

AGEING IMPLEMENTATION AND REFURBISHMENT DEVELOPMENT AT THE IEA-R1 NUCLEAR RESEARCH REACTOR: A 15 YEARS EXPERIENCE

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ABSTRACT

IPEN (Instituto de Pesquisas Energéticas e Nucleares) is a nuclear research center established into the Secretary of Science and Technology from the government of the state of São Paulo, and administered both technically and financially by Comissão Nacional de Energia Nuclear (CNEN), a federal government organization under the Ministry of Science and Technology. The institute is located inside the campus of the University of São Paulo, São Paulo city, Brazil.

One of major nuclear facilities at IPEN is the IEA-R1 nuclear research reactor. It is the unique Brazilian research reactor with substantial power level suitable for application with research in physics, chemistry, biology and engineering, as well as radioisotope production for medical and other applications. Designed and built by Babcock-Wilcox, in accordance with technical specifications established by the Brazilian Nuclear Energy Commission, and financed by the US Atoms for Peace Program, it is a swimming pool type reactor, moderated and cooled by light water and uses graphite and beryllium as reflector elements. The first criticality was achieved on September 16, 1957 and the reactor is currently operating at 4.0 MW on a 64h per week cycle.

Since 1996, an IEA-R1 reactor ageing study was established at the Research Reactor Center (CRPq) related with general deterioration of components belonging to some operational systems, as cooling towers from secondary cooling system, piping and pumps, sample irradiation devices, radiation monitoring system, fuel elements, rod drive mechanisms, nuclear and process instrumentation and safety operational system.

Although basic structures are almost the same as the original design, several improvements and modifications in components, systems and structures had been made along reactor life. This work aims to show the development of the ageing program in the IEA-R1 reactor and the upgrading (modernization) that was carried out, concerning several equipment and system in the last 15 years.

1. INTRODUCTION

The IEA-R1 reactor is a multidisciplinary facility used extensively for basic and applied research in nuclear and neutron related sciences and engineering. The reactor produces some radioisotopes with applications in industry and nuclear medicine, performs miscellaneous irradiation services, and has been used for training as well. Several departments of IPEN routinely use the reactor for their research and development work. Many scientists and students at universities and other research institutions in Brazil also use it quite often for academic and technological research. However, the main user of the reactor is the staff of the IEA-R1 Research Reactor Center (CRPq) with interest in basic and applied research in the areas of nuclear and neutron physics, nuclear metrology, and nuclear analytical techniques.

This facility is a swimming pool type reactor, light water moderated and with graphite reflectors, designed and built by Babcock & Wilcox Co. Start up operation and first criticality was obtained in September 16th, 1957. Although designed to operate at 5 MW thermal power, in the first three years the maximum power operation was 1 MWth and later 2 MWth in order to attend radioisotope production.

During 70's, domestic demand for radioisotopes has grown rapidly and it was no longer possible to meet the national demand with local production. IPEN therefore began to import these radioisotopes which were then processed and distributed to local medical centers.

Until 1980, all ^{99m}Tc generators used in the country were imported. To meet the ever increasing demand for this important radionuclide, IPEN started producing its own ^{99m}Tc generator kits from fission ⁹⁹Mo purchased from Canada.

In order to reduce the heavy importation costs of the primary radioisotope ⁹⁹Mo, as well as to minimize increasing reliance on only few world suppliers of this product, IPEN concluded a decision making process, starting the production of ⁹⁹Mo inside its own nuclear reactor using (n,γ) reaction.

Aiming at the local production of ⁹⁹Mo, precursor of the radioisotope ^{99m}Tc and widely used in nuclear medicine, the institute invested considerable effort, during the 1996-2005 period, to upgrade the reactor power from 2MW to 5MW and operational cycle from 8h a day/5 days a week to 120h continuous per week [1].

For this purpose, several modifications in the reactor systems and components had to be implemented. At the same time, a vigorous ageing management, inspection and modernization program was developed [2]. Figure 1 shows the reactor pool and its core structures.

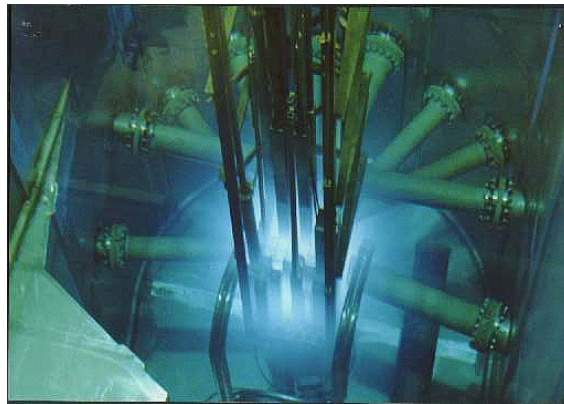


Figure 1. IEA-R1 reactor core under operational conditions.

2. IEA-R1 REACTOR – OPERATION AND MAINTENANCE

Although the basic structures are almost the same as the original project, several improvements and changes in components, systems and structures had been made along the reactor life (since 1974).

During 55 years, the reactor was used mainly in basic and applied research, neutron activation analysis, and produced radioisotopes for medicine, industry, universities and research centers.

In 1995, considering a favorable budget from the Federal Government, and the priorities given to the production of radioisotopes, the project to upgrade the IEA-R1 operation thermal power was implemented.

To achieve the upgrading (5 MW) and 5-day continuous operation goals to allow the commercial radioisotope production, the project was divided in three main groups of actions:

- improvement of fuel element production;
- adequacy of systems, structures and components, and
- adequacy of radioisotope production.

3. IMPORTANT IMPROVEMENTS MADE IN THE REACTOR SYSTEMS DURING THE LAST 15 YEARS

To accomplish safety requirements demanded by the Brazilian Regulatory Body (CNEN) to upgrade reactor power level, a set of actions were made which involved the adequacy of old components (ageing program) and design of new ones, featuring engineering systems, risk analysis, safety evaluation and licensing [2]. The most representative adequacies were:

3.1 Reactor core

The core configuration was changed from mixed (HEU, LEU) 5x6 array to a LEU 5x5. The new core configuration provides thermal fluxes of magnitude $5 \times 10^{13} \text{ n.cm}^{-2}.\text{s}^{-1}$. Also a berilium irradiator was bought from CERCA (France) and is used to produce ^{99}Mo in the center of the nuclear core (1996) [3, 4 and 5].

3.2 Emergency Core Cooling System (ECCS)

It is a fully passive system, employing two redundant legs with four automatic valves designed to work in fail safe concept, spraying water directly from reservoirs into uncovered reactor core, and avoiding fuel element melting. ECCS was designed to continuous operation cycles of 26 hours after reactor shutdown (1997) [6].

3.3 Quality Assurance

In the year 2000 we began a discussion about Strategic Planning and Quality Management System and its implementation for conducting the business strategic schedule of the Research Reactor Center.

With huge support from staff members, as well as from the higher management, documents such as “Business Plan”, “Quality Assurance Manual” and “Action Plan” were drafted. It was our goal to obtain NBR-ISO 9001:2000 certification for the “Reactor Operation and Irradiation Services”.

All the necessary documentation was prepared for external auditing carried out by “Fundação Vanzolini” and on December 13, 2002 the Reactor IEA-R1 obtained the NBR-ISSO 9001:2000 certification and the certificate was renewed in the following years after a series of internal and external auditing.

3.4 Cooling System pumps (Primary and Secondary Loops)

The IEA-R1 reactor also had components changed due to ageing, and are monitored in operation by a new Vibration Monitoring System. The objective of this implementation is to establish a strategy to monitor and diagnose vibrations of the motor pumps used in the reactor cooling system (primary and secondary loops), to verify the possibility of using this system in a continuous way (2002) [7]. Figure 2 shows the Vibration Monitoring system screens.

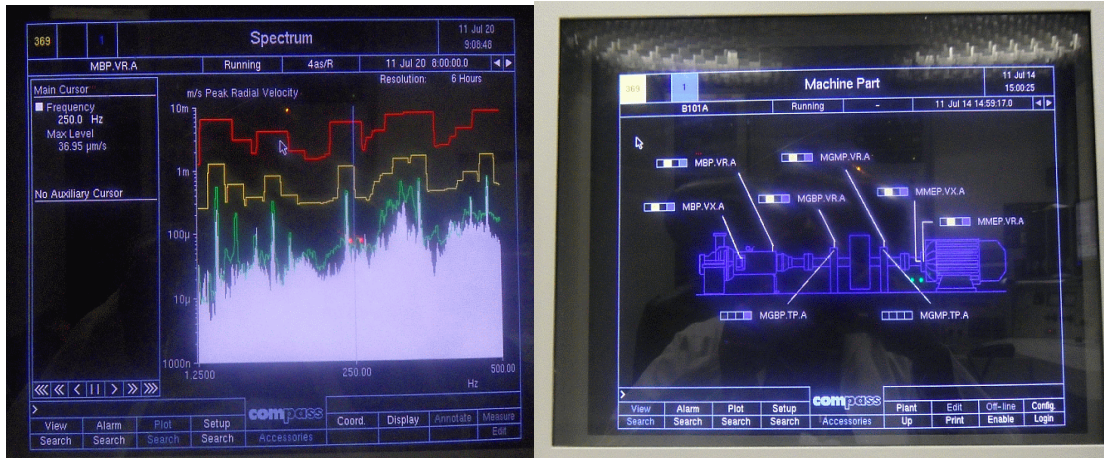


Figure 2. Cooling system pumps monitoring located in the control room.

3.5 Pool water treatment and purification system

With increasing demand and innovative applications for radioisotopes such as ^{153}Sm , ^{125}I and ^{99}Mo , the reactor operation schedule was modified and its maximum thermal power was established at 5 MW. A continuous modernization process has been occurring since then, resulting in NBR ISO 9001:2000 certification obtained in December 2002.

After 50 years of operation without any huge alteration in design and working schedule, water purification systems became obsolete, because the contamination levels of the primary cooling system increased continuously, with piping corrosion problems occurring at inadequate rates. With NBR ISO9001:2000 certification, a task force was created for the quality assurance within cooling systems, allowing higher safety operational levels. This objective was achieved even at the first commissioning operations, with water contamination levels decreasing to those established by technical specifications (2004). Figure 3 shows the new water treatment system implemented.



Figure 3. Water treatment located outside the reactor building.

3.6 Reactor control and safety elements

The older control and safety elements of the reactor began to show signs of ageing and after study and inspection the reactor Head Division decided for replacement with identical elements (fork type Ag-In-Cd) and this new devices were fabricated at IPEN (2004).

3.7 Radiation monitoring system

A new Portal Monitoring equipment was implemented together with replacement of cintillators detectors to air duct monitoring (2005).

3.8 Pneumatic Transfer Systems (PTS)

PTS are classified as mechanical equipment largely operated all over the world for transport of a huge sort of objects, samples and materials located at nearly terminals or even at separated ones. System applicability is often recognized in many activities, such as medicine (hospital settings, clinical analysis labs), industry (steel, automobiles, mining, chemical, food, construction), trading (gas station, movies, supermarkets, banks, e-commerce) and federal agencies (post services, federal courts, public enterprises). In the nuclear settings, PTS shows also a vast array of applications, being a part of radioisotope production, as well as short-lived radiopharmaceuticals, including ^{67}Ga , ^{201}Tl , ^{18}F and ultra-pure ^{123}I . Besides, PTS are also used at radioactive waste management plants and research institutes that apply neutron activation analysis (NAA). The old reactor transfer system (since 1957) was refurbished in 1979 (only electrical control circuit), no mechanical part or air injection system suffered any modernization. After a study and inspection of the old system and a technical report (Safety Analysis Report) about the risk of LOCA (Loss of Coolant Accident) involved the reactor operational division decided to design a new one. This new project took in account a new air injection system (Blower), pipelines (materials), electrical panel control and a new design (shape and material) of the irradiation capsule (carrier or rabbit). With this aim, it was calculated the charge of reactor core grid plate and sample transport testing. Rabbit Transit Time measurements were made (send and return) and through foil irradiation technique the neutron flux at irradiating position was determined as $3.70 \pm 0.26 \cdot 10^{12} \text{ n.cm}^{-2}.\text{s}^{-1}$ (2006) [8]. The new system is shown in the Figure 4.



Figure 4. Pneumatic irradiation system, user station (left) and control panel (right).

3.9 New heat exchanger

Studies regarding ageing management were conducted according to IAEA procedures described in the Technical Report 338 (IAEA, 2001) and Technical Document 792 (IAEA, 1995). As a result of these studies, many critical components within the Ageing Management Program were identified. Also recommendations on the implementation of a testing schedule and a procedure to organize data and documents were made. The main result was the needing to carry out the inspection of both heat exchangers, the two primary pumps and the data acquisition system. Along the monitoring process, difficulties were observed to operate the reactor at the 5 MW power level mainly due to the ageing of the TCA heat exchanger (Babcok&Wilcox) and vibration abnormalities observed at high flow rates on TCB heat exchanger (CBC – Mitsubishi Group).

By mid-2005, it was decided to work at 3.5 MW power level and to provide a new heat exchanger with 5 MW capacity, manufactured by IESA (Industrial Project), intended to substitute the old TCA heat exchanger. This action demonstrated that the IEA-R1 reactor can be safely and continuously operated at a power level of 5 MW with the new heat exchanger (2007). Both heat exchangers are shown in Figure 5.



Figure 5. Heat exchangers A and B located in the reactor basement.

3.10 Training of reactor Fire Brigade

With the aim of maintaining duties of the Fire Brigade, it were established two fire exercises per year, conducted by Sao Paulo City Fire Department (2008).

3.11 Maintenance of free spaces inside spent fuel storing compartment

Removal of 31 reflector elements (graphite) from storing compartment were carried out to allow more free spaces for spent fuel element storing for the next 5 years (2010).

3.12 Data acquisition/storage

Due to the needing of several other centers to access some information about reactor nuclear, thermohydraulic and radiation protection parameters, a Data Bank for IPEN scientific community was implemented (designed), where all IEA-R1 operational data are stored: nuclear, thermohydraulic and radiation protection parameters, as well as digital data from a domestic meteorologic tower (2010) are able to scientific staff. Figure 6 shows the new Data Bank system.



Figure 6. Data acquisition system in the control room.

3.13 Corrective maintenance of beam holes (BH4 and BH14)

IEA-R1 beam holes (BH's reactor irradiation system) deteriorated during the last few years (since 2005), showing small primary water leaking points. Risk analysis showed that the worst scenario could occur with the tangential beam hole and it was decided to proceed a general maintenance of this BH, It was done an internal disassembling of this BH and later the substitution of the hole cladding piping substitution. Valves and general cleaning; shielding substitution; implementation of a water reservoir to improve neutron shielding were done (2011).

3.14 Continuing education and training of the reactor operation team

It was renewed a total of 17 operator licenses (junior and senior) for 2010-2011 biennium according federal rule CNEN NN 1.01 (since its original publication in 1979) and the operational procedure PO-CRO-1801, that establish a total of 112 training hours yearly. At the moment there are eight new operators under training since November 2010 applying for a new Operation License and final exam will be done on November 2011, with a total of 243 training hours (2010).

Thus, during the past years, a concentrated effort has been made in order to upgrade the reactor power to 5 MW through ageing, refurbishment and modernization programs. One of the reasons for this decision was the ^{99}Mo production. The reactor cycle will be gradually increased to 120 hours per week of continuous operation. It is anticipated that these programs will assure the safe and sustainable operation of the IEA-R1 reactor for several more years, to produce important primary radioisotopes such as ^{99}Mo , ^{125}I , ^{131}I , ^{153}Sm and ^{192}Ir [9].

4. IEA-R1 OPERATIONAL ROUTINE

IEA-R1 nuclear research reactor operated mostly at a power of 3.5 or 4.0 MW and the operation schedule of 40 to 64 hours per week.

The operation and maintenance area of the reactor is composed of three groups as follows: operation group, maintenance group and technical support group.

4.1 The operational group

Has a crew of 18 licensed operators and 4 trainee operators, responsible for the reactor operation, routine of sample irradiation in several reactor core positions, safety and security tests, experiments and control of operational documents.

4.2 The maintenance group

Consisting of 10 technicians for the preventive and corrective reactor systems maintenance, study of ageing and maintenance records.

4.3 Technical support group

Consisting of two people dedicated to neutronics and termohydraulics calculations.

Once in a month, the reactor operation and maintenance staff prepares a technical report containing information on the monthly activities of the reactor. The report contains information such as the number of reactor operation schedule, energy dissipated in this period, reactor core configurations, chemical and physical characteristics of water systems, radioisotopes concentration in the pool water, number of reactor shutdowns, number of irradiated samples in the reactor core and pneumatic irradiation system and all radioprotection data. Figure 7 shows the IEA-R1 reactor control room.



Figure 7. Reactor control room, radiation monitoring, pumps vibration monitoring and SVAC system (left). Control console with data acquisition system and CCTV surveillance (right).

As in the previous years, several changes in the reactor systems were made under a continuous reactor modernization program, which aims at increasing the reactor power from 2 to 5 MW and the operation cycle initially to 64 hours continuous per week and then gradually to 120 continuous hours per week.

5. CONCLUSIONS

The reactor modernization program shall guarantee its safe and continuous operation for several additional years to achieve the goal of producing some of the important primary radioisotopes such as ^{99}Mo and ^{131}I among others.

New operational conditions will also allow the production of ^{125}I seeds, used for prostate cancer treatment, which are imported today.

As a consequence of an increased neutron flux and an extended period of reactor operation, many other applications and services such as NTD silicon production, neutron radiography and neutron activation analysis will show better performance.

The improved operational regime shall stimulate renewed interests in some other applications which are presently at experimental stages, like Boron-Neutron Capture Therapy (BNCT) and topaz coloration.

Neutron beam research will benefit mainly due to availability of more intense neutron beams.

One of the main goals of the reactor modernization program was the production of ^{99}Mo by (n, γ) reaction and ^{99}Tc generator using gel process. IPEN is the exclusive supplier of ^{99}Mo (^{99}Tc) generator kits to more than 260 hospitals and medical clinics in the country [10].

Power upgrade and extended operation schedule will also allow the production of ^{131}I fulfilling the entire demand of this isotope in the country with additional saving in the foreign exchange.

The Research Reactor Center had a Technical Cooperation (TC) project BRA/04/056: “Modernization of the IEA-R1 research reactor to secure safe and sustainable operation for radioisotope production,” supported by IAEA during 2005-2006.

The project contemplated several training programs for the reactor operation and maintenance personnel as well as improving the technical infrastructure of the reactor. Some of the goals achieved through the TC project were:

- * Replacement of some electrical and cooling systems; radiometric analysis system for water and air samples; radiation monitoring equipment.
- * Neutron flux mapping facility using self-powered neutron detectors (SPNDs).
- * Improved computational facility for neutronic calculations.
- * A highly radioactive sample handling facility.
- * Training of personnel engaged in electrical and mechanical maintenance, water chemistry and irradiation services.

Currently, all aspects dealing with fuel element fabrication, fuel transportation, isotope processing, and spent fuel storage are handled by IPEN at the site.

Research reactor utilization has more than fifty years in Brazil. The first three reactors, constructed in the late 50's and early 60's at university campus in Sao Paulo, Belo Horizonte and Rio de Janeiro, had their utilization for training, teaching and nuclear research. The IPEN/MB-01, designed and constructed in IPEN in the late 80's, is utilized for the development and qualification of reactor physics calculations for PWR core application, as a critical unit (zero power reactor).

Brazil has four nuclear research reactors and two nuclear power plants currently in operation, one unit starting construction and four more units planned for the next two decades. Some details of the characteristics of Brazilian research reactors are summarized in Table 1.

Table 1. Brazilian research reactors

	IEA-R1	IPR-R1	ARGONAUT	IPEN/MB-01
Criticality	September 1957	November 1960	February 1965	November 1988
Operator	IPEN/CNEN-SP	CDTN/CNEN-MG	IEN/CNEN-RJ	IPEN/CNEN-SP
Location	São Paulo	Minas Gerais	Rio de Janeiro	São Paulo
Type	Swimming Pool	Triga Mark I	Argonaut	Critical assembly
Power Level	2 – 5 MW	250 KW	200 W	100 W
Enrichment	20%	20%	20%	4.3%
Supplier	Babcock&Wilcox	General Atomics	USDOE	Brazil

A viability study has recently been made for the possibility of installing a low angle neutron scattering (SANS) facility at the IEA-R1 reactor. It should be emphasized that academic research and postgraduate teaching at the Reactor Center are very important programs in the effective utilization of the reactor. Research scientists, students, and professors from universities and other research institutions and their students have free access to the research facilities at the CRPq.

Brazil has significant amounts of uranium ore and has expertise in all the fuel cycle steps, including uranium enrichment, and produces fuel assemblies for the nuclear power plants.

These industrial activities demand the need of material and fuel irradiation tests.

Due to these new demands, the Brazilian Nuclear Energy Commission (CNEN) is analyzing the costs and benefits of developing and constructing a new multipurpose research reactor in Brazil, which besides radioisotope production and material testing can be a new tool for neutron beam application to the scientific community as well.

The study has to take into account all the aspects involved in the design and construction of a research reactor as well as the supporting installations needed for its application and

operation. One important point in the case of the Brazilian project decision is the aspect of multipurpose utilization. The neutron flux of the reactor has to be compatible to the needs described above (radioisotopes production and research). The studies had finished in 2010 for submission to the PNB advisory group.

There is today a big concern on the future perspectives on the radioisotope availability for medical use. The main radioisotope commercial producers in the world have their reactor facilities getting older, and in the second semester of 2008 there were a shortage of these products in the market. The prices are increasing, and the perspective for the future depends on new reactors construction.

In the case of IPEN, the increase in the radioisotope production depends on the power scale up of the IEA-R1 research reactor. But due to limitations on the reactor design and the site licensing, the reactor can not increase its power beyond 5 MW or IPEN can not construct any hot cell for ^{99}Mo processing from fission. These limitations lead to the need of a cost-benefit study concerning the construction of a new reactor.

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