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REVIEW OF 241 Pu RESONANCE PARAMETERS

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RESUME :

The status of 241 Pu resonance parameters is reviewed. The most important recent results are compared in some energy ranges, both from single level and multilevel point of view. It appears that an accurate set of resonance parameters is not still obtained for a general description of the cross-sections in the resonance region. Some recommendations are given for further experiments or evaluations.

INTRODUCTION

At the Harwell conference on Neutron Physics and Nuclear Data, G.A. KEYWORTH and M.S. MOORE (21) presented an extensive review of the status of the major actinide isotope resonance parameters. They pointed out that resonance cross-section measurements made for several isotopes on the same experimental arrangement, with the same resolution, using the same standards and analysed by the same technique should be of much greater value than measurements performed at different times in different laboratories, using different experimental techniques or analysis methods. It is also worthwile to mention that a complete set of accurate resonance parameters should be obtained from total, fission, scattering and capture measurements performed in the same laboratory and simultaneously analysed. That is an ideal case which is never accomplished, since the capture or the scattering cross-sections are often very difficult to be measured with a reasonable accuracy. In most cases the completeness of a resonance parameter set is achieved by using theoretical assumptions such as the non variation of the capture width from resonance to resonance. However, it is sometime possible to approach the ideal conditions of measurement. One can quote as example the ^{239}Pu total, fission and scattering cross-section measurements performed at Saclay.

The purpose of this paper is to review the status of ^{241}Pu resonance parameters and the problems encountered in the analysis of the experimental data. One should be tempted to believe that the conditions of measurements realized for ^{241}Pu are not too bad, since 1) a simultaneous measurement of the fission and the capture cross-sections have been performed at Oak-Ridge(17) ; 2) total and fission cross-sections have been measured at Geel (10),(11) and simultaneously analysed. Unfortunatly, it seems that there are some other reasons for which a consistent set of resonance parameters cannot be established at the present stage of the analysis. Particularly, the complexity of the resonance structure (see Fig.1.4), cannot be accuratly analysed without the use of a multilevel-multichannel formulation of the cross-sections.

One is faced with the important problem of the apparent non unicity of the R-matrix parameters and of the personal feeling of the evaluators.

The review is divided in the following parts :

- review and status of the experimental data,
- comparison of the most recent results,
- average parameters for the unresolved region,
- outstanding problems and recommendations.

REVIEW AND STATUS OF THE EXPERIMENTAL DATA

The first set of ^{241}Pu resonance parameters is due to O.D. SIMPSON et al.(1) who analysed the total cross-section measured in the energy range 0.02ev - 2 kev(2) (MTR fast chopper, 1961). They used the Reich-Moore multilevel formalism(22) and obtained all the parameters for 8 resonances up to 10.2 ev neutron energy by assuming a constant value of 40 mev for the capture width. The main feature of this analysis was the separation of the resonances in two non interfering families caracterised by different average fission widths and assumed to pertain to two different fission channels. The next set of parameters was obtained by M.S. MOORE et al.(3) from the analysis of their measured fission cross-sections in the energy range 2ev-100ev (RPI linac, 1964). All the parameters were also given for 21 resonances up to 35 ev, assuming a constant Γ_γ value of 40 mev. The previous results of SIMPSON et al(1) were confirmed and an attempt of interpretation was proposed : the large fission widths could be due to a fully open 2^+ fission channel belonging to the K=0 fondamental rotational band, and the small fission widths to one or several 3^+ fission channels open to a small extent. At the same time, D.S. CRAIG et al(4) measured the total cross-section in the energy range 0.025 ev -1 kev (Chalk River fast chopper, 1964) and obtained the single level parameters(energy, total widths and fission widths) for 14 resonances in the energy range 12.8 ev - 31 ev.

The fission cross-section was also measured by G.D. JAMES(5) from 0.01 ev to 3 kev (Harwell linac, 1964) and analysed with the VOGT formalism(23) in 6 resonances between 12.84 ev and 16.70 ev. Another measurement in this early period is the total cross-section measurement by N.J. PATTENDEN et al.(6) (Harwell linac, 1963) who obtained the energies and the neutron widths for 32 resonances from a single level analysis in the energy range 12ev to 50 ev.

All these measurements were performed with a relatively poor experimental resolution. The importance of these old data consists in the fact that very few recent data exist in the thermal region, in particular in the 0.26 ev resonance region for which no total cross-section measurement has been performed since the measurement of CRAIG et al.

Better resolution and more detailed fission data were obtained from the PETREL nuclear explosion(7). A Reich-Moore multilevel analysis of these fission cross-sections was performed by O.D. SIMPSON et al.(8) in the energy range 20 ev - 60 ev. A complete set of parameters was obtained for 56 resonances by assuming a constant value of 40 mev for Γ_γ as in the previous analysis (1), (3). The statistical accuracy of the nuclear explosion data is particularly excellent and the shape of the cross-section is very well defined, consequently the deformations or the dissymetries due to small resonances or interference effects are better seen on these data than on those obtained from classical time-of-flight experiments. However, SIMPSON et al. used 30% of unobserved small resonances to improve the fit to their data, in addition to 10 observed non interfering small resonances. As in the previous analyses, two groups of resonances were found, tentatively identified as belonging to the spin states 2^+ and 3^+ of the coumpound nucleus.

The only scattering cross-section measurement is due to G.D. SAUTER et al.(9) (Livermore linac, 1968). The spin assignment was made for 20 resonances in the energy range 4 ev - 30 ev from a simultaneous Reich-Moore fit to the scattering data and to the WATANABE et al(3) fission cross-sections.

The two groups of resonances resulting from this spin assignment were in agreement with those obtained by MOORE et al.(3) except for the resonances between 12.8 ev and 17.8 ev where the results were opposite. The average fission widths were found to be $<\Gamma f>_{2^+} = 510$ mev and $<\Gamma f>_{3^+} = 190$ mev, corresponding to an effective number of fission channels equal respectively to 0.77 and 0.55. These numbers were interpreted as evidence of one fission channel at least half open in each spin state. No consideration was made concerning a possible missing of small resonances.

In the last ten years several high resolution measurements have been performed on the linacs of Saclay, Geel and Oak-Ridge, with a nominal resolution equal or better than 1 ns/m. Such quality of resolution allows the resonance to be analysed up to about 150 ev. The fission and the total cross-sections have been measured at Geel(10),(11) and analysed up to 100 ev with the single level Breit-Wigner formalism. The simultaneous fit to the total and fission cross-sections provided with a complete set of single level parameters for 78 resonances between 12 ev and 100 ev. The authors proposed an average level spacing of (1.00±0.10) ev not corrected for a possible missing of small resonances. They obtained an average capture width of (47.5 ± 7.0) mev from 9 measured values considered as enough accurate and an average fission width of (253 ± 42) mev from all the resonances analysed.

Only the fission cross-section was measured by BLONS et al(12) at Saclay. A preliminary least-square shape analysis of the data, along with the transmission measured at Geel(10), was performed using the single level Breit-Wigner formalism(13). Neutron widths, fission widths and capture widths were given for 117 resonances in the energy range 4.28 ev to 160 ev which is the largest energy range analysed. These parameters were then used as starting point in a Reich-Moore multilevel analysis simultaneously on the Saclay fission and on the Geel total cross-sections(14). The results of this least square shape analysis - the programm and the code are described in reference(15) - are shown on fig. 1-4.

The difference between this analysis and the multilevel analyses of reference (2), (3), (8) is that two fission channels were used in each interfering group, each fission width being split in two parts Γ_{f1} and Γ_{f2}. The assumptions concerning the fission channels were the following : 1) in the group of wide resonances, most of the contribution to the fission is due to the 2^+ channel of the K=0 rotational band of the fondamental, fully open; this contribution is Γ_{f1} ; other 2^+ fission channels may exist in the K=0 and K=2 vibrationnal bands at about 1 Mev above ; they contribute in Γ_{f2} which is relatively small. 2) The group of narrow resonances is considered to be 3^+ resonances ; the 3^+ channels exist in the quadrupole and octopole vibrational bands, but none of them is fully open. Here, the splitting between Γ_{f1} and Γ_{f2} has no physical meaning ; it is only used to improve the fit to the experimental data by minimizing the interference effects in the narrow and nearly symmetrical resonances. The average fission widths of 595 mev and 87 mev were obtained for the two groups of resonance, which are somewhat different from the values of 500 mev and 180 mev obtained by SIMPSON at al.(8). No attempt was made to obtain the capture widths in the least square fitting, the shape of the cross-sections being not enough sensitive to the variations of Γ_γ around a reasonable average value. A constant value of 40 mev was then used in agreement with the value of 41.2 mev obtained from the single level analysis in the low energy range.

The most recent set of resonance parameters is due to WESTON et al.(16) from a Adler multilevel(24) analysis of a simultaneous measurement of the fission and capture cross-sections(17) in the energy range 0.01 ev to 100 ev. This analysis was considered as the most efficient method for an accurate representation of the experimental data. However, the results of WESTON et al. can be directly compared to the results of the other single level analyses, for the contribution of the Adler dissymetrical part of the resonances was taken equal to zero, apart the energy ranges thermal to 10 ev and 25 ev to 32 ev in the fission cross-sections. Then, for most of the resonances, the energy, the total width, the fission area and the capture area can be easily obtained and could be used for the determination of Γ_f and Γ_γ.

That will be done in the next section for sake of comparison in some energy ranges.

This brief review of the experimental data available for the evaluation of the ^{241}Pu resonance parameters shows a wide range of method used in deriving these parameters from the experimental cross-sections. As a matter of fact the value of $^{<\Gamma f>}/<D>$ is close to 0.5 and the probability of strong interferences in the fission channels and of resonance overlappings is very high. The interferences and resonance overlappings are a source of ambiguities in the interpretation of the shape of the cross-sections, since the dissymetries could be interpreted as hidden resonances or interference effects. That is probably the main reason of the apparent inconsistency which exists among the most important sets of data and which will be shown in the next section.

COMPARISON BETWEEN DIFFERENT SETS OF DATA

This comparison will be restricted to the PETREL (8), Geel(10),(11) Saclay(13),(14) and Oak-Ridge(16),(17) data, both from single level and multilevel point of view. The purpose of this review being not to propose an evaluation of ^{241}Pu resonance parameters, we will only compare the results in some selected energy ranges.

The single level data

The published single level parameters have been converted to $2g\Gamma n$, $\sigma_0\Gamma f$ and Γ which are directly comparable ; the other parameters such as Γf and $\Gamma\gamma$, are derived from these measured values with an accuracy correlated to the accuracies achieved on $2g\Gamma n$, $\sigma_0\Gamma f$ and Γ. A particular case is the conversion of the WESTON et al. Adler parameters ; that is done by the following relations :

$$\Gamma = 2\,\nu$$
$$\sigma_0\Gamma f = 2\,Gf/\sqrt{E}$$
$$\sigma_0\Gamma\gamma = 2\,Gc/\sqrt{E}$$

Table I shows the results obtained by BLONS et al., KOLAR et al. and WESTON et al. in the energy range 17.4 ev to 25 ev. Two series of parameters (A and B) were proposed by KOLAR et al. in this energy range. The parameters for the small resonances at 19.50 ev and 21.35 ev are not given in BLONS et al data. On the average the $2g\Gamma n$ values from KOLAR (A) and KOLAR (B) are 16% and 23% larger than those from BLONS, which is very surprising since the same transmission data were analysed . The total widths are very different for most of them. The fission area $\sigma_0\Gamma f$ represent quite well the average fission cross-sections (Table VI) in this energy range.

The results in the energy range 46 ev to 55 ev are compared in Table II. Only 4 resonances are given by BLONS et al. against 6 resonances by WESTON et al. and 7 by KOLAR et al., which correspond to different ways of analysing the cross-sections in the vicinity of the broad resonance at 48 ev. On the average the $2g\Gamma n$ values from KOLAR are still larger (10%) than those from BLONS. The sum of the fission area in KOLAR data are much smaller than the others and does not correspond to the average fission cross-section in this energy range (Table VI).

These two examples show the diversity of the results of the single level analyses. Then, a consistent set of fission widths and capture widths could hardly be obtained. However, the capture widths are given for all the resonances in KOLAR data and for 46 resonances in BLONS data. They are very different and fluctuate strongly from resonance to resonance. The fluctuations are obviously due to the fact that the capture widths were obtained by difference between the total widths and the other partial widths, the difference being in most cases of the same order of magnitude than the accuracy achieved on the total or the fission widths. The average value proposed by KOLAR et al. is (47.5 ± 7.0) mev against 43.6 mev obtained by averaging all the individual values of BLONS et al. More precise values could be obtained by using also the capture area from WESTON et al. analysis.

In table III, several ways of obtaining the capture widths are shown for some well isolated resonances for which the accuracy could be expected to be reasonably good. As a matter of fact, the fluctuations from resonance to resonance remain very strong within each set of data, and the results obtained for the same resonance from different ways are discrepant. Even for these well isolated resonances the capture width is not known with better than 30% of accuracy.

The multilevel data

We shall only compare the results from SIMPSON et al.(8) and from BLONS et al.(14) in two typical energy range. These analyses are of same nature, using both the Reich-Moore formalism. Table IV shows the results in the energy range 25ev - 37ev where SIMPSON et al. used 16 resonances and BLONS et al. only 12 resonances. The difference corresponds to 4 unobserved weak resonances used by SIMPSON et al. to improve the fit to the experimental data. The choice of the interfering groups is the same, except for the large resonance at 26.32 ev. The values of the neutron widths are quite similar. However, the values from BLONS et al. should be more accurate, for they were obtained from a simultaneous analysis of the total and fission cross-sections. More important are the differences which are seen on the total fission widths. That is mainly due to the different assumptions used by the authors : one fission channel and addition of unobserved weak resonances by SIMPSON et al ; use of two fission channels by BLONS et al.

Another example of results is shown in Table V in the energy range 46 ev - 56 ev ; 10 resonances are found in SIMPSON et al. data and only 5 resonances in BLONS et al. data. The 3 important resonances interfere in the same way, but the spin attribution should be inverted. . The large $2g\Gamma n$ values are different by 30%, but the total fission widths are quite similar.

One can consider that both analyses give an excellent fit to the corresponding experimental data, but the resonance parameters are different. There is an apparent non unicity of the set of resonance parameters. As a matter of fact, it depends mainly on the kind of data analysed, on the way the analysis is performed and on the assumptions made when starting the analysis. BLONS et al. work is an example of how far it is possible to go in the interpretation of ^{241}Pu cross-sections in the resonance region; but it is probably not the only interpretation possible.

THE AVERAGE RESONANCE PARAMETERS

Average level spacing, strength functions and average partial widths are needed to calculate the cross-sections in the unresolved resonance region and at higher energy from statistical model. Table VII collects all the average data available in the publication reviewed in the previous sections. The data from references (1) - (6) are only given for information ; they have not to be taken into account since more accurate values are given in references (8) - (14). The average level spacing depends on the estimation of the number of resonances missed in the experimental data. Such estimation has been made by SIMPSON et al(8) and by BLONS et al(14) and yields similar results. The So strength function should be obtained with good accuracy from the analysis of Geel total cross-sections. However the value proposed by KOLAR et al(10) is 25% larger than the one obtained in the single level or multilivel analysis of BLONS et al(13)(14). As a matter of fact, if one calculates the strength function by the relation :

$$S^o = \sum_{E_1}^{E2} 2g\Gamma_n^o / 2 \ (E_2 - E_1)$$

one find 1.158×10^{-4} from BLONS et al. multilevel parameters in the energy range 4ev - 104 ev and 1.153×10^{-4} from KOLAR et al. single level parameters in the energy range 12 ev - 100 ev.

From the selected resonances shown on Table III, one obtains an average capture width of about 41 mev by combinating BLONS analysis and WESTON analysis, and of about 44 mev by combinating KOLAR analysis and WESTON analysis. These values are significantly higher than those of (35.9 ± 1.0) mev and (35.6 ± 1.0) mev obtained by MOORE(25) from a systematics for the 2^+ and 3^+ spin states. As for the properties of the fission channels, the results depend strongly on the way the analysis has been performed ; one can only say that there is an overall agreement on the existence of one 2^+ fully open fission channel.

Figs. 5-7 show the neutron width distributions from SIMPSON et al(8), KOLAR et al(11) and BLONS et al(14). In SIMPSON data there is apparently an excess of small values ; this excess could be a part of the 30% non observed resonances used to improve the fit in the multilevel shape analysis ; this distribution can be hardly described by a Porter-Thomas law . In KOLAR data the absence of small Γ_n values is obvious, as the absence of very large values. Maximum likelihood or missing level estimator methods should not work when applied to these distributions. The data from BLONS are more regular and can be reasonably well described by a Porter-Thomas law by assuming that about 20% of small resonances are missed ; maximum likelihood and missing level estimator methods give respectively 0.97 ev and 0.92 ev for the average level spacing. On the other hand, BLONS et al.(14) have shown by using a Monte-Carlo technique that 9% of doublets - unresolved resonances with comparable neutron width values - coul also exist in the experimental data in addition to the 20% of hidden very small resonances. Then the average level spacing should be 0.88 ev or 0.84 ev.

OUTSTANDING PROBLEMS AND RECOMMENDATIONS

It appears from this review that an accurate set of resonance parameters which could be used for a general description of the 241Pu total, fission and capture cross-sections is not still obtained. However the parameters which are available from different authors have mostly been obtained by shape or least square shape analysis and give a good representation of the particular cross-sections from which they were derived. Several high resolution fission cross-section measurements are available(7),(11),(12),(17),(18); they are in rather good agreement, as it is shown on Table VI , and the parameters describing one of these cross-sections could also describe reasonably well the others. Only one total cross-section(10) and one capture cross-section(17) measurement have been performed with good resolution on a wide energy range. But it is not obvious that the parameters obtained in reference (8), (11), (14) or (15) should described the measured capture cross-section with enough accuracy.

An improvement of the situation should be obtained by performing a simultaneous shape analysis on the total, the capture and one or several fission cross-sections. This analysis could be achieved easily by using the Adler formalism and should be a complement of WESTON et al. work(16). However, in the purpose of obtaining the average R-matrix parameters for the calculations in the unresolved region, more informations should be obtained from the Reich-Moore formalism ; the analysis should not be too difficult, nor too much time consuming by using BLONS et al(14) parameters as starting point. Then the Reich-Moore parameters could be translated to the more easy to handle Adler parameters by the code POLLA of DE SAUSSURE et al(19). Part of this work was already done by WESTON et al(20). for ENDF/B - V starting from all the existing sets of REICH-MOORE parameters.

A particular problem is the cross-sections in the resonance at 0.26ev.

Evaluating the data in the thermal region WESTON et al.(20) found a discrepancy of 14% in the capture cross-section over the 0.26 ev resonance when compared to ENDF/B-IV evaluation (fig.8). The latter was based on SIMPSON et al.(2) total cross section and on WATANABE et al.(3) fission cross-section, which mean that the capture cross-section was calculated by difference. Now, if one compares the WESTON et al. absorption cross section to the total cross-section of SIMPSON et al. one finds that the absorption cross section is 4.5% larger than the total cross section on the peak of the resonance, 7.5% at 0.15 ev and equivalent around 0.33 ev, as it is shown on fig.9. One should note that the scattering cross-section is about 0.6% of the total at the resonance peak ; then, the absorption should be almost equal to the total. The discrepancy cannot be resolved without a remeasurement of the total cross-section. For the moment, one should trust the more direct capture measurement of WESTON et al., bearing in mind that integral experiments suggest a larger capture in the thermal range of energy(20).

The recommendations concerning the measurements or the evaluations of ^{241}Pu resonance parameters can be summarized as follows.

1) A Reich-Moore multilevel analysis performed simultaneously on the total and capture cross-sections and one or several fission cross-sections should give an accurate set of parameters for a general description of the cross-sections in the resonance region. More accurate average parameters could also be obtained from this set of R-matrix parameters.

2) This set of R-matrix parameter could then be translated to Adler parameters by using the code POLLA(19).

3) It is not clear from WESTON et al. report(20) if the above two recommendations are fulfilled or not by the evaluation for ENDF/B-V. Therefore, these recommendations depend on the availability of ENDF/B-V.

4) A total cross-section measurement should be performed in the thermal region including the resonance at 0.26 ev.

5) Polarization measurements should be most useful to obtain the spin separated cross-sections. Such measurements have shown to be most efficient in improving the status of 235 U resonance parameters(26) and should give the same improvement in the case of ^{241}Pu.

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ENERGIES (EV)				NEUTRON WIDTHS (MEV)			TOTAL WIDTHS(MEV)				FISSION AREA (B.EV)			
BLONS	WESTON	KOLAR		BLONS	KOLAR		BLONS	WESTON	KOLAR		BLONS	WESTON	KOLAR	
		A	B		A	B			A	B			A	B
17.83	17.87	17.81	17.81	2.98	3.17	3.46	57	56	56	67	73.7	76.2	74.4	75.9
18.22	18.26	18.22	18.21	0.19	0.26	0.21	64	24	173	108	4.5	4.4	8.7	6.1
	19.46	19.50			0.12			900	900			6.6		
20.71	20.76	20.69	20.68	0.36	0.47	0.48	105	180	109	102	15.4	20.3	16.0	16.3
	21.35	21.35			0.12			800	800			5.6		
21.93	21.98	21.91	21.92	0.16	0.20	0.19		80	82	68	3.2	2.1	2.7	2.7
23.02	23.05	22.99	22.97	1.17	1.25	1.10	368	214	380	320	57.8	43.2	54.6	49.4
23.71	23.71	23.66	23.64	0.38	0.57	0.55	286	416	394	380	16.9	26.0	24.8	24.7
24.07	24.11	24.07	24.03	1.31	1.66	1.32	118	120	114	126	45.5	45.1	39.5	41.8
24.61	24.62	24.70	24.31	0.20	0.51	0.51	600	376	1420	1130	9.0	7.5	20.1	18.9
SUM OF $\sigma o \ \Gamma_f$:											226.0	237.0	240.8	235.8
SUM OF $\frac{\pi}{2} \ \sigma o \ \Gamma_f$:											355.0	372.0		370.0
EXPERIMENTAL FISSION INTEGRAL :											(1) 351.0	(1) 385.5		(1) 378.5

(1) FROM WESTON PRIVATE COMMUNICATION (SEE ALSO TABLE 6)

TABLE 1
SINGLE LEVEL ANALYSES IN THE 17.4 EV TO 25.0 EV ENERGY RANGE

ENERGIES			N. WIDTHS (MEV)		TOTAL WIDTHS (MEV)			FISSION AREA (B.EV)		
BLONS	WESTON	KOLAR	BLONS	KOLAR	BLONS	WESTON	KOLAR	BLONS	WESTON	KOLAR
46.570	46.696	46.520	1.71	1.705	295	278	230	41.3	40.0	23.6
		47.300		0.908			100			13.5
48.110	47.970	48.020	6.20	4.019	500	114	345	144.0	11.4	64.3
	48.269	48.450		2.116		540	940		147.1	31.7
50.350	50.452	50.210	0.80	0.850	518	592	435	20.0	22.8	12.8
		52.000		N.GIV.			200			
52.240	52.348	52.600	0.10	N.GIV.	160	422	200	1.7	1.9	
	53.483					990			1.5	
SUM OF $\sigma_0 \Gamma_f$:								207.0	224.7	145.9
SUM OF $\frac{\pi}{2} \sigma_0 \Gamma_f$:								325.2	353.0	229.2
EXPERIMENTAL FISSION INTEGRAL :								(1) 319.8	(1) 345.2	(1) 294.4

(1) FROM WESTON PRIVATE COMMUNICATION (SEE ALSO TABLE 6)

TABLE 2
SINGLE LEVEL ANALYSES IN THE 44.0 EV TO 54.0 EV ENERGY RANGE

RESONANCE ENERGIE (EV)	1	2	3	4		5		6	
				A	B	A	B	A	B
4.28	41.5	36.7							
6.95	32.3	34.8							
8.63	27.6	30.0							
13.45	49.3	43.8		37.5		39.3		35.2	
14.78	48.1	38.4		40.6		34.7	35.1	39.9	43.0
17.87	32.7	31.6	35	40.7	44.6	40.7	44.6	34.7	43.3
20.76	45.4		33	47.3	43.4			49.1	46.0
21.98				45.5	39.8	44.4	46.8	63.0	51.3
24.11	45.5	45.9	41	42.9	45.3	45.2	43.2	47.0	51.2
26.45	50.6	46.0	38	50.6	49.1	44.6	47.1	64.9	50.3
31.09	42.8	55.3	54	49.0		55.0		57.9	53.7

1 - FROM BLONS PARAMETERS AND WESTON CAPTURE AREA
2 - FROM WESTON PARAMETERS AND BLONS TOTAL AREA
3 - DIFFERENCE BETWEEN TOTAL AND PARTIAL WIDTHS FROM BLONS SINGLE LEVEL ANALYSIS
4 - FROM KOLAR PARAMETERS AND WESTON CAPTURE AREA
5 - FROM WESTON PARAMETERS AND KOLAR TOTAL AREA
6 - DIFFERENCE BETWEEN TOTAL AND PARTIAL WIDTHS FROM KOLAR SINGLE LEVEL ANALYSIS

TABLE 3
CAPTURE WIDTHS FOR SOME ISOLATED LEVELS

ENERGIES (EV)		NEUTRON WIDTHS (MEV)		FISSION WIDTHS (MEV)			
SIMPSON (1)	BLONS (1)	SIMPSON	BLONS	SIMPSON	BLONS (2)		
25.64 B		0.005		- 50			
26.32 A	26.38 B	5.335	4.538	270	264	257	- 7
27.27 A	27.50 A	0.005	0.030	750	22	0	22
27.34 B	27.72 B	0.042	0.542	300	900	- 900	0
28.68 B	28.72 B	5.676	3.942	750	595	543	52
29.59 B	29.60 B	0.479	0.460	- 50	201	- 123	- 78
30.05 A	30.10	0.000	0.035	- 20	32		
30.91 A	30.97 A	2.613	2.553	220	212	0	-212
32.38 A		0.017		50			
33.27 A	33.30 A	0.214	0.176	-150	110	60	50
33.37 B		0.058		50			
33.65 A	33.74 A	0.366	0.327	-100	62	0	62
34.15 A		0.117		300			
34.72 B	34.97 B	2.003	2.167	-900	1292	-1169	123
	34.98 A		0.403		16	10	6
36.00 B	36.19 A	0.204	0.070	500	36	5	31
36.65 B		0.000		900			

(1) A AND B INDICATE THE INTERFERING GROUPS
(2) TOTAL , FIRST CHANNEL AND SECOND CHANNEL FISSION WIDTHS

TABLE 4
REICH-MOORE MULTILEVEL ANALYSIS IN THE 25 EV TO 37 EV ENERGY RANGE

ENERGIES (EV)		NEUTRON WIDTHS (MEV)		FISSION WIDTHS (MEV)			
SIMPSON (1)	BLONS (1)	SIMPSON	BLONS	SIMPSON	BLONS (2)		
46.38 B	46.51 A	2.111	1.605	-280	245	0	-245
47.05 B	47.10	0.137	0.120	300	227		
47.95 A	48.04 B	7.271	5.782	480	433	-291	142
50.14 B	50.31 A	0.637	0.697	300	441	6	435
50.90 B		0.036		-300			
51.90 B	52.13	0.036	0.100	50	32		
52.60 B		0.007		-200			
53.40 A		0.000		300			
54.15 A		0.022		500			
55.40 B		0.019		300			

(1) A AND B INDICATE THE INTERFERING GROUPS
(2) TOTAL , FIRST CHANNEL AND SECOND CHANNEL FISSION WIDTHS

TABLE 5
REICH-MOORE MULTILEVEL ANALYSIS IN THE 44 EV TO 54 EV ENERGY RANGE

E1 — E2 (EV)	ENDF/B5	WAGEMANS REF (18)	WESTON REF (16)	BLONS REF (13)		KOLAR MIGNECO REF (10)	SIMPSON REF (8)
0.02 — 0.03	10.20	10.36	10.15				
0.03 — 0.10	49.2	49.7	49.6				
0.10 — 0.50	270.1	272.6	275.7				
0.50 — 3.00	70.7		76.7				
3.00 — 4.90	348.8	361.1	367.6	347.8		358.1	
4.90 — 8.00	892.4	871.6	884.7	882.2		897.9	
8.00 — 9.00	239.3	239.9	241.6	235.7		236.7	
9.00 — 12.0	310.8	311.4	319.8	303.8		320.0	
12.0 — 14.0	260.9	290.0	283.4	273.9		286.4	
14.0 — 17.4	863.0	942.0	948.4	926.6		901.5	
17.4 — 20.0	122.8	136.3	145.2	133.7		139.9	
20.0 — 25.0	240.4	234.5	240.3	217.3	242.4	238.6	204.6
25.0 — 27.2	292.9	285.9	285.1	270.0	271.9	273.2	245.0
27.2 — 30.0	339.9	324.2	335.2	313.3	314.4	316.7	278.5
30.0 — 36.1	326.8	335.3	344.2	320.7	318.5	320.9	264.7
36.1 — 44.0	271.0	272.7	284.4	253.1	254.7	243.7	207.8
44.0 — 54.0	335.1		345.2	319.8	313.0	299.4	294.4
54.0 — 64.7	400.8		446.6	418.1	406.6	434.7	412.8
64.7 — 74.5	303.5		338.2	315.8	301.9	326.2	303.8
74.5 — 84.0	448.1		571.4	514.1	513.2	556.7	578.4
84.0 — 93.0	361.2		403.1	378.1	358.6	392.3	404.3
93.0 —100	203.4		227.2	231.3	205.5	241.1	253.1

TABLE 6
FISSION CROSS SECTIONS INTEGRALS IN THE RESONANCE REGION
(FROM L.W. WESTON , PRIVATE COMMUNICATION)

REFERENCE	LEVEL SPACING (EV)	STRENGTH FUNCTION X 10^4	AVERAGE FISSION WIDTHS (EV)	AVERAGE CAPTURE WIDTHS (MEV	DATA AND ENERGY RANGE
(1)			GROUP (A) : 0.847 GROUP (B) : 0.074	40 (ASSUMED)	TOTAL 0 - 12 EV
(2)	1.3	1.0			TOTAL 0 - 20 EV
(4)	1.3	1.9			TOTAL 12 - 31 EV
(5)	1.3 + _ 0.2	1.4 + _ 0.6		40 (ASSUMED)	FISSION 0 - 20 EV
(6)	1.13 + _ 0.21	1.3 + _ 0.3			TOTAL 13 - 50 EV
(8)	0.76		GROUP (A) : 0.500 GROUP (B) : 0.180	40 (ASSUMED)	FISSION 20 - 60 EV
(9)			2 + : 0.510 3 + : 0.190	42	SCATTERING FISSION 4 - 30 EV
(10),(11)	1.00 + _ 0.10	1.24 + _ 0.35	ALL SPIN STATES : 0.253 + _ 0.042	47.5 + _ 7.0 (FROM SELECTED VALUES)	TOTAL FISSION 12 - 100 EV
(13)		0.99 + _ 0.14	ALL SPIN STATES : 0.300	41.2 (FROM SELECTED VALUES)	TOTAL FISSION 1 _ 160 EV
(14)	0.83	1.08 + _ 0.17	TOTAL 2 + : 0.595 FOND. 2 + : 0.356 TOTAL 3 + : 0.087	40 (ASSUMED)	TOTAL FISSION 1 - 104 EV

TABLE 7
AVERAGE RESONANCE PARAMETERS

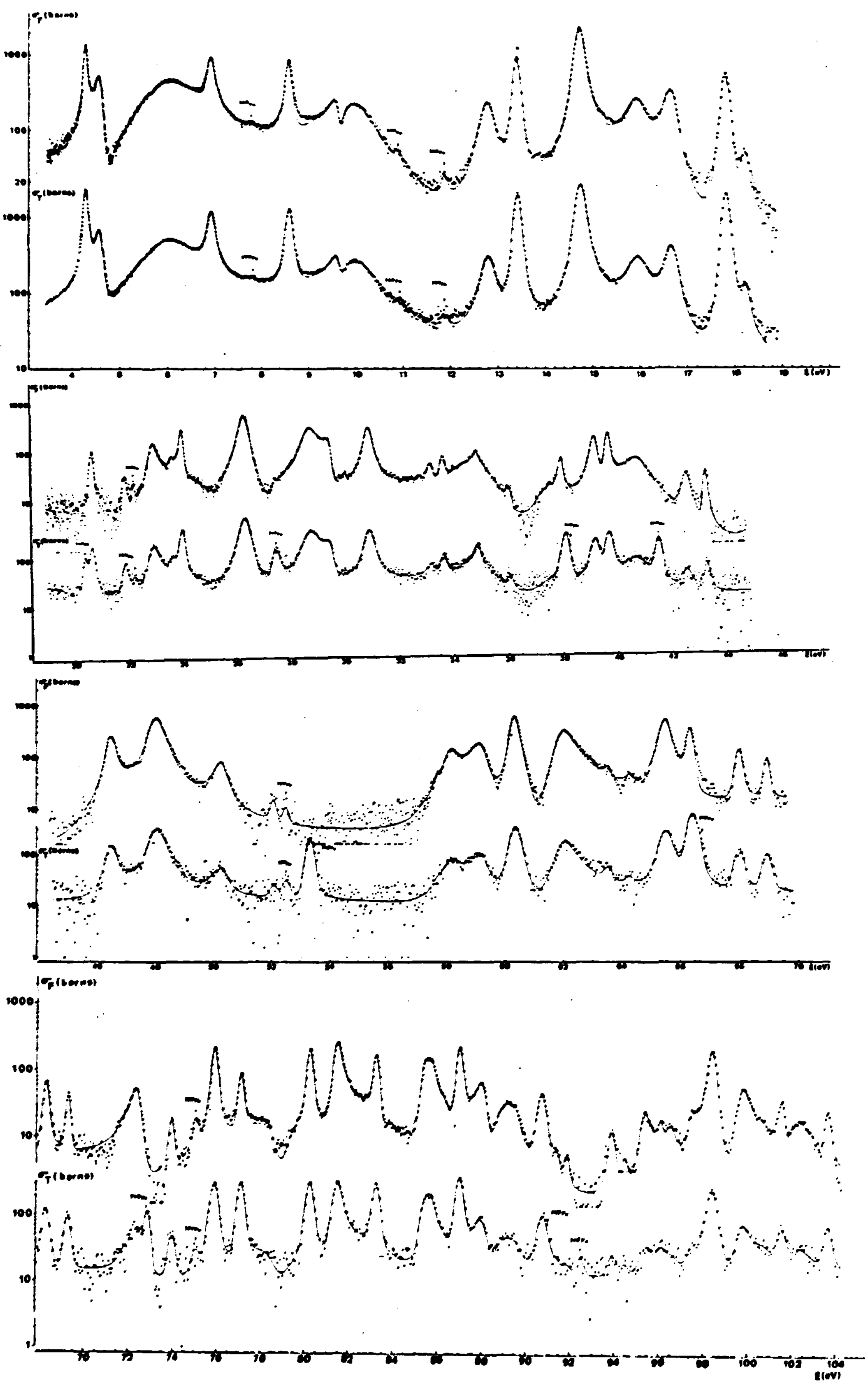
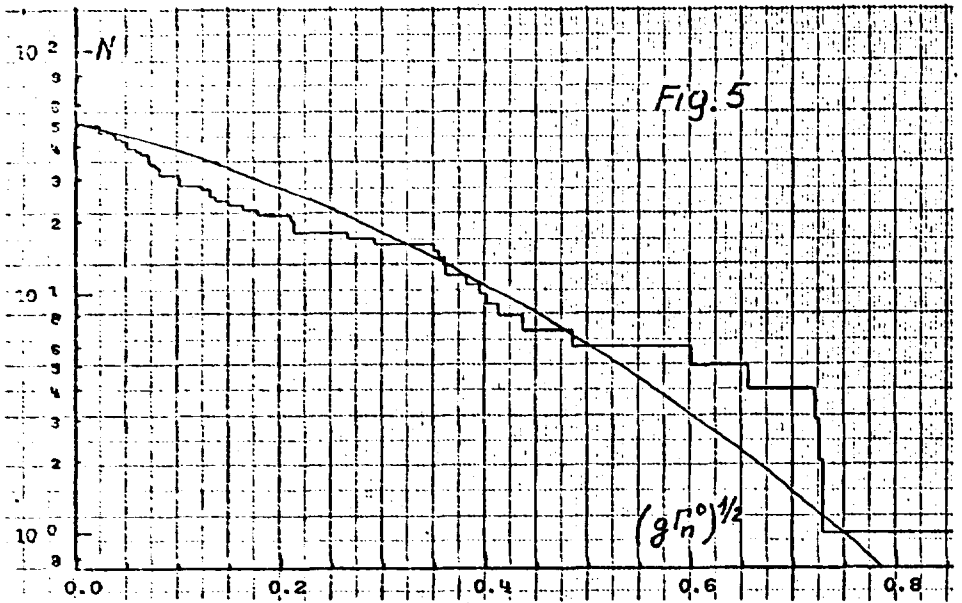
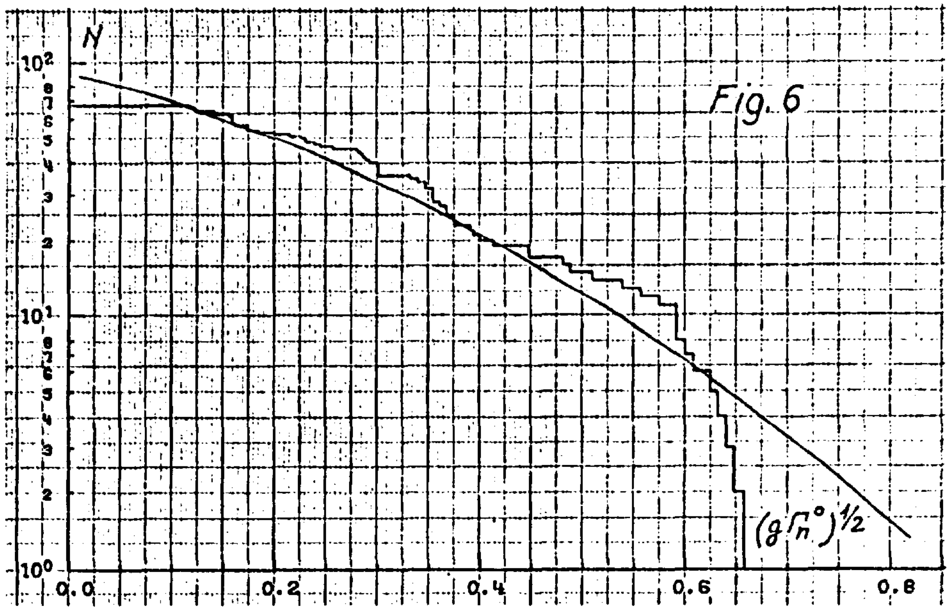
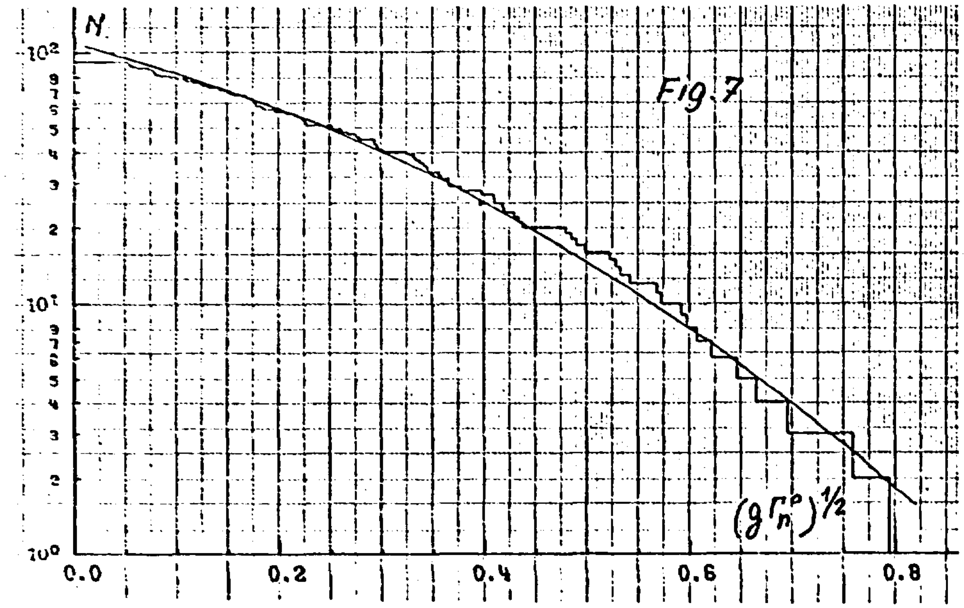


Fig. 1, 2, 3, 4 : Total cross-sections from KOLAR et al. ; fission cross-sections from BLONS et al. The curves represent the Reich Moore multilevel fit of BLONS and DERRIEN







Integral distribution of the fission widths from SIMPSON et al. (Fig. 5), KOLAR et al. (Fig. 6) and BLONS et al (Fig. 7). The curves are examples of Porter Thomas distributions.

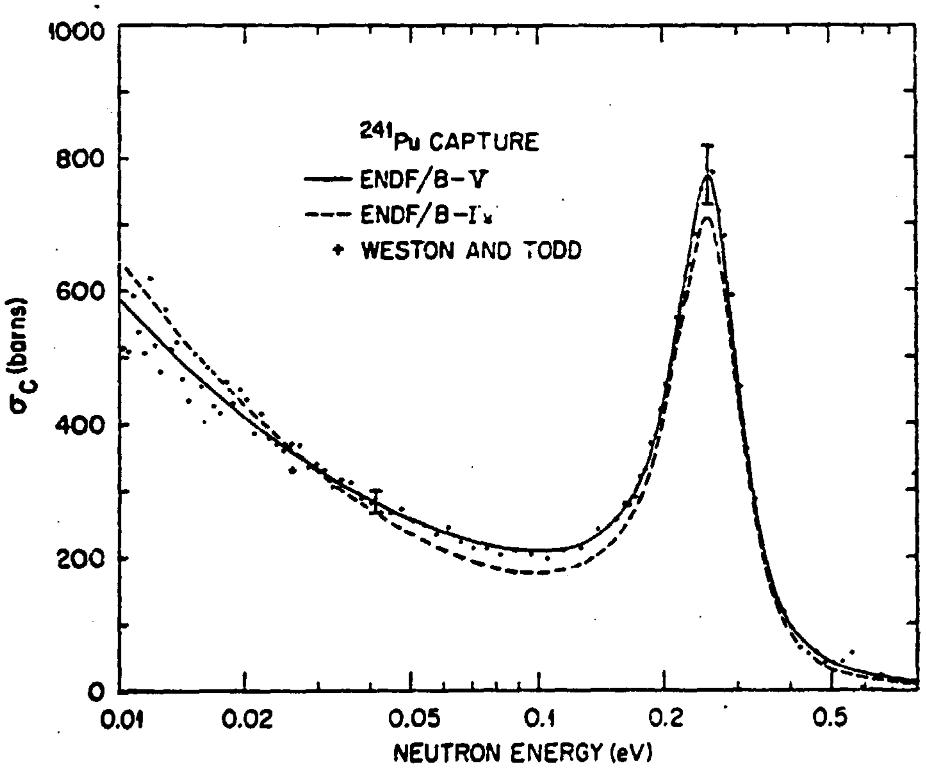


Fig. 8 : From WESTON et al.(20)

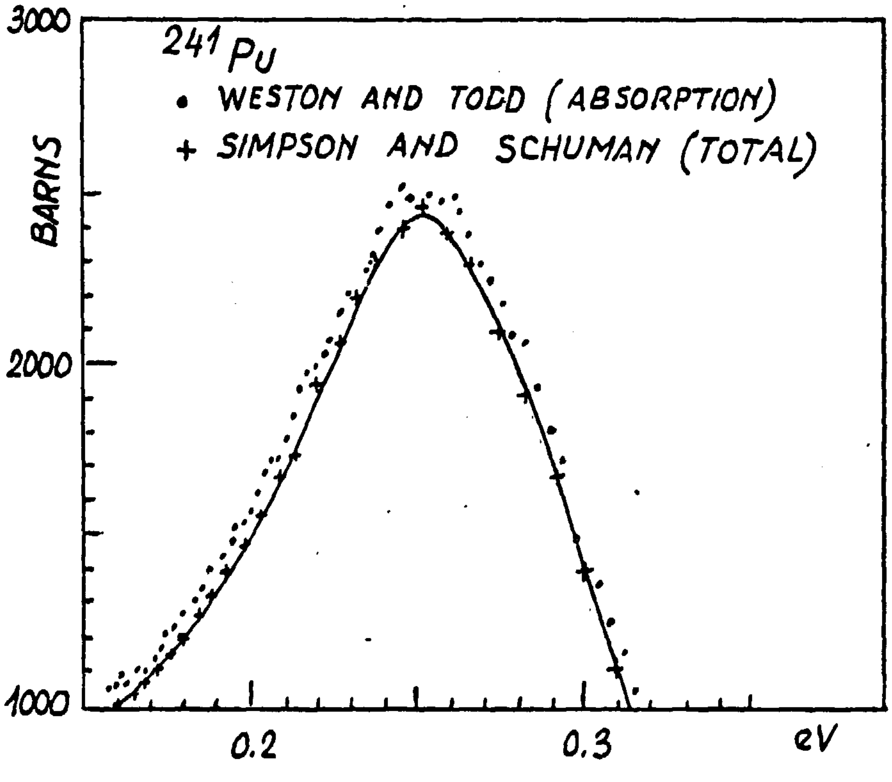


Fig. 9