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THE SELF-SHIELDING FACTORS IN ACTIVATION DETECTORS USED IN THE IPEN/MB-01 REACTOR

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ABSTRACT

This work aims to obtain self-shielding factors (G) to several activation foils, such as gold, cobalt, scandium, magnesium, uranium, thorium and indium foils used at measurements of the neutron spectrum energy in the IPEN/MB-01 reactor core. The knowledge of the self-shielding factors allows obtaining of precise nuclear reaction rates without the effects of neutron flux depression inside of activation foils. This study is carried out in two parts. First are determined the self-shielding factors for bare foils (without cadmium covered) and after the self-shielding factors to foils with cadmium covered.

1. INTRODUCTION

Every time an experimental apparatus is used to measure some physical parameter, occurs a perturbation about the parameter that is being measured. This perturbation some times is negligible. This is the case of the infinitely diluted foils used to measure absolute nuclear reaction rates inside of nuclear research reactor cores. Therefore, if this kind of actuation detector is being used to mesure the spacial and energetic neutron flux distribution, a self-shielding factor estimation won´t be necessary, but if pure activation detectors are being used, this estimation will be very important to estimate correctly these reactor physics parameters. The foil perturbation is larger when the magnitude of the macroscopic cross section or the thicknesses of the foils are larges.

The IPEN/MB-01 reactor [1] is a zero power reactor whose maximum power level is 100 watts and the maximum neutron flux is only $(5.13 \pm 0.18)10^9$ n/cm^{2}s [2]. Thus in order to measure the neutron flux with a good precision you need to use pure material that contain a lot of target nucleous per volume unit to increase the quantities of the nuclear reaction rate induced in the foils irradiated and after to measure them in the gamma spectrometry system with a good statistical counts. Thus, these large quantities of target nucleus originate a lot of nuclear reaction rates and the consequent decreasing of the neutron flux inside the foil. Therefore, the self-shielding factor can be understood as the decrease the neutron flux inside the pure activation detector by the internal layers of the foil.

The self-shielding factor (G) can be defined [3] by the following expression (1),

$$G = \frac{\int_{E1}^{E2} \Phi^*(E)\sigma(n,\gamma)dE}{\int_{E1}^{E2} \Phi(E)\sigma(n,\gamma)dE} \quad (1)$$

where E_1 and E_2 are lower and upper energy limits of the neutronic field that you desire to estimate the self-shielding factor, Φ^* is the neutron flux perturbed by the pure foil, Φ is the neutron flux not perturbed by infinitely diluted foil of the same material and $\sigma(n,\gamma)$ is the microscopic radioactive capture cross section. The radioactive capture cross section is represented in the expression (1) because in the most of materials used as activation foils, the nuclear reaction is of the kind (n, γ) and the cross section magnitude is very high (barns).

Therefore, the self shielding factor is the ratio between the nuclear reaction rate per target nucleus at the pure foil and the nuclear reaction rate per target nucleus at infinitely diluted foil.

The factor G can be measured by irradiation of pure and infinite dilute foils or can be evaluated by computational methodology. The computational methodology used was the MCNP-4C code that uses the statistical Monte Carlo method /4/.

2. ACTIVATION FOILS

The main foils used to measure nuclear reaction rates in the IPEN/MB-01 core [2] due thermal and intermediate neutrons, are Gold foils (^{197}Au), Scandium foils (^{45}Sc) and Uranium depleted foils (^{238}U). The fast nuclear reaction rates are those due fast neutrons (E> 0.5 MeV). The main foils used are Indium (^{115} In), Magnesium (^{24}Mg) and Nickel (^{58}Ni).

The cadmium (Cd) cover used in the foils are very small cadmium boxes (thickness 0.5 mm) that are used to discriminated the thermal neutrons at the total nuclear reaction rates at bare foils (without Cd). The Table 1 shows the nuclear reaction rates, the thickness and diameters of the different foils used in the IPEN/MB-01.

3. CALCULATIONAL METHODOLOGY

The self-shielding factor (G) was calculated by MCNP-4C code that used the ENDF-B-VI nuclear data library. The method being statistician makes possible modeling the reactor core aiming a variance reduction. For this purpose, a model using 8x8 fuel elements array and not the total (28x26) array, was made.

Then the first step is modeling the IPEN/MB-01 core and the main characteristics can be seen at Table 2 and Table 3.

The nuclear reaction rates were calculated for 4 distinct situations. The first one to bare pure foils, the second one to bare infinitely diluted foils, the third one to cadmium covered pure foils and the fourth one to cadmium covered infinitely diluted foils. The density (ρ) used to all infinitely diluted foil was $\rho_\infty = 10^{-6}\ \rho_{real}$ /3/ to avoid the self-shielding factor. Therefore using the expression (1) is possible to estimate self-shielding factors using the MCNP-4C code [4] to different materials of the activation detectors (foils). The number of cycles used to calculate the nuclear reaction rates vary of 60 to 300 and the number of stories vary of 1.8 10^7 to 9.0 10^7. The maximum process time at PC-Computer was 1170.97 minutes.

Table 1. Nominal dimensions of the foils, their densities and their nuclear reaction

Foils	*Nuclear Reaction*	*Density (g/cm^3)*	*Nominal Dimensions*	
			Thickness (mm)	*Diameter (mm)*
Mg	*(n,p)*	1.74	0.1270	12.70
Sc	*(n,γ)*	2.50	0.1400	12.70
In	*(n,n')*	7.31	0.1270	12.70
Au	*(n,γ)*	19.32	0.0254	12.70
Th	*(n,γ)*	11.71	0.1200	12.70
U	*(n,γ)*	19.10	0.1016	8.49
Co	*(n,γ)*	8.85	0.0562	12.70

Table 2. Geometric Data for the Fuel and Control Rods

Active Region	
Fuel	UO_2
Pellet Diameter	0.849 cm
Cladding Outer Diameter	0.980 cm
Cladding Thickness	0.060 cm
Pitch (Square)	1.500 cm
Alumina Region	
Pellet Diameter	0.849 cm
Cladding Outer Diameter	0.980 cm
Cladding Thickness	0.060 cm
Spacer Tube Region	
Inner Diameter	0.730 cm
Outer Diameter	0.840 cm
Control Rod Data	
Absorber Material	Ag-In-Cd
Absorber Diameter	0.832 cm
Outer Cladding Diameter	0.980 cm
Cladding Thickness	0.060 cm
Guide Tube Outer Diameter*	1.200 cm
Guide Tube Thickness*	0.035 cm

* Also for the safety rod

Table 3. Isotopic Composition of the Fuel and Control Rods

Fuel Rod	Concentration (atoms/barn-cm)
U^{235}	1.00349E-03
U^{238}	2.17938E-02
O^{16}	4.55138E-02
Cladding, Guide Tube and Bottom Plug	
Fe	5.67582E-02
Ni	8.64435E-03
Cr	1.72649E-02
Mn^{55}	1.59898E-03
Si	3.34513E-04
Alumina Pellet	
Al^{107}	4.30049E-02
O^{16}	6.45074E-02
Control Rod	
Ag^{107}	2.35462E-02
Ag^{109}	2.18835E-02
In^{113}	3.42506E-04
In^{115}	7.65996E-03
Cd	2.72492E-03

4. FINAL RESULTS

The values obtained to activation foils normally used in the activation measurements (see Table 1) in the IPEN/MB-01 reactor core can be seen in the Table 4 bare foils and Table 5 to covered cadmium foils.

Table 4. The self-shielding factors to bare foils calculated by MCNP-4C code

Foils	*Self-Shielding Factor (G)*	*Uncertainties (%)* [a]
Au	0.5160	2.83
Co	0.8616	0.32
Sc	0.9654	0.05
Mg	0.9834	0.14
U	0.3776	3.89
In	0.9999	0.08
Th	0.7531	1.81

[a.] Statistical confidence level: 1 Sigma .

Table 5. The self-shielding factors to infinitely diluted foils calculated by MCNP-4C code

Foils covered with Cd	*Self-Shielding Factor (G)*	*Uncertainties (%)* [a]
Au	0.3643	4.50
Co	0.7598	2.74
Sc	0.9836	0.10
Mg	0.8747	1.87
U	0.4089	2.79
In	1.0000	0.02
Th	0.6871	1.00

[a.] Statistical confidence level: 1 Sigma .

5. CONCLUSION

These values obtained for the self-shielding factors are very important to experimental application when you desire to measure the absolute nuclear reaction rates induced in different pure material (activation foils). Of course, the ideal condition is to use diluted activation foils, but this is not accurate when the magnitude of the neutron flux is small. This maximum magnitude ($\sim 9.10^8$ n/cm^2 s) at the central position of the IPEN/MB-01 reactor core is not enough to obtain good statistical counts during gamma spectrometry of the foils.

The methodology described in this work can be very useful to estimate with a good precision these factors and to contribute to accurate nuclear reaction rate measurements.

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