AECU-3527

COMPILATION OF TECHNICAL REPORTS ON THE SUBJECT OF
FAST NEUTRON SCATTERING

PART III

NUCLEAR PHYSICS SECTION

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Joint Program on ONR and AEC
Office of Naval Research Contract
N6-ORL-156 task 2
Project NR-024-028

WESTINGHOUSE RESEARCH LABORATORIES
PITTSBURGH • PENNSYLVANIA

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I

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Fast Neutron Scattering

Part III

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113-001

II

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III

Technical Reports on the Subject of Fast Neutron Scattering

Part III

Nuclear Physics Section, Westinghouse Research Laboratories

This compilation of technical reports on the subject of fast neutron scattering is the result of research sponsored by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and the Westinghouse Research Laboratories. For completeness, this compilation contains copies of papers which have been published in the Physical Review and additional reports which are unsuitable for publication due to lack of general interest. This technical report has been distributed only to those having a specific interest in fast neutron scattering.

1

Research Memo 60-94511-6-M-18

October 10, 1956

W. S. Emmerich

RESONANCE CAPTURE INTEGRALS AS A CHECK ON THE NEUTRON ABSORPTION CROSS SECTION IN MULTIGROUP TABULATIONS

For tabulations of multigroup neutron cross sections it is necessary to determine the average absorption cross section in each lethargy group.¹ This requires knowledge of the absorption cross section as a function of incident neutron energy.

Up to the present time, this quantity has been measured directly only at thermal energies or near strong resonances.² There exist also measurements for an average neutron energy of 1 Mev and in a few cases considerable details are known through activation experiments between $\sim .01$ and ~ 10 Mev.² This process is limited, however, to those isotopes for which the reaction product emits nuclear radiation with a measurable half-life.

Theoretically, the absorption cross section is expected to vary as $E^{-1/2}$ at low energies in the absence of nearby resonances whereas the scattering cross section may be assumed constant in this region.³ A limited amount of information can be gained from the Breit-Wigner theory of single level resonances and some semi-empirical data on average resonance widths.² By utilizing all available information of this type, it is possible to estimate the absorption cross section in some regions of the energy spectrum. At other energies, the absorption cross section must either be neglected or given an arbitrary value. In order to gain additional insight into the behavior in such energy regions, the experimental resonance capture integral may be utilized. It is defined as

$$\int_{E_1}^{\infty} \sigma_a \frac{dE}{E}$$

and can be determined through pile oscillator or activation measurements.⁴ The lower limit E_1 depends on details in the experiment and is usually

0.4 ev due to the use of cadmium absorbers. A summary of the methods and a table of results are given by R. L. Macklin and H. S. Pomerance.⁴

A comparison of the measured resonance capture integral with the same quantity computed from the absorption cross sections in the multigroup tabulation is shown in Table I. Although the resonance capture integral is not a sufficient condition for insuring the correctness of the absorption cross section, an indication of the magnitude of absorption in energy regions not well known may be inferred from the results. An example of computing the resonance capture integral is given in the appendix.

The author is indebted to Dr. R. L. Hellens and Dr. Harvey Amster for suggesting the use of resonance capture integrals.

TABLE I

Resonance Capture Integrals (10^{-24} cm^2)

<u>Element</u>	<u>Calculated</u>	<u>Experimental</u>	
		<u>Activation</u>	<u>Pile Oscillator</u>
Al	0.31	0.16	0.18
Fe	1.28	--	2.1
Zr	0.96	--	3
Nb	4.48	3.87	8.3
Hf	1975	~ 1750	1300
Au	1864	1558	--
Pb	.065	--	0.1
Th	63	69.8	--

Appendix

As an illustration of numerical computation, the resonance capture integral will be calculated for niobium in the 78 group structure of reference 1.

In the notation of reference 1, the resonance capture integral is given by

$$\int_{E_1}^{\infty} \sigma_a \frac{dE}{E} = \int_{0.625 \text{ ev}}^{14.5 \text{ Mev}} \sigma_a \frac{dE}{E} = \sum_{n=1}^{78} \Delta u_n \langle \sigma_a \rangle_n$$

The contributions from the separate groups are as follows: *

n	$\langle \sigma_a \rangle_n$	$\Delta u_n \langle \sigma_a \rangle_n$	n	$\langle \sigma_a \rangle_n$	$\Delta u_n \langle \sigma_a \rangle_n$	n	$\langle \sigma_a \rangle_n$	$\Delta u_n \langle \sigma_a \rangle_n$
78	.21	.061	56	1.40	.350	34	.19	.048
77	.18	.054	55	.40	.100	33	.17	.042
76	.15	.037	54	.50	.125	32	.16	.040
75	.13	.033	53	.60	.150	31	.14	.035
74	.12	.030	52	0.00	.000	30	.12	.030
73	.11	.028	51	.40	.100	29	.10	.025
72	.09	.022	50	.30	.075	28	.09	.022
71	.08	.020	49	.70	.175	27	.07	.018
70	.07	.018	48	.40	.100	26	.06	.015
69	.06	.015	47	.50	.125	25	.06	.015
68	.06	.015	46	.60	.150	24	.05	.012
67	.05	.012	45	.60	.150	23	.05	.012
66	.40	.100	44	.60	.150	22	.04	.010
65	.30	.075	43	.40	.100	21	.04	.005
64	.30	.075	42	.30	.075	20	.04	.005
63	1.40	.350	41	.30	.075	19	.03	.004
62	.20	.050	40	.30	.075	18	.03	.004
61	.10	.025	39	.30	.075	17	.02	.002
60	.10	.025	38	.20	.050	16	.02	.002
59	.60	.150	37	.20	.050	15	.01	.001
58	1.90	.475	36	.20	.050	14	.01	.001
57	0.00	.000	35	.20	.050	13	0.00	.000
								Total
								4.368

$\langle \sigma_a \rangle_n$ in the remaining groups is due to charged particle reactions and should not be included here.

In order to compare the calculated values with the measured ones, it is necessary to equalize the lower limit. In the present example, it is assumed that σ_a varies as $E^{-1/2}$ between 0.400 and 0.625 ev. Normalization to the calculated value in group 78 gives

$$\Delta u < \sigma_a > = .446 \times .25 = .112 \text{ barn}$$

which has to be added to the computed resonance capture integral giving 4.48 barns.

Measured values of the resonance capture integral are quoted in reference 4 and partially reproduced in Table I. For niobium, they are 8.3 from pile oscillator and 3.87 from activation experiments, the latter being considered the more accurate figure. The result indicates that the estimates made in reference 1 are consistent with the measured values of the resonance capture integral.

References

- ¹ J. B. Weddell, W. S. Emmerich, and H. J. Amster, Multigroup Neutron Cross Sections, Part I, (1956).
- ² D. J. Hughes and J. A. Harvey, Neutron Cross Sections, BNL 325, (1956).
- ³ J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics, J. Wiley and Sons (1952).
- ⁴ Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, August 1955, Volume 5, page 96, Paper No. P/833; see also a discussion by E. Wigner, page 175.

* In the case of niobium, chosen as example here, all the $\langle \sigma_a \rangle_n$ had to be estimated because no experimental data have been published except the total cross section and the thermal absorption cross section. The estimates were aided by knowledge of the parameters for resonances of similar energies in nearby elements such as molybdenum.

MULTIGROUP NEUTRON CROSS SECTIONS

Preliminary Note

The majority of information on which the present results are based has been obtained from experimental neutron cross section data. While ultimately it is expected that input information for nuclear reactor codes can be derived from such microscopic nuclear data, this aim has certainly not yet been achieved. It is therefore recommended that computations made with input data taken from this report be checked and corrected as far as possible by more empirical methods.

Introduction

This tabulation was undertaken primarily to provide the input cross sections for P-1 and B-1 multigroup codes.^{1,2} Seventy-eight groups were used with the group separation energies given in Table I. The tabulated values of the various quantities are lethargy averages over each group interval. The lethargy is defined as

$$u = \ln \frac{10 \text{ Mev}}{E}$$

where E is the neutron energy in Mev. Angle brackets will denote such an average. That is,

$$\langle x \rangle_j = \frac{1}{\Delta u_j} \int_{u_{j-1}}^{u_j} x(u) du, \quad (1)$$

where $\Delta u_j = u_j - u_{j-1}$ is the lethargy interval in group j .

For each element covered in this survey, the following group quantities are furnished:

- 1.) The elastic scattering cross section: $\langle \sigma_s \rangle_j$
- 2.) The inelastic scattering cross section: $\langle \sigma_{in} \rangle_j$
- 3.) The capture and charged particle cross section:
 $\langle \sigma_c \rangle_j$
- 4.) The fission cross section: $\langle \sigma_f \rangle_j$
- 5.) The (n, 2n) cross section: $\langle \sigma_{n,2n} \rangle_j$
- 6.) The mean cosine of the scattering angle in the laboratory coordinate system:

$$\bar{\mu}_j = \langle B_1 \rangle / \langle \sigma_s \rangle_j, \quad (2)$$

$$\text{where } B_1(u) = 2\pi \int_{-1}^1 \mu \sigma_s(u, \mu) d\mu,$$

and $\sigma_s(u, \mu)$ is the differential elastic scattering cross section at the lethargy u and the scattering angle $\cos^{-1} \mu$ in the laboratory system.

- 7.) The mean lethargy gain per elastic collision:

$$\xi_j = \langle \xi \sigma_s \rangle_j / \langle \sigma_s \rangle_j, \quad (3)$$

$$\text{where } \xi \sigma_s(u) = 2\pi \int_{-1}^1 \Delta u(\mu) \sigma_s(u, \mu) d\mu,$$

and $\Delta u(\mu)$ is the lethargy gain in a collision in which the neutron is elastically scattered through an angle $\cos^{-1} \mu$.

- 8.) The inelastic scattering matrix:

This is an array of elements σ_{jn} , each of which is the cross section per unit exit lethargy interval for neutrons initially in group j to

be scattered inelastically into group n:

$$\sigma_{jn} = \frac{1}{\Delta u_j \Delta u_n} \int_{u_{n-1}}^{u_n} \int_{u_{j-1}}^{u_j} \sigma(u', u) du' du, \quad (4)$$

where $\sigma(u', u) du$ is the cross section for inelastically scattering a neutron with lethargy u' into the interval of lethargy between u and $u + du$. The diagonal elements σ_{jj} do not include contributions from elastic scattering, only from inelastic scattering. They are omitted in certain machine codes. See also the discussion of the inelastic scattering cross section.

Although 1.) through 8.) are taken as definitions of the tabulated quantities, the lack of data frequently required estimates to be made without actually averaging in the specified manner. In order to provide a complete set of data for computational purposes, tabulations have been furnished for all the groups even in the absence of any experimental guidance. A number of tables are definitely in need of additional experimental data and further analysis. The number of digits to which the tabulated values are listed has been kept constant for use as machine input and do not indicate the known accuracy of the data.

Most of the quantities are based on the compilation of experimental neutron cross sections in BNL 325,³ with much additional material, especially on angular distributions of fast neutrons, having been collected privately.⁴ In addition to empirical methods, the complex potential model for neutron interaction was of help in estimating gaps in the data.⁵ In the present tabulation, only the complex square well model has been used, rather than the newer forms of the potential now under investigation.^{5,7} The treatment of the individual quantities will be discussed in the following sections.

1.) The elastic scattering cross section was obtained by subtracting all the other cross sections from the total cross section. In the Mev

range, the accuracy was greatly aided where sphere experiments were available to give the non-elastic cross sections.⁵ Otherwise, information from neighboring or similar elements was used as a guide. In the ev range, below resonances, the scattering cross section was taken to be equal to its value at thermal energies. Where resonance parameters were available, they were used both in the determination and in the averaging of the scattering cross section.

2.) The inelastic scattering cross section was obtained principally from sphere experiments and gamma ray yields. In the absence of experimental data, estimates were made on the basis of known excited states in neighboring elements.

For machine codes in which the contributions of the diagonal elements in the inelastic scattering matrices are omitted, the equivalent inelastic scattering cross section:

$$\langle \sigma'_{in} \rangle_j = \sum_{n=j+1}^{40} \sigma_{jn} \Delta u_n \quad (5)$$

should be used. It is given in the last row of the inelastic scattering matrix.

3.) The capture cross section includes not only radiative neutron capture but also charged particle reactions. The cross section for radiative capture was deduced from resonance parameters or otherwise estimated from measured cross sections. Near thermal energies, the capture cross section was assumed to be the difference between the total and a constant scattering cross section. In some cases, this was smaller than the experimental uncertainty, and an $E^{-1/2}$ relationship was used with normalization to the thermal value.

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The resonance capture integral

$$\int_{E_1}^{\infty} \sigma_c \frac{dE}{E} \quad (6)$$

was evaluated and compared to experimentally determined values.⁸

4.) The fission cross section was obtained either from direct experimental data or from resonance parameters.

5.) Cross sections for reactions such as $(n, 2n)$, (n, p) , (n, α) , etc., were included only for those elements where they had been measured experimentally and were of appreciable magnitude.

6.) The $\bar{\mu}_j$ were taken from experimental values whenever possible, but since measurements have been made for most substances at only a few discrete energies, the complex square well model has been used to estimate $\bar{\mu}$ in all other cases. The parameters for this model have been determined by finding what values will reproduce most accurately the experimental data and by interpolating the parameters for the lethargies in between.⁹

7.) The $\xi \sigma_s$ were evaluated conveniently as a linear combination of the Legendre Polynomial expansion coefficients of $\sigma_s(u, \mu)$.^{1, 10} The coefficients themselves were obtained from a sum over the expansion coefficients of the differential cross sections in the center-of-mass coordinates.

8.) The inelastic scattering matrices were constructed by means of energy spectra of scattered neutrons. Since measurements of the inelastic scattering cross sections or of de-excitation gamma-ray yields for individual excited states exist only in a few cases, many

interpolations were made with the aid of theory. For aluminum and heavier elements, the evaporation model was used at those energies where the density of levels appeared sufficiently great to justify its use.¹¹

A detailed account of the techniques used to obtain the various cross sections as a function of neutron energy, and their utilization in the construction of the type of table contained in this survey is being prepared separately.¹²

The authors are indebted to Dr. H. J. Amster and Dr. R. L. Hellens for many discussions regarding the definitions and meanings of the quantities tabulated in this report. Dr. R. M. Sinclair, Mr. J. A. Eisele, and Miss Nancy Camp assisted in various stages of the computation.

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2. R. L. Hellens, Neutron Slowing Down in Group Diffusion Theory, WAPD--1114; also Multigroup Fourier Transform Code, MUFT III.
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9. W. S. Emmerich and R. M. Sinclair, Phys. Rev. 104, 1399 (1956)
10. H. Amster, J. Appl. Phys. 27, 307 (1956); 27, 663 (1956)
11. E. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics, John Wiley and Sons (1952)
12. J. A. Eisele, W. S. Emmerich and J. B. Weddell, Westinghouse Research Report 6-94511-6-R18 (1957)

TABLE I - 78 Group Structure

<u>j</u>	<u>u</u>	<u>E(ev)</u>	<u>u</u>	<u>j</u>	<u>u</u>	<u>E(ev)</u>	<u>u</u>
0	-.375	14.5x10 ⁶	0.125	40	7.00	9.12	0.25
1	-.250	12.8		41	7.25	7.10	
2	-.125	11.3		42	7.50	5.53	
3	0.000	10.0		43	7.75	4.31	
4	0.125	8.82		44	8.00	3.35	
5	0.250	7.79		45	8.25	2.61	
6	0.375	6.87		46	8.50	2.03	
7	0.500	6.07		47	8.75	1.58	
8	0.625	5.35		48	9.00	1.23	
9	0.750	4.72		49	9.25	961x10 ⁰	
10	0.875	4.17		50	9.50	750	
11	1.000	3.68		51	9.75	538	
12	1.125	3.25		52	10.00	454	
13	1.250	2.86		53	10.25	354	
14	1.375	2.53		54	10.50	275	
15	1.500	2.23		55	10.75	214	
16	1.625	1.97		56	11.00	167	
17	1.750	1.74		57	11.25	130	
18	1.875	1.53		58	11.50	101	
19	2.000	1.35		59	11.75	78.7	
20	2.125	1.19		60	12.00	61.3	
21	2.25	1.05	0.125	61	12.25	47.8	0.25
22	2.50	821x10 ³	0.25	62	12.50	37.2	
23	2.75	639		63	12.75	29.0	
24	3.00	498		64	13.00	22.6	
25	3.25	367		65	13.25	17.6	
26	3.50	302		66	13.50	13.7	
27	3.75	235		67	13.75	10.7	
28	4.00	183		68	14.00	8.32	
29	4.25	143		69	14.25	6.50	
30	4.50	111		70	14.50	5.10	
31	4.75	86.5		71	14.75	3.97	
32	5.00	67.4		72	15.00	3.06	
33	5.25	52.5		73	15.25	2.38	
34	5.50	40.9		74	15.50	1.855	0.25
35	5.75	31.8		75	15.7538	1.440	0.2538
36	6.00	24.8		76	16.00	1.125	0.2462
37	6.25	19.3		77	16.30	0.835	0.3000
38	6.50	15.0		78	16.5884	0.625	0.2884
39	6.75	11.7	0.25				

Remarks on Individual Elements

For each element in this tabulation, certain comments regarding individual treatment are made in this section. Far from being a complete description of sources, approximations, etc., the only aim is to mention items that were thought to be of particular interest.

BORON: The scattering resonances in the Mev region were analyzed by the Breit-Wigner single-level formula¹. For energies below 0.1 Mev, it was assumed that $\sigma_c = \sigma_T - 4.0$ barns, and σ_c was then interpolated to the known values above 0.4 Mev. Above 3 Mev, it was assumed that $\sigma_c = 0.04$ barn. The inelastic scattering matrix was constructed by individual treatment of the levels in B^{10} and B^{11} ; the excitation functions of the higher levels were assumed similar in shape and height.

¹ Bockelman et al., Phys. Rev. 84, 69 (1951).

CARBON: In constructing the inelastic scattering matrix, the evaporation model was applied to groups 1 through 5. The nuclear temperature was computed from Graves and Rosen⁵, and excitation functions for the (n, n') and (n, n') $\beta\alpha$ processes were taken from Kalos and Goldstein.¹

¹ M. Kalos and H. Goldstein, Neutron Cross Section Data for Carbon, NDA 12-16.

OXYGEN: Angular distributions were obtained from experimental data and extrapolated by means of the complex potential model.¹ Excitation functions for the levels were assumed to be free from resonances. Lack of experimental data required considerable arbitrariness in the determination of individual level cross sections.

¹ W. S. Emmerich, Westinghouse Research Report 60-94511-6-R9 (1956).

ALUMINUM: σ_s was interpolated linearly from 3.6 to 12 kev. σ_c was assumed to follow the $1/v$ law above thermal energies until it fell to a value equal to the known σ_c at 12 kev. The (n, p) cross section was interpolated linearly from 7.6 to 14 Mev. The (n, α) cross section was treated similarly from its threshold at 3.155 Mev. The inelastic scattering matrix elements were obtained from the gamma ray yield curves of Kiehn and Goodman¹ up to 2.8 Mev. Linear interpolations were made between 2.8 Mev and the neutron spectrum measured at 4.4 Mev,² and again to 6 Mev where it was assumed that the evaporation model became applicable. The nuclear temperature was computed from the 14 Mev value of Graves and Rosen.³

¹ R. M. Kiehn and C. Goodman, Phys. Rev. 95, 989 (1954).

² J. B. Weddell, Phys. Rev. (to be published).

³ E. R. Graves and L. Rosen, Phys. Rev. 89, 343 (1953).

IRON: Inelastic levels below 4 Mev were approximated by the following scheme (spin in paranthesis): 0.845 (2), 2.08 (4), 2.60 (2), 2.95 (2), 3.32 (4), 3.96 (5), all even parity. The relative intensity was derived from a Hauser-Feshbach analysis¹ and normalized to experimental non-elastic data.

¹ W. S. Emmerich, Westinghouse Research Report 60-94511-6-R8 (1955).

ZIRCONIUM: The total cross section at low energies is so constant that a decrease slower than $1/v$ appears justified for σ_c . Even though it becomes quickly negligible the cross section of the 0.92 Mev gamma ray was assumed to represent inelastic scattering.¹ The matrix elements for 4.4 Mev neutrons were calculated on this basis rather than from the measured neutron spectrum, in which no corresponding group of neutrons was observed. The resonance

on 4.4 Mev neutrons was
assumed to be the same as for
iron.

region was treated by curve-fitting methods since no resonance parameters were available.

¹ G. L. Griffith, Westinghouse Scientific Paper 60-94511-6-P8.

NIOBIUM: The scattering cross section was interpolated from 10 to 120 kev, and from 3.2 to 14 Mev using the molybdenum cross sections as guidance. Almost no information exists on inelastic scattering. Even the level-scheme is uncertain. The first two levels were assumed to be at 0.69 and 0.91 Mev^{1,2} with excitation functions similar to the 0.92 Mev zirconium level. The part of the inelastic scattering matrix corresponding to higher levels was assumed identical to zirconium, except that the terms were normalized to the $\langle \sigma_{in} \rangle_j$ for niobium.

¹ Scherrer, Allison, and Faust, Phys. Rev. 96, 386 (1954).

² H. Mark and C. Goodman, Phys. Rev. 98, 1245 (1955).

CADMIUM: The strong resonance at 0.178 ev was analyzed by the Breit-Wigner formula, since contribution to σ_c exists above 0.625 ev. Other resonances were treated by curve-fitting. The scattering cross section was interpolated linearly from 10 to 60 kev. Excitation curves for low-lying levels were assumed similar to those in other medium-heavy elements. The evaporation model was applied above 4 Mev. The behavior of the (n, 2n) cross section was interpolated between silver and antimony.

HAFNIUM: The cross sections were interpolated linearly between 4 and 50 kev. Above 3 Mev, the results for Ta were used as guidance. Construction of the inelastic scattering matrix was simplified by the use of one level-scheme for the odd isotopes and another one for the even isotopes.

LEAD: The level structure was simplified by the assumption of two levels with energies of 0.8 and 1.6 Mev.

Hydrogen Cross Sections for 78 Lethargy Groups

Values in barns $\bar{\mu} = 2/3$

j	σ_s	σ_c	j	σ_s	σ_c
1	0.72	0.000015	41	19.2	0.00062
2	0.80	0.000016	42	19.5	0.00070
3	0.88	0.000017	43	19.7	0.00080
4	0.98	0.000018	44	19.8	0.00090
5	1.08	0.000020	45	19.9	0.00101
6	1.21	0.000021	46	19.9	0.00113
7	1.35	0.000022	47	20.0	0.00130
8	1.50	0.000023	48	20.0	0.00150
9	1.62	0.000024	49	20.0	0.00169
10	1.78	0.000026	50	20.0	0.00190
11	1.90	0.000027	51	20.0	0.0021
12	2.0	0.000029	52	20.0	0.0024
13	2.2	0.000031	53	20.0	0.0027
14	2.4	0.000033	54	20.0	0.0031
15	2.6	0.000035	55	20.0	0.0034
16	2.8	0.000037	56	20.0	0.0039
17	3.0	0.000039	57	20.0	0.0044
18	3.2	0.000042	58	20.0	0.0050
19	3.5	0.000045	59	20.0	0.0057
20	3.7	0.000047	60	20.0	0.0064
21	4.0	0.000050	61	20.0	0.0072
22	4.4	0.000055	62	20.0	0.0081
23	5.0	0.000063	63	20.0	0.0092
24	5.8	0.000071	64	20.0	0.0104
25	6.6	0.000080	65	20.0	0.0119
26	7.4	0.000091	66	20.0	0.0135
27	8.4	0.000102	67	20.1	0.0153
28	9.4	0.000116	68	20.1	0.0172
29	10.5	0.000132	69	20.2	0.0195
30	11.6	0.000153	70	20.2	0.022
31	12.5	0.000170	71	20.2	0.025
32	13.8	0.00020	72	20.3	0.028
33	14.8	0.00022	73	20.3	0.032
34	15.7	0.00025	74	20.4	0.037
35	16.4	0.00028	75	20.5	0.042
36	17.1	0.00032	76	20.7	0.048
37	17.7	0.00036	77	20.9	0.055
38	18.2	0.00041	78	21.2	0.063
39	18.6	0.00047			
40	18.9	0.00054			

Boron Cross Sections for 78 Lethargy Groups

Values in barns

$$\sigma_c = \sigma(n, \alpha)$$

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	σ_1
1	0.68	0.65	0.040	0.0617	0.042
2	0.68	0.65	0.040		0.042
3	0.68	0.65	0.040		0.042
4	0.70	0.65	0.040		0.043
5	0.74	0.65	0.040		0.045
6	0.79	0.65	0.040		0.049
7	0.82	0.65	0.040		0.051
8	0.85	0.65	0.040		0.052
9	0.86	0.65	0.040		0.053
10	0.83	0.63	0.042		0.051
11	0.80	0.59	0.040		0.049
12	0.87	0.50	0.040		0.054
13	1.15	0.38	0.040		0.071
14	2.4	0.25	0.040		0.148
15	2.6	0.16	0.039		0.160
16	1.5	0.12	0.054		0.092
17	2.0	0.11	0.093	0.0617	0.123
18	1.4	0.10	0.067	0.0617	0.086
19	2.0	0.10	0.046	0.05	0.10
20	10.4	0.09	0.039	-0.03	-0.31
21	2.0	0.08	0.037	+0.03	+0.060
22	1.7	0.05	0.041	0.14	0.24
23	2.2	0.01	0.060	0.19	0.42
24	2.7	0	0.095	0.23	0.62
25	11.8		0.16	0.25	3.0
26	3.2		0.22	0.20	0.64
27	3.3		0.25	0.09	0.31
28	3.5		0.29	0.062	0.22
29	3.6		0.34	0.0617	0.22
30	3.7		0.39		0.23
31	3.8		0.44		0.23
32	3.9		0.50		0.24
33	4.0		0.58		0.25
34	4.0		0.64		0.25
35	4.0		0.72		0.25
36	4.0		0.82		0.25
37	4.0		0.95		0.25
38	4.0		1.08		0.25
39	4.0		1.20		0.25
40	4.0	0	1.30	0.0617	0.25

Boron Cross Sections for 78 Lethargy Groups

Values in barns

$\sigma_c = \sigma(n, \alpha)$

j	σ_s	σ_{in}	σ_c	$\bar{u}$	σ_1
41	4.0	0	1.41	0.0617	0.25
42			1.53		
43			1.66		
44			1.77		
45			1.90		
46			2.0		
47			2.1		
48			2.2		
49			2.3		
50			2.5		
51			2.7		
52			3.0		
53			3.3		
54			3.7		
55			4.2		
56			4.9		
57			5.7		
58			6.8		
59	↓	↓	8.3	↓	↓
60	4.0	0	10.0	0.0617	0.25
61			12.0		
62			14.0		
63			16.2		
64			19.1		
65			23.		
66			26.		
67			29.		
68			34.		
69			40.		
70			46.		
71			52.		
72			60.		
73			70.		
74			81.		
75			92.		
76			106.		
77	↓	↓	121.	↓	↓
78	4.0	0	140.	0.0617	0.25

INELASTIC SCATTERING MATRIX
BORON
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j n	1	2	3	4	5	6	7	8	9	10
1	0.179									
2	0.060	0.186								
3	0.928	0.057	0.192							
4	0.449	0.964	0.055	0.167						
5	0.224	0.500	1.165	0.126	0.127					
6	0.075	0.214	0.411	1.674	0.279	0.082				
7	0.030	0.086	0.206	0.419	1.905	0.032	0.039			
8	0.022	0.071	0.103	0.502	1.270	1.205	0.352	0.000		
9	0.022	0.107	0.178	0.167	0.064	2.340	0.098	0.337	0.000	
10	0.031	0.054	0.069	0.084	0.127	0.059	2.403	0.027	0.271	0.000
11	0.043	0.040	0.038	0.063	0.114	0.117	1.016	1.242	0.112	0.245
12	0.054	0.051	0.049	0.063	0.102	0.105	0.049	2.129	0.052	0.179
13	0.063	0.061	0.061	0.067	0.089	0.094	0.098	0.213	2.366	0.018
14	0.073	0.071	0.069	0.067	0.080	0.082	0.088	0.000	1.870	0.424
15	0.075	0.079	0.082	0.067	0.070	0.074	0.078	0.089	0.000	2.506
16	0.082	0.086	0.089	0.067	0.064	0.064	0.071	0.089	0.000	1.507
17	0.082	0.086	0.089	0.071	0.057	0.059	0.064	0.071	0.005	0.000
18	0.090	0.093	0.096	0.075	0.051	0.053	0.057	0.028	0.032	0.000
19	0.239	0.143	0.096	0.080	0.051	0.047	0.049	0.064	0.027	0.000
20	0.396	0.179	0.096	0.084	0.044	0.047	0.044	0.057	0.023	0.000
21	0.224	0.214	0.082	0.084	0.044	0.041	0.039	0.071	0.006	0.020
22	0.224	0.250	0.274	0.117	0.038	0.041	0.039	0.062	0.022	0.026
23	0.194	0.200	0.212	0.100	0.038	0.041	0.034	0.053	0.054	0.021
24	0.157	0.150	0.151	0.092	0.036	0.035	0.034	0.044	0.043	0.006
25	0.112	0.114	0.116	0.084	0.032	0.035	0.029	0.040	0.033	0.000
26	0.067	0.071	0.075	0.075	0.028	0.033	0.029	0.035	0.021	0.000
27	0.044	0.050	0.056	0.059	0.025	0.029	0.024	0.031	0.017	0.000
28	0.022	0.028	0.034	0.033	0.023	0.026	0.024	0.031	0.006	0.000
29	0.019	0.021	0.024	0.021	0.020	0.023	0.020	0.027	0.005	0.000
30	0.010	0.016	0.014	0.015	0.018	0.021	0.018	0.018	0.004	0.000
31	0.005	0.011	0.010	0.012	0.015	0.019	0.016	0.013	0.003	0.000
32	0.003	0.006	0.006	0.008	0.013	0.016	0.014	0.011	0.003	0.000
33	0.001	0.004	0.005	0.006	0.010	0.014	0.012	0.009	0.002	0.000
34	0.001	0.003	0.003	0.004	0.008	0.004	0.010	0.007	0.002	0.000
35	0.001	0.002	0.003	0.003	0.006	0.002	0.008	0.005	0.002	0.000
36	0.001	0.001	0.002	0.003	0.005	0.001	0.006	0.003	0.001	0.001
37	0.001	0.001	0.001	0.002	0.004	0.001	0.004	0.002	0.001	0.007
38	0.000	0.001	0.001	0.002	0.003	0.001	0.003	0.001	0.001	0.006
39	0.000	0.000	0.001	0.001	0.001	0.000	0.002	0.001	0.001	0.004
40	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.003

σ_{in} 0.624 0.627 0.626 0.630 0.632 0.638 0.645 0.651 0.651 0.631

INELASTIC SCATTERING MATRIX
BORON
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j n	11	12	13	14	15	16	17	18	19	20
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.000									
12	0.200	0.000								
13	0.280	0.110	0.000							
14	0.000	0.370	0.000	0.000						
15	0.040	0.000	0.203	0.000	0.000					
16	0.050	0.000	0.124	0.248	0.000	0.000				
17	0.480	0.064	0.000	0.230	0.112	0.000	0.000			
18	1.840	0.150	0.000	0.000	0.335	0.000	0.000	0.000		
19	1.600	1.450	0.113	0.000	0.041	0.390	0.000	0.000	0.000	
20	0.000	1.280	0.113	0.000	0.000	0.240	0.197	0.000	0.000	0.000
21	0.000	0.560	0.396	0.051	0.000	0.000	0.429	0.000	0.000	0.000
22	0.000	0.000	0.723	0.083	0.000	0.000	0.089	0.390	0.000	0.000
23	0.000	0.000	0.316	0.293	0.052	0.000	0.000	0.020	0.380	0.000
24	0.027	0.000	0.000	0.257	0.048	0.000	0.000	0.000	0.024	0.290
25	0.027	0.000	0.000	0.202	0.003	0.064	0.000	0.000	0.000	0.070
26	0.024	0.000	0.000	0.000	0.086	0.052	0.000	0.000	0.000	0.000
27	0.021	0.000	0.000	0.000	0.069	0.044	0.000	0.000	0.000	0.000
28	0.016	0.000	0.000	0.000	0.048	0.003	0.000	0.000	0.000	0.000
29	0.012	0.000	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.000
30	0.009	0.000	0.000	0.000	0.031	0.000	0.000	0.000	0.000	0.000
31	0.003	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000	0.000
32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000
38	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000
40	0.000	0.001	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000
σ_{in}	0.596	0.498	0.379	0.250	0.160	0.120	0.109	0.103	0.101	0.090

INELASTIC SCATTERING MATRIX
BORON
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j	21	22	23	24	25	26	27	28	29	30
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	0.000									
22	0.000	0.000								
23	0.000	0.000	0.000							
24	0.000	0.000	0.000	0.0						
25	0.180	0.000	0.000	0.0	0.0					
26	0.140	0.023	0.000	0.0	0.0	0.0				
27	0.000	0.060	0.000	0.0	0.0	0.0	0.0			
28	0.000	0.044	0.000	0.0	0.0	0.0	0.0	0.0		
29	0.000	0.034	0.000	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.000	0.009	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.000	0.000	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.000	0.000	0.009	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.000	0.000	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.000	0.000	0.005	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.000	0.000	0.004	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.000	0.000	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.000	0.000	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.000	0.000	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.000	0.000	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.000	0.000	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_{in}^i	0.080	0.043	0.010	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Carbon Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\sigma_{n,2n}$	$\bar{\mu}$	ξ
1	0.80	0.330	0.195	0	0.760	0.046
2	0.69	0.425	0.115		0.675	0.059
3	0.58	0.520	0.055		0.570	0.076
4	0.54	0.580	0.020		0.455	0.094
5	0.88	0.500	0.007		0.365	0.108
6	1.32	0.300	0		0.270	0.123
7	1.00	0.200			0.200	0.134
8	1.07	0.097			0.125	0.147
9	1.16	0.033			0.075	0.156
10	1.50	0.002			0.055	0.160
11	1.97	0			0.048	0.162
12	2.27				0.041	0.163
13	1.98				0.035	0.163
14	1.70				0.076	0.156
15	1.60				0.100	0.151
16	1.73				0.100	0.151
17	1.80				0.160	0.140
18	1.94				0.118	0.147
19	2.15				0.080	0.154
20	2.30				0.650	0.156
21	2.45	0	0	0	0.059	0.157
22	2.65				0.056	0.158
23	2.97					
24	3.25					
25	3.6					
26	3.8					
27	4.0					
28	4.2					
29	4.4					
30	4.5					
31	4.5					
32	4.5					
33	4.5					
34	4.6					
35	4.6					
36	4.6					
37	4.6					
38	4.6					
39	4.7					
40	4.7	0	0	0	0.056	0.158

Carbon Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\sigma_{n,2n}$	$\bar{\mu}$	ξ
41	4.7	0	0	0	0.056	0.158
42	↓	↓	↓	↓	↓	↓
43	↓	↓	↓	↓	↓	↓
44	↓	↓	↓	↓	↓	↓
45	↓	↓	↓	↓	↓	↓
46	↓	↓	↓	↓	↓	↓
47	↓	↓	↓	↓	↓	↓
48	↓	↓	↓	↓	↓	↓
49	↓	↓	↓	↓	↓	↓
50	↓	↓	↓	↓	↓	↓
51	↓	↓	↓	↓	↓	↓
52	↓	↓	↓	↓	↓	↓
53	↓	↓	↓	↓	↓	↓
54	↓	↓	↓	↓	↓	↓
55	↓	↓	↓	↓	↓	↓
56	↓	↓	↓	↓	↓	↓
57	↓	↓	↓	↓	↓	↓
58	↓	↓	↓	↓	↓	↓
59	↓	↓	↓	↓	↓	↓
60	4.7	0	0	0	0.056	0.158
61	↓	↓	↓	↓	↓	↓
62	↓	↓	↓	↓	↓	↓
63	↓	↓	↓	↓	↓	↓
64	↓	↓	↓	↓	↓	↓
65	↓	↓	↓	↓	↓	↓
66	↓	↓	↓	↓	↓	↓
67	↓	↓	↓	↓	↓	↓
68	↓	↓	↓	↓	↓	↓
69	↓	↓	↓	↓	↓	↓
70	↓	↓	↓	↓	↓	↓
71	↓	↓	↓	↓	↓	↓
72	↓	↓	↓	↓	↓	↓
73	↓	↓	↓	↓	↓	↓
74	↓	↓	↓	↓	↓	↓
75	↓	↓	↓	↓	↓	↓
76	4.7	↓	↓	↓	↓	↓
77	4.8	↓	↓	↓	↓	↓
78	4.8	0	0	0	0.056	0.158

INELASTIC SCATTERING MATRIX
CARBON
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j	1	2	3	4	5	6	7	8	9	10
n										
1	0.000									
2	0.000	0.000								
3	0.368	0.000	0.000							
4	0.787	0.000	0.000	0.000						
5	0.320	0.910	0.000	0.000	0.000					
6	0.003	1.585	0.001	0.000	0.000	0.000				
7	0.006	0.002	2.092	0.000	0.000	0.000	0.000			
8	0.009	0.004	1.562	0.710	0.000	0.000	0.000	0.000		
9	0.015	0.008	0.004	2.381	0.000	0.000	0.000	0.000	0.000	
10	0.022	0.012	0.007	1.335	0.892	0.000	0.000	0.000	0.000	0.000
11	0.030	0.018	0.010	0.003	1.843	0.000	0.000	0.000	0.000	0.000
12	0.037	0.024	0.014	0.004	1.202	0.435	0.000	0.000	0.000	0.000
13	0.044	0.029	0.017	0.005	0.002	1.122	0.000	0.000	0.000	0.000
14	0.049	0.034	0.019	0.007	0.002	0.710	0.000	0.000	0.000	0.000
15	0.054	0.039	0.022	0.008	0.003	0.128	0.298	0.000	0.000	0.000
16	0.059	0.043	0.024	0.009	0.003	0.000	0.554	0.000	0.000	0.000
17	0.060	0.045	0.025	0.010	0.004	0.000	0.560	0.000	0.000	0.000
18	0.060	0.046	0.026	0.010	0.004	0.000	0.189	0.145	0.000	0.000
19	0.057	0.045	0.026	0.010	0.004	0.000	0.000	0.223	0.000	0.000
20	0.051	0.043	0.024	0.010	0.004	0.000	0.000	0.177	0.000	0.000
21	0.045	0.035	0.020	0.010	0.003	0.000	0.000	0.130	0.000	0.000
22	0.075	0.066	0.037	0.016	0.005	0.000	0.000	0.052	0.029	0.000
23	0.062	0.051	0.030	0.013	0.005	0.000	0.000	0.000	0.037	0.000
24	0.047	0.039	0.022	0.010	0.004	0.000	0.000	0.000	0.026	0.000
25	0.031	0.028	0.016	0.008	0.003	0.000	0.000	0.000	0.021	0.000
26	0.023	0.018	0.010	0.005	0.002	0.000	0.000	0.000	0.016	0.000
27	0.015	0.013	0.007	0.004	0.001	0.000	0.000	0.000	0.002	0.001
28	0.009	0.009	0.004	0.003	0.001	0.000	0.000	0.000	0.000	0.001
29	0.006	0.005	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.001
30	0.004	0.004	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.001
31	0.002	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.001
32	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001
33	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001
34	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
35	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ_{in}	0.330	0.425	0.521	0.580	0.502	0.299	0.200	0.097	0.033	0.002

ALL OTHER ELEMENTS ARE 0

Oxygen Cross Sections for 78 Lethargy Groups
Values in barns

J	σ_s	σ_{in}	σ_c	$\bar{\mu}$	$\xi\sigma_s$
1	0.7	0.49	0.4	0.60	0.032
2	0.7	0.39	0.4	0.60	0.032
3	0.6	0.38	0.3	0.61	0.026
4	0.5	0.28	0.3	0.60	0.023
5	0.7	0.20	0.3	0.50	0.041
6	1.1	0.10	0.3	0.41	0.076
7	0.8	0.10	0.3	0.50	0.046
8	1.1	0	0.3	0.36	0.082
9	1.1		0.3	0.41	0.076
10	1.5		0.2	0.33	0.12
11	2.1		0.1	0.27	0.18
12	3.0		0.0	0.25	0.27
13	1.6			0.25	0.14
14	1.2			0.25	0.11
15	0.8			0.21	0.08
16	1.5			0.16	0.15
17	2.3			0.14	0.24
18	2.4			0.13	0.25
19	2.8			0.12	0.29
20	3.7			0.10	0.40
21	3.7	0	0	0.10	0.40
22	5.1			0.07	0.57
23	3.0			0.07	0.33
24	3.6			0.06	0.41
25	9.6			0.042	1.10
26	4.2				0.48
27	3.5				0.40
28	3.6				0.41
29	3.7				0.42
30	3.7				0.42
31	3.7				0.42
32	4.2				0.48
33	3.4				0.39
34	3.1				0.35
35	3.1				0.36
36	3.2				0.37
37	3.5				0.40
38	3.6				0.41
39	3.6				0.41
40	3.5	0	0	0.042	0.40

Oxygen Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	$\xi\sigma_s$
41	3.4	0	0	0.042	0.39
42	3.3				0.38
43	3.3				0.38
44	3.3				0.38
45	3.3				0.38
46	3.4				0.39
47	3.5				0.40
48	3.6				0.41
49	3.7				0.42
50	3.8				0.44
51	3.8				0.44
52	3.8				
53					
54					
55					
56					
57					
58					
59					
60					
61					
62					
63					
64					
65					
66					
67					
68					
69					
70					
71					
72					
73					
74					
75					
76					
77					
78	3.8	0	0	0.042	0.44

INELASTIC SCATTERING MATRIX
OXYGEN
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j	1	2	3	4	5	6	7	8	9	10
n										
1	0.000									
2	0.000	0.000								
3	0.000	0.000	0.000							
4	0.000	0.000	0.000	0.000						
5	0.560	0.000	0.000	0.000	0.000					
6	0.990	0.000	0.000	0.000	0.000	0.000				
7	0.380	0.640	0.000	0.000	0.000	0.000	0.000			
8	0.072	0.990	0.000	0.000	0.000	0.000	0.000	0.000		
9	0.000	0.270	0.770	0.000	0.000	0.000	0.000	0.000	0.000	
10	0.128	0.104	0.860	0.000	0.000	0.000	0.000	0.000	0.000	
11	0.210	0.000	0.570	0.340	0.000	0.000	0.000	0.000		
12	0.210	0.000	0.136	0.660	0.000	0.000	0.000	0.000		
13	0.180	0.040	0.072	0.650	0.000	0.000	0.000	0.000		
14	0.160	0.088	0.000	0.360	0.200	0.000	0.000	0.000		
15	0.104	0.128	0.000	0.096	0.360	0.000	0.000	0.000		
16	0.064	0.144	0.000	0.088	0.310	0.000	0.000	0.000		
17	0.056	0.128	0.000	0.056	0.300	0.000	0.000	0.000		
18	0.080	0.112	0.000	0.000	0.128	0.120	0.000	0.000		
19	0.128	0.048	0.048	0.000	0.072	0.128	0.000	0.000		
20	0.080	0.072	0.048	0.000	0.064	0.112	0.000	0.000		
ALL OTHER ELEMENTS ARE 0										
21	0.064	0.080	0.040	0.000	0.056	0.104	0.000	0.000		
22	0.056	0.052	0.048	0.000	0.048	0.080	0.000	0.000		
23	0.044	0.024	0.056	0.000	0.004	0.024	0.080	0.000		
24	0.036	0.020	0.040	0.000	0.000	0.012	0.072	0.000		
25	0.024	0.016	0.032	0.000	0.000	0.008	0.056	0.000		
26	0.020	0.012	0.032	0.000	0.000	0.008	0.044	0.000		
27	0.016	0.008	0.024	0.000	0.000	0.006	0.032	0.000		
28	0.012	0.008	0.012	0.000	0.000	0.004	0.024	0.000		
29	0.008	0.006	0.008	0.004	0.000	0.004	0.020	0.000		
30	0.008	0.004	0.006	0.004	0.000	0.002	0.016	0.000		
31	0.006	0.002	0.004	0.000	0.000	0.001	0.012	0.000		
32	0.004	0.001	0.002	0.000	0.000	0.000	0.008	0.000		
33	0.004	0.000	0.001	0.000	0.000	0.000	0.008	0.000		
34	0.002	0.000	0.000	0.000	0.000	0.000	0.006	0.000		
35	0.001	0.000	0.000	0.000	0.000	0.000	0.004	0.000		
36	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000		
37	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000		
38	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000		
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
σ_{in}	0.494	0.394	0.384	0.283	0.199	0.095	0.097			

Aluminum Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	$\xi \sigma_s$
1	0.80	0.719	0.20	0.76	0.014
2	0.71	0.888	0.20	0.73	0.014
3	0.64	0.862	0.20	0.70	0.014
4	0.72	0.806	0.19	0.67	0.017
5	0.87	0.702	0.17	0.64	0.023
6	1.18	0.776	0.14	0.59	0.035
7	1.27	0.802	0.11	0.54	0.043
8	1.40	0.667	0.07	0.51	0.050
9	1.54	0.575	0.04	0.480	0.059
10	1.60	0.623	0.02	0.458	0.064
11	1.78	0.623	0.01	0.443	0.073
12	1.93	0.635	0.01	0.460	0.077
13	1.99	0.536	0	0.478	0.077
14	2.52	0.513	0	0.490	0.095
15	2.22	0.413	0	0.490	0.083
16	2.99	0.287	0	0.470	0.117
17	2.62	0.277	0	0.433	0.110
18	2.75	0.270	0	0.386	0.125
19	2.83	0.250	0	0.352	0.135
20	3.27	0.191	0	0.333	0.161
21	3.36	0.145	0	0.310	0.171
22	3.38	0.007	0.001	0.269	0.183
23	4.1	0	0.001	0.197	0.244
24	4.0	0	0.001	0.218	0.231
25	4.0	0	0.001	0.170	0.246
26	3.7	0	0.002	0.127	0.239
27	3.0	0	0.002	0.096	0.201
28	5.1	0	0.002	0.066	0.352
29	8.5	0	0.004	0.050	0.598
30	3.1	0	0.005	0.044	0.219
31	5.8	0	0.003	0.038	0.413
32	2.8	0	0.002	0.034	0.200
33	2.8	0	0.003	0.031	0.201
34	9.1	0	0.010	0.029	0.654
35	5.1	0	0.014	0.027	0.367
36	1.15	0	0.005	0.026	0.083
37	1.12	0	0.004	0.025	0.080
38	1.34	0	0.005	0.0247	0.096
39	1.52	0	0.006	0.0247	0.109
40	1.65	0	0.006	0.0247	0.119

Aluminum Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	$\xi \sigma_s$
41	1.60	0	0.006	0.0247	0.115
42	1.51		0.006		0.109
43	1.45		0.006		0.104
44	1.41		0.006		0.101
45	1.40		0.006		
46			0.006		
47			0.006		
48			0.006		
49			0.006		
50			0.007		
51			0.007		
52			0.007		
53			0.007		
54			0.007		
55			0.007		
56			0.008		
57			0.008		
58			0.008		
59			0.009		
60			0.009		
61	1.40	0	0.010	0.0247	0.101
62			0.011		
63			0.013		
64			0.017		
65			0.022		
66			0.028		
67			0.034		
68			0.040		
69			0.045		
70			0.055		
71			0.06		
72			0.06		
73			0.07		
74			0.08		
75			0.09		
76			0.10		
77			0.10		
78	1.40	0	0.11	0.0247	0.101

INELASTIC SCATTERING MATRIX
ALUMINUM
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j	1	2	3	4	5	6	7	8	9	10
n										
1	0.000									
2	0.000	0.000								
3	0.408	0.000	0.000							
4	0.440	0.320	0.000	0.000						
5	0.128	0.240	0.240	0.008	0.000					
6	0.184	0.160	0.240	0.199	0.014	0.000				
7	0.176	0.160	0.160	0.120	0.144	0.049	0.000			
8	0.264	0.170	0.120	0.080	0.108	0.245	0.088	0.000		
9	0.296	0.128	0.088	0.088	0.100	0.131	0.400	0.128	0.000	
10	0.200	0.176	0.128	0.127	0.144	0.180	0.184	0.600	0.200	0.000
11	0.120	0.240	0.176	0.167	0.187	0.237	0.240	0.600	1.200	0.288
12	0.176	0.288	0.232	0.243	0.230	0.286	0.288	0.160	0.000	1.416
13	0.216	0.344	0.280	0.271	0.280	0.343	0.344	0.280	0.080	0.216
14	0.192	0.376	0.336	0.374	0.316	0.376	0.376	0.720	0.720	0.000
15	0.272	0.408	0.368	0.351	0.344	0.408	0.408	0.400	0.720	0.720
16	0.264	0.416	0.400	0.390	0.359	0.417	0.416	0.320	0.160	0.720
17	0.280	0.416	0.408	0.398	0.366	0.417	0.416	0.320	0.320	0.080
18	0.256	0.416	0.408	0.406	0.373	0.286	0.416	0.280	0.320	0.368
19	0.256	0.384	0.408	0.398	0.344	0.384	0.384	0.320	0.240	0.336
20	0.232	0.360	0.376	0.367	0.323	0.359	0.360	0.240	0.120	0.288
21	0.200	0.320	0.352	0.335	0.287	0.319	0.320	0.160	0.064	0.048
22	0.164	0.260	0.252	0.247	0.222	0.257	0.260	0.080	0.028	0.016
23	0.128	0.200	0.220	0.215	0.179	0.196	0.196	0.080	0.028	0.032
24	0.100	0.144	0.192	0.187	0.144	0.143	0.144	0.060	0.024	0.036
25	0.072	0.096	0.140	0.135	0.100	0.098	0.100	0.040	0.016	0.024
26	0.048	0.064	0.096	0.092	0.068	0.065	0.064	0.032	0.016	0.012
27	0.024	0.048	0.064	0.064	0.050	0.049	0.048	0.028	0.016	0.016
28	0.016	0.028	0.048	0.048	0.032	0.029	0.028	0.024	0.020	0.020
29	0.012	0.020	0.028	0.028	0.022	0.020	0.020	0.020	0.016	0.016
30	0.008	0.012	0.020	0.020	0.014	0.012	0.012	0.016	0.016	0.016
31	0.008	0.008	0.012	0.012	0.007	0.008	0.008	0.008	0.012	0.012
32	0.004	0.004	0.000	0.008	0.004	0.004	0.004	0.008	0.012	0.016
33	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.008	0.008
34	0.004	0.000	0.004	0.004	0.004	0.000	0.000	0.004	0.008	0.008
35	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.008
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
37	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ_{in}	0.719	0.887	0.860	0.806	0.703	0.776	0.802	0.667	0.575	0.623

INELASTIC SCATTERING MATRIX
ALUMINUM
78 GROUP STRUCTURE
BARN PER LETHARGY INTERVAL

j	11	12	13	14	15	16	17	18	19	20
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.000									
12	0.060	0.000								
13	0.150	0.000	0.000							
14	1.201	1.000	0.000	0.000						
15	0.000	1.400	0.400	0.000	0.000					
16	0.000	0.000	1.000	0.120	0.000	0.000				
17	0.500	0.000	1.200	1.256	0.000	0.000	0.000			
18	1.000	0.000	0.000	1.384	0.128	0.000	0.000	0.000		
19	0.500	0.480	0.000	0.064	0.544	0.224	0.000	0.000	0.000	
20	0.000	0.480	0.000	0.000	1.456	1.104	0.000	0.000	0.000	0.000
21	0.300	0.360	0.000	0.000	0.832	0.400	0.216	0.000	0.000	0.000
22	0.450	0.180	0.200	0.000	0.000	0.172	0.680	0.180	0.000	0.000
23	0.050	0.020	0.200	0.000	0.000	0.112	0.320	0.480	0.088	0.000
24	0.000	0.160	0.200	0.248	0.000	0.000	0.000	0.420	0.340	0.040
25	0.030	0.120	0.000	0.212	0.000	0.000	0.000	0.000	0.396	0.160
26	0.015	0.120	0.000	0.180	0.000	0.000	0.000	0.000	0.176	0.120
27	0.015	0.080	0.004	0.000	0.056	0.000	0.000	0.000	0.000	0.260
28	0.015	0.000	0.040	0.000	0.040	0.000	0.000	0.000	0.000	0.180
29	0.010	0.000	0.060	0.000	0.028	0.000	0.000	0.000	0.000	0.004
30	0.010	0.000	0.040	0.000	0.020	0.000	0.000	0.000	0.000	0.000
31	0.010	0.000	0.032	0.000	0.012	0.000	0.000	0.000	0.000	0.000
32	0.010	0.000	0.024	0.000	0.008	0.000	0.000	0.000	0.000	0.000
33	0.005	0.000	0.016	0.000	0.004	0.000	0.000	0.000	0.000	0.000
34	0.005	0.000	0.012	0.000	0.004	0.000	0.000	0.000	0.000	0.000
35	0.005	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.005	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ_{in}	0.623	0.635	0.536	0.513	0.413	0.287	0.277	0.270	0.250	0.191

INELASTIC SCATTERING MATRIX
ALUMINUM
78 GROUP STRUCTURE
BARNs PER LETHARGY INTERVAL

j	21	22	23	24	25	26	27	28	29	30
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	0.000									
22	0.000	0.000								
23	0.000	0.000	0.0							
24	0.000	0.000	0.0	0.0						
25	0.000	0.000	0.0	0.0	0.0					
26	0.120	0.000	0.0	0.0	0.0	0.0				
27	0.080	0.000	0.0	0.0	0.0	0.0	0.0			
28	0.000	0.020	0.0	0.0	0.0	0.0	0.0	0.0		
29	0.100	0.004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.100	0.004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.080	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.040	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.040	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.020	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_{in}	0.145	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Iron Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	ξ
1	1.12	1.041	0.13	0.869	0.0043
2	1.31	1.163	0.12	0.865	0.0044
3	1.49	1.275	0.11	0.859	0.0046
4	1.55	1.296	0.09	0.853	0.0049
5	1.77	1.303	0.07	0.845	0.0051
6	2.02	1.331	0.05	0.833	0.0056
7	2.13	1.348	0.03	0.809	0.0064
8	2.31	1.246	0.02	0.766	0.0080
9	2.32	1.349	0.01	0.710	0.0100
10	2.33	1.327	0	0.653	0.0120
11	2.33	1.281	↓	0.597	0.0140
12	2.21	1.224		0.554	0.0155
13	2.10	1.153		0.511	0.0171
14	2.19	1.011		0.468	0.0186
15	2.22	0.954		0.427	0.0201
16	2.22	0.860		0.379	0.0218
17	2.11	0.770		0.322	0.0238
18	2.28	0.670		0.251	0.0263
19	2.18	0.590		0.244	0.0266
20	2.22	0.530		0.183	0.0288
21	1.95	0.450	0	0.198	0.0282
22	2.17	0.217	↓	0.225	0.0273
23	3.05	0		0.144	0.0302
24	2.65	↓		0.191	0.0285
25	4.10			0.132	0.0306
26	3.20			0.091	0.0321
27	2.71			0.087	0.0322
28	3.91			0.066	0.0329
29	3.41			0.024	0.0344
30	3.00			0.002	0.0352
31	4.21			↓	0
32	3.73	↓	↓		↓
33	3.15				
34	4.94				
35	6.32				
36	3.47				
37	2.70				
38	3.55				
39	3.55				
40	7.09			0	

Iron Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	ξ			
41	8.4	0	0	0	0.0353			
42	7.1	↓	0	↓	↓			
43	6.3		0.01					
44	6.4		0.01					
45	6.6		0.01					
46	7.0		0.01					
47	7.6		0.01					
48	8.3		0.01					
49	9.0		0.01					
50	9.6		0.01					
51	10.1		↓			0.02	↓	↓
52	10.5	0.02						
53	10.9	0.02						
54	11.1	0.02						
55	11.3	0.03						
56	11.4	0.03						
57	↓	0.03		↓	↓			
58		0.04						
59		0.04						
60		0.05						
61		0	0.06			0	0.0353	
62		↓	0.06			↓	↓	
63			0.07					
64			0.08					
65			0.09					
66			0.10					
67	0.12							
68	0.13							
69	0.15							
70	0.17							
71	11.4		↓	0.19	↓			↓
72	11.3	0.22						
73	11.3	0.25						
74	11.3	0.28						
75	11.3	0.32						
76	11.3	0.37						
77	11.2	0.42						
78	11.1	0		0.48		0	0.0353	

INELASTIC SCATTERING MATRIX
IRON
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j	1	2	3	4	5	6	7	8	9	10
n										
1	0.000									
2	0.000	0.000								
3	0.104	0.000	0.000							
4	0.200	0.028	0.000	0.000						
5	0.168	0.068	0.028	0.000	0.000					
6	0.019	0.120	0.068	0.028	0.000	0.000				
7	0.052	0.168	0.120	0.068	0.028	0.512	0.000			
8	0.088	0.144	0.096	0.128	0.068	0.512	1.440	0.000		
9	0.168	0.046	0.067	0.122	0.144	0.176	0.344	2.080	0.000	
10	0.368	0.065	0.069	0.073	0.128	0.232	0.440	0.256	2.720	0.000
11	0.288	0.112	0.112	0.104	0.080	0.088	0.144	0.424	1.440	1.520
12	0.216	0.168	0.184	0.168	0.144	0.208	0.320	0.600	0.128	2.720
13	0.272	0.304	0.272	0.216	0.224	0.552	0.880	0.568	0.400	0.000
14	0.304	0.336	0.352	0.312	0.256	0.552	0.880	0.536	0.664	0.512
15	0.544	0.408	0.440	0.392	0.352	0.472	0.800	0.640	0.704	1.440
16	0.472	0.528	0.512	0.488	0.432	0.400	0.536	0.744	0.736	0.880
17	0.448	0.560	0.592	0.568	0.528	0.416	0.536	0.568	0.800	0.552
18	0.408	0.576	0.664	0.616	0.616	0.616	0.720	0.408	0.880	1.200
19	0.568	0.664	0.664	0.680	0.640	0.552	0.504	0.432	0.568	0.784
20	0.504	0.624	0.656	0.680	0.688	0.608	0.504	0.464	0.256	0.688
21	0.440	0.592	0.656	0.672	0.680	0.664	0.480	0.408	0.272	0.128
22	0.232	0.344	0.560	0.600	0.640	0.560	0.400	0.180	0.140	0.096
23	0.368	0.480	0.520	0.560	0.600	0.480	0.280	0.196	0.116	0.000
24	0.272	0.360	0.400	0.440	0.440	0.332	0.188	0.212	0.092	0.000
25	0.192	0.264	0.296	0.324	0.352	0.236	0.116	0.152	0.088	0.000
26	0.116	0.164	0.188	0.220	0.256	0.176	0.068	0.084	0.088	0.000
27	0.068	0.096	0.108	0.140	0.172	0.112	0.036	0.052	0.052	0.000
28	0.040	0.064	0.084	0.100	0.120	0.072	0.020	0.021	0.020	0.000
29	0.024	0.048	0.060	0.068	0.080	0.048	0.010	0.013	0.012	0.000
30	0.015	0.030	0.044	0.044	0.040	0.021	0.005	0.004	0.004	0.000
31	0.009	0.022	0.033	0.019	0.006	0.004	0.003	0.003	0.002	0.000
32	0.005	0.011	0.016	0.010	0.002	0.002	0.002	0.001	0.000	0.000
33	0.003	0.006	0.008	0.004	0.001	0.001	0.000	0.000	0.000	0.000
34	0.002	0.003	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000
35	0.001	0.001	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

σ_{in} 1.041 1.162 1.275 1.297 1.303 1.331 1.348 1.246 1.350 1.327

INELASTIC SCATTERING MATRIX
IRON
78 GROUP STRUCTURE
BARN PER LETHARGY INTERVAL

j	11	12	13	14	15	16	17	18	19	20
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.000									
12	0.664	0.000								
13	3.760	0.000	0.000							
14	0.280	3.840	0.000	0.000						
15	0.000	1.680	2.800	0.000	0.000					
16	0.560	0.000	3.520	0.776	0.000	0.000				
17	1.120	0.000	0.000	4.560	0.000	0.000	0.000			
18	0.752	0.304	0.000	1.200	3.440	0.000	0.000	0.000		
19	0.384	0.800	0.000	0.000	3.440	0.800	0.000	0.000	0.000	
20	0.440	0.688	0.000	0.000	0.000	4.080	0.000	0.000	0.000	0.000
21	0.800	0.192	0.496	0.000	0.000	1.840	1.840	0.000	0.000	0.000
22	0.440	0.276	0.440	0.000	0.000	0.000	2.160	0.880	0.000	0.000
23	0.220	0.332	0.092	0.252	0.000	0.000	0.000	1.800	0.520	0.000
24	0.044	0.196	0.160	0.252	0.000	0.000	0.000	0.000	1.840	0.000
25	0.034	0.152	0.124	0.096	0.072	0.000	0.000	0.000	0.000	1.480
26	0.009	0.136	0.100	0.000	0.108	0.000	0.000	0.000	0.000	0.640
27	0.000	0.015	0.140	0.038	0.084	0.000	0.000	0.000	0.000	0.000
28	0.000	0.011	0.052	0.056	0.076	0.000	0.000	0.000	0.000	0.000
29	0.000	0.008	0.037	0.032	0.036	0.010	0.000	0.000	0.000	0.000
30	0.000	0.006	0.022	0.019	0.000	0.030	0.000	0.000	0.000	0.000
31	0.000	0.002	0.014	0.011	0.000	0.017	0.000	0.000	0.000	0.000
32	0.000	0.002	0.009	0.009	0.000	0.010	0.000	0.000	0.000	0.000
33	0.000	0.001	0.004	0.004	0.000	0.007	0.000	0.000	0.000	0.000
34	0.000	0.001	0.003	0.004	0.000	0.003	0.000	0.000	0.000	0.000
35	0.000	0.000	0.002	0.002	0.000	0.002	0.000	0.000	0.000	0.000
36	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
37	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ_{in}	1.282	1.223	1.152	1.011	0.954	0.860	0.770	0.670	0.590	0.530

INELASTIC SCATTERING MATRIX
 IRON
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j n	21	22	23	24	25	26	27	28	29	30
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	0.000									
22	0.000	0.000								
23	0.000	0.000	0.0							
24	0.000	0.000	0.0	0.0						
25	0.000	0.000	0.0	0.0	0.0					
26	0.520	0.000	0.0	0.0	0.0	0.0				
27	0.920	0.000	0.0	0.0	0.0	0.0	0.0			
28	0.360	0.136	0.0	0.0	0.0	0.0	0.0	0.0		
29	0.000	0.260	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.000	0.188	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.000	0.124	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.000	0.092	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.000	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.000	0.021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.000	0.012	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.000	0.006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_{in}	0.450	0.217	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Zirconium Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	ξ	
1	2.35	1.50	0.18	0.82	0.00376	
2	2.45	1.50	0.18	0.81	0.00398	
3	2.53	1.46	0.18	0.79	0.00441	
4	2.61	1.5	0.18	0.77	0.00485	
5	2.62	1.5	0.18	0.75	0.00528	
6	2.56	1.50	0.18	0.71	0.00615	
7	2.43	1.5	0.18	0.67	0.00702	
8	2.32	1.5	0.18	0.63	0.00789	
9	2.30	1.48	0.18	0.59	0.00876	
10	2.40	1.38	0.18	0.54	0.00985	
11	2.54	1.25	0.18	0.49	0.0109	
12	2.80	1.20	0.16	0.44	0.0120	
13	3.06	1.14	0.14	0.39	0.0131	
14	3.35	1.08	0.12	0.37	0.0135	
15	3.65	0.98	0.09	0.36	0.0138	
16	3.95	0.96	0.07	0.37	0.0135	
17	4.22	0.90	0.05	0.38	0.0133	
18	4.54	0.82	0.03	0.39	0.0131	
19	5.10	0.78	0.01	0.39	0.0131	
20	5.75	0.68	0	0.38	0.0133	
21	6.45	0.48	↓	0.35	0.0140	
22	7.36	0.07		0.32	0.0146	
23	8.16	0		0.29	0.0153	
24	8.73	↓		0.25	0.0162	
25	8.84			0.21	0.0170	
26	8.87			0.17	0.0179	
27	8.90			0.14	0.0185	
28	8.92			0.11	0.0192	
29	8.94			0.086	0.0197	
30	8.96			0.068	0.0201	
31	8.77			↓	0.056	0.0204
32	8.8				0.045	0.0206
33	8.3				0.035	0.0208
34	10.2				0.028	0.0210
35	7.6				0.024	0.0211
36	8.7				0.020	0.0211
37	9.7				0.017	0.0212
38	7.4				0.014	0.0213
39	7.0				↓	0.012
40	8.0	0	0		0.010	0.0214

Zirconium Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	ξ
41	9.3	0	0.00	0.0090	0.0214
42	8.4		0.00	0.0080	0.0214
43	7.8		0.00	0.0073	0.0214
44	6.9		0.00		
45	8.5		0.10		
46	6.5		0.00		
47	6.3		0.00		
48	6.7		0.20		
49	5.8		0.00		
50	6.0		0.00		
51	6.4		0.50		
52	6.0		0.00		
53	6.0		0.00		
54	6.7		2.20		
55	6.2		0.00		
56			0.00		
57			0.00		
58			0.00		
59			0.01		
60			0.01		
61		0	0.01	0.0073	0.0214
62			0.01		
63			0.02		
64			0.02		
65			0.02		
66			0.03		
67			0.03		
68			0.03		
69			0.04		
70			0.04		
71	6.2		0.04		
72	6.1		0.05		
73			0.05		
74			0.05		
75			0.06		
76			0.06		
77			0.06		
78	6.1	0	0.07	0.0073	0.0214

INELASTIC SCATTERING MATRIX
ZIRCONIUM
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j n	1	2	3	4	5	6	7	8	9	10
1	0.000									
2	0.000	0.000								
3	0.007	0.000	0.000							
4	0.014	0.003	0.000	0.000						
5	0.028	0.008	0.000	0.000	0.000					
6	0.049	0.019	0.001	0.000	0.000	0.000				
7	0.070	0.033	0.004	0.001	0.001	0.001	0.000			
8	0.110	0.057	0.006	0.005	0.001	0.005	0.019	0.000		
9	0.140	0.086	0.021	0.009	0.007	0.005	0.094	0.040	0.000	
10	0.180	0.120	0.036	0.027	0.011	0.010	0.019	0.240	0.110	0.000
11	0.250	0.170	0.097	0.054	0.033	0.020	0.019	0.040	0.440	0.210
12	0.320	0.240	0.160	0.089	0.054	0.043	0.026	0.040	0.066	0.830
13	0.390	0.300	0.220	0.150	0.083	0.075	0.048	0.037	0.000	0.085
14	0.460	0.390	0.280	0.210	0.160	0.120	0.090	0.059	0.220	0.000
15	0.560	0.480	0.390	0.320	0.210	0.210	0.140	0.120	0.220	0.470
16	0.530	0.580	0.490	0.420	0.350	0.270	0.230	0.180	0.140	0.420
17	0.530	0.610	0.590	0.530	0.470	0.410	0.310	0.280	0.150	0.160
18	0.490	0.650	0.690	0.630	0.580	0.530	0.420	0.380	0.260	0.110
19	0.740	0.690	0.750	0.720	0.680	0.640	0.520	0.480	0.320	0.210
20	0.740	0.760	0.800	0.750	0.760	0.770	0.620	0.580	0.420	0.210
21	0.700	0.730	0.770	0.780	0.760	0.780	0.680	0.640	0.510	0.310
22	0.740	0.720	0.730	0.770	0.770	0.790	0.700	0.690	0.580	0.390
23	0.630	0.640	0.620	0.710	0.710	0.750	0.710	0.710	0.660	0.520
24	0.490	0.510	0.520	0.620	0.650	0.670	0.690	0.720	0.670	0.530
25	0.350	0.380	0.410	0.480	0.520	0.530	0.600	0.610	0.600	0.520
26	0.220	0.270	0.300	0.350	0.390	0.410	0.490	0.500	0.490	0.420
27	0.180	0.200	0.220	0.250	0.290	0.290	0.370	0.380	0.390	0.360
28	0.088	0.110	0.140	0.160	0.190	0.200	0.260	0.260	0.300	0.310
29	0.063	0.082	0.100	0.120	0.140	0.140	0.180	0.190	0.240	0.270
30	0.039	0.048	0.059	0.075	0.091	0.095	0.130	0.130	0.190	0.210
31	0.025	0.032	0.039	0.051	0.062	0.061	0.087	0.090	0.130	0.160
32	0.014	0.016	0.018	0.026	0.034	0.037	0.053	0.052	0.083	0.110
33	0.011	0.011	0.012	0.019	0.026	0.027	0.035	0.038	0.061	0.079
34	0.007	0.007	0.007	0.013	0.020	0.021	0.024	0.024	0.040	0.053
35	0.004	0.004	0.005	0.009	0.012	0.015	0.021	0.022	0.028	0.032
36	0.002	0.002	0.003	0.003	0.004	0.007	0.016	0.019	0.021	0.021
37	0.001	0.001	0.002	0.002	0.003	0.003	0.009	0.012	0.012	0.011
38	0.000	0.001	0.001	0.001	0.002	0.002	0.004	0.005	0.004	0.004
39	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.001	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000
σ_{in}	1.505	1.499	1.460	1.502	1.499	1.498	1.500	1.503	1.482	1.377

INELASTIC SCATTERING MATRIX
ZIRCONIUM
78 GROUP STRUCTURE
BARNs PER LETHARGY INTERVAL

j n	11	12	13	14	15	16	17	18	19	20
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.000									
12	0.000	0.000								
13	2.400	0.000	0.000							
14	2.400	3.200	0.000	0.000						
15	0.240	3.200	1.400	0.000	0.000					
16	0.330	0.000	4.550	0.000	0.000	0.000				
17	0.330	0.190	0.700	3.800	0.000	0.000	0.000			
18	0.120	0.130	0.000	2.960	1.578	0.000	0.000	0.000		
19	0.120	0.130	0.140	0.000	4.181	0.000	0.000	0.000	0.000	
20	0.120	0.130	0.140	0.000	1.341	2.920	0.000	0.000	0.000	0.000
21	0.160	0.130	0.140	0.120	0.000	3.960	0.000	0.000	0.000	0.000
22	0.240	0.150	0.160	0.140	0.000	0.210	3.200	0.000	0.000	0.000
23	0.240	0.160	0.140	0.140	0.079	0.000	0.160	2.640	0.000	0.000
24	0.240	0.160	0.140	0.130	0.079	0.000	0.000	0.640	0.480	0.000
25	0.230	0.150	0.130	0.120	0.060	0.021	0.000	0.000	1.700	0.640
26	0.180	0.130	0.120	0.110	0.000	0.042	0.000	0.000	0.940	1.480
27	0.150	0.064	0.088	0.085	0.020	0.042	0.000	0.000	0.000	0.600
28	0.130	0.096	0.035	0.042	0.024	0.033	0.020	0.000	0.000	0.000
29	0.120	0.080	0.035	0.000	0.020	0.025	0.040	0.000	0.000	0.000
30	0.096	0.064	0.042	0.017	0.020	0.004	0.036	0.000	0.000	0.000
31	0.077	0.048	0.035	0.021	0.016	0.000	0.032	0.000	0.000	0.000
32	0.058	0.045	0.035	0.017	0.016	0.000	0.028	0.000	0.000	0.000
33	0.043	0.035	0.028	0.013	0.012	0.000	0.024	0.000	0.000	0.000
34	0.034	0.026	0.021	0.012	0.010	0.000	0.020	0.000	0.000	0.000
35	0.019	0.015	0.010	0.009	0.008	0.000	0.016	0.000	0.000	0.000
36	0.012	0.010	0.007	0.007	0.006	0.004	0.012	0.000	0.000	0.000
37	0.008	0.005	0.003	0.003	0.003	0.008	0.008	0.000	0.000	0.000
38	0.003	0.002	0.001	0.001	0.001	0.004	0.004	0.000	0.000	0.000
39	0.001	0.000	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ_{in}	1.248	1.199	1.141	1.077	0.982	0.959	0.900	0.820	0.780	0.680

INELASTIC SCATTERING MATRIX
 ZIRCONIUM
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j	21	22	23	24	25	26	27	28	29	30
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	0.000									
22	0.000	0.000								
23	0.000	0.000	0.000							
24	0.000	0.000	0.0	0.0						
25	0.000	0.000	0.0	0.0	0.0					
26	0.000	0.000	0.0	0.0	0.0	0.0				
27	0.440	0.000	0.0	0.0	0.0	0.0	0.0			
28	0.680	0.000	0.0	0.0	0.0	0.0	0.0	0.0		
29	0.560	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.220	0.120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.000	0.092	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.000	0.048	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.000	0.020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_{in}	0.475	0.070	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Niobium Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	ξ	σ_1
1	2.4	1.5	0.1	0.82	0.00376	2.1
2	2.4	1.5	0.1	0.81	0.00398	2.1
3	2.4	1.5	0.1	0.79	0.00441	2.0
4	2.5	1.5	0.1	0.77	0.00485	1.9
5	2.5	1.5	0.05	0.75	0.00528	1.9
6	2.5	1.5	0.05	0.71	0.00615	1.8
7	2.6	1.5	0	0.67	0.00702	1.7
8	2.6	1.5	↓	0.63	0.00789	1.6
9	2.6	1.5		0.59	0.00876	1.5
10	2.6	1.5		0.54	0.00985	1.4
11	2.6	1.5		0.49	0.0109	1.3
12	2.8	1.3	↓	0.44	0.0120	1.2
13	3.2	1.1		0.39	0.0131	1.2
14	3.5	1.0		0.37	0.0135	1.3
15	3.9	0.9		0.36	0.0138	1.4
16	4.2	0.8	0.01	0.37	0.0135	1.6
17	4.6	0.7	0.02	0.38	0.0133	1.8
18	4.9	0.7	0.03	0.39	0.0131	1.9
19	5.2	0.7	0.03	0.39	0.0131	2.0
20	5.6	0.7	0.04	0.39	0.0131	2.2
21	6.1	0.6	0.04	0.38	0.0133	2.3
22	6.9	0.5	0.04	0.38	0.0133	2.6
23	8.0	0.1	0.05	0.34	0.0142	2.7
24	8.5	0	0.05	0.29	0.0153	2.5
25	8.7	↓	0.06	0.24	0.0164	2.1
26	8.9		0.06	0.19	0.0174	1.7
27	8.9		0.07	0.15	0.0183	1.3
28	9.0		0.09	0.12	0.0190	1.1
29	9.1		0.10	0.090	0.0196	0.8
30	9.1		0.12	0.075	0.0199	0.7
31	9.0		0.14	0.065	0.0202	0.6
32	8.9		0.16	0.055	0.0204	0.5
33	8.8		0.17	0.048	0.0205	0.4
34	8.7		0.19	0.040	0.0207	0.3
35	8.6		0.20	0.034	0.0208	0.3
36	8.5		0.2	0.028	0.0210	0.2
37	8.4		0.2	0.023	0.0211	0.19
38	8.3		0.2	0.018	0.0212	0.15
39	8.2		0.3	0.014	0.0213	0.11
40	8.1		0.3	0.011	0.0213	0.09

Niobium Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\bar{\mu}$	ξ	σ_1
41	8.1	0	0.3	0.009	0.0214	0.07
42	8.0		0.3	0.008		0.06
43	7.2		0.4	0.0072		0.052
44	8.0		0.6			0.058
45	7.8		0.6			0.056
46	7.9		0.6			0.057
47	6.8		0.5			0.049
48	7.3		0.4			0.053
49	7.3		0.7			0.053
50	6.1		0.3			0.040
51	6.1		0.4			0.042
52	6.1		0.0			0.040
53	6.4		0.6			0.043
54	6.2		0.5			0.042
55	6.2		0.4			0.039
56	6.5		1.4			0.040
57	6.2		0.0			0.039
58	6.4		1.9			0.040
59	6.2		0.6			0.040
60			0.1			0.039
61		0	0.1	0.0072	0.0214	0.039
62			0.2			0.040
63			1.4			0.040
64			0.3			0.039
65			0.3			0.039
66			0.4			0.039
67			0.05			0.039
68			0.06			0.039
69			0.06			0.039
70			0.07			0.039
71			0.08			0.039
72			0.09			0.039
73			0.11			0.039
74			0.12			0.039
75			0.13			0.039
76			0.15			0.039
77			0.18			0.039
78	6.2	0	0.21	0.0072	0.0214	0.039

INELASTIC SCATTERING MATRIX
 NIOBIUM
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j n	1	2	3	4	5	6	7	8	9	10
1	0.000									
2	0.000	0.000								
3	0.007	0.000	0.000							
4	0.014	0.003	0.000	0.000						
5	0.018	0.008	0.000	0.000	0.000					
6	0.049	0.019	0.001	0.016	0.000	0.000				
7	0.070	0.033	0.004	0.001	0.040	0.016	0.000			
8	0.110	0.057	0.006	0.005	0.001	0.080	0.040	0.000		
9	0.140	0.086	0.021	0.009	0.007	0.080	0.160	0.080	0.000	
10	0.180	0.120	0.036	0.027	0.011	0.010	0.040	0.320	0.200	0.000
11	0.250	0.170	0.097	0.054	0.033	0.020	0.019	0.080	0.600	0.400
12	0.320	0.240	0.160	0.089	0.054	0.043	0.026	0.040	0.160	1.200
13	0.390	0.300	0.220	0.150	0.083	0.075	0.048	0.037	0.000	0.160
14	0.460	0.390	0.280	0.210	0.160	0.120	0.090	0.059	0.220	0.160
15	0.560	0.480	0.390	0.320	0.210	0.210	0.140	0.120	0.220	0.320
16	0.530	0.580	0.490	0.420	0.350	0.270	0.230	0.180	0.140	0.320
17	0.530	0.610	0.590	0.530	0.470	0.410	0.310	0.280	0.150	0.240
18	0.490	0.650	0.690	0.630	0.580	0.530	0.420	0.380	0.260	0.240
19	0.740	0.690	0.750	0.720	0.680	0.640	0.520	0.480	0.320	0.160
20	0.740	0.760	0.800	0.750	0.760	0.770	0.620	0.580	0.420	0.160
21	0.700	0.730	0.770	0.780	0.760	0.780	0.680	0.640	0.510	0.310
22	0.740	0.720	0.730	0.770	0.770	0.790	0.700	0.690	0.580	0.390
23	0.630	0.640	0.620	0.710	0.710	0.750	0.710	0.710	0.660	0.520
24	0.490	0.510	0.520	0.620	0.650	0.670	0.690	0.720	0.670	0.530
25	0.350	0.380	0.410	0.480	0.520	0.530	0.600	0.610	0.600	0.520
26	0.220	0.270	0.300	0.350	0.390	0.410	0.490	0.500	0.490	0.420
27	0.180	0.200	0.220	0.250	0.290	0.290	0.370	0.380	0.390	0.360
28	0.088	0.110	0.140	0.160	0.190	0.200	0.260	0.260	0.300	0.310
29	0.063	0.082	0.100	0.120	0.140	0.140	0.180	0.190	0.240	0.270
30	0.039	0.048	0.059	0.075	0.091	0.095	0.130	0.130	0.190	0.210
31	0.025	0.032	0.039	0.051	0.062	0.061	0.087	0.090	0.130	0.160
32	0.014	0.016	0.018	0.026	0.034	0.037	0.053	0.052	0.083	0.110
33	0.011	0.011	0.012	0.019	0.026	0.027	0.035	0.038	0.061	0.079
34	0.007	0.007	0.007	0.013	0.020	0.021	0.024	0.024	0.040	0.053
35	0.004	0.004	0.005	0.009	0.012	0.015	0.021	0.022	0.028	0.032
36	0.002	0.002	0.003	0.003	0.004	0.007	0.016	0.019	0.021	0.021
37	0.001	0.001	0.002	0.002	0.003	0.003	0.009	0.012	0.012	0.011
38	0.001	0.001	0.001	0.001	0.002	0.002	0.004	0.005	0.004	0.004
39	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.001	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000

σ_{in} 1.504 1.499 1.460 1.504 1.504 1.519 1.513 1.523 1.520 1.459

INELASTIC SCATTERING MATRIX
 NIOBIUM
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j n	11	12	13	14	15	16	17	18	19	20
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.000									
12	0.000	0.000								
13	2.900	0.000	0.000							
14	2.900	3.500	0.000	0.000						
15	0.290	3.500	1.400	0.000	0.000					
16	0.400	0.240	4.550	3.600	0.000	0.000				
17	0.400	0.210	0.700	2.800	1.656	0.000	0.000			
18	0.110	0.110	0.160	0.120	4.232	0.000	0.000	0.000		
19	0.110	0.110	0.110	0.160	0.074	3.600	0.000	0.000	0.000	
20	0.110	0.110	0.110	0.160	0.117	2.000	1.502	0.000	0.000	0.000
21	0.190	0.110	0.110	0.120	0.129	0.040	3.004	0.000	0.000	0.000
22	0.290	0.160	0.160	0.090	0.110	0.060	0.215	2.400	0.000	0.000
23	0.290	0.180	0.110	0.072	0.083	0.048	0.000	0.000	2.400	0.000
24	0.290	0.180	0.110	0.064	0.055	0.040	0.043	0.000	0.000	1.378
25	0.280	0.160	0.130	0.056	0.037	0.036	0.043	0.040	0.000	1.263
26	0.220	0.110	0.120	0.048	0.033	0.034	0.043	0.040	0.040	0.046
27	0.180	0.070	0.088	0.040	0.029	0.032	0.039	0.040	0.040	0.000
28	0.160	0.110	0.035	0.032	0.026	0.028	0.034	0.032	0.040	0.000
29	0.110	0.088	0.035	0.024	0.022	0.024	0.030	0.028	0.032	0.000
30	0.110	0.070	0.042	0.020	0.018	0.020	0.026	0.024	0.024	0.000
31	0.092	0.053	0.035	0.016	0.015	0.016	0.021	0.020	0.021	0.023
32	0.070	0.049	0.035	0.013	0.013	0.013	0.017	0.016	0.018	0.023
33	0.052	0.038	0.028	0.010	0.010	0.010	0.013	0.012	0.015	0.021
34	0.041	0.029	0.021	0.008	0.008	0.008	0.009	0.008	0.012	0.017
35	0.023	0.016	0.010	0.006	0.006	0.006	0.006	0.006	0.007	0.014
36	0.014	0.011	0.007	0.004	0.005	0.004	0.004	0.004	0.004	0.009
37	0.010	0.006	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.005
38	0.004	0.002	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
39	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

σ_{in}^f 1.504 1.342 1.161 0.997 0.899 0.801 0.700 0.668 0.664 0.701

INELASTIC SCATTERING MATRIX
 NIOBIUM
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j n	21	22	23	24	25	26	27	28	29	30
1										
2										
3										
4										
5										
6										
7										
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9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	0.000									
22	0.000	0.000								
23	0.000	0.000	0.000							
24	0.000	0.000	0.000	0.0						
25	1.800	0.000	0.000	0.0	0.0					
26	0.600	0.320	0.000	0.0	0.0	0.0				
27	0.000	0.480	0.000	0.0	0.0	0.0	0.0			
28	0.000	0.440	0.000	0.0	0.0	0.0	0.0	0.0		
29	0.000	0.400	0.000	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.000	0.360	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.000	0.000	0.060	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.000	0.000	0.056	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.000	0.000	0.052	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.000	0.000	0.044	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.000	0.000	0.036	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.000	0.000	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.000	0.000	0.020	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.000	0.000	0.012	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.000	0.000	0.008	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.000	0.000	0.004	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_{in}	0.600	0.500	0.080	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Cadmium Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\sigma_{n,2n}$	$\bar{\mu}$	ξ	σ_1
1	3.3	1.2	0	0.8	0.83	0.00316	2.7
2	3.0	1.5		0.6	0.82	0.00334	2.5
3	2.6	1.8		0.2	0.80	0.00371	2.1
4	2.3	2.0		0.03	0.79	0.00389	1.8
5	2.1	2.1		0	0.76	0.00443	1.6
6	2.0	2.1			0.74	0.00480	1.5
7	1.9	2.2			0.70	0.00553	1.4
8	1.9	2.3			0.65	0.00643	1.3
9	1.9	2.2			0.61	0.00716	1.2
10	1.9	2.1			0.59	0.00753	1.1
11	2.0	2.1			0.58	0.00771	1.2
12	2.2	2.0			0.56	0.00807	1.2
13	2.5	2.0			0.55	0.00826	1.4
14	2.9	1.9			0.54	0.00843	1.6
15	3.3	1.8			0.53	0.00862	1.7
16	3.7	1.7			0.52	0.00880	1.9
17	4.1	1.6			0.51	0.00898	2.1
18	4.5	1.5			0.50	0.00916	2.2
19	4.8	1.4			0.48	0.00953	2.3
20	5.1	1.3	↓	↓	0.47	0.00971	2.4
21	5.4	1.2	0	0	0.46	0.00989	2.5
22	5.9	1.0			0.45	0.0101	2.7
23	6.4	0.8			0.43	0.0104	2.8
24	6.7	0.5			0.40	0.0110	2.7
25	6.9	0.2			0.37	0.0115	2.6
26	7.1	0.1			0.32	0.0124	2.3
27	7.3	0.04			0.29	0.0130	2.1
28	7.3	0			0.26	0.0135	1.9
29	7.2				0.22	0.0142	1.6
30	7.2				0.18	0.0150	1.3
31	7.2				0.15	0.0155	1.1
32	7.1				0.12	0.0161	0.8
33	7.0				0.09	0.0166	0.6
34	7.0				0.07	0.0170	0.5
35	7.0				0.04	0.0175	0.3
36	7.0				0.02	0.0178	0.14
37	7.0				0.015	0.0179	0.10
38	7.0		↓	↓	0.010	0.0180	0.07
39	7.0	↓	↓	↓	0.008	0.0180	0.06
40	7.0	0	0	0	0.0059	0.0181	0.041

Cadmium Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\sigma_{n,2n}$	$\bar{\mu}$	ξ	σ_1
41	6.8	0	0	0	0.0059	0.0181	0.040
42	6.5						0.038
43	6.4						0.038
44	6.7						0.039
45	7.1						0.042
46	7.1		↓				0.042
47	6.7		0				0.039
48	6.3		0.01				0.037
49	5.7		0.1				0.034
50	5.5		1.1				0.032
51	5.4		0.2				0.032
52	5.2		0.7				0.031
53	5.0		2.8				0.030
54	4.9		0.6				0.029
55	4.8		1.5				0.028
56	4.7		0.5				0.028
57	4.5		1.1				0.027
58	4.4		2.3				0.026
59	4.4		11.0				0.026
60	4.3		2.1				0.025
61	4.3	0	0.2	0	0.0059	0.0181	0.025
62	4.3		0.01				0.025
63	4.3		0.9				0.025
64	4.3		11.0				0.025
65	4.3		0.8				0.025
66	4.4		0.3				0.026
67	4.5		0.02				0.027
68	4.7		0.03				0.028
69	4.8		0.05				0.028
70	5.0		0.12				0.030
71	5.1		0.23				0.030
72	5.2		0.45				0.031
73	5.4		0.8				0.032
74	5.6		1.6				0.033
75	5.9		3.6				0.035
76	6.4		7.2				0.038
77	6.9		16.				0.041
78	7.0	0	41.	0	0.0059	0.0181	0.041

INELASTIC SCATTERING MATRIX
CADMIUM
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j n	1	2	3	4	5	6	7	8	9	10
1	0.000									
2	0.000	0.000								
3	0.000	0.000	0.000							
4	0.000	0.000	0.000	0.000						
5	0.001	0.000	0.000	0.000	0.000					
6	0.002	0.001	0.001	0.000	0.000	0.000				
7	0.010	0.003	0.002	0.001	0.001	0.000	0.000			
8	0.016	0.006	0.005	0.002	0.002	0.001	0.001	0.001		
9	0.041	0.022	0.011	0.009	0.009	0.004	0.003	0.002	0.001	
10	0.065	0.036	0.034	0.015	0.015	0.011	0.009	0.005	0.003	0.006
11	0.117	0.100	0.051	0.044	0.045	0.035	0.030	0.018	0.010	0.015
12	0.171	0.165	0.110	0.071	0.074	0.062	0.055	0.035	0.020	0.100
13	0.256	0.227	0.200	0.109	0.118	0.106	0.100	0.075	0.055	0.250
14	0.331	0.289	0.300	0.218	0.226	0.203	0.190	0.130	0.089	0.150
15	0.416	0.392	0.400	0.336	0.353	0.309	0.300	0.240	0.180	0.130
16	0.491	0.506	0.530	0.472	0.489	0.442	0.400	0.330	0.270	0.210
17	0.566	0.609	0.670	0.626	0.652	0.601	0.600	0.510	0.420	0.310
18	0.630	0.712	0.780	0.780	0.815	0.672	0.740	0.650	0.560	0.460
19	0.651	0.764	0.900	0.889	0.932	0.751	0.850	0.790	0.720	0.600
20	0.662	0.815	0.930	0.998	1.050	0.999	0.980	0.940	0.880	0.740
21	0.608	0.784	0.950	1.016	1.068	1.025	1.090	1.000	0.960	0.870
22	0.544	0.753	0.900	1.025	1.077	1.034	1.120	1.060	1.040	0.950
23	0.459	0.640	0.840	0.952	0.996	0.955	1.140	1.090	1.070	1.040
24	0.384	0.537	0.690	0.862	0.905	0.884	1.040	1.110	1.090	0.990
25	0.288	0.423	0.540	0.689	0.724	0.796	0.940	0.980	0.920	0.910
26	0.203	0.310	0.420	0.517	0.543	0.619	0.720	0.740	0.750	0.760
27	0.139	0.227	0.290	0.390	0.407	0.477	0.055	0.560	0.570	0.580
28	0.086	0.144	0.210	0.245	0.262	0.327	0.380	0.390	0.400	0.410
29	0.064	0.102	0.130	0.190	0.199	0.239	0.280	0.290	0.290	0.300
30	0.043	0.061	0.095	0.118	0.127	0.168	0.190	0.200	0.190	0.200
31	0.028	0.039	0.054	0.083	0.087	0.106	0.120	0.130	0.140	0.140
32	0.013	0.019	0.038	0.044	0.046	0.062	0.072	0.075	0.079	0.090
33	0.011	0.012	0.024	0.035	0.037	0.049	0.056	0.057	0.058	0.060
34	0.009	0.007	0.014	0.027	0.028	0.035	0.040	0.040	0.036	0.032
35	0.006	0.005	0.006	0.015	0.016	0.020	0.025	0.027	0.029	0.022
36	0.004	0.003	0.004	0.005	0.005	0.009	0.015	0.020	0.024	0.015
37	0.002	0.001	0.002	0.003	0.004	0.005	0.009	0.013	0.018	0.010
38	0.001	0.000	0.001	0.002	0.002	0.003	0.004	0.005	0.007	0.006
39	0.001	0.000	0.000	0.001	0.001	0.001	0.002	0.003	0.004	0.003
40	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002

σ_{in} 1.200 1.500 1.799 1.999 2.098 2.103 2.221 2.288 2.200 2.109

INELASTIC SCATTERING MATRIX
 CADMIUM
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j	11	12	13	14	15	16	17	18	19	20
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.020									
12	0.300	0.080								
13	0.500	0.600	0.080							
14	0.250	1.000	0.800	0.060						
15	0.100	0.500	1.200	0.750	0.045					
16	0.140	0.180	0.500	1.200	0.600	0.020				
17	0.250	0.160	0.250	0.600	1.000	0.500	0.000			
18	0.360	0.270	0.180	0.300	0.700	0.800	0.400	0.000		
19	0.500	0.380	0.290	0.220	0.300	0.800	0.700	0.350	0.000	
20	0.650	0.510	0.410	0.330	0.260	0.300	0.700	0.600	0.272	0.000
21	0.760	0.640	0.510	0.440	0.360	0.300	0.300	0.700	0.362	0.359
22	0.870	0.760	0.620	0.540	0.470	0.390	0.400	0.400	0.634	0.478
23	0.950	0.880	0.760	0.700	0.610	0.560	0.520	0.500	0.544	0.717
24	1.040	0.970	0.900	0.850	0.760	0.730	0.650	0.600	0.507	0.657
25	0.910	0.870	0.830	0.840	0.770	0.740	0.700	0.670	0.571	0.538
26	0.770	0.760	0.760	0.750	0.750	0.730	0.700	0.710	0.634	0.538
27	0.600	0.600	0.610	0.610	0.600	0.600	0.610	0.620	0.571	0.478
28	0.420	0.430	0.450	0.460	0.470	0.470	0.500	0.520	0.489	0.382
29	0.320	0.330	0.340	0.350	0.360	0.370	0.400	0.420	0.399	0.299
30	0.200	0.210	0.230	0.240	0.250	0.260	0.290	0.310	0.299	0.227
31	0.150	0.160	0.160	0.170	0.180	0.190	0.210	0.230	0.227	0.203
32	0.100	0.100	0.098	0.100	0.100	0.110	0.120	0.140	0.145	0.167
33	0.063	0.065	0.067	0.075	0.081	0.087	0.095	0.100	0.100	0.120
34	0.026	0.031	0.037	0.044	0.051	0.058	0.060	0.062	0.058	0.078
35	0.017	0.020	0.022	0.029	0.036	0.044	0.045	0.047	0.044	0.057
36	0.007	0.007	0.007	0.011	0.020	0.030	0.031	0.032	0.031	0.039
37	0.006	0.006	0.006	0.008	0.012	0.017	0.018	0.019	0.018	0.025
38	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.008
39	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.006
40	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.003	0.005
σ_{in}	2.091	2.082	1.994	1.926	1.785	1.687	1.603	1.555	1.400	1.301

INELASTIC SCATTERING MATRIX
 CADMIUM
 78 GROUP STRUCTURE
 BARNs PER LETHARGY INTERVAL

j n	21	22	23	24	25	26	27	28	29	30
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21	0.000									
22	0.416	0.000								
23	0.624	0.413	0.000							
24	0.762	0.688	0.383	0.000						
25	0.554	0.688	0.703	0.025	0.000					
26	0.416	0.413	0.575	0.644	0.000	0.000				
27	0.416	0.330	0.243	0.582	0.070	0.000	0.000			
28	0.360	0.275	0.256	0.136	0.300	0.000	0.000	0.0		
29	0.277	0.261	0.217	0.000	0.330	0.000	0.000	0.0	0.0	
30	0.236	0.220	0.179	0.111	0.130	0.105	0.000	0.0	0.0	0.0
31	0.194	0.179	0.153	0.093	0.050	0.088	0.000	0.0	0.0	0.0
32	0.166	0.151	0.128	0.099	0.000	0.091	0.000	0.0	0.0	0.0
33	0.125	0.117	0.102	0.074	0.000	0.070	0.013	0.0	0.0	0.0
34	0.086	0.083	0.077	0.062	0.000	0.014	0.042	0.0	0.0	0.0
35	0.065	0.063	0.058	0.050	0.000	0.009	0.025	0.0	0.0	0.0
36	0.044	0.043	0.038	0.037	0.000	0.008	0.021	0.0	0.0	0.0
37	0.030	0.033	0.032	0.031	0.000	0.006	0.017	0.0	0.0	0.0
38	0.014	0.019	0.026	0.025	0.000	0.005	0.013	0.0	0.0	0.0
39	0.010	0.014	0.019	0.019	0.000	0.004	0.008	0.0	0.0	0.0
40	0.007	0.010	0.013	0.012	0.000	0.000	0.012	0.0	0.0	0.0
σ_{in}	1.201	1.000	0.800	0.500	0.220	0.100	0.038	0.0	0.0	0.0

Hafnium Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	$\sigma_{n,2n}$	$\bar{\mu}$	ξ	σ_1
1	2.1	2.2	0.01	0.9	0.75	.00275	1.6
2	1.8	2.5	0.01	0.6	0.73	.00298	1.3
3	1.6	2.9	0.01	0.3	0.72	.00309	1.2
4	1.6	3.1	0.01	0.05	0.72	.00309	1.2
5	1.7	3.1	0.02	0	0.71	.00320	1.2
6	1.9	3.1	0.02		0.71	.00320	1.3
7	2.1	3.1	0.02		0.72	.00309	1.5
8	2.3	3.1	0.03		0.73	.00298	1.7
9	2.6	3.1	0.03		0.73	.00298	1.9
10	2.9	3.1	0.04		0.74	.00286	2.1
11	3.2	3.1	0.05		0.74	.00286	2.4
12	3.5	3.0	0.06		0.74	.00286	2.6
13	3.7	3.0	0.08		0.74	.00286	2.7
14	3.7	3.0	0.10		0.74	.00286	2.7
15	3.7	3.0	0.12		0.74	.00286	2.7
16	3.7	3.0	0.13		0.69	.00342	2.6
17	3.7	3.0	0.15		0.63	.00409	2.3
18	3.7	3.0	0.15		0.50	.00554	1.8
19	3.8	2.9	0.16		0.42	.00644	1.6
20	3.9	2.8	0.17	0	0.38	.00688	1.5
21	4.0	2.6	0.18		0.36	.00711	1.4
22	4.2	2.5	0.2		0.34	.00733	1.4
23	4.5	2.2	0.2		0.30	.00778	1.4
24	4.9	1.8	0.3		0.27	.00811	1.3
25	5.3	1.6	0.3		0.24	.00845	1.3
26	5.9	1.2	0.3		0.21	.00878	1.1
27	6.4	0.8	0.4		0.18	.00912	1.2
28	6.8	0.6	0.4		0.16	.00934	1.2
29	7.2	0.5	0.5		0.14	.00957	1.0
30	7.6	0.3	0.6		0.12	.00979	0.9
31	7.9	0.1	0.6		0.10	.0100	0.8
32	8.2	0	0.7		0.08	.0102	0.7
33	8.4	0	0.8		0.06	.0105	0.5
34	8.7	0	0.9		0.05	.0106	0.4
35	8.9	0	1.0		0.03	.0108	0.3
36	9.1	0	1.2		0.02	.0110	0.2
37	9.4	0	1.3		0.015	.0110	0.14
38	9.8	0	1.5		0.010	.0111	0.10
39	10.3	0	1.7		0.007	.0111	0.07
40	10.9	0	1.9	0	0.005	.0111	0.05

Hafnium Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	$\sigma_{n,2n}$	$\bar{\mu}$	ξ	σ_1
41	11.5	0	2.1	0	.0037	.0111	.043
42	12.0	↓	2.3	↓	↓	↓	.045
43	12.2		2.5				.045
44	12.5		2.7				.046
45	13.2		3.0				.049
46	14.2		3.3				.053
47	14.5		3.5				.054
48	14.5		3.8				.054
49	14.2		4.1				.053
50	14.0		4.5				.052
51	14.0	↓	5.0	↓	↓	↓	.052
52	13.7		5.5				.051
53	13.5		5.8				.050
54	14.5		6.5				.054
55	14.0		6.4				.052
56	20.5		10.5				.076
57	14.0		5.7				.052
58	14.0		11.5				.052
59	10.4		15.0				.039
60	18.	0	40.	0	.0037	.0111	.067
61	25.	↓	38.	↓	↓	↓	.093
62	14.		21.				.052
63	15.		37.				.056
64	9.0		24.				.033
65	8.9		26.				.033
66	9.1		39.				.034
67	9.3		37.				.035
68	55.		220.				0.20
69	1070.		1530.				3.97
70	38.		380.				0.14
71	10.	↓	30.	↓	↓	↓	0.037
72	9.7		25.				0.036
73	70.		810.				0.26
74	120.		1400.				0.45
75	9.8		66.				0.036
76	40.		960.				0.15
77	70.		1680.				0.26
78	9.7	0	79.	0	.0037	.0111	0.036

INELASTIC SCATTERING MATRIX
HAFNIUM
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j n	1	2	3	4	5	6	7	8	9	10
1	0.000									
2	0.000	0.000								
3	0.000	0.000	0.000							
4	0.000	0.000	0.000	0.000						
5	0.000	0.000	0.000	0.000	0.000					
6	0.001	0.001	0.001	0.000	0.000	0.000				
7	0.005	0.003	0.002	0.002	0.001	0.000	0.000			
8	0.009	0.006	0.005	0.003	0.002	0.001	0.000	0.000		
9	0.032	0.025	0.020	0.013	0.008	0.003	0.002	0.000	0.000	
10	0.054	0.042	0.033	0.023	0.015	0.010	0.004	0.002	0.001	0.000
11	0.145	0.120	0.095	0.067	0.040	0.025	0.014	0.007	0.005	0.003
12	0.238	0.190	0.150	0.113	0.075	0.070	0.028	0.015	0.010	0.008
13	0.332	0.270	0.220	0.169	0.110	0.120	0.078	0.055	0.036	0.020
14	0.425	0.390	0.370	0.300	0.220	0.230	0.130	0.090	0.061	0.042
15	0.580	0.570	0.560	0.498	0.390	0.380	0.250	0.180	0.140	0.085
16	0.746	0.740	0.750	0.723	0.570	0.570	0.380	0.300	0.230	0.160
17	0.901	0.910	0.970	0.967	0.790	0.800	0.580	0.480	0.390	0.270
18	1.046	1.100	1.200	1.211	1.060	1.040	0.800	0.680	0.560	0.450
19	1.129	1.190	1.330	1.390	1.190	1.140	1.020	0.900	0.790	0.660
20	1.212	1.340	1.500	1.568	1.320	1.340	1.230	1.120	1.020	0.900
21	1.160	1.300	1.500	1.587	1.460	1.460	1.360	1.270	1.190	1.100
22	1.109	1.300	1.450	1.596	1.490	1.500	1.470	1.410	1.360	1.300
23	0.943	1.150	1.350	1.465	1.500	1.520	1.500	1.500	1.500	1.500
24	0.777	0.950	1.180	1.333	1.360	1.340	1.530	1.590	1.640	1.640
25	0.611	0.780	0.960	1.070	1.210	1.250	1.290	1.360	1.430	1.450
26	0.445	0.570	0.720	0.808	0.880	0.970	1.050	1.140	1.220	1.270
27	0.332	0.420	0.530	0.601	0.710	0.760	0.810	0.880	0.940	0.990
28	0.207	0.270	0.340	0.385	0.520	0.540	0.560	0.620	0.670	0.720
29	0.145	0.190	0.250	0.291	0.350	0.380	0.410	0.460	0.500	0.540
30	0.089	0.120	0.160	0.188	0.260	0.270	0.270	0.300	0.330	0.360
31	0.058	0.075	0.110	0.131	0.180	0.190	0.190	0.220	0.240	0.260
32	0.028	0.040	0.065	0.069	0.120	0.110	0.110	0.130	0.160	0.170
33	0.019	0.031	0.042	0.055	0.070	0.075	0.081	0.090	0.100	0.110
34	0.010	0.021	0.032	0.041	0.049	0.050	0.051	0.046	0.041	0.050
35	0.007	0.011	0.018	0.024	0.034	0.038	0.046	0.036	0.026	0.030
36	0.004	0.006	0.007	0.011	0.019	0.025	0.041	0.025	0.011	0.014
37	0.002	0.003	0.004	0.005	0.009	0.015	0.025	0.016	0.009	0.009
38	0.001	0.001	0.002	0.003	0.004	0.006	0.010	0.008	0.007	0.007
39	0.000	0.000	0.001	0.001	0.002	0.003	0.005	0.004	0.004	0.004
40	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.002	0.002	0.002
σ_{in}	2.199	2.509	2.894	3.098	3.098	3.160	3.098	3.087	3.102	3.069

INELASTIC SCATTERING MATRIX
HAFNIUM
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j	11	12	13	14	15	16	17	18	19	20
n										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.001									
12	0.005	0.002								
13	0.015	0.012	0.005							
14	0.055	0.021	0.018	0.010						
15	0.090	0.063	0.049	0.028	0.021					
16	0.140	0.110	0.083	0.070	0.039	0.028				
17	0.250	0.220	0.170	0.130	0.096	0.070	0.035			
18	0.390	0.330	0.280	0.210	0.151	0.120	0.090	0.042		
19	0.600	0.530	0.450	0.380	0.292	0.260	0.150	0.110	0.100	
20	0.810	0.730	0.630	0.540	0.433	0.420	0.280	0.180	0.300	0.300
21	1.000	0.910	0.800	0.720	0.612	0.560	0.440	0.310	0.300	0.700
22	1.200	1.100	1.000	0.920	0.800	0.800	0.640	0.450	0.550	0.700
23	1.420	1.360	1.290	1.260	1.157	1.160	1.000	0.870	0.950	1.000
24	1.630	1.620	1.580	1.600	1.524	1.390	1.250	1.280	1.200	1.150
25	1.470	1.490	1.510	1.560	1.524	1.500	1.470	1.450	1.400	1.200
26	1.310	1.360	1.410	1.510	1.506	1.480	1.550	1.610	1.500	1.300
27	1.040	1.090	1.140	1.240	1.252	1.260	1.350	1.430	1.250	1.050
28	0.770	0.810	0.870	0.960	0.979	1.030	1.140	1.250	1.150	0.950
29	0.580	0.610	0.650	0.730	0.762	0.820	0.930	1.010	0.900	0.760
30	0.390	0.420	0.470	0.510	0.555	0.600	0.680	0.760	0.720	0.630
31	0.280	0.300	0.330	0.380	0.395	0.440	0.600	0.570	0.550	0.500
32	0.170	0.180	0.200	0.220	0.235	0.270	0.320	0.370	0.360	0.360
33	0.120	0.120	0.140	0.160	0.179	0.190	0.210	0.260	0.260	0.280
34	0.058	0.066	0.083	0.100	0.113	0.120	0.130	0.150	0.160	0.200
35	0.034	0.039	0.053	0.075	0.092	0.093	0.100	0.110	0.120	0.140
36	0.013	0.012	0.025	0.045	0.063	0.065	0.070	0.077	0.090	0.100
37	0.009	0.010	0.014	0.024	0.037	0.038	0.041	0.045	0.052	0.065
38	0.007	0.008	0.009	0.010	0.010	0.010	0.012	0.013	0.016	0.028
39	0.004	0.005	0.005	0.006	0.006	0.006	0.007	0.008	0.010	0.012
40	0.002	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.005	0.006
σ_{in}	3.046	3.017	3.006	3.088	3.000	2.998	2.996	3.004	2.886	2.695

INELASTIC SCATTERING MATRIX
HAFNIUM
78 GROUP STRUCTURE

j n	21	22	23	24	25	26	27	28	29	30
1										
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16										
17										
18										
19										
20										
21	0.700									
22	1.200	1.000								
23	1.200	1.600	1.005							
24	1.100	1.600	2.010	0.639						
25	1.000	1.200	3.014	1.534	0.400					
26	0.900	1.000	0.628	1.448	2.440	0.000				
27	0.800	0.800	0.000	2.130	1.140	1.294	0.000			
28	0.700	0.600	0.502	1.193	1.000	1.294	0.628	0.000		
29	0.620	0.500	0.502	0.298	0.840	0.345	1.345	0.100	0.000	
30	0.540	0.400	0.502	0.043	0.260	0.690	0.381	1.080	0.000	0.000
31	0.450	0.320	0.251	0.000	0.200	0.539	0.000	0.880	0.360	0.000
32	0.360	0.280	0.000	0.000	0.150	0.302	0.067	0.300	0.760	0.000
33	0.300	0.240	0.251	0.000	0.000	0.095	0.202	0.032	0.640	0.000
34	0.250	0.200	0.201	0.000	0.000	0.078	0.157	0.000	0.120	0.400
35	0.200	0.160	0.151	0.072	0.000	0.060	0.123	0.000	0.120	0.300
36	0.140	0.120	0.126	0.060	0.000	0.043	0.094	0.000	0.100	0.200
37	0.080	0.080	0.088	0.043	0.000	0.032	0.072	0.000	0.100	0.120
38	0.040	0.040	0.038	0.021	0.000	0.016	0.054	0.000	0.020	0.080
39	0.015	0.020	0.019	0.011	0.000	0.009	0.040	0.000	0.000	0.060
40	0.008	0.010	0.009	0.006	0.000	0.004	0.031	0.000	0.000	0.040
σ_{in}^t	2.476	2.293	2.073	1.715	1.508	1.200	0.079	0.598	0.555	0.300

Lead Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	σ_F	$\sigma_{n,2n}$	$\bar{\mu}$	ξ
1	2.76	0.78	0	0	1.76	.92	.00074
2	2.29	0.81			1.76	.91	.00084
3	2.00	0.84			1.76	.89	.00103
4	1.93	0.89			1.74	.88	.00113
5	2.17	1.55			1.07	.87	.00123
6	2.81	2.48			0.06	.85	.00133
7	3.51	2.54			0	.84	.00142
8	4.22	2.43				.81	.00181
9	4.90	2.25				.78	.00209
10	5.32	2.05				.73	.00259
11	5.72	1.83				.65	.00336
12	6.03	1.57				.57	.00413
13	6.17	1.33				.50	.00480
14	5.97	1.13				.45	.00518
15	5.55	0.95				.39	.00586
16	5.12	0.78				.35	.00625
17	4.86	0.64				.32	.00654
18	4.67	0.53				.28	.00693
19	4.80	0.43				.25	.00721
20	5.16	0.36				.23	.00741
21	5.17	0.30	0	0	0	.20	.00770
22	5.73	0.19				.17	.00794
23	5.76	0.02				.11	.00857
24	5.20	0				.08	.00886
25	5.35					.13	.00837
26	7.10					.15	.00818
27	7.45					.13	.00837
28	7.93					.10	.00876
29	9.17					.08	.00886
30	10.22					.07	.00895
31	10.67					.05	.00915
32	10.60					.05	.00915
33	10.53					.03	.00934
34	11.07					.03	.00934
35	10.25					.02	.00944
36	10.44					.01	.00954
37	10.70					.01	.00954
38	10.57					0	.00963
39	10.43					0	.00963
40	10.50	0	0	0	0	0	.00963

Lead Cross Sections for 78 Lethargy Groups
Values in barns

j	σ_s	σ_{in}	σ_c	σ_F	$\sigma_{n,2n}$	$\bar{\mu}$	ξ
41	10.50	0	0	0	0	0	.00963
42	10.50	↓	↓	↓	↓	↓	↓
43	10.60	↓	↓	↓	↓	↓	↓
44	10.60	↓	↓	↓	↓	↓	↓
45	10.70	↓	↓	↓	↓	↓	↓
46	10.70	↓	↓	↓	↓	↓	↓
47	10.80	↓	↓	↓	↓	↓	↓
48	10.80	↓	↓	↓	↓	↓	↓
49	10.90	↓	↓	↓	↓	↓	↓
50	10.90	↓	↓	↓	↓	↓	↓
51	11.00	↓	↓	↓	↓	↓	↓
52	11.00	↓	↓	↓	↓	↓	↓
53	11.10	↓	↓	↓	↓	↓	↓
54	11.10	↓	↓	↓	↓	↓	↓
55	11.20	↓	↓	↓	↓	↓	↓
56	11.20	↓	↓	↓	↓	↓	↓
57	11.30	↓	↓	↓	↓	↓	↓
58	11.30	↓	↓	↓	↓	↓	↓
59	11.30	↓	↓	↓	↓	↓	↓
60	11.30	0	0	0	0	0	.00963
61	11.30	↓	0	↓	↓	↓	↓
62	↓	↓	0	↓	↓	↓	↓
63	↓	↓	.01	↓	↓	↓	↓
64	↓	↓	.01	↓	↓	↓	↓
65	↓	↓	.01	↓	↓	↓	↓
66	↓	↓	.01	↓	↓	↓	↓
67	↓	↓	.01	↓	↓	↓	↓
68	↓	↓	.01	↓	↓	↓	↓
69	↓	↓	.01	↓	↓	↓	↓
70	↓	↓	.01	↓	↓	↓	↓
71	↓	↓	.01	↓	↓	↓	↓
72	↓	↓	.02	↓	↓	↓	↓
73	↓	↓	.02	↓	↓	↓	↓
74	↓	↓	.02	↓	↓	↓	↓
75	↓	↓	.02	↓	↓	↓	↓
76	↓	↓	.03	↓	↓	↓	↓
77	↓	↓	.03	↓	↓	↓	↓
78	11.30	0	.04	0	0	0	.00963

INELASTIC SCATTERING MATRIX
 LEAD ^{82}Pb
 78 GROUP STRUCTURE
 BARNS PER LETHARGY INTERVAL

j n	1	2	3	4	5	6	7	8	9	10
1	0.000									
2	0.000	0.000								
3	0.000	0.000	0.000							
4	0.000	0.000	0.000	0.208						
5	0.001	0.000	0.000	0.512	0.280					
6	0.003	0.002	0.001	0.081	1.112	0.272				
7	0.007	0.005	0.003	0.002	0.209	1.873	0.000			
8	0.017	0.011	0.008	0.004	0.005	0.381	2.195	0.001		
9	0.034	0.025	0.018	0.011	0.012	0.051	1.407	2.372	0.002	
10	0.059	0.047	0.036	0.024	0.028	0.028	0.265	1.562	2.885	0.004
11	0.096	0.079	0.064	0.045	0.058	0.063	0.040	0.586	2.076	2.375
12	0.139	0.119	0.099	0.074	0.101	0.121	0.084	0.057	0.902	3.090
13	0.190	0.171	0.148	0.115	0.161	0.206	0.152	0.108	0.325	0.678
14	0.244	0.224	0.202	0.163	0.240	0.314	0.242	0.180	0.108	0.790
15	0.295	0.280	0.262	0.217	0.325	0.460	0.365	0.285	0.178	0.123
16	0.343	0.334	0.317	0.271	0.422	0.605	0.506	0.400	0.269	0.192
17	0.390	0.384	0.375	0.328	0.523	0.762	0.658	0.540	0.369	0.266
18	0.444	0.421	0.425	0.384	0.627	0.937	0.821	0.690	0.480	0.351
19	0.433	0.448	0.460	0.421	0.701	1.064	0.950	0.815	0.588	0.440
20	0.429	0.451	0.473	0.442	0.748	1.155	1.051	0.920	0.673	0.516
21	0.407	0.429	0.453	0.430	0.740	1.179	1.113	1.000	0.757	0.589
22	0.353	0.379	0.408	0.398	0.701	1.137	1.091	1.005	0.792	0.635
23	0.287	0.315	0.347	0.340	0.608	1.004	0.984	0.915	0.738	0.605
24	0.219	0.245	0.272	0.273	0.496	0.835	0.843	0.800	0.661	0.553
25	0.166	0.186	0.211	0.217	0.399	0.683	0.703	0.675	0.569	0.479
26	0.117	0.131	0.151	0.155	0.290	0.506	0.529	0.515	0.450	0.388
27	0.080	0.091	0.103	0.106	0.201	0.351	0.371	0.360	0.319	0.278
28	0.051	0.059	0.068	0.070	0.133	0.239	0.255	0.252	0.219	0.195
29	0.033	0.038	0.044	0.046	0.088	0.157	0.170	0.171	0.150	0.134
30	0.020	0.024	0.027	0.029	0.057	0.102	0.111	0.112	0.100	0.090
31	0.013	0.015	0.017	0.019	0.036	0.065	0.072	0.073	0.065	0.059
32	0.008	0.009	0.011	0.011	0.022	0.040	0.044	0.045	0.040	0.037
33	0.005	0.006	0.007	0.007	0.014	0.025	0.027	0.028	0.025	0.023
34	0.003	0.004	0.004	0.004	0.009	0.015	0.017	0.017	0.015	0.014
35	0.002	0.002	0.003	0.003	0.005	0.010	0.011	0.011	0.010	0.009
36	0.001	0.001	0.002	0.002	0.003	0.006	0.007	0.007	0.006	0.006
37	0.001	0.001	0.001	0.001	0.002	0.004	0.004	0.004	0.004	0.003
38	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.002	0.002
39	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
σ_{in}	0.778	0.806	0.837	0.862	1.519	2.446	2.542	2.438	2.244	2.054

INELASTIC SCATTERING MATRIX
LEAD ^{82}Pb
78 GROUP STRUCTURE
BARNS PER LETHARGY INTERVAL

j n	11	12	13	14	15	16	17	18	19	20
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.004									
12	1.496	0.007								
13	4.610	0.009	0.005							
14	0.149	5.100	0.008	0.005						
15	0.948	1.198	3.624	0.007	0.003					
16	0.560	0.418	2.822	1.622	0.005	0.000				
17	0.163	0.818	0.044	4.573	0.007	0.000	0.000			
18	0.225	0.425	0.490	0.034	3.957	0.000	0.000	0.000		
19	0.291	0.186	0.716	0.048	1.995	1.744	0.000	0.900	0.000	
20	0.352	0.229	0.430	0.305	0.026	3.488	0.000	0.000	0.000	0.000
21	0.407	0.271	0.144	0.553	0.034	0.448	2.544	0.000	0.000	0.000
22	0.454	0.308	0.167	0.301	0.206	0.000	1.168	1.188	0.000	0.000
23	0.454	0.322	0.184	0.110	0.313	0.000	0.000	0.892	0.860	0.000
24	0.421	0.305	0.180	0.111	0.063	0.140	0.000	0.000	0.860	0.452
25	0.374	0.276	0.163	0.103	0.048	0.116	0.000	0.000	0.000	0.988
26	0.306	0.230	0.140	0.090	0.043	0.024	0.036	0.000	0.000	0.000
27	0.225	0.172	0.106	0.069	0.034	0.000	0.032	0.000	0.000	0.000
28	0.159	0.125	0.077	0.051	0.025	0.000	0.032	0.000	0.000	0.000
29	0.110	0.087	0.055	0.037	0.018	0.000	0.020	0.000	0.000	0.000
30	0.075	0.059	0.038	0.025	0.013	0.000	0.000	0.012	0.000	0.000
31	0.049	0.040	0.026	0.017	0.009	0.000	0.000	0.008	0.000	0.000
32	0.031	0.025	0.016	0.011	0.005	0.000	0.000	0.008	0.000	0.000
33	0.019	0.016	0.010	0.007	0.003	0.000	0.000	0.008	0.000	0.000
34	0.012	0.010	0.006	0.004	0.002	0.000	0.000	0.004	0.000	0.000
35	0.007	0.006	0.004	0.003	0.001	0.000	0.000	0.000	0.000	0.000
36	0.005	0.004	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000
37	0.003	0.002	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000
38	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
39	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
σ'_{in}	1.827	1.580	1.329	1.128	0.949	0.780	0.640	0.530	0.430	0.360

INELASTIC SCATTERING MATRIX
 LEAD ^{82}Pb
 78 GROUP STRUCTURE
 BARNs PER LETHARGY INTERVAL

j	21	22	23	24	25	26	27	28	29	30
n										
1										
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19										
20										
21	0.000									
22	0.000	0.000								
23	0.000	0.000	0.0							
24	0.000	0.000	0.0	0.0						
25	0.000	0.000	0.0	0.0	0.0					
26	0.772	0.000	0.0	0.0	0.0	0.0				
27	0.428	0.068	0.0	0.0	0.0	0.0	0.0			
28	0.000	0.164	0.0	0.0	0.0	0.0	0.0	0.0		
29	0.000	0.132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
30	0.000	0.100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.000	0.068	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.000	0.068	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.000	0.068	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.000	0.032	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.000	0.032	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.000	0.032	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ'_{in}	0.300	0.191	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Lead Cross Sections for 78 Lethargy Groups

Values in barns

j	σ_s	σ_{in}	σ_c	σ_F	$\sigma_{n,2n}$	$\bar{\mu}$	ξ
1	2.76	0.78	0	0	1.76	.92	.00074
2	2.29	0.81	↓	↓	1.76	.91	.00084
3	2.00	0.84	↓	↓	1.76	.89	.00103
4	1.93	0.89	↓	↓	1.74	.88	.00113
5	2.17	1.55	↓	↓	1.07	.87	.00123
6	2.81	2.48	↓	↓	0.06	.85	.00133
7	3.51	2.54	↓	↓	0	.84	.00142
8	4.22	2.43	↓	↓	↓	.81	.00181
9	4.90	2.25	↓	↓	↓	.78	.00209
10	5.32	2.05	↓	↓	↓	.73	.00259
11	5.72	1.83	↓	↓	↓	.65	.00336
12	6.03	1.57	↓	↓	↓	.57	.00413
13	6.17	1.33	↓	↓	↓	.50	.00480
14	5.97	1.13	↓	↓	↓	.45	.00518
15	5.55	0.95	↓	↓	↓	.39	.00586
16	5.12	0.78	↓	↓	↓	.35	.00625
17	4.86	0.64	↓	↓	↓	.32	.00654
18	4.67	0.53	↓	↓	↓	.28	.00693
19	4.80	0.43	↓	↓	↓	.25	.00721
20	5.16	0.36	↓	↓	↓	.23	.00741
21	5.17	0.30	0	0	0	.20	.00770
22	5.73	0.19	↓	↓	↓	.17	.00794
23	5.76	0.02	↓	↓	↓	.11	.00857
24	5.20	0	↓	↓	↓	.08	.00886
25	5.35	↓	↓	↓	↓	.13	.00837
26	7.10	↓	↓	↓	↓	.15	.00818
27	7.45	↓	↓	↓	↓	.13	.00837
28	7.93	↓	↓	↓	↓	.10	.00876
29	9.17	↓	↓	↓	↓	.08	.00886
30	10.22	↓	↓	↓	↓	.07	.00895
31	10.67	↓	↓	↓	↓	.05	.00915
32	10.60	↓	↓	↓	↓	.05	.00915
33	10.53	↓	↓	↓	↓	.03	.00934
34	11.07	↓	↓	↓	↓	.03	.00934
35	10.25	↓	↓	↓	↓	.02	.00944
36	10.44	↓	↓	↓	↓	.01	.00954
37	10.70	↓	↓	↓	↓	.01	.00954
38	10.57	↓	↓	↓	↓	0	.00963
39	10.43	↓	↓	↓	↓	0	.00963
40	10.50	0	0	0	0	0	.00963

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CROSS SECTION CALCULATIONS FOR FAST NEUTRON SCATTERING

Part IV

Depth and Radius of the Real Potential in a
Diffuse Surface Optical ModelIntroduction

A comparison of experimental and computed fast neutron cross sections has been undertaken for the purpose of obtaining the best possible numerical values for the parameters in a diffuse surface optical model, and to determine their dependence on neutron energy and mass of the scattering nucleus. The real part of the potential consists of a constant spherical core of radius R_c to which a diffuse surface has been added, $(e^x - x)^{-1}$ times the value of the potential in the core, where $x = (r - R_c)/\tau$. The diffuseness is determined by the quantity τ . The imaginary part is taken to be zero in the core and λ times the derivative of the real part with respect to x in the surface region.¹

In order to simplify the analysis of the data as much as possible, a selection of the available experimental material was made so that for each element considered, the identical information could be used. This led to a study of the following elements and energies: Al, Fe, Zr, Sn, Ta, and Bi at 2.5, 4.1, and 7.0 Mev. For all the 18 possible combinations, the angular distribution of elastic scattering, as well as the total and non-elastic cross sections, are known.² In addition, an attempt was made to include some 14 Mev data in this work.³ Since no angular distribution measurements exist as yet for zirconium, this element had to be

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1. W. S. Emmerich and H. J. Amster, Physica, November, 1956.
 2. M. Walt and J. R. Beyster, Phys. Rev. 98, 677 (1955), Beyster, Henkel, Nobles, and Kister, Phys. Rev. 98, 1216 (1955), Beyster, Walt, and Salmi, Phys. Rev. 104, 1319 (1956).
 3. W. G. Cross and R. G. Jarvis, Phys. Rev. 99, 621 (1955).

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omitted at that energy. The angular distribution measurements for aluminum and tin were supplemented by those for magnesium and cadmium since the latter two elements have data available over a considerably wider angular range.

From the formalism of the theory, it is apparent that the angular distribution for elastic scattering depends primarily on the quantity VR_{eff}^2 . Here, V is the depth of the real part of the potential in the core, and R_{eff} is the effective radius as defined in one of the following sections. A study of V , therefore, requires a simultaneous development of the radius function. The other parameters are not very critical, and for the particular model used, exhibit only little variation.

Extensive surveys made previously with the square well model have been of considerable aid in the choice of parameters to be examined.⁴ A preliminary survey was made to establish the general range of the new parameters λ and $t = 1.32 \sqrt{V}$, after which the final comparison could be limited to the following set of values:

$$\begin{aligned} V &= 37, 40, 43 \text{ Mev} \\ \Delta R &= 0.2 \times 10^{-13} \text{ cm} \\ \lambda &= 0.35, 0.45 \\ t &= 6, 7, 8 \end{aligned}$$

where ΔR is the size of the increment by which R was varied. The radius was taken over a sufficiently wide range to cover the elements of interest.

The accuracy of the model naturally varies from case to case. Poor fits for the lighter elements Al and Fe are not surprising considering their resonance structure, and agreement may be fortuitous, especially at relatively low energies. The best fits were obtainable for the medium elements Zr and Sn.

A list of the final results for the choice of parameters is given in Table I. A qualitative estimate of the fit for angular dependence is stated separately for the forward and backward angles. Greater detail can be seen from the angular distributions as reproduced in the appendix.

4. Feshbach, Porter, and Weisskopf, Phys. Rev. 96, 448 (1954), W. S. Emmerich, Phys. Rev. 98, 1148 (1955).

Particular attention was paid to matching the angles at which minima and maxima occur rather than the absolute value of the cross sections. In most cases, some compromise had to be made in the selection of best fits.

The Potential Depth

In order to establish the dependence of the real part of the potential on energy and on mass number, certain averages were computed. Figure 1 shows the average potential depth for the six elements at 2.5, 4.1, and 7.0 Mev. Also shown is the extension to 14 Mev for Mg, Fe, Cd, and Bi.

The best fits for a given element did not always lead to the same radius at all the energies. Therefore, a compensation was made by plotting VR^2 , rather than V alone. Figure 2 shows the energy dependence of this quantity for each element. Very little uniformity exists in the data as judged from these results. The error bars shown here correspond to approximately ± 2 Mev in the potential if R remains fixed. Such a deviation would be clearly observable in the shape of the calculated angular distributions. An indication of the general trend of VR^2 with energy is obtained by dividing the individual values by their average for each element. The resulting ratios, averaged over all six elements, are shown in Figure 3. The 14 Mev average is based only on Mg, Fe and Bi.

This graph may be compared to Figure 1. The reduction of V at 7.0 Mev, indicated in Figure 1, is offset by the increase in R that accompanies it. On the other hand, the decrease at 14 Mev is sustained. It is apparent from Table I that for most of the elements, a change in diffuseness is required for the 14 Mev data. The natural question arises whether the apparent increase in R for 7.0 Mev may not be due to an actual increase in diffuseness. This point can be answered by further calculations which are in progress now.

The dependence of V on the mass number A can be demonstrated by taking the ratio of the actual potential V for one element at one energy

to the average potential at that energy shown in Figure 1. The results, after averaging over the three energies for each element, are shown in Figure 4. The indicated errors are the average linear deviations. This graph illustrates that the potential is essentially independent of nuclear size within the limits of the present work.

Effective Radius

The analysis of V so far has required the specification of a nuclear radius R for normalizing purposes. In a square well, the radius is uniquely determined, but in a diffuse surface well, the distance to which the radius is to be measured must be specified separately. For this purpose, an effective radius, R_{eff} , is defined as that radius which corresponds resonance-wise to a square well at zero energy. Suitable values are conveniently obtained by computing a $\overline{\sigma}_n/D$ curve with the diffuse surface model. The maxima in $\overline{\sigma}_n/D$ occur at the effective radius

$$R_{\text{eff}} = \frac{(n + 1/2)\pi}{K},$$

where K is the wave number of the neutron in the potential well. Machine calculations show that for the particular shape of the potential well used in this work,

$$R_{\text{eff}} = R_c + .279 \frac{t}{K}$$

The effective radius averaged over the 2.5, 4.1, and 7.0 Mev data for the actual potentials is plotted in Figure 5. A least squares analysis yields a radius function

$$R_{\text{eff}} = (1.27 A^{1/3} + 0.75) \times 10^{-13} \text{ cm}$$

which is similar to the previously obtained function for the square well.⁴

4. Op. cit.

The constant part of the radius function is very sensitive to parameter values of the lighter elements and thus not well established in a survey of this type.

Acknowledgment

The coding and programming of this model for the Naval Ordnance Research Calculator was done by Dr. Harvey Amster and Mr. Martin Culpepper. The author is also indebted to the Westinghouse Atomic Power Division for making computing machine and personnel time available for these calculations.

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Appendix

The angular distribution calculations using the parameters listed in Table I and the available experimental data are plotted in Figures A1 to A22.

References

1. W. S. Emmerich and H. J. Amster, Physica, November, 1956.
2. M. Walt and J. R. Beyster, Phys. Rev. 98, 677, (1955); Beyster, Henkel, Nobles, and Kister, Phys. Rev. 98, 1216 (1955); Beyster, Walt, and Salmi, Phys. Rev. 104, 1319 (1956).
3. W. G. Cross and R. G. Jarvis, Phys. Rev. 99, 621 (1955).
4. Feshbach, Porter, and Weisskopf, Phys. Rev. 96, 448 (1954),
W. S. Emmerich, Phys. Rev. 98, 1148 (1955).

TABLE I

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Parameters for Angular Distribution of Elastic Scattering

Complex Potential Model with Surface Absorbing Diffuse Well. E = Neutron energy in Mev. R = Effective radius in 10^{-13} cm. V = Real potential depth in Mev. t = Diffuseness parameter. All data take $\lambda \approx 0.4$. Criteria for ability to match in the forward and backward hemisphere are: E = excellent, G = good, F = fair, P = poor.

Element	R	V	t	Angles		R	V	t	Angles		
				Forward	Backward				Forward	Backward	
<u>E = 2.5</u>						<u>E = 4.1</u>					
Al	4.3	43	7	G	E	4.3	43	7	G	P	
Fe	5.3	43	7	E	G	5.1	43	7	F	G	
Zr	7.1	37	7	E	G	6.7	40	7	E	E	
Sn	6.8	43	7	E	G	6.8	43	7	E	E	
Ta	7.8	40	8	F	P	7.8	40	8	F	F	
Bi	8.1	43	7	E	E	8.5	40	7	E	E	
<u>E = 7.0</u>						<u>E = 11</u>					
Al	4.9	37	7	P	P	4.6	37	8	E	G (Magnesium)	
Fe	5.9	37	7	E	E	5.6	40	8	G	F	
Zr	6.5	40	7	E	G						
Sn	7.1	40	7	E	E	6.9	40	8	E	E (Cadmium)	
Ta	8.0	40	8	E	G						
Bi	8.3	40	7	G	G	8.2	40	8	E	G	

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FIGURE CAPTIONS

Figure 1 - (Curve 440375) The depth of the real part of the potential averaged over the elements in the survey and plotted as a function of incident neutron energy.

Figure 2 - (Curve 440124) The quantity VR_{eff}^2 as determined for each element at each energy.

Figure 3 - (Curve 440376) The ratio of VR_{eff}^2 to $\overline{VR_{\text{eff}}^2}$, averaged and plotted as in Figure 1. $\overline{VR_{\text{eff}}^2}$ is the mean value of VR_{eff}^2 for a given element at 2.5, 4.1, and 7.0 Mev incident neutron energy.

Figure 4 - (Curve 440126) The ratio of V to $\bar{V}$, plotted as a function of atomic mass number. The values shown in Figure 1 were used for $\bar{V}$. An average was taken over the data at 2.5, 4.1, and 7.0 Mev.

Figure 5 - (Curve 440127) The effective radii, plotted as a function of the cube root of the atomic mass number.

Figure A1.- (Curve 440400) The angular distribution of elastic scattering for aluminum at 2.5 Mev incident neutron energy. The points and error bars are experimental. The broken line is shape elastic scattering calculated with the parameters given in Table I and λ as shown in the figure. The solid line is shape plus compound scattering, where the latter has been assumed isotropic. The magnitude of the compound elastic scattering, shown as σ_{CE} , has been estimated from the experimental cross section at those angles where the shape elastic cross section vanishes effectively, i.e., in this case at 120° . The experimental total cross section σ_{T} and non-elastic cross section σ_{NE} are given as well as the corresponding computed quantities σ_{TT} and σ_{TNE} .

Fig. A2 to Fig. A12 - Same as Fig. A1 for other elements and energies.

Figures:	A2	Curves:	440408
	A3		440398
	A4		440401
	A5		440402
	A6		440403
	A7		440404
	A8		440405
	A9		440406
	A10		440407
	A11		440410
	A12		440409

Figure A13 to Figure A22 - Same as Fig. A1 for other elements and higher energies. For 7.0 Mev and up the σ_{TNE} is expected to be the entire computed compound nucleus formation σ_{TC} . Therefore only one curve needs to be shown.

Figures:	A13	Curves:	440411
	A14		440412
	A15		440415
	A16		440413
	A17		440417
	A18		440396
	A19		440414
	A20		440416
	A21		440397
	A22		440399

Dependence of V on energy

FIGURE 1

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FIGURE 2

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FIGURE 3

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Variation in potential with mass number

FIGURE 4

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Effective Radius

FIGURE 5

080-511

Figure A 1

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Figure A 2

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Figure A 3

CURVE 440401

Figure A 4

113-084

CURVE 440402

Figure A 5

113-085

CURVE 440403

Figure A 6

113-086

CURVE 440404

Figure A 7

Figure A 8

Figure A 9

Figure A 10

Figure A 11

Figure A 12

Figure A 13

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Figure A 14

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Figure A 15

113-095

Figure A16

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Figure A 17

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Figure A 1b

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Figure A 20

Figure A 21

CURVE 440399

Figure A 22

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THE CONSTRUCTION OF INELASTIC SCATTERING MATRICES

Introduction

This report describes in detail the techniques used in the preparation of inelastic scattering matrices for use in multigroup neutron cross section programs.¹ It is intended as a guide in the construction of similar matrices for other elements or for the same elements when warranted by improvements in experimental data.

The definitions and the numerical values of the various input quantities are given in reference 1 and will not be repeated here explicitly. The method will be illustrated by carrying out the detailed calculations for lead (Pb), for which the required input data were obtained from the tables on pages 53 and 54 of reference 1.

The Matrix Elements

The inelastic scattering matrix is an array of elements denoted by σ_{jn} which express the relative probability for inelastic scattering of neutrons from a lethargy group j to a lethargy group n . The matrix elements are based on the average $\langle \sigma_{in} \rangle_j$ of the inelastic scattering cross section over the j th group, and are in units of barns per unit lethargy.

Let $\sigma(u', u)du$ be the cross section for scattering an incident neutron of lethargy u' inelastically so that its lethargy is between u and $u + du$. Let u' be in the group j , so that $u'_j < u' \leq u'_j + \Delta u'_j$. Let u be in group n , so that $u_n < u \leq u_n + \Delta u_n$. The cross sections are normalized such that

$$\int_{u_n}^{\infty} \sigma(u', u) du = \sigma_{in}(u'), \quad (1)$$

where $\sigma_{in}(u')$ is the inelastic scattering cross section for neutrons with lethargy u' .

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The matrix element σ_{jn} is then defined as the average cross section for scattering from the j th group into the n th group, divided by the lethargy width of the n th group, i.e.,

$$\sigma_{jn} = \frac{1}{\Delta u_n} \frac{1}{\Delta u'_j \Delta u_n} \int_{u'_j}^{u'_j + \Delta u'_j} \int_{u_n}^{u_n + \Delta u_n} \sigma(u', u) du du'. \quad (2)$$

From (2) and the definition of the average inelastic scattering cross section in group j , which is

$$\langle \sigma_{in} \rangle_j = \frac{1}{\Delta u'_j} \int_{u'_j}^{u'_j + \Delta u'_j} \sigma_{in}(u') du', \quad (3)$$

it follows that the elements of the inelastic scattering matrix are given by

$$\sigma_{jn} = \frac{1}{(\Delta u_n)^2} \int_{u_n}^{u_n + \Delta u_n} \langle \sigma_{in} \rangle_j p_j(u) du, \quad (4)$$

where $p_j(u)du$ is the probability, averaged over the initial lethargy group j , that a neutron will be scattered with final lethargy in the interval $(u, u + du)$. The $p_j(u)$ are normalized such that

$$\int_{u'_j}^{\infty} p_j(u) du = 1 \quad (5)$$

i.e. so that the probability is unity for the scattered neutron to have greater lethargy than its initial lethargy.

It follows that the σ_{jn} are normalized to

$$\langle \sigma_{in} \rangle_j = \sum_{n=j}^{\infty} \sigma_{jn} \Delta u_n. \quad (6)$$

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Since energy is lost in inelastic scattering events, the sum (6) is extended only over $n \geq j$. The diagonal elements σ_{jj} are zero unless the energy of the first excited state is less than the energy width of the j th lethargy group. The matrix is limited to $j \leq 30$ and $n \leq 40$ due to programming of the multigroup code.² The probability of scattering into groups with $n > 40$ is usually negligible.

At low incident neutron energies, the cross sections for the excitation of each energy level may be known or inferred.³ Since the energy width of the lethargy groups decreases with increasing n , a given energy level may contribute to different σ_{jn} as the incident lethargy passes through the j th group. For levels not close to their thresholds, this partition is assumed to be linear; the contribution of the K th level to σ_{jn} is

$$\sigma_{jn}(K) = \frac{\Delta u_n \langle \sigma_{in}(K) \rangle_j}{\sum_n \Delta u_n} \quad (7)$$

where $\langle \sigma_{in}(K) \rangle_j$ is the average over the j th group of the cross section for the excitation of the K th level, and the sum extends over those groups to which this level can contribute.* If the incident energy is just above the threshold of the K th level, the right-hand member of (7) must be multiplied by a form factor corresponding to the average of the excitation function over each of the possible final lethargy groups.

The Statistical Model

For the proper construction of the matrix elements, it is necessary to know the excitation cross sections of all the levels as a function of energy from their thresholds to the highest energy group.

*If the lethargy region to which this level can contribute covers only a portion δu_m of one of the final groups, this partial width δu_m replaces the entire width Δu_m in (7) for $n = m$.

In practice, the required data are generally available only for the first few excited states near threshold, or at one energy, if at all. At higher energies, the level structure may become sufficiently dense, especially in the heavy elements, so that a statistical assumption can be made for the distribution and strength of the levels.⁴ In such a model the spectrum of inelastically scattered neutrons may be represented by evaporation from a nucleus with a given temperature T , which is proportional to the incident neutron velocity, i.e.,

$$T \propto E^{1/2} \quad (8)$$

Recent experiments have shown good general agreement with the model at 14 Mev and verified (8) for heavy elements as low as 2.5 Mev.

The evaluation of the matrix elements for the statistical model is governed by the energy distribution of the inelastically scattered neutrons:

$$d\sigma(E_0, E_n) \propto E_n e^{-E_n/T} dE_n \quad (9)$$

where $d\sigma(E_0, E_n)$ is the differential cross section per unit energy interval for the scattering of incident neutrons of energy E_0 into the energy interval between E_n and $E_n + dE_n$, and T is the temperature of the residual nucleus at the excitation energy E_0 .

The computation is greatly simplified by use of the graphs reproduced in Figures 1, 2, and 3. These graphs give the statistical weight for each of the 40 n groups over a temperature range from 0.2 to 1.0 Mev. At any given temperature (for group j) the elements in the j th column of the inelastic scattering matrix are given by

$$\sigma_{jn} = \frac{8 \langle \sigma_{in} \rangle_j I_n(T)}{2 - A} \quad (10)$$

where $\langle \sigma_{in} \rangle_j$ is the partial cross section estimated for the statistical model. $I_n(T)$ is the statistical weight as plotted in Figures 1, 2, and 3 (the index on the side of each graph refers to the group n .) The quantity

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Figure 1

The statistical weight per unit lethargy for neutrons scattered to group n (n is the number on the side of each graph) as a function of nuclear temperature.

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Figure 2

Same as Figure 1 for additional groups n.

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Figure 3

Same as Figures 1 and 2 for additional groups n.

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A is given by

$$A = \sum_{n=1}^{21} I_n(T) \quad (11)$$

The particular forms of (10) and (11) depend on the choice of the lethargy group widths in reference 1. (See Table I in reference 1.) The accuracy of reading the graphs in Figures 1, 2, and 3 can be verified by summation since

$$\sum_{n=1}^{\infty} I_n(T) = 1 \quad (12)$$

Contributions from $n > 40$ are usually negligible.

This scheme will give some entries for elements with $n < j$. The statistical weight is always small, so that the contribution could be neglected. However, it is known from experimental data that deviations occur from the statistical model due to direct interactions in the energy region where $n = j$ or is slightly larger. This effect can be approximated by distributing the entries for $n < j$ into the elements with n slightly greater than j . When a column has been completed, equation (6) may be used to check the accuracy of the entries.

The Pb Matrix

Lead (Pb) has four stable isotopes, of which Pb^{204} has an abundance of only 1.5 per cent and can therefore be neglected. Pb^{206} and Pb^{207} are about 23 per cent each, and the balance is Pb^{208} . The inelastic scattering cross section below 2.6 Mev must be due to levels in Pb^{206} and Pb^{207} because there are no levels in Pb^{208} in this energy range. The level schemes are known and fairly complicated.⁷ The excitation cross section of the first level in Pb^{206} has been measured near threshold.⁸

In this survey, a simplifying assumption has been made, namely, that the inelastic scattering up to 2.2 Mev is equivalent to that from one level of 0.8 Mev and another level of 1.6 Mev. Above 2.2 Mev, the statistical model is applied in such a manner that the available inelastic scattering

cross section is divided between these three possibilities (i.e., the two levels mentioned and the evaporation spectrum) as shown in Figure 4. It is expected that future experimental and theoretical work will result in considerable improvement of Figure 4.⁹

The contribution to the scattering matrix due to the 0.8 Mev level is shown in Table I. This example gives the actual cross sections in barns, not yet adjusted per unit lethargy width. Each column must therefore add up to the corresponding cross section in Figure 4. The 1.6 Mev level is handled in an analogous manner. Before adding these entries to the final matrix, the rows must be divided by the lethargy widths of the nth groups.

The contribution due to the statistical model has been computed from equations (10), (11), and the graphs in Figures 1, 2, and 3. The nuclear temperature for Pb

Figure 4

Excitation cross sections for assumed levels of 0.8 Mev and 1.6 Mev, and the statistical model in lead (Pb) as a function of the lethargy groups in Table I of reference 1

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is known from experiments to be 0.76 Mev at 14 Mev incident neutron energy. The corresponding average temperatures for groups 1 to 15 have been computed by means of (8) and are given in Table II. The $\langle \sigma_{in} \rangle_j$ in (10) are the values applicable to the statistical model in Figure 4 and are also given in Table II. The contributions to elements with $n < j$ have been redistributed as suggested in the previous section. All contributions less than .001 barns/unit lethargy width were neglected. The partial matrix due to the statistical model is given in Table III.

After the partial matrices for the statistical model and each individual level have been completed, they must be added together, i.e., the entry in each element of the final matrix is the sum of the corresponding entries in the partial matrices. The accuracy of the final matrix can be checked by the use of (6) which, in the present case, reduced to

$$\langle \sigma_{in} \rangle_j = 8 \sum_{n=1}^{21} \sigma_{jn} + 4 \sum_{n=22}^{40} \sigma_{jn} \quad (12)$$

The final result is given on pages 55 and 56 of reference 1.

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Table I

Cross Section Entries for the 0.8 Mev Level in Pb (cross section in barns)

j	1	2	3	4	5	6	7	8	9	10	11
n											
1											
2											
3											
4				.026							
5				.054	.035						
6					.125	.034					
7						.226					
8							.274				
9							.106	.296			
10								.144	.360		
11									.240	.296	
12										.384	.186
13											.574
<hr/>											
j	12	13	14	15	16	17	18	19	20	21	22
n											
13	.635										
14	.145	.451									
15		.349	.201								
16			.569								
17				.493							
18				.247	.218						
19					.436						
20					.056	.318					
21						.292	.297				
22							.223	.215			
23								.215	.113		
24									.247		
25										.193	
26										.107	.017
27											.041
28											.033
29											.025
30											.017
31											.017
32											.017
33											.008
34											.008
35											.008
36											
37											
38											
39											
40											

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Table II

Nuclear Temperatures For Lead (Pb)

<u>Lethargy Group</u>	<u>Average Energy in Mev</u>	<u>Nuclear Temperature in Mev</u>	<u>Cross Section for Statistical Model in barns</u>
1	13.65	.752	.78
2	12.05	.705	.81
3	10.65	.662	.84
4	9.41	.622	.79
5	8.30	.585	1.35
6	7.33	.550	2.16
7	6.48	.516	2.06
8	5.71	.486	1.87
9	5.03	.455	1.48
10	4.44	.428	1.20
11	3.92	.403	.89
12	3.46	.378	.63
13	3.06	.356	.36
14	2.70	.334	.22
15	2.38	.314	.10

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Table III

Inelastic Scattering Matrix for the Statistical Model in Pb
(Entries in barns per unit lethargy)

j n	1	2	3	4	5	6	7	8	9	10
1	0.000									
2	0.000	0.000								
3	0.000	0.000	0.000							
4	0.000	0.000	0.000	0.000						
5	0.001	0.000	0.000	0.000	0.000					
6	0.003	0.002	0.001	0.001	0.000	0.000				
7	0.007	0.005	0.003	0.002	0.002	0.001	0.000			
8	0.017	0.011	0.008	0.004	0.005	0.005	0.003	0.001		
9	0.034	0.025	0.018	0.011	0.012	0.011	0.007	0.004	0.002	
10	0.059	0.047	0.036	0.024	0.028	0.028	0.017	0.010	0.005	0.004
11	0.096	0.079	0.064	0.045	0.058	0.063	0.040	0.026	0.012	0.007
12	0.139	0.119	0.099	0.074	0.101	0.121	0.084	0.057	0.030	0.018
13	0.190	0.171	0.148	0.115	0.161	0.206	0.152	0.108	0.061	0.038
14	0.244	0.224	0.202	0.163	0.240	0.314	0.242	0.180	0.108	0.070
15	0.295	0.280	0.262	0.217	0.325	0.460	0.365	0.285	0.178	0.123
16	0.343	0.334	0.317	0.271	0.422	0.605	0.506	0.400	0.269	0.192
17	0.390	0.384	0.375	0.328	0.523	0.762	0.658	0.540	0.369	0.266
18	0.444	0.421	0.425	0.384	0.627	0.937	0.821	0.690	0.480	0.351
19	0.433	0.448	0.460	0.421	0.701	1.064	0.950	0.815	0.588	0.440
20	0.429	0.451	0.473	0.442	0.748	1.155	1.051	0.920	0.673	0.516
21	0.407	0.429	0.453	0.430	0.740	1.179	1.113	1.000	0.757	0.589
22	0.353	0.379	0.408	0.398	0.701	1.137	1.091	1.005	0.792	0.635
23	0.287	0.315	0.347	0.340	0.608	1.004	0.984	0.915	0.738	0.605
24	0.219	0.245	0.272	0.273	0.496	0.835	0.843	0.800	0.661	0.553
25	0.166	0.186	0.211	0.217	0.399	0.683	0.703	0.675	0.569	0.479
26	0.117	0.131	0.151	0.155	0.290	0.506	0.529	0.515	0.450	0.388
27	0.080	0.091	0.103	0.106	0.201	0.351	0.371	0.360	0.319	0.278
28	0.051	0.059	0.068	0.070	0.133	0.239	0.255	0.252	0.219	0.195
29	0.033	0.038	0.044	0.046	0.088	0.157	0.170	0.171	0.150	0.134
30	0.020	0.024	0.027	0.029	0.057	0.102	0.111	0.112	0.100	0.090
31	0.013	0.015	0.017	0.019	0.036	0.065	0.072	0.073	0.065	0.059
32	0.008	0.009	0.011	0.011	0.022	0.040	0.044	0.045	0.040	0.037
33	0.005	0.006	0.007	0.007	0.014	0.025	0.027	0.028	0.025	0.023
34	0.003	0.004	0.004	0.004	0.009	0.015	0.017	0.017	0.015	0.014
35	0.002	0.002	0.003	0.003	0.005	0.010	0.011	0.011	0.010	0.009
36	0.001	0.001	0.002	0.002	0.003	0.006	0.007	0.007	0.006	0.006
37	0.001	0.001	0.001	0.001	0.002	0.004	0.004	0.004	0.004	0.003
38	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.002	0.002
39	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.001
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001

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Table III - Continued

j n	11	12	13	14	15	16	17	18	19	20
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11	0.004									
12	0.008	0.007								
13	0.018	0.009	0.005							
14	0.037	0.020	0.008	0.005						
15	0.068	0.038	0.016	0.007	0.003					
16	0.112	0.066	0.030	0.014	0.005	0.0				
17	0.163	0.098	0.044	0.021	0.007	0.0	0.0			
18	0.225	0.137	0.066	0.034	0.013	0.0	0.0	0.0		
19	0.291	0.186	0.092	0.048	0.019	0.0	0.0	0.0	0.0	
20	0.352	0.229	0.118	0.065	0.026	0.0	0.0	0.0	0.0	0.0
21	0.407	0.271	0.144	0.081	0.034	0.0	0.0	0.0	0.0	0.0
22	0.454	0.308	0.167	0.097	0.042	0.0	0.0	0.0	0.0	0.0
23	0.454	0.322	0.184	0.110	0.049	0.0	0.0	0.0	0.0	0.0
24	0.421	0.305	0.180	0.111	0.051	0.0	0.0	0.0	0.0	0.0
25	0.374	0.276	0.163	0.103	0.048	0.0	0.0	0.0	0.0	0.0
26	0.306	0.230	0.140	0.090	0.043	0.0	0.0	0.0	0.0	0.0
27	0.225	0.172	0.106	0.069	0.034	0.0	0.0	0.0	0.0	0.0
28	0.159	0.125	0.077	0.051	0.025	0.0	0.0	0.0	0.0	0.0
29	0.110	0.087	0.055	0.037	0.018	0.0	0.0	0.0	0.0	0.0
30	0.075	0.059	0.038	0.025	0.013	0.0	0.0	0.0	0.0	0.0
31	0.049	0.040	0.026	0.017	0.009	0.0	0.0	0.0	0.0	0.0
32	0.031	0.025	0.016	0.011	0.005	0.0	0.0	0.0	0.0	0.0
33	0.019	0.016	0.010	0.007	0.003	0.0	0.0	0.0	0.0	0.0
34	0.012	0.010	0.006	0.004	0.002	0.0	0.0	0.0	0.0	0.0
35	0.007	0.006	0.004	0.003	0.001	0.0	0.0	0.0	0.0	0.0
36	0.005	0.004	0.003	0.002	0.001	0.0	0.0	0.0	0.0	0.0
37	0.003	0.002	0.002	0.001	0.001	0.0	0.0	0.0	0.0	0.0
38	0.002	0.001	0.001	0.001	0.000	0.0	0.0	0.0	0.0	0.0
39	0.001	0.001	0.001	0.000	0.000	0.0	0.0	0.0	0.0	0.0
40	0.001	0.001	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0

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