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MEASUREMENT OF THE NEUTRON FLUX IN THE CORE OF THE IPEN/MB-01 REACTOR BY IRRADIATION OF ACTIVATION FOILS

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ABSTRACT

The knowledge of the neutron flux in the core of a reactor is of fundamental importance for determining the power it generated, the burning of nuclear fuel and the consequent estimate of the lifetime of a particular configuration of a core, in addition to the validation of the methodology of calculation used in the design of the reactor's core. Through the technique of activation analysis it was determined the neutron flux in three separated bands of energy, thermal, intermediate and fast. For this purpose it was used activation foils, in special infinitely diluted gold foils to determine the thermal and intermediate flux and indium foils to determine the fast flux. For the analysis it was used the gamma spectrometry that has been made using a detection system of hyper-pure germanium detector (HPGe) and MAESTRO software for the gamma spectra data analysis. The knowledge of the net count of the element formed for each position of the irradiation, which is obtained by the induced activity and consequently the neutron flux in the point in question. The measured values of thermal, intermediate and fast neutron flux in the core of the reactor in its default configuration rectangular 28x26 fuel rods were compared with those obtained by the reactor physics codes MCNP and the result shows a good agreement.

1. INTRODUCTION

The neutron flux in a reactor can be obtained through several techniques and the technique used in this work is called the activation analysis. This technique consists in submitting a metallic foils to a neutron flux in the core of the reactor and in obtaining the activation of the nucleus present in the target.

After the activation of the nucleus, we are interested in obtaining the counting of the radioactive nucleus formed in the irradiation by the gamma spectrometry. Thus, we can obtain the activity from the target in the point of irradiation and consequently the neutron flux.

This work aims of calculating the values of the thermal, the intermediate and the fast neutron flux in several points of interest in the IPEN/MB-01 reactor and also comparing these experimental values with the values obtained through the MCNP-4C code.

2. EXPERIMENTAL METHODOLOGY

In this work we chose infinitely diluted gold foils as activation detectors to determine the thermal and intermediate neutron flux. These foils are chosen because of the phenomena of flux disturbance, as the self-shielding factors to the neutrons become worthless. These foils have only 1% of dispersed gold atoms in an aluminum matrix containing 99% of this element [1].

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The dimensions of these foils are 0.02 mm and 7.50 mm of thickness and diameter, respectively. The distribution of them was done in an acrylic plate in an arrangement of 5x7 and a total of 35 foils irradiated, as showed in the Fig. 1.

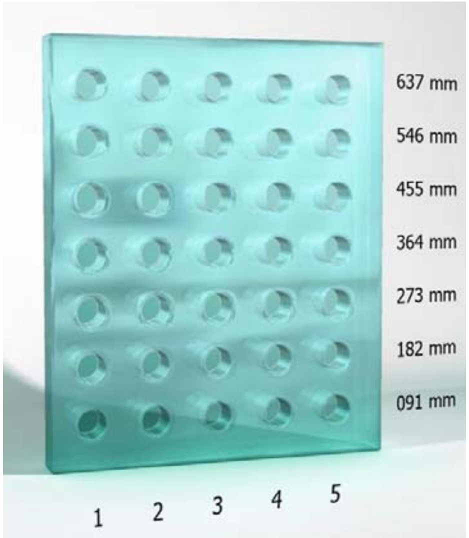

Figure 1. Illustration of the acrylic plate and the axial positions of the activation foils.

The first line of the acrylic plate is indicated as 91 mm and corresponds to the beginning of the active region (fuel rod → UO_2) and the last line is indicated as 637 mm and it is the end of the active region. The height of the active region is 546 mm and corresponds to the height of the fuel rod. These positions are called axial.

The radial positions 1 to 5 in each axial cote correspond to 15.0 mm, 112.5 mm, 210.0 mm, 307.5 mm and 405.0 mm. The radial length of the core of the IPEN/MB-01 reactor is 420 mm.

In this work we mapped half of the core of the IPEN/MB-01 reactor (the north region) and 4 planes of irradiation were chosen. These planes are positioned between the fuel rods and located in the moderator (light water), as showed in the Fig. 2.

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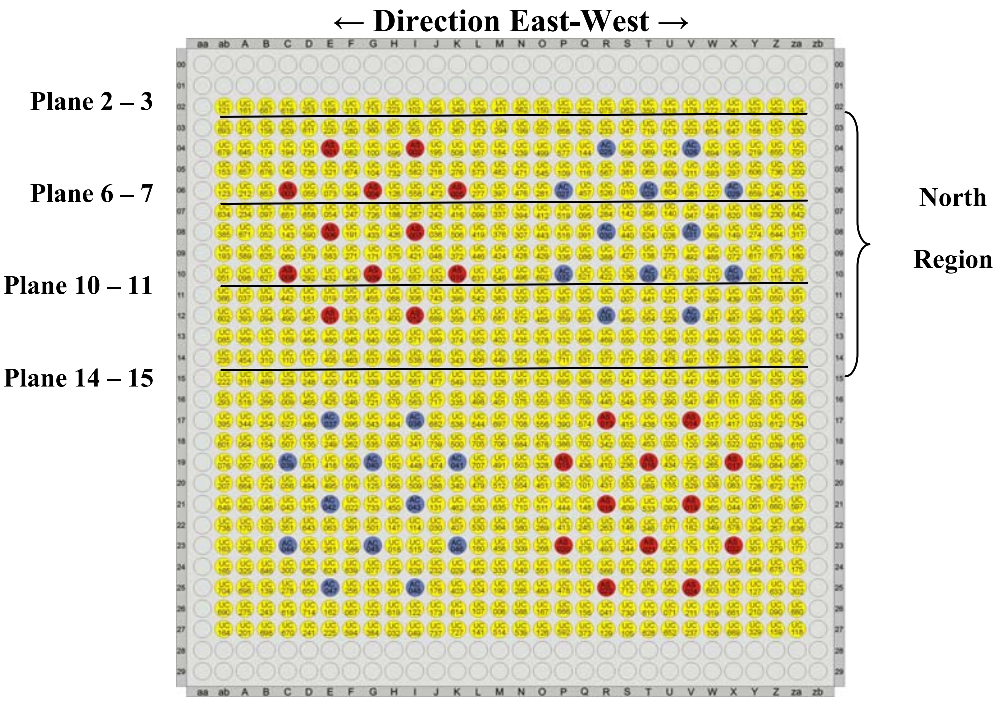

Figure 2. Configuration of the IPEN/MB-01 reactor and the planes of irradiation.

In the core 140 points are mapped, thus, 35 positions per plane of irradiation. For each point it was irradiated a bared foil and a foil covered with cadmium. We adopted this procedure to determine the cadmium ratio, R_{cd}, in each position.

After the irradiations, the foils were analyzed in the detection system of hyper-pure germanium (HPGe), as showed in the Fig. 3:

Figure 3. The detection system of hyper-pure germanium (HPGe).

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With the values of the net counting for each foil, the next step is to obtain the saturation activity by the following Equation (1) [2],

$$A^{\infty} = \frac{e^{\lambda t_e} C}{\varepsilon \; I \; LT(1 - e^{-\lambda t_i})} \frac{F_r F_a}{F_n}, \tag{1}$$

where λ is the decay constant, t_e is the waiting time to the gamma spectrometry after the irradiation, C is the net counting of the gamma energy, ε is the global efficiency of the system of the gamma spectrometry, I is the branching ratio to the gamma energy, LT is the counting time during the gamma spectrometry discounted the background, t_i is the irradiation time, F_r is the ramp factor, F_n is the factor which considers the little fluctuation in the power level between the several irradiations and F_a is the self-absorption factor.

The thermal neutron flux can be obtained by the following Equation (2) [3],

$$\phi_{th} = \frac{A^{\infty}_{Bared}\left(1 - \frac{F_{cd}}{R_{cd}}\right) P_a}{N_a m \sigma_{atv}} \tag{2}$$

where P_a is the atomic weight of the target nucleus, N_a is the Avogadro's number, m is the mass of the activation foil, σ_{atv} is the microscopic activation cross section and F_{cd} is the factor cadmium (1.054) [1].

The intermediate neutron flux can be obtained by the following Equation (3) [3],

$$\phi_{\text{int}} = \frac{A^{\infty}_{Bared}}{N_T I^{\infty}_R R_{cd}} \ln \frac{E_2}{E_{cd}} \tag{3}$$

where N_T is the total number of atoms in the target, I^{∞}_R is the resonance integral, R_{cd} is the cadmium ratio, E_2 is the energy between intermediate and fast regions (1.05 MeV) and E_{cd} is the cut-off energy (0.55 eV) [4].

Thus, we can calculate the values of the thermal and intermediate neutron flux in each irradiated position. Then, we obtain the average to the neutron fluxes per plane of irradiation and consequently the average neutron fluxes in the core of the reactor.

3. RESULTS OF THE THERMAL AND INTERMEDIATE NEUTRON FLUX

The value obtained of the average thermal neutron flux in the reactor core at 100 watts power level is given below:

$$\overline{\phi}_{th} = 9.4340 \text{ x } 10^8 \text{ n/cm}^2 \text{ s} \pm 2.45\%,$$

and the Fig. 4 shows the thermal neutron flux per plane of irradiation.

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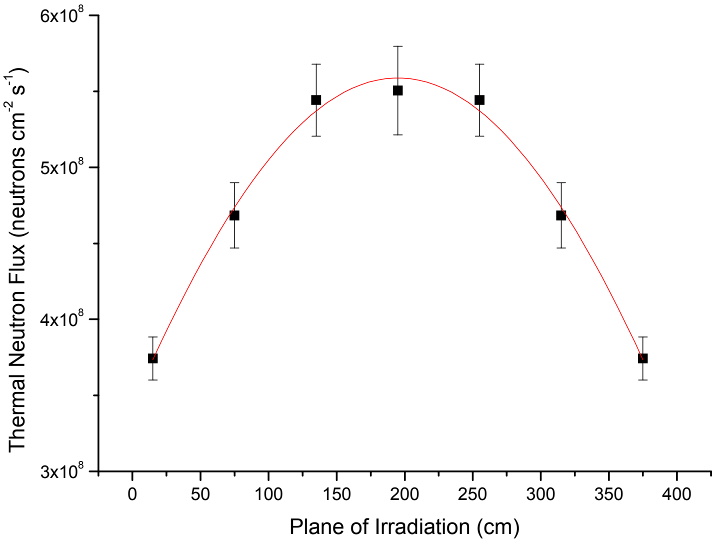

Figure 4. Thermal neutron flux in each plane of irradiation.

The average intermediate neutron flux obtained in the reactor core at 100 watts power level is given below:

$$\overline{\phi}_{int} = 7.9846 \text{ x } 10^8 \text{ n/cm}^2 \text{ s} \pm 0.32\%,$$

and the Fig. 5 shows the intermediate neutron flux per plane of irradiation.

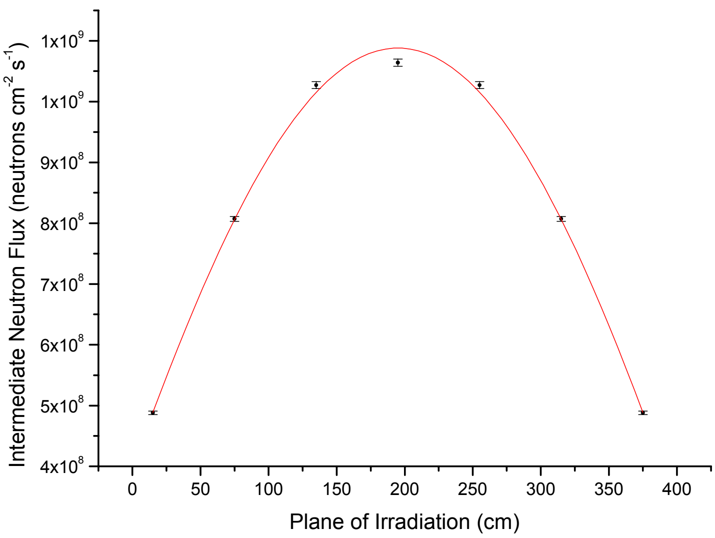

Figure 5. Intermediate neutron flux in each plane of irradiation.

The next tables show the comparisons between the experimental and MCNP-4C [5] values of the thermal and intermediate neutron flux in determined positions in the core of the IPEN/MB-01 reactor.

All the next positions correspond to the plane of irradiation 14-15 (central plane), as showed in the Fig. 2. The first column in the Table 1 corresponds the axial positions.

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Table 1. Comparison between the experimental and MCNP-4C relative results of the thermal neutron flux in the central axial positions of the core.

Axial Position (mm)	Experimental	MCNP-4C	C/E
91	0.6656	0.6810	1.0231
182	0.6792	0.7897	1.1626
273	0.8972	1.0000	1.1146
364	1.0000*	0.9220	0.9220
455	0.5877	0.7710	1.3118
546	0.4717	0.4594	0.9739
637	0.2996	0.2835	0.9462

* Absolute value at central position of the core: $(9.4754 \pm 0.06679).10^8$ $n/cm^2.s$ at 100 watts power level.

The radial positions of the plane of irradiation 14-15 correspond to the middle of the height of the active region (Axial Position 364 mm).

Table 2. Comparison between the experimental and MCNP-4C relative results of the thermal neutron flux in the radial positions in the direction West-East.

Radial Position (mm)	Experimental	MCNP-4C	C/E
15.00	0.5974	0.5542	0.9277
112.50	0.8399	0.8032	0.9563
210.00	1.0000*	1.0000	1.0000
307.50	0.7431	0.7912	1.0647
405.00	0.5695	0.5799	1.0183

* Absolute value at central position of the core: $(1.7529 \pm 0.02524).10^9$ $n/cm^2.s$ at 100 watts power level.

The Tables 3 and 4 refer to the intermediate neutron flux.

Table 3. Comparison between the experimental and MCNP-4C relative results of the intermediate neutron flux in the central axial positions of the core.

Axial Position (mm)	Experimental	MCNP-4C	C/E
91	0.3801	0.3633	0.9558
182	0.7743	0.7989	1.0317
273	1.0000*	1.0000	1.0000
364	0.9882	0.8993	0.9100
455	0.7815	0.7001	0.8958
546	0.5098	0.5033	0.9872
637	0.2235	0.1990	0.8904

* Absolute value at central position of the core: $(1.7529 \pm 0.02524).10^9$ $n/cm^2.s$ at 100 watts power level.

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Table 4. Comparison between the experimental and MCNP-4C relative results of the intermediate neutron flux in the radial positions in the direction East-West.

Radial Position (mm)	Experimental	MCNP-4C	C/E
15.00	0.4272	0.4419	1.0344
112.50	0.8408	0.8643	1.0295
210.00	1.0000*	1.0000	1.0000
307.50	0.8522	0.8256	0.9688
405.00	0.4506	0.4508	1.0004

* Absolute value at central position of the core: (1.7529 ± 0.02524).10^9 n/cm^2.s at 100 watts power level.

The nuclear data library used was the ENDF/B-VI library for all chemical elements used in the MCNP code. Only for the element cadmium it was used the nuclear data library NJOY.

4. RESULTS OF THE FAST NEUTRON FLUX

The research group of the IPEN/MB-01 made a study about the spatial distribution of fast neutron flux in the core of the reactor at 100 watts power reactor [6].

In this experiment indium foils were irradiated in several points. To compare the results we simulated some points of interest in the MCNP-4C. In this work, we adopted as fast neutron flux, the neutrons above 0.82 MeV. The cross section above this value of energy was obtained by Santos [7] to inelastic nuclear reaction ^{115}In(n,n')^{115m}In using reactor physics codes. The value of the cross section calculated above 0.82 MeV is 0.23385 barns ± 5%. This kind of nuclear reactions (n,n') are typically endothermics, because it is necessary a minimum of neutron energy to start to occur.

The fast neutron flux can be obtained by indium foils using the following Equation (4), [6]

$$\phi(E \geq 0.82MeV) = \frac{A^{\infty}}{N_T \sigma(n,n')} \tag{4}$$

where N_T is the total number of atoms presents in the foil, A^{∞} is the saturation activity in the indium foils and $\sigma(n,n')$ is the cross section to inelastic nuclear reaction between the indium atoms and the fast neutron with energy above 0.82 MeV.

The Table 5 compares the relative radial positions of the plane of irradiation 14-15 and the height where the indium foils were distributed in the core of the reactor which is 225 mm from the beginning of the active region.

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Table 5. Comparison between the experimental and MCNP-4C relative results of the fast neutron flux in the radial positions West-East.

Radial Position (mm)	Experimental	MCNP-4C	C/E	Citation Code	C/E
-25[b]	0.2064	0.1599	0.7747	0.2089	1.0121
15	0.5137	0.4335	0.8439	0,4819	0.9381
55	0.6661	0.6472	0.9716	0.6633	0.9958
95	0.8171	0.7643	0.9354	0.8108	0.9923
135	0.9176	0.8724	0.9507	0,9184	1.0009
175	0.9638	1.0000	1.0376	0,9849	1.0219
215	1.0000[a]	0.9032	0.9032	1.0000[c]	1.0000
255	0.9404	0.9029	0.9601	0,9604	1.0213
295	0.8540	0.8555	1.0018	0.8741	1.0235
335	0.7515	0.7091	0.9436	0.7461	0.9928
375	0.5924	0.5970	1.0077	0.5844	0.9789

a - Absolute value: ($1.408.10^{9} \pm 0.116$) $n/cm^2.s$ at 100 watts power reactor;
b - Out of the core 25 mm at west face of the core;
c - Calculated value by Citation code at central position of the core: $1.263.10^9$ $n/cm^2.s$.

5. CONCLUSION

The experimental values obtained are very important to know the neutron flux in determined positions in the core of the reactor IPEN/MB-01 and also to compare them with the calculated methodology using MCNP and Citation code [8,9] and its nuclear libraries associates.

The experimental uncertainties of the thermal, intermediate and fast neutron flux measured are 7.0%, 1.5% and 8.3%, respectively. The uncertainties calculated by the MCNP are 5%, 2% and 4% for the thermal, intermediate and fast neutron flux, respectively. Thus, when the relative neutron flux distribution in the core is compared with its associated uncertainties most results have good agreement as it can be seen in the Tables 1, 2, 3, 4 and 5.

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