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CALIBRATION OF THE NUCLEAR POWER CHANNELS OF THE IPEN/MB-01 REACTOR: MEASUREMENTS OF THE SPATIAL NEUTRON FLUX DISTRIBUTION IN THE CORE USING INFINITELY DILUTE GOLD FOILS

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ABSTRACT

Several nuclear parameters are obtained through the spectrometry gamma of targets irradiated in a research reactor core and this is the case of the activation foils which make possible through the measurements of the activity induced to determine the neutron flux in the place where they had been irradiated. The power level operation of the reactor is a parameter directly proportional to average neutron flux in the core. This work aims to get the spatial neutron flux distribution in the core of IPEN/MB-01 reactor by the gold foil irradiation infinitely diluted and prudently located in its interior. These foils were made in the form of metallic alloy in concentration levels such, that phenomena of flux disturbance, as the self-shielding factors to neutrons, if become worthless. These activation foils has only 1% of dispersed gold atoms in an aluminium matrix contend 99% of this element. The irradiations of foils have been carried through with and without cadmium plate. The total correlation between the average thermal neutron flux obtained by irradiation of infinitely diluted activation foils and the average digital value of current of the nuclear power channels 5 and 6 (compensated ionisation chambers), provide the calibration of the nuclear channels of the IPEN/MB-01 reactor calibration.

1. INTRODUCTION

The accurate determination of the operational power level of a nuclear research reactor is very important by several accounts such as safety conditions, operational limits, burn up fuel, irradiations to activations purposes, etc.

This work aims to measure the power level of the IPEN/MB-01 [1] by irradiation of the gold infinite dilute foils irradiation to account the average thermal neutron flux in the reactor core. The same ways during the irradiation of the foils are made the measurements of the nuclear power channel and the correlation between the nuclear power channel signal and the average thermal neutron make possible the nuclear channels reactor calibration.

The determination of the power level by activation method can be obtained by the following expression (1). [2]

$$P = G.\overline{\Sigma}_f \,.\, \overline{\Phi_{th}} \,.F.R.V \qquad (1)$$

Where G is the recoverable energy per fission (200 MeV = $3.2.10^{-11}$ joules), $\overline{\Sigma}_f$ the average macroscopic cross section, $\overline{\Phi_{th}}$ the average thermal neutron flux, F is a factor that considers the ratio between the neutron flux in the fuel to neutron flux in the moderator (disadvantage thermal factor), R the fast fission factor and V is the volume of the fuel in the reactor core. This value to IPEN/MB-01 core is 21019 cm^3.

Therefore, since measured the average thermal neutron flux in the reactor core it is possible to obtain the reactor power because the other parameters can be estimate by calculation methodology using cellular transport codes such as Hammer-Technion code [2]. Thus the parameters estimate by cells representative of the IPEN/MB-01 core were $\overline{\Sigma}_f$ = 0.3494 cm^{-1}, F = 0.769 and R = 1.155 [2]. These values can be calculated too by Monte Carlo methodology by MCNP-4C code [3].

2. EXPERIMENTAL METHODOLOGY

The infinite dilute foil used in this work is a gold-aluminum alloy. The 1% of the total mass is due gold atoms and 99 % aluminum atoms. These foils were manufactured by Institute of Material and Measurements (Joint Research Centre at European Commission). The diameters and the thickness are 7.5 mm and 0.2 mm, respectively.

The advantage of the using infinite dilute foils instead of gold pure foils is that the perturbation of the neutron flux is negligible [4] because the self-shielding factor is very small. The disadvantage is that the foils have few quantities of the gold atoms then the activation is small and the statistical count obtained during the gamma spectrometry is poor. Thus in order to avoid this disadvantage is necessary to irradiate the foils in the maximum power level reactor. The maximum power level to IPEN/MB-01 reactor is 100 watts that corresponds to the thermal neutron flux of $\Phi_{th} = (9.8087 \pm 0.4974).10^8$ $n/cm^2.s$ [5] at central position of the core (rectangular configuration 28x26 fuel rods).

Therefore, in order to measure the average thermal neutron flux the strategy was to irradiate bare and covered with cadmium infinite dilute foils in the same position and conditions (position of the control rods and same current value to nuclear power channels 5 and 6). The foils were irradiated in seven (07) axial quotes (91, 182, 273, 364, 455, 546 and 637 mm) each one of them with five (05) radial quotes (15.0, 112.5, 210.0, 307.5 and 405.0 mm) at direction west-east of the core. The positions (quotes) can be seen at Figures 1 and 2. Thus, the total number of the foils irradiated were 280 (half with cadmium plate) at 140 positions inside of the core.

The nuclear reaction rate A^{∞} (Saturate Activity) is obtained [5] for each foil irradiated by the following expression (2).

$$A^{\infty} = \frac{\lambda.C.e^{\lambda.t_e}}{\varepsilon.I.\left(1-e^{-\lambda.t_i}\right)\left(1-e^{-\lambda.t_c}\right)}.CF \tag{2}$$

Where λ decay constant of the radioactive product formed (^{198}Au), C is the net counts of the gamma energy (411.80 keV), I is the branching ratio to gamma energy, t_e is the waiting time to gamma spectrometry after the irradiation, t_i is the irradiation time and t_c is the counting time during the gamma spectrometry. The factor CF is the total correction factor. This factor is a product of little fluctuation power level factor between the several irradiations foils and it discounts the contribution activity foil due ramp power elevation until the irradiation level (ramp factor) and the gamma self-absorption during the gamma spectrometry (self-absorption factor).

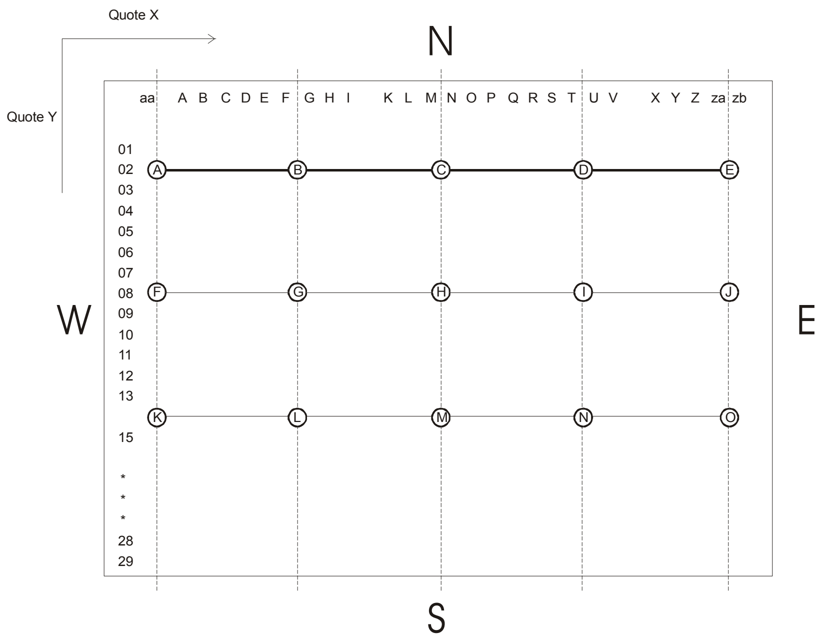

Figure 1. Radial Positions of the Infinitely Dilute Foils in the core.

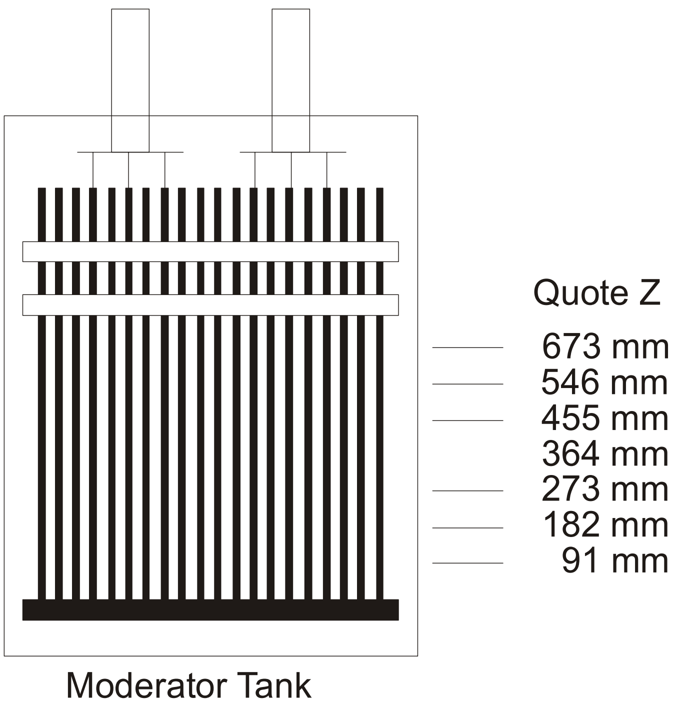

Figure 2 – Axial positions of the Infinitely Dilute Foils in the Core.

Thus, since obtained A^{∞} and the cadmium ratio R_{cd} given by the ratio between nuclear reaction rates between bare foil and cadmium plate foil at same irradiation position in the core it is possible to estimate the thermal neutron flux by expression (3) [5].

$$\Phi_{th} = \frac{A^{\infty}{}_{bare}\left(1 - \frac{F_{Cd}}{R_{Cd}}\right).P_a}{N_{av}.m.\sigma_{atv}} \tag{3}$$

The expression (3) has been used to estimate the thermal neutron flux by irradiation of the bare gold foils and cadmium plate gold foils at each irradiation position in the IPEN/MB-01 core.

3. RESULTS

The thermal neutron fluxes have been measured along of the core using the expression (3). The cadmium ratio (R_{cd}) it was estimated by irradiation of the bare infinite dilute foils and cadmium plate infinite dilute foils and the results can be seen below. This value is valid along of the asymptotic region of the core where do not exist the neutron flux disturbance effects (control rods and reflector).

$$R_{cd} = 1.42 \pm 0.01$$

Thus, thermal neutron flux at center of the core (Φc) was estimated and the value is given bellow.

$$\Phi c = (8.67 \pm 0.54)\times 10^{8}\ n/cm^{2}.s$$

The average thermal neutron flux ($\overline{\Phi}$) was obtained considering the weight statistical of each measure at 140 internal points of the core.

$$\overline{\Phi}_{th} = (5.04 \pm 0.32)\times 10^{8}\ n/cm^{2}.s$$

This value when inserted in the expression in the expression (1) we give the power level of the IPEN/MB-01. Thus,

$$P = (105.20 \pm 5.43)\ watts$$

The power level is totally correlated with the average electric current values of the nuclear channels number 5 and 6. The Figure 1 and 2 shows the values of electric current to nuclear channels 5 and 6, respectively. These values were acquired during the reactor operations to foils irradiation. The Figure 3 and 4 show the calibration straight line to same nuclear channels obtained by foil irradiation at different power levels of the IPEN/MB-01 reactor.

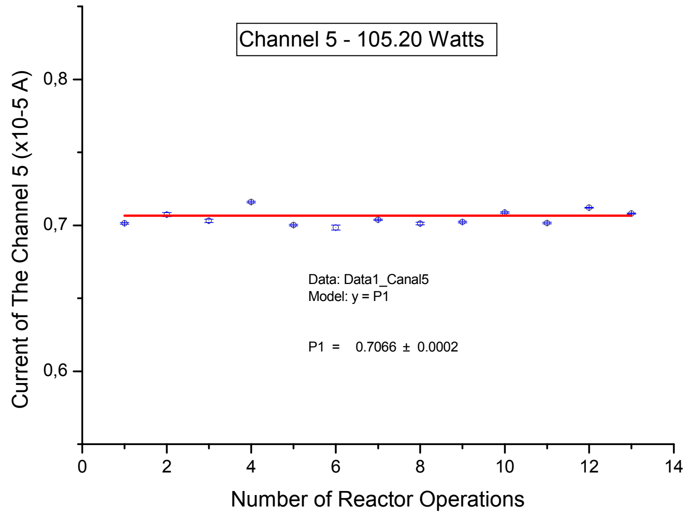

Figure 1 – Average electric Current in the channel 5.

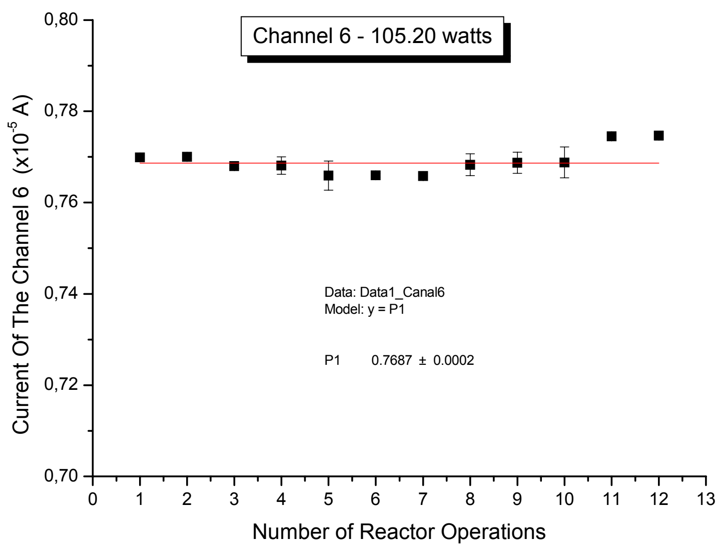

Figure 2 – Average electric Current in the channel 6.

Therefore, the Calibration Straight Lines to Channel 5 and 6 are the following:

P (Channel 5) = $1.49216.\ 10^7.\ I_5$

P (Channel 6) = $1.37161.\ 10^7.\ I_6$

Where I_5 and I_6 are the electric current level of the nuclear channels 5 and 6, respectively.

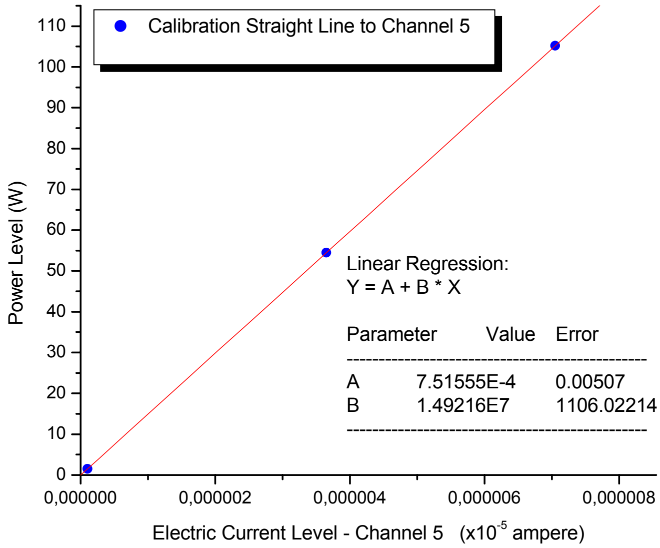

Figure 3 – Calibration Straight Line To Channel 5.

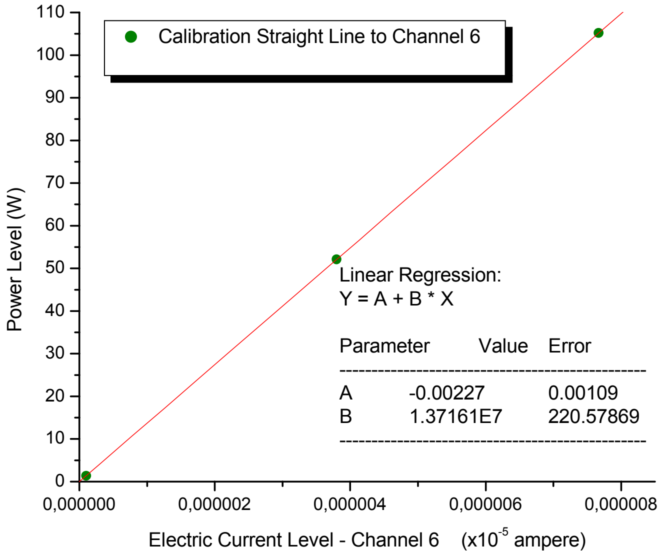

Figure 4 – Calibration Straight Line To Channel 6.

CONCLUSION

This work shows the experimental methodology to get the nuclear power level of the IPEN/MB-01 reactor by irradiation of the infinite dilute gold foils. These results show good agreement with the other experimental techniques (noise analysis) [6]. The difference with the last calibration made in 1988 [2] show that the aging of the nuclear channels of the IPEN/MB-01 reactor not changed the response of them along of the time.

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