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THERMAL CROSS SECTIONS OF THE FISSILE AND FERTILE NUCLEI FOR ENDF/B-II

B.R. LEONARD, Jr.

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ABSTRACT

The thermal cross section files for three fissile nuclei (^{235}U, ^{239}Pu, and ^{241}Pu) and for three fertile nuclei (^{232}Th, ^{238}U, and ^{240}Pu) were re-evaluated for version 2 of ENDF/B (ENDF/B-II). For the fissile nuclei, the objective was to provide thermal cross section files which were consistent with the least-squares adjusted 2200 m/s values and shapes (Westcott "g" factors) of the 1969 IAEA review. The thermal cross sections of the fertile nuclei were re-evaluated to incorporate new data.

INTRODUCTION

The thermal cross section files of the fissile nuclei for version 1 of ENDF/B were the individual results of existing evaluations. Based on the recommendations of the Normalization and Standards Subcommittee of the Cross Section Evaluation Working Group (CSEWG) these files were to have been normalized to the recommended 2200 m/s values of the 1965 IAEA review[1]. This was not accomplished with adequate precision for all fissile isotopes. Equally important, however, was the fact that the cross section shapes provided in ENDF/B-I were not necessarily those which were most consistent with the recommended 2200 m/s values.

For version 2 of ENDF/B the same group recommended that the thermal cross sections of the fissile nuclei be consistent with the 2200 m/s values and shapes of the then recently completed 1969 IAEA review[2].

In the 1969 study the shapes of the cross sections were included in the regression analysis through the index of the (20.44°C) Westcott "g" factors. The 1969 study thus provided for the first time a least-squares-fit (LSF) consistent set of cross section values and shapes. In the application of these results to reactor and other non-monoenergetic situations the 2200 m/s values are, by themselves with arbitrary cross section shapes, not necessarily a consistent or best-estimate set of values. Indeed, comparison of the 1969 2200 m/s values with the 1965 IAEA results is not particularly meaningful since the earlier study did not define the best-estimate shapes.

The purpose of the work reported here was to provide cross section shapes for the fissile nuclei which are consistent with the LSF output index of shapes. Although Westcott[3] has recently completed an extensive study of the accuracy of "g" factors as part of the 1969 IAEA review, the results of that study are not directly applicable to defining the best shapes. The Westcott study, rather, defines the best-estimate input shape index and their variability. The LSF output indexes on the other hand, give some evidence as to which sets or combination of sets of basic data are the more probable behavior of the cross sections.

For each of the fertile nuclei significant new experimental results had been published since the ENDF/B-I evaluations. These results were incorporated in evaluating new files for ENDF/B-II.

Concurrent with the work reported here re-evaluated thermal cross section files were prepared for ^{233}U and ^{242}Pu. Since revised cross section files for these isotopes were not issued for ENDF/B-II, the results of these evaluations are not included here. It has been noted since the completion of that work that the shapes of the ^{233}U cross sections in the region 0.2- to 0.5 eV were not as intended and those recommendations are, thus, considered to be withdrawn. For ^{242}Pu, the main impact of the re-evaluation was to change the ENDF/B-I 2200 m/s capture cross section from the erroneous 30b value to a value of 20 barns.

EVALUATION OF CROSS-SECTION SHAPES OF FISSILE NUCLEI

The LSF recommended index of shape, the Westcott "g" factor, is, of course, ambiguous as to the details of the best-estimate shape. In the present evaluation, the "g" factor obtained by others in the evaluation of differential cross-section data were the starting point for deriving shapes which reproduced the LSF g factors.

The cross section shapes in this evaluation were derived, in general, by perturbing the results of an existing evaluation in order to reproduce the desired g values. The results of existing precision experimental differential measurements were used as a guide to the nature of the perturbations.

An objective of the evaluation was to provide cross-section shapes which were smooth in the thermal region and would not produce irregularities in the behavior of thermally averaged quantities as a function, say, of neutron temperature. To this end the primitive cross-section files, $\sigma_f(E)$, $\sigma_a(E)$, and $\eta(E)$, were subjected to the mathematical restriction of maintaining reasonably smooth first and second derivatives. The perturbations were iterated until the primitive g factors, above, were within about 0.01 percent of the LSF-values.

Another approach would have been to derive the smooth shapes on the basis of a resonance analysis. This was not done, in part, because of the stringencies of time and money. Because of the ambiguities of the multi-level fission analyses that would have been required, particularly those due to the strong influence of negative-energy levels, it is debatable that the resonance analysis would yield a physically better-estimate shape.

The accuracy with which the "g" factors have been calculated should be commented upon. All of the "g" factors were calculated using the ENDF/B SLAVE program with the relative error test set at 10^{-4}. In ENDF/B-I all of the files for the fissile nuclei were terminated at a lower energy of 10^{-3} eV. In the SLAVE calculation, this causes a systematic error of about 0.5 percent in the calculated "g" values. Thus all of the revised files have been extended to 10^{-5} eV. In addition, improper interpolation schemes can cause systematic errors of several tenths of a percent depending on the data mesh in the file. Thus comparisons of "g" factor values with results quoted by others for purportedly the same data files are somewhat uncertain. The accuracy of the present calculation is of the order of 0.01 percent based on comparisons of values for ^{239}Pu calculated in an independent manner at Chalk River.[4]

New scattering files were provided for ^{239}Pu and ^{241}Pu. These files were calculated by the multi-level Breit-Wigner program UNICORN[5] using single-level parameters which reproduce the fission cross sections to a few percent. These files were completed before the LSF regression on scattering cross sections was completed and do not accurately reproduce the LSF values. They do, however, provide a comparison of the ENDF/B-II total cross sections with experimental data to well within the uncertain effects of scattering in real measurements.

The remaining cross section files were derived from the primitive files using the ENDF/B retrieval program COMB. In order to assure an entry for the discrete energy of 0.0253 eV in each file, it was necessary to create an unnecessarily large number of data points in the derived files.

COMMENTS ON THE EVALUATIONS FOR EACH ISOTOPE

In the following the derived shapes of the cross sections for each isotope are discussed. Since the ENDF/B-II data of these evaluations have all been released, the detailed listings of the evaluated cross-sections are not given in this report.

URANIUM-235

Point representation of the data intended to be in the ENDF/B-I files[6] were received from C. R. Lubitz. These files covered the energy range 10^{-3} to 5 eV. It was determined that these files contained apparently unintended irregularities as large as one percent in the entries below 4 meV. These entries were smoothed and the data files extended to 10^{-4} eV. Calculation of "g" factors showed that the value of g_f was about 0.2 percent greater than the desired value. The original evaluation of the low-energy fission cross section was reported[6] to have been made by fitting σ_f data of LRL and Hanford. Accordingly, a new fit was made including these data and also the fission data of Safford and Melkonian.[7] A smooth fit was obtained, the main difference from the original fit being the reduction of the rise in cross section at energies below about 0.02 eV. The fission cross section was fitted simultaneously with the capture cross section using an alpha variation deduced by Westcott.[8] In order to achieve a smooth fit to the fission data the file was modified slightly for energies up to 0.18 eV. The capture cross section file was modified for energies up to 0.1 eV. The following table shows the calculated "g" factors for 20.44°C and for the presently recommended cross sections along with the input and LSF output "g" factors of the 1969 IAEA study.

	ENDF/B		1969 IAEA	
	ENDF/B-I	ENDF/B-II (Present Evaluation)	Input	LSF Output
g_f	0.9784	0.9768	0.9772	0.9766 ± 0.0016
g_γ	0.9837	0.9907	------	0.9909
g_η	0.9992	0.9980	0.9984	0.9979 ± 0.0018
g_a	0.9792	0.9788	0.9787	0.9787 ± 0.0010

The cross-section shapes derived for sub-thermal neutron energies are based in large part on precision total cross section measurements of Safford, et al.[9] and of Palevsky, et al.[10] and the $1 + \alpha$ measurement of Safford and Melkonian[7]. The total cross section data of Safford, et al.[9] obtained with liquid samples is shown below compared with the ENDF/B-II values.

	$\sigma_T \sqrt{E}$	
Neutron Energy	Safford, et al.[9]	ENDF/B-II
0.000818 eV	115.71 ± 0.35	115.56
0.00128 eV	115.79 ± 0.29	115.49

The ENDF/B-II scattering cross sections at these energies is 16 b and a ±3 b uncertainty in this cross section contributes about ±0.1 b - $eV^{1/2}$ to calculated $\sigma_T \sqrt{E}$ values.

Palevsky, et al.[10] measured $\left(\sigma_T \sqrt{E}\right)_{ave}$ = 115.15 ± 0.57 b - $eV^{1/2}$ over the energy range 0.00167 eV to 0.00348 eV. At the higher energy values the measurement should include some scattering contribution and the ENDF/B-II value of $\sigma_T \sqrt{E}$ is 115.16 b - $eV^{1/2}$ at 0.003 eV. At the lower energy of the measurements the observed cross section should be $\sigma_a \sqrt{E}$ and the ENDF/B-II value is $\sigma_a\sqrt{E}$ = 114.93 at 0.00125 eV.

Safford and Melkonian reported a measured value of 1.171 ± 0.75% at 0.002912 eV which was re-evaluated in this work to 1.1724 ± 0.0088 based on a recalculation of the incoherent scattering cross section. The ENDF/B-II value of $1 + \alpha$ at these energies is 1.1754.

PLUTONIUM-239

The original ENDF/B data(11) for neutron energies below 1 eV were obtained from the fitted curves given in TNCC(US)-58.(12) The recommended curve shapes have been derived from the original curves with slight alterations in shape. The slight modification of the fission cross section was accomplished by a small shape change for energies below 0.0253 eV where the shape is not established with high precision by the experimental data. The difference in shape is only 0.5 percent at a neutron energy of 10^{-3} eV.

The absorption cross section shape required a somewhat larger shape change. One reason for this is the assignment of an 11 barn scattering cross section in the original evaluation(12) which is 3 to 4 barns higher than the effective value evaluated for the 1969 IAEA study. Secondly, the total cross section measurements of Safford and Havens(13) made after the original evaluation(12) show a slightly different shape. The recommended absorption cross section curve agrees quite well with the Safford and Havens data for energies below 0.0253 eV but is closer to the original evaluation at higher energies. It was also discovered that the ratio of absorption to fission cross sections through the 0.3 eV resonance as given in the original ENDF/B files(11) showed an erratic behavior. It was determined(14) that this had resulted from reading values separately from the graphs of TNCC(US)-58. Actually in TNCC(US)-58 the plots of $\sigma\sqrt{E}$ were intended to reproduce the smooth variation deduced for the energy variation of eta based on a simultaneous consideration of experiments of that type. Accordingly, it was determined that the fission cross section data given in the original ENDF/B files were a reasonably accurate representation of the intended shape. The recommended absorption cross section in the region 0.15-1.0 eV was then obtained from the fission cross section and the smooth behavior of $1 + \alpha$ as given in TNCC(US)-58 modified by the slightly revised cross section shapes at lower energies.

The scattering cross sections given in the original ENDF/B files are considerably different from those used as input in the 1969 IAEA study. Since the input values are in excellent agreement with the output values for ^{239}Pu, a new scattering cross section file has been created in the region 10^{-5}-1.0 eV which is identical to that used in the 1969 IAEA study. The scattering values in the original ENDF/B files gave about 11 barns in the thermal region. This large value came about probably because the large negative energy resonance at -1.2 eV proposed by Vogt(15) was used to generate the cross section. However, the multilevel fission parameters of Vogt do not accurately reproduce the thermal cross sections of ^{239}Pu which can be fitted by single level parameters to within a few percent. Accordingly, the scattering cross section values were calculated from the following resonance parameters and the value σ_p = 10.3 b:

E_0(eV)	Γ_n(meV)	Γ_γ(meV)	Γ_f(meV)	g
-0.22	0.04662	40.0	500.0	0.25
0.296	0.0807	39.0	60.0	0.75

Note that the spin assignments given above are reversed from those usually given but are consistent with more recent studies which identify levels with large values of Γ_f with states of g=0.25 and with other data which indicates which levels mutually interfere in ^{239}Pu fission. The parameters of these two resonances given in ENDF/B-II were not changed from ENDF/B-I and will not reproduce the scattering cross section given in file 3-2.

The following table shows the "g" factors which were calculated for the ENDF/B-I and ENDF/B-II cross sections along with the input and output "g" factors of the 1969 IAEA study.

	ENDF/B		IAEA	
	I	II	Input	LSF Output
g_f	1.0540	1.0548	1.0522	1.0548 ± 0.0030
g_a	1.0775	1.0752	1.0762	1.0752 ± 0.0030
g_η	0.9787	0.9808	0.9777	0.9810 ± 0.0027

PLUTONIUM-241

The original[16] ENDF/B cross section shapes in the low-energy region were found to give Westcott "g" factors which differed significantly (+0.8% in g_a, -0.3% in g_f) from the LSF adjusted output values of the 1969 IAEA study. In addition, the low energy values of σ_a were grossly discrepant with total cross section data which have been obtained at the MTR[17] since the original evaluation. It was determined that the analytical fits made by Fluharty, et. al.[18] in 1966 to the then existent data gave g values which were very close to the desired values and were not badly discrepant with the new σ_T results. Consequently, these fits, along with the new data, formed the basis for deriving the recommended curve shapes.

The analytic fits had different functional shapes in two regions, 0-0.1 eV and 0.1-0.5 eV. These fits were joined in the region around 0.1 eV to insure continuity of value and first derivative.

The new total cross section data from the MTR show an almost constant value of $\sigma\sqrt{E}$ at low energies (below 5-8 meV). The behavior appears to be consistent with what would be expected from a resonance at nearly zero energy with a small width (30-40 meV) and, hence, would have only a small fission width. The desired "g" factor was obtained by fitting the low energy data subject to the constraint of reasonably smooth first and second derivatives. The resulting shape falls slightly below the analytic fit in the region 0.03-0.05 eV which is consistent with the shape derived by Westcott[3] in his study of the data as part of the 1969 IAEA study. The shape of the absorption cross section differs from the earlier analytic fit below 0.06 eV and above 0.4 eV.

The analytic fit[18] to the fission cross section was fitted to data only for energies greater than 0.03 eV and did not reflect the low energy shape observed in the total cross section. The fission cross section shape was re-evaluated below 0.1 eV according to the smoothness criteria. The resultant shape is very nearly that deduced from the Hanford data[19] above 0.03 eV and closely fits other Hanford data[20] at 5 meV. The 5 meV data had been ignored in the analytic fitting of Fluharty, et al.[18] on the author's recommendation because of obvious systematic errors at lower energies. It now appears that the data near 5 meV were reasonably valid. The resultant shape of the recommended fission cross section at low energies is consistent with the assumption of the small level near zero energy with a small fission width. The resonance behavior, however, is not apparent unless the extrapolated smooth behavior at higher energies is subtracted.

The ENDF/B-II data files above 0.4 eV were evaluated jointly with the evaluation of the resolved resonance region by Smith[21]. The cross sections in the region 0.5- to 1.8 eV were calculated from a single-level resonance analysis using the following parameters:

E_o (eV)	Γ_n(meV)	Γ_γ (meV)	Γ_f(meV)	g
-6.94	0.656	18.0	160.0	.5833
-6.11	3.139	20.0	1,360.0	.4167
-4.57	3.100	20.0	130.0	.4167
-4.29	0.4805	30.0	41.0	.5833
-0.209	0.06215	40.0	92.0	.5833
0.258	0.0528	40.0	90.0	.5833
4.29	0.4805	30.0	41.0	.5833
4.57	0.3100	20.0	130.0	.4167
6.11	3.139	20.0	1,360.0	.4167
6.94	0.656	18.0	160.0	.5833

In order to maintain a smooth variation of alpha, the shape of the absorption cross section in the region 0.4- to 0.5 eV was modified from the analytic fit[18].

A new scattering cross section file was also calculated using the resonance parameter calculation given above with a value σ_{pot} = 10.938 b.

The following table shows the Westcott "g" factors which were calculated from the ENDF/B-I and ENDF/B-II files along with the input and LSF output values of the 1969 IAEA study.

	ENDF/B		IAEA	
	I	II	Input	LSF Output
g_a	1.0458	1.0377	1.0376	1.0376 ± 0.0014
g_f	1.0453	1.0486	1.0505	1.0486 ± 0.0053

There remains a discrepancy in the ^{241}Pu cross sections which is disturbing. Smith and Reeder[22] have reported monoenergetic measurements of eta at 0.06- and 0.0253 eV. Their measurements gave a ratio of η (0.06 eV)/η (0.0253 eV) = 1.014. The accuracy on the ratio was not stated but was certainly the order of one percent. The MTR analytical fits[18] gave 1.0714 and the present cross sections are only slightly closer, giving a value of 1.051. Westcott[3] in his polynomials fits resulted in a similar discrepancy. Although the scatter in total and fission cross section data would cover the monoenergetic value it does not seem likely that it could be reproduced if the average behavior, and the derived "g" factors, are correct.

THORIUM-232

Since the original ENDF/B data files[23] were prepared, Lundgren[24] has measured the energy dependence of the capture cross section in the region 0.1 to 3.4 eV and has derived parameters for the negative-energy level which dominates the capture in this region. A revised set of cross sections has been prepared in the ENDF/B format from a resonance calculation which included the doublet of resonances at 21.78 eV and 23.45 eV and the negative level. The ENDF/B parameters for the resonance doublet contribute 0.245 b to the 0.0253 eV capture cross section. In the calculations an additional 1/v component of 0.195 b was added to represent the contribution of the remainder of the known positive levels. Actually, a better estimate would have been obtained by adding an equal amount to represent the remaining negative levels. The negative energy level parameters used in the calculation differ slightly from those given by Lundgren when the number of significant figures is increased to give exactly 6.96 b as the negative level contribution. The parameters used were:

$$E_o = -5.10 \text{ eV} \qquad \Gamma_n = 4.204 \text{ meV} \qquad \Gamma_\gamma = 24.0 \text{ meV}$$

The resonance calculations were made including the negative level and the first positive doublet in order to obtain the minimum bias due to resonance-potential scattering interference. In order to reproduce the measured total cross section from thermal to 15 eV it was found that the best fit was obtained with a value of σ_p = 10.15 barns. If the 1/v capture component due to negative levels had been included properly this value would have been reduced slightly. The extent of the agreement of the present calculations can be seen by comparison with some precise total cross section values which have been measured at 6- and 12-eV.(25)

E (eV)	σ_T (Barns) Experiment	Present Calculation (σ_p = 10.15 b)
6	10.78 ± 0.04	10.79
12	10.26 ± 0.04	10.22

The uncertainty in the value 10.15 b due to the possible effect of unknown negative energy levels has been estimated to be of the order of ±0.6 barns. Thus the value is significantly different from the value 12.0 ± 0.3 b deduced by Uttley[26] from average total cross section measurements in the keV region and used for the resonance region calculation in ENDF/B-I.

PLUTONIUM-240

The original ENDF/B files[27] gave a capture cross section of 276 barns at 0.0253 eV which was calculated from the chosen resonance parameters. The direct information bearing on the thermal cross section was displayed in Table IV of Ref. 27. The only measurements of appreciable significance which were listed were: (1) An integral measurement by Tattersall[28] which gave a value of 290 ± 9 b and (2) a total cross section value of 273 ± 8 b by Pattenden and Rainey[29] which was interpreted by them to give an absorption cross section value of 271 barns. The equally important total cross section value of 290 ± 8 b obtained by Block, et al.[30] was not considered.

Since the original evaluation further measurements have been reported. At a panel discussion[31] at Cadarache, France, two integral measurements were reported which gave values of 297.0 b from a substitution type measurement and 287.0 b from an oscillator measurement. The weighted mean of these two values was reported to be 290 ± 5 barns. In addition, Lounsbury, et al.[32] at Chalk River have reported an effective cross section value $\hat{\sigma}$ = 301.7 ± 1.6 b in a well-thermalized flux which they interpret to give a value σ = 289.3 ± 1.6 b at 0.0253 eV.

Considering all of the values reported above, the only discrepant value is that of Pattenden and Rainey[29] and it is only slightly over two standard deviations away from the precise value of Lounsbury, et al.[32] Thus the Lounsbury value is considered to be the best estimate of the thermal absorption cross section. However, the value has been rounded to 290 b, particularly since the cross section shape used to interpret the integral experiment did not consider any possible shape effects of negative energy levels.

The assignment of the parameters of the negative level necessary to produce a capture cross section of 290.0 barns at 0.0253 eV was made using only the positive levels at 1.056 eV and 20.44 eV in order to obtain the best unbiased estimate of the scattering cross section. Thus if the recommended negative energy level parameters were used in a calculation including all of the positive energy levels, the strength of the negative level would need to be reduced slightly to maintain the 290.0 b value.

In the calculation of the thermal cross sections the parameters of the 1.056 eV resonance were altered slightly in order to provide a better estimate of the capture width. The best estimate of the capture width is obtained from the total width value of 32.3 ± 1.5 meV reported by Leonard, et al.[33] In the adjustment, the strength of the resonance, $\Gamma_n \times \Gamma_\gamma$, was kept constant in order to yield the same thermal cross section as the ENDF/B-I parameters. The revised resonance parameters are recommended for future use.

The assignment of the negative energy level parameters was made by fixing the value of Γ_n^o = 2.0 meV/eV$^{1/2}$ which is approximately the arithmetic average value of the positive energy parameters. A fission width was used of 9.0 x 10^{-6} eV which is the average of those for the first three levels. The energy assignment was then adjusted to give the desired thermal cross section which resulted in a value of E_o = -4.099 eV which is not inconsistent with the average level spacing. The recommended parameters of the -4.099 eV and 1.056 eV resonances are:

E_o (eV)	Γ_n (meV)	Γ_γ (meV)	Γ_f (meV)
-4.099	4.0492	30.0	0.009
1.056	2.4400	29.86	0.0057

The calculations gave a value of σ_f = 57.48 mb at 0.0253 eV which is only 4 mb larger than given from the known positive energy level fission widths and is consistent with the value of 30 ± 45 mb obtained by Bigham.[(34)]

The value of σ_p = 10.6 b used in the original ENDF/B files is considered to be a valid best estimate and was used in the calculation of the recommended thermal cross sections. The calculations give a value of σ_s = 3.73 b at 0.0253 eV. This value is substantially different from the values of 2 ± 1 b used by Block, et al.[(30)] and 2.0 ± 0.5 b used by Pattenden and Rainey[(29)], neither of whom considered the consequences of the anticipated negative levels. The inferred absorption cross sections from these measurements should be changed accordingly.

The Westcott "g" factor calculated for the capture cross section at a temperature appropriate to the Lounsbury, et al.[32] experiment is slightly different from the value used in their analysis. With the revised "g" factor we calculate an effective cross section $\hat{\sigma}$ = 302.2 b from the ENDF/B-II data compared to the experimental value of 301.7 ± 1.6 b.

URANIUM-238

The original ENDF/B data files for ^{238}U[35] gave a capture cross section at thermal energies which was intended to be the representation of the cross section calculated from the first 22 positive-energy resonances plus that due to a single negative-energy level at -5 eV defined with a strength to produce a value of 2.73 barns at 0.0253 eV. The actual entries in the file, however, consisted of only two points at 10^{-3} and 10^{-1} eV to define the thermal region. With the ℓn-ℓn interpolation prescribed these two values resulted in an 0.0253 eV value of 2.750 barns and a shape which was different from that intended.

In the present evaluation the capture cross section has been taken to be 2.720 barns. This value is based on the recent measurement of Bigham, et al.[36] who obtain a value of 2.721 ± 0.016 barns from an irradiation in a very well-thermalized flux. A re-evaluation of the other experiments, all of which were made in or prior to 1955, indicates that they make no significant contribution to the knowledge of this quantity in view of the small error assignment of the Bigham result.

The shape of the ^{238}U cross sections at low energies has been deduced from:

- A value of σ_{pot} = 10.6 barns which is the value used by Pitterlee[27] in his evaluation of higher energy ^{238}U data and which is not in significant disagreement with the results of this evaluation obtained from fitting σ_T data in the region 1- to 400-eV,
- The contribution, 2.472 b, to the capture cross section from the positive-energy S-wave resonances up to 400 eV using the parameters proposed by Pitterlee,[37]
- An estimated 0.023 b, of the contribution of levels above 400 eV,
- The estimated contribution, 0.139 b, of negative levels calculated from a "picket fence" model of average resonances beginning at -74 eV,
- The contribution, 0.086 b, of a fiducial level at negative energy whose parameters were determined by the simultaneous requirement of the normalization value, 2.72 barns, and a fit to the total cross section data of Bollinger et al.[38] in the region 1- to 5- eV.

The actual calculation of the data file was done with the UNICORN program using the first 9 positive-energy S-wave resonance parameters of Pitterlee (through the 116.9 eV resonance), the value σ_p = 10.6 b, and four resonances at negative energy with the following parameters:

E_0(eV)	Γ_n(MeV)	Γ_γ(MeV)
-111.0	18.332	23.5
- 92.5	16.735	23.5
- 74.0	14.968	23.5
- 69.93	36.728	23.5

The contributions of resonances outside this region (-111 to +117 eV) to the capture cross section, 0.14 b, was added as a 1/v cross section. Calculations using all resonances to 400 eV gave no significant shape difference in σ_γ over the interval 10^{-5}- to 5-eV. The calculation of the scattering cross section over this approximately symmetric energy region gives a minimum bias due to resonance-potential scattering.

The 0.0253 eV g factor for capture calculated by the SLAVE program from these files was 1.0021.

Shortly after this work was completed a new measurement by Hunt, et al.[(39)] was reported for the activation cross section of ^{238}U. Their reported value was 2.69 ± 0.03 b. A simple weighted-mean of this result with the value of 2.721 ± 0.016 b of Bigham, et al.[(36)] would result in a value closer to 2.713 b, well within the experimental error assigned to either result.

ERRATA

Please insert the following Acknowledgment at the bottom of page 20.

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