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Void Coefficient of Reactivity in the IPEN/MB-01 Research Reactor with Plate-Type Fuel Elements

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1. Introduction

The IPEN/MB-01 reactor is a zero power reactor (100 watts maximum power level) specially designed to measure a wide variety reactor physics parameters [1]. One of these parameters is the Void Coefficient of Reactivity, which plays a very important role in transient analysis.
During an accident condition in a LWR, voids can be produced due to the boiling of the coolant/moderator. If this Void Coefficient is negative, in an uncontrolled high power condition, more voids are produced, a negative reactivity is added to the core, and the power tends to decrease. On the other hand, if this Coefficient is positive, in an uncontrolled high power condition, the increase in void tends to increase power even more, creating a harsh condition to the operators to deal.
This work aims to show the results of the experimental determination of the Void Coefficient of Reactivity. Since the new core of the IPEN/MB-01 is similar to the future Brazilian Multipurpose Reactor (RMB) core, defining this parameter is very important to garantee both its own and RMB's safety. Besides, another task attributed to IPEN/MB-01 is to validate calculation methodologies and related nuclear data libraries.

2. Methodology

In order to define the Void Coefficient of Reactivity (α_V), given by the Equation 1, it is necessary to measure a difference in reactivity ($\Delta\rho$) due to a difference in moderator volume (ΔV_V). Note that ΔV_V is usually expressed in % instead of a volume unit.

$$\alpha_V = \frac{\Delta\rho}{\Delta V_V} \tag{1}$$

Since the maximum power of this research reactor is unable to boil water, it is used aluminum plates, which has a very low neutron cross section (also said to be transparent to neutrons), to create these voids in the moderator.
The standard core consists of 19 Plate-Type fuel elements and one massive aluminum element assembled in a 4 per 5 arrangements. Each fuel element contains 21 fuel plates, the fuel being of U_3Si_2 enriched to 19.75%, and the criticality is maintained by the insertion of four hafnium control elements (BC#1 to BC#4) into the core, usually all of them at the same position. Around the core boxes full of heavy water (D_2O) serve as neutron reflector, and the reactor is moderated by light water (H_2O). The active core height is 61.5 cm. Figure 1 shows the transverse secction of the core.

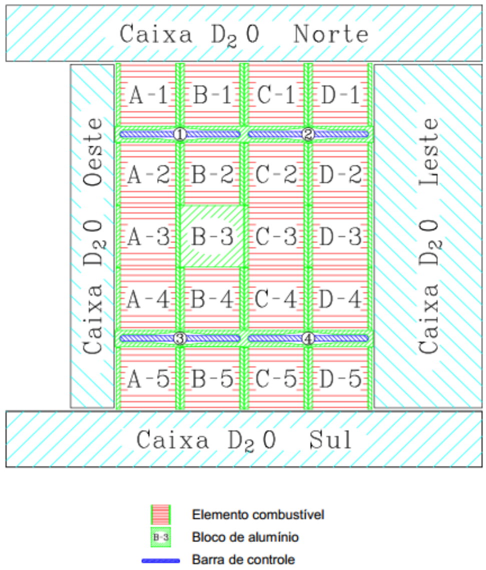

Figure 1: Transverse secction of the IPEN/MB-01 core, in a 4x5 arrangement with 19 fuel elements and one massive aluminum element.

The first step of the experiment is defining the standard condition of operation. Using the standard core described above, at the temperature of (20.5 ± 0.5) °C, criticallity is reached and maintained with all four control elements at the same position.
The next step is adding moderator voids distributed into the core. This is done by inserting 19 aluminum plates, each one in the 13^{th} water channel of each fuel element (counting from north to south face). The dimensions of each Al plate are (6.9 x 81 x 0.115 cm), so it covers entirely the active height (61.5 cm).
With this new core configuration, at the same temperature of (20.5 ± 0.5) °C, three control elements are positioned at the previous height, and criticallity is reached and maintained by moving the last one. The difference in position is due to the reactivity added by the Al plates.
It is possible to measure this difference in reactivity by using a reactimeter based on the point reactor kinetics equations installed in the Digital Acquisition System (SAD): From the critical position, the last control element is moved to the position the reactor was critical with the standard core. The reactivity measured by SAD is equivalent to the amount added by the voids.
At last, the volume of the voids at the active region is calculated by simply multiplying 19 x (6.9 x 61.5 x 0.115). The initial volume of the moderator at the same active region is calculated using the software SolidWorks.

3. Results and Discussion

Using the standard core, criticallity was reached with all of the control elements (BC#1 to BC#4) 64.66% withdrawn, and the volume of the moderator at the active region was 48423.31 cm^3.
After inserting 19 aluminum plates, 927 cm^3 of moderator at the active region were replaced by aluminum (ΔV_V = 1.91% of the initial volume). At the temperature of (20.03 ± 0.05) °C, to reach criticallity, BC#4 new position was 80.45% withdrawn (with BC#1 to BC#3 still at 64.66%).
When BC#4 was moved back to 64.66%, the SAD's reactimeter indicated an average $\Delta\rho$ of (-491.83 ± 26.24) pcm, using a sample of 80 values (40 samples of two different power channels).

Using Equation 1, the Void Coefficient of Reactivity obtained experimentally is $\alpha_V = -256.92$ pcm/%void. Theoretically, α_V calculated in similar conditions of temperature is (-261 ± 4) pcm/%void [2]. Even though the methodology used was slightly different (the voids were calculated using the density variation of the moderator from 20 °C to 50 °C), it can be noted the difference between experimental and theoretical values is 1.57%.

4. Conclusions

The experiment allowed a measurement of Void Coefficient of Reactivity of $\alpha_V = -256.92$ pcm/%void, which is a very negative number, assuring the safety for both IPEN/MB-01 and RMB. Besides that, the difference between experimental and theoretical values is less than 10%. This difference is acceptable to validate the methodology used in the design of RMB.

References

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