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An Evaluation of the Resolved-Resonance-Region Cross Sections of ^{232}Th

D. K. Olsen

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ABSTRACT

An evaluation of the neutron-induced resolved-resonance-region (5 to 4000 eV) cross sections of ^{232}Th is described in terms of explicit resonance parameters and pointwise cross sections. The evaluated average capture width, 24.4±2.0 meV, and the 0-to-4-keV s-wave strength function, $0.826 \pm 0.37 \times 10^{-4}$, are appreciably larger than those of the ENDF/B-V evaluation. The present evaluation, together with the ENDF/B-V thermal and unresolved-resonance region cross sections, give a dilute capture resonance integral of 86.1b. The bound levels of ENDF/B-V are retained and pointwise cross sections are given to smoothly connect this evaluation to the ENDF/B-V thermal cross sections.

I. INTRODUCTION

This technical memo gives an evaluation of the ^{232}Th cross sections in the resolved-resonance region, 5 to 4000 eV, and is intended to serve as a modification to the existing ^{232}Th ENDF/B-V evaluation. This file (MAT=1390) was assembled and organized by M. Bhat in 1980.[1] The thermal and resolved-resonance-region cross sections were largely taken from a 1977 evaluation intended for ENDF/B-V and used for a study of temperature coefficients of reactivity for ^{233}U-^{232}Th HTGR lattices.[2] Since that time four measurements of resolved-resonance cross sections have been completed: the ORELA transmission measurements,[3] the ORELA capture measurements[4,5] and the BNL low-energy resonance-parameter determination.[6] Together, these new measurements indicate that the capture and neutron widths of the resolved ^{232}Th resonances may be substantially larger than those contained in the ENDF/B-V file.

This evaluation incorporates these new experimental results with the older measurements and is strictly limited to the resolved resonance region. Implications on the thermal (< 5 eV) and unresolved-resonance (> 4000 eV) regions are not considered. The goal of this evaluation is to correct major deficiencies, if any, in the 5-to-4000-eV cross sections, and it is not intended to be a comprehensive study. Cross-section parameters and other information are freely borrowed from the 1980 ENDF/B-V evaluation,[1,2] the 1978 evaluation of Keyworth and Moore[7] and the 1974 evaluation of Derrien.[8] This last evaluation[8] is particularly well documented and gives a good discussion of the problems associated with the earlier data.

The next section describes the evaluation of the resonance parameters. Section III describes the pointwise files necessary to account for all the capture cross sections, to correct for formalism deficiencies, and to smoothly connect the resolved-resonance cross sections to the ENDF/B-V thermal cross sections. The last section gives the infinitely-dilute-capture resonance integral from this evaluation and discusses the uncertainties and problems with these cross sections.

II. EVALUATION OF RESOLVED RESONANCE PARAMETERS, AND CROSS SECTIONS FROM 8 TO 4000 eV

A. Effective Radius and Formalism

Newman *et al.*[2] evaluated an effective radius of $0.971\pm0.008\times10^{-12}$ cm for ENDF/B-V. The ORELA transmission measurements[3] give $0.972\pm0.005\times10^{-12}$ cm. An effective radius of $0.972\pm0.004\times10^{-12}$ cm is adopted. The multi-level Breit Wigner cross-section formalism should be used.

B. Resonance Energies

The energy scale of the 40-m ^{232}Th ORELA transmission measurements[3] has been normalized to within ±0.02% of the ORELA 150-m ^{238}U energy scale,[9] which has an absolute accuracy of ±0.02%. The resonance energies of the Keyworth and Moore evaluation[7] agree well on a resonance by resonance basis with those of Olsen *et al.*,[3] but are between 0.02% to 0.04% systematically smaller. Consequently, for this evaluation the resonance energies of Olsen *et al.*[3] are used below 2 keV and those of Keyworth and Moore,[7] multiplied by 1.00030, are used above 2 keV.

C. The First Four s-Wave Resonances

Widths for the first four s-wave resonances were evaluated in detail. These resonances are particularly important for thermal reactors and more measurements exist for their widths than for the higher-energy resonances. Most of these measured widths are listed in Table I along with the results of recent evaluations. The older Harwell measurements are assumed to be superseded and/or contained in the Asghar results.[10] There are some very large discrepancies between some of the measured widths and many of the older measurements have large uncertainties. For example, the 23.5-eV neutron widths of Asghar *et al.*[10] and Bollinger[15] are extremely inconsistent with each other, whereas the neutron widths of Haddad *et al.*[17] have large uncertainties and do not significantly affect the evaluated average. Nevertheless, no measurement is rejected and the evaluated widths, listed in line 12, are simply the inverse-variance-weighted average on a resonance by resonance basis of the Table I measurements. The most recent measurement of Olsen *et al.*[3] has small uncertainties; however, it is important to appreciate that the evaluated widths excluding their uncertainties are almost independent of this measurement. Excluding the Olsen *et al.*[3] values, the Table I measurements yield neutron widths of 2.04, 3.86, 3.77 and 43.1 meV and capture widths of 24.8, 26.3, 23.8 and 22.0 meV, respectively. The evaluated widths are also in excellent agreement with the recent results of Chrien *et al.*[6] and are similar to those of the 1974 evaluation of Derrien.[8] The uncertainties, however, have been considerably reduced, mostly as a result of the Olsen *et al.*[3] data.

D. Neutron Widths

Remaining neutron widths were evaluated from the Olsen *et al.*[3] transmission results (0.0 to 2.0 keV); the Ribon[14] transmission results (0.0 to 3.0 keV); the Rahn *et al.*[12] transmission, capture and self-indication results (0.0 to 4.0 keV); the Macklin[4] capture results (2.6 to 4.0 keV);

Table I. Widths (meV) for the First-Four ^{232}Th S-Wave Resonances

Measurement	Ref.	21.8 eV		23.5 eV		59.5 eV		62.2 eV	
		Γ_n	Γ_γ	Γ_n	Γ_γ	Γ_n	Γ_γ	Γ_n	Γ_γ
Olsen (80)	3	2.08±.03	25.3±0.6	3.82±.06	26.9±0.7	3.86±.07	24.6±1.0	43.2±0.5	24.1±0.6
Chrien (79)	6	2.10±.10	24.0±1.5	3.70±.20	26.0±1.5	4.00±.30	25.0±2.0	41.2±3.0	22.6±2.0
Halperin (75)	11			3.72±.11					
Rahn (72)	12	1.91±.09	20.0±2.0	3.24±.24	25.0±2.0	3.93±.23	25.0±2.0	44.0±2.0	25.0±2.0
Forman (71)	13					4.01±.31	22.7±6.0	42.5±1.7	21.9±2.8
Ribon (69)	14	1.96±.08	21.3±3.7	3.64±.12	28.2±2.9	3.93±.08	23.6±0.7	44.0±0.5	20.5±1.0
Bollinger (68)	15	2.09±.03	26.5±1.2	4.11±.05	25.2±1.1	3.77±.15	31.7±2.9	42.0±0.8	23.5±1.4
Bhat (67)	16	2.61±.17	22.4±2.4	4.17±.25	22.0±2.6	4.41±.27	16.2±2.3	42.9±2.6	21.5±4.7
Asghar (66)	10	1.88±.05	24.6±1.2	3.41±.08	29.9±1.6	3.34±.09	23.2±2.0	41.4±1.2	21.2±1.0
Haddad (64)	17	2.10±.20	21.0±5.0	4.00±.30	22.0±4.0	4.00±.40	22.0±7.0	47.0±15.0	24.0±2.0
Palevsky (64)	18	2.60±.20	30.0±2.0	3.70±.20	27.6±1.5	4.50±.30	37.0±5.0	38.0±6.0	26.0±5.0
This Evaluation		2.06±.03	25.1±0.6	3.85±.06	26.6±0.5	3.80±.05	24.0±0.6	43.2±0.3	23.0±0.6
ENDF-V (1980)	1	2.02	23.0	3.88	25.0	4.04	23.2	44.0	21.9
ENDF-IV (1965)	19	2.00	25.9	3.74	25.9	4.00	25.9	42.0	25.9
LASL (1978)	7	1.97±.05	20.9±11.3	3.72±.15	19.0±7.7	3.92±.10	20.1±7.2	44.0±1.0	22.9±1.5
Derrien (1974)	8	2.02±.06	24.5±2.0	3.88±.40	26.6±1.5	3.90±.15	23.7±1.0	43.2±1.0	21.9±0.7

and the Forman *et al.*[13] capture results (0.0 to 2.0 keV). The Columbia results of Rahn *et al.*[12] are assumed to supersede the Columbia results of Garg *et al.*[20] In addition, the Asghar *et al.*[10] neutron widths, 23 s-wave resonances from 21 to 842, are not selected for evaluation above 63 eV since many seem systematically low by many standard deviations of their published uncertainties.

Following the various ENDF evaluations of ^{238}U, an attempt was made to correct these sets of ^{232}Th neutron widths for systematic discrepancies by multiplication with a linear function of neutron energy prior to their combination into an evaluated set. The numerous sets of ^{238}U neutron widths from 0 to 4 keV have obvious, perhaps even understandable, systematic discrepancies which increase with increasing neutron energy.[21] To obtain the assumed linear discrepancies for ^{232}Th, the ratios of the Ribon[14] neutron widths to those of Rahn *et al.*,[12] the Olsen *et al.*[3] neutron widths to those of Ribon,[14] and the Olsen *et al.*[3] neutron widths to those of Rahn *et al.*[12] were plotted as a function of neutron energy and are shown in Figs. 1 to 3, respectively. Only ratios with fractional uncertainties less than 20% for s-wave resonances were plotted. These ratios were least-squares fitted to obtain <u>on average</u>:

$$\Gamma_n \text{ (Ribon)} = (1.002+0.000023\ E)\ \Gamma_n \text{ (Rahn)}$$

$$\Gamma_n \text{ (Olsen)} = (0.964+0.000053\ E)\ \Gamma_n \text{ (Ribon)}$$

$$\Gamma_n \text{ (Olsen)} = (0.968+0.000080\ E)\ \Gamma_n \text{ (Rahn)},$$

where the neutron energy E is in eV.

These relationships do not indicate which set of neutron widths is correct, but only show the systematic deviations between the various sets. In order to produce an evaluated set of neutron widths the assumption was

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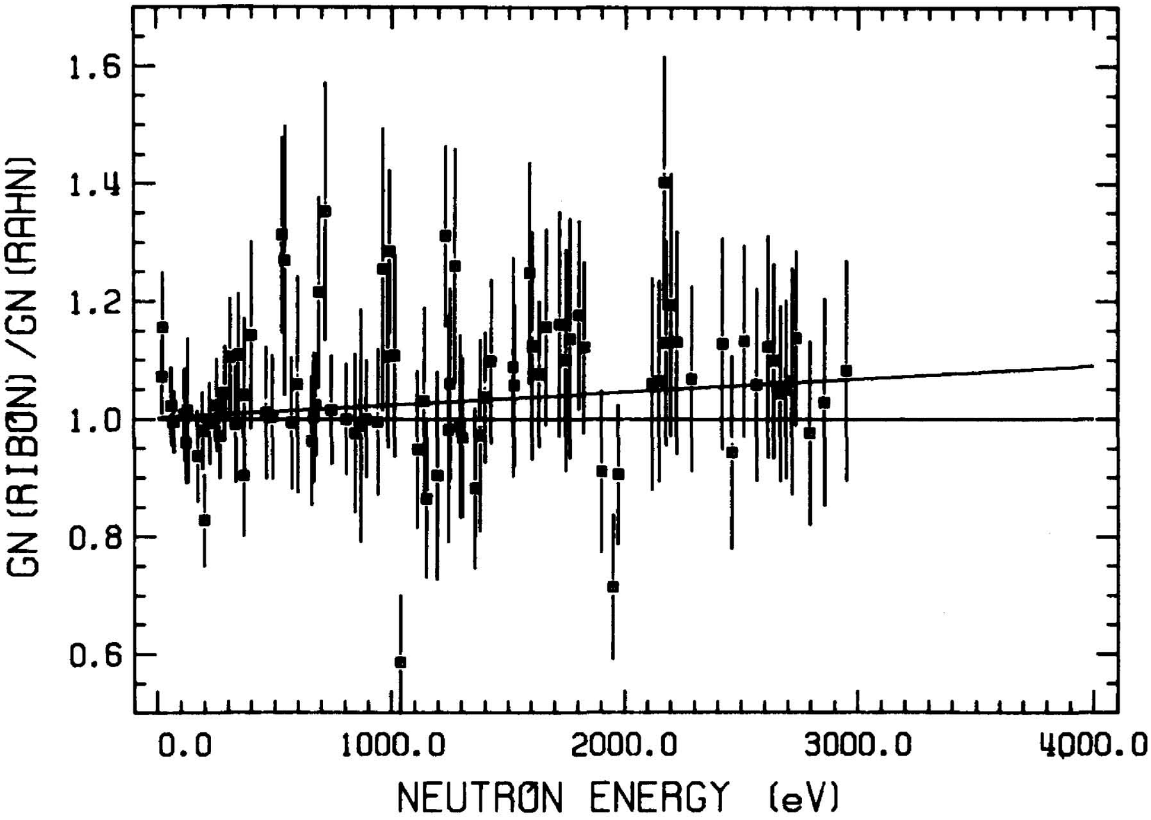

Fig. 1. Ratios of the Ribon[14] neutron widths to those of Rahn *et al.*[12] for s-wave resonances with ratio uncertainties less than 20%. The straight line, 1.002+.000023E, is a least-squares fit to these ratios which is assumed to be the systematic discrepancy between the two measurements.

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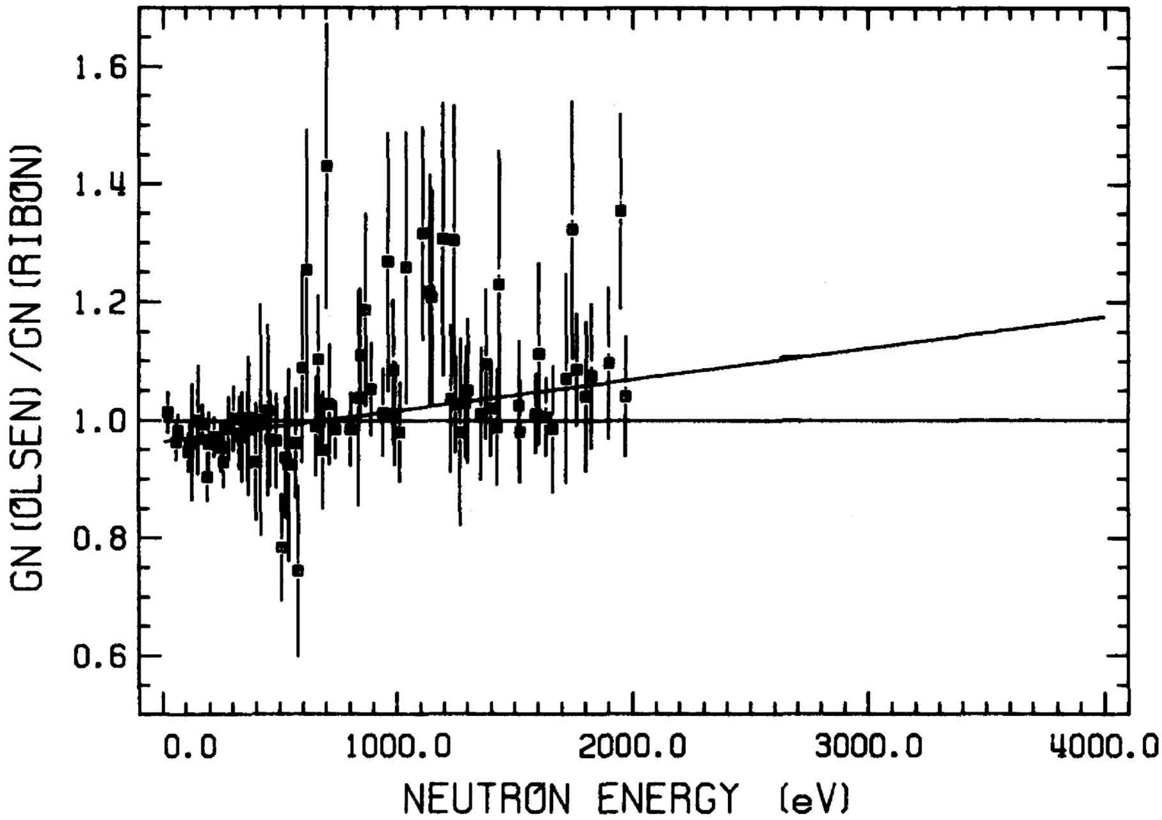

Fig. 2. Ratios of the Olsen *et al.*[3] neutron widths to those of Ribon[14] for s-wave resonances with ratio uncertainties less than 20%. The straight line, 0.964+0.000053E, is a least-squares fit to these ratios which is assumed to be the systematic discrepancy between the two measurements. The two measurements were corrected equally for this systematic difference in this evaluation.

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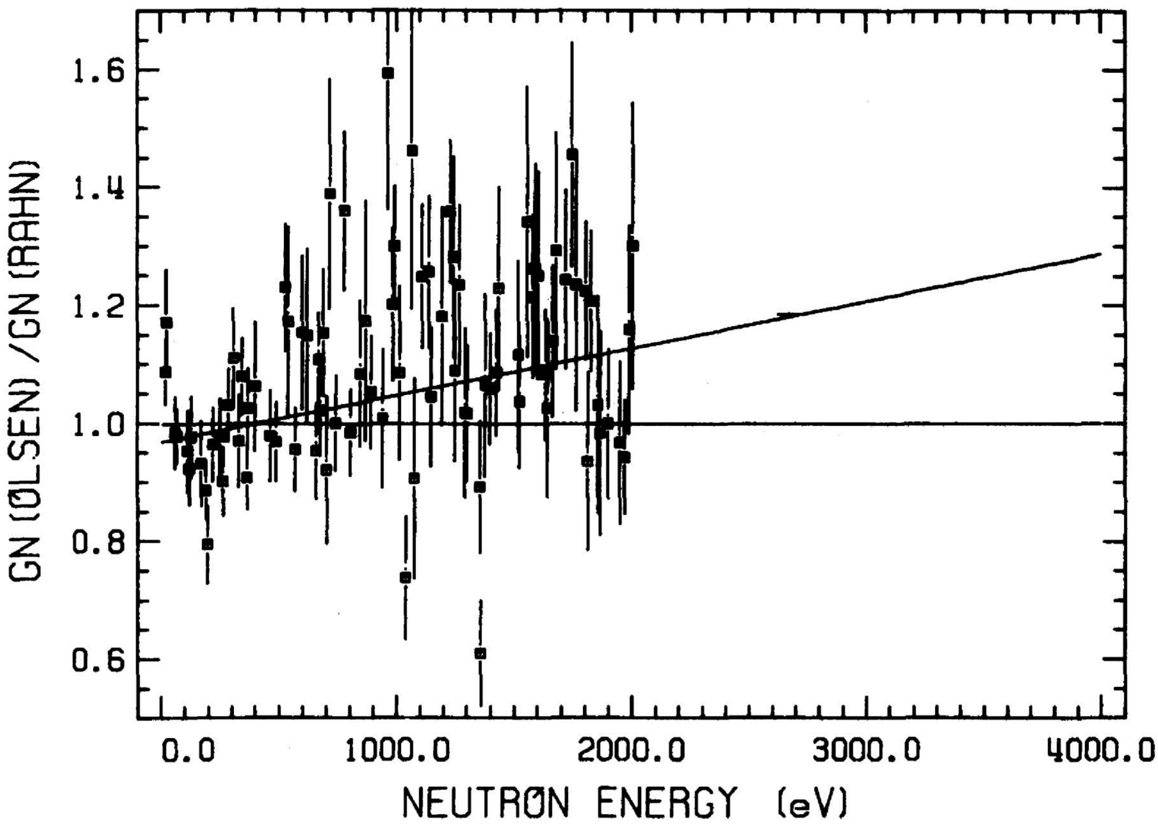

Fig. 3. Ratios of the Olsen *et al.*[3] neutron widths to those of Rahn *et al.*[12] for s-wave resonances with ratio uncertainties less than 20%. The straight line, 0.968+0.000080E, is a least squares fit to these ratios which is assumed to be the systematic discrepancy between the two measurements. This relationship is almost identical to the one obtained for the corresponding ^{238}U measurements in the ^{238}U ENDF/B-V evaluation.[21]

made that the neutron widths of Olsen *et al.*[3] and Ribon[14] were equally likely to be systematically discrepant. This leads to the correction factors of Table II. At very low neutron energies the neutron widths of Olsen *et al.*[3] need to be increased by 1.8%, whereas those of Ribon[14] need to be decreased by 1.8%. At 2 keV the neutron widths of Olsen *et al.*[3] need to be decreased by 3.2% whereas those of Ribon[14] need to be increased by 3.2%. At 4 keV the neutron widths of Rahn *et al.*[12] require a 20% increase to account for systematic discrepancies. Considering the ratios in Figs. 1 to 3, and the limited number of data sets, this procedure is not entirely satisfactory, particularly the extrapolation of the correction factor for Rahn *et al.*[12] to 4 keV. However, the comparison of the Olsen *et al.*[3] transmission data with those calculated from ENDF/B-V indicates that the ENDF/B-V neutron widths are appreciably low above $\sim$ 2 keV. Above 2 keV the ENDF/B-V neutron widths are those of Rahn *et al.*[12] In addition, the Table II correction factors for both the Olsen *et al.*[3] and Rahn *et al.*[12] ^{232}Th neutron widths are almost identical to those obtained for corresponding ^{238}U measurements in the ^{238}U ENDF/B-V evaluation.[21]

Figure 4 shows neutron widths from the two capture measurements plotted as ratios to the systematically-corrected average of the three transmission measurements. These ratios are only for small resonances. The neutron widths of Forman *et al.*[13] (0.0 to 2.0 keV) are in reasonable agreement with the average of the three transmission measurements. Those of Macklin[4] (2.6 to 4.0 keV) seem to scatter more; however, from 3 to 4 keV the comparison is only with the renormalized Rahn *et al.*[12] results and transmission measurements have increasing difficulties with increasing energy for small resonances. For this evaluation no correction factors for systematic

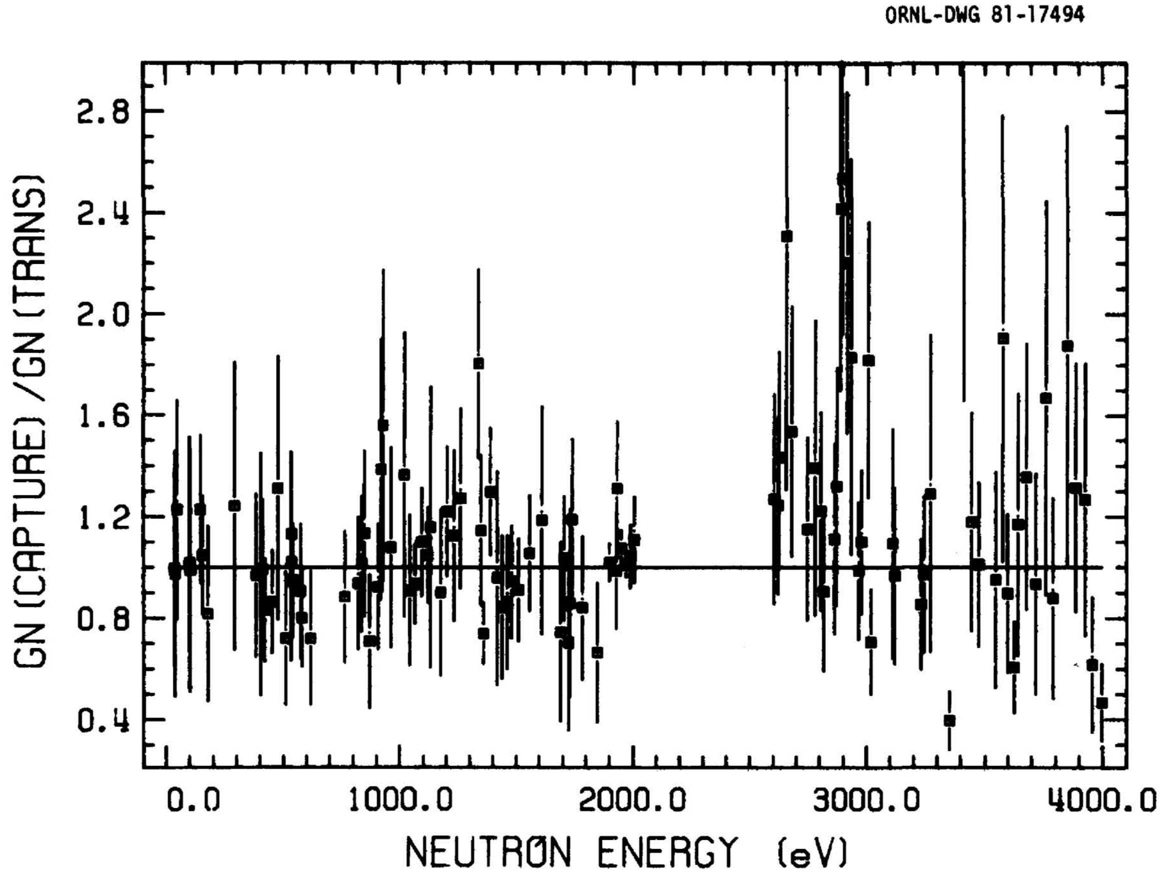

Fig. 4. Ratios of the Forman *et al.*[13] neutron widths (0.0 to 2.0 keV) and Macklin[4] neutron widths (2.6 to 4.0 keV) to the weighted average from the transmission measurements.

Table II. Correction Factor for Γ_n Evaluation Where the Neutron Energy E Is in eV

Experiment	Ref.	Correction Factor
Olsen	3	1.018-0.000025 E
Ribon	14	0.982+0.000025 E
Rahn	12	0.985+0.000050 E
Forman	13	1.000+0.000000 E
Macklin	4	1.000+0.000000 E

discrepancies were applied to the neutron widths from these capture measurements; however, the Macklin[4] neutron widths were recalculated from his data assuming a statistical factor, g, of 1.5 and the uncertainties increased for all resonances to cover the fact that many of these resonances can be either g=1 or g=2.

The neutron widths and their uncertainties were multiplied by the Table II correction factors and combined with inverse-variance weighting resulting in the Appendix A neutron widths. The variances for the Appendix A neutron widths are the usual inverse weight-factor sum. Averaged over all resonances the Olsen *et al.*,[3] Rahn *et al.*,[12] Ribon[14] and Forman[13] neutron widths tend to agree with the evaluated neutron widths better than their published uncertainties should allow; that is, their uncertainties are probably overestimated. No correction was made for this fact in the Appendix A uncertainties. In addition, the Appendix A neutron widths are believed to have a relative systematic error, correlated over all neutron widths of 1% at very low energies and increasing linearly to 9% at 4 keV.

E. Capture Widths

The capture widths for the first four s-wave resonances result from the average of nine measurements and seem reasonably well determined.

For the higher-energy resonances this is not the case. For these, the recent ORELA measurements[3,4] give capture widths on average ∿ 20% larger than the four older measurements[10,12-14] which give higher-energy capture widths. The problem is outlined in Table III. Another possible difficulty is that the older measurements tend to give larger capture widths for the first-three-or-four resonances than for the higher-energy resonances. This difference is unlikely and does not exist in the ORELA data. With these discrepancies, simply averaging one or more capture widths from the six Table-III measurements for each resonance up to 4.0 keV does not seem reasonable.

The capture widths of Olsen *et al.*,[3] Macklin,[4] Rahn *et al.*[12] and Ribon[14] are believed to be the most reliable and are used for this evaluation. Those of Forman *et al.*[13] are rejected since their corresponding measurement for ^{238}U was seriously discrepant. Those of Asghar *et al.*[10] are rejected since they have small uncertainties which do not seem warranted by their corresponding neutron-width results. The evaluated capture widths for the resonances from 113 to 342 eV are the inverse-variance-weighted average of the results listed in Table IV. All the remaining resonances, both s-wave and p-wave, were assigned a value of 24.4 which is the inverse-variance-weighted average of the 17 evaluated s-wave capture widths plus the Macklin average value[4] for resonances between 2.6 and 4.0 keV. Macklin's value[4] is from 14 resonances between 2.6 and 4.0 keV with a small correction for unresolved p-waves. The error on this measurement was decreased by a factor of two to give this recent measurement a weight comparable to the older results. Perez *et al.*[5] gave a pointwise low-energy capture yield normalized to and compared to that calculated from ENDF/B-V. These data

Table III. Average Capture Widths (meV)

Measurement	Ref.	Γ_γ
Evaluated first-four resonances		24.7
Olsen (0 to 350 eV)	3	25.2±0.6
Macklin (2.6 to 4.0 keV)	4	25.5±1.2
Rahn (0 to 2.5 keV)	12	21.2±1.2
Ribon (0 to 300 eV)	14	21.8±0.8
Ashar (0 to 900 eV)	10	21.5±0.8
Forman (0 to 2.0 keV)	13	21.3±3.0
ENDF/V	2	21.1
ENDF/B-IV	19	25.9

suggest the need for more evaluated capture cross section at least at higher energies.

The uncorrelated uncertainty of ±2.6 meV is simply the standard deviation of the 17 evaluated widths and is meant to represent the fluctuation of the individual capture widths about their average value because of the finite number of γ-ray decay transitions. More importantly, the first four s-wave capture widths are believed to have a correlated standard deviation of ±1.0 meV. The remaining resonances are believed to have a correlated uncertainty of ±2.0 meV.

The discrepancies in Table IV are obvious and the evaluation methodology is not perfect; however, a reasonable compromise between the ORELA and older measurements is obtained. The basic inconsistency of the differential data requires resolution with new measurements.

F. Fission Widths

Unpublished results from a recent ORELA ^{232}Th fission cross-section measurement indicate that the resolved resonances have no measureable fission widths;[22] consequently, no fission widths are given for the resolved resonances. The fission width of 1.3×10^{-7} eV assigned in ENDF/B-V to each

Table IV. Capture Width (meV) Evaluation With Uncorrelated[a] Uncertainties

E(eV)	Experiment			Evaluation
21.8				25.1±0.6
23.5		average of 9 measurements		26.6±0.5
59.5				24.0±0.6
62.2				23.0±0.6
	Olsen	Rahn	Ribon	
113.0	26.1±1.4	20.0±2.0	20.4± 2.7	23.5±1.1
120.8	24.4±0.8	22.0±2.0	20.7± 3.5	24.0±0.7
129.2	27.5±3.4	18.0±2.0	16.4± 2.5	19.2±1.4
170.4	25.3±0.8	26.0±2.0	19.3± 6.0	25.3±0.7
192.7	25.8±1.7	17.0±2.0	16.8± 3.5	21.5±1.2
199.4	22.9±2.6	18.0±2.0	17.9± 2.9	19.4±1.4
221.3	26.1±1.5	22.0±2.0	22.0± 4.4	24.5±1.2
251.7	27.6±1.6	24.0±2.0	25.2± 4.8	26.1±1.2
263.2	23.9±2.3	19.0±2.0	28.0± 5.3	21.6±1.5
285.8	24.6±2.1	20.0±2.0	24.9± 4.7	22.5±1.4
305.5	25.1±2.5	20.0±2.0	22.0± 5.3	22.0±1.5
329.0	27.5±1.6	26.0±2.0	23.7±10.9	26.9±1.3
341.9	26.7±2.9	19.0±2.0	21.0± 9.5	21.5±1.6
	Macklin (2.6-4.0 keV)			25.5±0.6[b]
	All other resonances			24.4±2.6[c]

[a]The first-four s-wave capture widths have a correlated uncertainty of ±1.0 meV which is fully correlated with the ±2.0 meV correlated uncertainty of the other capture widths.

[b]The uncertainty on this determination was reduced by a factor of two in order to give it a weight more comparable to the other measurements.

[c]This uncertainty is the standard deviation of the above evaluated widths and is meant to represent the fluctuation caused by the finite number of γ-decay branches.

resolved s- and p-wave resonance, to account for the thermal fission cross section measured by Block *et al.*,[23] is not experimentally established and has no practical consequences.

G. s- and p-Wave Populations

Keyworth and Moore[7] carried out angular-momentum assignments for the known resonances in ^{232}Th using the following four criteria: (1) the potential-resonance interference effect for large resonances; (2) the p-wave assignments of Corvi *et al.*;[24] (3) the Bollinger and Thomas[25] prescription of calculating Bayes conditional probability so that the number of misassigned p-waves equals the number of misassigned s-waves; and (4) adjusting the resulting assignments so that the s-wave population is consistent with the Δ_3 statistic of Dyson and Mehta.[26] Since no new resonances have been reported since this work and no better method of making angular momentum assignments has been reported, the angular momentum assignments of Keyworth and Moore[7] are adopted. The resulting evaluated resonance parameters with uncorrelated uncertainties for the 241 s-wave and 192 p-wave resonances are listed in Table A-I and A-II of Appendix A. . Two-thirds and one-third of the p-wave resonances are expected to have g=2.0 and g=1.0, respectively. In this evaluation all the p-wave resonances are assumed to have g=1.0.

III. POINTWISE CROSS SECTIONS

The ENDF/B-V ^{232}Th evaluation is constructed with pointwise cross sections below 5 eV and resonance-formalism-calculated cross sections above 5 eV. If needed, these calculated cross sections from explicit resonances are augmented by pointwise cross sections. Pointwise cross sections are required in this evaluation (a) to account for the cross-section difference between the expected p-wave capture from average resonance parameters and that calculated from the explicit p-wave resonances; (b) to account for a possible 1/v capture cross section above 5 eV which is not given by the explicit resonances; (c) to account for truncation effects in the scattering cross section caused by summing over a finite number of explicit s-wave resonances; and (d) to smoothly connect these evaluated cross sections above 5.0 eV to the existing thermal evaluation below 5.0 eV. It is assumed that this thermal evaluation will not be modified and in addition the two explicit bound resonances of ENDF/B-V will remain unchanged. The bound levels are not critical since the calculated cross sections from them can always be augmented by pointwise files to fit experimental data.

A. Smooth Cross Section for Missed p-Wave Resonances

The ENDF/B-V resolved-resonance-region p-wave strength function of 1.6×10^{-4} is adopted unchanged for this evaluation. An uncertainty of $\pm 0.3 \times 10^{-4}$ is assigned. This strength function is consistent with the Camarda[27] ($1.5 \pm .4 \times 10^{-4}$) and Utley *et al.*[28] ($1.64 \pm .24 \times 10^{-4}$) values from analyses of smooth transmissions in the keV region; the Macklin[4] value ($1.48 \pm .07 \times 10^{-4}$) from analysis of smooth capture in the keV region; the ENDF/B-V unresolved-resonance-region evaluation[29] ($1.6 \pm .2 \times 10^{-4}$); and the Keyworth and Moore[7] ($1.64 \pm .50 \times 10^{-4}$), Derrien[8] ($1.58 \pm 0.50 \times 10^{-4}$), and Corvi *et al.*[24] ($2.0 \pm .4 \times 10^{-4}$) values from statistical analyses of resolved-resonance parameters. The uncertainties on the statistical-analysis values arises mainly from ambiguities in estimating the number of missed p-wave resonances. The strength functions from the smooth cross sections depend on assumed values for other average parameters.

The upper solid histogram in Fig. 5 is the calculated p-wave capture cross section, averaged over 500-eV intervals, using the evaluated p-wave

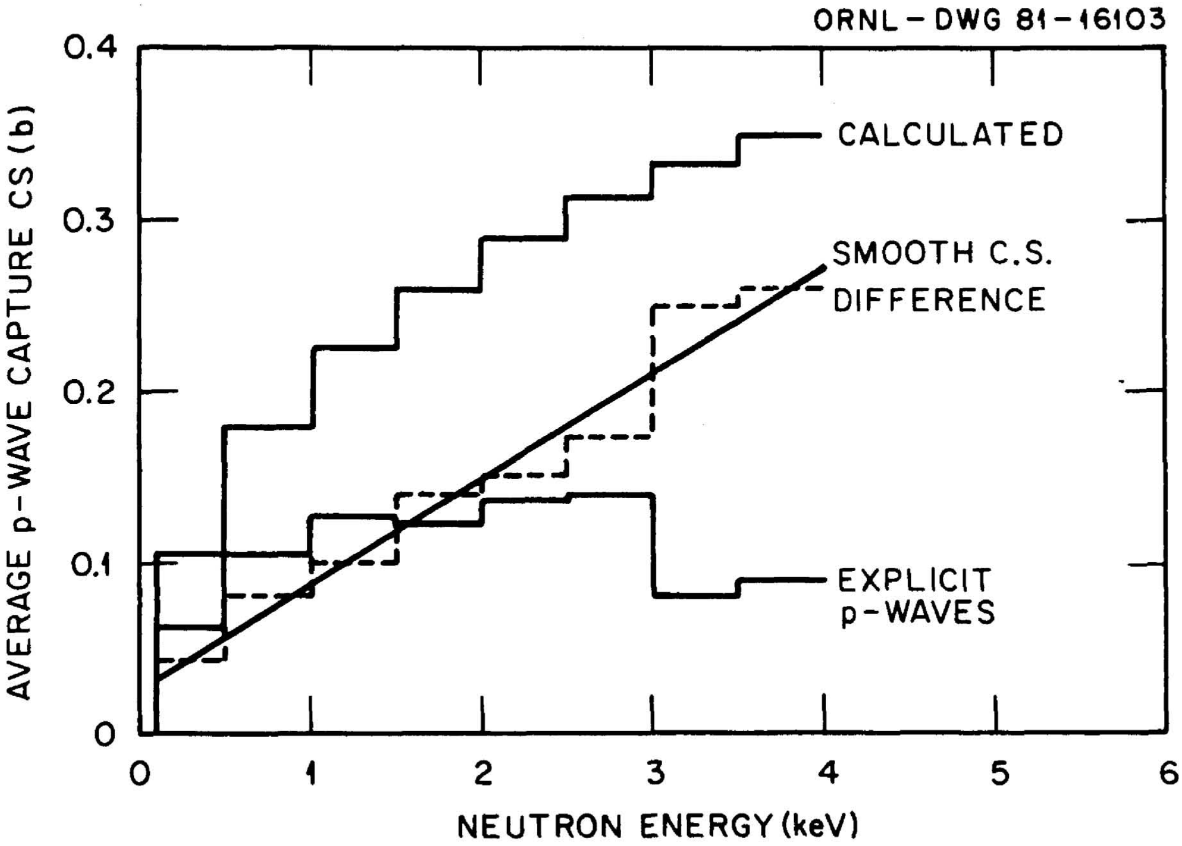

Fig. 5. The upper solid histogram is the calculated p-wave capture from average resonance parameters, whereas the lower solid histogram is that from the explicit p-wave resonances. Their difference, dashed-histogram, is approximated by the straight line $\sigma_\gamma = (0.0235 + 0.000622E)$b which gives the desired integrals.

strength function 1.6×10^{-4}, the evaluated average capture width 24.4 meV, and the Keyworth and Moore[7] average p-wave spacing 5.69 eV. The lower solid histogram is the capture cross section for the Table A-II p-wave resonances assuming they all have g=1. The dashed histogram is the difference between these two which must be accounted for with a pointwise cross section. This pointwise cross section was obtained by assuming a linear form A+BE and requiring A and B to give the exact differences between the calculated and explicit resonances for the integrated capture cross section and dilute capture resonance integral. That is, over the interval from 60 to 4000 eV,

$$\int(A + BE)dE = \int<\sigma_\gamma>dE - \sum \frac{2\pi^2}{k^2} \frac{\Gamma_n\Gamma_\gamma}{\Gamma} = 1021.2 - 430.9 = 590.3 \text{ b.eV},$$

$$\int(A + BE)dE/E = \int<\sigma_\gamma>dE/E - \sum \frac{2\pi^2}{k^2} \frac{\Gamma_n\Gamma_\gamma}{\Gamma E_o} = 0.701 - 0.357 = 0.344 \text{ b}.$$

Solving these equations gives a cross section of (0.0235+0.0000622E)b, which is shown as the straight line in Fig. 5. A lower limit of 60 eV was chosen for this smooth cross section because the 5-to-60-eV interval contains enough explicit p-wave resonances to give the average spacing.

This capture is not self-shielded; however, this is expected to be of no practical significance in reactor calculations. Likewise the assumption that the explicit p-wave resonances all have g=1 affects the self-shielding, but is expected to be of no practical significance. The corresponding pointwise scattering cross section, $\sim <\Gamma_n>/<\Gamma_\gamma>$ of the pointwise capture cross section, is negligible and has been ignored. The explicit p-wave resonances contribute 0.40b to the dilute-capture resonance integral and the pointwise p-wave cross section contributes 0.34b. Their sum depends only on the assumed average resonance parameters and not on the explicit p-wave resonance parameters.

B. 1/v Capture Above 5 eV

The ENDF/B-V evaluation gives a capture cross section varying from 7.400b at 0.0253 eV to 0.308b at 5 eV and largely follows the data of Chrien *et al.*[6] At 5.0 eV the bound levels of ENDF/B-V give a capture cross section of 0.064b and the unbound levels of this evaluation give 0.046b; the explicit resonances do not give enough low-energy capture. This difference of 0.308-0.063-0.046=0.198b of capture must be accounted for and connected smoothly into the resolved-resonance region with a pointwise file. For this a capture cross section of 0.4427 $E^{-1/2}$ is assumed over the energies from 5 to 4000 eV and contributes $\sim$ 0.40b to the dilute-capture resonance integral. This capture plus that calculated from the explicit resonances follows the data of Chrien *et al.*[6] and gives 0.207b at 12 eV.

C. Scattering-Cross-Section Truncation Compensation

Cross sections will be calculated from resonances spanning neutron energies from -22.2 to 4996.4 eV, whereas in reality the resonances essentially span $-\infty$ to $+\infty$. This truncation will cause resonance imbalance in the calculation at the extremes of the resolved-resonance range so that the scattering cross section will be $\sim$ 1.5b low near 5 eV and $\sim$ 1.5b high near 4 keV. To correct for this the total cross section was calculated from all the explicit resonances at various energies between resonances from 10 eV to 4 keV. The difference between the Olsen *et al.*[3] measured total cross section and this calculated cross section, plus the two pointwise capture cross sections, was least-squares fitted with the term S ℓn

[(EH-E)/(E-EL)]. This term gives the main truncation correction for uniformly distributed s-wave strength function from $-\infty$ to EL and EH to $+\infty$. Allowing S, EH and EL to be variables produced a correction of 0.48 ℓn [(4180-E)/(E+132)]b, which together with the calculated scattering cross section should produce potential scattering accurate to ±0.2b. Above 2024 eV this term is negative. Other possible truncation terms are negligible and have been ignored.

D. Other Pointwise Cross Sections

An additional pointwise scattering cross section is required to smoothly connect the thermal evaluation to the unresolved-resonance region evaluation. At 5 eV ENDF/B-V gives a 12.068b of scattering, whereas the explicit resonances give 10.068b and the truncation correction gives +1.640b. The 0.360b difference should be accounted for by the scattering cross section (0.540-0.036E)b. This term is zero above 15 eV and is caused mostly by the discrepancy in the Olsen *et al.*[3] and ENDF/B-V total cross sections at 5 eV. This discrepancy is probably in the scattering and is of no substantial consequence.

These pointwise cross sections are summarized in Table A-III. The pointwise total cross section is the sum of the two pointwise capture cross sections and two pointwise scattering cross sections.

IV. DISCUSSION AND CONCLUSIONS

A. Dilute Capture Resonance Integral

The ENDF/B-V ^{232}Th evaluation[1] gives an infinitely dilute capture resonance integral of 84.0b which agrees within error with the Greneche[30] evaluated value of 85.8±1.9b. The contributions to this integral from the resolved-resonance region are listed in the upper part of Table V. The

Table V. Infinitely Dilute Capture Resonance Integral

ENDF/B-V		84.0b
Resonance region contribution		
21.8-eV resonance	-16.15b	
23.5-eV resonance	-25.24b	
59.5 eV resonance	- 4.01b	
69.2 eV resonance	-12.65b	
Other s-wave resonances	-20.50b	
Resolved p-wave resonances	- 0.28b	
Unresolved p-wave resonances	- 0.69b	
1/v capture	- 0.20b	
	-79.72b	
ENDF/B-V minus 5 to 4000-eV contribution		4.28b
This evaluation		
21.8-eV resonance	+16.54b	
23.5-eV resonance	+25.26b	
59.5-eV resonance	+ 3.82b	
69.2-eV resonance	+12.92b	
Other s-wave resonances	+22.16b	
Resolved p-wave resonances	+ 0.40b	
Unresolved p-wave resonances	+ 0.35b	
1/v capture	+ 0.40b	
	+81.85b	
ENDF/B-V plus this evaluation		86.1b
Greneche (Ref. 30)		85.8±1.9b

ENDF/B-V thermal capture cross section, $E \leqslant 5$ eV, and unresolved-resonance-region capture cross section, $E \geqslant 4$ keV, contribute 4.28b to the integral.

The bottom part of Table V lists the corresponding integral contributions from this evaluation. Together with this 4.28b this evaluation gives 86.1b, a 2.1b increase. About 0.5b increase is from the first four s-wave resonances, a 1.7b increase is from the other resolved s-wave resonances, and the summed 1/v and p-wave capture is unchanged.

B. Uncertainties

The uncorrelated standard deviations for the individual neutron and capture widths are listed in columns three and five of Table A-I and A-II. The neutron widths are estimated to have an additional uncertainty, correlated over all neutron energies, increasing linearly from a 1% standard deviation at 0.0 keV to 9% at 4.0 keV; that is, $\Delta\Gamma_n/\Gamma_n$=0.010+0.00002E. Likewise, the capture widths are estimated to have an additional uncertainty, correlated over all neutron energies, of ±1.0 meV for the first-four s-wave resonances and ±2.0 meV for the others. It is assumed that on average the p- and s-wave capture widths are identical. No uncertainty is given for this assumption and no uncertainties are given for resonance energies.

The effective scattering radius is believed to be accurate to $\pm 0.004 \times 10^{-12}$ cm. The pointwise scattering and capture cross sections (within the resolved resonance region) are estimated to have uncertainty standard deviations, correlated over all neutron energies, of ±0.2b and ±20%, respectively.

C. Average Resonance Parameters

Average resonance parameters derived from or used in this evaluation are listed in Table VI. The average capture width, assumed identical for both s- and p-wave resonances was evaluated at 24.4±2.0 meV. ENDF/B-V[1-2] and Derrien[8] have evaluated averages of 2.1. meV and 21.45±0.25 meV, respectively.

Over the interval from 21.8 to 3996.4 eV the Table A-I neutron widths give a strength function of $0.826 \pm 0.084 \times 10^{-4}$, where the standard deviation is the quadratic sum of a $\pm 0.037 \times 10^{-4}$ uncertainty from the systematic error of the neutron widths and a $\pm 0.075 \times 10^{-4}$ uncertainty from the finite sample of 241 levels. This is larger than the ENDF/B-V[1,2] value (0.775×10^{-4}) and smaller than the Keyworth and Moore[7] ($0.88 \pm 0.07 \times 10^{-4}$) and Derrien[8] ($0.89 \pm 0.11 \times 10^{-4}$) values. However, the latter two strength functions were determined from levels only up to 3 keV. Over this interval the Table A-I neutron widths also give $S^\circ \sim 0.89 \times 10^{-4}$.

The p-wave strength function is essentially identical to that used in other evaluations. The level spacings are taken directly from the Keyworth and Moore[7] evaluation and are almost identical to those of the evaluation of Derrien[8] who used different procedures to arrive at the same spacings. The p-wave spacing is only used in this evaluation to calculate the width fluctuation factor for p-wave capture from the average resonance parameters.

D. Conclusions

The Table A-I and A-II resonance parameters using a MLBW formalism with a 0.972×10^{-12} cm effective radius and the Table A-III corrections define cross sections for the resolved resonance region. These cross

Table VI. Average Resonance Parameters

s-wave resonances	
$<\Gamma_\gamma>$	$=24.4\pm2.0$ meV
S°	$=0.83\pm0.08\times10^{-4}$
$D_\circ$	$=16.4\pm1.0$ eV
R	$=0.971\pm0.004\times10^{-12}$ cm
p-wave resonances	
$<\Gamma_\gamma>$	$=24.4\pm2.0$ meV
S^1	$=1.6\pm0.3\times10^{-4}$ $eV^{-1.2}$
D_1	$=5.69\pm0.35$ eV

sections with the remaining ENDF/B-V evaluation give a dilute capture resonance integral of 86.1b.

The first four s-wave resonances give ∿ 70% of this integral. The evaluated parameters for these resonances are very similar to those of the 1974 evaluation of Derrien;[8] however, the recent ORELA[3] and BNL[6] results have tended to substantially reduce their uncertainties. Likewise, the higher-energy neutron widths are similar to those of Keyworth and Moore[7] and Derrien[8] with substantially smaller uncertainties up to 2 keV because of the ORELA data.[3] The most significant change from the older evaluations is the increase of the average capture width from ∿ 21.5 meV to 24.4 meV. This change rests mostly on the recent ORELA data;[3-5] however, there is other information indicating that this increase is desirable: (1) although it is possible, it is both suspicious and unlikely that the first three s-wave resonances have substantially larger capture widths than the previously-accepted lower average value; (2) although it is possible, there is no supporting experimental evidence for the required use of a p-wave capture width larger than the s-wave capture width for recent[1,8] unresolved-resonance-region evaluations; (3) older evaluations have tended to give dilute-capture resonance integrals near the lower limit of the integral measurements; and (4) older evaluations have tended to give shielded-capture resonance integrals smaller than those required by integral measurements.[31] The present evaluation should alleviate some of these difficulties.

Obviously the recent ORELA capture widths are discrepant with the older measurements. There is an important need for this discrepancy to be resolved with one or more additional capture measurements in the resolved-resonance region. In addition, a transmission measurement is required above 2 keV to verify the Macklin neutron widths[4] and the extrapolated correction to the Rahn *et al.*[12] results. The higher-energy neutron widths have large uncertainties and require clarification. When this data is available, a new ENDF/B evaluation would be in order.

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Appendix A. Evaluated Resonance Parameters and Pointwise Cross Sections for ^{232}Th from 5.0 eV to 4.0 keV

Uncertainties are discussed in Section IV-B. This evaluation also requires the ENDF/B-V bound s-wave levels at -2.952 and -22.2 eV with neutron widths of 9.277×10^{-4} and 6.2665×10^{-3} eV, respectively. These have capture widths of $2.12 \times 1\text{-}^{-2}$ eV.

Table A-I. Evaluated s-Wave Resonance Parameters

E(eV)	$\Gamma_n \pm \Delta\Gamma_n$(eV)		$\Gamma_\gamma \pm \Delta\Gamma_\gamma$(eV)	
2.1806E+01	2.060E-03	3.0E-05	2.51E-02	6.0E-04
2.3464E+01	3.850E-03	6.0E-05	2.66E-02	5.0E-04
5.9519E+01	3.800E-03	5.0E-05	2.40E-02	6.0E-04
6.9232E+01	4.320E-02	3.0E-04	2.30E-02	6.0E-04
1.1303E+02	1.313E-02	1.7E-04	2.35E-02	1.1E-03
1.2087E+02	2.251E-02	2.7E-04	2.40E-02	7.0E-04
1.2919E+02	3.381E-03	7.3E-05	1.92E-02	1.4E-03
1.5436E+02	1.986E-04	7.6E-06	2.44E-02	2.6E-03
1.7039E+02	6.125E-02	6.7E-04	2.53E-02	7.0E-04
1.9272E+02	1.690E-02	2.7E-04	2.15E-02	1.2E-03
1.9940E+02	1.024E-02	2.1E-04	1.94E-02	1.4E-03
2.1952E+02	4.364E-05	5.4E-06	2.44E-02	2.6E-03
2.2129E+02	3.025E-02	4.3E-04	2.45E-02	1.2E-03
2.5165E+02	3.178E-02	4.7E-04	2.61E-02	1.2E-03
2.6323E+02	2.222E-02	3.8E-04	2.16E-02	1.5E-03
2.8591E+02	3.103E-02	5.1E-04	2.25E-02	1.4E-03
3.0562E+02	2.888E-02	5.2E-04	2.20E-02	1.5E-03
3.0947E+02	5.641E-05	1.2E-05	2.44E-02	2.6E-03
3.2911E+02	7.448E-02	1.1E-03	2.69E-02	1.3E-03
3.4200E+02	3.889E-02	7.3E-04	2.15E-02	1.6E-03
3.6536E+02	2.606E-02	5.9E-04	2.44E-02	2.6E-03
3.6949E+02	2.571E-02	5.9E-04	2.44E-02	2.6E-03
4.0110E+02	1.112E-02	3.6E-04	2.44E-02	2.6E-03
4.0292E+02	1.059E-04	2.5E-05	2.44E-02	2.6E-03
4.2103E+02	5.025E-04	4.1E-05	2.44E-02	2.6E-03
4.5447E+02	1.227E-03	6.1E-05	2.44E-02	2.6E-03
4.6277E+02	6.407E-02	1.2E-03	2.44E-02	2.6E-03
4.8905E+02	5.857E-02	1.1E-03	2.44E-02	2.6E-03
5.0027E+02	4.972E-05	4.2E-05	2.44E-02	2.6E-03
5.1064E+02	4.307E-03	2.1E-04	2.44E-02	2.6E-03
5.2880E+02	1.411E-02	4.9E-04	2.44E-02	2.6E-03
5.4056E+02	1.030E-03	6.2E-05	2.44E-02	2.6E-03
5.7013E+02	2.806E-02	8.1E-04	2.44E-02	2.6E-03
5.7843E+02	2.199E-03	1.4E-04	2.44E-02	2.6E-03
5.9443E+02	1.178E-04	3.5E-05	2.44E-02	2.6E-03
5.9857E+02	1.068E-02	4.3E-04	2.44E-02	2.6E-03
6.1820E+02	4.827E-03	2.5E-04	2.44E-02	2.6E-03
6.5698E+02	4.894E-02	1.2E-03	2.44E-02	2.6E-03
6.6563E+02	2.680E-02	8.1E-04	2.44E-02	2.6E-03
6.7555E+02	2.097E-01	2.9E-03	2.44E-02	2.6E-03
6.8785E+02	5.146E-02	1.4E-03	2.44E-02	2.6E-03
7.0147E+02	1.502E-02	7.0E-04	2.44E-02	2.6E-03
7.1326E+02	2.929E-02	1.1E-03	2.44E-02	2.6E-03
7.2453E+02	1.258E-04	5.0E-05	2.44E-02	2.6E-03
7.4150E+02	1.903E-01	2.9E-03	2.44E-02	2.6E-03
7.7205E+02	1.277E-04	5.7E-05	2.44E-02	2.6E-03
7.7909E+02	1.276E-02	6.1E-04	2.44E-02	2.6E-03
8.0464E+02	1.775E-01	3.0E-03	2.44E-02	2.6E-03
8.2933E+02	2.487E-04	6.8E-05	2.44E-02	2.6E-03
8.3733E+02	1.540E-03	1.2E-04	2.44E-02	2.6E-03

Table A-I. Continued

8.4276E+02	2.928E-02	1.1E-03	2.44E-02	2.6E-03
8.6676E+02	1.430E-02	7.8E-04	2.44E-02	2.6E-03
8.9058E+02	3.910E-02	1.3E-03	2.44E-02	2.6E-03
9.0702E+02	1.897E-03	1.6E-04	2.44E-02	2.6E-03
9.2758E+02	3.623E-04	6.2E-05	2.44E-02	2.6E-03
9.4372E+02	4.533E-02	1.5E-03	2.44E-02	2.6E-03
9.6320E+02	6.764E-03	4.2E-04	2.44E-02	2.6E-03
9.8347E+02	3.680E-02	1.4E-03	2.44E-02	2.6E-03
9.9109E+02	8.640E-02	2.4E-03	2.44E-02	2.6E-03
1.0111E+03	1.218E-01	3.5E-03	2.44E-02	2.6E-03
1.0300E+03	2.192E-04	6.7E-05	2.44E-02	2.6E-03
1.0397E+03	1.085E-02	6.9E-04	2.44E-02	2.6E-03
1.0650E+03	5.371E-03	3.7E-04	2.44E-02	2.6E-03
1.0778E+03	1.062E-02	7.9E-04	2.44E-02	2.6E-03
1.0936E+03	1.961E-03	1.8E-04	2.44E-02	2.6E-03
1.1105E+03	2.525E-02	1.1E-03	2.44E-02	2.6E-03
1.1211E+03	3.585E-03	2.9E-04	2.44E-02	2.6E-03
1.1395E+03	1.705E-02	8.1E-04	2.44E-02	2.6E-03
1.1510E+03	2.008E-02	1.0E-03	2.44E-02	2.6E-03
1.1679E+03	1.000E-04	9.9E-05	2.44E-02	2.6E-03
1.1952E+03	3.806E-03	5.9E-04	2.44E-02	2.6E-03
1.2183E+03	5.652E-04	1.4E-04	2.44E-02	2.6E-03
1.2287E+03	3.439E-02	1.4E-03	2.44E-02	2.6E-03
1.2438E+03	2.189E-02	1.2E-03	2.44E-02	2.6E-03
1.2496E+03	1.255E-01	4.0E-03	2.44E-02	2.6E-03
1.2702E+03	2.212E-02	1.1E-03	2.44E-02	2.6E-03
1.2929E+03	1.045E-01	3.7E-03	2.44E-02	2.6E-03
1.3024E+03	5.231E-02	2.3E-03	2.44E-02	2.6E-03
1.3357E+03	2.282E-03	2.4E-04	2.44E-02	2.6E-03
1.3557E+03	8.506E-02	3.4E-03	2.44E-02	2.6E-03
1.3607E+03	8.087E-03	4.7E-04	2.44E-02	2.6E-03
1.3788E+03	5.486E-02	2.6E-03	2.44E-02	2.6E-03
1.3987E+03	1.411E-01	4.2E-03	2.44E-02	2.6E-03
1.4276E+03	1.093E-01	3.8E-03	2.44E-02	2.6E-03
1.4345E+03	3.960E-02	2.3E-03	2.44E-02	2.6E-03
1.4427E+03	1.142E-03	1.9E-04	2.44E-02	2.6E-03
1.4615E+03	1.336E-03	1.9E-04	2.44E-02	2.6E-03
1.4792E+03	2.229E-03	2.3E-04	2.44E-02	2.6E-03
1.5095E+03	8.238E-04	4.1E-04	2.44E-02	2.6E-03
1.5197E+03	1.969E-01	6.5E-03	2.44E-02	2.6E-03
1.5253E+03	2.004E-01	6.2E-03	2.44E-02	2.6E-03
1.5565E+03	7.697E-03	5.9E-04	2.44E-02	2.6E-03
1.5822E+03	2.342E-02	1.3E-03	2.44E-02	2.6E-03
1.5906E+03	3.578E-01	8.8E-03	2.44E-02	2.6E-03
1.6036E+03	5.722E-02	3.1E-03	2.44E-02	2.6E-03
1.6320E+03	5.430E-01	1.3E-02	2.44E-02	2.6E-03
1.6416E+03	4.482E-02	3.1E-03	2.44E-02	2.6E-03
1.6625E+03	1.272E-01	4.7E-03	2.44E-02	2.6E-03
1.6789E+03	2.827E-02	2.0E-03	2.44E-02	2.6E-03
1.6982E+03	1.902E-03	3.3E-04	2.44E-02	2.6E-03

Table A-I. Continued

1.7066E+03	2.922E-03	3.1E-04	2.44E-02	2.6E-03
1.7209E+03	3.877E-02	2.2E-03	2.44E-02	2.6E-03
1.7411E+03	7.348E-03	6.4E-04	2.44E-02	2.6E-03
1.7479E+03	3.607E-02	2.1E-03	2.44E-02	2.6E-03
1.7546E+03	7.181E-04	7.2E-04	2.44E-02	2.6E-03
1.7638E+03	1.205E-01	4.9E-03	2.44E-02	2.6E-03
1.8045E+03	9.842E-02	4.0E-03	2.44E-02	2.6E-03
1.8131E+03	4.325E-02	3.1E-03	2.44E-02	2.6E-03
1.8252E+03	9.470E-02	3.9E-03	2.44E-02	2.6E-03
1.8556E+03	4.200E-02	3.0E-03	2.44E-02	2.6E-03
1.8629E+03	3.929E-02	2.9E-03	2.44E-02	2.6E-03
1.8903E+03	9.015E-04	2.6E-04	2.44E-02	2.6E-03
1.9015E+03	1.224E-01	5.7E-03	2.44E-02	2.6E-03
1.9295E+03	6.982E-03	7.8E-04	2.44E-02	2.6E-03
1.9324E+03	1.189E-02	1.2E-03	2.44E-02	2.6E-03
1.9518E+03	1.143E-01	5.1E-03	2.44E-02	2.6E-03
1.9726E+03	2.286E-01	7.8E-03	2.44E-02	2.6E-03
1.9891E+03	4.750E-02	3.3E-03	2.44E-02	2.6E-03
2.0062E+03	2.674E-02	2.4E-03	2.44E-02	2.6E-03
2.0167E+03	3.909E-04	3.9E-04	2.44E-02	2.6E-03
2.0362E+03	1.033E-03	7.7E-04	2.44E-02	2.6E-03
2.0532E+03	1.995E-02	2.8E-03	2.44E-02	2.6E-03
2.0632E+03	6.639E-02	7.1E-03	2.44E-02	2.6E-03
2.0749E+03	7.564E-03	1.9E-03	2.44E-02	2.6E-03
2.0802E+03	1.001E-02	1.8E-03	2.44E-02	2.6E-03
2.0984E+03	1.074E-03	4.1E-04	2.44E-02	2.6E-03
2.1176E+03	8.191E-02	5.8E-03	2.44E-02	2.6E-03
2.1488E+03	9.741E-02	6.6E-03	2.44E-02	2.6E-03
2.1636E+03	1.006E-01	6.9E-03	2.44E-02	2.6E-03
2.1793E+03	8.263E-02	5.7E-03	2.44E-02	2.6E-03
2.1985E+03	5.332E-02	4.7E-03	2.44E-02	2.6E-03
2.2176E+03	2.571E-02	1.9E-03	2.44E-02	2.6E-03
2.2233E+03	9.538E-02	7.8E-03	2.44E-02	2.6E-03
2.2351E+03	1.763E-03	4.6E-04	2.44E-02	2.6E-03
2.2723E+03	3.035E-02	3.4E-03	2.44E-02	2.6E-03
2.2776E+03	5.297E-02	5.1E-03	2.44E-02	2.6E-03
2.2878E+03	2.878E-01	2.0E-02	2.44E-02	2.6E-03
2.3225E+03	4.440E-03	1.1E-03	2.44E-02	2.6E-03
2.3372E+03	1.258E-01	1.3E-02	2.44E-02	2.6E-03
2.3539E+03	1.974E-02	2.9E-03	2.44E-02	2.6E-03
2.3551E+03	1.551E-02	3.2E-03	2.44E-02	2.6E-03
2.3765E+03	1.264E-01	1.3E-02	2.44E-02	2.6E-03
2.3927E+03	3.918E-03	8.7E-04	2.44E-02	2.6E-03
2.4201E+03	9.756E-02	7.6E-03	2.44E-02	2.6E-03
2.4289E+03	2.870E-03	7.9E-04	2.44E-02	2.6E-03
2.4416E+03	1.142E-02	1.4E-03	2.44E-02	2.6E-03
2.4572E+03	1.813E-01	1.6E-02	2.44E-02	2.6E-03
2.4640E+03	3.930E-03	1.4E-03	2.44E-02	2.6E-03
2.4760E+03	1.307E-03	5.9E-04	2.44E-02	2.6E-03
2.4931E+03	7.649E-03	1.4E-03	2.44E-02	2.6E-03

Table A-I. Continued

2.5107E+03	3.631E-01	2.5E-02	2.44E-02	2.6E-03
2.5286E+03	5.282E-02	5.5E-03	2.44E-02	2.6E-03
2.5587E+03	4.141E-03	1.0E-03	2.44E-02	2.6E-03
2.5647E+03	3.442E-01	2.6E-02	2.44E-02	2.6E-03
2.5710E+03	6.937E-02	9.3E-03	2.44E-02	2.6E-03
2.6052E+03	2.554E-03	3.3E-04	2.44E-02	2.6E-03
2.6142E+03	9.939E-02	8.4E-03	2.44E-02	2.6E-03
2.6261E+03	1.022E-02	1.5E-03	2.44E-02	2.6E-03
2.6367E+03	1.819E-01	1.4E-02	2.44E-02	2.6E-03
2.6651E+03	2.215E-01	1.6E-02	2.44E-02	2.6E-03
2.6789E+03	1.383E-02	1.9E-03	2.44E-02	2.6E-03
2.6901E+03	2.188E-01	1.6E-02	2.44E-02	2.6E-03
2.7147E+03	1.073E-01	9.7E-03	2.44E-02	2.6E-03
2.7244E+03	1.338E-02	1.7E-03	2.44E-02	2.6E-03
2.7351E+03	4.140E-01	2.6E-02	2.44E-02	2.6E-03
2.7499E+03	1.684E-02	2.4E-03	2.44E-02	2.6E-03
2.7751E+03	8.192E-02	9.4E-03	2.44E-02	2.6E-03
2.7945E+03	1.763E-01	1.4E-02	2.44E-02	2.6E-03
2.8045E+03	5.992E-03	7.7E-04	2.44E-02	2.6E-03
2.8172E+03	3.102E-02	3.6E-03	2.44E-02	2.6E-03
2.8347E+03	4.495E-02	4.8E-03	2.44E-02	2.6E-03
2.8540E+03	2.302E-01	1.8E-02	2.44E-02	2.6E-03
2.8629E+03	9.113E-03	1.3E-03	2.44E-02	2.6E-03
2.8856E+03	6.897E-03	1.1E-03	2.44E-02	2.6E-03
2.8972E+03	3.769E-03	4.8E-04	2.44E-02	2.6E-03
2.9165E+03	5.783E-03	8.5E-04	2.44E-02	2.6E-03
2.9501E+03	1.092E-01	9.0E-03	2.44E-02	2.6E-03
2.9585E+03	5.060E-02	5.5E-03	2.44E-02	2.6E-03
2.9680E+03	1.550E-02	2.1E-03	2.44E-02	2.6E-03
2.9901E+03	3.945E-02	5.0E-03	2.44E-02	2.6E-03
3.0194E+03	2.994E-02	2.8E-03	2.44E-02	2.6E-03
3.0292E+03	2.614E-01	2.8E-02	2.44E-02	2.6E-03
3.0417E+03	6.708E-02	5.6E-03	2.44E-02	2.6E-03
3.0630E+03	3.294E-02	3.1E-03	2.44E-02	2.6E-03
3.0845E+03	6.262E-02	7.0E-03	2.44E-02	2.6E-03
3.1061E+03	1.717E-02	4.8E-03	2.44E-02	2.6E-03
3.1115E+03	2.499E-02	3.0E-03	2.44E-02	2.6E-03
3.1507E+03	2.115E-01	2.3E-02	2.44E-02	2.6E-03
3.1551E+03	2.227E-01	2.3E-02	2.44E-02	2.6E-03
3.1690E+03	3.839E-03	8.0E-04	2.44E-02	2.6E-03
3.1871E+03	8.395E-03	2.2E-03	2.44E-02	2.6E-03
3.1907E+03	8.595E-02	7.8E-03	2.44E-02	2.6E-03
3.2099E+03	1.031E-01	1.2E-02	2.44E-02	2.6E-03
3.2313E+03	1.848E-02	2.6E-03	2.44E-02	2.6E-03
3.2448E+03	1.615E-02	2.5E-03	2.44E-02	2.6E-03
3.2549E+03	9.556E-02	9.2E-03	2.44E-02	2.6E-03
3.2720E+03	3.011E-02	4.4E-03	2.44E-02	2.6E-03
3.2974E+03	4.693E-01	5.1E-02	2.44E-02	2.6E-03
3.3091E+03	1.510E-03	5.3E-04	2.44E-02	2.6E-03
3.3200E+03	5.625E-03	9.6E-04	2.44E-02	2.6E-03

Table A-I. Continued

3.3339E+03	4.720E-02	6.6E-03	2.44E-02	2.6E-03
3.3449E+03	1.958E-01	2.1E-02	2.44E-02	2.6E-03
3.3537E+03	9.378E-03	1.4E-03	2.44E-02	2.6E-03
3.3859E+03	8.057E-02	1.0E-02	2.44E-02	2.6E-03
3.4122E+03	7.498E-03	1.8E-03	2.44E-02	2.6E-03
3.4345E+03	9.851E-03	1.6E-03	2.44E-02	2.6E-03
3.4448E+03	2.360E-02	3.2E-03	2.44E-02	2.6E-03
3.4594E+03	2.818E-03	4.8E-04	2.44E-02	2.6E-03
3.4743E+03	2.123E-02	3.0E-03	2.44E-02	2.6E-03
3.5032E+03	4.250E-03	5.5E-04	2.44E-02	2.6E-03
3.5136E+03	5.484E-03	7.9E-04	2.44E-02	2.6E-03
3.5237E+03	1.234E-01	2.1E-02	2.44E-02	2.6E-03
3.5463E+03	7.949E-03	1.2E-03	2.44E-02	2.6E-03
3.5693E+03	6.413E-03	1.1E-03	2.44E-02	2.6E-03
3.5769E+03	2.029E-02	3.4E-03	2.44E-02	2.6E-03
3.5966E+03	2.350E-02	3.8E-03	2.44E-02	2.6E-03
3.6137E+03	1.401E-01	1.8E-02	2.44E-02	2.6E-03
3.6262E+03	9.260E-03	1.3E-03	2.44E-02	2.6E-03
3.6399E+03	1.023E-02	1.9E-03	2.44E-02	2.6E-03
3.6535E+03	7.832E-02	9.2E-03	2.44E-02	2.6E-03
3.6764E+03	1.559E-02	3.0E-03	2.44E-02	2.6E-03
3.6949E+03	3.736E-03	7.3E-04	2.44E-02	2.6E-03
3.7100E+03	6.455E-03	1.3E-03	2.44E-02	2.6E-03
3.7179E+03	3.041E-02	4.6E-03	2.44E-02	2.6E-03
3.7249E+03	1.151E-01	2.4E-02	2.44E-02	2.6E-03
3.7352E+03	5.655E-02	7.9E-03	2.44E-02	2.6E-03
3.7614E+03	1.208E-02	2.7E-03	2.44E-02	2.6E-03
3.7887E+03	3.322E-02	5.2E-03	2.44E-02	2.6E-03
3.8133E+03	5.273E-03	1.1E-03	2.44E-02	2.6E-03
3.8227E+03	4.725E-02	7.3E-03	2.44E-02	2.6E-03
3.8291E+03	1.281E-01	2.0E-02	2.44E-02	2.6E-03
3.8510E+03	1.629E-02	3.9E-03	2.44E-02	2.6E-03
3.8711E+03	7.697E-02	9.5E-03	2.44E-02	2.6E-03
3.8863E+03	1.499E-02	2.8E-03	2.44E-02	2.6E-03
3.9086E+03	2.597E-01	3.5E-02	2.44E-02	2.6E-03
3.9261E+03	1.205E-02	2.3E-03	2.44E-02	2.6E-03
3.9342E+03	4.371E-02	7.4E-03	2.44E-02	2.6E-03
3.9638E+03	4.840E-02	7.4E-03	2.44E-02	2.6E-03
3.9727E+03	8.502E-02	1.0E-02	2.44E-02	2.6E-03
3.9791E+03	1.418E-01	2.0E-02	2.44E-02	2.6E-03
3.9976E+03	2.928E-02	4.3E-03	2.44E-02	2.6E-03

Table A-II. Evaluated p-Wave Resonance Parameters

E(eV)	$\Gamma_n \pm \Delta\Gamma_n$(eV)		$\Gamma_\gamma \pm \Delta\Gamma_\gamma$(eV)	
8.3505E+00	2.750E-07	3.6E-08	2.44E-02	2.6E-03
1.3124E+01	2.095E-07	3.2E-08	2.44E-02	2.6E-03
3.6991E+01	9.407E-07	1.8E-07	2.44E-02	2.6E-03
3.8191E+01	5.758E-07	1.4E-07	2.44E-02	2.6E-03
4.1032E+01	5.868E-07	1.5E-07	2.44E-02	2.6E-03
4.7044E+01	1.531E-06	2.7E-07	2.44E-02	2.6E-03
4.9875E+01	4.333E-07	1.9E-07	2.44E-02	2.6E-03
5.4156E+01	1.100E-06	5.5E-07	2.44E-02	2.6E-03
5.8771E+01	3.976E-06	6.3E-07	2.44E-02	2.6E-03
6.4499E+01	6.940E-07	4.0E-07	2.44E-02	2.6E-03
9.0167E+01	6.145E-06	1.4E-06	2.44E-02	2.6E-03
9.8069E+01	3.976E-06	9.1E-07	2.44E-02	2.6E-03
1.0366E+02	5.540E-06	1.3E-06	2.44E-02	2.6E-03
1.1205E+02	3.939E-06	3.9E-06	2.44E-02	2.6E-03
1.1782E+02	1.970E-06	2.0E-06	2.44E-02	2.6E-03
1.2820E+02	6.857E-05	4.3E-06	2.44E-02	2.6E-03
1.4586E+02	8.919E-05	4.3E-06	2.44E-02	2.6E-03
1.4805E+02	1.035E-05	2.4E-06	2.44E-02	2.6E-03
1.6717E+02	1.865E-05	3.6E-06	2.44E-02	2.6E-03
1.7896E+02	2.940E-05	4.5E-06	2.44E-02	2.6E-03
1.9625E+02	8.172E-05	7.1E-06	2.44E-02	2.6E-03
2.0272E+02	3.050E-05	5.3E-06	2.44E-02	2.6E-03
2.1100E+02	1.629E-05	3.9E-06	2.44E-02	2.6E-03
2.3215E+02	1.300E-05	9.2E-06	2.44E-02	2.6E-03
2.3435E+02	2.000E-05	1.1E-05	2.44E-02	2.6E-03
2.4241E+02	4.192E-05	6.3E-06	2.44E-02	2.6E-03
2.5843E+02	9.885E-06	9.9E-06	2.44E-02	2.6E-03
2.7276E+02	1.900E-05	1.5E-05	2.44E-02	2.6E-03
2.7697E+02	3.500E-05	3.0E-05	2.44E-02	2.6E-03
2.9058E+02	6.269E-05	1.0E-05	2.44E-02	2.6E-03
2.9984E+02	4.152E-05	8.7E-06	2.44E-02	2.6E-03
3.0268E+02	1.415E-04	1.4E-05	2.44E-02	2.6E-03
3.2183E+02	4.434E-05	1.1E-05	2.44E-02	2.6E-03
3.3523E+02	3.466E-05	3.5E-05	2.44E-02	2.6E-03
3.3834E+02	5.361E-05	1.4E-05	2.44E-02	2.6E-03
3.5200E+02	7.700E-05	3.5E-05	2.44E-02	2.6E-03
3.6135E+02	8.999E-05	1.7E-05	2.44E-02	2.6E-03
3.8072E+02	1.229E-04	1.7E-05	2.44E-02	2.6E-03
3.9183E+02	1.445E-04	2.7E-05	2.44E-02	2.6E-03
4.1199E+02	2.114E-04	2.3E-05	2.44E-02	2.6E-03
4.2734E+02	1.900E-05	1.2E-05	2.44E-02	2.6E-03
4.5920E+02	6.548E-05	1.7E-05	2.44E-02	2.6E-03
4.6641E+02	1.068E-04	3.4E-05	2.44E-02	2.6E-03
4.7087E+02	4.362E-05	2.2E-05	2.44E-02	2.6E-03
4.7658E+02	1.282E-04	2.2E-05	2.44E-02	2.6E-03
5.3358E+02	2.459E-04	3.4E-05	2.44E-02	2.6E-03
5.3587E+02	3.606E-04	4.0E-05	2.44E-02	2.6E-03
5.5061E+02	4.100E-04	3.7E-04	2.44E-02	2.6E-03
5.7389E+02	6.518E-04	6.7E-05	2.44E-02	2.6E-03
5.8432E+02	8.500E-05	8.4E-05	2.44E-02	2.6E-03

Table A-II. Continued

6.2544E+02	5.300E-05	3.7E-05	2.44E-02	2.6E-03
6.2834E+02	5.500E-05	4.1E-05	2.44E-02	2.6E-03
6.3455E+02	7.300E-05	5.7E-05	2.44E-02	2.6E-03
6.4472E+02	1.392E-04	4.3E-05	2.44E-02	2.6E-03
6.6107E+02	1.985E-04	8.1E-05	2.44E-02	2.6E-03
6.9618E+02	1.700E-04	1.2E-04	2.44E-02	2.6E-03
6.9931E+02	1.499E-04	1.1E-04	2.44E-02	2.6E-03
7.0477E+02	2.101E-04	5.9E-05	2.44E-02	2.6E-03
7.2060E+02	9.300E-05	5.2E-05	2.44E-02	2.6E-03
7.4970E+02	3.400E-04	3.4E-04	2.44E-02	2.6E-03
7.5896E+02	2.402E-04	1.2E-04	2.44E-02	2.6E-03
7.6526E+02	7.349E-04	8.9E-05	2.44E-02	2.6E-03
7.7480E+02	5.007E-05	3.8E-05	2.44E-02	2.6E-03
7.9344E+02	3.300E-05	7.4E-05	2.44E-02	2.6E-03
8.0884E+02	1.350E-04	5.5E-05	2.44E-02	2.6E-03
8.1730E+02	1.804E-04	9.0E-05	2.44E-02	2.6E-03
8.2138E+02	1.084E-03	1.2E-04	2.44E-02	2.6E-03
8.4730E+02	1.452E-04	7.3E-05	2.44E-02	2.6E-03
8.5116E+02	1.034E-03	1.1E-04	2.44E-02	2.6E-03
8.6994E+02	6.749E-04	9.3E-05	2.44E-02	2.6E-03
8.7878E+02	1.900E-04	1.1E-04	2.44E-02	2.6E-03
8.8539E+02	3.533E-04	6.5E-05	2.44E-02	2.6E-03
9.0009E+02	8.200E-05	7.3E-05	2.44E-02	2.6E-03
9.1500E+02	1.608E-04	1.2E-04	2.44E-02	2.6E-03
9.1950E+02	4.439E-04	7.8E-05	2.44E-02	2.6E-03
9.3431E+02	2.589E-04	6.5E-05	2.44E-02	2.6E-03
9.5651E+02	1.311E-04	1.4E-04	2.44E-02	2.6E-03
9.7483E+02	2.540E-04	1.0E-04	2.44E-02	2.6E-03
9.9680E+02	3.921E-04	1.4E-04	2.44E-02	2.6E-03
1.0017E+03	2.533E-04	8.7E-05	2.44E-02	2.6E-03
1.0221E+03	4.640E-04	6.1E-05	2.44E-02	2.6E-03
1.0445E+03	6.219E-04	1.0E-04	2.44E-02	2.6E-03
1.0501E+03	2.600E-04	7.8E-05	2.44E-02	2.6E-03
1.0554E+03	3.400E-04	7.5E-05	2.44E-02	2.6E-03
1.0611E+03	2.600E-04	1.6E-04	2.44E-02	2.6E-03
1.0743E+03	2.095E-04	1.0E-04	2.44E-02	2.6E-03
1.1153E+03	1.301E-03	2.6E-04	2.44E-02	2.6E-03
1.1171E+03	1.100E-03	2.5E-04	2.44E-02	2.6E-03
1.1286E+03	2.310E-04	6.5E-05	2.44E-02	2.6E-03
1.1332E+03	3.852E-04	8.4E-05	2.44E-02	2.6E-03
1.1770E+03	3.557E-04	6.5E-05	2.44E-02	2.6E-03
1.1856E+03	1.000E-04	9.9E-05	2.44E-02	2.6E-03
1.2052E+03	1.692E-03	1.8E-04	2.44E-02	2.6E-03
1.2148E+03	3.037E-04	3.0E-04	2.44E-02	2.6E-03
1.2249E+03	4.263E-04	1.2E-04	2.44E-02	2.6E-03
1.2347E+03	9.240E-04	1.4E-04	2.44E-02	2.6E-03
1.2617E+03	8.820E-04	1.2E-04	2.44E-02	2.6E-03
1.2625E+03	9.417E-04	3.0E-04	2.44E-02	2.6E-03
1.2671E+03	2.838E-04	2.1E-04	2.44E-02	2.6E-03
1.2885E+03	2.108E-04	8.8E-05	2.44E-02	2.6E-03

Table A-II. Continued

1.3085E+03	3.500E-04	1.8E-04	2.44E-02	2.6E-03
1.3467E+03	1.086E-03	1.4E-04	2.44E-02	2.6E-03
1.3502E+03	8.216E-04	3.0E-04	2.44E-02	2.6E-03
1.3732E+03	1.120E-03	2.0E-04	2.44E-02	2.6E-03
1.3854E+03	3.110E-04	1.7E-04	2.44E-02	2.6E-03
1.3884E+03	2.328E-03	2.2E-04	2.44E-02	2.6E-03
1.4094E+03	4.146E-04	1.9E-04	2.44E-02	2.6E-03
1.4184E+03	5.505E-04	1.2E-04	2.44E-02	2.6E-03
1.4504E+03	2.800E-04	2.8E-04	2.44E-02	2.6E-03
1.4662E+03	1.500E-04	1.5E-04	2.44E-02	2.6E-03
1.4701E+03	2.986E-04	1.7E-04	2.44E-02	2.6E-03
1.4850E+03	1.500E-04	1.5E-04	2.44E-02	2.6E-03
1.5034E+03	6.436E-04	2.1E-04	2.44E-02	2.6E-03
1.5103E+03	5.325E-03	4.6E-04	2.44E-02	2.6E-03
1.5165E+03	1.637E-03	2.9E-04	2.44E-02	2.6E-03
1.6122E+03	9.917E-04	1.7E-04	2.44E-02	2.6E-03
1.6696E+03	5.000E-04	3.0E-04	2.44E-02	2.6E-03
1.6908E+03	1.204E-03	2.9E-04	2.44E-02	2.6E-03
1.7268E+03	1.325E-03	3.2E-04	2.44E-02	2.6E-03
1.7319E+03	1.505E-03	3.2E-04	2.44E-02	2.6E-03
1.7682E+03	1.567E-03	6.3E-04	2.44E-02	2.6E-03
1.7866E+03	1.871E-03	3.1E-04	2.44E-02	2.6E-03
1.7942E+03	4.929E-04	3.5E-04	2.44E-02	2.6E-03
1.8376E+03	1.024E-03	3.1E-04	2.44E-02	2.6E-03
1.8498E+03	5.009E-03	5.4E-04	2.44E-02	2.6E-03
1.8984E+03	3.828E-03	6.0E-04	2.44E-02	2.6E-03
1.9411E+03	3.298E-04	3.3E-04	2.44E-02	2.6E-03
1.9829E+03	1.341E-03	1.3E-03	2.44E-02	2.6E-03
2.0216E+03	1.033E-03	7.7E-04	2.44E-02	2.6E-03
2.0273E+03	1.343E-03	1.0E-03	2.44E-02	2.6E-03
2.0568E+03	5.429E-04	2.9E-04	2.44E-02	2.6E-03
2.1407E+03	1.035E-03	7.2E-04	2.44E-02	2.6E-03
2.1593E+03	2.392E-03	8.9E-04	2.44E-02	2.6E-03
2.1717E+03	3.034E-03	9.0E-04	2.44E-02	2.6E-03
2.2088E+03	2.276E-03	6.7E-04	2.44E-02	2.6E-03
2.2444E+03	7.267E-04	7.3E-04	2.44E-02	2.6E-03
2.2489E+03	6.229E-04	5.0E-04	2.44E-02	2.6E-03
2.2634E+03	6.231E-04	4.4E-04	2.44E-02	2.6E-03
2.3034E+03	3.316E-03	9.2E-04	2.44E-02	2.6E-03
2.3143E+03	1.664E-03	6.7E-04	2.44E-02	2.6E-03
2.3311E+03	2.214E-03	7.2E-04	2.44E-02	2.6E-03
2.3457E+03	5.872E-03	1.5E-03	2.44E-02	2.6E-03
2.3630E+03	6.246E-04	5.0E-04	2.44E-02	2.6E-03
2.3707E+03	1.145E-03	8.6E-04	2.44E-02	2.6E-03
2.3841E+03	2.785E-03	9.3E-04	2.44E-02	2.6E-03
2.4079E+03	5.211E-04	3.9E-04	2.44E-02	2.6E-03
2.4144E+03	6.254E-04	4.4E-04	2.44E-02	2.6E-03
2.4254E+03	2.398E-03	1.8E-03	2.44E-02	2.6E-03
2.4363E+03	2.323E-03	6.5E-04	2.44E-02	2.6E-03
2.4538E+03	5.217E-03	3.7E-03	2.44E-02	2.6E-03

Table A-II. Continued

2.4822E+03	6.264E-04	4.7E-04	2.44E-02	2.6E-03
2.5025E+03	6.267E-04	4.4E-04	2.44E-02	2.6E-03
2.5374E+03	2.300E-03	1.5E-03	2.44E-02	2.6E-03
2.5453E+03	4.182E-04	2.9E-04	2.44E-02	2.6E-03
2.5496E+03	4.183E-04	2.9E-04	2.44E-02	2.6E-03
2.5842E+03	1.151E-03	8.1E-04	2.44E-02	2.6E-03
2.5912E+03	2.093E-03	1.5E-03	2.44E-02	2.6E-03
2.5968E+03	8.375E-04	5.9E-04	2.44E-02	2.6E-03
2.6563E+03	5.949E-03	1.0E-03	2.44E-02	2.6E-03
2.6697E+03	7.000E-04	5.0E-04	2.44E-02	2.6E-03
2.7007E+03	2.713E-03	4.9E-04	2.44E-02	2.6E-03
2.7652E+03	2.596E-03	3.6E-04	2.44E-02	2.6E-03
2.7834E+03	3.509E-03	4.0E-04	2.44E-02	2.6E-03
2.8118E+03	2.104E-04	1.9E-04	2.44E-02	2.6E-03
2.8258E+03	1.474E-03	5.9E-04	2.44E-02	2.6E-03
2.8408E+03	1.733E-03	3.7E-04	2.44E-02	2.6E-03
2.8456E+03	9.803E-04	4.4E-04	2.44E-02	2.6E-03
2.8720E+03	2.307E-03	3.0E-04	2.44E-02	2.6E-03
2.9103E+03	3.160E-03	4.5E-04	2.44E-02	2.6E-03
2.9245E+03	1.477E-03	1.0E-03	2.44E-02	2.6E-03
2.9337E+03	2.939E-03	3.6E-04	2.44E-02	2.6E-03
2.9418E+03	1.969E-03	3.0E-04	2.44E-02	2.6E-03
2.9731E+03	3.612E-03	4.9E-04	2.44E-02	2.6E-03
2.9811E+03	1.059E-02	1.4E-03	2.44E-02	2.6E-03
2.9975E+03	2.431E-03	1.8E-03	2.44E-02	2.6E-03
3.0062E+03	2.688E-03	3.7E-04	2.44E-02	2.6E-03
3.0521E+03	5.654E-03	3.1E-03	2.44E-02	2.6E-03
3.0785E+03	5.213E-03	1.1E-03	2.44E-02	2.6E-03
3.1217E+03	8.083E-03	1.3E-03	2.44E-02	2.6E-03
3.2174E+03	7.341E-03	1.5E-03	2.44E-02	2.6E-03
3.2328E+03	4.408E-03	8.9E-04	2.44E-02	2.6E-03
3.3631E+03	5.594E-03	1.0E-03	2.44E-02	2.6E-03
3.5531E+03	4.250E-03	6.5E-04	2.44E-02	2.6E-03
3.6190E+03	7.399E-03	1.7E-03	2.44E-02	2.6E-03
3.6674E+03	4.300E-03	1.0E-03	2.44E-02	2.6E-03
3.7476E+03	3.739E-03	3.6E-03	2.44E-02	2.6E-03
3.7799E+03	1.932E-03	6.7E-04	2.44E-02	2.6E-03
3.8016E+03	5.794E-03	3.6E-03	2.44E-02	2.6E-03
3.8370E+03	3.443E-03	8.5E-04	2.44E-02	2.6E-03
3.8620E+03	4.142E-03	7.6E-04	2.44E-02	2.6E-03
3.9180E+03	5.003E-03	9.0E-04	2.44E-02	2.6E-03
3.9541E+03	7.237E-03	1.5E-03	2.44E-02	2.6E-03

Table A-III. Pointwise Cross Sections With Neutron Energy E in eV

CAPTURE	
Missed p-waves: $(0.0235+0.0000622E)$b	$60 \leqslant E \leqslant 4000$
1/v above 5.0 eV: $0.4427E^{-1/2}$ b	$5 \leqslant E \leqslant 4000$
SCATTERING	
Truncation: $0.48\ \ell n[(4180-E)/(E+132)]$b	$5 \leqslant E \leqslant 4000$
Connection: $(0.540-0.036E)$b	$5 \leqslant E \leqslant 15$
TOTAL	
Sum of the above 4 pointwise cross sections	

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