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Detector Foil Self-Shielding Correction Factors

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Abstract

In the detail reaction-rate measurements in a critical assembly using the foil activation method, the measured activations of detector foils have inevitably errors caused by detector foil self-shielding effect. If neutron flux could be approximated to Westcott flux; i.e. well thermalized Maxwellian distribution, these activations of detector foil could be corrected to represent the unperturbated flux at any detected position in the cell with using Westcott option and reaction-rate option of the lattice code, WIMS-AECL. These calculated detector material self-shielding correction factors of the tested fuel, CANFLEX, provided much information about neutron spectrum of test lattice cell as well as the correction factors themselves. The results could be verified by another lattice calculations.

1. Introduction

In the detail reaction-rate measurements like the fine-structure reaction-rate experiments of test fuels in any critical assembly there is usually used the foil activation method. Activations of detector foils have inevitably many experimental errors to represent the unperturbed flux at detected positions. One of them is caused by the detector foil self-shielding depending on neutron energy spectrum, detected positions, and geometry of foil. This paper is to describe calculations, and present results, of foil self-shielding correction factors to be applied to the activation data of foils in CANDU-type lattices of any critical assembly using CANFLEX test fuels with heavy water moderator, and heavy water coolant and air coolant, respectively.

2. Foil Activation Data

Measured detector foil relative activities are proportional to the reaction rate of foil which were converted to relative total neutron flux and effective cross section and sensitivity of a foil material. Using the Westcott convention [1][2] to describe the neutron spectrum, the effective neutron absorption cross section of a foil material is given by

$$\sigma = \sigma_o \; (G_T \, g \; + \; G_R \, r\sqrt{T/T_o} \; s_o) \qquad (1)$$

where s_0 is the cross section for 2200 m s^{-1} neutrons, G_T and G_R are self-shielding factors for thermal and resonance neutrons respectively, g and s_o are the Westcott cross section parameters, r is the epithermal index; i.e. approximately the fraction of epithermal neutrons, and T is the temperature of the Maxwellian distribution of thermal neutrons (T_o = 293.6 K is the neutron temperature corresponding to 2200 m s^{-1}).

3. Description of the Self-Shielding and Correction Factors

Foil self-shielding factors for thermal and resonance activation; G_T [3] and G_R [4], respectively, are shown in Table 1. Note that no factors are listed for the uranium-metal foils to be used for conversion-ratio measurements. The major source of error for conversion-ratio data results from the difference in density between the fuel meat and the foil material. It is recommended that a separate calculation be performed using MCNP to determine these correction factors.

For the other fissile foils, the G_R values are all close to unity and, resonance self-shielding will not significantly affect the activation data. The G_T values are all equal and shelf-shielding correction factors are not required for the other fissile foils.

All of the G_T values of the non-fissile foils are very close to unity. However, the G_R values for the non-fissile foils range from 0.51 to 0.984 and epithermal self-shielding effects will be significant in the activation data. Self-shielding effects must be corrected for in these data.

In general, the magnitude of foil shelf-shielding effects is spectrum dependent and the correction factors will vary at each location where a reaction rate is measured. Correction factors for the non-fissile activation data have been calculated using the following expression:

$$F=\frac{R^{c}(S)/R^{w}(S)}{R^{c}(NS)/R^{w}(NS)} \tag{2}$$

where $R(S)$ is a calculated reaction-rate value corrected for foil shielding and $R(NS)$ is the non-corrected value. The superscripts ^{C} and ^{W} indicate that the value are for positions within the cell and in the reference spectrum, respectively.

4. Calculations

WIMS-AECL was used to calculate these correction factors. The fuel specifications in Table 2 and the fuel bundle characteristics contained in Figure 1 define the input data for the calculations. Each cell was divided into two regions. A two-dimensional integral transport (Pij) calculation was used in the first region, extending out to the outer radius of the calandria tube. For the outer region a one-dimensional annular option (Perseus) was used.

The reaction-rate edit was used to calculate reaction rates at the various locations within the cells studied, and at the reference-wheel location. For the reference-wheel calculation, the Westcott option was used.

The partition option was used to separate out the thermal and resonance contributions to each reaction-rate value. The partitions were chosen so that the resonance region of each foil type was contained within the partition boundary; e.g. Lu^{176} has a large thermal resonance at 0.141eV, and the Lu-capture calculations used a special energy partition so that the resonance was centered between the partition boundaries.

The self-shielding factors contained in Table 1 were used to calculate *R(S)*, as follows:

$$R(SHIELDING) = \sum_{i=1}^{3} (R_i * G_i) \qquad (3)$$

where i are energy partitions, R_i are calculated reaction-rates and G_i are self-shielding factors for each foil in partition i.

5. Results and Discussion

Two fine-structure experiments were considered: one using D_2O coolant in the CANFLEX channels and one using air (void) coolant. Both experiments were assumed to be performed at low power and at room temperature. The appropriate correction factors for both experiments are given in Table 3.

As the foil positions were depart from the center of cell, the correction factors were approaching unit, and finally to be 1 at the reference position. This indicated the validity of assumption that the reference flux was not perturbed by epithermal flux; i.e. its flux was close to the well thermalized Maxwellian flux.

When coolant was voided, in the fuel region the correction factors of Cu^{63} and Mn^{55} having essentially 1/v absorbers and only small thermal resonance internals but large resonance self-shielding factors were become smaller since the neutron temperature was increased and flux distribution was hardening. Besides, the correction factors of Au^{197} having most large resonance in the epithermal region at the energy 4.916 eV were become larger. However, out the fuel region all the correction factors of these three foils were larger when voided, which macroscopically indicated void reactivity of test fuel was positive and microscopically total neutron density in the moderator were larger than one in the fuel.

6. Conclusion

This paper summarized the analysis of the detector foil self-shielding correction factors which would be used to correct to activations of detector foils, especially with CANFLEX test fuel in CANDU-type lattice in any critical assembly. This method, however, could be applied to the reaction-rate experiments with any test fuel, if the neutron flux were able to be approximated to Westcott flux.

The calculations of detector foil self-shielding correction factors provide lots of information about neutron spectrum of test fuel lattices as well as correction factors themselves of the detector foils. These calculations, therefore, would be conformed by lattice calculations using cell codes, like WIMS-AECL.

7. References

[1] E.S.Y. Tin and P.C. Loken, "POWDERPUFS-V Physics Manual", AECL, TDAI-31, July 1979.

[2] R.T. Jones, "Experiments Performed in ZED-2 in Support of the Irradiation of $(Th,Pu)O_2$ Fuel (BDL-422) in NRU", AECL-7918, January 1984.

[3] G.C. Hanna, "The Neutron Flux Perturbation due to an Absorbing Foil; A comparison of Theories and Experiments", Nuclear Science and Engineering: 15, 325-327, 1963.

[4] G.M. Roe, "The Absorption of Neutrons in Doppler Broadened Resonances", KAPL-1241, 1954.

Table 1 - Details of the activation foils used

Foil Material	wt%	Diameter	Thickness (mm)	Self-Shielding		Comments
				(G_T)	(G_R)	
Cu	100	10.74 11.74	0.127 0.254	0.986 0.975	0.644 0.510	23 °C
U	100	10.74	0.127	-	-	
Al	100	10.74	0.254	-	-	
Lu-Mn-Al	10 Lu	10.74	0.254	0.99	0.984	
	5 Mn	10.74	0.127	0.99	0.878	
Au-Al	5 Au	10.74	0.127	1.00	0.845	
In-Al	1 In	10.74	0.127	1.00	0.934	
U^{235}-Al	5 U^{235}	10.74	0.127	0.99	1.000	
Pu-Al	3 Pu	10.74	0.127	0.99	0.976	Pu isotopic at% Pu^{239} - 94.1 Pu^{240} - 5.4 Pu^{241} - 0.2

Table 2 - Specifications of the CANFLEX fuel

Isotopic Compositions

Nuclide	Content (wt%)
U^{235}	0.627
U^{238}	87.523
Oxygen	11.850

Table 3 - Non-fissile foil self-shielding correction factors

Location	Coolant	Cu^{63}	Mn^{55}	Lu^{176}	In^{115}	Au^{197}
Center Ring	D_2O	0.9748	0.9938	0.9993	0.9992	0.9356
	Air	0.9795	0.9946	0.9993	0.9993	0.9341
Inner Ring	D_2O	0.9759	0.9940	0.9993	0.9992	0.9371
	Air	0.9791	0.9945	0.9993	0.9992	0.9341
Middle Ring	D_2O	0.9790	0.9947	0.9994	0.9993	0.9393
	Air	0.9808	0.9949	0.9994	0.9993	0.9356
Outer Ring	D_2O	0.9829	0.9956	0.9995	0.9993	0.9424
	Air	0.9831	0.9955	0.9995	0.9993	0.9379
Calandria Tube	D_2O	0.9868	0.9966	0.9997	0.9994	0.9499
	Air	0.9859	0.9963	0.9996	0.9994	0.9466
Cell Boundary	D_2O	0.9923	0.9978	0.9999	0.9995	0.9579
	Air	0.9914	0.9975	0.9999	0.9995	0.9552
Wheel	D_2O Air	1.0000	1.0000	1.0000	1.0000	1.0000

Figure 1 - CANFLEX fuel bundle