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Evaluation of the Thermal Constants of ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu, and the fission neutron yield of ^{252}Cf

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Abstract.

In 1982 a simultaneous evaluation of the thermal neutron constants of 233U, 235U, 239Pu, and 241Pu, together with the fission neutron yield from the spontaneous fission of 252Cf, was performed with, for the first time, a full covariance matrix to describe the correlations in the uncertainties of the input data. The input data set was limited in that measurements in Maxwellian reactor spectra were excluded. In 1984 the Maxwellian data were added, and all measurements were renormalized to the latest values of reference data such as half-lives and cross sections, and some of the earlier measurements were re-interpreted. In this third paper on the subject the input data are again renormalized to the latest reference data, new measurements added, and some older measurements re-interpreted, in order to provide an up to date set of values for possible inclusion in the evaluated nuclear data files of ENDFB. This paper should be regarded as a supplement to the earlier two in this series.

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1. Introduction.

The importance of these data stems from the role they play in the prediction of the neutron economy in thermal power reactors. As new measurements appear, reference standards become more accurate, and methods of data analysis improve, a continual process of re-evaluation has taken place since the late 1950's. In 1982 (**Axton, 1984- hereafter referred to as (1)**), a simultaneous evaluation of the data was performed, by a least-squares minimization technique which included for the first time a full covariance matrix to describe the correlations between the uncertainties of the measurements. The data set was limited in that measurements made in Maxwellian reactor spectra were excluded. In 1984, (**Axton, 1985,- hereafter referred to as (2)**),the Maxwellian data were added, the measurements were normalized to the most recent reference data such as half-lives and standard cross sections, some new measurements were added, and some of the older measurements were re-interpreted.

The purposes of the present study are as follow:-

a. To update the input data with any new measurements, re-interpretations of old measurements, and changes in the reference data which have occurred since the November 1984 cut-off date of (2).

b. To consider the suitability of the output data set, i.e. the fitted values of the floating variables, derived functions of the fitted variables, their uncertainties, and the associated correlation matrix, for inclusion in the forthcoming ENDFB VI evaluated nuclear data file, and to what extent it can be accommodated in ENDFB format.

In order to avoid too much repetition, this report should be regarded as a supplement to (1) and (2), and should be read in conjunction with them. Measurements will not be discussed or referenced unless there have been changes to them, but for convenience, the reference lists of (1) and (2) appear in Appendices 1 and 2. Other evaluations dating back to 1961 which are relevant to this study are referenced in (2).

2. Comments on the least squares minimization procedure.

The fitting procedure has been fully described in (1) and (2), so only a brief summary is included here. The problem is programmed in IBM APL language (Bastian, 1984). The input data are described in terms of APL executable functions, which provide an extremely flexible method for the interpretation of the measurements as functions of the unkown parameters to be determined. A list of the functions used in this work appears in Appendix 3.

The normal equations $A^TZ^{-1}A\ b = A^TZ^{-1}y$ can be solved by matrix inversion of the covariance matrix Z to provide the solution b given by :-

$$b = (A^TZ^{-1}A)^{-1}\ A^TZ^{-1}y \quad \text{with covariance } V = (A^TZ^{-1}A)^{-1}\ ,$$

where A is the n by p design matrix containing the differentials of each of the n measurements with respect to each of the p parameters to be determined, and y is the n-element observation vector. However, it is numerically more accurate to obtain b by a modified form of the method of Cholesky factorization of Z.(*) The procedure is to derive directly a matrix R such that $R^TR = Z^{-1}$. Then if $A' = RA$, and $y' = Ry$,the solution is given by :-

$$b = (A')^{-1}y'\ \text{,with covariance } V = ((A')^TA')^{-1} \qquad (**)$$

with (weighted) residual vector $r' = y' - A'b$, residual vector $r = y - Ab$, and the statistical parameter χ^2 given by $\chi^2 = r'^T r'$.

Because the problem is nonlinear, it is necessary to introduce 'guess parameters', which are guessed values for the unknown parameters to be determined. The observation vector y consists of relative differences between each measured function and its value calculated from the guess parameters.(***) Z is constructed from the relative uncertainties of the measurements, A from relative differentials, and the solution b consists of relative corrections to the guess parameters. The calculation is then iterated until b becomes zero or negligible.

(*) The Cholesky method derives R from $R^TR = Z$ and requires subsequent inversion of R.

(**) In (2) R was erroneously described as a vector, and the solution b was misprinted as R A y $(R\ A)^{-1}$.

(***) As in (1) and (2) all uncertainties are estimated at the one standard deviation (68 % confidence) level.

3. Changes to the November 1984 Input Data Set.

3.1. Half-lives.

The half-lives used in (2), (Reich, 1985), have been replaced by those of Reich 1986. The values are the same as before, except that the uncertainty of the half-life of ^{234}U has been reduced from 0.204 % to 0.122 %. In addition, the half-lives are now fixed so that they do not change in the least squares fit. This is a somewhat arbitrary decision, which makes almost no difference to the outcome. In an ideal world where all the nuclear data are contained in one file, and evaluated simultaneously, it is obvious that all parameters should float within the constraints of their uncertainties. However, in the present situation, if the half-lives are allowed to float, their values will change slightly, and they will no longer be in harmony with half-life values in other data files within the system.

3.2. g-factors.

The new g-factor 0.9778 ± 0.0009 for fission of ^{235}U (Wagemans and Deruytter, 1986) replaces the previous value of 0.9774 ± 0.0016 (Divadeenam and Stehn, 1984). As with the half-lives the arbitrary decision has to be made as to whether the g-factors should float. The situation with g-factors is slightly different, because they form part of the data set which is required for reactor calculations. If the g-factors do not float their values do not appear in the output table of fitted values. They can of course be added at the end, but then the correlation with the other parameters will be lost. The importance of these correlations will be discussed in a later section. It was decided therefore that the g-factors should float as in (1) and (2).

3.3. Criticality parameters.

The input data contain a number of measurements of the quantity $(\hat{\eta}-1)\,\hat{\sigma}_a$ which is the same as $\bar{\nu}\,\hat{\sigma}_f-\hat{\sigma}_a$. In reactor circles it is known as K1, and it is represented in this evaluation by the function F3ETA. As discussed by Divadeenam (1985), the 1962 experiments of Gwin and Magnuson have been re-interpreted several times, (Magnuson 1971, Gwin 1976, Ullo and Hardy 1977, and finally Hardy 1985). Gwin proposed that definitive calculations, including an analysis of uncertainties, should be performed for all of the critical systems. The only definitive calculations available for these systems are those of Hardy, 1985 which result in values of K1 for ^{233}U and ^{235}U of 744.7 ± 4.0, and 722.7 ± 3.9 for these two nuclides respectively. These values, with an estimated 50 % correlation, replace the values of 740.35 ± 1.186 %, and 724.1 ± 1.050 % as in (2). In view of the importance of K1 to reactor physicists, K1 (F3ETA) has been added as an additional derived function to the output tables, and the uncertainties and correlations are derived according to the recipe given in appendix 6 of (1).

3.4. Total cross sections.

Preliminary results for the measurements of the total cross sections of ^{235}U and ^{239}Pu have been received from Spencer (1986). They are 690 ± 4b, and 1025.8 ± 5.7b respectively. Because of the preliminary nature of the information the uncertainties have been increased to ± 1 %, and they are regarded as 50 % correlated.

3.5. Half-life dependent Maxwellian fission cross sections.

The measurements of the half-life dependent fission cross sections of ^{233}U, and ^{235}U, by Keith, 1968, have been re-valued. In (1) and (2) they were taken from Divadeenam, 1984. The original values had been converted to 2200 m/s values with a ^{233}U half-life measured internally to the experiment. Lemmel (1982) reconstructed the originally measured product of half-life and Maxwellian cross section, normalised it to the latest value for the cobalt cross section, and included also an additional correction for fission product counting losses which had been proposed by Deruytter (1971). The values used here are derived following Lemmel, but normalized to the currently accepted cobalt cross section. The main difference from (2) is the introduction of the Deruytter correction, which was not retained by Divadeenam.

3.6. Californium $\bar{\nu}$.

In (2), the INEL value of Smith (1984) for $\bar{\nu}$ for ^{252}Cf was the published value subjected to a minor correction to a common average energy for the fission neutron spectrum as in (1). However, in the process of analysing the international intercomparison of neutron source emmission rates organised by the Bureau International des Poids et Mesures, it was noted that the published results for the INEL emission rates both for the source NZ90 which was part of the intercomparison, and for the fission chamber FC4 which was the basis for the INEL $\bar{\nu}$ measurements, were noticeably dependent on the concentration of the manganese sulphate solution. After eliminating the half-life, this slope was attributed to the choice of value for the ratio $\sigma H/\sigma Mn$. A re-analysis of the data using the method of Axton (B1985) resulted in a lowering of the cross section ratio and both emission rates, and hence $\bar{\nu}$ for ^{252}Cf, by approximately 0.1 %. However, stimulated by a proposal of Smith, a measurement of the ratio $\sigma S/\sigma H$, and some new measurements of σS provided sufficient material for a simultaneous least squares fit to the cross sections of S, Mn, and H (Axton 1986), which results in a recommended value of 535 ± 6 mb for sulphur. A repeat of the analysis of NZ90 and FC4 with the new σS produces values for the H/Mn cross section ratio and for the two emission rates which are very close to the INEL published values. In other words, the slope of the measurements is due not to the H/Mn cross section ratio, but to the sulphur cross section. As a result of this the INEL $\bar{\nu}$ value is unchanged from (2), but since the emission rates derived from manganese bath measurements are proportional to the value assumed by the experimenter for the factor $(1+\sigma_S/\sigma_H)$, the values of all other manganese bath measurements of $\bar{\nu}$ for californium are raised by 0.11 %.

4. Input data and results.

The input data are listed in Table 1. The number in parentheses following the date identifies the reference list, i.e. appendices 1 and 2 for papers (1) and (2) respectively, and (3) signifies this report. The measured function is described in the third column, the key to which is in appendix 3. The notes in the fourth column refer to the notes in appendix 1 of (2). An asterisk following the note indicates either a new measurement or one which was changed as discussed in section 3. The following three columns contain the (revised) measured values, their relative uncertainties (%), and the weighted residuals r', the sum of squares of which is χ^2. The final column contains a serial number to facilitate cross-reference to other tables.

Table 2 shows all the causes of correlations between the uncertainties of the measurements, each one having an identification symbol for cross reference to table 3, which gives the relative correlated uncertainty (%) contributed by each cause. The fitted values of the relevant floating variables are presented in table 4 together with their uncertainties and their relative uncertainties. Relevant functions of these fitted variables, (capture, eta, alpha, and K1) have been added, and their uncertainties and correlations calculated according to the recipe provided in appendix 6 of (1). The correlation matrix for the uncertainties of the fitted parameters, and of functions derived from them is shown in table 5. The reference data used for re-normalization are presented in table 6.

5. Comments on the results.

5.1. Fission of ^{235}U.

Following the publication of (2) it was observed by some reactor physicists that some of the ouput parameters seemed to conflict with the results of criticality experiments. In particular, the fission cross section of ^{235}U which is 582.78b in table 4 of (2) was thought to be too low, and the value of 585.20b in table 6 of (2) obtained with only monoenergetic input data was preferred. A careful diagnostic study of the Maxwellian input data was carried out to discover which Maxwellian data entries were responsible for pulling this cross section down. It turned out that the measurements were reasonably distributed, and there was no question of finding one or two measurements that stood out. It was necessary to delete no less than sixteen measurements to achieve a fitted value of 585.1b for this cross section. However it transpired that, from Hardy (1985), the function K1 provided a better criterion for judging the output data. K1 had values of 716.87 in table 4, and of 719.29 in table 6 of (2). Its value in table 4 of this report is 718.57.

5.2. Eta for ^{239}Pu

Similarly, from discussions at the United Kingdom Nuclear Data Forum in December 1984 (R.J.Brissenden, 1984) it appeared that the value of eta for ^{239}Pu, which is 2.116 in table 4 of (2), is too high, a value of 2.091 being more in harmony with the criticality experiments. Again, it turned out to be the value of K1 which is more important. Some calculations have commenced at the Atomic Energy Establishment, Winfrith (AEEW) which hopefully will yield a preferred value of K1 for this nuclide. This may help to resolve this apparent discrepancy. In all the diagnostic tests which have been carried out so far in this review, the value of eta has never changed significantly from 2.116.

5.3. Scattering cross sections.

From time to time criticisms are voiced of the input scattering data, and the role they play in this evaluation. It is true that there are not many measurements of scattering cross sections available. The scattering data for (1) were taken from Lemmel (1982), and they relied heavily on the work of Leonard (1972). They have not changed since (1). Traditionally the scatter data are believed to be required in order to derive absorption cross sections from total cross sections by subtraction. However, the absorption cross sections are also evaluated from measurements of σ_f, eta, alpha, and $\bar{\nu}$. If the input scattering data are omitted, their fitted values are derived from total and absorption cross sections, as can be seen in table 7. The values of the scattering cross sections may seem a little strange, but overall the data could be regarded as quite a respectable alternative to table 4. K1 for ^{235}U is 719.97. Again, the value of eta for ^{239}Pu is hardly changed. If the scattering data are not used, it is no longer necessary to input the total cross sections since they serve only to evaluate scattering cross sections which are no longer needed, and this saves considerable effort, as well as computer time and space.

5.4. Results obtained with measurements in Maxwellian Spectra omitted.

Results obtained with Maxwellian data omitted appear in Table 4a of (1), and in Table 6 of (2). Small changes occur in these results as a consequence of the changes to the input data which were described in Section 3. To complete the picture, Table 8 shows the result of omitting the Maxwellian data from the present input set.

6. Implementation in ENDFB format.

The primary functions involved in this work which are of interest in reactor calculations are the cross sections for fission and absorption, which together with $\bar{\nu}$, and the Westcott g-factors, can be used to calculate derived parameters such as eta, alpha, the capture cross section, and the quantity K1, which is represented here by the APL function F3ETA. The uncertainties and correlations associated with the derived functions are obtained by using the recipe described in appendix 6 of (1). However, it appears from discussions with experts from the Nuclear Energy Agency (NEA) Nuclear Data Bank (OECD countries) at Saclay in France that with the present structure of ENDFB it is not possible to accomodate all of the correlations. Those between cross sections such as absorption and fission can be entered, even between cross sections at different energies, but the structure of the files is rather cumbersome and not designed for this purpose. With the file structure in its present form it is not possible to enter correlations for example, of $\bar{\nu}$ with the cross sections or with the g-factors, or of the cross sections with the g-factors, or of cross sections with those of other nuclides.

The consequences of neglection of correlations can be exemplified by considering the uncertainty of K1 for ^{235}U, which appears in table 4 as 2.218. K1 of ^{235}U is a function of five parameters, namely σ_f, σ_a, g_f, g_a, and $\bar{\nu}$, so the calculation of the uncertainty involves the use of ten numbers out of the matrix in table 5. If the uncertainty of K1 is recalculated neglecting the nine correlations which cannot be accomodated in ENDFB, thus including only the correlation between σ_f and σ_a, the value becomes 3.010, which is an overestimate of 36 % This is due to the negative correlation between $\bar{\nu}$ and σ_f, which reduces the uncertainty in their product. Similarly, if the correlation between σ_f and σ_a is also dropped, the overestimate reaches 76 %. This is due the fact that the high positive correlation between σ_f and σ_a reduces the uncertainty in their difference. It is therefore worthwhile again to stress the importance of table 5 to reactor calculations.

Since entering some correlations and not others could lead to a sense of false security it would be better to put none in the file. The entire correlation matrix can be entered instead in a comments file, for example in EXFOR format.

7. Conclusions.

The output data sets presented in tables 4 and 7 are both internally consistent, and consistent with each other. They have χ^2 values of 103 and 100 for 129 and 121 degrees of freedom respectively. With the exception of the scattering cross sections, which are believed to be of little interest in reactor calculations, there is no significant difference between any of either the basic or the derived parameters. Among the weighted residuals in table 1, which are calculated from the fit to all data presented in table 4, only 35 have an absolute value greater than unity, compared with an expectation figure of 53. When the input data are compared with the results presented in table 7, the corresponding figures are 31 compared with an expectation figure of 51. In neither case is there a weighted residual with an absolute value greater than 2, whereas between seven and eight would be expected. It can be concluded that the uncertainties of the input data have not been underestimated. It can be seen that the present total and scattering cross section data contribute little, if any, information to the system. This situation would undoubtedly change if more accurate measurements of these data were to become available.

It is suggested that before any further effort is expended on this subject some feedback is required from users and potential users of the results. These results, always including the output correlation matrix, need to be carefully tested and compared with expectations from reactor calculations and criticality experiments. Any apparent discrepancies or conflicts should be reported with full documentation so that they can be investigated thoroughly, and they could possibly provide additional input data in the future.

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In table 1 the suffixes following the function identify the nuclide measured. Thus 33, 34, 35, 39, 40, 41, and 42 refer to ^{233}U, ^{234}U, ^{235}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu respectively.

Primary Functions

ABS	Monoenergetic absorption cross section (0.0253 ev)
FIS	Monoenergetic fission cross section (0.0253 ev)
SCA	Scatter cross section (0.0253 ev)
SCR	Scatter cross sexction (0.0253 ev), (rolled metal)
WGA	Westcott g-factor for absorption (20° C)
WGF	Westcott g-factor for fission (20° C)
GC116	Westcott (g+rs) factor for capture for T=116° C and r=0.00075
GC116	Westcott (g+rs) factor for absorption for T=116° C and r=0.00075
HLF	Relative half-life in years (omitting powers of 10)
NUB	Nubar $(\bar{\nu})$

Derived functions

FA	Maxwellian absorption cross section =ABS×WGA
FF	Maxwellian fission cross section =FIS×WGF
CA	Monoenergetic capture = ABS-FIS
CAP	Maxwellian capture = (ABS× GA)-(FIS×WGF)
ETA	NUB×FIS÷ABS
F1ETA	Maxwellian eta = NUB×FF÷FA
F2ETA	F1ETA×FA = NUB×FF
F3ETA	(F1ETA-1)×FA = (NUB×FF)-FA
FH1	FIS×HLF
FFH	FF×HLF eg (33 FFH 35) = (FF 35)×(HLF 33)

Special functions to describe specific measurements

FLEM	((CAP 33)÷((FA 33)-(CAP 34))
F1CAB	((CA 40)×(GC116 40))-((CA 42)×(GC116 42))
F2CAB	((ABS 39)×(GA116 39))-((CA 42)×(GC116 42))
F3CAB	((ABS 39)×(GA116 39))÷((CA 39)×(GC116 39))
F4CA3	(((ABS 41)×(GA116 41))-(AES 39)×(GA116 39))÷F1HLF
F5CAB	(ABS 41)×(GA116 41))÷((CA 41)×(GC116 41)×F2HLF)
F1BIG	(FF 41)÷((39 FFH 39)×F3HLF)
F1HLF	1+(0.12966×((HLF 41)-14.05))
F2HLF	1+(0.0225×((HLF 41)-14.05))
F3HLF	1+(0.00395×((14.5-(HLF 41))÷(14.5-12.9)))

Author	Reference	Measured Functions	Notes	Input Value	Uncert-tainty %	Weighted Residual	No.
LAPONCHE	1972(2)	(FA 39)÷FA 35	7	1.6491E00	.583	.329	1
CORNISH	1956(2)	CAP 39	8	3.1200E02	4.490	.179	2
HALPERIN	1963(2)	CAP 33	10	4.9530E01	6.400	.615	3
CABELL	1971(2)	FLEM	11	9.8270E-02	3.348	-.256	4
LEMMEL	1982(1)	CAP 34	3	9.5900E01	2.086	.032	5
POPOVIC	1953(2)	FF 35	13	5.7110E02	2.211	.119	6
POPOVIC	1955(2)	33 FFH 33	13	8.4472E02	3.147	.136	7
KEITH	1968(2)	33 FFH 33	14*	8.3415E02	1.371	-.608	8
KEITH	1968(2)	33 FFH 35	14*	8.8901E02	1.446	-1.383	9
KEITH	1968(2)	39 FFH 39	14*	1.8844E03	.949	-1.014	10
BIGHAM	1975(2)	33 FFH 33	15	8.3520E02	.659	-1.071	11
JAFFEY	1955(2)	(FF 41)÷FF 39	17	1.3552E00	1.424	.823	12
WHITE	1967(2)	(FF 39)÷FF 35	18	1.3583E00	2.139	-.932	13
WHITE	1967(2)	(FF 41)÷FF 35	18	1.8806E00	2.802	.477	14
VIDAL	1970(2)	(FF 33)÷FF 35	2	9.3200E-01	.966	.495	15
BIGHAM	1975(2)	(FF 33)÷FF 35	15	9.3230E-01	.450	1.134	16
SWEET	1973(2)	(39 FFH 39)÷34 FFH 35	2	1.3544E00	1.414	-.263	17
BIGHAM	1975(2)	(39 FFH 39)÷33 FFH 33	15	2.2796E00	.669	1.156	18
BIGHAM	1975(2)	(39 FFH 39)÷33 FFH 35	15	2.1239E00	.709	1.714	19
BIGHAM	1975(2)	F1BIG	15	5.5270E-01	.562	-.859	20
LOUNSBURY	1970(1)	(CA 33)÷FIS 33	19	8.6100E-02	2.239	.167	21
LOUNSBURY	1970(1)	(CA 35)÷FIS 35	19	1.6970E-01	1.709	-.088	22
LOUNSBURY	1970(1)	(CA 39)÷FIS 39	19	3.5550E-01	1.603	-1.305	23
INGHRAM	1956(2)	(CAP 33)÷FF 33	2	9.4030E-02	3.190	1.324	24
CORNISH	1960(2)	(CAP 35)÷FF 35	2	1.8800E-01	7.447	1.156	25
OKAZAKI	1964(2)	(CAP 33)÷FF 33	20	9.0200E-02	1.731	.090	26
OKAZAKI	A1964(2)	(CAP 35)÷FF 35	20	1.7050E-01	1.056	-.730	27
LISMAN	1967(2)	(CAP 33)÷FF 33	21	9.3000E-02	2.128	1.486	28
LISMAN	1967(2)	(CAP 35)÷FF 35	21	1.7120E-01	.886	-.405	29
CONWAY	1967(2)	(CAP 33)÷FF 33	21	8.5100E-02	4.935	-1.181	30
CONWAY	1967(2)	(CAP 35)÷FF 35	21	1.7050E-01	4.223	-.182	31
DURHAM	1967(2)	(CAP 35)÷FF 35	22	1.7460E-01	1.145	1.394	32
DURHAM	1967(2)	(CAP 39)÷FF 39	22	3.8820E-01	1.520	-.679	33
CABELL	1971(2)	(CAP 33)÷FF 33	23	8.5700E-02	3.048	-1.669	34
CABELL	1971(2)	(CAP 35)÷FF 35	23	1.6960E-01	1.759	-.742	35
CABELL	1971(2)	(CAP 39)÷FF 39	23	3.8120E-01	4.808	-.601	36
DEBOISBLANC	1961(2)	(F1ETA 33)÷F1ETA 35	24	1.1150E00	.717	1.599	37
FAST	1960(2)	(F1ETA 39)÷F1ETA 35	25	9.9700E-01	1.625	.004	38
FAST	1960(2)	(F1ETA 41)÷F1ETA 35	25	1.0528E00	1.653	.407	39
CABELL	1965(2)	(F3ETA 33)÷F3ETA 35	26	1.0461E00	2.357	.533	40
CABELL	1965(2)	(F3ETA 39)÷F3ETA 35	26	1.6079E00	2.403	-.733	41
CABELL	1965(2)	(F3ETA 33)÷F3ETA 35	26	1.0309E00	3.919	-.051	42
CABELL	1965(2)	(F3ETA 39)÷F3ETA 35	26	1.6223E00	4.161	-.206	43
GWIN	1962(2)	(F2ETA 33)÷F2ETA 35	27	9.5300E-01	1.414	.146	44
GWIN	1962(2)	(F2ETA 39)÷F2ETA 35	27	1.6310E00	1.414	-.429	45
GWIN	A1962(2)	F3ETA 33	28*	7.4470E02	.537	.612	46
GWIN	A1962(2)	F3ETA 35	28*	7.2270E02	.540	1.057	47
LAPONCHE	1972(2)	(F3ETA 39)÷F3ETA 35	7	1.6058E00	1.107	-1.711	48
LAPONCHE	1972(2)	(F3ETA 41)÷F3ETA 39	7	1.4687E00	3.580	.759	49

Author	Reference	Measured Functions	Notes	Input Value	Uncert-tainty %	Weighted Residual	No.
ALIKHANOV	1956(2)	(F3ETA 33)÷F3ETA 35	29	1.0390E00	3.561	.163	50
ALIKHANOV	1956(2)	(F3ETA 39)÷F3ETA 35	29	1.5650E00	6.709	-.678	51
MUELHAUS	1959(2)	(F3ETA 33)÷F3ETA 35	30	1.0221E00	1.811	-.586	52
MUELHAUS	1959(2)	(F3ETA 39)÷F3ETA 35	30	1.6043E00	2.271	-.876	53
DIVADEENAM	1984(2)	WGA 33	4	9.9884E-01	.120	-.518	54
DIVADEENAM	1984(2)	WGA 35	4	9.7870E-01	.092	-.251	55
DIVADEENAM	1984(2)	WGA 39	4	1.0767E00	.269	-.504	56
DIVADEENAM	1984(2)	WGA 41	4	1.0444E00	.191	.083	57
DIVADEENAM	1984(2)	WGF 33	4	9.9664E-01	.201	.551	58
DERUYTTER	1985(3)	WGF 35	4	9.7780E-01	.092	.475	59
DIVADEENAM	1984(2)	WGF 39	4	1.0562E00	.275	.259	60
DIVADEENAM	1984(2)	WGF 41	4	1.0452E00	.670	.100	61
EGELSTAFF	1954(1)	(ABS 35)+SCR 35	5	7.2433E02	3.590	1.088	62
MELKONIAN	1953(1)	(ABS 35)+SCR 35	5	6.9432E02	2.016	-.123	63
PALEVSKY	1954(1)	(ABS 35)+SCR 35	5	7.0032E02	1.428	.428	64
NITIKIN	1955(1)	(ABS 35)+SCA 35	5	7.1032E02	2.956	.596	65
SIMPSON	1960(1)	(ABS 35)+SCR 35	5	6.9032E02	1.391	-.596	66
SAFFORD	1959(1)	(ABS 35)+SCA 35	5	6.9632E02	.359	-.598	67
SAFFORD	1959(1)	(ABS 35)+SCR 35	5	6.9832E02	.730	.448	68
BLOCK	1960(1)	(ABS 35)+SCR 35	5	6.9332E02	.721	-.544	69
SAPLAKOGLU	1961(1)	(ABS 35)+SCR 35	5	6.9632E02	.359	.112	70
GERASIMOV	1962(1)	ABS 35	5	6.7031E02	2.089	-.823	71
ZIMMERMAN	1955(1)	(ABS 39)+SCR 39	5	1.0225E03	1.271	-.254	72
NITIKIN	1955(1)	(ABS 39)+SCA 39	5	1.0405E03	2.979	.439	73
BOLLINGER	1958(1)	(ABS 39)+SCR 39	5	1.0225E03	1.369	-.236	74
PATTENDEN	A1956(1)	(ABS 39)+SCR 39	5	1.0125E03	3.003	-.438	75
SAFFORD	1961(1)	(ABS 39)+SCR 39	5	1.0185E03	.727	-.985	76
MUETHER	1954(1)	(ABS 33)+SCR 33	5	5.9727E02	2.344	.724	77
NITIKIN	1955(1)	(ABS 33)+SCR 33	5	5.7726E02	3.638	-.470	78
PATTENDEN	1956(1)	(ABS 33)+SCR 33	5	5.9627E02	3.019	.508	79
GREEN	1957(1)	ABS 33	5	5.7426E02	3.483	-.098	80
SIMPSON	1960(1)	(ABS 33)+SCR 33	5	5.8727E02	.800	.029	81
SAFFORD	1960(1)	(ABS 33)+SCA 33	5	5.8577E02	.990	-.454	82
SAFFORD	1960(1)	(ABS 33)+SCR 33	5	5.8567E02	.410	-.611	83
BLOCK	1960(1)	(ABS 33)+SCR 33	5	5.8727E02	.511	.045	84
SIMPSON	1961(1)	(ABS 41)+SCA 41	5	1.3866E03	3.606	.025	85
CRAIG	1964(1)	(ABS 41)+SCA 41	5	1.3806E03	2.897	-.119	86
SMITH	1984(3)	(ABS 41)+SCR 41	31	1.3956E03	1.433	.563	87
LEMMEL	1982(1)	SCA 33	3	1.2306E01	5.688	.171	88
LEMMEL	1982(1)	(SCA 33)-SCR 33	3	1.2006E00	49.977	-.115	89
LEMMEL	1982(1)	SCA 35	3	1.6508E01	7.875	.404	90
LEMMEL	1982(1)	(SCA 35)-SCR 35	3	1.7008E00	44.097	-.100	91
LEMMEL	1982(1)	SCA 39	3	8.0037E00	12.494	.107	92
LEMMEL	1982(1)	(SCA 39)-SCR 39	3	8.0037E-01	137.437	-.269	93
LEMMEL	1982(1)	SCA 41	3	1.2006E01	21.657	-.070	94
LEMMEL	1982(1)	(SCA 41)-SCR 41	3	1.2006E00	249.886	.061	95
DERUYTTER	1974(1)	39 FH1 39	5	1.8121E03	.454	1.165	96
DERUYTTER	1973(1)	34 FH1 35	5	1.4391E03	.445	1.117	97
DERUYTTER	1961(1)	FIS 35	5	5.8937E02	1.325	.844	98
WHITE	1967(1)	(FIS 39)÷FIS 35	18	1.2530E00	1.800	-1.323	99
WHITE	1967(1)	(FIS 41)÷FIS 35	18	1.7630E00	2.751	.551	100
BERCEANO	1977(1)	34 FH1 35	5	1.4430E03	.791	.975	101
RAFFLE	1959(1)	33 FH1 33	5	8.3426E02	3.302	-.385	102
RAFFLE	1959(1)	FIS 35	5	5.8197E02	3.092	-.045	103
RAFFLE	1959(1)	39 FH1 39	5	1.7148E03	2.843	-1.800	104

Author	Reference	Measured Functions	Notes	Input Value	Uncert-tainty %	Weighted Residual	No.
RAFFLE	1956(1)	(FIS 41)÷FIS 39	5	1.3319E00	6.000	-.270	105
MASLIN	1965(1)	FIS 35	5	5.8371E02	1.449	.109	106
SAPLAKOGLU	1959(1)	FIS 35	5	5.9317E02	2.232	.785	107
WATANABE	1964(1)	FIS 41	5	9.8545E02	4.569	-.587	108
FRAYSSE	1965(1)	(39 FH1 39)÷34 FH1 35	5	1.2425E00	1.557	-.843	109
BORCEA	1970(1)	(39 FH1 39)÷34 FH1 35	5	1.2578E00	1.624	-.050	110
BOLDEMAN	1977(1)	NUB 52	5	3.7549E00	.431	-.783	111
BOLDEMAN	1980(1)	(NUB 33)÷NUB 52	5	6.6049E-01	.255	-.027	112
BOLDEMAN	1980(1)	(NUB 35)÷NUB 52	5	6.4318E-01	.255	-1.636	113
BOLDEMAN	1980(1)	(NUB 39)÷NUB 52	5	7.6614E-01	.243	.617	114
BOLDEMAN	1980(1)	(NUB 41)÷NUB 52	5	7.8028E-01	.231	-.959	115
SPENCER	1982(1)	NUB 52	5	3.7831E00	.221	1.856	116
GWIN	1984(1)	(NUB 33)÷NUB 52	32	6.5996E-01	.340	-1.009	117
GWIN	1984(1)	(NUB 35)÷NUB 52	32	6.4701E-01	.265	.663	118
GWIN	1984(1)	(NUB 39)÷NUB 52	32	7.6530E-01	.257	.157	119
GWIN	1984(1)	(NUB 41)÷NUB 52	32	7.8423E-01	.290	.978	120
HOPKINS	1963(1)	NUB 52	5	3.7767E00	.838	.287	121
HOPKINS	1963(1)	(NUB 33)÷NUB 52	5	6.5483E-01	.895	-1.261	122
HOPKINS	1963(1)	(NUB 35)÷NUB 52	5	6.4587E-01	.838	.000	123
HOPKINS	1963(1)	(NUB 39)÷NUB 52	5	7.5047E-01	.996	-1.943	124
ASPLUND	1963(1)	NUB 52	5	3.7910E00	1.066	.578	125
CONDE	1965(1)	(NUB 35)÷NUB 52	5	6.4222E-01	.847	-.671	126
WHITE	1968(1)	NUB 52	33*	3.8194E00	1.033	1.314	127
AXTON	A1985(3)	NUB 52	33*	3.7547E00	.300	-1.148	128
COLV/AXT	1966(1)	NUB 52	33*	3.7299E00	.806	-1.254	129
COLV/ULL	1965(1)	NUB 52	5	3.7405E00	.438	-1.651	130
COLVIN	1965(1)	(NUB 33)÷NUB 35	5	1.0204E00	.587	-.821	131
COLVIN	1965(1)	(NUB 39)÷NUB 35	5	1.1835E00	.675	-.116	132
COLVIN	1965(1)	(NUB 41)÷NUB 35	5	1.2102E00	.905	-.051	133
COLVIN	1965(1)	(NUB 35)÷NUB 52	5	6.4334E-01	.472	-.832	134
MATHER	1964(1)	(NUB 33)÷NUB 52	5	6.7093E-01	1.235	1.051	135
MATHER	1964(1)	(NUB 35)÷NUB 52	5	6.4145E-01	.537	-1.282	136
MATHER	1964(1)	(NUB 39)÷NUB 52	5	7.7307E-01	1.122	.931	137
ALEK-ROV	1981(1)	NUB 52	33*	3.7618E00	.483	-.320	138
SMITH	1984(1)	NUB 52	33*	3.7678E00	.303	.024	139
EDWARDS	1982(1)	NUB 52	33*	3.7641E00	.711	-.131	140
BOZ-NESH	1977(1)	NUB 52	33*	3.7475E00	.580	-.922	141
DEVOLPI	1972(1)	NUB 52	33*	3.7507E00	.463	-.970	142
ZHANG	1981(1)	NUB 52	5	3.7534E00	.490	-.768	143
SPIEGEL	1981(1)	NUB 52	33	3.7828E00	.759	.530	144
SMITH	1984(1)	ETA 33	5	2.2972E00	.350	-.083	145
SMITH	1984(1)	ETA 35	5	2.0842E00	.386	.537	146
SMITH	1984(1)	ETA 39	5	2.1120E00	.380	-.333	147
SMITH	1984(1)	ETA 41	5	2.1690E00	.419	-.223	148
MACKLIN	1960(1)	ETA 33	5	2.3121E00	.375	1.642	149
MACKLIN	1960(1)	ETA 35	5	2.0757E00	.382	-.526	150
MACKLIN	1962(1)	ETA 39	5	2.1163E00	.851	.091	151
CABELL	1968(1)	F1CAB	35	2.7384E02	4.960	-1.195	152
CABELL	1968(1)	F2CAB	35	1.1719E03	3.176	-.320	153
CABELL	1968(1)	F3CAB	35	3.2690E00	2.776	-.149	154
CABELL	1968(1)	F4CAB	35	3.0339E02	5.836	-.053	155
CABELL	1968(1)	F5CAB	35	3.8710E00	1.602	.512	156
BNL 325	1973(1)	CA 40	36	2.8950E02	.484	.122	157
BNL 325	1973(1)	CA 42	36	1.8500E01	2.162	-.036	158

Author	Reference	Measured Functions	Notes	Input Value	Uncert-tainty %	Weighted Residual	No.
BNL325 +	1973(1)	GC116 39	37	1.3265E00	6.056	-.326	159
WESTCOTT	1960(1)	GC116 40	37	1.0860E00	2.000	.498	160
BNL325 +	1973(1)	GC116 41	37	1.1085E00	2.457	.707	161
WESTCOTT	1960(1)	GC116 42	37	1.1335E00	2.670	-.045	162
BNL325 +	1973(1)	GA116 39	37	1.1846E00	1.521	.125	163
WESTCOTT	1960(1)	GA116 41	37	1.1073E00	.819	-.194	164
LLOYD	1982(1)	(ETA 39)÷FIS 39	4	2.7820E-03	2.072	-.807	165
SPENCER	1985(3)	(ABS 35)+SCR 35	*	6.9000E02	1.000	-.875	166
SPENCER	1985(3)	(ABS 39)+SCR 39	*	1.0258E03	1.000	.003	167

* Indicates new measurement or value changed as discussed in Section 3.

Codes	Causes of Correlated uncertainty.
A	Deruytter Common Uncertainty
B	Deruytter Timing
C	Deruytter-Berceano Assay
D	White U235 Assay
E	Maslin-Saplakoglu Lem./Deruyt.Correction
F	NPL Common Mn-bath Uncertainty
G	Uncertainty in (1+σS/σMn) in Mn-baths
H	Energy Uncertainty of U233 Neutrons
I	Energy Uncertainty of U235 Neutrons
J	Energy uncertainty of PU239 Neutrons
K	Energy Uncertainty of Pu241 Neutrons
L	Energy Uncertainty of CF252 Neutrons
M	Detector slope (Different Authors)
N	Boldeman Detector Slope
O	Gwin Detector Slope
P	Hopkins Detector Slope
Q	Asplund Detector Slope
R	Colvin Detector Slope
S	Mather Detector Slope
U	U233 Delayed Neutrons
V	U235 Delayed Neutrons
W	PU239 Delayed Neutrons
X	PU241 Delayed Neutrons
Y	CF252 Delayed Neutrons
Z	Delayed Gamma-rays
Δ	Boldemans Foil Thickness corrections
$\underline{A}$	Gwin Common Uncertainty
$\underline{B}$	Spiegel Bozorgmanesh Common Uncertainty
$\underline{C}$	Boldeman Common Uncertainty
$\underline{D}$	Diven Common Uncertainty
$\underline{E}$	Boron Pile Common Uncertainty
$\underline{F}$	Smith/Aleksandrov Common Uncertainty
$\underline{G}$	Smith Eta/Nubar Common Uncertainty
$\underline{H}$	Eta Montecarlo Corrections
$\underline{I}$	Mather Common Uncertainty
$\underline{J}$	White Pu239 Assay
$\underline{K}$	White PU241 Assay

(...continued on next page)

Codes	Causes of Correlated uncertainty.
M	Cabell Fluence
N	Cabell Temperature
O	DIDO Reflector g+rs For CAP, ABS PU239
P	DIDO Reflector g+rs For CAP,ABS PU241
Q	CABELL 86° Spectrum Uncertainty
R	Cabell Uncertainty (Sjostrand and Story)
S	Cabell Uncertainty (Sjostrand and Story)
T	Gwin Uncertainty evaluated By Hardy
U	Muelhaus uncertainty evaluated by Axton
V	Spectral Uncertainties from IN1060
W	MTR 70° Spectrum Uncertainty
X	NRU 40° Temperature Uncertainty
Y	NRU Westcott r Uncertainty
Z	Lounsbury Temperature Uncertainty
Δ	Popovic Uncertainty (Na Cross Section)
ρ	Keith Uncertainty (Deruytter correction)
↑	Uncertainty in Co Cross Section
↓	+-20° Uncertainty in T
+	Common Uncertainty in U235 Reactivity
▮	Common Uncertainty in U235 Reactivity
⊂	Half-life U233
⊃	Half-life U234
∩	Half-life PU239
∪	Half-life AM241
α	Spencer Common Uncertainty

No.	Codes	Individual Uncertainties (Percent)			
2	↑	.161			
3	↑	.161			
6	$\underline{\Delta}$	.943			
7	$\underline{\Delta}\subset$	.943	.126		
8	ρ↑⊂	.935	.161	.126	
9	ρ↑⊂	.935	.161	.126	
10	ρ↑∩	.500	.161	.124	
11	⊂	.126			
13	D$\underline{J}$	1.225	.940		
14	D$\underline{K}$	1.225	2.140		
17	⊃∩	-.122	.124		
18	⊂∩	-.126	.124		
19	⊂∩	-.126	.124		
20	∪	.025			
21	$\underline{Z}$	.226			
22	$\underline{Z}$	.247			
23	$\underline{Z}$	.818			
26	$\underline{XY}$	-.660	.697		
27	$\underline{XY}$	.237	.533		
28	$\underline{W}$	1.280			
29	$\underline{W}$	-.531			
30	$\underline{W}$	.433			
31	$\underline{W}$	-.562			
34	$\underline{Q}$	1.802			
35	$\underline{Q}$	.862			
36	$\underline{Q}$	3.102			
38	$\underline{V}$	.479			
39	$\underline{V}$	.479			
40	$\underline{R}$	1.701			
41	$\underline{R}$	1.701			
42	$\underline{S}$	2.830			
43	$\underline{S}$	2.830			
44	+	1.000			
45	+	1.000			
46	$\underline{T}$	.380			
47	$\underline{T}$	.382			
50	▮	1.500			
51	▮	1.500			
52	$\underline{U}$↓	1.233	.691		
53	$\underline{U}$↓	1.233	1.614		
96	AB∩	.207	.232	.124	
97	ABC⊃	.207	.232	.185	.122
98	B	.232			
99	D$\underline{J}$	1.225	.940		
100	D$\underline{K}$	1.225	2.140		
101	C⊃	.300	.122		
102	⊂	.126			
104	∩	.124			
106	E	1.000			
107	E	-2.000			
109	⊃∩	-.122	.124		
110	⊃∩	-.122	.124		
111	LYZ$\underline{C}$	.056	.106	.070	.010

No.	Codes	Individual Uncertainties (Percent)								
112	HLMNUYZΔC	.074	-.056	-.033	-.104	.009	-.106	.040	.024	.041
113	ILMNVYZΔC	.069	-.057	-.047	-.149	.021	-.106	.040	.047	.060
114	JLMNWYZΔC	.061	-.056	-.018	-.056	.011	-.106	.110	.005	.010
115	KLMNXYZΔC	.074	-.056	-.017	-.052	.055	-.106	.110	.028	.020
116	LMOYZ	. 019	.007	.022	.106	.051				
117	UYZA	.009	-.106	.120	.139					
118	VYZA	.021	-.106	.040	.117					
119	WYZA	.011	-.106	.096	.125					
120	XYZA	.055	-.106	.120	.078					
121	LMPYZ	.030	.018	.058	.106	.100				
122	HLMPUYZΔD	.039	-.030	-.018	-.056	.009	-.106	.025	.006	.341
123	ILMPVYZΔD	.036	-.030	-.025	-.079	.021	-.106	.025	.056	.383
124	JLMPWYZΔD	.033	-.030	-.009	-.029	.011	-.106	.050	.051	.550
125	LMQYZ	.077	-.003	-.010	.106	.201				
126	ILMQVYZ	.094	-.077	-.083	-.263	.021	-.106	.125		
127	FGL	.211	.073	.057						
128	FGL	.211	.073	.057						
129	FGLYE	.211	.073	.057	.106	.231				
130	LYE	.013	.106	.231						
131	HIMRUV	.017	-.016	.003	.009	.009	-.021			
132	IJMRVW	-.016	.014	.007	.021	-.021	.011			
133	IKMRVX	-.016	.017	.007	.022	-.021	.055			
134	ILMRVYΔ	.016	-.013	-.011	-.034	.021	-.106	.056		
135	HLMSUYZΔI	.074	-.056	-.033	-.104	.009	-.106	.050	.067	1.000
136	ILMSVYZΔI	.069	.057	-.047	-.149	.021	-.106	.050	.084	.300
137	JLMSWYZΔI	.061	-.056	-.018	-.056	.011	-.106	.136	.060	.500
138	GLF	.073	.028	.111						
139	GLMFG	.073	.034	.003	.111	.150				
140	FGLMY	.211	.073	.028	-.001	.106				
141	GLMB	.073	.028	-.001	.441					
142	G	.073								
143	LMYZ	.077	.010	.106	.070					
144	GLB	.073	.055	.508						
145	HMGH	.036	.008	.150	.167					
146	IMGH	.034	.009	.150	.167					
147	JGH	_.030	.150	.167						
148	KGH	_.036	.150	.167						
149	HMH	_.036	.008	.167						
150	IMH	.034	.009	.167						
151	JMH	.030	.002	.167						
152	MN↑	2.230	.310	.161						
153	MN↑	2.230	1.210	.161						
154	N	-.540								
155	MN↑U	2.230	-1.310	.161	-.090					
156	U	-.016								
159	Q	2.700								
161	P	1.100								
163	Q	.680								
164	P	.370								
166	α	.707								
167	α	.707								

	Parameter	Fitted	Uncertainty	Relative Uncertainty %
1	SCA 33	12.1861	.6681	5.483
2	SCA 35	15.9828	1.1051	6.914
	SCA 39	7.8966	.9739	12.333
	SCA 41	12.1878	2.6168	21.470
	SCR 33	10.9169	.8788	8.050
	SCR 35	14.2071	1.2671	8.919
	SCR 39	6.8000	1.7494	25.726
	SCR 41	11.1717	3.6126	32.337
	ABS 33	576.2174	1.3000	.226
	ABS 35	681.8303	1.3099	.192
	ABS 39	1018.9667	2.8747	.282
	ABS 41	1373.2025	9.0860	.662
	FIS 33	530.6953	1.3424	.253
	FIS 35	582.7836	1.1442	.196
	FIS 39	747.6236	2.0105	.269
	FIS 41	1011.8730	6.5974	.652
	CA 33	45.5221	.6990	1.535
	CA 35	99.0467	.7432	.750
	CA 39	271.3431	2.1340	.786
	CA 40	289.3296	1.3933	.482
	CA 42	18.5144	.4001	2.161
	CA 41	361.3294	4.9387	1.367
	CAP 34	95.8369	1.9849	2.071
	NUB 33	2.4950	.0040	.161
	NUB 35	2.4334	.0036	.147
	NUB 39	2.8822	.0051	.177
	NUB 41	2.9463	.0058	.196
	NUB 52	3.7676	.0047	.126
	ETA 33	2.2979	.0041	.180
	ETA 35	2.0799	.0035	.167
	ETA 39	2.1147	.0051	.243
	ETA 41	2.1710	.0077	.353
	ALPHA 33	.0858	.0014	1.634
	ALPHA 35	.1700	.0013	.792
	ALPHA 39	.3629	.0031	.841
	ALPHA 41	.3571	.0049	1.376
	WGA 33	.9995	.0011	.107
	WGA 35	.9789	.0008	.084
	WGA 39	1.0782	.0024	.227
	WGA 41	1.0442	.0020	.190
	WGF 33	.9955	.0014	.142
	WGF 35	.9774	.0008	.083
	WGF 39	1.0555	.0022	.212
	WGF 41	1.0445	.0055	.527
	F3ETA 33	742.2525	2.3692	.319
	F3ETA 35	718.5735	2.2183	.309
	F3ETA 39	1175.7377	5.5862	.475
	F3ETA 41	1679.8787	14.2078	.846

681.83
15.98
697.81

The value of χ^2 is 103. There are 167 measurements, and 38 unknown parameters, leading to 129 degrees of freedom.

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000											
2	.033	1.000										
3	.004	.016	1.000									
4	.001	.004	.002	1.000								
5	.716	.044	.005	.002	1.000							
6	.035	.811	.018	.004	.047	1.000						
7	.007	.031	.522	.003	.009	.035	1.000					
8	.002	.004	.002	.716	.002	.005	.004	1.000				
9	-.265	-.123	-.014	-.005	-.355	-.132	-.027	-.006	1.000			
10	-.071	-.462	-.026	-.008	-.096	-.496	-.049	-.010	.269	1.000		
11	-.038	-.116	-.108	-.016	-.051	-.121	-.204	-.019	.143	.286	1.000	
12	-.015	-.043	-.020	-.083	-.020	-.046	-.038	-.100	.057	.100	.187	1.000
13	-.228	-.114	-.011	-.003	-.305	-.123	-.020	-.004	.861	.249	.112	.040
14	-.075	-.380	-.026	-.008	-.100	-.409	-.048	-.009	.282	.825	.276	.092
15	-.043	-.133	-.072	-.014	-.058	-.141	-.135	-.017	.163	.309	.671	.174
16	-.017	-.045	-.018	-.071	-.022	-.048	-.034	-.085	.062	.103	.170	.848
17	-.055	-.010	-.005	-.002	-.074	-.010	-.010	-.003	.207	.023	.051	.029
18	-.011	-.229	-.006	-.003	-.014	-.246	-.011	-.003	.040	.493	.080	.034
19	-.010	-.031	-.078	-.007	-.014	-.031	-.147	-.009	.039	.094	.715	.088
20	.000	.000	.000	.000	.000	.000	.000	-.001	.000	.001	.002	.006
21	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	-.001
22	-.006	-.019	-.013	-.059	-.007	-.020	-.024	-.071	.021	.045	.117	.707
23	.001	-.001	.000	.000	.002	-.001	.000	.000	-.004	.002	.000	.000
24	.041	.031	.000	.000	.055	.033	.001	.000	-.155	-.066	-.008	.000
25	.017	.051	.001	.000	.023	.054	.002	.000	-.065	-.109	-.017	-.002
26	.017	.028	-.008	.000	.023	.031	-.016	.000	-.064	-.058	.073	.003
27	.017	.028	-.002	-.007	.023	.030	-.004	-.009	-.065	-.059	.015	-.090
28	.011	.019	-.001	-.001	.015	.021	-.001	-.001	-.043	-.041	.003	.007
29	.049	.022	.003	.001	.065	.023	.005	.001	-.183	-.047	-.029	-.015
30	.009	.128	.001	.001	.012	.138	.001	.001	-.035	-.275	-.020	-.008
31	.009	.008	.040	.002	.011	.008	.075	.002	-.032	-.032	-.366	-.022
32	.007	.013	.003	.021	.010	.014	.005	.026	-.027	-.029	-.028	-.258
33	-.016	.008	-.003	-.002	-.022	.009	-.007	-.002	.061	-.017	.031	.021
34	.009	-.122	.001	-.001	.011	-.132	.001	-.001	-.032	.262	.007	.009
35	.004	.013	-.050	-.002	.006	.016	-.094	-.003	-.016	-.011	.454	.026
36	.002	.003	-.004	-.025	.003	.003	-.007	-.030	-.009	-.004	.035	.300
37	.056	-.025	-.002	.000	.075	-.027	-.003	.000	-.210	.054	.019	.005
38	-.012	.088	-.004	-.001	-.016	.095	-.008	-.001	.046	-.188	.030	.006
39	-.007	-.032	.031	-.001	-.010	-.035	.059	-.002	.028	.058	-.282	.015
40	.000	-.001	.000	.002	.000	-.001	.000	.003	.000	.002	.002	-.026
41	.053	-.024	-.005	-.002	.072	-.025	-.009	-.002	-.202	.052	.047	.025
42	-.014	-.010	-.002	-.001	-.019	-.011	-.003	-.001	.054	.022	.017	.008
43	-.019	-.021	.016	-.007	-.026	-.024	.029	-.009	.073	.041	-.141	.088
44	-.006	-.011	-.004	.043	-.007	-.012	-.008	.051	.021	.025	.041	-.513
45	-.111	-.078	-.010	-.004	-.149	-.083	-.020	-.004	.419	.171	.104	.044
46	-.039	-.181	-.015	-.005	-.052	-.194	-.029	-.006	.147	.393	.158	.057
47	-.027	-.065	-.025	-.013	-.037	-.069	-.047	-.016	.103	.148	.237	.158
48	-.013	-.036	-.018	.000	-.017	-.039	-.035	.000	.048	.084	.171	-.004

	13	14	15	16	17	18	19	20	21	22	23	24
13	1.000											
14	.283	1.000										
15	.176	.357	1.000									
16	.073	.125	.221	1.000								
17	-.320	-.019	-.035	-.023	1.000							
18	.003	-.086	-.003	-.009	.069	1.000						
19	-.015	.035	-.039	.020	.102	.111	1.000					
20	.000	.001	.002	.005	.000	.000	.001	1.000				
21	.000	.000	.000	-.001	.000	.000	.000	.003	1.000			
22	-.023	.004	.024	.225	.084	.074	.134	.004	-.001	1.000		
23	-.001	.002	.001	.001	-.007	.001	-.001	.000	.000	.000	1.000	
24	-.265	-.095	-.056	-.025	.221	.030	.042	.000	.000	.034	-.004	1.000
25	-.100	-.223	-.082	-.037	.071	.151	.054	.000	.000	.046	-.001	.575
26	-.100	-.105	-.160	-.063	.073	.059	.250	.000	.000	.089	-.001	.512
27	-.099	-.104	-.092	-.084	.070	.055	.107	.001	.000	.277	-.001	.466
28	-.064	-.070	-.049	-.024	.042	.036	.050	.000	.000	.046	-.001	.322
29	.089	-.041	-.007	.001	-.513	-.020	-.032	.000	.000	-.029	.001	.718
30	-.041	.031	-.009	-.005	.014	-.533	-.019	.000	.000	-.007	.000	.468
31	-.008	-.002	.212	.002	-.045	-.053	-.693	.000	.000	-.044	.000	.320
32	.004	-.001	.032	.210	-.057	-.049	-.068	-.002	.000	-.755	.000	.212
33	-.456	-.062	-.060	-.033	.989	.065	.098	.000	.000	.082	-.006	.248
34	-.068	-.329	-.092	-.040	.071	.969	.096	.000	.000	.069	.000	.052
35	-.071	-.081	-.356	-.052	.106	.105	.948	.001	.000	.118	-.001	.058
36	-.058	-.055	-.081	-.251	.094	.078	.124	.002	.000	.887	-.001	.046
37	-.051	.071	.048	.021	-.293	-.015	-.019	.000	.000	-.019	-.005	-.088
38	.065	.112	.070	.030	-.039	-.504	-.025	.000	.000	-.028	.001	-.040
39	.042	.066	-.054	.039	-.029	.000	-.328	.000	.000	-.024	.000	-.024
40	.001	.002	.003	-.018	-.002	.000	-.001	.000	.000	-.025	.000	-.001
41	-.486	.023	-.001	-.006	.559	.056	.063	.000	.000	.054	.008	.090
42	.029	-.278	-.033	-.014	.044	.468	.054	.000	.000	.034	.000	.012
43	.053	.016	-.389	.084	.033	.047	.177	.000	.000	.050	.001	.000
44	.011	.015	.041	-.628	.018	.021	.017	-.003	.000	-.104	.000	.003
45	.326	.159	.095	.036	.152	.057	.050	.000	.000	.034	.005	.702
46	.111	.373	.149	.044	.061	.118	.073	.000	.000	.046	.001	.465
47	.086	.146	.296	.158	.027	.035	.040	.001	.000	.079	.001	.323
48	.047	.089	.207	.105	-.002	.012	.036	.000	.000	-.148	.000	.168

	25	26	27	28	29	30	31	32	33	34	35	36
25	1.000											
26	.557	1.000										
27	.506	.570	1.000									
28	.361	.369	.352	1.000								
29	.456	.399	.360	.254	1.000							
30	.740	.431	.390	.281	.406	1.000						
31	.335	.466	.297	.211	.317	.328	1.000					
32	.216	.196	.232	.137	.229	.221	.211	1.000				
33	.082	.084	.082	.049	-.496	.019	-.041	-.055	1.000			
34	.198	.082	.078	.051	-.009	-.513	-.050	-.047	.077	1.000		
35	.077	.284	.129	.063	-.028	-.015	-.716	-.074	.111	.119	1.000	
36	.063	.118	.315	.057	-.029	-.005	-.045	-.850	.097	.088	.142	1.000
37	-.038	-.033	-.033	-.021	.113	-.011	.006	.012	-.268	-.032	-.033	-.029
38	-.098	-.042	-.042	-.027	-.002	.261	.012	.020	-.046	-.505	-.046	-.042
39	-.037	-.059	-.037	-.017	.002	-.021	.224	.023	-.034	-.016	-.290	-.042
40	-.004	-.002	.003	.000	.001	-.003	.000	.018	-.002	-.001	-.002	-.016
41	.039	.030	.029	.017	-.351	.002	-.033	-.041	.600	.047	.059	.056
42	.038	.023	.017	.009	-.016	-.318	-.040	-.033	.037	.512	.061	.041
43	.027	.006	.001	.000	-.016	-.005	-.264	-.009	.022	.041	.290	.010
44	.015	.006	.028	.003	-.008	.002	.002	-.183	.015	.016	.003	.194
45	.451	.386	.346	.242	.563	.385	.266	.175	.092	.014	.017	.017
46	.751	.438	.390	.280	.387	.644	.300	.192	.041	.019	.021	.024
47	.360	.535	.319	.218	.281	.317	.443	.173	.012	-.003	-.057	.004
48	.183	.161	.282	.116	.157	.168	.147	.358	-.009	-.011	-.033	-.196

	37	38	39	40	41	42	43	44	45	46	47	48
37	1.000											
38	.021	1.000										
39	.017	.037	1.000									
40	.001	.002	.003	1.000								
41	.414	-.016	-.019	-.001	1.000							
42	.000	.176	.000	-.001	.033	1.000						
43	.006	-.002	.260	.000	.033	.066	1.000					
44	.00[illegible]	-.003	.008	.038	.014	.026	.059	1.000				
45	.032	.012	.003	.000	.189	.048	.060	.018	1.000			
46	.017	-.005	.004	-.002	.055	.154	.055	.032	.531	1.000		
47	.015	.011	-.167	.000	.032	.028	.403	.073	.375	.436	1.000	
48	.012	.016	.039	-.154	.004	.011	.130	.604	.190	.230	.342	1.000

Capture Cross Sections

197 Au	98.65 ± 0.09b	a
59 Co	37.18 ± 0.06b	b
55 Mn	13.41 ± 0.04b	c

Absorption

10 B	3838 ± 6b	a
Sulphur	0.535 ± 0.006b	c
Natural boron (Argonne)	757.3 ± 3.0b	d

Half-lives

233 U (Alpha)	(1.592 ± 0.002)E05y	e
234 U (Alpha)	(2.457 ± 0.003)E05y	e
239 Pu (Alpha)	(2.411 ± 0.003)E04y	e
241 Pu (Beta)	(14.35 ± 0.1)y	e

a	Holden (1981)
b	Mughabgab, Divadeenam, and Holden (1981)
c	Axton (1986)
d	Sjostrand and Story (1961)
e	Reich (1985)

Parameter	Fitted	Uncertainty	Relative Uncertainty %
SCA 33	7.8630	6.1136	77.751
SCA 35	12.8074	3.1269	24.415
SCA 39	18.6407	31.2208	167.487
SCA 41	9.3639	33.1126	353.619
SCR 33	8.7259	2.5856	29.631
SCR 35	11.8099	2.6534	22.468
SCR 39	.8936	6.1200	684.850
SCR 41	22.0204	22.8225	103.643
ABS 33	577.9050	1.9355	.335
ABS 35	683.7142	1.9015	.278
ABS 39	1021.8393	3.7405	.366
ABS 41	1373.6196	10.9948	.800
FIS 33	532.2123	1.8558	.349
FIS 35	584.2303	1.5465	.265
FIS 39	749.3155	2.3986	.320
FIS 41	1012.3920	7.6546	.756
CA 33	45.6927	.7183	1.572
CA 35	99.4839	.8220	.826
CA 39	272.5238	2.4205	.888
CA 40	289.3312	1.3933	.482
CA 42	18.5146	.4001	2.161
CA 41	361.2276	5.4576	1.511
CAP 34	95.8339	1.9849	2.071
NUB 33	2.4941	.0041	.164
NUB 35	2.4327	.0036	.148
NUB 39	2.8818	.0051	.178
NUB 41	2.9455	.0058	.197
NUB 52	3.7672	.0048	.126
ETA 33	2.2969	.0042	.183
ETA 35	2.0787	.0036	.173
ETA 39	2.1132	.0053	.251
ETA 41	2.1709	.0078	.359
ALPHA 33	.0859	.0014	1.637
ALPHA 35	.1703	.0014	.811
ALPHA 39	.3637	.0032	.880
ALPHA 41	.3568	.0050	1.402
WGA 33	.9993	.0011	.109
WGA 35	.9788	.0008	.085
WGA 39	1.0779	.0025	.231
WGA 41	1.0442	.0020	.190
WGF 33	.9954	.0014	.145
WGF 35	.9774	.0008	.083
WGF 39	1.0555	.0023	.214
WGF 41	1.0455	.0058	.553
F3ETA 33	743.7336	2.6484	.356
F3ETA 35	719.9649	2.4339	.338
F3ETA 39	1177.7338	5.8356	.495
F3ETA 41	1683.2380	14.4175	.857

The value of χ^2 is 100. There are 159 measurements, and 38 unknown parameters, leading to 121 degrees of freedom.

Table 8. Results with Maxwellian Data Omitted

Parameter	Fitted	Uncertainty	Relative Uncertainty %
SCA 33	12.3204	.6999	5.681
SCA 35	16.2388	1.1994	7.386
SCA 39	7.8966	.9776	12.380
SCA 41	11.9740	2.5857	21.595
SCR 33	11.1480	.9083	8.147
SCR 35	14.5259	1.3723	9.448
SCR 39	6.8131	1.7462	25.630
SCR 41	10.8285	3.8599	35.646
ABS 33	575.2391	1.8484	.321
ABS 35	681.1651	1.6956	.249
ABS 39	1018.8813	3.6895	.362
ABS 41	1382.1872	14.9131	1.079
FIS 33	533.2694	2.4363	.457
FIS 35	585.0603	1.6181	.277
FIS 39	748.5181	2.5460	.340
FIS 41	1020.5836	11.4887	1.126
CA 33	41.9697	1.7551	4.182
CA 35	96.1049	1.7408	1.811
CA 39	270.3632	3.1728	1.174
CA 41	361.6036	6.1868	1.711
NUB 33	2.4856	.0054	.218
NUB 35	2.4261	.0046	.188
NUB 39	2.8794	.0060	.207
NUB 41	2.9406	.0065	.220
NUB 52	3.7644	.0050	.132
ETA 33	2.3042	.0062	.271
ETA 35	2.0838	.0053	.255
ETA 39	2.1153	.0066	.311
ETA 41	2.1713	.0087	.399
ALPHA 33	.0787	.0035	4.494
ALPHA 35	.1643	.0032	1.962
ALPHA 39	.3612	.0046	1.280
ALPHA 41	.3543	.0059	1.668
WGA 33	.9988	.0012	.120
WGA 35	.9787	.0009	.092
WGA 39	1.0767	.0029	.269
WGA 41	1.0444	.0020	.191
WGF 33	.9966	.0020	.201
WGF 35	.9778	.0009	.092
WGF 39	1.0562	.0029	.275
WGF 41	1.0452	.0070	.670
F3ETA 33	746.4586	5.0978	.683
F3ETA 35	721.2735	3.6582	.507
F3ETA 39	1179.4821	9.4998	.805
F3ETA 41	1693.1349	30.0340	1.774

The value of X^2 is 48. There are 101 measurements, and 38 unknown parameters, leading to 63 degrees of freedom.

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