

R-Matrix Analyses of the ^{235}U and ^{239}Pu Neutron Cross Sections*

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Abstract: The resonance parameter analysis code SAMMY was used to perform consistent resonance analyses of several ^{235}U and ^{239}Pu fission and capture cross section and transmission measurements up to 110 eV for ^{235}U and up to 1 keV for ^{239}Pu . The method of analysis, the measurement selection and the results are briefly outlined in this paper.

(^{235}U , ^{239}Pu , Reich-Moore Resonance Parameters)

Introduction

The representation of the ^{235}U and ^{239}Pu neutron cross sections in the resonance region in most national and international evaluations is generally considered unsatisfactory.^{1,2} Most evaluations are based on several year old resonance analyses and hence do not include results of recent high accuracy and good resolution measurements. Particularly in the case of ^{239}Pu the good resolution of recent measurements allows the extension of the resolved resonance region to energies beyond the upper limit of existing evaluations. Several evaluations represent the cross sections with a resonance formalism which is inadequate to properly describe the level-level interferences in the fission channels. Indeed, a 1981 IAEA Consultant Meeting on Uranium and Plutonium Resonance Parameters recommended that new evaluations of the ^{235}U and ^{239}Pu resonance parameters be performed.³

The aim of this paper is to present new analyses of the ^{235}U and ^{239}Pu neutron cross sections; to discuss the choice of experimental data, to outline the method of analysis and to show graphical and tabular comparisons between the cross sections obtained from the parameters and several experimental data sets and the ENDF/B-V evaluations. After the analyses are finalized and extensively tested, the resonance parameters will be proposed for the ENDF/B-VI and JEF evaluations.

Selection of Measurements

Four sets of measurements were given most weight in both the ^{235}U and ^{239}Pu resonance analyses: the 1984 fission measurements of Gwin *et al.*⁴ were used mostly below 20 eV and the 1984 fission measurements of Weston and Todd⁵ were used above 15 eV. The 1984 transmission measurements of Spencer *et al.*⁶ were used below a few eV, and the recent transmission measurements of Harvey *et al.*⁷ were used at higher energies. These recent measurements were chosen because they had good energy resolution and relatively low backgrounds, and because detailed information on the experimental conditions and on the uncertainties were readily accessible to the authors.

The recent measurements of Harvey *et al.* were done in conjunction with this evaluation and are discussed in another paper at this conference. These measurements were done on an 80-m flight path with samples cooled at the liquid nitrogen temperature, and they provide the

best resolution data available at the upper end of the resolved resonance region.

Most of the neutron cross-section data on the CSISRS file,⁸ or listed in CINDA⁹ were examined for possible inclusion in the analysis. Several data sets were found very helpful in resolving the resonance structures.

The ^{235}U and ^{239}Pu fission measurements of Blons¹⁰ are unique in that the detector was cooled to the liquid nitrogen temperature. The reduction in Doppler broadening helps resolve nearby fission resonances. But these data were not included in the final consistent fits, because the measurements had large backgrounds and appeared to have an energy dependent normalization error.

The ^{235}U spin separated fission data obtained by Moore *et al.*¹¹ from an analysis of the polarized neutron polarized target measurement of Keyworth *et al.*,¹² was used to assign each resonance structure to the proper spin state. However, these data were not included in the final fit because of the large statistical uncertainties on the data and on the resolution parameters.

Similarly, the ^{235}U simultaneous measurements of fission and capture of de Saussure *et al.*¹³ and Perez *et al.*,¹⁴ the ^{239}Pu capture and fission data of Gwin *et al.*¹⁵ and the ^{235}U and ^{239}Pu absorption and fission data of Gwin *et al.*¹⁶ provided capture cross-section information which was very helpful in analyzing the resonance structures. However, these data were not included in the final fits because these capture measurements have relatively large backgrounds and are contaminated with spurious resonances due to impurities in the samples or detectors.

Fission data of Deruytter¹⁷ and Wagemans^{18,19} were used, particularly below 30 eV, to normalize other fission measurements. The information on the point by point statistical uncertainties was insufficient to include these data sets in the differential cross section fits.

Method of Analysis

The resonance parameter analysis code SAMMY²⁰ was used to perform consistent R-matrix multilevel analyses of the selected ^{235}U and ^{239}Pu neutron cross-section and transmission measurements. The computer code SAMMY is described in another contribution to this meeting. It uses the Reich-Moore formalism which leads to a physically sound representation of the neutron cross sections. The fitting procedure is based on Bayes' method and allows the successive incorporation of new

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data in a consistent manner. The option to search not only for resonance parameters but also for experimental parameters such as sample thickness, sample effective temperature, backgrounds, normalizations and the parameters of the instrumental resolution, all consistent with predetermined uncertainty limits, lead to realistic parameter uncertainties and covariance matrices.

The experimental partial cross-section data were renormalized to the 2200 m/s values proposed by the ENDF/B-VI standards committee.²¹ The energy scales of all the data sets were aligned on the energy scale of the 80-m flight path transmission measurements of Harvey *et al.* The length of that flight path has been measured with great accuracy.²²

Results of the Analyses

²³⁵U

The resolved resonance region from 0 to 110 eV was described with 262 levels. Four of these levels are bound levels with energies between -100 eV and 0. Twelve levels are between 110 and 160 eV. These 16 outside levels are fictitious levels which mock up the contribution of the truncated levels in the energy range of interest. An effective radius of 10.02F was obtained. The values of the 2200 m/s cross sections are compared to the values of ENDF/B-V²³ and to the values proposed by the ENDF/B-VI standard committee²¹ in Table 1. A comparison between integrated fission and capture cross sections obtained from our resonance parameters and from other data sets is shown in Table 2. A graphical comparison of fission cross sections between 80 and 100 eV is shown on Fig. 1.

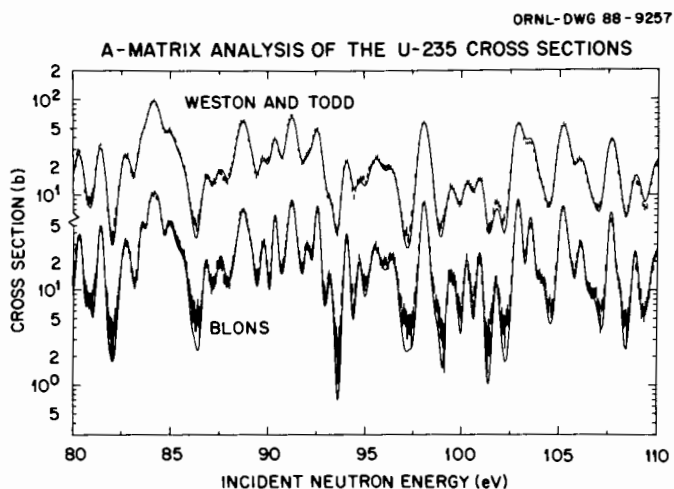


Figure 1. ²³⁵U fission cross sections from 80 to 100 eV.

²³⁹Pu

The resolved region up to 1 keV was described with 393 levels, of which four are bound levels and three are fictitious levels above 1 keV. The resolution of the measurements permits to resolve more than 80% of the resonances up to 1 keV. A constant effective radius of 9.48F was used. The values of the 2200 m/s cross sections are compared to the values of ENDF/B-V²⁴ and to the values proposed by the ENDF/B-VI standard committee²¹ in Table 1. The value of the fission cross-section average over several energy intervals obtained from our resonance parameters, is compared with values obtained from several measurements and to values proposed by the ENDF/B-VI standards evaluators in Table 3. Our values of the fission cross sections are about 3.5% lower than the standard committee values.²¹ We believe that this difference is due to a different appreciation of the amount of residual background in several experimental data sets. Figure 2 shows a comparison of the total, absorption, fission, and capture cross sections over the first ²³⁹Pu resonance, as computed from our evaluated parameters, with several experimental data sets. Figures 3 and 4 show comparisons of computed and measured transmission and fission cross-section measurements. The transmissions are measurements of Harvey *et al.* on three different sample thicknesses. The upper fission curve is the measurement of Blons, the lower curve is the measurement of Weston *et al.* Note the better resolution and the residual background in the experimental data of Blons.

Summary and Conclusions

This paper describes resonance parameter analyses of the two important fissile isotopes ²³⁵U and ²³⁹Pu. These analyses improve on most previous analyses in several respects: they utilize a physically sound formalism which is adequate to properly describe the interference effect in the fission channels; they are based on recent high resolution, low background measurements which were not available to previous evaluators; the measured cross sections were renormalized to the latest thermal values proposed by the ENDF/B-VI standard committee; for ²³⁵U the analysis is consistent with the spin separated fission data; and finally the resolved resonance region was extended to 110 eV for ²³⁵U and to 1 keV for ²³⁹Pu.

It is planned to examine very recently completed measurements and measurements still in progress,²⁵ when the results become available, and to perform some data testing of these new evaluations. They will then be proposed for ENDF/B-VI and the latest JEF evaluation.

Table 1. 2200 m/s value of cross sections at 300K (b)

	²³⁵ U			²³⁹ Pu		
	This work	ENDF/B-V	Proposed Standard*	This work	ENDF/B-V	Proposed Standard*
Total	696.92	694.64	698.67 ± 1.71	1026.88	1019.90	1027.30 ± 5.00
Scattering	15.09	14.74	15.46 ± 1.06	8.85	8.00	7.88 ± 0.97
Absorption	681.83	681.90	683.22 ± 1.34	1017.83	1011.90	1019.42 ± 4.00
Fission	582.93	583.52	584.25 ± 1.11	747.34	741.70	747.99 ± 1.87
Capture	98.90	98.38	98.96 ± 0.74	270.49	270.20	271.43 ± 2.14

*See Ref. 21.

Table 2. Comparison of ^{235}U integrated cross sections $\int \sigma dE$ (b eV)

Interval (eV)	Fission			Capture	
	This work	Gwin <i>et al.</i> (84)	Wagemans	This work	de Saussure <i>et al.</i> (67)
0.0206 - 0.06239	19.12	19.260*	$19.26 \pm 0.08^*$	3.248	
7.8 - 11.0	244	247.4	246 ± 2.5	102.96	85.16
0.5 - 10.0	399	406	406	245.9	231.6
10.0 - 50.0	1786	1838.5	1838	1230	1178
50.0 - 100.0	1551	1632	1647.5	689	721
100.0 - 110.0	180	183	190.6	117	158

*Normalized over this interval.

Table 3. ^{239}Pu average fission integrals (b)

Energy (keV)	This work	Weston and Todd	Blons	Proposed Standard*
0.1 - 0.2	18.135	18.095	18.93	18.66 ± 0.13
0.2 - 0.3	17.311	17.441	17.79	17.88 ± 0.12
0.3 - 0.4	8.080	8.130	8.91	8.43 ± 0.06
0.4 - 0.5	9.389	9.337	9.71	9.57 ± 0.07
0.5 - 0.6	15.062	15.170	15.51	15.56 ± 0.11
0.6 - 0.7	4.129	4.192	4.63	4.46 ± 0.04
0.7 - 0.8	5.323	5.385	5.94	5.63 ± 0.04
0.8 - 0.9	4.729	4.765	5.11	4.98 ± 0.04
0.9 - 1.0	8.228	8.165	8.57	8.30 ± 0.07

*See Ref. 21.

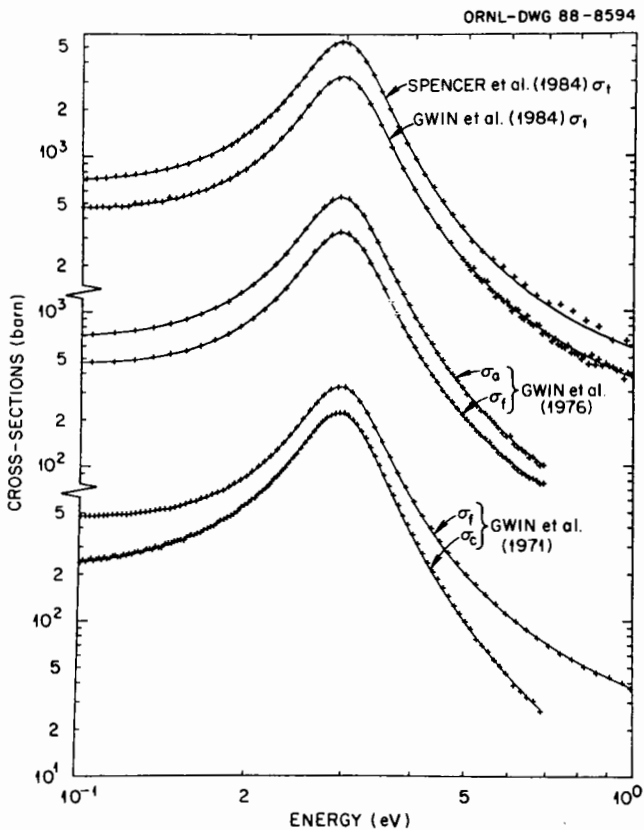


Figure 2. ^{239}Pu cross sections between 0.1 and 1.0 eV.

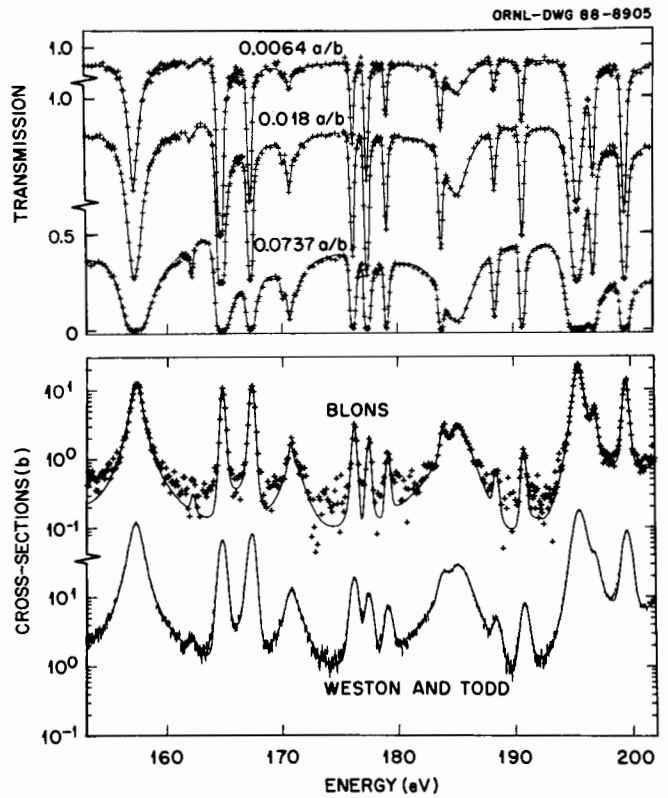


Figure 3. ^{239}Pu transmissions and fission cross sections between 150 and 200 eV.

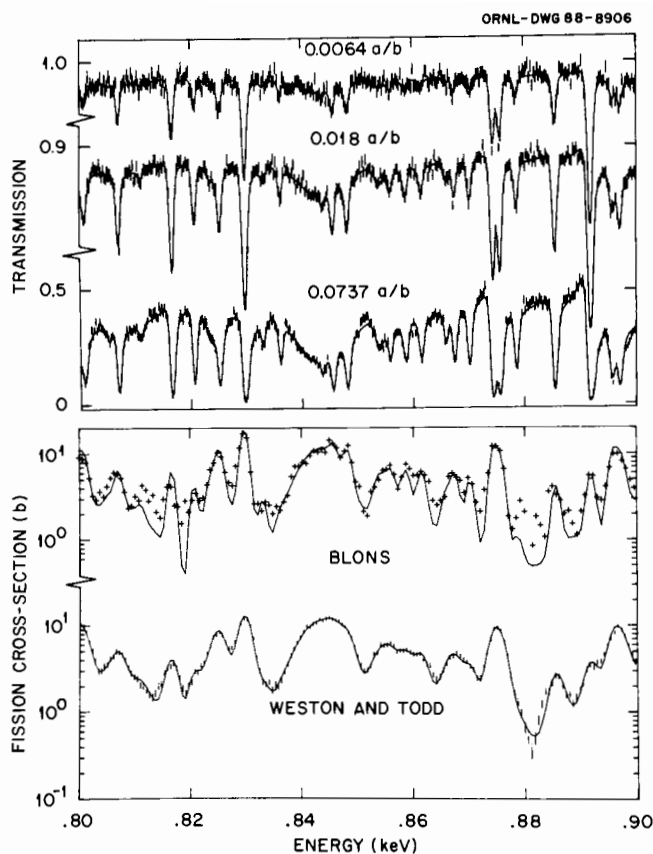


Figure 4. ^{239}Pu transmissions and fission cross sections between 800 and 900 eV.

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