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CROSS SECTIONS FOR OCUSOL-A PROGRAM

I. Introduction

The OCUSOL-A program (ORNL-CF-57-6-4) for Univac is a modification of the Eyewash (ORNL-1925) multi-group, multi-region reactor code. The group-energy-lethargy-temperature relationships are given in Table A. The element code numbers are given in Table B. The cross sections now on the sigma-tape are given in tables in the Appendix numbered with the element code number. This report explains the bases for choosing the cross sections.

Five Eyewash groups, 6-10, in the 30-30,000 volt region were subdivided into 13 OCUSOL-A groups, 6-18, in order to get more information about intermediate reactors, especially those containing thorium. It was necessary to combine Eyewash group 19 with 20 and 21 with 22 and to drop groups 23-30 in order to stay within the 30-group limit, thus OCUSOL-A is not designed for low-temperature, thermal reactors. The over-all Eyewash group-lethargy pattern was retained to make conversions from one code to the other easy.

Special attention was paid to including the self-shielding and Doppler effects on resonance absorption in thorium. The availability of resonance parameters for thorium in the 22-310 ev region influenced the choice of group energy limits in that region (for example, the dividing line between groups 14 and 15 corresponds to that between resolved and unresolved resonances, otherwise the two groups could just as well have been combined into one).

II. Discussion of Cross Sections(00) Uranium-233

The $\xi\sigma_t$ and $\overline{\sigma}_{tr}$ values were based on the Eyewash values. The $\overline{\sigma}_f$ values for groups 3-9 and 23-30 were based on BNL-325, the others on Eyewash.

Table A

OCUSOL-A LETHARGY GROUP DESIGNATIONS

Group Number	Energy (ev) (at lower limit)	Lethargy	Lethargy Width	Neutron Temperature	Equivalent Eyewash Group No.
0	1×10^7	0	--		0
1	6.065×10^6	0.5	0.5		1
2	3.679	1.0	0.5		2
3	2.231	1.5	0.5		3
4	1.353	2.0	0.5		4
5	8.208×10^5	2.5	0.5		5
6	3.876	3.25	0.75		}6
7	1.830	4.	0.75		
8	6.733×10^4	5.	1.0		}7
9	2.478	6.	1.0		
10	9.118×10^3	7.	1.0		}8
11	3.355	8.	1.0		
12	1.234	9.	1.0		}9
13	4.540×10^2	10.	1.0		
14	3.199	10.35	0.35		}10
15	2.255	10.7	0.35		
16	1.120	11.4	0.7		}11
17	61.47×10^0	12.	0.6		
18	33.74	12.6	0.6		}12
19	15.15	13.4	0.8		
20	10.16	13.8	0.4		}13
21	4.564	14.6	0.8		
22	1.375	15.8	1.2		}14
23	0.9214	16.2	0.4		
24	0.6716	16.6	0.4		}15
25	0.4140	17.0	0.4		
26	0.2775	17.4	0.4		}16
27	0.1860	17.8	0.4		
28	0.1247	18.2	0.4	1704°F	}17
29	0.07735	18.680	0.48	1180°F	
30	0.07595	18.698	0.018	1150°F	19 + 20

Table B

NUCLIDE CODE NUMBERS IN OCUSOL-A

Code Number <u>jj</u>	<u>Nuclide or Mixture</u>	<u>Date Edited on Tape 7</u>
00	U-233	2-25-57
01	U-235	"
02	U-238	"
03	Be + 2.3 Li	"
04	Two fission products	"
05	F	"
06	Li ⁶	
07	Li ⁷	
08	Na	
09	Be	
10	Cl	
11	Pu	
12	Fe	2-25-57
13	Ni	"
14	Cr	"
15	Not available	
16	Pa	
17	0.9999 Li ⁷ + 0.0001 Li ⁶	2-25-57
18	C	
19		
20	Th-A (with no self-shielding)	2-25-57
21	Th-B (in 67 LiF - 32 BeF ₂ - 1 ThF ₄) at 1150°F	"
22	Th-C (in 68 LiF - 28 BeF ₂ - 4 ThF ₄) at 1150°F	"
23	Th-D (in 70 LiF - 20 BeF ₂ - 10 ThF ₄) at 1150°F	"
24	Th-E (in 75 LiF - 25 ThF ₄) at 1150°F	"
25		
26	Not available	
27		
28		
29		
30		

Table B Nuclide Code Numbers in OCUSOL-A (continued)

<u>Code Number</u>	<u>Nuclide or Mixture</u>	<u>Date Edited</u> <u>on Tape 7</u>
31		
32		
33		
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The $\overline{\sigma}_a$ values were obtained by multiplying $\overline{\sigma}_f$ by $(1 + \overline{\alpha})$. In the intermediate region α was estimated from recent MTR (PTR-141, -142) and Knolls (KAPL-1611) data, whereas Eyewash uses the thermal value of 0.1 up to 183 kev. The Eyewash α values were used in the $\frac{1}{v}$ and fast regions.

The Eyewash $\overline{\sigma}_f$ values used in groups 10-22, where most of the fissions occurred in a reference design molten salt power reactor (CF-57-4-27), may be too high. The curves in BNL-325 in this region are too rapidly varying to permit accurate estimation of average cross sections over a group, but the Eyewash $\overline{\sigma}_f^{23}$ values give the appearance of possibly being high by comparison.

(01) Uranium-235

The Eyewash values for $\xi\sigma_t$ were used, but $\overline{3\sigma}_{tr}$ was based on σ_t , instead of σ_s as in Eyewash. The $\overline{\sigma}_f$ values were based on BNL-325 for groups 3-17 and 24-30 and on Eyewash for the remaining groups. The $\overline{\sigma}_a$ values were calculated from $\overline{\sigma}_f(1 + \overline{\alpha})$, with $\overline{\alpha}$ based on BNL-325 for groups 24-30, on Weinberg and Wigner (Chapter 5, Table VI) from 100-500,000 ev, and on Eyewash in the remaining groups.

(02) Uranium-238

The $\overline{\sigma}_a$ values were based on the BNL-325 curve in groups 1-10, on the BNL-325 thermal cross section and a $\frac{1}{v}$ extrapolation for groups 22-30, and on BNL-325 resonance parameters in groups 16-21. The remaining $\overline{\sigma}_a$ values were calculated from the Weinberg-Wigner equation (page 4.33) for heavy, even-even nuclides. The $\overline{\sigma}_f$ values were based on the BNL-325 curve. The σ_t values were taken to be $\sigma_a + \sigma_f + 9$ (an underestimate in the resonance region, but not important in molten fluoride reactor calculations). The $\overline{3\sigma}_{tr}$ values are based on $\overline{\sigma}_t$.

(03) Beryllium-Lithium

These cross sections are the sum of $\sigma^{\text{Be}} + 2.33 \sigma^{\text{Li}}$, i.e., the Be plus Li cross sections per atom of Be in 70 LiF-30 BeF₂ salt using 99.99% Li⁷. See Sections (09) and (17) for discussions of the individual elements. These "combined" cross sections were used to reduce the number of "elements" in molten fluoride reactor calculations since the Eyewash-Ocusol codes allow for only seven elements in each region.

(04) Fission Products

The microscopic cross sections given in Table 04 are for two "average" fission products, so that for OCUSOL purposes one fission gives one fission product. The $\overline{\sigma}_a$ values below 100 ev are those of Greebler and Hurwitz (KAPL-1440), except that the giant Sm-149 resonance has been taken out of groups 27-30. The $\overline{\sigma}_a$ values above 100 ev are those of Greebler, Hurwitz and Storm ("Statistical Evaluation of Fission-Product Absorption Cross Sections at Intermediate and High Energies", to be published), modified (as suggested by them) by doubling their values at 10^5 ev. The σ_t and σ_{tr} values were obtained by adding 6 barns to σ_a . To calculate $\xi = \frac{2}{A + 2/3}$ the fission products were assumed to have an atomic weight of 116.

The Sm-149 resonance was left out because its primary effect depends strongly on burn-out, whereas for the present calculations it was assumed that in intermediate reactors poisoning would build up linearly. For reactors in which the captures in groups 27-30 are important, the effective fission product absorption cross sections should be re-evaluated. Better values of $\xi\sigma_t$ and $\overline{\sigma}_{tr}$ are probably not worth the trouble since they do not contribute much to $\xi\Sigma_t$ and Σ_{tr} in reactors of interest.

(05) Fluorine

The $\overline{\sigma}_a$ values in groups 10-30 are based on a $1/v$ extrapolation of the BNL-325 cross section at 2200 m/s. The $\overline{\sigma}_a$ values in groups 6-9 were calculated using the Γ_n values in BNL-325 and an estimate (by W. K. Ergen, ORNL) of 1 ev for Γ_γ . The $\overline{\sigma}_a$ values in groups 4-5 were assumed to be zero and in groups 1-3 were assumed to be equal to the sum of the (n,α) and (n,p) cross sections given by Marion and Brugger (Phys. Rev., 100, 72, 1955). The σ_{tr} values were taken as equal to σ_t from BNL-325. The ξ values for groups 9-30 were calculated from $\frac{2}{A + 2/3}$. The ξ values for groups 1-8 are estimates of the average logarithmic energy decrement for collisions in the group based on the inelastic scattering and total cross sections in BNL-325, assuming that the elastic scattering cross section was equal to the difference between the total cross section and the sum of the two inelastic scattering cross sections. The inelastic scattering causes ξ to be appreciably higher in groups 6-8 than in the other groups.

(09) Beryllium

The σ_t values were taken from BNL-325. The value of ξ was taken to be $\frac{2}{A + 2/3}$. The σ_{tr} values were taken to be $\sigma_t (1 - \frac{2}{3A})$ for slowing down and σ_t at thermal. The $\overline{\sigma}_a$ values in groups 1-2 were taken from the Eyewash code. In groups 3-4, σ_a was assumed to be equal to the (n,α) cross section given in BNL-325. In groups 5-30, absorption cross sections were calculated by a $\frac{1}{v}$ extrapolation from 0.025 ev.

(12) Iron

These cross sections were taken from the Eyewash code.

(13) Nickel

These cross sections were taken from the Eyewash code.

(14) Chromium

The σ_t values were read from the BNL-325 curves. The value of ξ was taken to be $\frac{2}{A + 2/3}$ and σ_{tr} was taken to be equal to σ_t . For lack of better data, the σ_a^{Cr} values were calculated by assuming that the ratio $\sigma_a^{Cr}/\sigma_a^{Fe}$ had the same value at all energies as at 2200 m/s.

(17) 99.99% Lithium-7

The σ_a and σ_t values were based on the BNL-325 curves. The value of ξ was taken to be $\frac{2}{A + 2/3}$. The σ_{tr} values were taken to be equal to σ_t at thermal and to $\sigma_t(1 - \frac{2}{3A})$ in the slowing down groups.

(20) Thorium-A (no resonance shielding)

The parameters for 18 thorium resonances between 22 and 310 ev are given in BNL-325. Assuming that these are the only resonances from thermal energy to ~ 320 ev and that Γ_γ for all the resonances is equal to the 30 mv value given for the first two, the contribution from resolved resonances to the total resonance integral is 80.3 barns. The $\frac{1}{v}$ contribution to the measured resonance integral, above cadmium cutoff, is 3.5 barns. The contribution to the resonance integral of the unresolved resonances is

$$\int_{320}^{\infty} \sigma_a \frac{dE}{E}$$

Almost all of this contribution is due to neutrons of zero angular momentum, for which Weinberg and Wigner (CF-56-11-43, p. 4.44) predict theoretically that

$$\sigma_a \approx \frac{4.09 \times 10^6}{\sqrt{E}} \frac{\Gamma_n^0}{D} \frac{\Gamma_\gamma}{\Gamma_\gamma + \Gamma_n^0 \sqrt{E}}$$

and estimate $\Gamma_n^0 \approx 0.00132$ ev, $\Gamma_\gamma \approx 0.030$ ev, $D \approx 20$ ev. This relationship,

when integrated from 320 ev to ∞ , indicates a contribution of 12.2 barns to the total resonance integral. Thus a total resonance integral of 96 barns is calculated, while the measured value (Macklin and Pomerance, Geneva Paper No. 83) is 67 barns.

For OCUSOL purposes, the discrepancy between calculated and measured values was resolved in favor of the measured value by reducing the BNL-325 and Weinberg-Wigner estimated neutron widths by one-third. Thus in groups 20-30, σ_a was calculated by a $\frac{1}{v}$ extrapolation from 7.0 barns at 2200 m/s; in groups 15-19, the individual resonance integrals were calculated from BNL-325 parameters, multiplied by $\frac{2}{3}$ and "smeared" over the appropriate group; and in groups 12-14, σ_a was calculated from the Weinberg-Wigner equation, given above, multiplied by $\frac{2}{3}$. At higher energies resonance absorption of higher angular momentum neutrons becomes significant and the Weinberg-Wigner equation underestimates σ_a . For OCUSOL groups 5-11, the empirical equation

$$\sigma_a = 30.7 E^{-0.397}$$

σ_a in barns, E in ev

was used. This fits the few experimental (n, γ) points in BNL-325 and agrees qualitatively with estimates of the higher angular momenta contribution. In groups 1-4, the BNL-325 curves were used for σ_f , and these values added to $\sigma_{n, \gamma}$ estimated from the above empirical equation to give σ_a .

In groups 1-12 and 20-30, the σ_t values were taken from the BNL-325 curves and it was assumed that $\sigma_{tr} = \sigma_t$. In all groups, $\xi = \frac{A}{A + \frac{2}{3}}$ was used. In groups 13-19, the region of prominent resonances, σ_s was taken to be 13 barns (neglecting resonance scattering) and σ_{tr} was taken to be $\sigma_a + \sigma_s$. Also in these groups, $\xi \sigma_s$, non-resonant was used instead of $\xi \sigma_t$ since the effect of σ_a and

σ_s , resonant on absorption was put into σ_a , effective (see following section on Thorium-B-C-D-E).

(21, 22, 23, 24) Thorium-B-C-D-E (with resonance absorption reduced by self-shielding)

In Tables 21, 22, 23 and 24 the $\xi\sigma_t$, $\overline{\sigma_{tr}}$ and $\overline{\sigma_f}$ values are the same as those in Table 20. The $\overline{\sigma_a}$ values in groups 1-5 and 20-30 are also the same as in Table 20, but in groups 6-19, new "effective" values of $\overline{\sigma_a}$ have been used to approximate the effect on resonance absorption of self-shielding and Doppler effects at high thorium concentrations.

The resonance integral is defined as

$$I = \int \sigma_a \frac{dE}{E}$$

In calculating the resonance absorption of neutrons in homogeneous mixtures of moderator and resonance absorber, an important quantity is the effective resonance integral (Dresner, Nuclear Sci. and Eng., 1, 68, 1956), defined by

$$I_{\text{eff}} = \int \frac{\sigma_a}{1 + \frac{\sigma_a + \sigma_s}{\sigma_p}} \frac{dE}{E}$$

where σ_a is the resonance absorption cross section, σ_s the resonance scattering cross section, and σ_p the energy-independent scattering cross section, all normalized to one absorbing atom. The self-shielding factor for resonance absorption in homogeneous mixtures is defined as

$$f_H = \frac{I_{\text{eff}}}{I}$$

For a Breit-Wigner resonance with Doppler broadening (Roe, KAPL-1241)

$$\sigma_a = \frac{8.18 \times 10^6}{\pi} \frac{g \Gamma_n \Gamma_\gamma}{E_0 \Gamma^2} \psi(x, \theta)$$

$$\sigma_a + \sigma_s = \frac{8.18 \times 10^6}{\pi} \frac{g \Gamma_n}{E_o \Gamma} \psi(x, \theta)$$

$$x = \frac{2(E - E_o)}{\Gamma}$$

$$\theta = \frac{4 E_o k T}{A \Gamma^2}$$

$$\psi(\theta, x) = \frac{1}{2\sqrt{\pi\theta}} \int_{-\infty}^{\infty} \frac{e^{-(x-y)^2/4\theta}}{1+y^2} dy$$

$$I = 4.09 \times 10^6 \frac{g \Gamma_r \Gamma_\gamma}{E_o^2 \Gamma}$$

$$f_H(\theta, \alpha \zeta) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\psi}{1 + \zeta \psi} dx$$

$$\alpha(\theta) = \frac{1}{\psi(\theta, 0)}$$

$$\zeta = \frac{2 E_o I}{\pi \Gamma_\gamma \sigma_p}$$

Roe (KAPL-1241) has tabulated $\alpha(\theta)$ and has presented curves for $f_H(\theta, \alpha \zeta)$, hence it is possible to calculate I_{eff} for a resonance given the resonance parameters $g, \Gamma_n, \Gamma_\gamma$ and E_o , the thermal energy kT , the atomic mass number of the absorber A , and the scattering parameter σ_p .

Effective absorption cross sections were calculated for thorium in the resonance region for the following molten fluoride salt mixtures at 1150°F:

jj	LiF-BeF ₂ -ThF ₄	σ_p (barns)
	(mole %)	
20	67 - 33 - 0	∞
21	67 - 32 - 1	756
22	68 - 28 - 4	172
23	70 - 20 - 10	86
24	75 - 0 - 25	41

The $\overline{\sigma}_a$ values for Thorium-A ($jj = 20$), for which $f_H = 1$, have been discussed in the preceding section. For Thorium-B-C-D-E ($jj = 21-24$) in the resolved resonance region (groups 15-19), $g = 1$ and Γ_{eff} was calculated for each resonance (using the same resonance parameters as for Thorium-A) and spread over the appropriate group to give $\overline{\sigma}_{a,eff}$. In the unresolved resonance region, Γ_γ was assumed to remain constant at 20 mv, D was assumed to remain constant at 20 ev, and an average Γ_n for each group was estimated from

$$I = 4.09 \times 10^6 \frac{\Gamma_n \Gamma_\gamma}{E_o^2 \Gamma} = \frac{\overline{\sigma}_a D}{E_o}$$

$$\therefore \frac{\Gamma_n}{\Gamma_n + \Gamma_\gamma} = \frac{1}{4.09 \times 10^6} \frac{\overline{\sigma}_a D E_o}{\Gamma_\gamma}$$

using an average $\overline{\sigma}_a E_o$ for each group. This gave all the necessary information to calculate an average f_H for each group and hence $\overline{\sigma}_{a,eff}$ from

$$\overline{\sigma}_{a,eff} = f_H \overline{\sigma}_a$$

These calculated effective group absorption cross sections for thorium somewhat overestimate the effect of resonance self-shielding since second collisions in a resonance are neglected, i.e., any scattering collision in the resonance is assumed to remove a neutron from the resonance. The possibility that an appreciable number of neutrons might make second collisions in a resonance was examined briefly, and it was concluded that while the effect might be significant in some of the resonances at high thorium concentrations, the over-all error on typical molten salt reactor calculations (high thorium in blanket, low thorium in core) was no greater than that due to uncertainties in the intermediate energy $\overline{\sigma}_a$ for other elements.

A P P E N D I X

III. Cross Section Tables

Table 00

URANIUM-233

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.080			
1	0.086	26	2.5	2.5
2	0.083	29	1.8	1.8
3	0.085	29	1.85	1.85
4	0.085	30	1.9	1.9
5	0.086	30	1.95	1.95
6	0.092	30	2.05	2.05
7	0.092	30	2.28	2.2
8	0.10	34	2.8	2.5
9	0.11	34	3.2	2.8
10	0.12	34	4.9	4.3
11	0.24	64	7.9	6.9
12	0.27	64	12.	10.5
13	0.30	64	21.2	18.6
14	0.40	133	28.5	25.
15	0.50	133	33.1	29.
16	0.60	133	44.5	39.
17	0.90	248	66.1	58.
18	0.93	248	84.4	74.
19	0.982	334	111.	94.
20	1.13	370	124.	105.
21	0.784	321	109.	90.
22	2.24	648	229.	189.
23	1.26	594	209.	173.
24	1.32	441	139.	126.
25	1.60	453	137.	125.
26	1.75	507	157.	142.
27	1.84	620	189.	172.
28	2.22	740	233.	212.
29	2.7	890	294.	267.
30	2.75	999	330.	300.
Th-29	2.75	999	289.7	263.4
Th-30	2.75	999	292.4	265.8

Table 01

URANIUM-235

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.060			
1	0.063	23	1.31	1.3
2	0.067	23	1.33	1.3
3	0.068	23	1.34	1.30
4	0.068	20	1.35	1.30
5	0.062	22	1.36	1.25
6	0.081	24	1.37	1.20
7	0.081	28	1.44	1.35
8	0.127	34	1.9	1.7
9	0.127	40	2.6	2.3
10	0.127	44	4.1	3.4
11	0.156	50	6.8	4.7
12	0.156	60	9.3	6.4
13	0.156	81	14.	9.6
14	0.276	102	20.	13.
15	0.276	120	25.	16.5
16	0.276	120	30.	20.
17	0.441	150	39.	26.
18	0.441	190	53.	36.
19	0.568	210	59.	41.
20	0.606	220	64.	45.
21	0.801	290	88.	42.
22	0.272	100	24.	15.
23	0.744	270	81.	62.
24	0.597	220	63.	58.
25	0.813	310	92.	85.
26	1.61	580	184.	150.
27	1.96	720	231.	185.
28	2.06	710	228.	192.
29	2.44	900	291.	250.
30	2.88	999	336.	290.
Th-29	2.88	999	295.1	254.6
Th-30	2.88	999	297.8	256.9

Table 02
URANIUM-238

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.080			
1	0.081	29	0.57	0.55
2	0.081	29	0.57	0.55
3	0.081	29	0.58	0.55
4	0.078	28	0.46	0.4
5	0.075	27	0.10	
6	0.075	27	0.14	
7	0.078	28	0.19	
8	0.078	28	0.27	
9	0.078	28	0.39	
10	0.081	29	0.58	
11	0.084	30	1.00	
12	0.089	32	1.61	
13	0.101	36	3.11	
14	0.120	43	5.47	
15	0.159	57	10.0	
16	0.151	54	8.9	
17	0.363	130	35.0	
18	0.838	300	90.0	
19	0.698	250	75.0	
20	0.075	27	0.11	
21	1.42	510	162.0	
22	0.077	27.6	0.24	
23	0.080	28.5	0.41	
24	0.080	28.5	0.51	
25	0.080	28.5	0.63	
26	0.080	28.5	0.74	
27	0.080	28.8	0.90	
28	0.081	29.1	1.11	
29	0.083	29.7	1.39	
30	0.084	30.0	1.56	
Th-29	0.084	30.0	1.369	
Th-30	0.084	30.0	1.382	

Table 03

Be + 2.33 Li (99.99% Li⁷)

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	1.40			
1	1.48	16.8	0.000018	
2	1.73	19.5	0.0070	
3	1.69	19.2	0.040	
4	1.46	16.9	0.030	
5	1.55	18.3	0.000111	
6	1.62	19.4	0.000296	
7	2.97	33.7	0.000890	
8	1.74	21.8	0.000486	
9	1.87	23.6	0.000489	
10	1.87	23.6	0.000769	
11	1.87	23.6	0.00116	
12	1.87	23.6	0.00120	
13	1.92	23.8	0.00258	
14	1.92	23.8	0.00337	
15	1.92	23.8	0.00397	
16	1.92	23.8	0.00493	
17	1.92	23.8	0.00663	
18	1.92	23.8	0.00872	
19	1.92	23.8	0.0117	
20	1.92	23.8	0.0155	
21	1.92	23.8	0.0213	
22	1.92	23.8	0.0337	
23	1.92	23.8	0.0470	
24	1.92	23.8	0.0554	
25	1.92	23.8	0.0681	
26	1.92	23.8	0.0853	
27	1.92	23.8	0.102	
28	1.92	23.8	0.116	
29	1.92	23.8	0.158	
30	1.92	23.8	0.180	
Th-29	1.92	26.	0.1574	
Th-30	1.92	26.	0.1589	

Table 04

TWO FISSION PRODUCTS

Group	$\xi \sigma_a$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.10			
1	0.10	18.	0.043	
2	0.10	18.	0.050	
3	0.10	18.	0.060	
4	0.10	18.	0.072	
5	0.10	18.	0.09	
6	0.10	18.	0.10	
7	0.10	18.	0.14	
8	0.10	18.	0.19	
9	0.10	18.	0.29	
10	0.10	18.	0.38	
11	0.12	21.	0.74	
12	0.14	24.	1.6	
13	0.17	30.	3.3	
14	0.20	36.	5.4	
15	0.22	39.	6.9	
16	0.27	48.	9.5	
17	0.58	100.	28.	
18	0.58	100.	28.	
19	0.42	75.	19.	
20	0.44	78.	20.	
21	1.0	170.	52.	
22	0.75	130.	38.	
23	0.61	110.	30.	
24	0.70	120.	35.	
25	0.70	120.	35.	
26	0.49	87.	23.	
27	0.61	110.	30.	
28	0.61	110.	30.	
29	0.61	110.	30.	
30	0.61	110.	30.	
Th-29	0.61	110.	30.	
Th-30	0.61	110.	30.	

Table 05

FLUORINE

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.070			
1	0.075	4.8	0.20	
2	0.125	5.1	0.16	
3	0.238	6.6	0.01	
4	0.367	6.6	0.00	
5	0.597	8.1	0.00	
6	0.940	15.	0.0001	
7	2.28	18.	0.0003	
8	1.04	18.	0.0006	
9	0.610	18.	0.01	
10	0.610	11.	0.00001	
11	0.376	11.	0.00002	
12	0.376	11.	0.00003	
13	0.376	11.	0.00005	
14	0.376	11.	0.00007	
15	0.376	11.	0.00009	
16	0.376	11.	0.00011	
17	0.346	10.	0.00016	
18	0.346	10.	0.00024	
19	0.346	10.	0.00033	
20	0.346	10.	0.00040	
21	0.346	10.	0.00056	
22	0.346	10.	0.00092	
23	0.346	10.	0.00135	
24	0.346	10.	0.00160	
25	0.346	10.	0.00200	
26	0.346	10.	0.00240	
27	0.346	10.	0.00300	
28	0.346	10.	0.00365	
29	0.346	10.	0.00460	
30	0.346	10.	0.00520	
Th-29	0.346	10.	0.004565	
Th-30	0.346	10.	0.004607	

Table 09

BERYLLIUM

Group	$\xi \sigma_t$	$\bar{3} \sigma_{tr}$	$\bar{\sigma}_a$	$\bar{\sigma}_f$
0	0.35			
1	0.36	4.9	0.000	
2	0.40	5.5	0.007	
3	0.48	6.4	0.04	
4	0.43	5.9	0.03	
5	0.66	9.0	0.000001	
6	0.83	11.	0.000002	
7	0.89	12.	0.000003	
8	1.11	15.	0.000005	
9	1.24	16.8	0.000008	
10	1.24	16.8	0.000013	
11	1.24	16.8	0.000021	
12	1.24	16.8	0.000035	
13	1.24	16.8	0.000059	
14	1.24	16.8	0.000081	
15	1.24	16.8	0.000096	
16	1.24	16.8	0.000125	
17	1.24	16.8	0.00017	
18	1.24	16.8	0.00023	
19	1.24	16.8	0.000335	
20	1.24	16.8	0.00044	
21	1.24	16.8	0.00061	
22	1.24	16.8	0.00105	
23	1.24	16.8	0.00150	
24	1.24	16.8	0.00175	
25	1.24	16.8	0.00215	
26	1.24	16.8	0.00270	
27	1.24	16.8	0.00330	
28	1.24	16.8	0.00410	
29	1.24	16.8	0.00510	
30	1.24	16.8	0.00575	
Th-29	1.24	18.	0.005048	
Th-30	1.24	18.	0.005095	

Table 12

Group	IRON			
	$\xi \sigma_t$	$\bar{3} \sigma_{tr}$	$\bar{\sigma}_a$	$\bar{\sigma}_f$
0	0.100			
1	0.107	8.55	0.050	
2	0.109	8.87	0.050	
3	0.091	8.45	0.050	
4	0.087	6.96	0.050	
5	0.095	6.92	0.050	
6	0.11	8.0	0.050	
7	0.15	11.0	0.050	
8	0.24	13.0	0.050	
9	0.26	14.0	0.050	
10	0.28	16.0	0.050	
11	0.29	18.0	0.050	
12	0.30	20.0	0.050	
13	0.31	21.0	0.050	
14	0.39	29.0	0.050	
15	0.39	30.0	0.050	
16	0.39	31.0	0.050	
17	0.39	32.0	0.052	
18	0.39	33.0	0.054	
19	0.41	33.4	0.080	
20	0.40	33.0	0.107	
21	0.42	32.9	0.147	
22	0.42	33.6	0.243	
23	0.42	34.4	0.359	
24	0.41	32.7	0.437	
25	0.41	32.3	0.539	
26	0.42	32.4	0.656	
27	0.42	32.3	0.800	
28	0.43	32.2	0.975	
29	0.43	32.2	1.20	
30	0.44	32.1	1.45	
Th-29	0.44	32.1	1.273	
Th-30	0.44	32.1	1.285	

Table 13

NICKEL

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.090			
1	0.094	7.86	0.050	
2	0.095	8.03	0.050	
3	0.087	7.74	0.050	
4	0.102	7.74	0.050	
5	0.117	9.76	0.050	
6	0.15	10.	0.050	
7	0.25	16.	0.050	
8	0.62	36.	0.050	
9	0.62	42.	0.050	
10	0.62	48.	0.050	
11	0.56	48.	0.050	
12	0.56	49.	0.050	
13	0.56	50.	0.050	
14	0.56	50.	0.09	
15	0.56	50.	0.09	
16	0.56	50.	0.09	
17	0.57	49.	0.09	
18	0.57	48.	0.09	
19	0.58	49.	0.146	
20	0.57	50.	0.195	
21	0.59	49.	0.268	
22	0.63	50.	0.450	
23	0.60	51.	0.668	
24	0.60	50.	0.811	
25	0.63	51.	0.999	
26	0.63	51.	1.22	
27	0.63	51.	1.48	
28	0.64	51.	1.82	
29	0.65	50.	2.22	
30	0.66	49.	2.60	
Th-29	0.66	49.	2.283	
Th-30	0.66	49.	2.304	

Table 14

CHROMIUM

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$
0	0.130			
1	0.133	10.	0.06	
2	0.133	10.	0.06	
3	0.133	10.	0.06	
4	0.133	10.	0.06	
5	0.133	10.	0.06	
6	0.133	10.	0.06	
7	0.133	10.	0.06	
8	0.133	10.	0.06	
9	0.133	10.	0.06	
10	0.133	10.	0.06	
11	0.760	60.	0.06	
12	0.380	30.	0.06	
13	0.171	14.	0.06	
14	0.159	13.	0.06	
15	0.159	13.	0.06	
16	0.159	13.	0.06	
17	0.159	13.	0.06	
18	0.159	13.	0.06	
19	0.159	13.	0.09	
20	0.163	13.	0.12	
21	0.163	13.	0.17	
22	0.167	13.	0.28	
23	0.171	14.	0.41	
24	0.175	14.	0.50	
25	0.178	14.	0.62	
26	0.186	15.	0.75	
27	0.194	15.	0.92	
28	0.205	16.	1.12	
29	0.216	17.	1.38	
30	0.228	18.	1.67	
Th-29	0.228	18.	1.466	
Th-30	0.228	18.	1.480	

Table 17

99.99% Li^7 - 0.01% Li^6

Group	$\xi \sigma_t$	$\overline{3 \sigma}_{tr}$	$\overline{\sigma}_a$	$\overline{\sigma}_f$
0	0.40			
1	0.48	5.1	0.000008	
2	0.57	6.0	0.000015	
3	0.52	5.5	0.000027	
4	0.44	4.7	0.000040	
5	0.38	4.0	0.000047	
6	0.34	3.6	0.000126	
7	0.89	9.3	0.000380	
8	0.27	2.9	0.000206	
9	0.27	2.9	0.000206	
10	0.27	2.9	0.000324	
11	0.27	2.9	0.000490	
12	0.27	2.9	0.000711	
13	0.29	3.0	0.00108	
14	0.29	3.0	0.00141	
15	0.29	3.0	0.00166	
16	0.29	3.0	0.00206	
17	0.29	3.0	0.00277	
18	0.29	3.0	0.00364	
19	0.29	3.0	0.00490	
20	0.29	3.0	0.00648	
21	0.29	3.0	0.00886	
22	0.29	3.0	0.0140	
23	0.29	3.0	0.0195	
24	0.29	3.0	0.0230	
25	0.29	3.0	0.0283	
26	0.29	3.0	0.0354	
27	0.29	3.0	0.0425	
28	0.29	3.0	0.0514	
29	0.29	3.0	0.0655	
30	0.29	3.0	0.0744	
Th-29	0.29	3.3	0.06532	
Th-30	0.29	3.3	0.06592	

Table 20

THORIUM-A-B-C-D-E

Group	$\xi \sigma_t$	$\overline{3 \sigma_{tr}}$	$\overline{\sigma_a}$	$\overline{\sigma_f}$					
0	0.050								
1	0.05415	18.9	0.385	0.35					
2	0.05845	20.4	0.195	0.15					
3	0.06016	21.0	0.190	0.13					
4	0.05673	19.8	0.180	0.10					
5	0.05845	20.4	0.100						
6	0.06532	22.8	(A) 0.163	(B) 0.162	(C) 0.161	(D) 0.160	(E) 0.157		
7	0.08251	28.8	0.217	0.216	0.215	0.212	0.206		
8	0.1031	36.0	0.306	0.304	0.301	0.296	0.284		
9	0.1176	39.0	0.456	0.451	0.444	0.432	0.408		
10	0.1246	43.5	0.679	0.673	0.650	0.621	0.572		
11	0.1246	43.5	1.00	0.984	0.934	0.871	0.772		
12	0.1246	43.5	1.61	1.47	1.41	1.26	1.04		
13	0.1117	48.	3.11	2.88	2.34	1.90	1.39		
14	0.1117	56.	5.47	4.44	3.28	2.42	1.61		
15	0.1117	69.	10.0	7.08	3.85	2.62	1.64		
16	0.1117	84.	15.1	10.3	5.52	3.68	2.31		
17	0.1117	87.	16.1	6.04	2.17	1.36	0.883		
18	0.1117	54.	5.07	3.73	2.05	1.36	0.827		
19	0.1117	138.	33.4	18.0	8.25	5.24	3.24		
20	0.09884	34.5	0.315						
21	0.1031	36.0	0.435						
22	0.1071	37.5	0.735						
23	0.1117	39.0	1.060						
24	0.1160	40.5	1.295						
25	0.1203	42.0	1.585						
26	0.1246	43.5	1.945						
27	0.1289	45.0	2.350						
28	0.1332	46.5	2.848						
29	0.1375	48.0	3.560						
30	0.1418	49.5	3.998						
Th-29	0.1418	49.5	3.526						
Th-30	0.1418	49.5	3.558						