The Experimental Determination of the Spectral Indices $^{28}\rho$ and $^{25}\delta$ inside of the Fuel Pellet of the IPEN/MB-01 Reactor

Ulysses d'Utra Bitelli*, Adimir dos Santos*, Paulo D. Siqueira*, Rogério Jerez*, Leda C.C.B. Fanaro* and Rosangela R. Cacuri*

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

Abstract. This work presents the measurements of the spectral indices $^{28}\rho$ and $^{25}\delta$ inside of the fuel pellet. To reach this goal an appropriate gamma-counting system based on a cylindrical collimator to shield the gammas arising from the outermost ring is employed. The proposed system is shown to be adequate and in principle can be used to measure these spectral indices across the pellet radius. The theory comparison of the spectral indices shows that the currently released library ENDF/B-VI.8 agrees reasonably well with the measurements.

INTRODUCTION

The spectral indices [1] in a nuclear reactor are of great importance to correlate theory and experiment. Based on a theoretical analysis one can infer the adequacy and quality of several nuclear-data libraries currently in use in the reactor physics area. There has been 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. The need for new experiments has also been recognized. The main concern is the longstanding 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 capture in ^{238}U). The main purpose of this work is to present the measurements performed at the IPEN/MB-01 research reactor facility [2] for the determination of the spectral indices $^{28}\rho$ and $^{25}\delta$ (ratio of the epithermal-to-thermal fissions in ^{235}U). The measurements were realized in the asymptotic region of the IPEN/MB-01 reactor and inside of the fuel pellets by means of an appropriate cylindrical collimator system. MCNP-4C [3] is being used for the theoretical analyses together with the nuclear data library ENDF/B-VI.8 [4].

EXPERIMENTAL PROCEDURE

The experimental approach for the determination of the spectral indices $^{28}\rho$ and $^{25}\delta$ in the interior part of the fuel pellet consists of the irradiation of an experimental fuel (dismountable) having uranium foils as shown in Fig. 1.

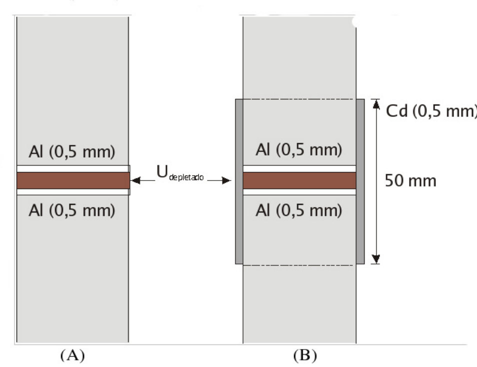

FIGURE 1. Experimental fuel rod with uranium foils and aluminum "catcher:" (A) bare and (B) covered with a cadmium sleeve.

This figure shows that the uranium foils are involved by aluminum foils (catchers) and also that the experimental fuel rod can be irradiated either bare or covered with a cadmium sleeve having the uranium foils at its center. The experimental fuel rod in the aforementioned conditions is irradiated (one case each time) at a power of 100 W for a period of one hour. The irradiation is performed at the central region of the IPEN/MB-01 core and in the asymptotic region. After that, the experimental fuel rod is dismounted and the uranium foil is removed and taken to a HPGe detector system where gamma spec-

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trometry is performed. The foils considered are: highly enriched foil (93%) for the $^{25}\delta$ determination and depleted uranium foil (400 ppm in ^{235}U) for the $^{28}\rho$ case. The ^{235}U fission rate in the highly enriched foil is inferred from the ^{143}Ce (293.3 keV) photopeak counting and the ^{238}U neutron capture from the ^{239}Np (277.6 keV) photopeak counting. Each counting is performed for the bare and cadmium-covered cases. The cadmium thicknesses considered here are 1.0 mm for $^{25}\delta$ and 0.5 mm for $^{28}\rho$. In both cases a cadmium sleeve length of 5.0 cm is utilized. From these conditions $^{28}\rho$ and $^{25}\delta$ can be obtained in a straightforward fashion.

The artifact to measure the reaction rates only in the interior region of the uranium foil was obtained employing an appropriate lead collimator together with a centralizer system as shown in Fig. 2.

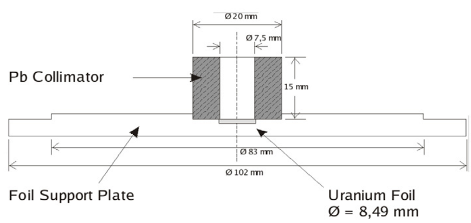

FIGURE 2. Centralizer system and lead collimator for the gamma spectrometry of the uranium foils.

As shown in Fig. 2 the lead collimator shields only the gammas arising from the outermost ring whose inner diameter is 7.5 mm. The other gammas are allowed to reach the detector. The centralizer system is made of acrylic and its function is to guarantee the concentric geometry and to position the lead collimator. This procedure was used for both cases ($^{28}\rho$ and $^{25}\delta$) and the results are very encouraging. In principle the collimator inner diameter can be made of any specified dimension less than that of the pellet. The only thing is to guarantee that the gammas arising from the outermost region of the uranium foil be effectively shielded. This work considers only the case of an inner radius of 7.5 mm. The measured $^{28}\rho$ and $^{25}\delta$ along with their corresponding uncertainties are shown in Table 1.

TABLE 1. Measured $^{28}\rho$ and $^{25}\delta$ in the interior of the fuel pellet: inner radius of 7.5 cm.

$^{28}\rho$	$^{25}\delta$
2.1886±0.0107	0.1353±0.0001

THEORY/EXPERIMENT COMPARISON

The theory/experiment comparison performed in this work considers the couple of NJOY/MCNP-4C systems. NJOY [5] was used to generate the point-wise cross sections required by MCNP-4C. This program solves the neutron transport equation and calculates the reaction rates needed for the $^{28}\rho$ and $^{25}\delta$ determination. This work considers a novice approach for the calculation of the spectral indices $^{28}\rho$ and $^{25}\delta$. Instead of the determination of the correction factors for the cadmium sleeve and foil perturbations, this work will model exactly the experimental conditions. To reach this goal a procedure based on the surface source current (WSSA) of a specific region will be employed. In this case, a region, which contains in its interior the uranium foils and also the cadmium sleeve for the cadmium-covered case, is delimited in the MCNP-4C input. Every neutron that enters this region as well as all the neutrons that are generated in this region is recorded for further utilization. The region that was considered consists of a parallelepiped of a 3-cm side and is 20 cm high. This region is centered at the uranium foil position. In a second stage, the reactor system is simulated by representing only the parallelepiped region, and the surface source previously created as the input source is utilized. Figure 3 gives some insight into the simulation. In the second run, the foil is simulated explicitly. The geometry as shown in Fig. 1 is modeled at the center of the parallelepiped, respectively, for cases (A) and (B). The tally now is the reaction rate in the foil but considering only the diameter 0.75 cm.

Following this approach a very large number of neutron histories can be reached in a reasonable amount of CPU time. More important in this case is that the proposed method can simulate exactly the experimental geometry in the second run and allows the calculation of the reaction rate in the uranium foils at any specified inner radius. This procedure overcomes the need of a huge number of neutron histories in the first run and allows an accurate treatment of all the physics involved in the real situation.

The theory/experiment comparison is shown in Table 2.

As shown in Table 2, the currently released library ENDF/B-VI.8 has reasonably good agreement with the experimental values.

CONCLUSIONS

The experiment for the determination of the spectral indices $^{28}\rho$ and $^{25}\delta$ in the interior of the fuel pellet has been successfully performed at the IPEN/MB-01 reactor. The uncertainties are small and suitable for a benchmark

TABLE 2. Theory/experiment comparison (C/E).

Library	$^{28}\rho$ C/E(deviation %)	$^{25}\delta$ C/E(deviation %)
ENBF/B-V1.8	0.9814(0.61)	0.9904(0.01)

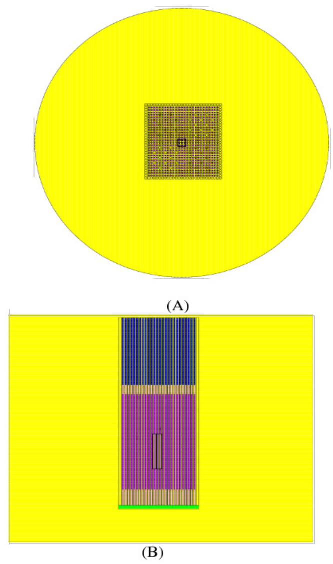

FIGURE 3. Schematic illustration of the geometry for the surface source determination. (A) perpendicular plane; (B) longitudinal plane.

experiment. The theory/experiment comparison reveals that the currently released nuclear data library ENDF/B-VI.8 has reasonably good agreement with the experimental values.

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