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POWER UPGRADING AND MODERNIZATION OF IEA-R1 BRAZILIAN RESEARCH REACTOR

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ABSTRACT

The present paper describes the changes that will be necessary to upgrade the power of the Brazilian Research Reactor IEA-R1 from 2 MW to 5 MW. The operation at 5 MW will require changes in the reactor systems, replacement of some structures and introduction of new systems, mainly those related with safety and aging problems. After power upgrading, plant modernization will follow with the substitution of all nuclear instrumentation and control room. Power upgrading and continuous operation will allow the reactor to become actually a radioisotope producer and help meet part of the demand for medical isotopes in the country.

I. INTRODUCTION

The IEA-R1 reactor is a pool type, light water cooled and moderated, graphite reflected research reactor. It was designed and built by Babcock & Wilcox Co. in accordance with specification furnished by the Brazilian Nuclear Energy Commission, and financed by the US *Atoms for Peace* program.

The first start-up was in September 16, 1957, being the first criticality achieved in the Southern hemisphere [1], [2]. The first core was a 5x6 arrangement designed to operate up to 5 MW. Although designed to operate up to 5 MW, it never operated at this power level, being operated at 2 MW since early fifties.

Since its first start-up to present time (April, 1997), 185 core configuration had been installed. In the 40 years the reactor has been used intensively for basic and applied research in nuclear, neutron and solid state physics, radiochemistry, radiobiology and material science. The reactor has also been used for training purpose, for production of some useful radioisotopes for application in the industry, and nuclear medicine, and also for irradiation service.

In the beginning of 1995, in view of a favorable budget from the Federal Government, and the priorities given to the production of some useful radioisotopes, IPEN (Institute for Nuclear and Energetic Research) took an important decision to modernize and upgrade the power of the IEA-R1 from 2 MW to 5 MW and to increase its operational cycle from 8 h day, 5 days a week, to 120 h continuous per week. Power upgrading and continuous operation of the IEA-R1 reactor will allow it to become actually a radioisotope producer and help meet part of the demand for primary radioisotopes (RI) in the country. Also, as a consequence of the increase in the level of neutron flux other applications such NTD silicon production, neutron radiography, and neutron activation analysis will have better performance. Basic and applied research will certainly benefit from this new operational condition of the reactor due the availability of more intense neutron beams. This will also stimulates renewed interest in other applications, which are presently at an experimental stage, for example, boron neutron capture therapy (BNCT) and coloration of Topaz.

This paper presents the changes that will be necessary to operate the reactor at 5 MW. This operation will require changes in some of reactor systems, replacement of some structures, and introduction of new systems, mainly those related with safety and design problems, for example: reactor cooling system, fire systems, ventilation system, electrical system, instrumentation and control, radiation monitoring systems, etc.. A new emergency cooling system of passive spray cooler will also been installed. Optimization of all these systems is needed mainly to comply with the requirements of licensing by CNEN (Brazilian Nuclear Energy Commission). After power upgrading, plant modernization will follow with the substitution of all nuclear instrumentation and control room. To optimize in core irradiation position, beryllium reflectors will be acquired. Aged components and equipment will be changed. It is expected that the IEA-R1 reactor should be operating at 5 MW and 120 h continuous per week in the third quarter of 1997.

II. GENERAL DESCRIPTION

The reactor building is located in the limits of the IPEN, in the *campus* of São Paulo University. The building has 2.000 m^2 (18.7 m x 25.4 m x 28.0 m) area. with 4 floors. The core cooling system and the machine room are in the basement. The first floor is the experimental floor. The second floor contains the air conditioning and ventilation system and in the third floor is located the reactor hall and the control room.

Figure 1: IEA-R1 Reactor Building External View.

The reactor pool is located in a steel lined concrete structure (5.2 m x 13.7 m x 9.5 m) inside the reactor building. The primary system has two heat exchangers. each with 5 MW thermal capacity. and the secondary system has also two independent cooling tower. with a capacity to dissipate 5 MW of heat each. Besides these systems. the reactor has auxiliary systems. such as water make-up. purification. ventilation and air conditioning systems. The emergency electrical supply system has four diesel generators and two no-break devices. one feeding the primary pumps and the other the control table. The diesel generators supply power for the non-essential charges.

The reactor core is assembled on a 8x10 grid plate in which the fuel elements. reflectors and irradiation elements are inserted. The grid is suspended by an aluminum structure link to a bridge located on the top of the pool.

The first fuel load was composed by 40 $20^{w}/_{o}$ enriched fuel elements with curved plates. fabricated by B&W and had been used for a short irradiation time. when fuel failure occurred (pit corrosion). The second load was also with curved plates $20^{w}/_{o}$ enriched U-Al fuel elements. fabricated by U.S. (39 elements). and operated up to 1968. when a third load of plane plates, $93^{w}/_{o}$ U-Al standard fuel elements were bought from the same company. At this time. the control elements were changed from oval type (B_4C) to fork type (Ag-In-Cd) fabricated by CERCA (France). In the beginning of eighties with the international effort to core conversion from high enriched fuels (HEU) to low enriched fuels (LEU). five elements (20 $^{w}/_{o}$) were bought from Germany (NUKEM). and introduced in the core, initiating the IEA-R1 conversion to LEU. Also, at that time, researches had been developed to fabricate locally fuel elements. and in 1985 two prototypes were introduced into the core for performance tests and qualification.

With the good performance of the Brazilian fabricated LEU prototypes, the Institute decided to convert all core with Brazilian produced fuel. and in 1988 a first LEU, plate type (18 plates). U_3O_8-Al. 1,9gU/cm3. $20^{w}/_{o}$ enriched was introduced in the core. Up to day, 20 Brazilian fuel elements, including two control elements. were already introduced in the core. with maximum accumulated burn-up ~ $30^{w}/o$. For the operation at 5 MW new plate fuel elements (18 plates), U_3O_8-Al, $20^{w}/_{o}$ enriched, with uranium density of 2.3 gU/cm^3 will be fabricated by IPEN. These new fuel elements will replace the present IPEN fabricated fuel elements with uranium density of 1.9 gU/cm^3.

The irradiation elements are the following types:

EIRA - Water Cooled Irradiation Element consisting of two concentric aluminum tubes. The sliding internal tube has 8 receiving positions to lodge standard water proof aluminum cans. called "AOMR capsules". Installed in the grid plate is used mainly for permanent irradiation of elemental tellurium, sulfur, metallic gold.

EIGRA - Water Cooled Graphite Irradiation Element. A rectangular aluminum profile with a sliding shelf in the interior having 24 receiving positions for AOMR capsules and fixed on the grid plate. It is filled with graphite that acts as reflector optimizing the neutron flux over the samples. Three EIGRA are available to be used mainly for permanent irradiation of elemental tellurium for ^{131}I production.

CICON - Irradiation Loop for Miniplates. Closed loop, with cooling, monitoring and control system for irradiation of fuel miniplates.

CAFE - Boiling Water Loop (in construction). Closed loop with a cooling, monitoring and control system for irradiation of fuel pins (light water reactors).

EIX - Water Cooled Irradiation Element. used to irradiate 2 pressurized capsules of Xenonium to produce ^{125}I.

EIF - Similar to EIGRA. used to irradiate Iridium Wires to be used in "in situ" cancer therapy.

EIC - Aluminum tube fixed in the matrix plate (Ø = 40 cm and L = 30 cm) used to irradiate films to produce nuclear microfilters

EIS - Silicon Irradiation Element. which consists of two parts. the one fixed on the grid plate is a square cross-sectional aluminum guide tube. The other part consists of a freely rotating aluminum tube driven by a electric motor installed on top of the pool. The rotating cylinder serves as the irradiation tube for silicon crystals.

Beam holes are available at two core positions. In front of the thermal column position. are located two 6" beam holes. At the main core positions there are six 6" and two 8" beam holes. and one 6" through tube. Each beam hole can accommodate three different types of plugs.

Another experimental facilities. include: a ***pneumatic irradiation system*** **(rabbit system)**: with four pneumatic transfer system installed at different positions on the side of the core near the reflecting zone of the reactor. The thermal flux at irradiation position of the rabbit is 2-4 x 10^{11}n/cm^{2}sec

Figure 2 shows an across-sectional view of the IEA-R1 reactor core (core configuration 179-A, May 1996, 30 fuel elements, 17 U_3O_8-Al, 20^w/$_o$, 1.9 gU/cm^3).

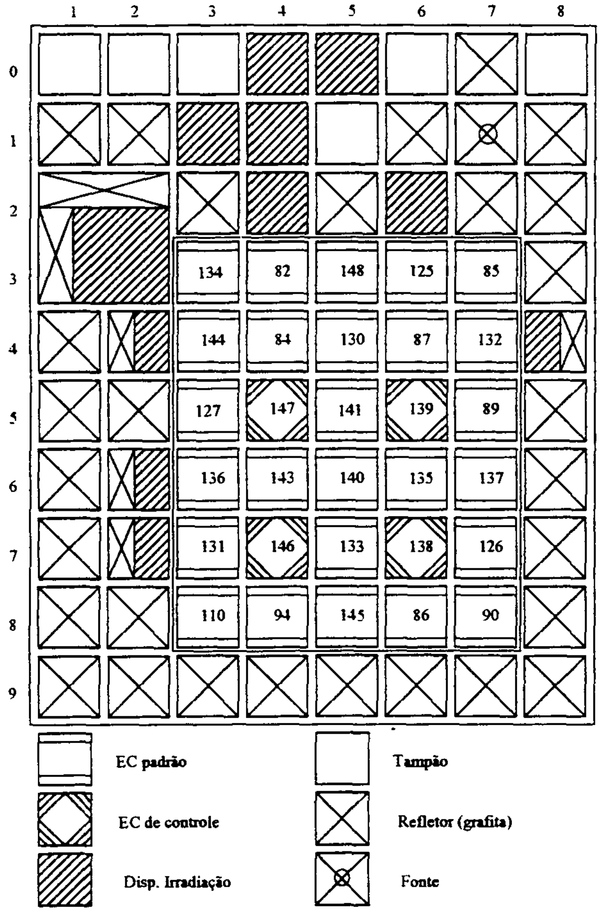

Figure 2: Across-sectional view of the IEA-R1 reactor core (Configuration 179-A)

Four neutron detectors are used to monitor and control the reactor power level and the period. The four detectors are: one wide range fission chamber type detector, one compensated B-10 ionization chamber, and two non-compensated BF3 ionization chambers. The wide range detector, a fission chamber with ^{235}U connected to its electronic circuit constitutes a Campbell channel. It is used to monitor the reactor power from start up to 120 percent of the nominal power. It is also used to monitor the period of the reactor in the start up region (below 10 percent of nominal power).

Other signals used to trip the reactor are: high radiation level (in the reactor pool or in the room of experiments), low core ΔP, low primary coolant flow, high core outlet temperature, bridge position indication, core header position indication and beam ports indication.

A N-16 channel, using a gamma ionization chamber, is used as a redundant indication of the reactor power, mainly for calibration of the neutron detectors.

In 1996 was designed by IPEN and bought from CERCA (France) a new Beryllium Irradiation Element (EIBE) that will be used for the production of ^{99}Mo. The proposed upgrading of the power for 5 MW as well as the continuous 120 h per week operational cycle of the reactor will permit the production of ^{99}Mo from (n,γ) reaction by irradiating molybdenum targets and the preparation of ^{99}Mo-^{99m}Tc generators using the gel technique. The ^{99m}Tc generators represent about 90 % of all the medical radioisotopes used by hospitals and clinics in the country. The EIBE consist of a block of beryllium (72.6 mm x 72.6 mm x 600mm) with two holes of 33 mm of diameter each, and cladded with aluminum.

III. OPERATIONAL EXPERIENCE AND REACTOR UTILIZATION

The IEA-R1 operation is one of the branches of the Reactor Department of IPEN. The operational staff consist of 17 technicians of which 5 are senior reactor operators (SRO), 4 reactor operators (RO), licensed by CNEN, and 8 are reactor operator trainees. The staff is responsible by the operation program, reactor maintenance, handling of irradiation facilities, in core fuel management, personal training, treatment of pool water, etc.. The radiological protection is made by an independent staff, consisting of a health physicist and two technicians which are responsible by performing surveys during reactor operation, including air activity measurements, assisting in beam experiment planning, measuring radiation level in operations such as handling of irradiated materials, and personal monitoring. Until last year, the reactor operation schedule was eight hour per day, five day per week. Today, the reactor operates 64 h continuously, mainly to produce ^{153}Sm, which is distributed to hospitals in the form of Sm-EDTMA. With the upgrading of power to 5 MW it is expected to operate the reactor 5 days per week continuously (120 h), Monday to Friday. The operational experience of IEA-R1 accumulates almost 8000 h of operation. To accomplish the planned operational turn it will be necessary training additional reactor operators (3RO, 1SRO) which will work in a four operational group. All the operation documents and procedures follow a quality program previously approved by the regulatory body (CNEN). Operational irradiation and experimental routines are previously approved by a *Safety Committee* which is constituted by seniors professionals in nuclear engineering, safety analysis, reactor physics, radiation protection, etc.

The reactivity excess of IEA-R1 is limited by the Technical Specification, presently being 4800 pcm which allows the reactor to operate continuously. Fuel shuffling or refueling are realized around each 3 months, being the calculation performed by LEOPARD [3] or HAMMER [4] cell calculations, by 2DB [5] or CITATION [6] for reactor calculation and by COBRA3C-RERTR [7] for termohydraulics. These calculations are performed not only for fuel management, but also to operational and safety reasons (reactivity excess; Keff; neutron flux; power distribution; control rod worth, and the reactivity worth of irradiation samples which are limited to 500 pcm, as recommended by IAEA-SS-35 [8], [9]. Figure 3 illustrates a flux distribution for the core configuration 179A with sufficient reactivity excess to operate at 5 MW in September 1997. Figure 4 illustrates a flux distribution with 25 fuel elements, made possible by using plate type fuel elements with Uranium density of 2.3 gU/cm^3.

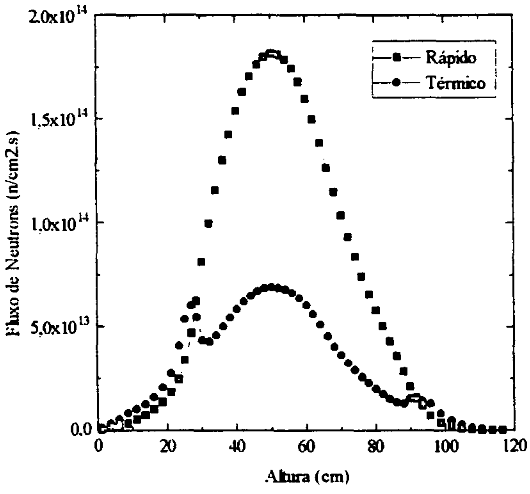

Figure 3: Thermal and fast axial neutron flux distributions in the middle of the core (configuration with 30 fuel elements)

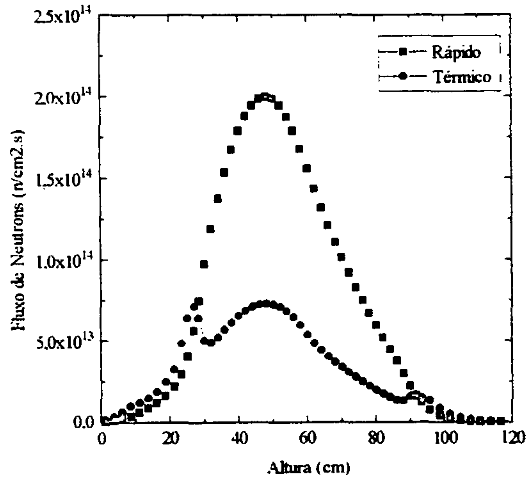

Figure 4: Thermal and fast axial neutron flux distributions in the middle of the core (configuration with 25 fuel elements)

The IEA-R1 Research Reactor can be considered as a multipurpose reactor. It has been used for basic and applied research in nuclear, neutron and solid state physics, radiochemistry, radiobiology, training and also in the production of some radioisotopes.

In research, the IEA-R1 is used as a neutron source. In the beam holes, the main researches are in neutron scattering, neutron radiography studies, studies of the crystalline state of matter, and the study of photo nuclear reactions with gamma rays from thermal neutron capture. Neutron Activation Analysis (NAA) in the rabbit irradiation system alloys research in biology, geology, environmental sciences, and life science. Besides the use of the experimental facilities, sample irradiation in core are used for several other research such as: Neutron Transmutation Doping, Irradiation of Samples for production of radiotracers (^{82}Br, ^{110}Au) and research to produce new radioisotopes for medical use such as ^{166}Ho, ^{186}Re and ^{125}I. With the upgrade of power, it is planned to irradiate gems to induce centers of colors, increasing the market price of the gems.

IV. POWER UPGRADING

To accomplish safety requirements a set of actions were programmed, and presently are in progress following recommendations from Safety Series 35-IAEA applied to research reactors. Such actions have consisted in the adequacy of old systems and design of new ones, involving engineering, analysis, safety evaluation and licensing. Also, new operators are under selection and training to complete operator team.

The following are the most representative adequacies considering exiting systems:

Reactor Core. Power upgrading will increase the reactor performance to in core irradiation facilities, satisfying reactivity excess suggested by international recommendations [10]. Brazilian produced fuel elements in a array 5x5, 2.3 gU/cm^3,will compose the new 5 MW core, and thermal neutron fluxes of magnitude 5.0E13 n/cm^2.s [11] are expected to be achieved at defined irradiation positions. It is planned to acquire new beryllium reflectors to build a new core configuration with 20 fuel elements fabricated by IPEN with Uranium density of 3.0 gU/cm^3. With this new configuration will be possible to achieve thermal neutron fluxes up to 1.0E14 n/cm^2.s.

Cooling Systems. Both the cooling towers were revised and all secondary piping completely changed. Pumps from Primary and Secondary Systems will have components changed due aging, and will be continuously monitored in operation by means of a Vibration Monitoring System being commissioned.

Fire System. A new detection and extinguish Fire System was installed covering all areas of risk, according evaluation previously performed.

Heating, Ventilation and Air Conditioning (HVAC) System. An adequacy of the HVAC System is in progress, where the separation of reactor building into two distinct and isolated areas (cold and hot areas) in respect to radiation exposition was assumed as the most important system design criteria. The cold area will be completely free of radioactivity contamination risk, due isolation of rooms where experiments or management of hot materials are performed. A new set of filter batteries, shutoff dampers, fan coils, blowers, isolated air ducts and instruments will be installed.

Electricity. New power panels will be provided to distribute power from main switchgear and emergency generators directly to set of consumers and motor control centers. all wiring will be checked, revised, and distributed into new cable trays, making possible the isolation of instrumentation and power cables for new systems. Older systems will be revised in the modernization phase.

Instrumentation and Control. Some improvement will be conducted in The Reactor Protection System and in safety related instrumentation. New interlocks were concepted into 2 out of 3 logic, specifically to drive primary circuit isolation and emergency core cooling system valves using pool level signals as initializing events. An interlock to protect core against power excursion at lower power level will also be designed. Nuclear measuring channels and control rod drivers remain unchanged, being scope of future works.

Radiation Monitoring System. INSARR/IAEA mission had recommended (1991) some improvements. According suggestions, a new system is under design, with replacement of old monitors due aging and introduction of gaseous effluent monitors.

For safety in a Loss of Coolant Accident, a new Emergency Core Coolant System is in construction. Resumed system description is as follow:

Emergency Core Cooling System - ECCs. Is a fully passive system, employing two redundant trains with four automatic valves designed to work in fail safe concept [11], spraying water directly from reservoirs into uncovered reactor core, and avoiding fuel elements melting. ECCS is designed to operate continuously during 26 hours after reactor shutdown.

Licensing. A formal process has started in November 1996 with the regulatory branch from CNEN. For the licensing process a new version of the Safety Analysis Report was furnished to CNEN.

Project Management. Project started on July 1995, when a proposal was presented and approved by the competent authorities. The reactor operation at 5 MW is expected to occur in September 1997. Project budget is presented on next table, with financial resources distributed on the period 1995-1997.

year	US$
1995	420,000.00
1996	1,016,269.00
1997	810,000.00
overall cost	2,246,269.00

Plant modernization. After power upgrading, plant modernization will follow with substitution of all nuclear instrumentation and control room MMI (man-machine interface), acquisition of 10 beryllium reflectors/irradiators to optimize in-core irradiation, and changing of aged components and equipment. Also a partial fuel element with a hole in the center (Al) is planned.

V. CONCLUSION

To accomplish safety requirements a set of actions have been programmed to upgrade the power of the Brazilian Research Reactor IEA-R1 from 2 MW to 5 MW. Such actions have consisted in the adequacy of old systems and design of new ones, involving engineering, analysis, safety evaluation and licensing. The required changes were described in the new version of the IEA-R1 Safety Analysis Report. Power upgrading and continuous operation of the IEA-R1 Research Reactor will allow it to become actually a radioisotope producer and help meet part of the demand for primary radioisotopes in the country.

VI. REFERENCES

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