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PRELIMINARY CONCEPT OF A ZERO POWER NUCLEAR REACTOR CORE

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ABSTRACT

The purpose of this work is to define a zero power core to study the neutronic behavior of a modern research reactor as the future RMB (BRAZILIAN NUCLEAR MULTIPURPOSE REACTOR). The platform used was the IPEN/MB-01 nuclear reactor, installed at the Nuclear and Energy Research Institute (IPEN-CNEN/SP). Equilibrium among minimal changes in the current reactor facilities and an arrangement that will be as representative as possible of a future core were taken into account. The active parts of the elements (fuel and control/safety) were determined to be exactly equal the elements of a future reactor. After several technical discussions, a basic configuration for the zero power core was defined. This reactor will validate the neutronic calculations and will allow the execution of countless future experiments aiming a real core. Of all possible alternative configurations for the zero power core representative of a future reactor - named ZPC-MRR (Zero Power Core – Modern Research Reactor), it was concluded, through technical and practical arguments, that the core will have an array of 4 x 5 positions, with 19 fuel elements, identical in its active part to a standard MTR (Material Test Reactor), 4 control/safety elements having a unique flat surface and a central position of irradiation. The specifications of the fuel elements (FEs) are the same as defined to standard MTR in its active part, but the inferior nozzles are differentiated because ZPC-MRR will be a set without heat generation. A study of reactivity was performed using MCNP code, and it was estimated that it will have around 2700 pcm reactivity excess in its 19 FEs configuration (alike the present IPEN/MB-01 reactivity). The effective change in the IPEN/MB-01 reactor will be made only in the control rods drive mechanism. It will be necessary to modify the center of this mechanism. Major modifications in the facility will not be necessary.

1. INTRODUCTION

A representative critical arrangement of a modern nuclear research reactor can help researchers validate theoretical calculations, and also help them to obtain experimental measurements of the characteristics of a real core as well as its performance (ex.: determination of the spectral indices [1], inversion point of the isothermal reactivity coefficient [2], noise analysis approach for measuring the decay constants and the relative abundance of delayed neutrons [3], measurement of β_{eff} based on Rossi-α and Feynman-α experiments and the two-region model [4,5], etc.). That is fundamental for a future project. In addition, an arrangement like this makes the simulation of all the characteristics of a real nuclear research reactor possible, without the necessity of building a complex system of heat removal.

A critical arrangement like this, called ZPC-MRR (“Zero Power Core – Modern Research Reactor”), shall be built in the current facilities of the IPEN/MB-01 reactor of the Nuclear and Energy Research Institute (CNEN/IPEN-SP), São Paulo, Brazil.

In order to accomplish it, the following items were established:

1- minimum changes in the hot cell of the current IPEN/MB-01 reactor,

2- an arrangement that will be as close as possible to the modern cores with the MTR (Material Test Reactor) fuel elements (FEs) and

3- FEs and control/safety elements (CSEs) equal or as close as possible to this reactor type.

One possible application of the zero power core should be the future Brazilian Nuclear Multipurpose Reactor (RMB) [6], currently been designed. The RMB has been designed to supply national needs for material testing, scientific research, medical and commercial applications, training, and especially for the radioisotope production. The project must also supply requirements for operation versatility, security, and meaningful national participation in its construction and maintenance.

2. CRITICAL CELL OF THE CURRENT IPEN/MB-01 REACTOR

The critical cell of the current IPEN/MB-01 reactor has a parallelepiped shaped core formed by an array of 28x26 positions for insertion of fuel rods that are similar to those used in LWR reactors, whose active dimensions are 390x420x546 mm. It has also 48 guide-tubes for inserting the control/safety rods. This arrangement provides a reactivity excess of about 2415 pcm, with 4.3% of enrichment.

The critical cell of the current IPEN/MB-01 reactor is shown below in figure 1.

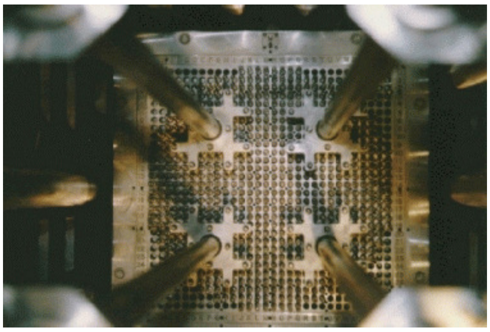

Figure 1. Top view of IPEN/MB-01 reactor critical cell

2.1. Critical Cell of IPEN/MB-01 Reactor With ZPC-MRR Core

After several technical and practical considerations by the neutronic team of IPEN/CNEN-SP, it was concluded that the core will have the layout shown in figures 2 and 3, with 19 fuel elements, identical in their active part to a standard MTR, four flat control/safety elements and a central position of irradiation. The external dimensions will be: 450.5 x 327 x 655 mm.

The core structure will be held by a 3 mm thick and 10 mm wide upper support aluminum ring (*a priori*) .

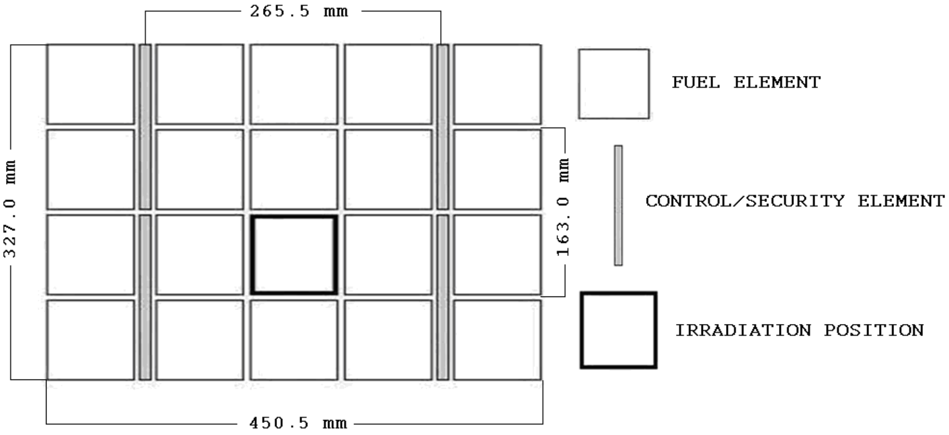

Figure 2. Schematic top view of the ZPC-MRR reactor critical cell

The distance between the centers of control/safety plates will be, according to figure 2, 265.5 mm on the side with 5 FEs and 163 mm on the side with 4 FEs. These differences from the original design of the IPEN/MB-01 reactor should be corrected by changing the upper supports of these control plates.

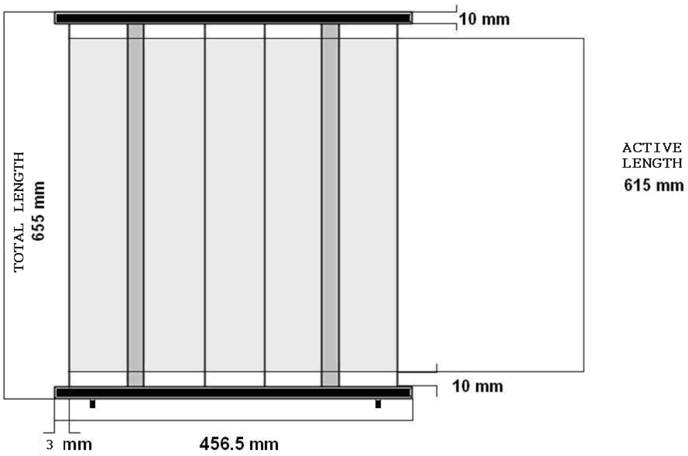

Figure 3. Schematic side view (5 FEs) of the ZPC-MRR core.

2.2. The Fuel Element

The fuel element defined for the ZPC-MRR core [7] is practically the same of MTR type, it consists of 21 U_3Si_2-Al plates, as illustrated in figure 4. The dotted lines that involve the element represent the dimensions between the centers of two adjacent fuel elements. There will be no lower nozzles in the ZPC-MRR fuel elements, and at the top, their plates will be smaller and not beveled. The overall height will be 655 mm.
Table 1 lists the preliminary general data of the fuel element

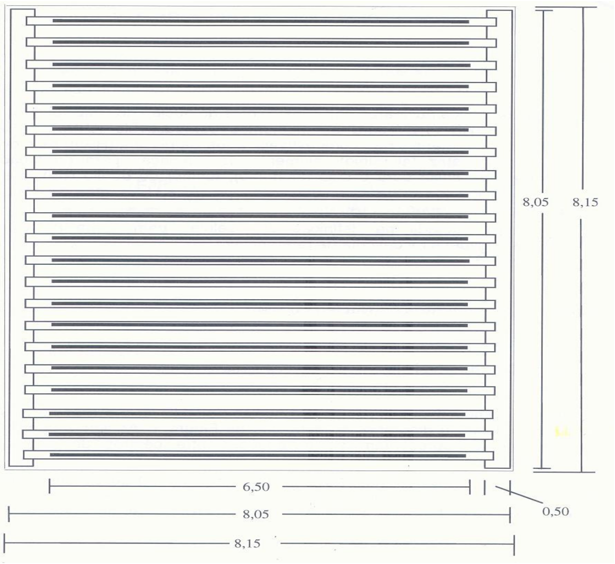

Figure 4. ZPC- MRR Fuel Element Dimensions [7]

The possibility of making a FE with one or more removable plates has been analyzed in order to make their study possible in laboratories.

Table 1. Data of the fuel element [7]

. Cross section dimensions	80.49 mm x 80.49 mm
. Number of fuel plates	21
. Active length	615 mm
. Active width	65 mm
. Fuel plate thickness	1.35 mm (internal plates) 1.50 mm (external plates)
. Cooling channel dimensions	2.45 mm x 70.5 mm
. Fuel meat thickness	0.61 mm
. U_3Si_2 density	12.2 g/cm^3
. Maximum uranium density of the meat	3.0 g/cm^3
. Meat density	6.5g/cm^3
. Mass fraction of Al in the mix	60 %
. Isotopic composition (^{235}U content in the powder)	19.75 ± 0.20 weight % of the total U
. Content of total uranium	≥ 91.3 % (weight)
. Content of silicon	≥ 7.4 % (weight)
. Content of Aluminum	≥ 99.5 % (weight)
. Cladding Material	Aluminum alloy (6061)
. Aluminum density	2.7 g/cm^3

2.3. Control Elements and Control Guides

The set of control elements of the ZPC-MRR core will consist of Ag-In-Cd plates coated with 306L stainless steel, with Aluminum guides,, as illustrated in figure 5.

Table 2 lists the ZPC-MRR control elements and control guides preliminary general data .

Table 2. Data of the control elements and control guides [7]

CONTROL ELEMENTS	
. Absorber Material	Ag-In-Cd
. Weight fraction of the absorber material	80-15-5 (%)
. Absorber plate thickness	4.5 mm
. Cladding Material	SS304
. Cladding thickness	1.0 mm
. absorber width	146 mm
CONTROL GUIDES	
. Material	Al
. Plate thickness	3 mm
. Total thickness	20 mm

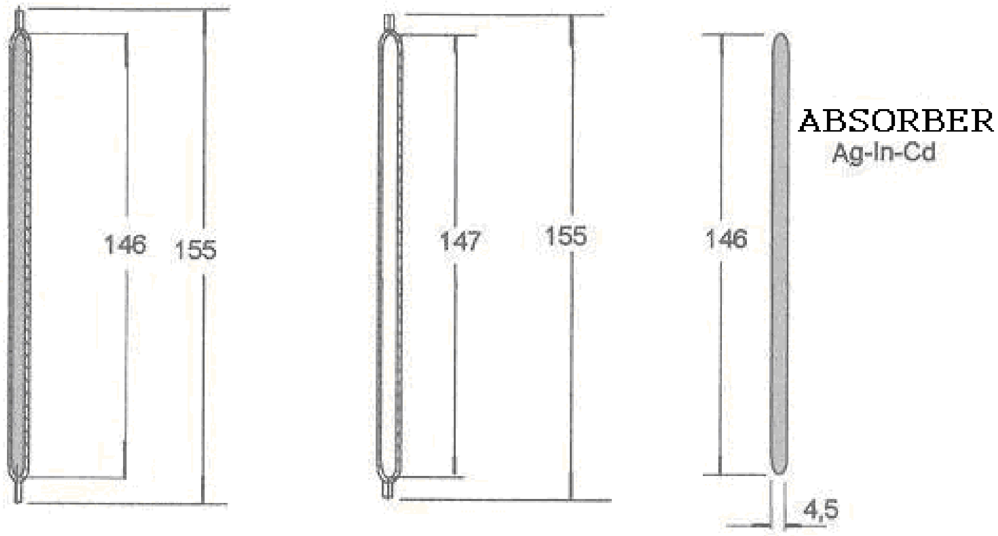

Figure 5. Dimension details of the Control/Safety element of the ZPC-MRR core (mm).

2.4. Control/Safety (C/S) Element Guide Plates

There will be hollows in the guide plates as shown in figure 6. These hollows are intended to allow a fast and, at the same time, controlled falling of the control/safety elements despite having a damping system in its drive mechanism, above the core.. The final dimensions of the hollows will still be determined through experiments. The positioning of FEs, in relation to the fuel plates (parallel or perpendicular) will also be crucial to the falling speed of the C/S elements. The neutronic implication of this positioning shall also be investigated.

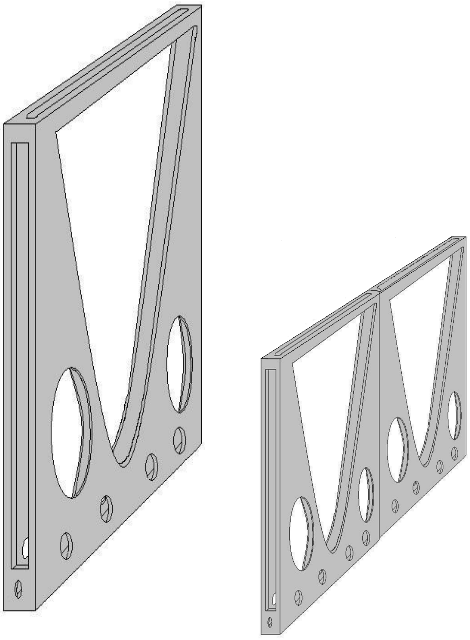

Figure 6. Control/safety element guide plates of the IPEN/MB-01 reactor with ZPC-MRR core.

2.5. Top and Bottom Rings

A ring will be placed on the top of the core to hold the fuel set together, enclosing all FEs. Another ring, holding the FE's on their bottom part, will be fixed on the top of supporter tray. These rings will also stand to replace the original spacers in the current core.

2.6. Matrix Board

For convenience, the matrix board will be the same one which is in the current IPEN/MB-01 core (figure 7). Above the matrix board there will be a hollow "tray" with 4 pins that will be fitted in the holes of the original matrix board.

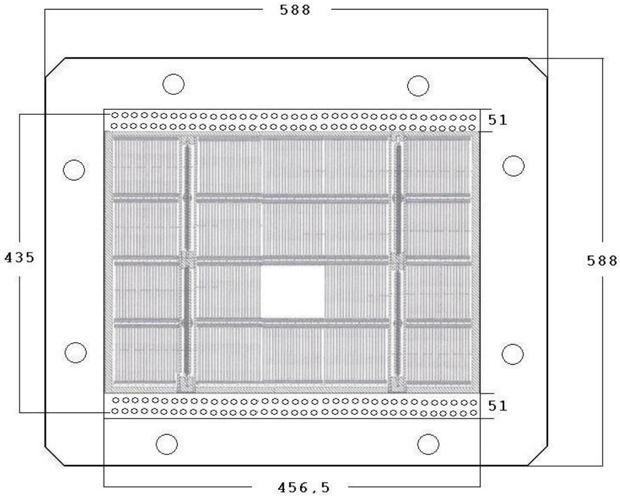

Figure 7. Matrix board of the IPEN/MB-01 reactor with ZPC-MRR core (mm).

3. REACTIVITY ADJUSTMENTS

Given the geometric and material constraints here described, a parametric study involving the uranium density (g U/cm^3) was performed. In addition, if necessary, tanks of heavy water (D_2O) can be used on the sides of the core that do not have detectors. The dimensions of these tanks should be also determined.

The parametric study of the uranium density (g U/cm^3) and the reactivity excess of ZPC-MRR core was performed by four series of simulations using the MCNP-5 code [8], which is a radiation transport code based on the Monte Carlo method.

3.1. Geometric Representation

The geometry here defined was modeled and the simulated data were obtained by only changing the fuel densities and concentrations (meat).

The geometric specifications of the figures used in the construction of the hollow elements and their positions were obtained only to represent the proposed idea (figure 7). Afterwards these specifications will be experimentally determined.

3.2. Calculations

The four series of simulations are distinguished by the U concentration. The simulated configurations were:

a. 19 FEs without C/Ss
b. 19 FEs with C/Ss
c. 20 FEs without C/Ss
d. 20 FEs with C/Ss

Simulations without C/Ss aimed to estimate the reactivity excess for the proposed set (19 or 20 FEs) while those with C/Ss aimed to estimate the C/Ss efficiency, ensuring their effectiveness. The simulations with different numbers of FEs aimed to estimate the FE reactivity.

The ENDF-B7 cross section library for all nuclides specified in the input file and the table Lwtr.01t to describe the water S(A,B) scattering were used.

Table 3. k_{eff} estimated dependence on U concentration for the 4 studied configurations.

g[U]/cm^3 nominal	19 FEs				20 FEs				U Mass per plate (g)
	Control/Safety Element				Control/Safety Element				
	without		with		without		with		
	k_{eff}	σ_{keff}	k_{eff}	σ_{keff}	k_{eff}	σ_{keff}	k_{eff}	σ_{keff}	
1.9	0.95630	11	0.82092	11	1.00033	11	0.87171	12	43.661
2.1	0.97822	11	0.84213	12	1.02162	12	0.89227	12	48.257
2.4	1.00562	11	0.86918	12	1.04784	12	0.91805	12	55.151
2.7	1.02784	12	0.89120	12	1.06929	12	0.93903	12	62.044
3.0	1.04616	13	0.90975	12	1.08655	12	0.95639	13	68.938

Each simulation was performed for 5000 cycles (4800 active cycles) with about 10,000 stories each.

The estimated mass of U per plate was given by multiplying the volume of fuel in each plate (24.38475 cm^3) by the density of U. Table 4 shows the amount of uranium needed to make a FE with 21 plates, as well as the core loading for sets with 19 and 20 FEs.

Table 4 Uranium mass dependence on its concentration to make 1, 19 and 20 FEs.

g[U]/cm^3 nominal	U Mass (kg)		
	1 FE	19 Fes	20 FEs
1.9	0.917	17.421	18.337
2.1	1.013	19.254	20.268
2.4	1.158	22.005	23.163
2.7	1.303	24.756	26.059
3.0	1.448	27.506	28.954

Therefore, it is estimated that it will take a little more than 26 kg of U to manufacture 20 FEs with concentration about 2.7 g/cm^3, in order to have a reactivity excess around 2,700 pcm, to have the ZPC-core configuration with 19 FEs.

4. CONCLUSIONS

After several technical discussions about the alternatives to the ZPC-MRR core, it was concluded through theoretical and practical considerations that this core will have the layout shown in Figure 2, with 19 plates of fuel elements, identical in their active part to a standard MTR, four control/safety elements, each one consisted of a unique flat surface, and a central position of irradiation. The external dimensions will be 450.5 x 327 x 655 mm.

The specifications of FEs and C/S elements will be the same as defined for a standard MTR in its active part, but the lower nozzles will be differentiated, as observed in this work.

A reactivity study was performed, and it was estimated that it will take a little more than 26 kg of U to manufacture 20 FEs (1 extra FE) with a U concentration of 2.7 g/cm^3, so that the ZPC-MRR core will have a reactivity excess close to 2700 pcm in its configuration with 19 FEs.

The effective change in the IPEN/MB-01 reactor will be performed only in the drive mechanism of the control rods. It will be necessary to modify the center of this mechanism. Major modifications in the facility will not be necessary.

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