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ABOUT MEASURENTS OF NUCLEAR REACTOR'S ROD WORTH WITH THE ROD DROP TECHNIQUE

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1. Introduction

A major step for physical tests at reactor startup is to experimentally obtain the reactivity of the control rods. These tests are necessary to ensure that operational characteristics are met after the reactor fuel reload or some kind of large change.

In nuclear reactors there are control systems and safety rods as items of their formation, reactivity should be well known and, in power reactors, should be analyzed by direct measures [4].There are technical rods to determine the reactivity of the control rod, we can cite a few, such as: "neutron source multiplication method" [3], "Source Jerk" [8] and a "boron dilution" [2]. "Rod drop" is one of the best known techniques that come out to be an advantage over some other techniques because it is easy and quick to perform.

The concept of the technique is to drop a control at the moment when the reactor reaches is critically or very close to it, doing so in the position where reactivity is measured. Kinetics equations can be used to measure the reactivity of security rods in nuclear reactors [4], monitoring the neutron flow. With the fall of the security rods there is a change in the distribution of neutron flow, which causes the effect of shading on neutrons, especially those closest to the stem. The shadowing effect, by [10], can be understood as being a change in the efficiency of the detectors as soon as neutrons are detected, being more in evidence in the detectors closest to the inserted bank.

The neutron flux in the core can be analyzed through one or more neutron detectors, installed either in the central region or in the peripheral region of the core. These detectors emit signals that are interpreted by software that determines the reactivity. The method used in the reactor at the IPEN/ MB-01 is based on the reverse point kinetics equations, which come from the point kinetics equations.

Thus, the neutron detector will measure the flow of neutrons at a specific point in the reactor core, and the behavior of a nuclear reactor will depend on the average flow of neutrons in the core, the amount of neutrons produced in each generation. The introduction of the control rods distributes the neutron flux and, as a consequence, the measurements made by the neutron detector will not be proportional to the variation of the neutron flux in the core. The shadow effect can then be determined as a nonlinear variation in the detector for a linear variation in the total mean neutron flux.

This work aims to study and quantify the shadowing effect, which is the "wrong" measure of reactivity by flux distortion.

2. Methodology

Using the Monte Carlo method to obtain results from the Markov chains of probability theory, the MCNP software is used to develop the reactor model [1]. When dealing with nuclear reactors, this method will simulate a certain amount of neutrons and their descendants from the detailed calculation of their routes and collisions. From a sampling process, the random variables are selected by the sampling process, allowing the simulation of different processes with correct probabilities, having as an advantage the elimination of theneed to solve differential equations. However, its disadvantage is the computational cost to generate the amount of stories needed to get the desired statistical results.

Being a static model - which is sufficient for the success of this study - the MCNP does not describe a temporal behavior of the reactor and it is important to highlight that the codes cited are able to describe well the variation of the neutron flux spatial distribution. This is due to the insertion of a set of control rods, which is the main problem that this research proposes to solve.

It is also noteworthy that all the neutron calculations on which the work was based, used a complete three-dimensional model of the IPEN/MB-01 reactor written with the MCNP-6.2 code, in a semi-static regime, without considering any temporal evolution.

3. Results and Discussion

3.1 Control rod calibration curve

To construct the results we prefer to use a control rod calibration curve, which causes a graph of the insertion of the set ofcontrol rods versus the inserted reactivity. The calibration data of this set of control rods of the IPEN/MB-01reactor described in a COPESP report [7] allowed a proper comparison with the results. The computational model diluted the boron in the moderator so that the reactivity is zero, with all reactor rods removed from the core. In this critical state, a series of simulations was performed by inserting 10% of the length of a control rod in each simulation, until the complete insertion of all control rods. We can see the curve in the figure below (Figure 1).

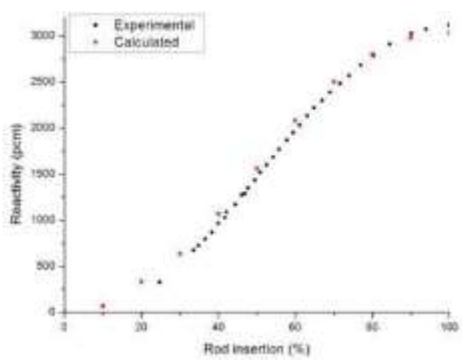

Figure 1: Reactivity versus Rod Insertion A for configuration

The data prove the legitimacy of the model performed in the MCNP-6.2 code. The propositions of reactor physics assert that [8];[5]: if the system is disturbed by more than one set of control rods, then a redistribution of the neutron flux, with a greater drop in the core flow, may occur.

This shadowing attached to the control rods, is caused by a type of black absorbent material. This means that if part of the control rods are partially inserted to keep the reactor in a critical state, and another set is fully inserted, then the reactivity will be greater than due to a single set of control rods.

Shadowing effect and correction factors

Based on the theory of shadowing effect quantification discussed earlier, it is possible to ascertain this effect in the IPEN/MB-01 reactor with the 28x26 configuration. Since the objective of this work is to measure the integral reactivity for only one set of control rods and to correct the reactivity of the core without any disturbance, it is also necessary to correct the initial state, which is already disturbed due to the insertion of 68% of the control rod set B, to the core criticalization.

As in the previous topic, the study of the shadowing effect for a set of control rods is similar to the study of the control rod calibration curve, because boron is initially diluted in the moderator to achieve zero reactivity (keff1) in the reactor, suggesting that the reactor is in a critical state with a uniform distribution of neutron flux. From this critical state, the set of control rods is inserted 10% of their total length at each stage of the simulation, until the complete insertion of the rods. The figure below (figure 2) represents the results obtained for the critical core with 28x26 configuration, inserted as described above, gradually.

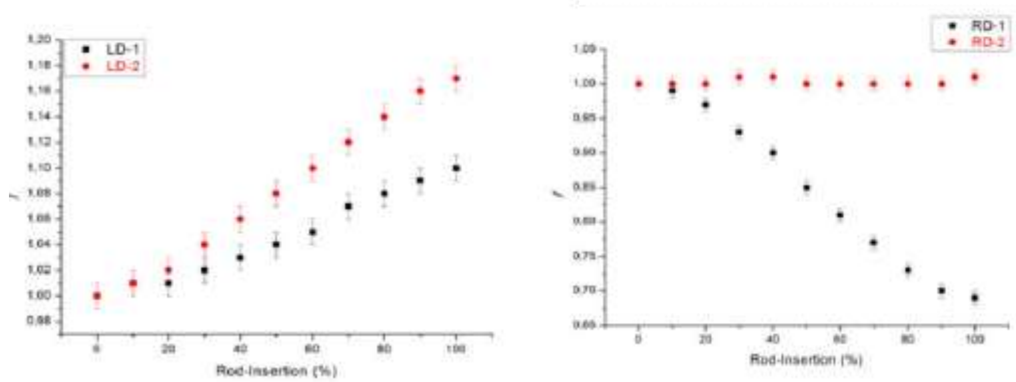

Figure 2.Shadowing effect over the detectors for a 28x26 configuration without diluted boron in the water and insertion of set A of control rods.

It is observed that the RD-1 detector presents the most disturbances, reaching a variation of the shadowing effect of 30%, because it is the detector closest to the set of control rods A, which are being inserted. On the other hand, the detector that suffers less perturbation with the shadow effect is not at a greater distance, the RD-2 remains almost constant during the simulation, varying around 1%, while the detector that is at a greater distance has a variation of 7% (LD-2).

Thus, the effect on the LD-1 detector will be proportional to that caused in the RD-2 detector by the set of control rods, because, symmetrically, the insertion effect on the set of control rods B is exposed based on A.

Rod-drop experiment

The results of the rod drop experiment were performed before the source method Jerk, using the software MCNP - 6.2. The simulation was performed in two different cases, both with 28x26 core configuration. The set of rods A was 0% and rods B with 68% inserted in the first, and 100% and 68% inserted in the second.In both, the analyzed data was the mean flow.

Estimation of reactivity using the Jerk Souce technique is also calculated for the average fuel flow through the MCNP-6.2 simulations. The measure of reactivity is important to determine the correction factor caused by the shadowing effect of the stems. We can see the results in Table I.

Detector	Calculated (pcm)	Experimental (pcm)	Difference (%)
LD-2	-3150±42	-3214±55	1.96
RD-1	-5650±70	-4852±188	-16.45
RD-2	-3520±46	-3592±35	2.00
LD-1	-2877±39	-3007±32	4.32
Fuel	-3614±46	-	-

Table I**:** Reactivity measured in the detectors determined through the rod-drop experimente and calculations with MCNP-6.2.

The questions raised at the beginning of this work were well related to the values obtained, in a generic way. Although the calculations were not made to correspond with the IPEN/MB-01 reactor configuration, since there is no experimental data for the calibration of the control rods of this reactor that took into account the **s**hadowing effect, its concepts can then be extended to other configurations, assuming that the physics described by the code will cover this effect. It is necessary to emphasize that the shadowing effect must take into account if the corrections in the rod drop experiment are applied, as a form of integral reactivity ina single group of control rods without the interference of the second.

Regarding the results of the **s**hadowing effect and the correction factors, it was expected that the detector closest to the control rods was the one that recorded the most disturbances, with the shadowing effect varying 30% in RD-1. On the other hand, the RD-2 detector remained constant in most of the experiment, with disturbances of only 1%, and without varying monotonically, and it is also possible to compare the simulated results with the experimentally obtained results.

4. Conclusions

The study used two approaches: a theoretical approach, using computational simulations of the shadowing effect in neutron detectors; and a technical approach of the rod drop technique to measure the integral reactivity of control rods. This shadowing effect represents a loss of efficiency in the measurement of reactivity in neutron detectors caused by the insertion of a black absorber (control rod). The work successfully described the use of the MCNP-6.2 software and achieved the quantification of the effect. Furthermore, these studies should build a more detailed model of neutron detectors. Further, methods to reduce experimental uncertainty must be investigated, and even the experiment is subject to re-evaluation in order to propose a way to improve data acquisition.

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