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FISSION CROSS SECTION OF Pu-241 FROM 0.01 eV TO 0.5 eV

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T. Watanabe

Abstract

The fission cross section of Pu-241 has been measured from 0.01 to 0.5 eV using the Materials Testing Reactor (MTR) fast chopper with a flight path of 4 meters. The fission events were detected by a gas scintillation fission chamber. Curves of $\sigma_f \sqrt{E}$ as a function of energy are given. Comparisons are made with previously measured fission cross section.

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FISSION CROSS SECTION OF Pu-241 FROM 0.01 eV TO 0.5 eV

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T. Watanabe

I. Introduction

The reported Pu-241 fission cross section measurements^(1,2,3) which have been made in the past have a common deficiency in the region from 0.1 eV down to 0.01 eV. The data are missing or contain too much uncertainty. Good cross-section data in this region are highly desirable from two standpoints. First, to obtain the cross section at 0.0253 eV, it has been the practice to do a least square fit to the data in the vicinity of 0.0253 eV using a linear or quadratic function. With these measurements, the goodness of the assumed least square fits can be verified. Second, extension of the measured data down to energies near or below 0.01 eV will allow a more precise theoretical fit. As an example, the postulated negative level will need to be examined more closely. With these objectives in mind, the fission measurements reported by Watanabe and Simpson⁽²⁾ were extended down to energies below 0.01 eV.

II. Experimental Procedure

The measurements were taken on the MTR fast chopper at a flight path of 4 meters with resolution of 7.5 μ sec/meter. The gas scintillation fission counter described by Watanabe and Simpson⁽²⁾ was used for these measurements. However, only one of the four chambers was employed since the neutron beam at four meters has a dimension which covered only one chamber. The beam monitor consisted of depleted BF_3 proportional counters which covered the same region of the

beam as the fission chamber. Aside from these two changes, the experimental procedures were the same as described earlier.⁽²⁾

III. Fission Cross Section Data

The raw data were normalized at 0.0253 eV to a cross section value of 962 barns⁽²⁾ and corrected for the Pu-239 contaminant. The correction for Pu-239 was more involved since the measurements which were taken at 4 meters are affected by instrumental resolution. Instead of using the Pu-239 data at 0.3 eV as given in BNL-325, it was necessary to resolution broaden the Pu-239 data over the resonance at 0.3 eV before using it. Resolution broadening of the Pu-239 data was made in the following manner. The difference between the theoretical fit to the Pu-239 data which were not resolution broadened and which were resolution broadened was first determined. The difference was then added to, or subtracted from, the Pu-239 data given in BNL-325. This procedure was used in order to avoid the inadequacies of the fit to the Pu-239 data.

The plots of data are presented in Figures 1 to 5 in a form $\sigma_f \sqrt{E}$ versus E . For comparison, a plot of the Pu-241 data in this energy region obtained by other measurements⁽²⁾ is included. The comparison plot was obtained from MTR data⁽²⁾ and from least squares fitting of the MTR data⁽²⁾ in the region $0.3 \text{ eV} \leq E \leq 0.5 \text{ eV}$.⁽⁴⁾

IV. Results and Discussion

Inspection of these plots gives good evidence that the data below 0.1 eV do not show a slope change near 0.0253 eV as indicated from the theoretical fit to the total data.⁽⁵⁾ This substantiates the correctness of the procedure used by Watanabe and Simpson⁽²⁾ to

obtain the fission cross section at 0.0253 eV. Results also indicate that the negative level does not contribute to the cross section in this region to the degree which has always heretofore been assumed.⁽⁵⁾ Either a shift in the negative level, or a change in parameters such as assuming mostly capture for the negative level, or both, will be required to obtain more adequate fit to the total and fission cross section in this region.

From these plots, it is also evident that on the high energy side of the 0.255 eV resonance, the 4 meter data are in disagreement with the comparison plot. The disagreement is attributable to instrumental resolution and to a situation as shown in Figure 6. In Figure 6, there are plotted the counts per channel as function of energy as recorded from the fission chamber and the BF_3 proportional counter, and the Pu-239 fission cross section in the vicinity of 0.3 eV. It may be observed that in the energy interval 0.3 to 0.4 eV, there occurs a rapid decrease in fission counts, a transition in the neutron spectrum from a Maxwellian to a $1/E$ spectrum and a resonance in the Pu-239 fission cross section. Because the fission counts and the neutron spectrum are changing rapidly in this region, the fission cross section which is related to the ratio of these two quantities will be affected very strongly by any factor which causes the fission counts and neutron counts to be shifted relative to each other in time of flight. The fission data and neutron spectrum are taken essentially simultaneously, but because of the electronics (auto delay, detector control, etc.) there can occur a half a channel shift ($\text{CW} = 16 \mu\text{sec}$) between the two measurements. In addition, since the physical dimensions of the two counters are not the same along the

direction of the flight path, the two counters will also have different resolution due to flight path uncertainty. Last of all, it is necessary to use Pu-239 data which have been convoluted by the appropriate resolution function corresponding to the experimental situation if the data are to be properly corrected for the presence of Pu-239. Because of the approximate nature of the convolution that was used, a small error may have been introduced.

The combined effect of all factors will produce a broadening of the high energy side of the 0.255 eV resonance in Pu-241 fission cross section. Most likely, channel shift contributes the most to the broadening. This is based on the large change noted in the high energy side of the resonance when the fission data were shifted one channel (16 μ sec) relative to the neutron spectrum data.

To check whether this broadening is due to a resolution effect, the integrals $\int \sigma_f dE / \int dE$ for the data taken at 4 meters and for the data taken at 8.5 meters⁽²⁾ were evaluated. The results are shown in Table I. The results for the three runs 1392, 1393, 1394, which are considered better than the remaining two, are in good agreement with the 8.5 meter data. This agreement might possibly be improved as the 8.5 meter data⁽²⁾ appeared to be low in the region 0.3 to 0.35 eV. By raising the data in this region, the value of the integral for 8.5 meters will become larger.

Another possible factor which can cause distortion of the cross section data is the variation in the transmission characteristic (cut-off characteristic) of the chopper across the lateral dimension of the beam. This variation distorts the ratio of fission counts to monitor BF_3 counts unless the two counters cover the same part of the beam.

The distortion, if it occurs, will be most pronounced in the energy interval near rotor cutoff. In the energy region removed from cutoff energy, the variation in transmission characteristic will not affect the ratio. In addition, if the fission foil is non-uniform, distortion can occur in the ratio since the neutron beam monitor will not have the same response as the fission detector even though it sees the same part of the beam as the fission detector. The non-uniformity was minimized by painting the foil in a manner which gave the most uniform distribution of material on the foil. The pattern of brush movement was such that no particular region was favored and the material was deposited on the foil in several layers. The latter procedure also tends to produce a more uniform deposition of material since each layer is expected to have a distribution of material different from the other layers. The data taken at 4 meters were taken with both fission chamber and neutron beam monitor covering the same portion of the beam, and the measured ratio is not expected to be affected significantly by either foil non-uniformity or variation in transmission characteristic of the rotor.

In summary, it may be stated (a) that the results of these measurements on Pu-241 agree with previous measurements⁽²⁾ in the interval between 0.1 eV and 0.25 eV, (b) that the Pu-241 $\sigma_f \sqrt{E}$ below 0.1 eV does not show a change in slope at 0.0253 eV and that furthermore a function (linear or quadratic) derived from a least square fit to the data will be required to have a positive slope at 0.0253 eV.

V. Acknowledgment

The author would like to express his appreciation to Miss B. K. Sidle for writing the computer programs and Mrs. A. L. Dittmer for her prompt processing of the data.

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Table I

The value of the integral $\int \sigma_f dE / \int dE$ from 0.1 eV to 0.4 eV.

Run No.	Flight Path (meters)	$\int \sigma_f dE / \int dE$	% Difference from 8.5 meter value
1209	8.5	830	—
1394	4	850	2.4
1393	4	860	3.6
1392	4	840	1.2
1389	4	893	7.5
1387	4	900	8.4

Fig. 1 - The fission cross section of Pu-241 multiplied by the square root of the neutron energy as a function of neutron energy below 0.5 eV.

Fig. 2 - The fission cross section of Pu-241 multiplied by the square root of the neutron energy as a function of neutron energy below 0.5 eV.

Fig. 3 - The fission cross section of Pu-241 multiplied by the square root of the neutron energy as a function of neutron energy below 0.5 eV.

Fig. 4 - The fission cross section of Pu-241 multiplied by the square root of the neutron energy as a function of neutron energy below 0.5 eV.

Fig. 5 - The fission cross section of Pu-241 multiplied by the square root of the neutron energy as a function of neutron energy below 0.5 eV.

Fig. 6 - Neutron and fission counts per channel as a function of energy below 1 eV and the fission cross section of Pu-239 in the vicinity of the 0.3 eV resonance.