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MCNP ISOTHERMAL REACTIVITY CALCULATIONS OF THE IPEN/MB-01 ZERO-POWER REACTOR

Wilson J. Vieira, Luiz H. Claro, and Hélio Yoriyaz *

Instituto de Estudos Avançados, CTA/IEAv
Caixa Postal 6044
12231-970, São José dos Campos, SP

* Instituto de Pesquisas Energéticas e Nucleares, IPEN
Av. Prof. Lineu Prestes, 2242 – Cidade Universitária
05508-000, São Paulo, SP

ABSTRACT

The inversion point of the isothermal reactivity coefficient of the IPEN/MB-01 critical assembly was calculated using a correlated sampling Monte Carlo technique. Several sets of cross sections were generated for temperatures from 8.5° up to 25° Celsius to account for $S(\alpha,\beta)$ corrections. Also, a very detailed geometry representation was modeled. The results show that the inversion point is around 13 degrees Celsius. Although the standard deviation of the criticality coefficient calculations were very large, around 0.002, the correlated sampling technique allowed the utilization of the Monte Carlo method with errors smaller than 0.001. Although more studies are necessary, this work illustrates a very promising application of Monte Carlo methods in the solution of perturbations in criticality problems.

Keywords: zero-power reactors, Monte Carlo analysis, isothermal reactivity.

I. INTRODUCTION

In this work is attempted the calculation of the temperature for which the isothermal reactivity coefficient of a reactor system becomes positive. The calculations were based on an experiment in the IPEN/MB-01 reactor facility [1]. Besides being an extremely difficult experimental procedure, this problem is poses a real challenge to Monte Carlo analysis.

It is well known that Monte Carlo is not very suitable for sensitivity analysis. This is because of the statistical nature of the method, which makes very difficult to measure small differences or small perturbations. New methodologies, such as the correlated sampling Monte Carlo technique [2], are being developed to make possible the utilization of Monte Carlo for the calculation of perturbations in criticality problems.

Section II gives a brief description of the IPEN/MB-01 reactor and Section III gives details of the cross section libraries that were used. Section IV shows the major steps in the setup of the MCNP [3] simulation. The results are illustrated and commented in Section V.

II. IPEN/MB-01 REACTOR DESCRIPTION

To take advantage of the MCNP program geometry capacity, the IPEN/MB-01 zero-power reactor was modeled with great precision of details [1]. This reactor consists of a square assembly of 28 x 26 UO_2 fuel rods inside a water tank. The control bank is made of 12 Ag-In-Cd rods and the safety bank of 12 B_4C rods. There are two safety banks that are considered 100% inserted, and two control banks, one is considered always 58.50% withdrawn and the other is used to achieve criticality.

All dimensions, compositions, and diagrams can be found in greater detail in Reference [1].

III. CROSS SECTION LIBRARY

For the MCNP-4B Monte Carlo solution of the problem it was used the **.50c** library for all elements except Silver and Indium, which was used the **.60c** library. The calculations were made for temperatures between 8.5° C and 25° C. This makes extremely important to consider the scattering effects on the cross sections, due to atomic and molecular crystal bonding. In this case the Hydrogen bonding in water. To account for this condition, the NJOY

[4] system was used, in especial the LEAPR module that prepares the Hydrogen cross-section containing the scattering laws $S(\alpha,\beta)$.

There was one NJOY calculation for 34 temperature values between 8.5°C and 25°C. Each calculation generated a set of $S(\alpha,\beta)$ cross sections, which were used in another 34 MCNP fixed source calculations.

Fig.1 shows a diagram explaining the NJOY modules that were used.

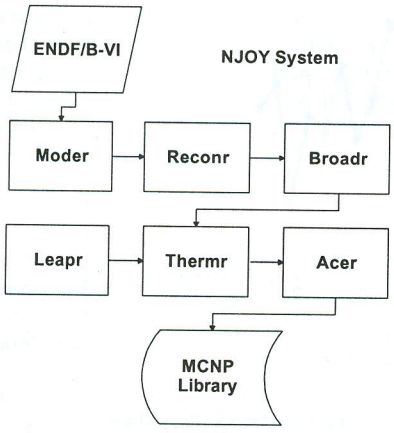

Figure 1. Cross Section Generation.

There was no attempt to use other cross sections libraries. However, this problem requires more cross section studies considering more details of temperature, fuel, control and safety rods, moderator, and structural material. This studies will need much more processing time.

IV. METHODOLOGY

In this work, the application of the correlated sampling technique consisted of the transformation of the criticality problem into a fixed source problem. Therefore, the analysis using the same random number stride could be easily implemented.

It is important to know in advance that the control bank insertion and withdrawal range to obtain criticality from 10° to 20°C is of the order of 2 mm [1]. Initial runs of the multiplicative problem showed that the processing times to obtain the necessary standard deviations would not be feasible.

The MCNP Monte Carlo procedure is detailed below and the MCNP card nomenclature is used to facilitate description. The necessary steps are:

1. A small run using a KSRC source cards with fuel rods coordinates yields an initial SRCTP source.
2. A very large SRCTP source is generated for the critical position of the BC1 control bank at a given temperature. MDAS had to be change to 16 millions words to use a batch of 5 million particles. This was necessary to yield a very well sampled fission source.
3. The fission source is then transformed into a fixed volumetric source RSSA using card SSW. To do this its necessary to use cards NONU and TOTNU in the fixed problem solution.
4. To calculate k_{eff} in the fixed source problem solution it is used a F4 detector with an FM4 card to multiply by $\nu\Sigma_f$, and a SD1 card.
5. All calculations used the same RSSA source.

V. RESULTS

Table 1 shows the results for several temperatures and corresponding water densities.

TABLE 1. k_{eff} Results for 500 000 Particles

Temp. (Celsius)	k_{eff}	Mean Difference	SD of the Difference
8.50	1.0033	0.00000	0.00000
9.00	1.0033	0.00000	0.00071
9.50	1.0029	-0.00046	0.00058
10.00	1.0020	-0.00090	0.00065
10.50	1.0035	0.00144	0.00067
11.00	1.0031	-0.00040	0.00070
11.50	1.0037	0.00082	0.00098
12.00	1.0044	0.00053	0.00095
12.50	1.0044	0.00011	0.00055
13.00	1.0051	0.00053	0.00081
13.50	1.0046	-0.00033	0.00073
14.00	1.0033	-0.00124	0.00084
14.50	1.0034	0.00004	0.00072
15.00	1.0027	-0.00070	0.00067
15.50	1.0024	-0.00041	0.00092
16.00	1.0030	0.00049	0.00091
16.50	1.0023	-0.00076	0.00053
17.00	1.0027	0.00057	0.00089
17.50	1.0012	-0.00139	0.00083
18.00	1.0018	0.00054	0.00076
18.50	1.0019	0.00010	0.00083
19.00	1.0030	0.00110	0.00055
19.50	1.0017	-0.00136	0.00071
20.00	1.0018	-0.00001	0.00093
20.50	1.0027	0.00112	0.00099
21.00	1.0031	0.00029	0.00080
21.50	1.0019	-0.00114	0.00082
22.00	1.0012	-0.00070	0.00067
22.50	1.0024	0.00120	0.00058
23.00	1.0013	-0.00104	0.00084
23.50	1.0016	0.00030	0.00065
24.00	1.0003	-0.00136	0.00060
24.50	1.0021	0.00180	0.00080
25.00	1.0017	-0.00040	0.00073

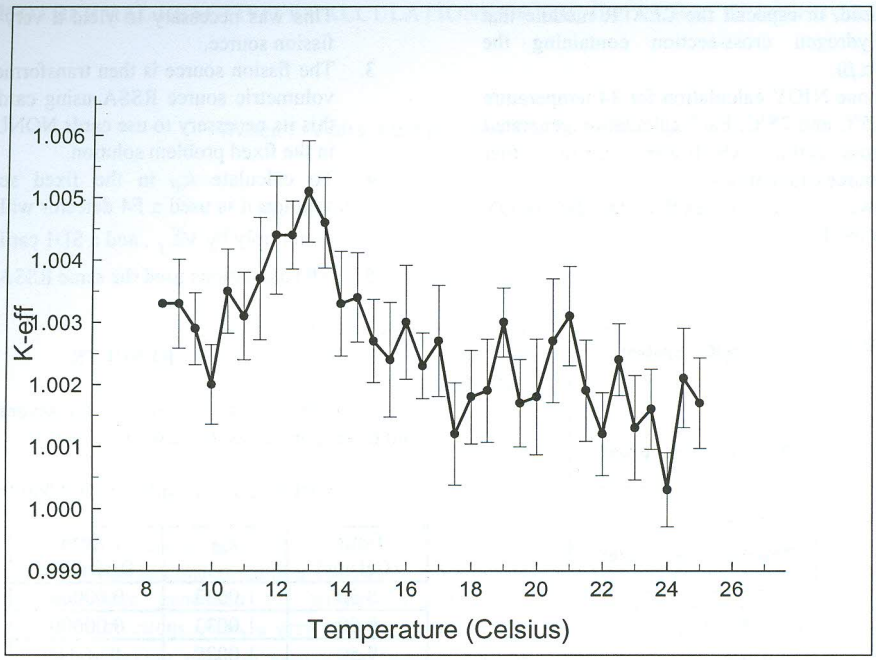

Figure 2. k_{eff} and Standard Deviation of the Mean of Differences versus Temperature.

The application of the correlated sampling concept considers that the differences between successive calculations is also a random variable, and the expected value of this random variable and of its standard deviation are measures of the perturbation effects.

The preliminary attempts to calculate reactivity differences using the multiplicative problem yielded fractional standard deviations for all temperatures of the order of 0.2%, which are large enough to encompass all results in the same confidence interval. For the correlated sampling method, however, the same random number stride and the same fixed source were used for each problem, so that the differences between the solutions are expected to be due to only minor differences in the equivalent histories in each of the problems.

To take into account only those minor differences between equivalent histories, a correlated sampling technique, which uses batch intermediate results to calculate the mean of the difference between two successive calculations and its associated batch standard deviation. This technique was verified to be not very effective in this case because the temperature perturbation is not a local perturbation. In a local perturbation most histories in the perturbed and unperturbed calculations are the same and the standard deviation will come from only those histories that had contributions affected by the presence of the perturbation. On the contrary, the temperature perturbation is not a localized perturbation and causes that all histories present small differences. Therefore, it is necessary to increase the number of histories and to decrease the temperature intervals to obtain even smaller standard deviations.

The column "Mean Difference" in Table 1 is calculated taking into account the batch output of the MCNP code, which in this case printed out sixteen intermediate values of the calculation. Obviously, the mean difference is the same as the difference between two successive calculations, however, the sixteen batches calculation allows the calculation of the standard deviation of these sixteen differences between subsequent values of k_{eff}. The first line is null because the difference calculation looses one degree of freedom. The expected value of the difference is the effect of the perturbation, which ideally should be very small. Therefore, the standard deviation of a small quantity with smaller variations will be smaller than the standard deviation of the total mean. In this problem the k_{eff} estimates had standard deviations around 0.002, and the standard deviations of the differences caused by the temperature perturbations were less than 0.001 (see Table 1), which is only a factor of 2 increase in the calculational efficiency.

The use of the same control bank position for all temperatures is of course not correct, but the differences in reactivity given by the differences in subsequent estimates of the k_{eff} for each temperature variation are expected to yield the inversion point. This is also the main difference between the approach taken in this work and the experimental procedure [1], which measures the control bank position for the critical reactor at each temperature.

Fig. 1 shows the k_{eff} for temperatures from 8.5 up to 25 degrees Celsius with a 0.5 degree interval, and the standard deviation of the mean of differences. It is possible to infer that the inversion point is around 13 degrees Celsius. The experimental inversion point of the temperature published in Ref. [1] is $14.99 \pm 0.15^{\circ}C$.

The standard deviations that were calculated are extremely large to guarantee the inversion point. However, the correlated sampling technique proved to be very attractive, although, the computer processing time to achieve sufficient confidence in the Monte Carlo results is still very large.

VI. CONCLUSIONS

The Monte Carlo results obtained in this work show that the correlated sampling technique is very well suited to perform reactor perturbation calculations. Although, it is far more computationally expensive than deterministic solutions, it showed the possibility of obtaining reasonably accurate solutions.

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