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Evaluation of ^{239}Pu Data in the keV and Resolved Resonance Region

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On the Evaluation of ^{239}Pu Data in the keV and Resolved Resonance Region*

Summary

The new evaluation for ^{239}Pu cross-sections in the keV region is described. The present evaluation gives a better interpretation to both the α-value and fission cross-section. This evaluation confirms the applicability of the channel theory of fission. In the resolved resonance regions a fit to the cross-section is obtained suitable for use with the GENEX code. For users convenience the resonance parameters are listed.

April 1968

C DURSTON**
FRPD, A.E.E. Winfrith

S. KATSURAGI
Tokai Research Establishment,
Japan Atomic Energy Research Institute

keV 領域と分離域の ^{239}Pu データの評価**

要　　旨

keV 領域の ^{239}Pu 断面積の評価がおこなわれた．その結果は，α の値と分裂断面積をよく説明すると考えられる．この評価の過程から，核分裂に対するチャネル理論を適用する可能性が確かめられた．分離域においては，共鳴パラメータの組を最近の実験にもとずいて修正した．巻末にパラメータの表を付してある．

1968 年 4 月

C. Durston**
FRPD, A.E.E. Winfrih

桂 木　学
日本原子力研究所　東海研究所
原子炉工学部

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* This work has been done, when S. KATSURAGI was in A. E. E. Winfrith on attachment from JAERI
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JAERI 1162 Errata

page	line	as printed	to read
Title	Japanese Title	評価**	評価*
Title	4th from bottom	Winfrih	Winfrith
Title	foot note	This work has been done	This work was performed
1	Fig. 1 title	The effect of increasing number of fission channels	The effect of increasing the number of *p*-wave fission channels
2	3rd from bottom	threshould	threshold
4	Fig. 4 (b), 4 (c) titles	superposed	superimposed
5	heading of TABLE 3	two vertical dividing lines missing	E_r(eV) | g_r
7	Acknowledgment	Dr. B. H. Datrick	Dr. B. H. Patrick

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1. Introduction

The nuclear data for ^{239}Pu plays a very important role in predicting the safety and economics of fast power reactors and its accuracy has been remarkably improved in the last few years. Progress in this field has been reviewed by SCHMIDT[1] in his elaborate evaluation work.

There is, however, some evidence from time of flight experiments and from Zebra integral measurements showing that the data is still less accurate than desired. One indication is the shape of the α-curve obtained from time of flight measurements[11] and another is the measurement of α-value, averaged over a reactor spectrum[3]. The shape of the α-curve is too low in the keV region and the measured α-value is rather high compared with the calculated one. As a result the SCHMIDT recommended α-value is thought to be too low. The α-value affects the breeding gain, that is the rate of excess production of ^{239}Pu and consequently the doubling time, though the latter quantity depends on power level.

GREEBLER's[5] new evaluation is adequate for reproducing existing experimental fission cross-sections, the α-values, however, are still too low. Although GREEBLER's α-value is 9% higher in the unresolved resonance region than SCHMIDT's value, it still gives answers which are far from the measured α-value in time of flight and Zebra measurements. From the British Nuclear Data File standpoint HART[6] has made an evaluation recommending a higher α-value but does not reject the possibility of a lower α-value because of large uncertainties.

The purpose of this report is to select a better interpretation of the available data and reproduce the α-curve and fission cross-section curve in the keV region.

2. Unresolved region

Our first objective in this region was to explain the shape of the α-curve using the channel theory of fission. The earlier DIVEN and HOPKINS experiment has been reinforced by an experiment

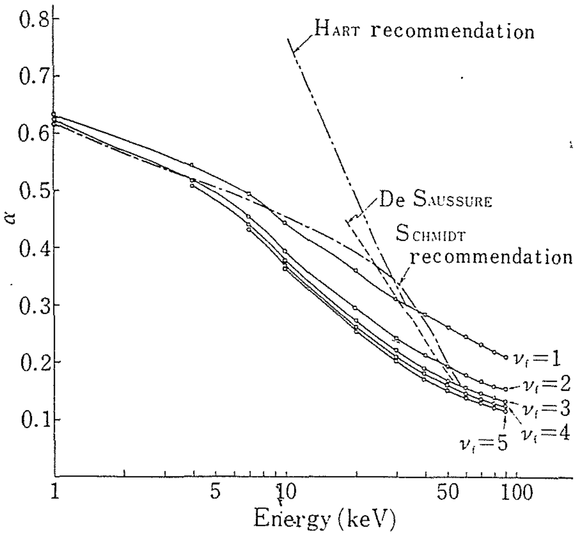

Fig. 1 The effect of increasing number of increasing fission channels

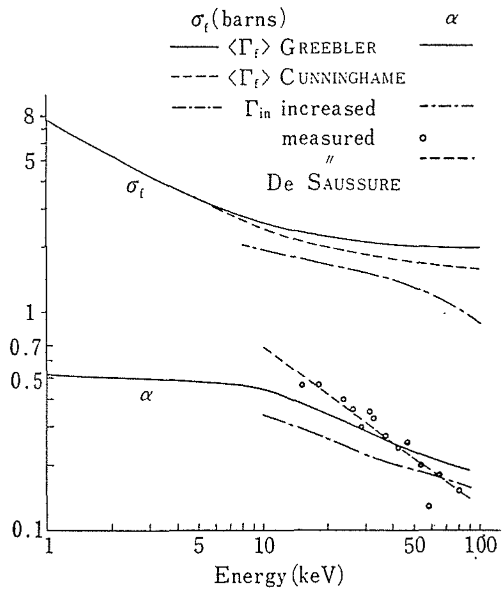

Fig. 2 The effect of increasing Γ_{in}

by de SAUSSURE *et al.*[12] giving excellent definition for the α-curve above 15 keV. However between 15 keV and the resolved region the only direct measurements of α have been two KAPL broad spectrum measurements. Previous evaluations have always tried to include these, thus giving a sharp change of slope in the region of 15 keV and have also explained this change of slope solely in terms of a sharp increase in Γ_f keeping the number of fission channels ν_f constant. We feel however that although Γ_f does increase it is because there are more fission channels available to the fission process, hence ν_f must be increased also allowing Γ_f to increase less rapidly. In Fig. 1 the effect of ν_f is shown. Calculations are made by using parameters listed in TABLE 1.

TABLE 1(a) *s* wave resonance parameters

J	0	1
$<\Gamma_n^0>$ (eV)$^{1/2}$	0.939×10^{-3}	0.334×10^{-3}
$<D>$ eV	8.78	3.12
$<\Gamma_\gamma>$ eV	0.0387	0.0387
$<\Gamma_f>$ eV	2.8	$\frac{<D>_{J=1}}{2\pi}\Big/\left[1+\exp\left(-2\pi\frac{E_{\mathrm{keV}}-50}{150}\right)\right]$
ν_n	1	1
ν_f	2	1
ν_γ	∞	∞

TABLE 1(b) *p* wave resonance parameters

J	0	1	2
$<\Gamma_n^0>$ (eV)$^{1/2}$	2.195×10^{-3}	1.56×10^{-3}	0.53×10^{-3}
$<D>$ eV	8.78	3.12	2.12
$<\Gamma_\gamma>$ eV	0.0387	0.0387	0.0387
$<\Gamma_f>$ eV	0	1.003～1.024	0.636～0.688
ν_n	1	2	1
ν_f	0	1	1
ν_γ	∞	∞	∞

An alternative explanation was investigated that the inelastic levels at 7.85 keV, and 52.7 keV were responsible for the sharp increase but this was unacceptable because it gave the wrong shape to the α-curve and gave too small σ_f, as shown in Fig. 2. At this time SOWERBY[11] did some calculations using the Uttley total and JAMES fission experimental results producing α-values in the 1–10 keV region with values greater than 1. These results together with integral experiment indications led us to regard the KAPL experiment with some suspicion. Our early calculations with parameters recommended by LYNN however went through the KAPL points although not tying in with de SAUSSURE. The effect of changing the LYNN[7] recommended parameters to increase the α-value in the range 1–10 keV was then investigated and it was found that most changes had very little effect, except for $J=1^+$. *s*-wave state. Here it was discovered that the values quoted by LYNN[7] were based on *s*-wave resolved region analysis giving $<\Gamma_f>=61$ meV. A paper by ASGHAR[8] indicated that $<\Gamma_f>$might be as low as 37 meV and on moving the fission threshould for the 1^+ *s*-wave state from +0.15 to +0.2 the$<\Gamma_f>$was reduced from 61 meV to 35 meV. Our calculations with this amendment to the parameters gave a much better fit to the Sowerby α-values (see Fig. 3.) and also a good

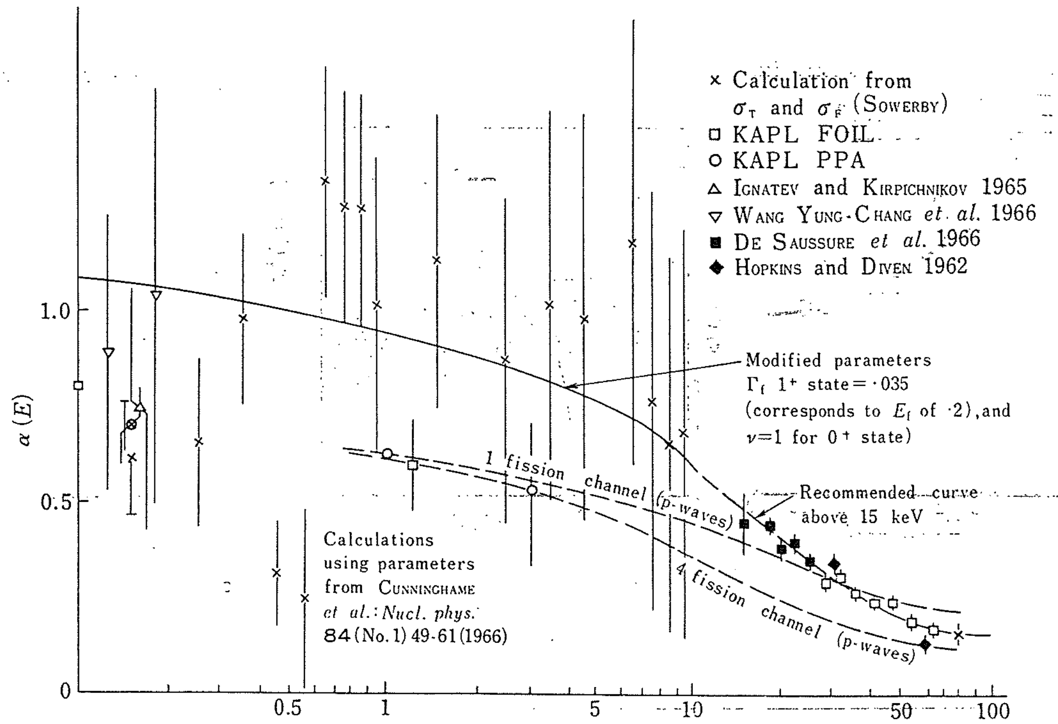

Fig. 3 α of ^{239}Pu

TABLE 2 Barrier position for fission
(Barrier height $\hbar_w$=.5 MeV)

l	J^π	K	E_f (MeV)
0	0+	0	−1.5
		0	0.0
	1+	1	0.20
1	1−	0	−0.9
		1	−0.45
		0	0.6
		1	0.3
	2−	1	−0.45
		2	−0.15
		0	0.6
		1	0.3

extrapolation to the de SAUSSURE α-values. We were however reluctant to reduce the Γ_f much further than this (hence increase the α-value further) because of lack of evidence in the resolved data. The value of 0.035 eV seemed to be the lowest value that would be compatible with the known resolved levels.

The method of calculation used was based on the isolated level assumption as indicated in the paper of CUNNINGHAME *et al.*[7] (see TABLE 2).

Having fitted the α-curve it only remained to check our fission cross-sections. These are compared with the Petrel data and James fission data, and a few others (see Fig. 4).

Using the parameters of TABLE 2, derived from the previous calculations we used our RESP-GENEX system to produce a set of unresolved resonances and cross-sections on magnetic tape. The

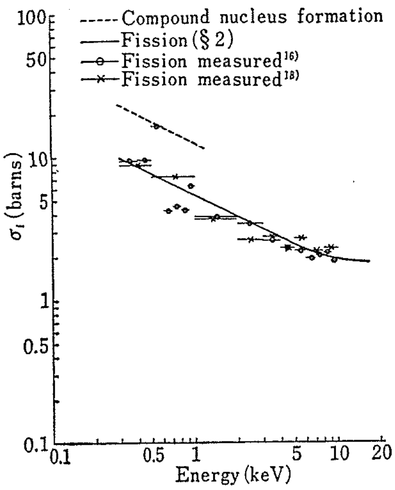

Fig. 4(a) σ_f in the range 300 eV to 10 keV

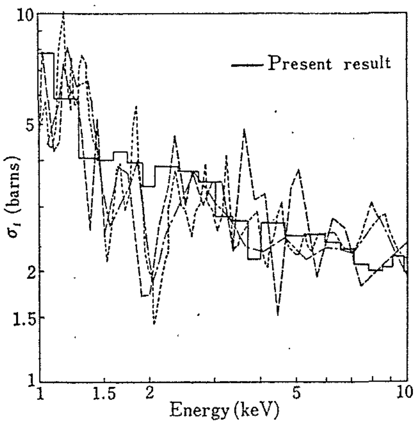

Fig. 4(b) σ_f in the energy range 1 to 10 keV (superposed on SCHMIDT' figure(1))

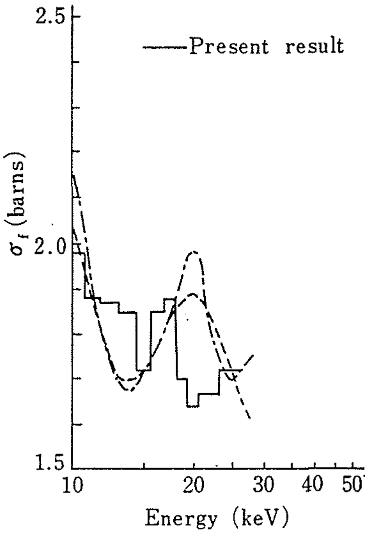

Fig. 4(c) σ_f in the energy range 10 to 25 keV (superposed on SCHMIDT' figure(1))

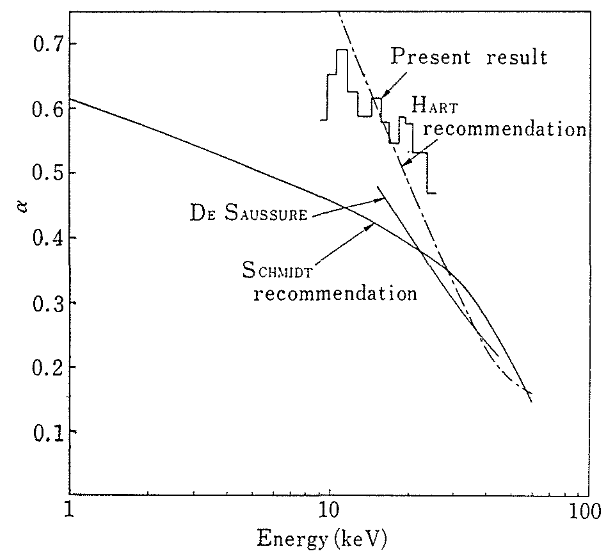

Fig. 5(a) α of ^{239}Pu above 10 keV

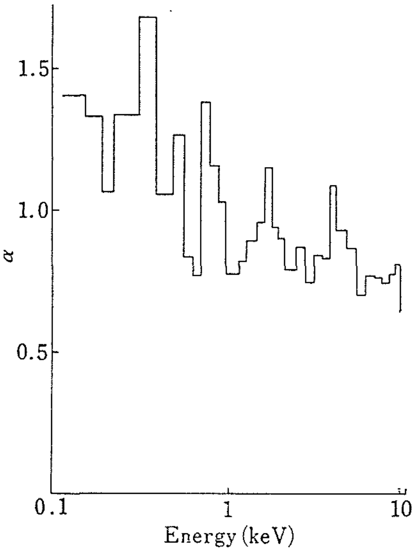

Fig. 5(b) Calculated α of ^{239}Pu from 100 eV to 10 keV

resultant cross-sections and α-values are shown in the appropriate figures (Fig. 4. and 5). The fluctuations in the GENEX tape are seen to have a magnitude similar to the Sowerby calculations.

3. Resolved resonances

The previous GENEX tape[13] used resolved resonance data up to 52 eV, which were the only parameters available at that time. Since that evaluation, a lot of experiments have been performed. SCHMIDT has made an evaluation of resolved resonance parameters up to 300 eV using some of these experimental results. This work has been thought reliable for the last few years. In his evaluation, however, the spin assignment for each resonance is not correct, because at that time spin assignments were made only for a few resonances.

Following the analysis of § 2 ASGHAR's spin assignments[8] seem consistent with the α-curve and

TABLE 3 Resolved resonance parameters up to 300 eV

E_r (eV)	g_r	Γ_{nr}^0 (meV)	$\Gamma_{\gamma r}$(meV)	Γ_{fr} (meV)	E_r (eV)	g_r	Γ_{nr}^0 (meV)	$\Gamma_{\gamma r}$(meV)	Γ_{fr} (meV)
298.1	0.75	0.58	38.7	46.3	146.3	0.75	0.64	54.2	14.2
296.	0.5	0.27	38.7	86.7	143.2	0.5	0.92	38.7	53.4
291.8	0.5	0.41	38.7	304.	136.8	0.25	0.82	38.7	26.5
286.7	0.5	0.19	38.7	1000.	135.4	0.5	0.05	38.7	92.7
282.5	0.75	1.43	38.7	5.3	133.8	0.75	0.46	27.6	11.4
279.1	0.25	1.42	38.7	19.5	131.9	0.25	3.02	38.7	3.74
275.2	0.75	1.69	38.7	299.	127.6	0.5	0.07	38.7	215.
272.3	0.75	1.45	38.7	15.3	126.3	0.5	0.25	50.	32.2
269.2	0.5	0.52	38.7	333.	123.4	0.5	0.07	23.2	51.
262.2	0.5	0.23	38.7	1000.	121.3	0.5	0.38	38.7	35.3
261.8	0.25	5.24	38.7	6320.	118.9	0.75	1.35	52.3	65.7
255.8	0.75	0.35	38.7	1000.	116.1	0.25	0.92	27.	188.
254.2	0.5	0.24	38.7	1000.	110.4	0.5	0.13	38.7	3.1
250.9	0.75	1.51	38.7	15.3	106.8	0.75	0.77	34.9	33.1
248.5	0.75	0.93	38.7	34.3	105.4	0.75	0.57	38.7	102.5
247.1	0.5	0.08	38.7	1000.	103.0	0.25	0.52	38.7	83.7
242.6	0.25	1.1	38.7	52.7	101.2	0.5	0.03	38.7	311.
238.7	0.75	0.33	38.7	68.5	97.6	0.5	0.09	38.7	360.
234.0	0.25	0.89	38.7	19.7	95.5	0.25	0.28	38.7	230.
231.1	0.75	6.7	38.7	12.1	90.9	0.75	0.26	38.7	114.6
227.5	0.5	0.21	38.7	1000.	85.6	0.25	1.	38.7	216.7
224.6	0.5	0.15	38.7	1000.	82.0	0.5	0.34	38.7	1500.
222.8	0.5	0.31	38.7	51.7	75.21	0.75	2.55	44.9	95.
219.6	0.5	1.07	38.7	1000.	74.31	0.75	0.38	36.6	29.5
216.3	0.75	0.43	38.7	21.7	66.83	0.5	0.15	38.7	1000.
210.9	0.5	0.12	38.7	1000.	65.96	0.75	1.54	22.4	77.
207.1	0.75	0.47	38.7	11.3	63.4	0.5	0.36	38.7	13.9
203.6	0.25	3.92	38.7	298.	61.1	0.5	1.43	38.7	2000.
199.2	0.75	0.63	21.6	125.	59.39	0.25	2.18	48.6	133.
196.4	0.75	0.36	58.5	68.9	58.0	0.5	0.79	38.7	805.
195.1	0.25	3.56	38.7	337.	57.6	0.5	1.12	38.7	546.
190.3	0.5	0.17	38.7	118.9	55.79	0.25	0.58	26.	22.
188.4	0.5	0.05	38.7	1000.	52.6	0.75	1.39	39.3	7.7
185.1	0.5	0.51	38.7	1750.	50.22	0.75	0.43	41.3	11.2
183.7	0.5	0.27	38.7	1000.	49.85	0.5	0.03	59.8	750.
178.8	0.5	0.15	38.7	14.6	47.6	0.25	0.78	38.7	301.
177.1	0.75	0.29	62.2	7.0	44.5	0.75	0.95	27.8	4.2
175.8	0.5	0.24	32.9	43.9	41.4	0.75	0.94	59.2	10.7
170.5	0.5	0.34	38.7	1260.	35.3	0.5	0.08	38.7	4.1
166.9	0.75	0.45	38.7	47.7	34.6	0.5	0.003	38.7	1000.
164.4	0.75	1.98	40.2	11.8	32.3	0.5	0.08	38.7	189.
160.9	0.5	0.24	38.7	508.	27.3	0.5	0.04	38.7	2.8
157.0	0.25	2.78	38.7	704.	26.2	0.75	0.34	38.7	35.7
151.8	0.5	0.05	38.7	1000.	23.9	0.5	0.03	38.7	37.1
149.4	0.5	0.18	51.3	36.5	22.2	0.75	0.47	31.3	75.
148.0	0.5	0.16	38.7	9.1	17.6	0.75	0.38	39.1	46.3

TABLE 3 continued

E_r (eV)	g_r	Γ_{nr}^0 (meV)	$\Gamma_{\gamma r}$ (meV)	Γ_{fr} (meV)	ξ_1*	ξ_2*
15.5	0.75	0.2	38.7	760.5	−1.	0.
14.68	0.75	0.57	38.7	31.7	0.	0.
14.28	0.5	0.22	38.7	52.5	0.	0.
11.9	0.75	0.31	40.9	22.	0.	0.
10.93	0.75	0.55	31.5	146.7	−1.	0.
7.83	0.75	0.31	40.6	41.5	−0.60042	0.79685
.296	0.25	0.42	38.6	55.4	0.	0.
− 1.2	0.75	0.771	39.	201.	1.	0.

* components of the unit vector representing fission interference

fission cross-section in keV region. Thus we have adopted his assignment up to 300 eV. In addition to this we have included spin assignment which were already established. In this connection the neutron widths determined by Schmidt should be changed. That is Γ_n have to be changed so as to preserved $g\Gamma_n^0$. Generally Γ_n is very small compared with total width, so this alteration in Γ_n does not produce significant errors in Γ_f and Γ_γ except for a few resonances. The parameters adopted (up to 300 eV) are shown in TABLE 3. For low lying resonances VOGT's formula is used so that parameters representing fission interference are also listed in TABLE 3. continued.

For fission widths Γ_f SCHMIDT's recommendation is adopted. When changes are made for the spin of each resonance, we will obtain different $<\Gamma_{f1}^s>$ value from ASGHAR's, which is slightly larger than ASGHAR's value, but rather smaller than SCHMIDT's recommendation. Because the purpose of the present evaluation is to reproduce reliable cross-section from available experimental data, the fission width is rather different from those obtained by nuclear physics experiments. And a slight apparent inconsistency in mean value of resolved and unresolved region is permissible (LYNN's Antwerp Paper)[14], if the accurate shape of the cross-section and the accurate temperature dependence of this shape are expected. Thus a slight discrepancy in mean fission width $<\Gamma_f^s>$ is acceptable to the present authors.

The calculated cross-sections from these parameters should follow the total and fission cross-section curves found in the literature. The most reliable curves at present are found in BNL's barn book[15]. Unfortunately the cross-section curves of ^{239}Pu are not satisfactory in respect of consistency between the total and fission cross-sections. The total cross-sections are thought to be more reliable than fission cross-sections. Recent σ_t measurements made by SOWERBY and PATRICK[16] at Harwell do not differ significantly except at some valleys between resonances. Thus we have chosen total cross-sections as the base for the present evaluation.

A part of the total cross-section curve obtained from the parameters of TABLE 3 was compared with σ_t in BNL-325. At some resonances the calculated peak was rather small, whereas widths seem adequate. By this comparison the neutron widths of these resonances have been changed so as to

TABLE 4 Improved resonance parameters

E_r (eV)	Γ_{nr}^0 (meV)	E_r (eV)	Γ_{nr}^0 (meV)
286.7	0.522	183.7	0.702
262.2	0.503	127.6	0.143
261.8	6.912	123.4	0.084
255.8	0.644	103.0	0.665
254.2	0.457	101.2	0.04
231.1	8.978	97.6	0.117
227.5	0.479	95.5	1.064
224.6	0.324	90.9	1.3
219.6	1.712	85.6	4.4
213.0	0.104*	82.0	0.85
210.9	0.156	75.21	5.865
207.1	0.705	63.4	0.864
195.1	3.92	58.0	1.106
188.4	0.138		

* inserted

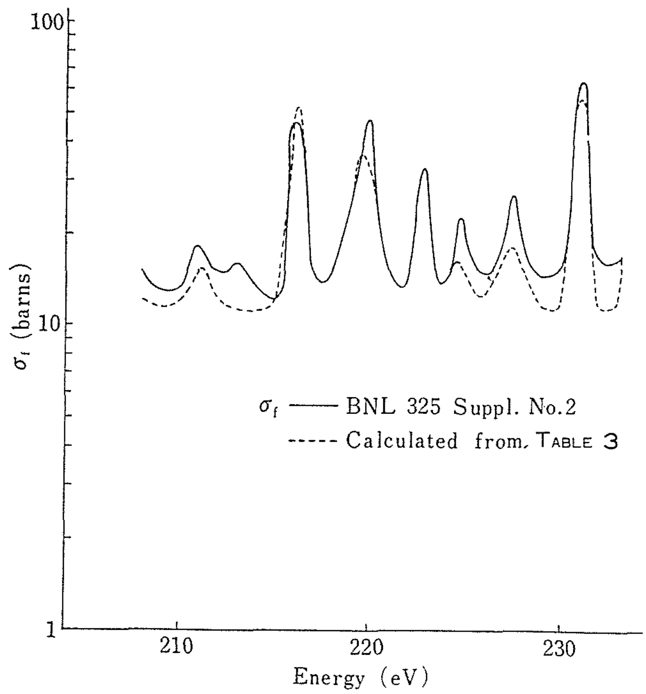

Fig. 6 Comparison of σ_f measured and calculated

reproduce measured peak values. By a few iterations resonable parameter set are obtained as shown in TABLE 4.

It might be argued that the parameters of TABLE 3 and 4 fail to reproduce the fission cross-sections. For the sake of satisfaction comparisons have been made with the measured fission cross-sections, and significant discrepancies were not found. The fission cross-section obtained is shown in Fig. 6.

4. Conclusions

The present evaluation seems satisfactory in the current circumstances. The remaining draw-back is that some of broad resonances, presumably having large fission width, are still missing especially above 300 eV. This tendency is found in DERRIEN's Fig. 1[17]. However, if users are careful in utilizing the present results, for example adding some background values to fission cross-sections, the present evaluation will be sufficient for predicting both reaction rates and temperature effects. The differences in the measured and calculated total cross-sections are very close to those in the fission cross-sections.

Acknowledgements

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