NEW PLATE-TYPE CORE OF THE IPEN/MB-01 RESEARCH REACTOR FACILITY FOR VALIDATION OF RMB PROJECT

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Abstract. The IPEN/MB-01 research reactor had its first criticality in November 1988 and, ever since, has been of major importance in Brazilian reactor physics researches, achieving international level for experiments comparison and validation (benchmarks). In this facility it is possible to build many different core configurations (i.e., rectangular, square and cylindrical), once versatility and flexibility were both taken into account on its initial project. The core is a fissile material assembly, inserted in a water tank, where the chain reaction is self-maintained and controlled at low power levels, so that, in normal operation, the feedback effects of temperatures are negligible. The core is intended for neutrons simulation of light water moderated reactors allowing the experimental verification of the calculation methods, reactor cell and mesh structures, control rods effectiveness, isothermal reactivity coefficients and core dynamics due to reactivity insertions. The first standard IPEN/MB-01 core had UO_2 rod-type fuel, 4.3 % enriched in U-235 and using B_4C and Ag-In-Cd rods for safety and control of the reactor. The facility is located at IPEN/CNEN-SP (Nuclear and Energy Research Institute), in Sao Paulo - Brazil. Within the scope of the new research reactor project, the Brazilian Multipurpose Reactor (RMB), it was designed a new critical configuration for the IPEN/MB-01. After thirty years of work, the rod-type fuels were replaced by plate-type fuels, in order to validate the RMB calculation methodologies, as well as the nuclear data libraries used. The RMB is an open pool-type reactor with maximum power of 30 MW, being the core a 5x5 configuration, consisting of 23 fuel elements, made of U_3Si_2-Al, having a medium density of 3.7 gU/cm^3 and 19.75% enriched in U-235, and two positions available in the core for materials irradiation devices. The production of radioisotopes, silicon doping, neutron activation analysis, nuclear fuels and structural materials testing and the development of scientific and technological research using neutron beams are the main targets of the RMB enterprise. The new IPEN/MB-01 core has a 4×5 configuration, having 19 fuel elements, consisting of U_3Si_2-Al, 2.8 gU/cm³ and 19.75% enriched in U-235, plus one aluminum block. The IPEN/MB-01 new plate-type fuel assembly uses Cadmium wires as burnable poison, as the one used in RMB core for controlling the core power density and excess of reactivity during its operation. The core is also reflected by 4 boxes of heavy water (D_2O), inserted in a moderator tank of light water. The maximum nominal power is 100 W and, for a safe operation, the critical assembly has both safety and auxiliaries' systems. This paper presents a description of the new core and the principal neutronic parameters. The new core of the IPEN/MB-01 will be certainly a world class benchmark core for the core physics calculation of research reactors.
Key Words: Brazilian Multipurpose Reactor, IPEN/MB-01 research reactor, New plate-type core, Reactor Physics.

1. INTRODUCTION

Prior to the conclusion of a nuclear reactor enterprise, the applied calculation methodology must be verified and validated through experimental analysis. Zero power reactors, as IPEN/MB-01, play an important role in this context. Theses reactors are usually used to validate neutronics results predicted by computational simulations (i.e., light water moderated reactor cell and mesh structures, control rods effectiveness, isothermal reactivity coefficients and core dynamics due to reactivity insertions). The IPEN/MB-01 research reactor facility achieved international level for experiment comparison and validation (benchmarks) and its versatility allows building many different core configurations, such as rectangular, square and cylindrical as well. Today, it´s running in Brazil, the Brazilian Multipurpose Reactor (RMB) project, focused on the production of radioisotopes, silicon doping, neutron activation analysis, nuclear fuels and structural materials testing and the development of scientific and technological research using neutron beams. Therefore, in order to validate, experimentally, the RMB project, a new critical configuration for the IPEN/MB-01 was designed, changing the core from the rod-type to the plate-type fuels, as will be presented in the next subsections in this paper.

1.1. IPEN/MB-01 Research Reactor Facility

The IPEN/MB-01 achieved its first criticality in the year of 1988 (November 9), in which also started its operation. As mentioned before, due to a high level of versatility, this research reactor core allows setting up different configurations. Its first core was a rectangular-type (parallelepiped), with 39 x 45 x 54.6 cm^3 as active dimensions, being an assembly of 28 x 26 fuel rods, 48 guide tubes for the control and safety rods using demineralized D_2O as moderator in this facility. In this configuration, there are a total of 680 fuel rods and an excess of reactivity of, approximately, 2415 pcm [1]. FIG.1. shows one of the IPEN/MB-01 rod-type core configuration. Aiming to accommodate new core configurations, the matrix plate has 900 roles (30 x 30) equally spaced by 15mm. The Fuel rods are made of UO_2, enriched 4.3% in ^{235}U and, as cladding, stainless steel AISI-304. The control rods are made up of Ag-In-Cd and the safety ones, B4C (the safety rods are completely withdrawn during normal operation).

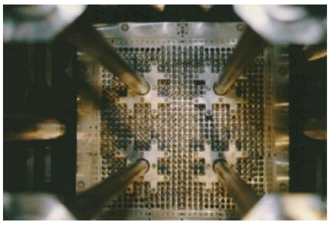

FIG. 1. IPEN/MB-01 research reactor core (top view).

The associated nuclear instrumentation used for safety and control consists of 10 nuclear channels, being 2 startup channels (BF3 detectors), 2 power channels (compensate ionization chamber - CIC), 2 linear channels (non-compensate ionization chamber - CINC), 3 safety channels in the power range (2 CINC + 1 B-10 detector) and 1 safety channel in the startup range (BF3 detector). All of them are placed around the reactor core, within the moderator tank, in many axial positions, protected by aluminum tubes [1]. This nuclear instrumentation set up is preserved for the new plate-type fuel core of the IPEN/MB-01 reactor. This facility is able to simulate real power plants without having to build a complex system for heat removal and, because of these many features, in the next subsection it´s presented its usage within the RMB project, the largest nuclear engineering enterprise running in Brazil for the time being.

1.2. IPEN/MB-01 and the RMB Project

The Brazilian Multipurpose Reactor (RMB) project is being developed in Brazil (current in the detailed engineering project stage) and has, as main targets, the following items:

- Radioisotopes production;
- Material irradiation;
- Nuclear fuels structural testing;
- Development of scientific and technological research using neutron beams.

This research reactor will be placed at Iperó/SP, being a 30MW open pool-type reactor, keeping the core in a 5x5 configuration (23 plate-type fuel elements, each one with 21 fuel plates made of U_3Si_2-Al and Al 6061 as Cladding, 3.7 gU/cm^3, 19.75% enriched in ^{235}U and two extra positions available for materials irradiation). With eception to the uranium density in the meat, the fuel elements in the new plate-type core have the same design as the ones employed in the RMB. As control elements, 6 plates made of Hafnium are presented in the core. FIG.2. depicts the RMB research reactor core, showing the fuel assembly configuration, along with the Al blocks (positions for in core material irradiation) and the control plates.

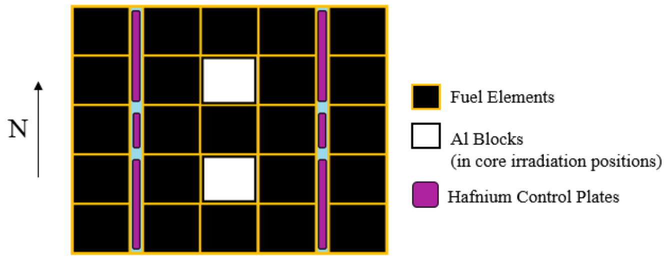

FIG. 2. RMB research reactor (top view).

Once the RMB has a plate-type core, in order to validate and to provide support for the neutronic calculation methodology used during its project, it was designed a new critical assembly, named new plate-type core, for the IPEN/MB-01 research reactor facility, replacing the old rod-type one, after 30 years of operation. The new critical configuration will be operated by the National Nuclear Energy Commission (CNEN) and it´s placed at the Nuclear and Energy Research Institute (IPEN/CNEN-SP) in Sao Paulo, Brazil. The next subsection presents the IPEN/MB-01 new plate-type core.

1.3. IPEN/MB-01 New Plate-Type Core

The new IPEN/MB-01 plate-type core is a tank-type research reactor. The core configuration is disposed in a 4×5 configuration (FIG.3.), with 19 fuel elements (U_3Si_2-Al, 2.8gU/cm³ and 19.75% enriched in U-235), plus one aluminum block (internal irradiation position). As burnable poison, cadmium wires were used, once they are also employed at the RMB project to control the power density and the excess of reactivity during its operation.

The core is reflected by four boxes of heavy water (D_2O), having Hafnium control plates (4) and its maximum nominal power is 100W. FIG.4. depicts the fuel assembly geometry. Table 1 presents the general description of the IPEN/MB-01 plate-type core fuel assembly and Table 2, other relevant information.

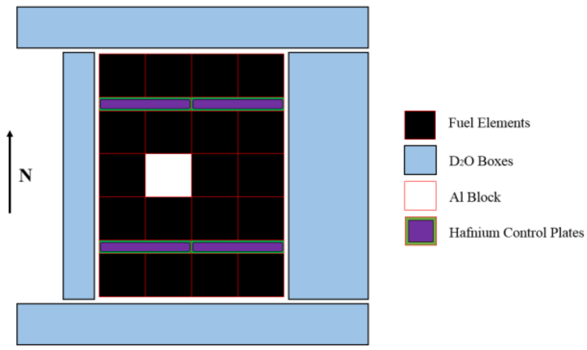

FIG. 3. IPEN/MB-01 new plate-type core and D_2O boxes (top view).

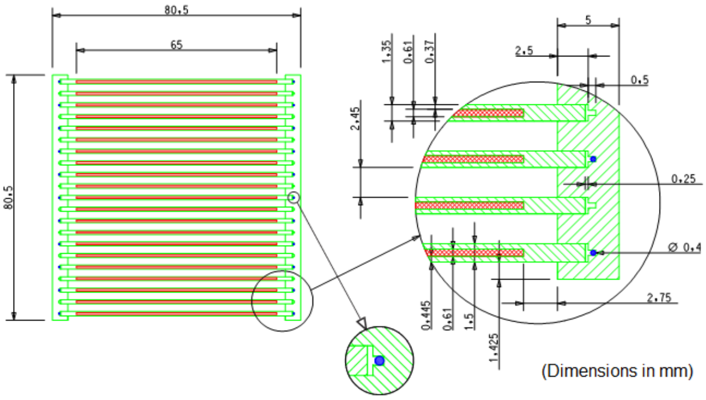

FIG. 4. Standard fuel assembly schematic diagram.

TABLE I: GENERAL DESCRIPTION OF THE IPEN/MB-01 PLATE-TYPE CORE FUEL ASSEMBLY

Fuel assembly type	MTR - U_3Si_2-Al	
Enrichment in U-235	19.75 %	
Uranium density (meat)	2.8 gU/cm³	
U-235 mass per fuel assembly	283.08 g	
Amount of plates	21	
Plates array	Parallel	
Fuel plates dimensions	Inner plates	Outer plates
	1.35 x 75 x 655 mm³	1.50 x 75 x 825 mm³
Meat dimensions	0.61 x 65 x 615 mm³	
Coolant channel dimensions	2.45 x 70.5 mm²	
Fuel assembly dimensions	80.5 x 80.5 x 1045 mm³	
Cladding material	Al 6061 (2.7 g/cm³)	
Burnable poison	Cadmium (8.636 g/cm³)	
Burnable poison dimensions	Diameter	Length
	0.4215 mm	400 mm

TABLE II: OTHER RELEVANT DIMENSIONS AND THE STARTUP SOURCE

Al block dimensions	80.5 x 80.5 x 835 mm³
Hafnium plates dimensions	7 x 152 x 635 mm³
North/South D2O box dimensions	76.25 x 608 x 715 mm³
East D2O box dimensions	140 x 452.5 x 715 mm³
West D2O box dimensions	58 x 452.5 x 715 mm³
Startup source	Am-Be (1Ci, ANM-9022)

2. IPEN/MB-01 NEW PLATE-TYPE CORE NEUTRONIC MODELING

The new core was modeled using three types of methodology. With exception to the control rod worth the Monte Carlo N-Particle code (MCNP) [2], [3], along with NJOY [4] (coupled system NJOY/MCNP, where NJOY (99.90) to generate the nuclear material data used in MCNP) was employed in all other neutronic calculations. The version 5 [2] of MCNP was used, except during the kinetic parameters evaluation, where it was applied the version 6 [3]. The MCNP solves the neutron transport equation through the Monte Carlo method and has a very powerful way to build 3D geometries using Boolean logic. The continuous energy cross sections (70c) and the thermal cross sections for the light water, heavy water, beryllium and polyethylene (10t) were used in the model. The integral and differential reactivity worth curves were calculated using the code CITATION [5].

2.1. Coupled System NJOY/MCNP3

This methodology was employed for the isothermal reactivity determination and followed when modeling with NJOY and MCNP is depicted in FIG.5. The Nuclear data library ENDF/B-VII.0 [6] was used to feed NJOY and generate a new set of nuclear material data accounting the Doppler effect (BROADR), unresolved resonance region (UNRESR), $S(\alpha,\beta)$ (LEAPR) and thermal neutron treatment (THERMR). The NJOY´s modules RECONR and ACER are used to prepare the ENDF/B-VII.0 library and to create an ACE file to be used in MCNP, respectively. When using the MCNP 6 for the kinetic parameters calculations, the JENDL 3.3 [7] nuclear data library was used for the tallies and for the delayed neutron nuclear data and ENDF/B-VII.0 for the cross sections of the reactor materials.

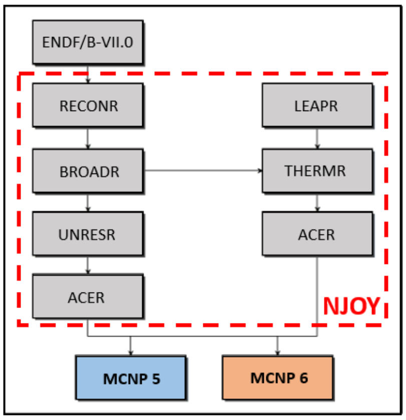

FIG. 5. Calculation Methodology.

2.2. CITATION Cross Section Preparation and Generation

The nuclear data libraries were generated considering four different structures. The code NJOY access the basic libraries, interpolate them, rebuild and expand the resonances, pondering the punctual cross section using a typical spectrum of the problem.

The program HRC, developed by IPEN/CNEN-SP, which is a union of HAMMER-TECHNION [8], AMPX-II [9] ROLAIDS module and CINDER-2 [10], is able to generate the cross section in four different groups for any temperature within 20°C – 1800°C. The cross sections in four groups for the non-fuel regions including those of cadmium wires were generated using the code AMPX-II. FIG.6. shows the methodology schematic diagram for the NJOY/AMPII – CITATION [11], [12].

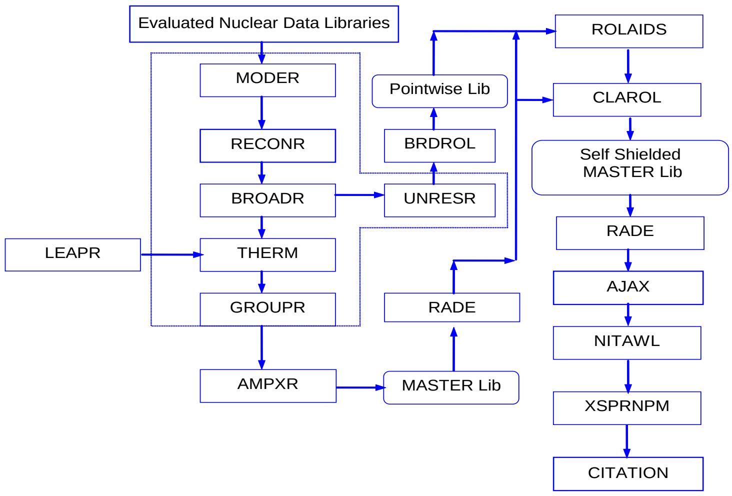

FIG. 6. NJOY/AMPII – CITATION schematic diagram.

3. PRINCIPAL DESIGN NEUTRONIC PARAMETERS

In this section the main neutronic calculations are presented for the IPEN/MB-01 new plate-type core (considering all data adopted *as designed*), such as isothermal reactivity coefficient (α_{ISO}), effective kinetic parameters and the total control plates worth. Table III presents the control plates reactivity. Table IV, the reactivity Doppler coefficient. Table V, the isothermal reactivity coefficient. Table VI, the kinetic parameters.

TABLE III: CONTROL PLATES REACTIVITY

Status	Reactivity (pcm)	Calculated Shutdown Margin	Shutdown Margin Design Criteria
Reactivity Excess	3511 ± 2	Reference	
Total Control Plates Reactivity	-16576 ± 4	372%	100%
Stuck Control Plate (BS#3 Fully Withdrawn)	-10622 ± 3	203%	50%

TABLE IV: REACTIVITY DOPPLER COEFFICIENT

T (^{0}C)	k_{eff}	$\Delta\rho$ (pcm)	ΔT (^{0}C)	α_F (pcm/^{0}C)
20	0.99905 ± 0,00001	Reference		
50	0.99835 ± 0,00001	-70 ± 1	50 – 20	-2.34 ± 0,05
100	0.99721 ± 0,00001	-185 ± 1	100 – 20	-2.309 ± 0,018
300	0.99337 ± 0,00001	-572 ± 1	300 – 20	-2.044 ± 0,005

TABLE V: ISOTHERMAL REACTIVITY COEFFICIENT

T (^{0}C)	k_{eff}	$\Delta\rho$ (pcm)	α_{iso} (pcm/^{0}C)
20	0.99905 ± 0,00001	-547 ± 3	-18.23 ± 0,11
50	0.99362 ± 0,00003		

TABLE VI: IPEN/MB-01 KINETIC PARAMETERS

Precursor Group	β_i	β_i/β_{eff}	λ_i
1	0.00023 ± 0,00001	0.0314 ± 0,0014	0.01249 ± 0,00000
2	0.00122 ± 0,00002	0.1664 ± 0,0029	0.03181 ± 0,00000
3	0.00121 ± 0,00002	0.1651 ± 0,0029	0.10944 ± 0,00000
4	0.00337 ± 0,00003	0.460 ± 0,005	0.31730 ± 0,00001
5	0.00097 ± 0,00002	0.1323 ± 0,0029	1.35320 ± 0,00002
6	0.00033 ± 0,00001	0.0450 ± 0,0014	8.6581 ± 0,0010
β_{eff}	0.00733 ± 0,00005		
Λ (μs)	65.44 ± 0,08		

4. CONCLUSIONS

The IPEN/MB-01 research reactor, located at IPEN/CNEN-SP, is passing through a new transformation aiming the Brazilian Multipurpose Reactor project. The old rod-type core is being replaced by a plate-type one, in order to, experimentally, validate the neutronic methodology used in the RMB enterprise. Some neutronic calculations were presented in this paper for the new plate-type core configuration. Considering future works, besides presenting more neutronic calculations for this reactor, the data used for modeling will be updated by the ones presented in the IPEN/MB-01 data book (*as built* modeling). A comparison between the results from the modeling and the real ones (through experiments), when the new reactor core starts its operation, will also be presented in prospective works.

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