Control Rod Calibration and Reactivity Effects at the IPEN/MB-01 reactor

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Abstract. Researches that aim to improve the performance of neutron transport codes and quality of nuclear cross section databases are very important to increase the accuracy of simulations and the quality of the analysis and prediction of phenomena in the nuclear field. In this context, relevant experimental data such as reactivity worth measurements are needed. Control rods may be made of several neutron absorbing materials that are used to adjust the reactivity of the core. For the reactor operation, these experimental data are also extremely important: with them it is possible to estimate the reactivity worth by the movement of the control rod, understand the reactor response at each rod position and to operate the reactor safely. This work presents a temperature correction approach for the control rod calibration problem. It is shown the control rod calibration data of the IPEN/MB-01 reactor, the integral and differential reactivity curves and a theoretical analysis, performed by the MCNP-5 reactor physics code, developed and maintained by Los Alamos National Laboratory, using the ENDF/B-VII.0 nuclear data library.

Keywords: **IPEN/MB-01, MCNP-5, Control Rod Calibration, Reactivity, Temperature Correction**
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INTRODUCTION

It is known that the reactor neutron flux has its profile changed when an absorbing material is introduced. The introduction of a neutron absorbing material changes the multiplication factor and, therefore, the reactivity of the system. Thus, the determination of various reactivity effects in nuclear reactors is generally performed by compensating the reactivity given with the control rods to maintain the reactor critical.

The term “control rod calibration” is normally employed as the determination of the magnitude of the total reactivity of the rod, as well as the determination of the reactivity of each of its increments. In this context, calibration data are essential when are used as standards to measure reactivity changes caused by any disturbance in a reactor.

This work presents a comparison between the experimental data of the control rod calibration for the IPEN/MB-01 nuclear reactor and the correspondent results of simulations performed by the MCNP-5 reactor physics code using the ENDF/B-VII.0 nuclear data library and considering a temperature correction.

MATERIALS AND METHODS

It is known that the reactivity can be obtained through various methods. In this work, the inverse kinetics method was chosen. This method is based on the temporal evaluation in real time of the reactor neutronic population through signs of the neutron detectors. The application of this method begins with the analysis of the point kinetic equations:

$$\frac{dN(t)}{dt} = \frac{\rho(t) - \beta}{\Lambda} N(t) + \sum_{i=1}^{6} \lambda_i C_i(t) \tag{1}$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} N(t) - \lambda_i C_i(t) \tag{2}$$

In which “N(t)” is the neutronic population at the instant “t”; “ρ(t)” is the reactivity at the instant “t”; “β” is the delayed neutrons effective fraction ; “β_i” is the delayed neutrons abundance of the i-th precursors group; “λ_i” is the decay constant of the i-th precursors group; “$C_i(t)$” is the precursors concentration of the i-th group at the instant “t”; “Λ” is the prompt neutrons generation time.

Solving the differential equation (2), substituting the result of “$C_i(t)$” in equation (1) and expliciting “ρ(t)”, it leads us to the inverse kinetic equation:

$$\rho(t) = \frac{\Lambda}{N(t)} \frac{dN(t)}{dt} + \beta - \frac{N_0}{N(t)} \sum_{i=1}^{I} \beta_i e^{-\lambda_i t} - \frac{1}{N(t)} \sum_{i=1}^{I} \lambda_i \beta_i e^{-\lambda_i t} \int_{t'}^{t} N(t'') e^{\lambda_i t''} dt'' \tag{3}$$

For an accurate determination of the reactivity, it was used a "reactivity meter", developed at IPEN. This device is able to measure both positive and negative reactivity and the conversion of the signals from the detector in reactivity is performed by an algorithm based on the inverse kinetic theory, solving equation (3).

It is important to note that reactivity worth measurements are very delicate and easily influenced by temperature.[2,3,4,5] It was necessary to correct all results of the experiments[6] for the temperature of 20.5°C, to be possible make the comparison with the theoretical results. The theoretical analysis was performed by the reactor physics code MCNP-5, using the nuclear data library ENDF/B-VII.0.

The temperature is monitored from twelve thermocouples distributed by the reactor core as shown in Figure 1.

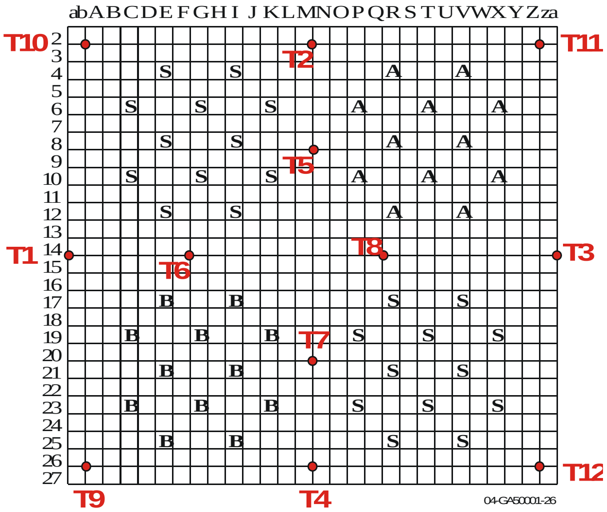

FIGURE 1. Position of termocouples at IPEN/MB-01 nuclear reactor. S, A and B means, respectively: security rods and control rods (A and B).

First of all, the control bank B was initially completely inserted and the control bank A completely withdrawn from the active region (the A and B positions can also be seen in figure 1). The measurements were being performed by inserting the control bank A (moving it little by little, each more inside the nuclear core); then moving the control bank B (removing it little by little from the core) and measuring, then, the difference of reactivity and the accumulated reactivity in each step. The total number of steps considered were 54. During this kind of experiment the reactor should remain in critical condition, and the movement of a control bank compensates the withdrawn of the another.

Considering the values of the acquired reactivity, it was possible to plot the differential and integral curves for each control bank, using the mathematical software pakage OriginLAB^{TM} v7.5. The differential curve presents the control bank reactivity for each step considered, and the integral curve presents the total reactivity inserted by the control bank.

The differential data may be adjusted as a non linear fitting, as a sine function; and the integral data may also be adjusted as a non linear fitting, but as a sigmoidal (Boltzmann) function.

RESULTS

The figures 2 and 3 show some experimental Control Rod Calibration data, the respective theoretical results for the IPEN/MB-01 nuclear reactor, and the coefficients obtained through the non-linear curve fitting. All results were corrected for a temperature of 20.5°C, the temperature considered by the MCNP-5 code.

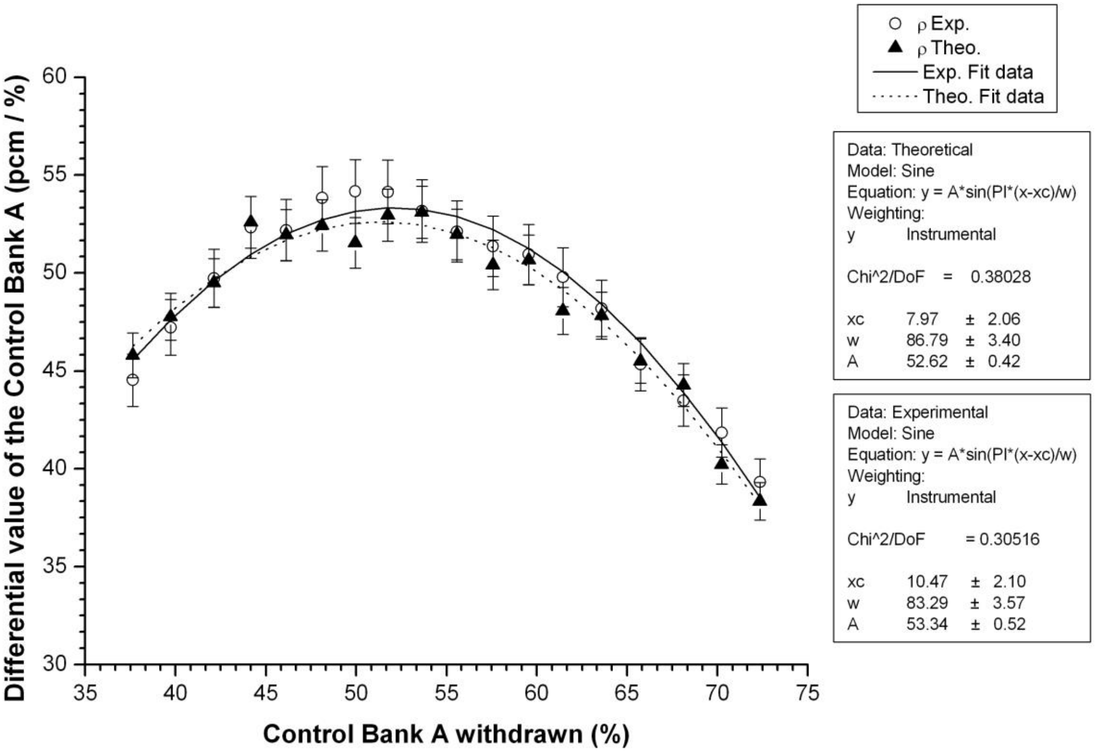

FIGURE 2. Differential Curve for Control Bank A.

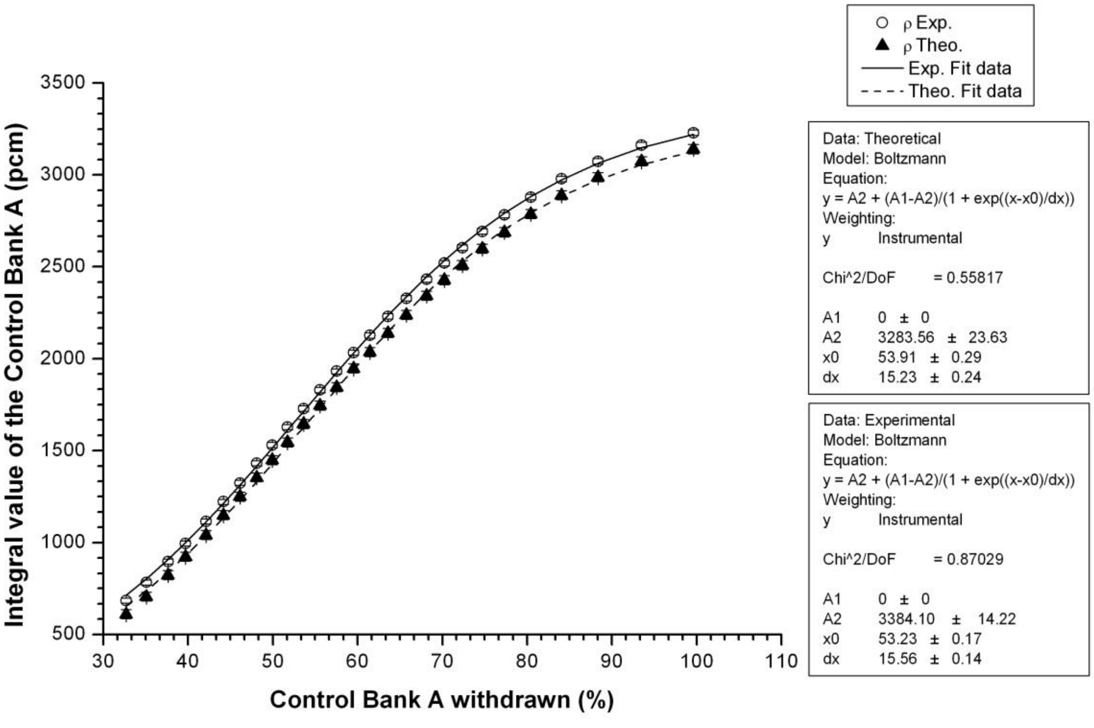

FIGURE 3. Integral Curve for Control Bank A.

It is possible to notice, in Figure 2, and also in Figure 3, that the graph does not show the Control Bank withdrawn from 0% up to 100%. This is due to the fact that the experiment was carried out in critical condition and, to maintain the criticality during the experiment, the Control Banks could not be completely removed or completely withdrawn from the nuclear reactor core.

One should also notice that, in figures 2 and 3 it appears a value “Chi^2/DoF”. It is not the same as the Chi-Square, but the Chi-Square divided by the number of the degrees of freedom. Thus, these values led us to a Chi-Square of 5.7042 for the theoretical case presented in figure 2, and a Chi-Square of 4.5774 for the experimental one presented also in figure 2, corresponding to the differential curve. In figure 3, corresponding to the integral curve, the value of Chi^2/DoF led us to a Chi-Square of 7.81438 for the theoretical case and 20.88696 for the experimental one. Considering these results, it can be concluded that the adjustments were excellent and the mathematical models used describe very well the physics of the problem.

CONCLUSIONS

It must be noticed that the temperature correction for the reactivity and the respective computer simulation are a sophisticated approach for the control rod calibration problem, and in this context this work is considered relevant.

The theoretical and experimental curves obtained were extremely similar, indicating a good reliability of the ENDF/B-VII.0 nuclear data library utilized by the MCNP-5 reactor physics code.

The results can be considered especially important because, besides being able to contribute as a reference, they confirm the quality and accuracy that can be obtained in the reactor facility IPEN/MB-01[7], using the digital reactivity meter developed therein.

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