CONF-880546--14

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

H. Derrien,† G. de Saussure, N. M. Larson, L. C. Leal,** and R. B. Perez**
Engineering Physics and Mathematics Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6354 USA

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)

CONF-880546--14

DE88 011015

* Research sponsored by the Office of Nuclear Physics, U.S. Department of Energy, under contract DE-AC05-84OR21400 with the Martin Marietta Energy Systems, Inc.

† Centre d'Etudes Nucleaires de Cadarache, Saint-Paul-Lez-Durance, France
** The University of Tennessee, Knoxville, Tennessee

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 Todd[5] 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 CINDA[9] 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 Blons[10] 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, but 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 Deruytter[17] 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 SAMMY[20] 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 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 evaluators.[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

^{235}U

The unresolved 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-V[23] and to the values proposed by the ENDF/B-VI standard evaluators[21] 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.

^{239}Pu

The unresolved 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-V[24] and to the values proposed by the ENDF/B-VI standard evaluators[21] 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 evaluators 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 ^{239}Pu 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 ^{235}U and ^{239}Pu. 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 evaluators; for ^{235}U the analysis is consistent with the spin separated fission data; and finally the resolved resonance region was extended to 110 eV for ^{235}U and to 1 keV for ^{239}Pu.

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.

REFERENCES

1. M. S. Moore *et al.*, p. 74 in *Proc. IAEA Consultant Meeting on Uranium and Plutonium Isotope Resonance Parameters*, INDC(NDC)-129/GJ (1982).
2. E. D. Arthur, *et al.*, *Nucl. Sci. Eng.* 88, 56 (1984).
3. Op. cit. Ref. 1, p. 13 (1982).
4. R. Gwin *et al.*, *Nucl. Sci. Eng.* 88, 37 (1984).
5. L. W. Weston and J. H. Todd, *Nucl. Sci. Eng.* 88, 567 (1984).
6. R. R. Spencer *et al.*, *Nucl. Sci. Eng.* 96, 318 (1987).

7. J. A. Harvey *et al.*, paper presented at this Conference (1988).

8. CSISRS: "Cross-Section Information Standard Retrieval System," available from Brookhaven National Laboratory.

9. CINDA: "The Index to Literature and Computer Files on Microscopic Neutron Data," Internat. Atomic Energy Agency, Vienna (1987).

10. J. Blons, *Nucl. Sci. Eng.* **51**, 130 (1973).

11. M. S. Moore *et al.*, *Phys. Rev.* **C18**, 1328 (1978).

12. G. A. Keyworth *et al.*, *Phys. Rev. Lett.* **31**, 1077 (1973).

13. G. de Saussure *et al.*, ORNL/TM-1804, 1967.

14. R. B. Perez *et al.*, *Nucl. Sci. Eng.* **52**, 46 (1973).

15. R. Gwin *et al.*, *Nucl. Sci. Eng.* **45**, 25 (1971).

16. R. Gwin *et al.*, *Nucl. Sci. Eng.* **59**, 79 (1976); also *Nucl. Sci. Eng.* **61**, 116 (1976).

17. A. J. Deruytter *et al.*, *J. Nucl. Ener.* **26**, 293 (1972).

18. C. Wagemans *et al.*, *Annals Nucl. En.* **7,8**, 495 (1980).

19. C. Wagemans and A. J. Deruytter, p. 499 in *Proc. of Nucl. Data for Basic and Applied Science*, Santa Fe, NM, May 13-17, 1985, Vol. 1 (1986).

20. N. M. Larson, ORNL/TM-9719/R1, 1985; also N. M. Larson and F. G. Perey, paper presented at this Conference (1988).

21. A. Carlson *et al.*, "Results of the ENDF/B-VI Standards Evaluation," communication of 8/31/87.

22. D. C. Larson and N. M. Larson, ORNL/TM-9097, 1985.

23. M. R. Bhat, BNL-NCS-51184, 1980.

24. E. Kujawski *et al.*, MAT-1399; available from Brookhaven National Laboratory, 1979.

25. Measurements in progress include high resolution fission cross section for ^{235}U and ^{239}Pu (L. W. Weston, private communication); fission measurement on ^{235}U (R. C. Schrack, private communication); ^{235}U and ^{239}Pu fission in the energy region 0.001 eV to 0.4 eV (C. Wagemans, private communication) and measurements of η (U-235) at low energy (M. C. Moxon, private communication).

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

	^{235}U			^{239}Pu		
	This work	ENDF/B-V	Standard	This work	ENDF/B-V	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

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

Interval (eV)	Fission			Capture	
	This work	Gwin *et al.* (84)	Wagemans	This work	de Saussure *et al.* (67)
0.0206 – 0.06239	19.12	19.260*	19.26 ± 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 their interval.

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

Energy (keV)	This work	Weston and Todd	Blons	Standard V-VI
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

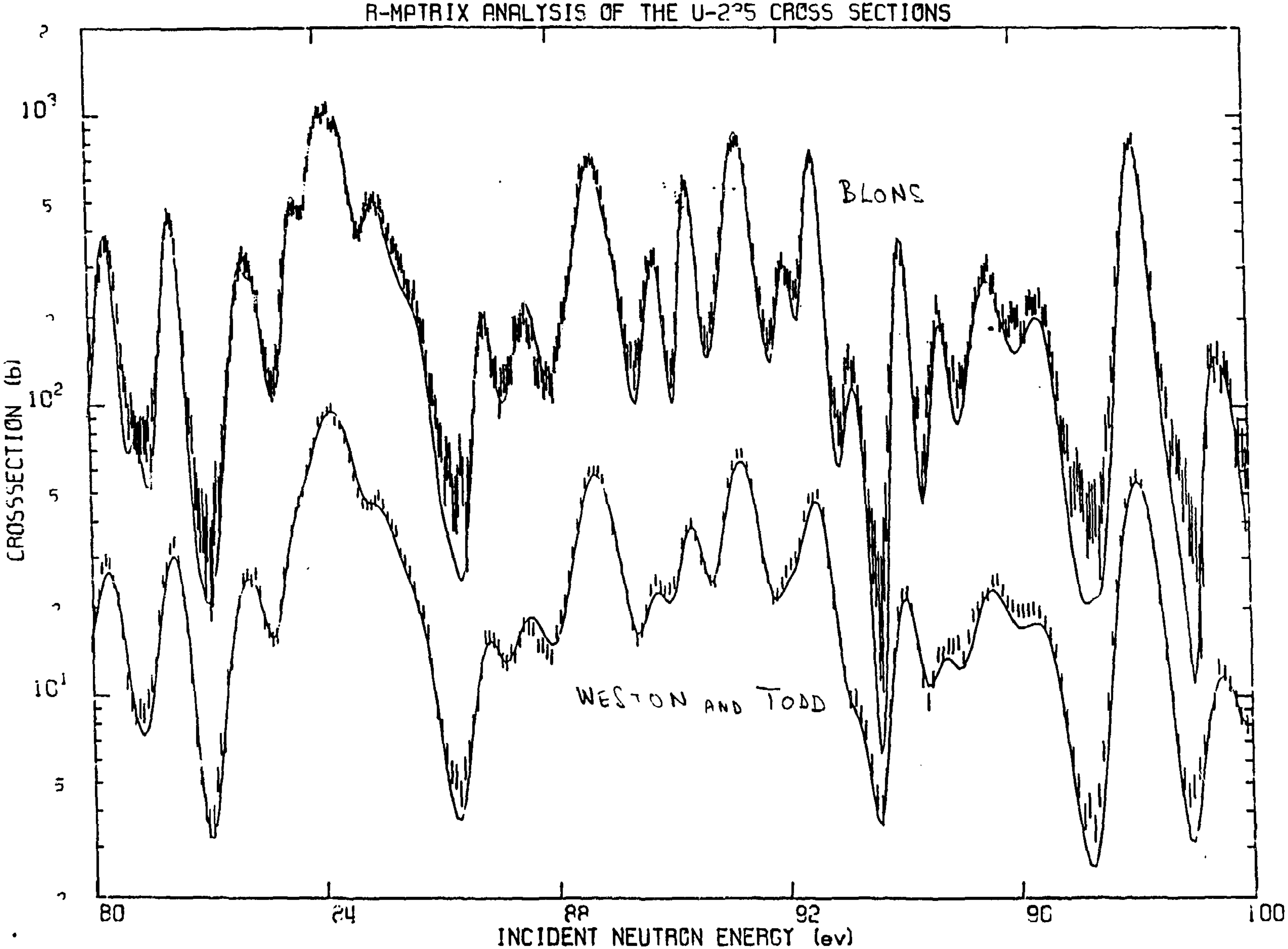
FIGURE CAPTIONS

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

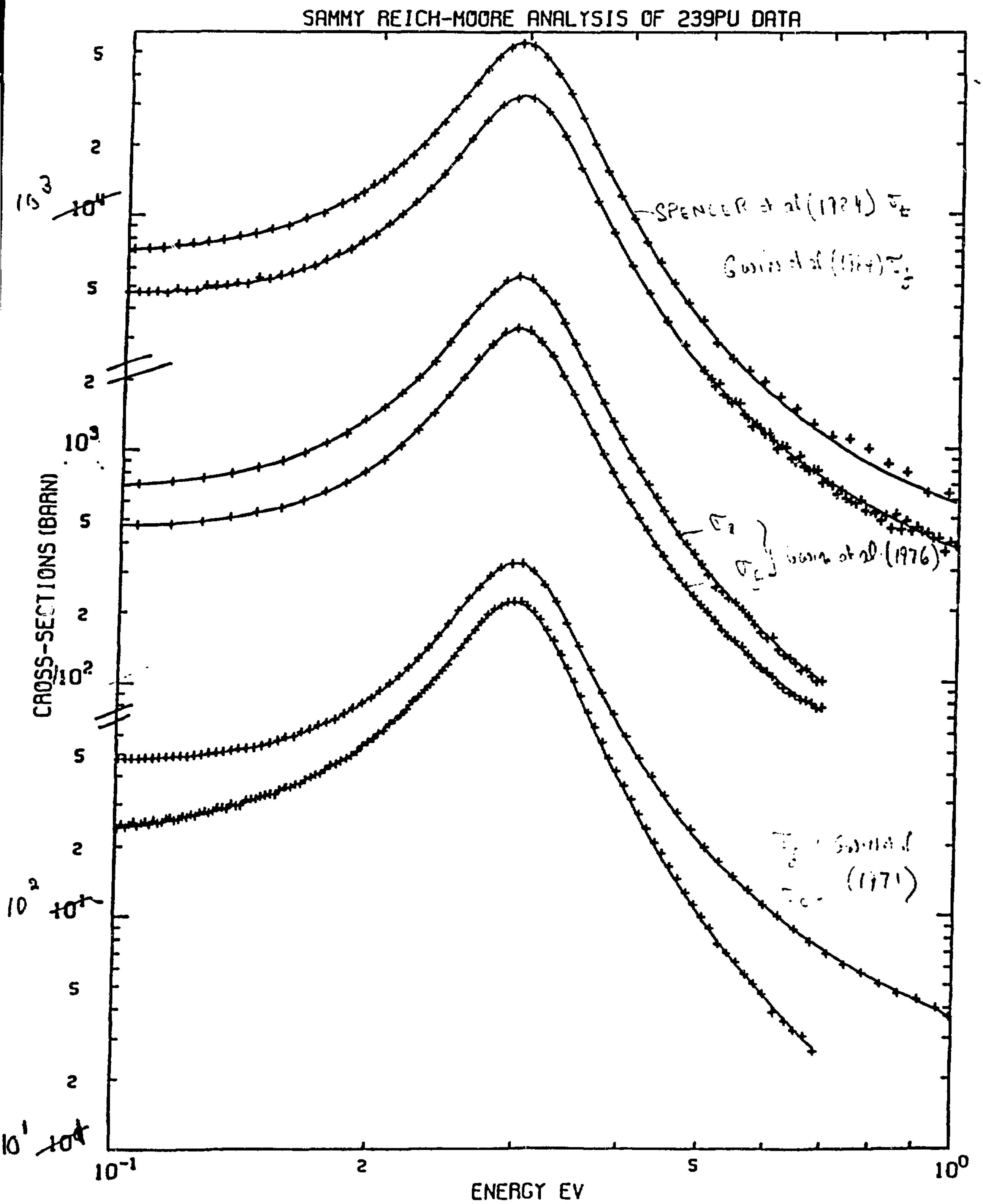
Figure 2. ^{239}Pu cross sections between 0.1 and 1.0 eV.

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

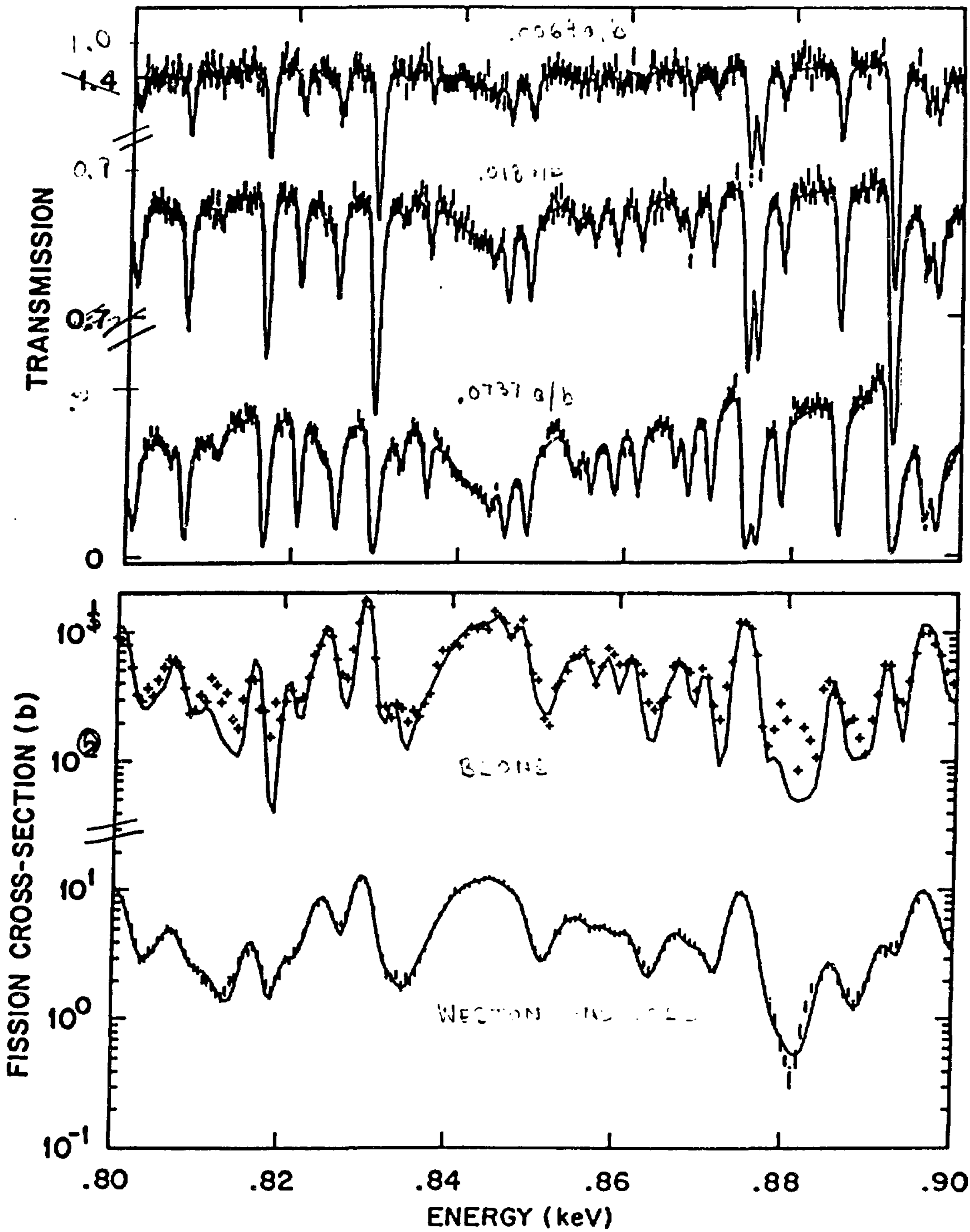
Figure 4. ^{239}Pu transmissions and fission cross sections between 800 and 900 eV.



R-MPTRIX ANALYSIS OF THE U-2°5 CROSS SECTIONS
BLONS
WESTON AND TODD
CROSSECTION (b)
10³
5
10²
5
10¹
5
80
84
88
92
96
100
INCIDENT NEUTRON ENERGY (ev)


SAMMY REICH-MOORE ANALYSIS OF 239PU DATA
CROSS-SECTIONS (BARN)
ENERGY EV
10^{-1}
2
5
10^{0}
SPENCER et al (1984) σ_t
σ_f
σ_t
(1976)
(1971)

ORNL-DWG 88-7847



ORNL–DWG 88–7842