MEASUREMENTS OF THE AVERAGE CROSS SECTIONS IN U-235 FISSION NEUTRON SPECTRUM FOR THRESHOLD REACTIONS IN $^{95,98}Mo$, ^{127}I AND ^{31}P

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ABSTRACT

Measurements of the fission neutron spectrum averaged cross sections for four important threshold reactions $^{95}Mo(n,p)^{95}Nb$, $^{98}Mo(n,\alpha)^{95}Zr$ $^{127}I(n,2n)^{126}I$ and $^{31}P(n,p)^{31}Si$ have been performed in a ^{235}U fission neutron spectrum obtained near the core of the IEA-R1 2MW pool-type research reactor. The activation technique has been employed together with high-resolution γ-ray spectroscopy. The results are presented with a complete uncertainty covariance matrix and are compared with evaluated values and previous measurements.

I. INTRODUCTION

Experimental data on cross sections averaged over the ^{235}U fission neutron spectrum (σ) are important for fast neutron dosimetry[1,2], radioisotope production[3-5] and for consistency tests of the corresponding differential cross sections[6]. The reactions $^{95}Mo(n,p)^{95}Nb$ and $^{98}Mo(n,\alpha)^{95}Zr$ are particularly important in diagnostic nuclear medicine because in the production of ^{99}Mo, via the $^{98}Mo(n,\gamma)^{99}Mo$ reaction, the radionuclides ^{95}Nb, and ^{95}Zr appear as long-lived impurities. Moreover, the recent cross-section results presented in the literature[5] show large discrepancies among different authors. The other two reactions, namely $^{127}I(n,2n)^{126}I$ and $^{31}P(n,p)^{31}Si$, are important for dosimetry applications. The reported uncertainties *for these reactions are large, mainly due to the* error quoted for the γ-ray intensity per decay (Iγ). Recently, we have measured Iγ for ^{31}Si [7] with lower uncertainty than those reported in the literature. For ^{126}I our data analysis is in nearing completion and a preliminary result is reported in the present paper. For this reason, we have undertaken new measurements of σ for these important threshold reactions

II. EXPERIMENTAL

The complete details on the experimental methodology adopted in the present work has been described in previous papers [8,9], Here only a summary is given. The irradiations have been performed near the IEA-R1 reactor core, very close (≅ 4mm) to the fuel element. According to these previous studies, the fast neutron spectrum at this position is similar to a ^{235}U fission spectrum. The measured fast neutron flux was around 5×10^{12}. The reactions considered for neutron flux monitoring, were: $^{27}Al(n,\alpha)^{24}Na$, $^{58}Ni(n,p)^{58}Co$ and $^{54}Fe(n,p)^{54}Mn$ and the corresponding average cross sections for these reactions were: (0.706± 0.028)mb, (109±3)mb and (80.5±2.3)mb, respectively. These experimental data were taken from Mannhart[10]. The samples were high purity metal foils (Reactor Experiments Inc.-USA). The Mo sample was a high purity metal wire (Reactor Experiments Inc., USA), bended in spiral in order to obtain an aproximate disk shape. The I and P samples were high purity $NH_4H_2PO_4$ and KI in powder form, previously dehidrated and sealed inside quartz ampoules. Before measuring the activities, the I and P samples were removed from the quartz ampoules, weighed, and wrapped in aluminium foil, in order to obtain a geometry aproximated to the other samples. In order to minimize the thermal neutron induced activities, the samples were irradiated inside a box made with 0.5mm thick cadmium foil.

The sample activities were determined by means of a high purity germanium detector HPGe (20% INTERTECHNIQUE), previously calibrated in a well defined geometry (172 mm source-detector distance). The γ-ray efficiency curve has been established in the

244 to 1408 keV energy interval, using standard sources of ^{60}Co, ^{133}Ba, ^{137}Cs and ^{152}Eu, supplied by the International Atomic Energy Agency. The experimental efficiency values have been fitted as a function of the γ-ray energy, using least square methods and covariance analysis. The best curve obtained was a second degree polynoinial in log-log scale. Corrections for pile-up effects, self-absorption, dead-time, geometry and decay have been applied in the activity calculation. The amount of ^{95}Nb activity arising from the decay of ^{95}Zr has been taken into account and resulted about 6% at the time of the measurement.

III. RESULTS AND DISCUSSION

The total errors envolved in cross section determination, together with the corresponding correlation matrix are shown in Table 1. The average cross sections obtained in this experiment are compared with experimental data from other authors in Table 2.

Table 1. Errors and Correlation matrix for the measured cross sections

Reactions	Relat. Stand. dev. (%)	Correlation matrix (x 1000)			
$^{98}Mo(n,\alpha)^{95}Zr$	4.23	1000			
$^{95}Mo(n,p)^{95}Nb$	2.90	643	1000		
$^{127}I(n,2n)^{126}I$	3.38	552	806	1000	
$^{31}P(n,p)^{31}Si$	3.26	576	842	304	1000

Table 2. ^{235}U neutron spectrum average cross sections (in mb)

Reaction	This Work	Kobayashi (11,12)	Fabri (14)	Calamand (15)	Cohen (13)	Horibe (16)	Zaidi (4)
$^{98}Mo(n,\alpha)^{95}Zr$	0.00947 ±0.00040	-x-	-x-	0.0139 ±0.0016	0.008 ±0.001	-x-	0.014 ±0.002
$^{95}Mo(n,p)^{95}Nb$	0.174 ±0.0050	-x-	-x-	0.140 ±0.010	0.150 ±0.010	0.200 ±0.020	0.140 ±0.010
$^{127}I(n,2n)^{126}I$	1.292 ±0.040	1.040 ±0.046	1.050 ±0.046	0.90 ±0.10	-x-	-x-	-x-
$^{31}P(n,p)^{31}Si$	37.9 ±1.2	34.0 ±2.5	35.0 ±2.7	36.0 ±3.0	-x-	-x-	-x-

For $^{98}Mo(n,\alpha)^{95}Zr$ reaction, the result of the present work lies between the other values taken from the literature and agrees with the value obtained by Cohen (13). The same happens in the case of reaction $^{95}Mo(n,p)^{95}Nb$, for which the present result agrees roughly with the value from Horibe(16). For $^{31}P(n,p)^{31}Si$, our result is somewhat larger than the other values, but this can be explained by the value adopted for Iγ taken from Koskinas(7) which is lower than the previous reasults. In the case of $^{127}I(n,2n)^{126}I$, the result of the present work confirms the value obtained previously [8], but is somewhat larger than the results given by the other authors.

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