2020, respectively, in addition to the revision of its internal norms on cooperation mechanisms for promoting innovation. The new structure comprehends the Innovation Committee (CI), all technical-scientific units[1] and the TTOs[2]. The CI is an Advisory Forum aiming at discussing and proposing activities and training related to intellectual property and innovation, as well as studies and strategies on technology transfer, technology roadmapping and competitive intelligence.

Our efforts to make R&D developed at CNEN reach society, in the form of new products, processes and services, can be highlighted as opportunities for cooperation with industry and other stakeholders, such as RD&I partnerships, provision of innovation-oriented services, technology extension services, among other mechanisms. Our actions involve the Institution's commitment and responsibility with sustainable development and innovation, what we believe that can contribute to and generate positive impact in the country.

1. Centro Regional de Ciências Nucleares do Centro-Oeste (CRCN-CO); Centro Regional de Ciências Nucleares do Nordeste (CRCN-NE); Centro de Desenvolvimento da Tecnologia Nuclear (CDTN); Instituto de Engenharia Nuclear (IEN); Instituto de Pesquisas Energéticas e Nucleares (IPEN); Instituto de Radioproteção e Dosimetria (IRD); Laboratório de Poços de Caldas (LAPOC).
2. The TTO at CNEN headquarters (TTO-HQ) gives support in intellectual property and innovation management to the technical-scientific units with no established TTOs (CRCN-CO, CRCN-NE and LAPOC).

CNEN’s Innovation Management System



To learn more about CNEN and its technical-scientific units (centers, divisions, laboratory infrastructure and research teams, please access our website: www.gov.br/cnen.

Our Innovation Policy is available at: https://www.gov.br/cnen/pt-br/avulsos/resolucao-cnen-pr-245-2019-pdf.

How does Innovation work at CNEN?

Our R&D programs comprehend the following areas:

Nuclear technologies (reactors, systems, instrumentation and materials, fuel cycle)

- Nuclear fuels
- Safety, prospecting and thermo-fluid dynamics of nuclear power plants
- Engineering of nuclear reactors and energy systems
- Fuels for nuclear research reactors
- Chemical qualification of nuclear material
- Operation and use of research reactors
- Facilities and equipment for applications of nuclear techniques
- Neutron activation analysis
- Experimental nuclear physics and condensed matter physics
- Radiochemistry and nuclear chemistry
- Development and characterization of structural and functional materials for the nuclear sector
- Development of nuclear instrumentation and systems for nuclear reactors
- Reactor safety and technology, including innovative nuclear reactors

Applications of ionizing radiation in health, industry, agriculture and environment

- Development of molecules with pharmaceutical or radiopharmaceutical potential
- Ionizing radiation, radioisotopes and nuclear techniques applied to industry and environment
- Ionizing radiation in food and agricultural products
- Environmental chemistry and wastewater treatment
- Hydrometallurgical techniques for environmental radiological impact assessment and mitigation
- Sustainability and minimization of environmental impacts from the use of rare earths
- Hydrology

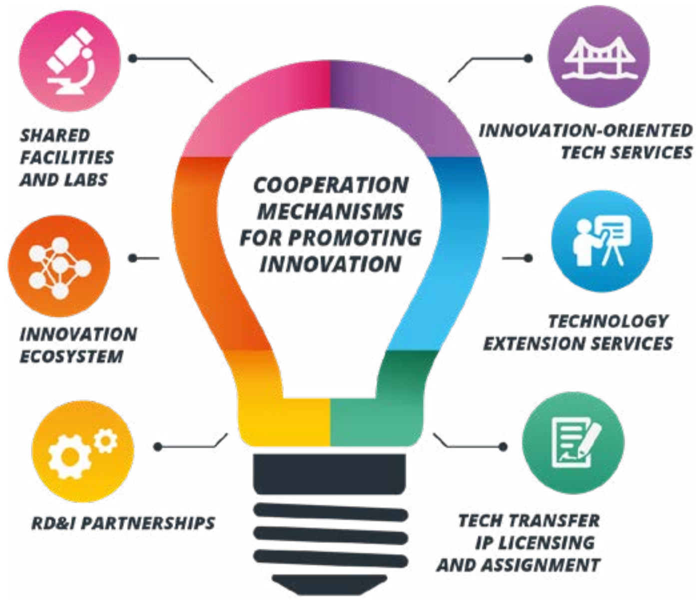
Radioprotection and dosimetry

- Metrology of ionizing radiation
- Development of computational methods and computational exposure models for occupational, environmenta, medical and accidental dosimetry calculations
- Development of new materials for dosimetry and dosimetry systems
- Experimental dosimeter calibration procedures
- Development of reference system and calibration methodology for dose calibrators
- Dosimetry and image quality in mammography and radiology
- Development of nuclear instrumentation, equipment for radioprotection and nuclear medicine
- Nuclear instrumentation systems for ionizing radiation beams used in radiotherapy and radiodiagnosis
- Medical physics

We also conduct R&D activities in other fields aligned with global trends and sustainable development goals, such as **clean technologies, sustainable energies, low-energy radiation, nanotechnology and other advanced materials, biotechnology, strategic minerals, automation technologies and systems integration**. These fields are complementary to nuclear technologies and ionizing radiation applications and contribute to the development of new competencies:

- Corrosion and applied electrochemistry
- Hydrogen and fuel cells
- Development of lasers, laser applications and high intensity lasers
- Microwave applications to assist refinery and biorefinery processes
- New materials – ceramic, metallic, composites, magnetic materials, polymeric materials, biomaterials, nanomaterials and their chemical, physical and isotopic characterization
- Cellular and molecular biology of cancer
- Cloning, synthesis, purification, characterization and application of recombinant hormones and proteins
- Pilot production of biotherapeutics in E. coli
- Development and validation of preclinical tests applied to radiopharmaceuticals
- Use of mining waste, geochemistry of uranium deposits, technology development for the application of rare earths, graphene production
- Development and optimization of extractive metallurgy processes
- Scientific visualization and applied virtual reality
- Development of complex systems technology – resilience engineering; design of advanced control rooms and human-system interfaces; emergency management in complex systems; human reliability analysis; artificial intelligence in complex systems.

We create opportunities through cooperation mechanisms in connection with our R&D programs and the new Brazilian Science, Technology and Innovation legal framework.



Shared facilities and laboratories and innovation ecosystems

These two mechanisms together have the potential to increase synergy between CNEN and the business sector. Small, medium and large companies can take advantage of our competences accumulated in the form of intellectual capital, technologies and research infrastructure to enhance firm's technological capabilities. Startups, characterized by small companies with incubation activities, can take advantage of infrastructure sharing (authorization to use), while larger companies can make use of the infrastructure (permission to use). Letter of intent from a company, a call for companies (by sector or by laboratory/ facility), as well as consortia and alliances are examples of the modes of interaction for these two cooperation mechanisms.

Innovation-oriented technological services and technology extension services

Both mechanisms aim to organize and streamline CNEN's competences in areas and laboratories with the potential to provide oriented services and activities as an initial path to improving the competitiveness of companies, creating and increasing trust and advancing towards more complex partnerships aiming at developing new technological solutions.

Research, Development and Innovation (RD&I) partnerships, technology transfer and intellectual property licensing and assignment

CNEN develops in-house R&D and can also collaborate with other institutions and companies in RD&I partnerships. This mechanism refers to joint activities of mutual interest aiming at scientific and technological research and the development of a technology, product, service or process. The results of our in-house R&D and RD&I partnerships enhance company's innovation capabilities through technological solutions, know-how and intellectual property that can be transferred, licensed or assigned for royalties or remuneration.

Success stories

Our success stories are selected initiatives of nuclear sciences and applications aligned with environmental and sustainable solutions.

CDTN/CNEN

MGGRAFENO PROJECT – GRAPHENE PRODUCTION FROM THE CHEMICAL EXFOLIATION OF NATURAL GRAPHITE AND APPLICATIONS

(Photo: MGgrafeno pilot plant at CDTN in Minas Gerais, Brazil. Source: CDTN/CNEN)

Graphene is a carbon nanomaterial with unique properties, such as high thermal and electrical conductivity, flexibility and high mechanical resistance. Brazil is the third largest producer of graphite in the world and Minas Gerais leads the production national level, with more than 70% of the total in the country.

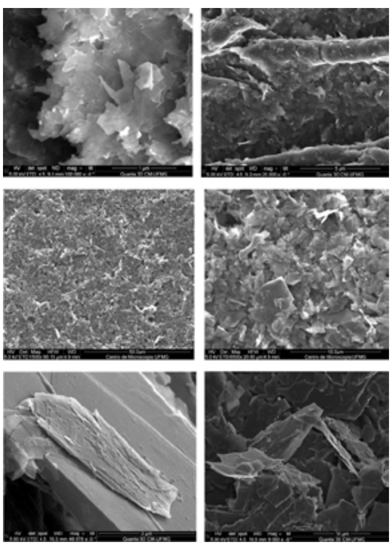
The MGgrafeno Project is an initiative of the Minas Gerais Development Company (CODEMGE), in partnership with CDTN/CNEN and UFMG, established in 2016. The pilot plant is located at CDTN and is the first graphene production unit in Brazil with 100% national technology for obtaining graphene through the chemical exfoliation of graphite. The production process is at a low cost, reproducible and scalable. All waste generated is reused or recycled, all water returns to the cycle and the air is monitored, making the plan safe and sustainable.

In 2021 the graphene production plant reached 1.25 ton/year, in special due to a process optimization implemented in the year, which allowed to quadruple production (the previous capacity was 300 Kg/year) and reduce the conversion time from graphite to graphene by four times with no additional cost.

Three types of products are developed in the project:

- Low-layer graphene (1 to 5 layers, centered on 3)
- Graphene nanoplates (6 to 10 layers, centered on 6)
- Nanographite (small graphite flakes of 10 to 100 layers)

Each product has its specific applications. In addition to the production of graphene in scale, the project has already tested and demonstrated more than 20 applications and materials with several business partners. Products customized in the project comprise graphene sulfur composite, conductive inks and functionalized graphenes (oxygenated and nitrogenated).



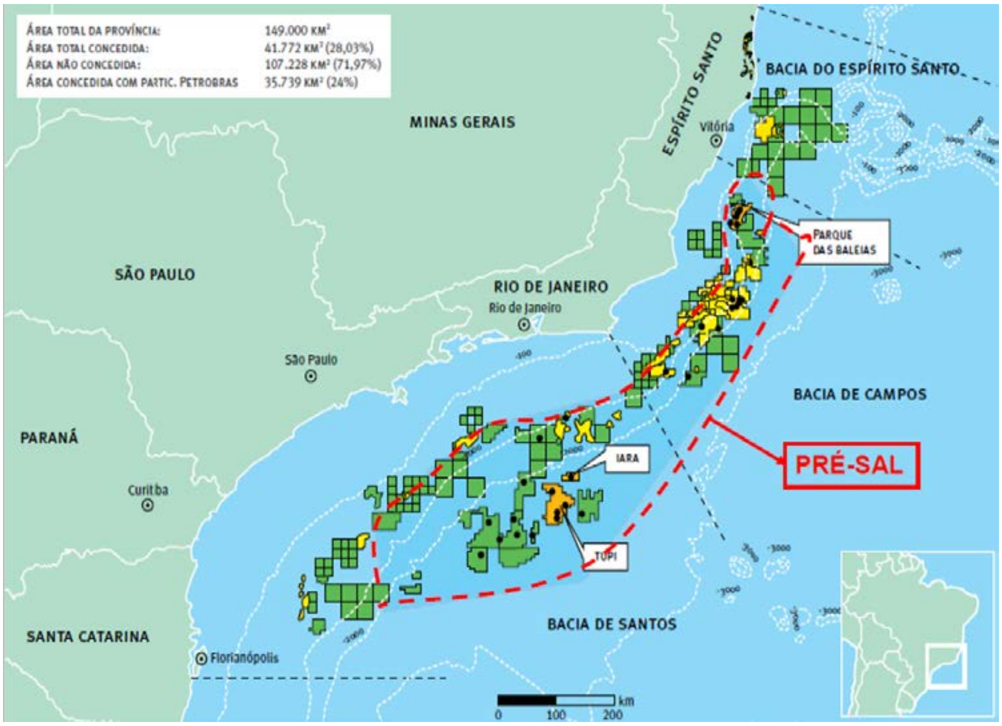
MATERIAL/ PRESENTATION	CHARACTERISTICS	APPLICATIONS
Low-layer graphene (dispersion in water or powder)	1 to 5 layers, centered on 3	Transparent conductive films sensors and devices, conductive textiles, batteries, supercapacitors, 3D printing
Graphene nanoplates (solid product: powder or cake)	6 to 10 layers, centered on 6	Thermoplastics, composites, conductive links, batteries, cements, refractories, coatings
Nanotgraphite (solid product: powder or cake)	Small graphite flakes (10 to 100 layers)	Sintered metal parts, lubricants, plastics, batteries

56 professionals work at the MGgrafeno project, including chemists, physicists, biologists and engineers. Clascidia Furtado and Adelina Santos are the researchers from CDTN responsible for the scientific coordination.

The project resulted in the protection of 10 intellectual property assets: three softwares, three know-how secrets, three patent applications and one industrial design.

IEN/CNEN

RADIOTRACERS TECHNIQUE IN OFFSHORE OIL AND GAS PLATFORM AND PROCESSING PLANTS



(Photo: Pre-salt water mapping region in the Southeast of Brazil)

Radiotracers are used to monitor and track fluids, such as oil, water, and gas, throughout the entire offshore production chain or processing plants. This technology provides valuable insights into the behavior and flow of these fluids, identifying points of obstruction, leaks or operational inefficiencies.

Pre-salt ("Pré-sal") is composed of unconventional, heterogeneous oil and natural gas reservoirs located in ultra-deep waters, under high pressure, presenting fluids with contaminants. In offshore oil platforms, where extraction takes place in deep and remote waters, safety is a critical factor. The compact nature of a platform requires careful planning and optimization of available space.

Either in the case of an offshore platform or a processing plant, conventional techniques detecting oil and gas flow and leaks and require direct-contact measuring instruments and the interruption of the industrial activity. Radiotracer techniques have the advantage of conducting tests without influencing the normal operation of a facility using low concentration of radiotracers.

Innovative design solutions and compact shielding and collimators are essential to ensure the effective implementation of radiotracer technology in these constrained environments. Efficient logistics planning and coordination are also key factors in minimizing transportation time and maintain the integrity of radiotracer measurements upon arrival at the site.

(Photo: Collimator/scintillator detector set fixing device in a natural gas high pressure line. Source: IEN/CNEN)

Some applications of radiotracers in high pressure pipelines in the natural gas industry can be highlighted: fluid flow profile studies to evaluate the operating conditions of flow conditioners; and assessment of flow meters installed in gas pipelines. These applications have been developed and provided to industry through RD&I partnerships and innovation-oriented technological services:

- Gaseous radiotracer injector for high pressure lines (200 – 400 Bar)
- Methodology for the evaluation of flow profile in natural gas pipelines

IEN/CNEN established a partnership with a small technology-based spin-off company (ATOMUM) aiming at developing a synthesis unit and a methodology for producing organic radiotracers (petroleum derivatives marked with halogens ^{82}Br and ^{123}I) for inspections in oil and natural gas industry plants. Additionally, another partnership with ATOMUM and the Brazilian Petroleum Company (PETROBRAS) focuses on a synthesis development of an ideal gaseous radioactive tracer for applications in oil and natural gas offshore platforms and a gaseous radioactive tracer injection system for facilities and units that operate at pressures up to 200 bar. The development is under a confidential agreement due to a patent application in progress.

Luiz Eduardo Brandão is responsible for the technical coordination of the research team, also composed by Valeska Peres and Marcelo Rama, researchers from IEN, and Raphael Gomes, Eduardo Ramos and Eduardo Archanjo, from ATOMUM.

(Photo: Scintillator detectors installed to measure flow speed in a natural gas processing plant in Aracaju, Brazil. Source: IEN/CNEN)

IPEN/CNEN

MOBILE UNIT WITH ELECTRON BEAM ACCELERATOR

Water quality is one of the main challenges that societies face in this century, threatening human health, limiting food production, reducing ecosystem functions, and hindering economic growth. Water quality degradation translates directly into environmental, social and economic problems. The availability of water resources is increasingly limited due to the worsening pollution of freshwater resources caused by the disposal of large quantities of insufficiently treated, or untreated, wastewater into rivers, lakes, aquifers and coastal waters. Furthermore, pollutants like personal care products and pharmaceuticals, pesticides, and industrial and household chemicals, and changing climate patterns represent a new water quality challenge, with still unknown long-term impacts on human health and ecosystems.

Industries have been concentrating efforts in decontamination programs of industrial effluents. However, the existing wastewater treatment plants may have a low efficiency for removal of refractory pollutants, mainly organochloride compounds. The main gaps are associated with the following problems:

- Removal of odorific substances, such as geosmine (GEO) and methylisoborneol (MIB), in drinking water to treat these chemical compounds responsible for taste and odor problems
- Removal and degradation of toxic and refractory pollutants (organic compounds) from sewage and industrial wastewater
- Sewage and sludge disinfection
- Wastewater from a municipal treatment plant for evaluation of the electron-beam technology in different steps of the plant
- Evaluation of the sludge dewatering
- Toxicity removal by decomposition of surfactants and organic compounds in sewage and industrial wastewater treated by electron-beam process.

These problems require an alternative technology to be used in combination with conventional treatment. With this purpose, the project “Mobile Unit with Electron Beam Accelerator” was developed aiming at enlarging the national capacity to treat industrial effluents using electron beam accelerators in Brazil. The efficiency of e-beam on site to solve industrial effluent problems was demonstrated in two cases: São Paulo Sanitation Company (SABESP) and Brazilian Petroleum Company (PETROBRAS).

The state of São Paulo in Brazil has the main and major industrial park of the country and in the metropolitan region. Metallurgic (including mechanical and automobile), textile, food, chemical, electric and electronics, cellulose and paper industries contribute with nearly 40% of organic and inorganic load discharged without a suitable treatment, directly to the main river (Tiete) of the city of São Paulo. The water is taken from this and other rivers, lakes, streams, dams and groundwater or springs before treatment at SABESP stations. In the case of PETROBRAS, some aspects concerning its industrial effluents can be highlighted as technological innovation: effluent treatment from petroleum production by electron beam irradiation; enhancement of petroleum and diesel fuel desulfurization by electron beam processing; and degradation of hydrocarbons from petroleum in water production and seawater for beneficial reuse.

(Photos: Construction of the IPEN/CNEN’s mobile electron beam irradiation unit. First photo in second line shows the radiological shielding built and installed by NUCLEP in the mobile unit. Source: IPEN/CNEN)

The mobile unit with electron beam accelerator (700 keV, 28 mA and 20 kW) was developed on site with the capacity to treat from 1 m^3/h up to 1,000 m^3/day of effluents, providing an effective facility between a laboratory-scale plant and a large-scale plant to demonstrate the efficacy and transfer the technology. Under a RD&I partnership agreement between IPEN/CNEN and company TRUCKVAN, the largest manufacturer of mobile units in Brazil, the mobile irradiation unit was built in 2022 comprising the installation of EBA (700 keV, 28 mA and 20 kW), control panel, radiological shielding, hydraulic units, ventilation system, cooler, irradiation device, transformer, power source supply, analytical instruments and components.

(Photo: Rear section of the mobile unit with electron beam accelerator. Source: IPEN/CNEN)

The project also comprises several partners in the spirit of open innovation. Besides TRUCKVAN, the International Atomic Energy Agency (IAEA), the Brazilian Innovation Agency (FINEP), NUCLEP (Nuclebras Heavy Equipment) provided for financial support to the construction of the mobile unit and specific devices. In addition, CNPq (National Council for Scientific and Technological Development) approved research grants for operating analytical equipment and assembling the mobile unit. SABESP and PETROBRAS were the companies selected for the successful demonstration of the technological and commercial viability of the wastewater treatment. It is worth noting that the industrial electron accelerator, manufactured by the company EB-TECH in 2019 was acquired and imported with FINEP's financial support.

Wilson Aparecido Parejo Calvo is responsible for the technical coordination of the research team, also composed by Samir Luiz Somessari, Celina Lopes Duarte, Francisco Edmundo Sprenger, Anselmo Feher, Fabiana de Faria Lainetti, Renato Rache Gaspar, Maria Helena Oliveira Sampa, researchers from IPEN, Alcides Braga and Marcos Rodrigues from TRUCKVAN.

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1. WHAT IS THE NEW BRAZILIAN SCIENCE, TECHNOLOGY AND INNOVATION (STI) LEGAL FRAMEWORK?

The new Brazilian legal framework for Science, Technology and Innovation (STI) was approved on January 11, 2016, with the sanction of Law 13243[1], and regulated by Decree 9283[2], on February 7, 2018. It is the result of a discussion process among stakeholders of the national innovation system within the scope of the Science and Technology Committees of the Chamber of Deputies and the Senate. The starting point was the recognition and need to change some aspects in the original Innovation Law 10973[3], enacted on December 2, 2004, and other laws related to public procurement, temporary hiring, bidding, supporting foundations, exemption/reduction of import taxes, goods and inputs import process for research and higher education career. It aimed to reduce legal and bureaucratic obstacles and provide greater flexibility to institutions operating in the system.

Inspired by the American Bayh-Dole Act (PL 96-517 – University and Small Business Patent Procedures Act of 1980) and the French Innovation Law (*Loi 82-610, du 15 juillet, 1982, d'orientation et de programmation pour la recherche et le développement technologique de la France*), the Brazilian Innovation Law focus on stimulating innovative activity in different spheres, strengthening R&D and knowledge production in the country, in particular the promotion of cooperative environments for STI production in the country.

Since the late 1990s and early 2000s, public and private stakeholders have mobilized to the construction of a more favorable environment for innovation in the country. A series of policies were implemented in Brazil, besides the Innovation Law. Some examples are the creation of sectoral funds, the Good Law 11196-2005 (tax benefits for companies that contribute to RD&I projects aiming at technological innovation), the creation of innovation support programs for small businesses, as well as the enactment of several state laws that sought to transfer the advances from the federal Innovation Law.

Innovation is essential for Brazil to have a greater insertion in global markets, more competitiveness, significant productivity gains, creation of better jobs, and growth in workers' income in a sustainable manner.

1. https://www.planalto.gov.br/ccivil_03/_Ato2015-2018/2016/Lei/L13243.htm
2. https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2018/decreto/d9283.htm
3. https://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/lei/l10.973.htm

2. HOW DOES CNEN IMPLEMENT THE COOPERATION MECHANISMS FOR PROMOTING INNOVATION?

There are currently six cooperation mechanisms comprised by CNEN's Innovation Management System, institutional policy and internal norms that serve as a bridge to the business sector, industry and other public or private organizations. These mechanisms are foreseen in articles 1, 3, 4, 6, 8, 9 and 11 of the Innovation Law, respectively: creation of innovation ecosystems, authorization or permission to use shared facilities and laboratories, innovation-oriented technological services, technology extension services, RD&I partnerships, technology transfer and intellectual property (IP) licensing and assignment.

CNEN promotes innovation with the assistance of supporting foundations regulated by Law 8958-1994[4]. In other words, innovation projects are conducted by CNEN's technical-scientific units within the scope of these cooperation mechanisms directly managed by the supporting foundation or through its intervention to partner with business sector, industry and other organizations, when it involves the partner's financial resources or government budgetary resources.

Several projects can result in "innovation revenue", such as royalties from IP and technology licensing, and remuneration from innovation-oriented technological services and technology extension services. In this matter, CNEN delegates to the supporting foundations the application of the innovation revenue to be exclusively employed in institutional RD&I objectives, including its project portfolio and the management of the innovation policy. In doing so, CNEN expects to achieve a desired level of social, economic and environmental of sustainability in the long term.

3. WHAT IS THE ROLE OF THE TECHNOLOGY TRANSFER OFFICES (TTO) IN PROMOTING INNOVATION?

TTOs were officially created in Brazilian public scientific and technological institutions (universities, federal institutes and research organizations) by the Innovation Law (article 16) for assisting them in dealing with the business sector and other organizations and managing the institution's innovation policy. The law also establishes their responsibilities and competencies which were amplified by the new STI legal framework.

TTO's performance is essential and laborious. It is responsible not only for managing the innovation policy, but also the guidelines and processes for achieving technology transfer. This includes IP policy, protection and management; technology roadmap and prospecting studies; competitive intelligence in the field of IP; technology transfer and market studies and strategies; relationship with companies; negotiation and management of technology transfer agreements and contracts; and evaluation of R&D and technology transfer results.

In this regard, each TTO under CNEN's Innovation Management System assists its respective technical-scientific unit with policies, norms and procedures, and bridges the relationship between researchers and companies and other organizations through innovation projects and cooperation mechanisms for promoting innovation.

4. https://www.planalto.gov.br/ccivil_03/leis/L8958.htm

4. ARE THERE OTHER MECHANISMS PROVIDED BY THE STI LEGAL FRAMEWORK?

Yes. The Brazilian STI legal framework is comprehensive. Besides the cooperation mechanisms for promoting innovation, other possibilities are real estate assignment; participation in the creation, governance and management of S&T parks or business incubators; minority interest in company's equities; creation of a non-profit legal entity for managing the TTO, public procurement for innovation and internationalization of Brazilian public scientific and technological institutions, the latter allowing them to conduct STI activities abroad, including the establishment of physical facilities (laboratories, centers and offices).

5. ARE THERE OTHER SUCCESSFUL CASE STUDIES CONDUCTED BY CNEN'S TECHNICAL-SCIENTIFIC UNITS?

Yes. Our technical-scientific units have a long tradition in conducting innovation projects with the business sector, universities and other research institutions. Here you can find some examples of innovation projects in the nuclear and related sectors.

INNOVATION PROJECTS IN THE NUCLEAR SECTOR

CNEN

- Brazilian Multipurpose Reactor (RMB)
- Brazilian Radioactive Waste Repository (CENTENA)

CDTN

- Partnership with Nuclear Industries of Brazil (INB) – Hydrological, hydrogeological and isotopic studies in the Caldas Decommissioning Unit
- Postgraduate program in Radioactive Waste Management

IEN

- Modernization of the Argonauta Research Reactor
- Technical-Scientific Training Program in the radiological and nuclear areas
- Postgraduate Program in Nuclear Law
- Nuclear Security Training Center (CTSFN)

IRD

- Expansion and modernization of Research Laboratories LMRI (in ionizing radiation metrology) and LFM (in medical physics)
- Technology (know-how) transfer to Brazilian company METROBRAS – Process of calibration and irradiation of area and individual monitors in neutron reference fields generated by radioisotope sources

IPEN

- Partnership with SMEs and startups – SIA-GAUGIT (PET system for preclinical studies), Radiotarget (R&D in new radiopharmaceuticals)
- Partnership with ELETRONUCLEAR – Determination of the isotopic composition of radioactive waste
- Partnership with INB – Corrosion and effect of the welding process on zirconium alloys used in the production of nuclear fuel elements / Improved technology development on the manufacturing process of uranium dioxide tablets
- Partnership with Brazilian Lithium Company (CBL) – Lithium isotopic separation process via ion exchange
- Partnership with the Navy Technological Center (CTMSP) – Laser proton acceleration technology development for nuclear applications
- INTRA-Centers Projects – budgetary resources applied in different R&D potential projects in the nuclear field (nuclear and research reactors, particle accelerator, nuclear medicine, radioactive waste, among others)

INNOVATION PROJECTS IN OTHER SECTORS

CDTN

- Technological solutions and routes for NORM waste in the oil and gas sector
- Partnership with the Minas Gerais Development Company (CODEMGE) and the Federal University of Minas Gerais (UFMG) – Graphene production from the chemical exfoliation of natural graphite and applications
- Partnership with Brazilian company VALE – utilization of iron ore mines waste as a construction material through geopolymerization
- Shared Infrastructure of the Nanotechnology Laboratories and Reprocessing Laboratory with startups NANOS, BOLIS & GOULART and RECICLI
- Technological services provided by the Gamma Irradiation Laboratory (LIG), the Analysis and Environment Service (SEAMA), the Radiation Dosimetry Service (SECDOS) and the Strategic Minerals and Advanced Materials Service (SEMAV) to Brazilian companies and research institutions

IEN

- Partnership with the Brazilian Oil Company (PETROBRAS) and startup ATOMUN - Radiotracers technique in offshore oil and gas platforms

IPEN

- Implementation of mobile units to make technologies available to the productive sector and society
- Partnership with PETROBRAS – Development of nuclear batteries for applications in bottom hole environments and Logistical alternatives for the disposal of NORM waste
- Partnership with NISSAN Brazil Automobiles – Internal reforming of ethanol at intermediate temperature of solid oxide fuel cells

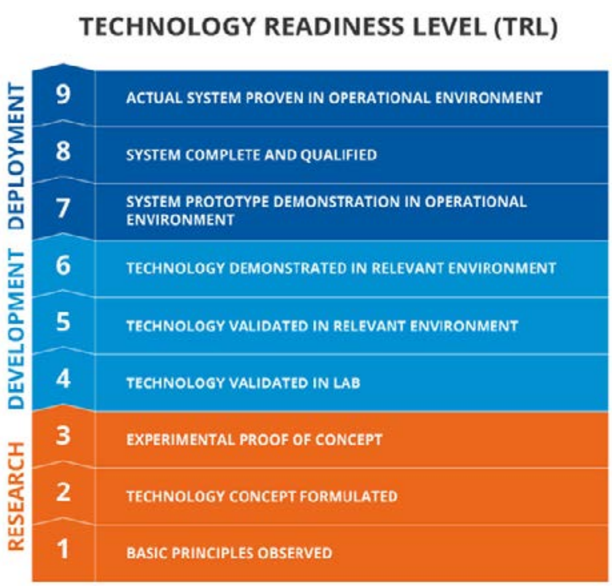
- Partnership with SHELL Brazil Oil – Sustainable route for methane conversion with advanced electrochemical technologies
- Partnership with TRUCKVAN – Mobile Unit with Electron Accelerator for industrial waste treatment and reuse and environmental decontamination
- Partnership with BUTANTAN Institute – Inactivation of SARS-CoV-2 virus by ionizing radiation
- INTRA-Centers Projects – budgetary resources applied in different R&D potential projects in other fields (nanotechnology, biotechnology, graphene, lasers, metallic materials, polymeric materials, electrochemistry, among others)

6. WHAT DOES THE TECHNOLOGY READINESS LEVEL (TRL) MEAN IN THE TECHNOLOGY SHOWCASE?

Technology Readiness Level (TRL) is a method for understanding and measuring the maturity of a technology throughout its research, development and deployment phase progression, based on consistent data of reference on technology evolution, regardless of its technical background. It is based on a scale from 1 to 9, TRL 1 being the lowest and TRL 9 the highest.

Originally developed by NASA in the 1970s for space exploration technologies, many organizations have implemented TRL for their own purposes, further normalizing the NASA readiness level definitions, allowing for easier translation to multiple industry sector.

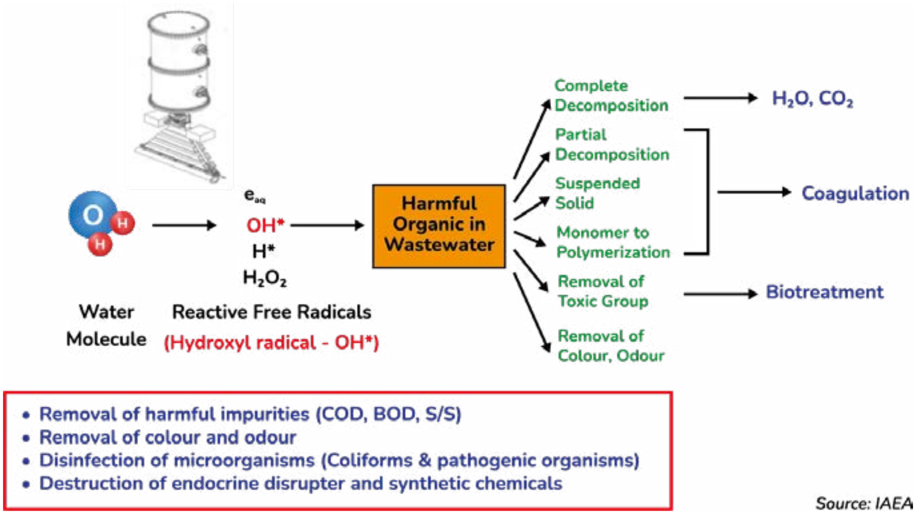
Universities and research institutions, along with government funding sources, normally focus on TRLs 1 to 4, while the private sector focuses on TRLs 7 to 9. The term “Valley of Death” represents the often neglected addressing of TRLs 4 through to 7, where neither academia nor the private sector prioritize investment. Consequently, many technologies, albeit promising, finish their maturity journey prior to deployment. In this connection, collaborative efforts in the spirit of open innovation and university-industry linkage are often essentially required.



TRL	DESCRIPTION	EXAMPLE
1	Basic principles observed	Scientific observations made and reported. Examples could include paper-based studies of a technology's basic properties.
2	Technology concept formulated	Envisioned applications are speculative at this stage. Examples are often limited to analytical studies.
3	Experimental proof of concept	Effective and development initiated. Examples include studies and laboratoty measurements to validade analytical predictions.
4	Technology validated in lab	Technology validated through designed investigation. Examples might include analysis of the technology parameter operating range. The results provide evidence that envisioned application performance requirements might be attainable.
5	Technology validated in relevant environment	Reliability of technology significantly increases. Examples could involve validation of a semi-integrated system/model of technological and supporting elements in a simulated environment.
6	Technology demonstrated in relevant environment	Prototype system verified. Examples might include a prototype system/model being produced and demonstrated in a simulated environment.
7	System model or prototype demonstration in operational environment	A major step increase in technological maturity. Examples could include a prototype model/system being verified in an operational environment.
8	System complete and qualified	System/model produced and qualified. An example might include the knowledge generated from TRL 7 being used to manufacture an actual system/ model, which is subsequently qualified in an operational environment. In most cases, this TRL represents the end of development.
9	Actual system proven in operational environment	System/model proven and ready for full commercial deployment. An example includes the actual system/model being successfully deployed for multiple missions by end users.

FAQs | *IPEN/CNEN's MOBILE UNIT WITH ELECTRON BEAM ACCELERATOR*

1. WHAT ARE THE PRINCIPLES OF THE ELECTRON BEAM IRRADIATION AND HOW DOES IT WORK IN THE CASE OF WASTEWATER TREATMENT?



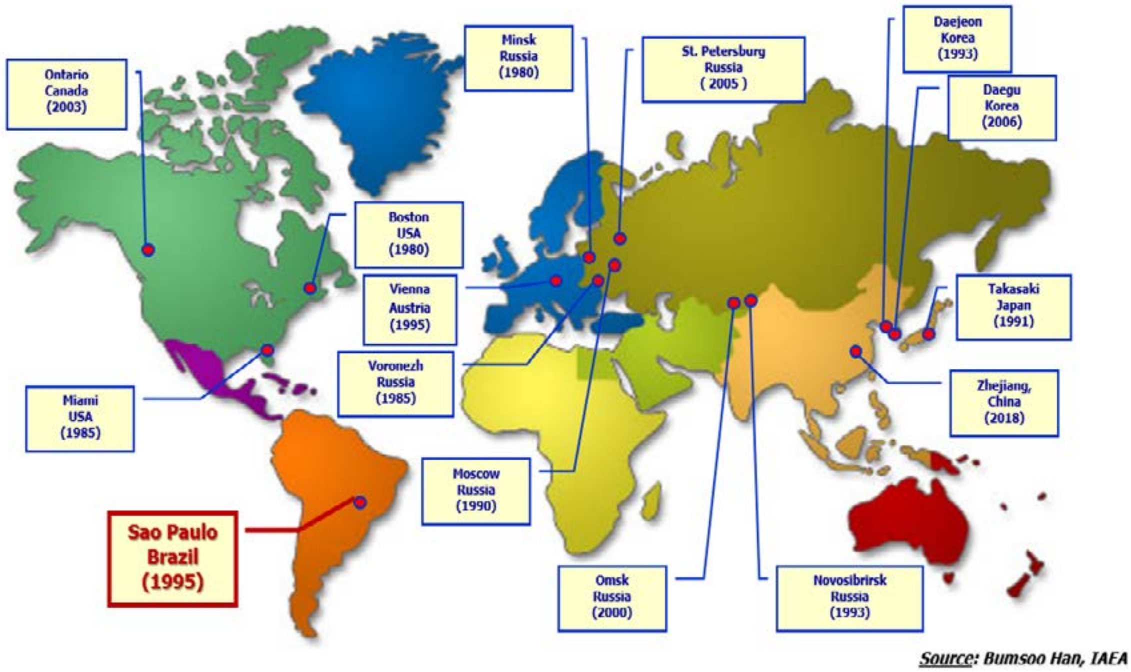
Source: IAEA

Radiation processing can be defined as the treatment of materials and products with radiation or ionizing energy to change their physical, chemical or biological characteristics, to increase their usefulness and value, or to reduce their impact on the environment. Accelerated electrons, X-rays emitted by energetic electrons and gamma rays emitted by radioactive nuclides are suitable energy sources. These are all capable of ejecting atomic electrons, which can then ionize other atoms in a cascade of collisions. In this sense, they can produce similar molecular effects. The choice of energy source is usually based on practical considerations, such as absorbed dose, dose uniformity (max/min) ratio, material thickness, density and configuration, processing rate, capital and operating costs.

In the case of electron beam (EB) processing, the incident electron energy determines the maximum material thickness, while the electron beam current and power determine the maximum processing rate. For high throughput industrial processes, the capital costs and operating costs of an irradiation facility are competitive with more conventional treatment methods. Successful irradiation processes provide significant advantages in comparison to typical thermal and chemical processes, such as higher throughput rates, reduced energy consumption, less environmental pollution, more precise control over the process and the production of products with superior qualities. In some applications, radiation processing can produce unique effects that cannot be duplicated by other means.

2. HOW MANY WASTEWATER TREATMENT FACILITIES USING ELECTRON BEAM TECHNOLOGY ARE AVAILABLE IN THE WORLD?

There are currently 15 facilities worldwide as pointed out in the map below.



In São Paulo, the first wastewater treatment facility was developed by the Nuclear and Energy Research Institute (Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN) under the IAEA Technical Cooperation (TC) Project BRA8025 "Electron Beam Treatment of Wastewater", between 1993 and 1997. The model project was designed and built in 1995 with a capacity to treat 3 m^3 per hour of wastewater. The process is efficient in removing organic compound and color from wastewater by electron beam irradiation.

3. WHAT IS THE IAEA TC PROJECT BRA1035 "ESTABLISHING A MOBILE UNIT WITH AN ELECTRON BEAM ACCELERATOR TO TREAT INDUSTRIAL EFFLUENTS FOR REUSE PURPOSES"?

The project was submitted by IPEN/CNEN and approved by the International Atomic Energy Agency (IAEA) to contribute to the objectives described in the cooperation topic 5.4 of the Country Programme Framework (CPF) and in the National Development Plan/Programme (NDP). The National Program N. 2059 "Nuclear Politic and Strategic Objective (CNEN N. 328/2013)" under the Pluriannual Plan (2016-2020) was aligned with developing nuclear technology and its applications to meet various uses in civil area.

The project outputs were defined as: a) mobile irradiation unit with EBA, operational and technologically established for treating industrial pollutants; b) capabilities on tests and demonstration of the mobile built; c) know-how in the design, manufacture and installation of the radiological shielding for the EBA irradiation device; and d) treatment methodologies for different pollutants developed and demonstrated using radiation processing technology to end users.

4. WHAT ARE THE PROMISING RESULTS OF THE MOBILE ELECTRON BEAM ACCELERATOR UNIT IN WASTEWATER TREATMENT?

The efficiency of e-beam on site to solve industrial effluent problems was demonstrated in two cases: São Paulo Sanitation Company (SABESP) and Brazilian Petroleum Company (PETROBRAS).

In the case of SABESP, the water taken from Tiete River, among others, as well as from lakes, streams, dams and groundwater or springs, is treated at SABESP stations. For the removal of geosmine (GEO) and methilisoborneol (MIB) pollutants, it is necessary to treat 1,000m^3/day of drinking water with a dose of 1kGy.

Regarding PETROBRAS, technological innovations in the treatment of its industrial effluents can be highlighted. For the removal of organic compounds (benzene, toluene, ethylbenzene, xylenes and phenol) from petroleum production water, it is necessary to treat 50m^3/day of these compounds with a dose of 20 kGy. The electron beam process can also enhance petroleum and diesel fuel desulfurization and promote the degradation of hydrocarbons from petroleum in water production and seawater for beneficial reuse.

The table below shows some of the effluents treated with electron beam accelerator in terms of dose, power, amount, capital cost and operating costs.

EFFLUENTS	Dose (kGy)	Amount (m^3/day)	Power (kW)	Capital cost (Million US$)	*Variable cost ** (Variable and fixed costs) (US$)	Cost/m^3 of effluent treated (US$)
Removal of geosmine (GEO) and methilisoborneol (MIB) from drinking water	1	1,000	20	1.5	0.20 (0.38)	0.60 (1.14)
Removal of industrial textile dyeing from wastewater	2	500	20	1.5	0.20 (0.38)	1.20 (2.28)
Elimination of coliforms from raw sewage, secondary and chlorinated effluents	3	340	20	1.5	0.20 (0.38)	1.77 (3.36)
Removal of organic compounds from petroleum production water	20	50	20	1.5	0.20 (0.38)	12.0 (22.8)
Removal of PCB from transformers oils	50	20	20	1.5	0.20 (0.38)	30.1 (57.1)

5. WHAT IS THE CURRENT STAGE OF THE MOBILE UNIT WITH AN ELECTRON BEAM ACCELERATOR?

The mobile unit stage of development is characterized by the Technology Readiness Level (TRL), which is is positioned in the transition levels between TRL 6 and TRL 7, in which the scale ranges from TRL 1 (lowest) and TRL 9 (highest).

At the end of the IAEA TC Project BRA1035, the mobile unit was positioned at **TRL 6** as a fully functional prototype or representational model. The evidence was the successful prototype demonstration in a high-fidelity laboratory environment. A pilot plant for the treatment of liquid effluents by electron beam is in operation at IPEN/CNEN, with a capacity of $3m^3/h$ of treated effluents and recognized results of this radiation technology with SABESP, PETROBRAS and CLARIANT, among other textiles and pharmaceuticals industries, since 1993.

As the installation of electron beam accelerator (700 keV, 28 mA and 20 kW), irradiation device, radiological shielding, control panel and other associated systems, analytical instruments and components were completed, the mobile unit is now positioned at **TRL 7**. In other words, the working model or prototype was demonstrated in a space environment.

A new partnership agreement between IPEN/CNEN and TRUCKVAN is about to be established for the completion, demonstration and operation of the Mobile Irradiation Unit in several industries throughout Brazil. In this regard, technology will be fully positioned at TRL 9.

In addition, IPEN-CNEN is also establishing a licensing agreement with TRUCKVAN to receive royalties from the upcoming exploration of this innovation in the market.

6. ARE THERE OTHER CASE STUDIES CONDUCTED BY IPEN/CNEN ON THE USE OF IRRADIATION TO TREAT WASTEWATER?

Yes. IPEN/CNEN has been carrying out several studies on wastewater treatment using irradiation, comprising the degradation of reactive dyes for reuse purposes with particular focus on wastewater containing organic pollutants, such as red reactive Remazol (RR 198) and reactive black 5 (RB5), and the detoxification of drinking water due to algal toxins and cyanobacteria.

Additionally, The IAEA TC Project BRA1035 is also linked with on-going projects and activities being conducted at IPEN/CNEN:

a. Regional Cooperation Agreement for the Promotion of Nuclear Science and Technology in Latin America and the Caribbean (ARCAL)

   - Project RLA1020 (ARCAL CLXXIX) “Promoting Radiation Technology in Natural and Synthetic Polymers for the Development of New Products, with Emphasis on Waste Recovery” (2022-2026) – Objective: to demonstrate the feasibility of radiation technology to convert different polymeric wastes into value-added products.

b. Coordinated Research Projects (CRP) on Wastewater/Sludge Treatment and Recycling of Polymer Wastes

- Radiation Inactivation of Biohazards Using High Powered Electron Beam Accelerators (2018-2022) – Objective: to enhance and strengthen the use of electron beam accelerators for the treatment of biohazards of concern under changing conditions such as at high dose rates, different ambient conditions, and varying substrates in applications such as radiation sterilization, hygienization of biosolids, sanitizing infectious hospital waste or toxic effluents and eliminating deliberate biohazards.

- Removal of Emerging Organic Pollutants in the Wastes by Radiation (2019-2023) – Objective: to exploit the innovative methodologies and technologies to remove the emerging pollutants such as endocrine disruptors, pharmaceutical residues, and other toxic pollutants in wastewater/sludge by radiation.

- Recycling of Polymer Waste for Structural and Non-Structural Materials by using Ionizing Radiation (2021-2025) – Objectives: a) to adapt the radiation process to develop novel materials for high performance structural and non-structural applications; b) to promote international collaborations among Member States involving industries, research institutions and foundations, universities and other environmental and manufacturing enterprises; c) to generate feasibility studies for developing a pilot recycling project, and design and development guidelines; d) to create a collaborative interdisciplinary network of radiation technology experts and their laboratories to address the current challenges in recycling of plastic wastes, working jointly to develop innovative formulations and methodologies, and establishing advanced structure-properties relationships for the design and the scaling-up of plastic waste recycling facilities for specific uses.