JAERI-M
93-251

REVISION OF THE ^{241}Pu REICH-MOORE RESONANCE PARAMETERS BY COMPARISON WITH RECENT FISSION CROSS SECTION MEASUREMENTS

January 1994

Herve DERRIEN*

日本原子力研究所
Japan Atomic Energy Research Institute

JAERI-Mレポートは，日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11 茨城県那珂郡東海村）あて，お申しこみください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11 茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

JAERI-M reports are issued irregularly.
Inquiries about availability of the reports should be addressed to Information Division Department of Technical Information, Japan Atomic Energy Research Institute, Tokaimura, Naka-gun, Ibaraki-ken 319-11, Japan.

編集兼発行　日本原子力研究所
印　　刷　ニッセイエブロ株式会社

Revision of the ^{241}Pu Reich-Moore Resonance Parameters by Comparison with Recent Fission Cross Section Measurements

Herve DERRIEN*

Department of Reactor Engineering
Tokai Research Establishment
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken

(Received December 3, 1993)

The fission cross section of ^{241}Pu was re-measured recently by Wagemans et al. They found that the shape of the cross section in the thermal energy range was compatible with the 1/v law, in contradiction with the previously reported data. As a consequence, the re-normalization of the experimental data used for evaluation purpose is needed. In order to take into account this re-normalization, the resonance parameters of ENDF/B-VI were revised, resulting in a decrease of the fission cross section by about 3% on average, in the energy range from thermal to 300 eV. The present results will be adopted in JENDL-3.2.

Keywords: Neutron Cross Section, Resonance Parameter, Plutonium-241, Evaluation, ENDF/B-VI, JENDL-3.2

---

* Research Fellow (March 1991 - June 1993)

最近の核分裂断面積測定値との比較を基にした ^{241}Pu Reich-Moore型共鳴パラメータの改訂

日本原子力研究所東海研究所原子炉工学部
Herve DERRIEN*

(1993年12月3日受理)

最近、^{241}Pu の核分裂断面積が Wagemans 等によって測定された。彼らは、以前に報告されたデータに反して、熱中性子エネルギー領域の断面積が 1/v 法則に従っていることを見つけた。その結果、核データ評価に使われた実験データの再規格化が必要となった。この再規格化を考慮にいれて、ENDF/B-VI に格納されている共鳴パラメータの改訂を行い、その結果、熱中性子エネルギーから 300 eV で核分裂断面積が平均約 3 %小さくなった。今回の結果は JENDL-3.2 に採用される。

東海研究所：〒319-11　茨城県那珂郡東海村白方字白根2－4
＊リサーチ　フェロー（1991年3月～1993年6月）

Contents

目　　次

1. INTRODUCTION

The resonance parameters of the neutron cross sections of ^{241}Pu were obtained by Derrien and de Saussure[1)] in the energy range from thermal to 300 eV by a Bayesian fit of selected experimental effective total cross sections, fission and capture cross sections by using the Reich-Moore fitting code SAMMY[2)]. The results of this work were used in the ENDF/B-VI evaluated data file. Some difficulties were encountered in the normalization of the experimental fission cross sections due to the discrepancies in the shape of the available experimental data both in thermal and high energy ranges. The consistency among the experimental data base could not be obtained without large renormalization and background correction parameters in the SAMMY fits. Particularly, it was shown that the discrepancy between the fission cross sections in the thermal energy range was due to a deviation from the 1/v shape below about 0.05 eV.

New fission cross section measurements were recently performed by Wagemans et al.[3,4)] in the energy range from 0.002 eV to 20 eV in order to check the shape of the cross section in the thermal energy range. They showed that the shape of the fission cross section was clearly compatible with the 1/v law, in contradiction to all the previous measurements reported in the literature. Consequently, the normalization of all the previous results using the data in the low energy region could be erroneous. Particularly, the discrepancy observed in the average fission cross section over the 0.26 eV resonance could be due to the errors of normalization in the thermal region. Wagemans et al. compared the ENDF/B-VI data with their new results and concluded that the evaluated data files using the evaluation of Derrien and de Saussure should be revised in the energy range up to 300 eV.

2. COMMENTS ON ENDF/B-VI EVALUATION

In the energy range from 0.01 eV to 3 eV the new data of Wagemans et al. are on the average 2.2 % smaller than ENDF/B-VI. This difference is mainly due to a difference of 3% between the 1976 data of Wagemans et al.[5)] and the new values of Wagemans et al.[3,4)] The 1976 data of Wagemans et al. were used in the evaluation of Derrien and de Saussure in the low energy region. In the intermediate energy range from 3 eV to 12 eV, the average fission cross section of ENDF/B-VI is in excellent agreement with the new data of Wagemans et al. In this energy range, the SAMMY fits of Derrien and de Saussure were

1. INTRODUCTION

The resonance parameters of the neutron cross sections of ^{241}Pu were obtained by Derrien and de Saussure[1] in the energy range from thermal to 300 eV by a Bayesian fit of selected experimental effective total cross sections, fission and capture cross sections by using the Reich-Moore fitting code SAMMY[2]. The results of this work were used in the ENDF/B-VI evaluated data file. Some difficulties were encountered in the normalization of the experimental fission cross sections due to the discrepancies in the shape of the available experimental data both in thermal and high energy ranges. The consistency among the experimental data base could not be obtained without large renormalization and background correction parameters in the SAMMY fits. Particularly, it was shown that the discrepancy between the fission cross sections in the thermal energy range was due to a deviation from the 1/v shape below about 0.05 eV.

New fission cross section measurements were recently performed by Wagemans et al.[3,4] in the energy range from 0.002 eV to 20 eV in order to check the shape of the cross section in the thermal energy range. They showed that the shape of the fission cross section was clearly compatible with the 1/v law, in contradiction to all the previous measurements reported in the literature. Consequently, the normalization of all the previous results using the data in the low energy region could be erroneous. Particularly, the discrepancy observed in the average fission cross section over the 0.26 eV resonance could be due to the errors of normalization in the thermal region. Wagemans et al. compared the ENDF/B-VI data with their new results and concluded that the evaluated data files using the evaluation of Derrien and de Saussure should be revised in the energy range up to 300 eV.

2. COMMENTS ON ENDF/B-VI EVALUATION

In the energy range from 0.01 eV to 3 eV the new data of Wagemans et al. are on the average 2.2 % smaller than ENDF/B-VI. This difference is mainly due to a difference of 3% between the 1976 data of Wagemans et al.[5] and the new values of Wagemans et al.[3,4] The 1976 data of Wagemans et al. were used in the evaluation of Derrien and de Saussure in the low energy region. In the intermediate energy range from 3 eV to 12 eV, the average fission cross section of ENDF/B-VI is in excellent agreement with the new data of Wagemans et al. In this energy range, the SAMMY fits of Derrien and de Saussure were performed on the transmission data of Harvey and Simpson[6], the fission cross section of Weston and Todd[7], of Blons[8] and of Migneco et al.[9] and the capture cross section of Weston and Todd[7] with an adjustment of the normalization factor and of the background correction parameters of all the experimental data; the agreement between the new data of Wagemans et al. and ENDF/B-VI shows that, at least in this energy range, SAMMY performed on the data of Weston and Todd a renormalization equivalent to that recommended by Wagemans et al.[4]

In the high energy range up to 300 eV, the SAMMY fits relied mainly on the high resolution transmission measurements of Harvey and Simpson and on the high resolution fission measurements of Blons and of Migneco et al. for the accurate determination of the resonance parameters. Quite large normalization coefficients and background correction parameters were also needed in this energy range to obtain the consistency between the calculated cross sections and the experimental data. However, the result of the fits was in quite good agreement with the data of Weston and Todd normalized to the 1976 data of Wagemans et al. in the low energy region, which is also equivalent to the normalization to the 1983 data of Wagemans et al.[10] Since the earlier data of Wagemans et al. should decrease by 3% to be consistent with the new data, it is likely that the ENDF/B-VI fission cross section could be too large by about 3% in the energy range above 12 eV.

3. REVISION OF THE RESONANCE PARAMETERS

An accurate up-dating of the ^{241}Pu resonance parameters could be obtained by renormalizing the fission experimental data base according to the new data of Wagemans et al. and by restarting the SAMMY fits of the new experimental data base, including the high resolution transmission data of Harvey and Simpson. Due to lack of time a new SAMMY analysis was performed only in the energy range from 0.002 eV to 3 eV. In the energy range above 3 eV the up-dating was performed by applying some small corrections to the resonance parameters.

The SAMMY analysis of the new Wagemans et al. data was performed along with the total cross section of Young and Smith[11] in the energy range from 0.002 eV to 3 eV, by starting with the ENDF/B-VI resonance parameters. Only the parameters of the 3^+ resonances at −0.122 eV and at 0.265 eV were adjusted in this energy range. A quite good fit of the experimental data was obtained with the parameters shown in Table 1. The performed on the transmission data of Harvey and Simpson[6], the fission cross section of Weston and Todd[7], of Blons[8] and of Migneco et al.[9] and the capture cross section of Weston and Todd[7] with an adjustment of the normalization factor and of the background correction parameters of all the experimental data; the agreement between the new data of Wagemans et al. and ENDF/B−VI shows that, at least in this energy range, SAMMY performed on the data of Weston and Todd a renormalization equivalent to that recommended by Wagemans et al.[4]

In the high energy range up to 300 eV, the SAMMY fits relied mainly on the high resolution transmission measurements of Harvey and Simpson and on the high resolution fission measurements of Blons and of Migneco et al. for the accurate determination of the resonance parameters. Quite large normalization coefficients and background correction parameters were also needed in this energy range to obtain the consistency between the calculated cross sections and the experimental data. However, the result of the fits was in quite good agreement with the data of Weston and Todd normalized to the 1976 data of Wagemans et al. in the low energy region, which is also equivalent to the normalization to the 1983 data of Wagemans et al.[10] Since the earlier data of Wagemans et al. should decrease by 3% to be consistent with the new data, it is likely that the ENDF/B−VI fission cross section could be too large by about 3% in the energy range above 12 eV.

3. REVISION OF THE RESONANCE PARAMETERS

An accurate up−dating of the ^{241}Pu resonance parameters could be obtained by renormalizing the fission experimental data base according to the new data of Wagemans et al. and by restarting the SAMMY fits of the new experimental data base, including the high resolution transmission data of Harvey and Simpson. Due to lack of time a new SAMMY analysis was performed only in the energy range from 0.002 eV to 3 eV. In the energy range above 3 eV the up−dating was performed by applying some small corrections to the resonance parameters.

The SAMMY analysis of the new Wagemans et al. data was performed along with the total cross section of Young and Smith[11] in the energy range from 0.002 eV to 3 eV, by starting with the ENDF/B−VI resonance parameters. Only the parameters of the 3^+ resonances at −0.122 eV and at 0.265 eV were adjusted in this energy range. A quite good fit of the experimental data was obtained with the parameters shown in Table 1. The corresponding covariance matrix is given in Table 2. The values of the cross sections calculated at 0.0253 eV are compared to the standard data[12)] in Table 3. The calculated average total, fission and capture cross sections are displayed in Tables 4, 5 and 6 with the corresponding experimental data and the values obtained from ENDF/B-VI. The results of the fit are shown in Fig.1 in the energy range from 0.002 eV to 0.1 eV and in Fig.2 in the energy range from 0.1 eV to 3.3 eV. One should point out that an energy shift of dE/E=+0.00384 was applied to the data of Young and Smith in order to achieve a good consistency with the energy scale of the fission data over the resonance at 0.265 eV. The renormalized data of Weston and Todd are also compared to the cross sections calculated with the new resonance parameters in Fig. 3.

In the energy range above 3 eV the small corrections applied to the resonance parameters result in a decrease of the average fission cross section and in an increase of the average capture cross section, with a variation of the average total cross section smaller than the errors of the experimental data of Harvey and Simpson. The average values of the fission and capture cross sections calculated with the new resonance parameters are shown in Tables 7 and 8 along with the renormalized fission cross section of Weston and Todd and the values calculated from ENDF/B-VI. Examples of fission and capture cross sections calculated from the new resonance parameters are shown in Figs. 4, 5 and 6 and compared with the renormalized experimental data of Weston and Todd.

4. CONCLUSION

The results of the recent measurement of the ^{241}Pu fission cross section in the energy range from 0.002 eV to 20 eV of Wagemans et al. were used in a new evaluation of the resonance parameters. The accuracy of the calculated cross sections was greatly improved in the resonance at 0.265 eV. The cross sections averaged over this resonance should have the same accuracy as the standard values at 0.0253 eV. In the high energy region up to 300 eV the SAMMY analysis of the new experimental data base obtained by the renormalization of the experimental fission cross sections is recommended in order to improve the corrections to the resonance parameters performed in the present work. The present results will be adopted in JENDL-3 revision 2 (JENDL-3.2).

corresponding covariance matrix is given in Table 2. The values of the cross sections calculated at 0.0253 eV are compared to the standard data[12)] in Table 3. The calculated average total, fission and capture cross sections are displayed in Tables 4, 5 and 6 with the corresponding experimental data and the values obtained from ENDF/B-VI. The results of the fit are shown in Fig.1 in the energy range from 0.002 eV to 0.1 eV and in Fig.2 in the energy range from 0.1 eV to 3.3 eV. One should point out that an energy shift of dE/E=+0.00384 was applied to the data of Young and Smith in order to achieve a good consistency with the energy scale of the fission data over the resonance at 0.265 eV. The renormalized data of Weston and Todd are also compared to the cross sections calculated with the new resonance parameters in Fig. 3.

In the energy range above 3 eV the small corrections applied to the resonance parameters result in a decrease of the average fission cross section and in an increase of the average capture cross section, with a variation of the average total cross section smaller than the errors of the experimental data of Harvey and Simpson. The average values of the fission and capture cross sections calculated with the new resonance parameters are shown in Tables 7 and 8 along with the renormalized fission cross section of Weston and Todd and the values calculated from ENDF/B-VI. Examples of fission and capture cross sections calculated from the new resonance parameters are shown in Figs. 4, 5 and 6 and compared with the renormalized experimental data of Weston and Todd.

4. CONCLUSION

The results of the recent measurement of the ^{241}Pu fission cross section in the energy range from 0.002 eV to 20 eV of Wagemans et al. were used in a new evaluation of the resonance parameters. The accuracy of the calculated cross sections was greatly improved in the resonance at 0.265 eV. The cross sections averaged over this resonance should have the same accuracy as the standard values at 0.0253 eV. In the high energy region up to 300 eV the SAMMY analysis of the new experimental data base obtained by the renormalization of the experimental fission cross sections is recommended in order to improve the corrections to the resonance parameters performed in the present work. The present results will be adopted in JENDL-3 revision 2 (JENDL-3.2).

REFERENCES

1) Derrien H. and de Saussure G.: Nucl. Sci. Eng. **106**, 415(1990).
2) Larson N.M. and Perey F.G.: ORNL/TM-9719(1985).
3) Wagemans C., Schillebeeckx P., Deruytter A. and Barthelemy R.: Proc. Int. Conf., PHYSOR 90, Marseille, France, Vol.1, III-9 (1990).
4) Wagemans C., Schillebeeckx P., Deruytter A. and Barthelemy R.: Proc. Conf. on Nuclear Data for Science and Technology, Juelich 13-17 May 1991, p.35 (1991).
5) Wagemans C. and Deruytter A.: Nucl. Sci. Eng. **60**, 44(1976).
6) Harvey J.A. and Simpson O.D.: Oak-Ridge National Laboratory (1973), unpublished.
7) Weston L.W. and Todd J.H.: Nucl. Sci. Eng. **65**, 454(1978).
8) Blons J.: Nucl. Sci. Eng. **51**, 130(1973).
9) Migneco E., Theobald J.P. and Wartena J.A.: Proc. Conf. Nuclear Data for Reactors, Helsinki, June 15-19, 1970, Vol.I, p.437, IAEA(1970).
10) Wagemans C. and Deruytter A.: Proc. Conf. on Nuclear Data for Science and Technology, Antwerp, Belgium, 69 (1983).
11) Young T.B. and Smith J.R.: WASH-1093, p.60 (1968).
12) Carlson A. et al.: ENDF/B-VI standard evaluation, private communication from Peelle R.W. (1987).

Table 1 The parameters of the resonances at −0.1225 eV and 0.2647 eV and their standard deviations.

	parameters	value	standard deviation
1	Energy(eV)	−0.12250	0.00294
2	Capture Width(meV)	43.706	1.38100
3	Neutron Width(meV)	0.01677	0.00072
4	Fission Width 1(meV)	20.542	0.73210
5	Fission Width 2(meV)	0.940	0.04700
6	Energy(eV)	0.26469	0.00026
7	Capture Width(meV)	33.35	0.46040
8	Neutron Width(meV)	0.04252	0.00018
9	Fission Width 1(meV)	-50.422	1.07400
10	Fission Width 2(meV)	25.358	1.01800

Numbers 1 through 5 : parameters of the resonance at −0.1225eV.
Numbers 5 through 10 : parameters of the resonance at 0.2647 eV.

Table 2 Correlation matrix of the parameters of the resonances at −0.1225 eV and 0.2647 eV.

	1	2	3	4	5	6	7	8	9	10
1	100									
2	−23	100								
3	−79	−26	100							
4	−33	70	−24	100						
5	−2	0	3	5	100					
6	−22	22	4	7	−4	100				
7	8	−23	−9	1	0	4	100			
8	29	−29	−23	−17	0	1	71	100		
9	22	4	−24	−38	4	50	−14	−7	100	
10	−12	−2	16	28	−4	−52	−5	−2	−88	100

The numbers 1 through 10 are the identification numbers of the parameters shown in Table 1.

Table 3 Cross sections at 0.0253 eV

	Present results (b)	ENDF/B-VI Standard[12] (b)
Fission	1012.50(-0.0%)	1012.68±6.58
Capture	361.52(+0.1%)	361.29±4.95
Scattering	11.36(-7.1%)	12.17±2.62
Total	1385.38(-0.1%)	1386.14±8.64

Table 4 The total cross section integral in the energy range from 0.0021 eV to 3 eV.

Energy range (eV)	Present work (b•eV)	ENDF/B-VI (b•eV)	Young and Smith[11] (b•eV)
0.0021-0.020	43.54	43.09(-1.0%)	43.25(-0.7%)
0.0200-0.030	14.03	14.02(-0.1%)	14.01(-0.1%)
0.0300-0.100	65.09	66.17(+1.7%)	64.99(-0.1%)
0.1000-0.500	378.38	385.27(+1.8%)	380.10(+0.4%)
0.5000-1.000	29.74	29.41(-1.1%)	31.19(+4.4%)
1.0000-3.000	83.36	83.92(+0.7%)	82.50(-1.0%)
0.0021-3.000	614.14	621.88(+1.3%)	616.04(+0.3%)

Table 5 The fission cross section integral in the energy range from 0.0021 eV to 3 eV.

Energy range (eV)	Present work (b•eV)	ENDF/B-VI (b•eV)	Wagemans et al.(b•eV)[4]	Weston and Todd(b•eV)[7]
0.0021-0.020	31.06	30.61(-1.5%)	31.09(+0.1%)	
0.0200-0.030	10.24	10.22(-0.2%)	10.24(0.0%)	
0.0300-0.100	49.02	50.02(+2.0%)	48.70(-0.6%)	
0.1000-0.500	262.76	270.84(+3.1%)	264.58(+0.7%)	262.53(-0.1%)
0.5000-1.000	17.93	17.64(-1.6%)	17.60(-1.8%)	17.67(-1.4%)
1.0000-3.000	54.88	55.62(+1.3%)	54.40(-0.9%)	55.06(+0.3%)
0.0021-3.000	425.89	434.95(+2.1%)	426.61(+0.2%)	
0.1000-3.000	335.57	344.10(+2.5%)	336.58(+0.3%)	335.26(-0.1%)

Weston and Todd experimental data were normalized to Wagemans et al.[4] in the energy range from 0.1 eV to 12 eV (original EXFOR data multiplied by 0.952).

Table 6 The capture cross section integral in the energy range from 0.0021 eV to 3 eV.

Energy range (eV)	Present work (b•eV)	ENDF/B-VI (b•eV)	Weston and Todd[7] (b•eV)
0.0021-0.020	12.25	12.28(+0.2%)	
0.0200-0.030	3.67	3.68(+0.3%)	
0.0300-0.100	15.28	15.39(+0.7%)	15.27(-0.1%)
0.1000-0.500	110.58	109.47(-1.0%)	110.49(-0.1%)
0.5000-1.000	5.90	5.87(-0.5%)	6.51
1.0000-3.000	7.30	7.14(-2.2%)	8.96
0.0021-3.000	154.98	153.83(-0.7%)	
0.0300-3.000	139.06	137.87(-0.9%)	141.29(+1.6%)

Weston and Todd experimental data were normalized to the calculated average capture cross section over the resonance at 0.264 eV(original EXFOR data multiplied by 0.914); in the energy range from 0.5 eV to 3 eV the experimental data are not accurate due to large corrections of impurities.

Table 7 The fission cross section integral in the energy range from 3 eV to 300 eV.

Energy range (eV)	Present work (b•eV)	ENDF/B-VI (b•eV)	Weston and Todd[7] (b•eV)
3- 20	3038.63	3066.37(+0.9%)	3036.23(-0.1%)
20- 50	1683.69	1739.68(+3.3%)	1705.50(+1.3%)
50-100	1971.15	2030.10(+3.0%)	1931.50(-2.0%)
100-200	2554.85	2628.39(+2.9%)	2531.00(-0.9%)
200-300	2741.23	2820.75(+2.9%)	2747.00(+0.2%)
3-300	11989.55	12285.29(+2.5%)	11951.23(-0.3%)

Weston and Todd experimental data were normalized to Wagemans et al.[4] in the energy range from 0.1 eV to 12 eV (original EXFOR data multiplied by 0.952).

Table 8 The capture cross section integral in the energy range from 3 eV to 300 eV

Energy range (eV)	Present work (b•eV)	ENDF/B-VI (b•eV)	Weston and Todd[7] (b•eV)
3- 20	1213.07	1138.52(-6.5%)	1192.90(-1.7%)
20- 50	330.34	307.48(-7.5%)	338.09(+2.3%)
50-100	605.40	585.88(-3.2%)	594.83(-1.8%)
100-200	609.83	581.77(-4.8%)	652.68(+7.0%)
200-300	684.97	661.12(-3.6%)	700.53(+2.3%)
3-300	3443.36	3274.77(-5.1%)	3479.04(+1.0%)

Weston and Todd experimental data were normalized to the calculated average capture cross section over the resonance at 0.265 eV(original EXFOR data multiplied by 0.914).

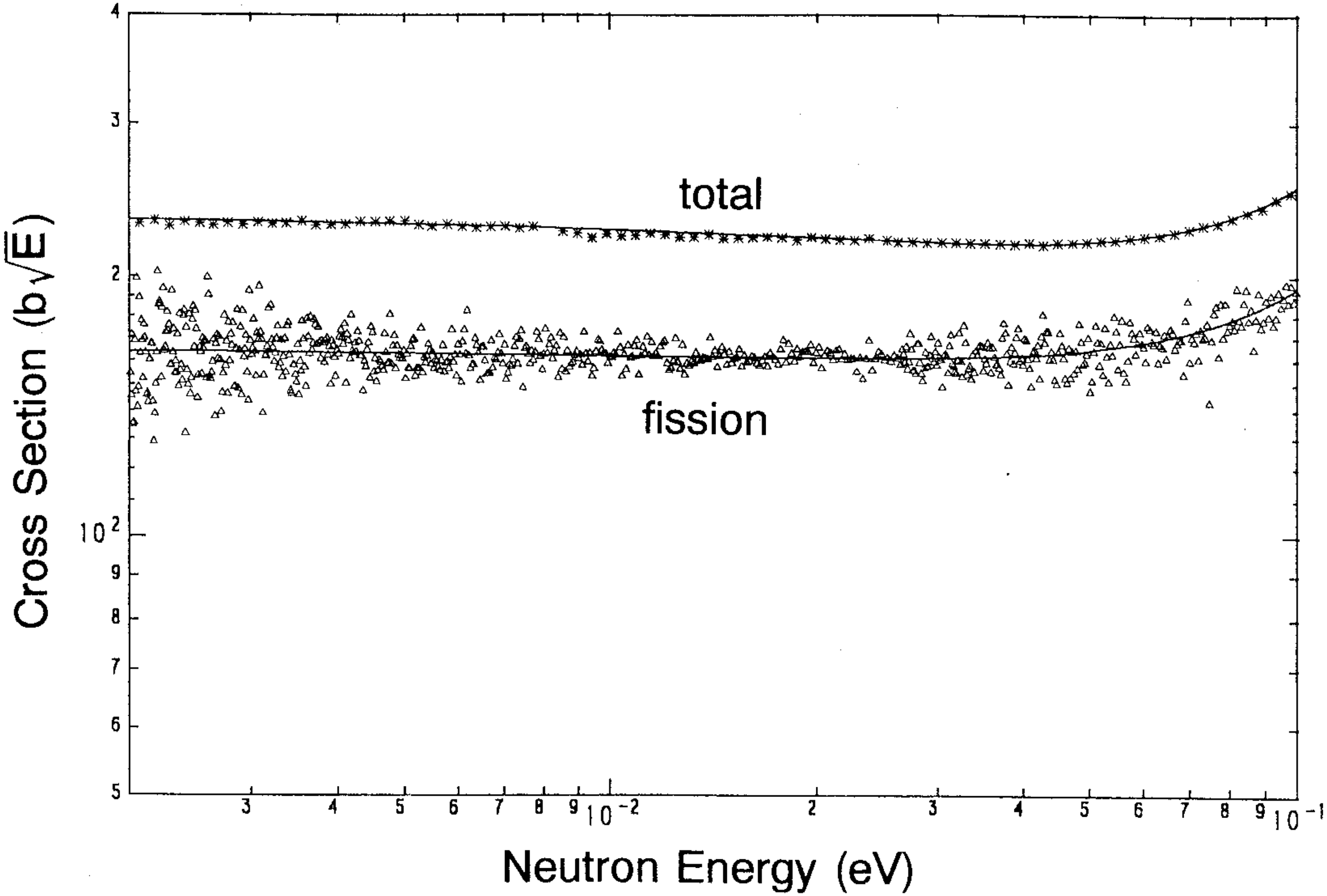

Fig.1 Total and fission cross sections in the energy range from 0.002 eV to 0.1 eV. The experimental data are those of Young and Smith[11] and of Wagemans et al.[4] The solid lines represent the cross sections calculated with the new resonance parameters.

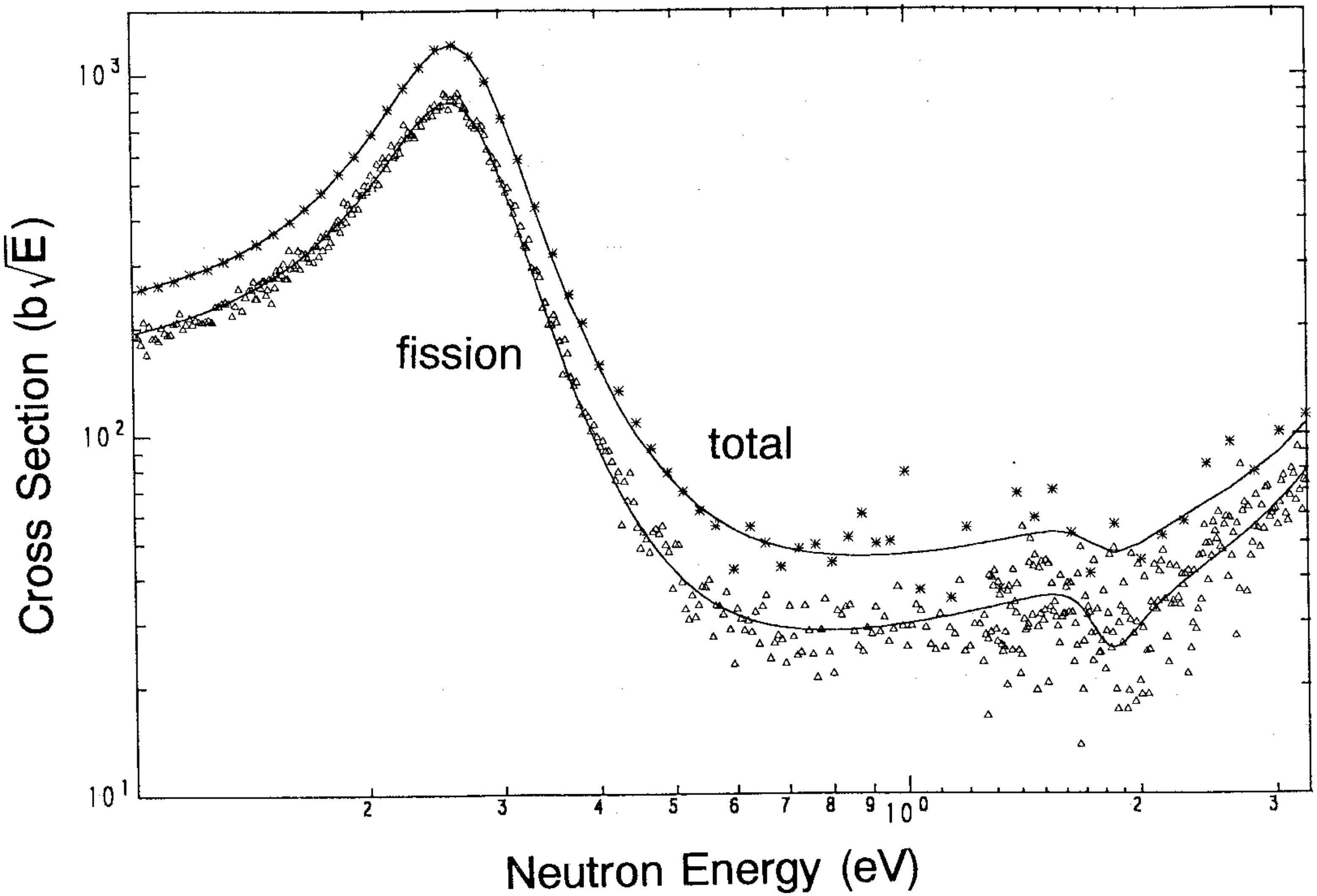

Fig. 2 Total and fission cross sections in the energy range from 0.1 eV to 3.3 eV. The experimental data are those of Young and Smith[11] and of Wagemans et al.[4] The solid lines represent the cross sections calculated with the new resonance parameters.

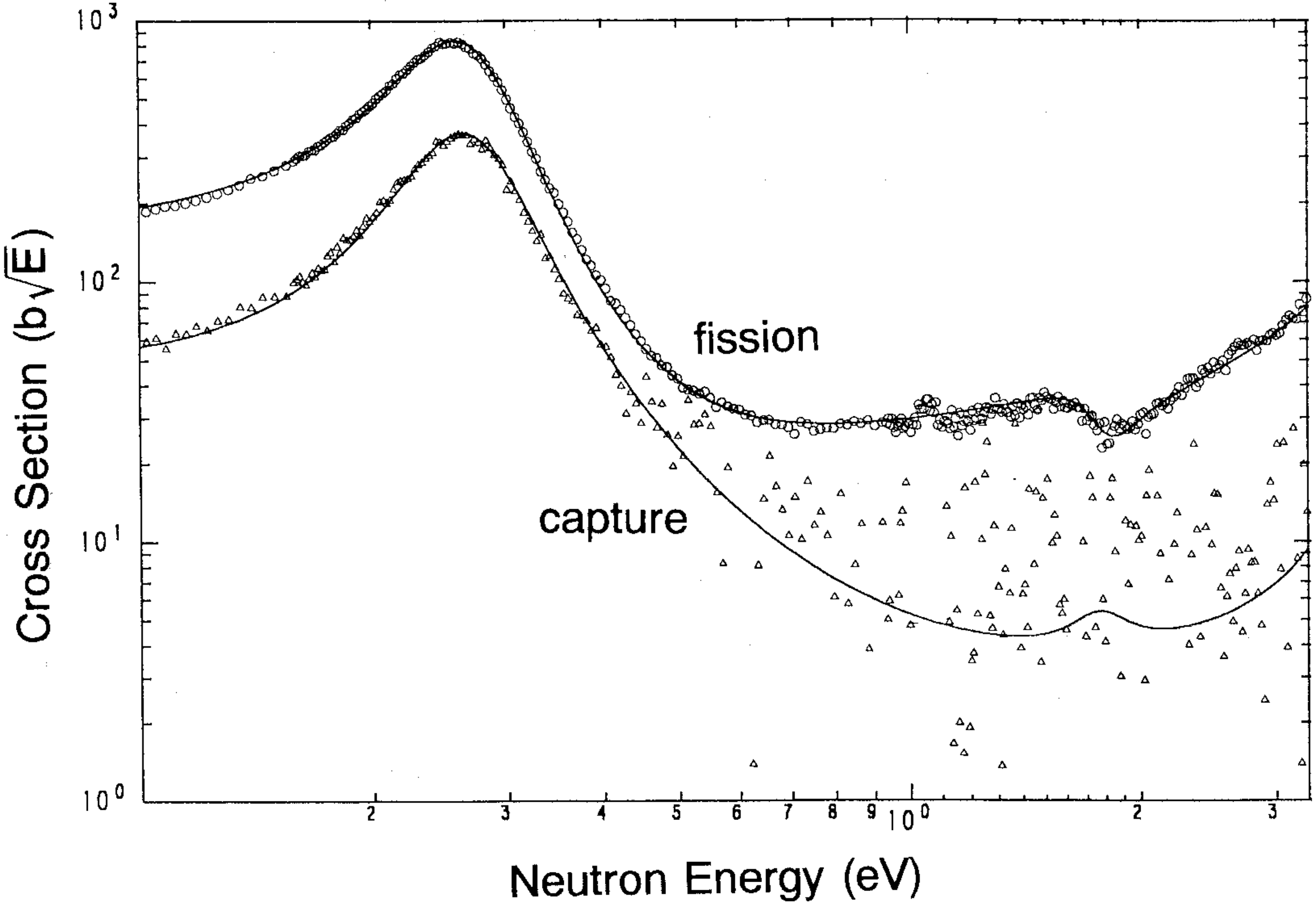

Fig. 3 Fission and capture cross sections in the energy range from 0.1 eV to 3.3 eV. The experimental data are the renormalized data of Weston and Todd[7]. The solid lines represent the cross sections calculated with the new resonance parameters.

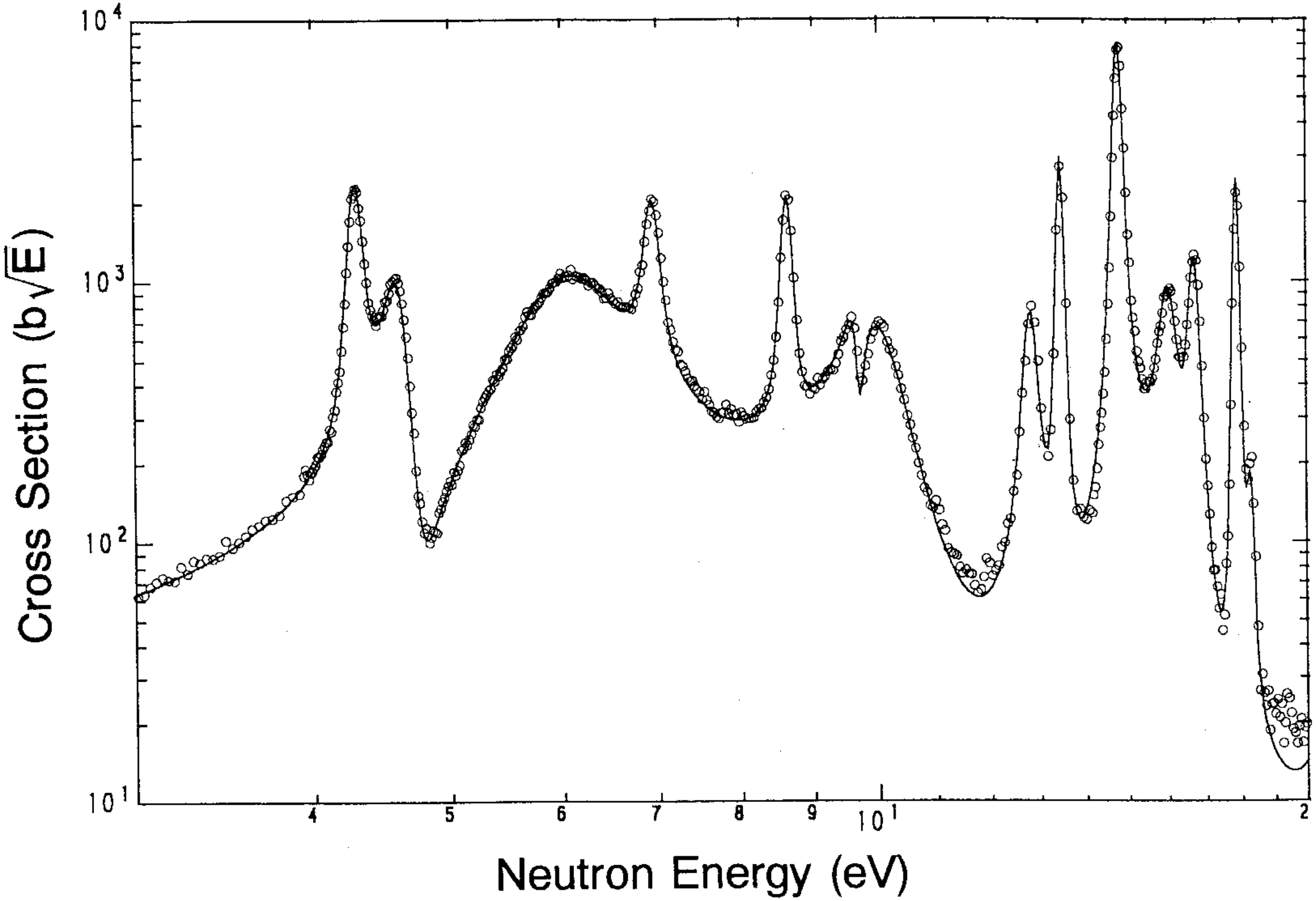

Fig. 4 Fission cross section in the energy range from 3 eV to 20 eV. The experimental data are the renormalized data of Weston and Todd[7]. The solid line represents the cross sections calculated with the new resonance parameters.

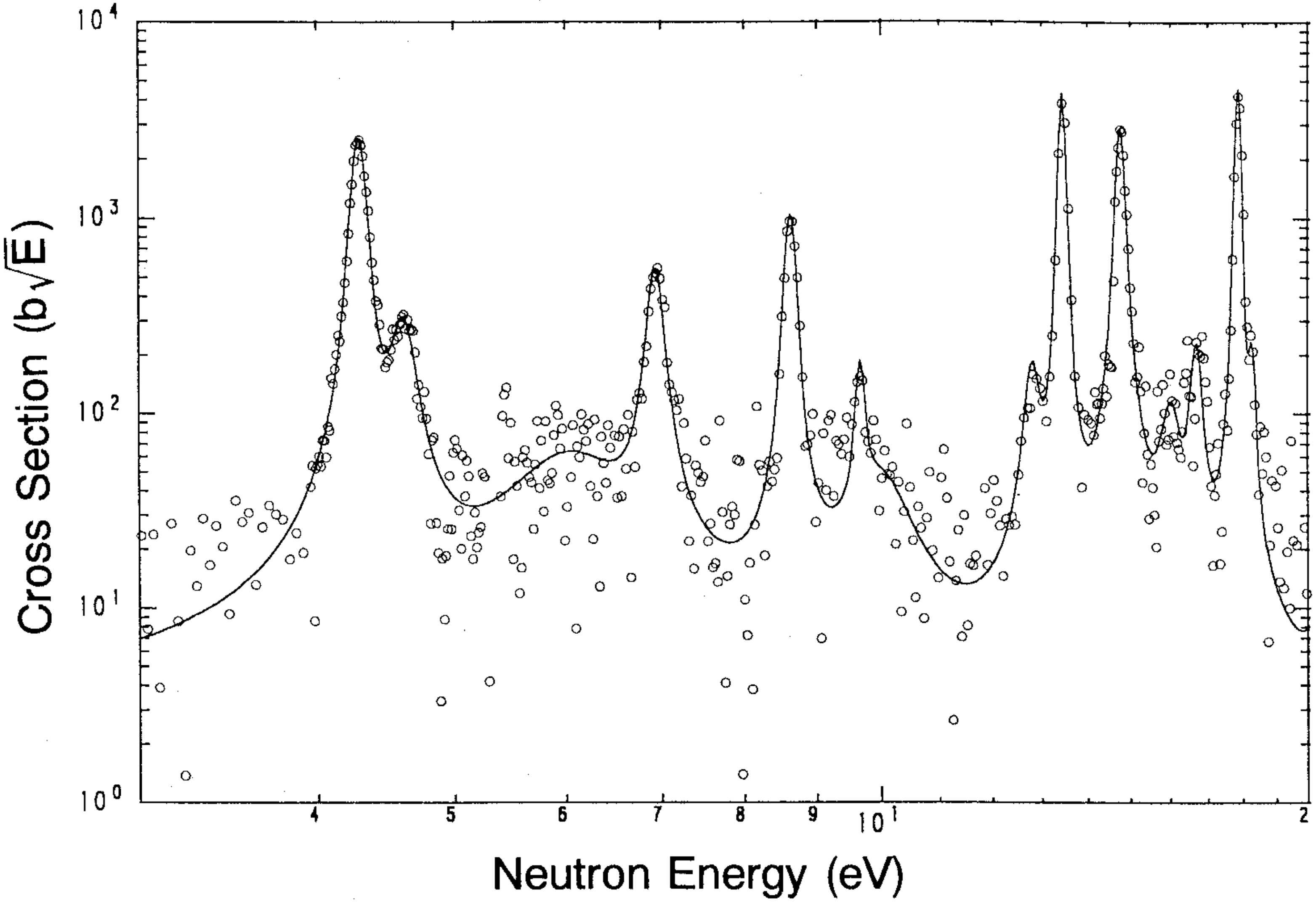

Fig.5 Capture cross section in the energy range from 3 eV to 20 eV. The experimental data are the renormalized data of Weston and Todd[7]. The solid line represents the cross sections calculated with the new resonance parameters.

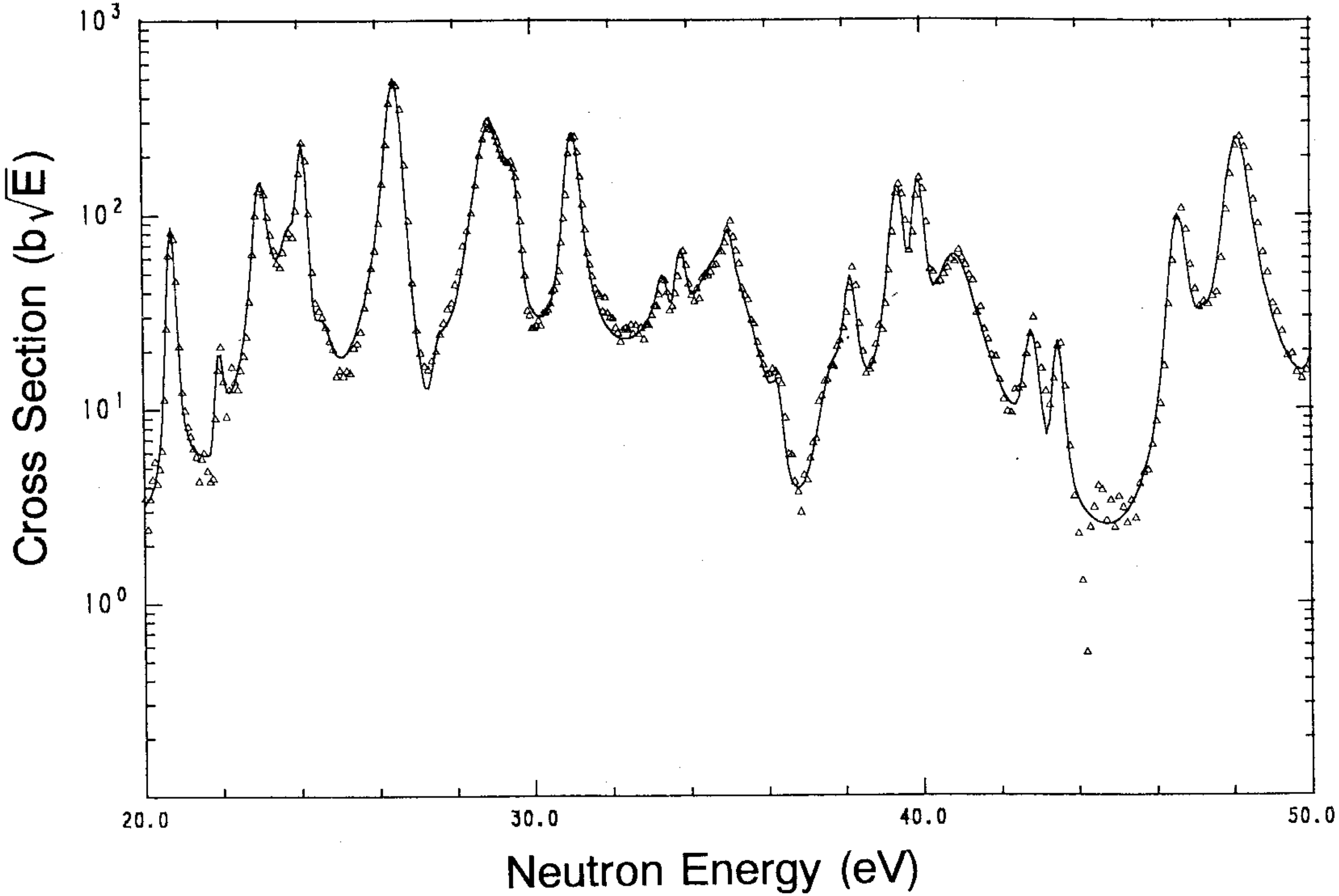

Fig. 6 Fission cross section in the energy range from 20 eV to 50 eV. The experimental data are the renormalized data of Weston and Todd[7]. The solid line represents the cross sections calculated with the new resonance parameters.