A New Approach for the Experimental Determination of the Spectral Indices $^{28}\rho$ and $^{25}\delta$

Adimir dos Santos*, Leda C.C.B. Fanaro*, Rogério Jerez* and Paulo D. Siqueira*

**Instituto de Pesquisas Energéticas e Nucleares - IPEN/CNEN-SP*
05508-900 Butantã, Cidade Universitária, S.P., Brazil

Abstract. A new experimental approach for the experimental determination of the spectral indices $^{28}\rho$ and $^{25}\delta$ is proposed in this work. The proposed method, which is based on a gamma scanning technique of the fuel rod, eliminates the need of correction factors for the cadmium and foil perturbations, and also allows the bare and cadmium covered positions of the fuel rods to be irradiated simultaneously. The results are obtained with very high degree of accuracy. The theoretical analyses reveal that for the spectral index $^{25}\delta$ the results are in a very good agreement for several libraries. Considering the case of $^{28}\rho$ the nuclear data libraries ENDF/B-VI.8, JENDL3.3 and JEF3.0 slightly overestimated this parameter. In contrast, the newly released nuclear data for ^{238}U (ORNL2) and preliminary ENDFB-VII data for ^{235}U overestimated heavily the spectral index $^{28}\rho$.

INTRODUCTION

The so called spectral indices [1] are very important to correlate theory and experiment. Based on a theoretical analysis the adequacy and quality of several nuclear data libraries can be inferred. It has been having a great deal of effort related to the ^{238}U resonance absorption of thermal reactors (see http:/www.nea.fr/lists/ueval for details). New libraries have been generated at Los Alamos and at Oak Ridge and several benchmark calculations are underway. It has also been recognized the need of new experiments. The main concern is the long-standing problem of the overprediction of the ^{238}U neutron absorption reaction rate and consequently of the spectral index $^{28}\rho$ (ratio of epithermal to thermal neutron captures in ^{238}U). The main purpose of this work is to present a new approach for the measurements of the spectral indices $^{28}\rho$ (ratio to the epithermal to thermal neutron captures in ^{238}U) and $^{25}\delta$ (ratio of the epithermal to thermal fissions in ^{235}U). The main advances will be the eliminations of the need of the calculated correction factors for the cadmium sleeve and aluminum and uranium foil perturbations as well as the need to convert the experimental data to a 0.625 eV thermal cutoff. The correction factors are very common in the measurements of such spectral indices [2]. The measurements are performed in the asymptotic region of the IPEN/MB-01 [3] research reactor facility.

EXPERIMENTAL PROCEDURE

The proposed method is based on a gamma scanning technique of the fuel rod. Such apparatus has an opening collimator size of 1.0 cm. The experimental methodology considers an experimental fuel rod. Initially, two positions along its axial direction are chosen such that the reaction rates (either ^{238}U captures or ^{235}U fissions) show symmetric values. After that, one position is kept bare while the other one is covered with a sleeve of cadmium of specific size and thickness. A final requirement is that the two axial positions are also chosen so that when one is covered with a cadmium sleeve the reaction rate in the other symmetric position remains unchanged. This experimental fuel rod is subsequently irradiated at the central region of the IPEN/MB-01 core for a period of one hour at 100W. After that, it is removed from the core and taken to the scanning equipment. The countings start after a cooling period, which is typically 48 hours. The gamma spectrometry countings are performed for a suitable period of time alternately in the bare position and in the central position of the cadmium covered region. The data are then fitted in an exponential function and the countings at the end of irradiation are then obtained.

The spectral indices are subsequently obtained in the following way. Starting from the analytical expressions for the ^{238}U captures and ^{235}U fissions as in [4], one can readily derive that the spectral index (SI) as:

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$$SI = \frac{\varepsilon_i \frac{\eta_i}{\eta_i^*} N_i^*}{N_i - \varepsilon_i \frac{\eta_i}{\eta_i^*} N_i^*} \qquad (1)$$

where all the physical quantities with a superscript * refer to the cadmium covered case and unless otherwise stated the quantities without superscript refers to the bare case, η_i, is the gamma detector efficiency for nuclide i, N_i is the gamma countings of photopeak of nuclide i at the end of irradiation and

$$\varepsilon_i = 1.0 \quad \text{for} \quad {}^{28}\rho \quad \text{and} \quad \varepsilon_i = \frac{F_{25}^* Y_{Ce}}{F_{25} Y_{Ce}^*} \quad \text{for} \quad {}^{25}\delta \quad (2)$$

F_{25} is the ^{235}U fission fraction, and Y_{Ce} is the effective fission yield of ^{143}Ce.

The quantities arising from the experimental data are the photopeak countings of ^{239}Np (277.6 keV) and ^{143}Ce (293.3 keV) both at the end of the irradiation. The only quantities that come from a computational approach are the ratio of the detector efficiency, the effective yields of ^{143}Ce and ^{235}U fission fractions. All these quantities have to be considered for the bare and cadmium covered cases. The majority of the quantities from the calculational approach applies to $^{25}\delta$.

The spectral indices obtained in this way are functions of the cadmium sleeve length and thickness. Also, in this case, the thermal cutoff is a quantity that is allowed to be free. In fact, it will also depend on the cadmium sleeve length and thickness.

EXPERIMENTAL RESULTS

The first part of the experiment was to prove that the cadmium sleeve does not perturb the opposite bare position. This condition was perfectly demonstrated in all cases of this work. Figure 1 illustrates the axial countings of the experimental fuel rod for the case of ^{239}Np for several cadmium sleeve lengths and thicknesses. It can clearly be seen that for the chosen positions (10 cm for the bare and 35 cm for cadmium covered cases) the cadmium sleeve does not perturb the opposite bare position. The referential point for the bare and cadmium covered positions is the bottom of the active fuel length.

Table 1 shows the final values for the measured spectral indices. The experimental uncertainty is given between parenthesis. They are shown as a function of the cadmium sleeve length and thickness.

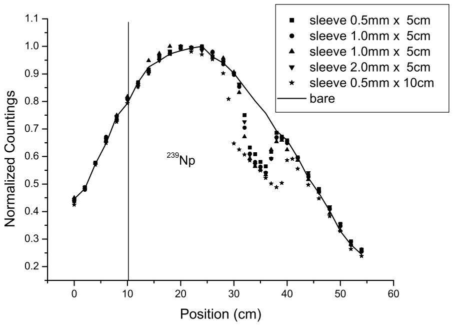

FIGURE 1. ^{239}Np gamma countings as a function of the axial position of the fuel rod.

TABLE 1. Measured spectral indices and uncertainties.

Cd Sleeve			
L(cm)	**e(mm)**	$^{28}\rho$	$^{25}\delta$
5	0.5	2.3469(0.0113)	0.1389(0.00072)
5	1.0	2.1366(0.0069)	0.1291(0.00050)
5	2.0	1.8379(0.0075)	0.1172(0.00066)
7	0.5	2.2359(0.0101)	0.1336(0.00066)
10	0.5	2.1748(0.0099)	0.1314(0.00067)

THEORY/EXPERIMENT COMPARISON

The theoretical analyses of the spectral index experiment were performed in companion NJOY/MCNP-4C systems. NJOY [5] was used for the cross section generation and MCNP-4C [6] for the solution of the neutron transport equation and the calculation of the reaction rates in the tally cylindrical volume of the fuel rod having a height of 1.0 cm and a diameter of 0.849 cm (bare and cadmium covered cases). These cylinders are centered at the position 10.0 cm and 35.0 cm from the bottom of the active length, for the bare and cadmium covered cases respectively. These are the same regions where the scanning equipment performed the gamma countings. The IPEN/MB-01 core was initially simulated in a 3-D system. Everything was modeled explicitly. Because the tally volume is rather small, an artifact based on the surface source technique was employed in order to reach good statistics. Initially from the 3-D explicit calculation surface sources were built in regions that surrounded the tally volumes(both bare and cadmium covered cases located at 10 cm and 35 cm from the bottom of the active fuel length respectively). For this specific case, the surface source region comprises a parallelepiped of 4.5×4.5 cm^2 (a 3×3 fuel rod array with the experimental fuel rod at the center) and a length of the whole fuel rod (98.0 cm). In a second level MCNP-4C is rerun again but now the system will be delimited by the surface source. The run is a source driven problem, which together with a subsequent and systematic change of the seed can reach very high statistics and low standard deviations. This procedure is somehow also time consuming and it was applied only for specific cases. To illustrate the results Table 2 shows the Calculation/Experiment (C/E) comparison for the case of a cadmium sleeve length of 5 cm and 2 mm of thickness. The nuclear data libraries considered are ENDF/B-VI.8 [7], JENDL3.3 [8], JEF3.0 [9]. In addition to that some results from the newly released evaluations of ^{235}U and ^{238}U [9] are also considered. In this case the remaining data comes from the ENDF/B-VI.8. Only the nuclear data of ^{235}U and ^{238}U were changed.

As shown in Table 2 there is a good agreement for the recently released libraries ENDF/B-VI.8, JENDL3.3, JEF3.0 regardless of the spectral index considered. However, the same cannot be said for the case of $^{28}\rho$ considering the preliminary ENDF/B-VII data for ^{235}U and ^{238}U (ORNL-2). The reminder data are from ENDF/B-VI.8. Both cases overpredicted $^{28}\rho$.

TABLE 2. C/E comparison for several nuclear data libraries.

library	C/E	
	$^{28}\rho$	$^{25}\delta$
ENDF/B-V1.8	1.001(9)	1.005(6)
JENDL-3.3	1.003(8)	0.991(6)
JEFF-3.0	1.008(9)	1.001(6)
ENDF/B-VII data for ^{235}U	1.041(12)	1.011(6)
^{238}U ORNL2	1.038(11)	1.008(6)

CONCLUSIONS

The experiment for the determination of the spectral indices $^{28}\rho$ and $^{25}\delta$ has been successfully performed in the IPEN/MB-01 reactor. The experimental values have very good accuracy and can be very helpful for checking the adequacy of the nuclear data libraries commonly used in reactor calculations. The final results show that a good agreement is achieved for the ^{235}U($^{25}\delta$) cases for several libraries. However, for the ^{238}U case ($^{28}\rho$) there is a good agreement considering the currently released libraries. However, for the $^{28}\rho$ case, both the preliminary ENDF/B-VII data and the new evaluation for ^{238}U (ORNL2) overestimated heavily this spectral index. The recent improvement of the k_{eff} comparison reported by several works at the ueval page related to the new ^{238}U release (ORNL2) does not have the proper support when the spectral indices are considered.

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