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by Numerical Integration

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FROM: Melvin Tobias

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974 001

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3.

AN ORACLE CODE FOR CALCULATION OF FERMI AGES BY NUMERICAL INTEGRATION

SUMMARY

An oracle code has been prepared for the calculation of Fermi Ages by numerical integration. This memorandum describes the code and its uses.

The code is designed to compute values of τ and fast and slow diffusion constants for two-group calculations from cross section data. The values of τ and the diffusion constants may be obtained for mixtures of any or all of sixteen elements. While the present tapes do not contain cross sections for sixteen different elements, cross sections may be changed in a simple and rapid manner. It should be noted in this connection that the thermal cross sections used for the calculation of slow diffusion constants have not yet been critically evaluated, and caution should be exercised in their use.

No special provision has yet been made for handling slowing down in hydrogenous mixtures or in mixtures involving inelastic scattering, or for first flight corrections. However, the user of the code may incorporate such features by empirical cross section changes.

Using this code, the age to indium resonance for heavy water was calculated to be 95 which compares well with the value of $100 \pm 5 \text{ cm}^2$ cited in the Reactor Handbook. On the other hand, the age calculated for light water was about half that currently accepted, pointing up the need for revision of the cross sections used for hydrogenous materials.

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974 002

EQUATIONS

The code performs a numerical integration of the following expression:

$$\tau = \frac{\int_0^{u_{th}} Z(u) du \int_u^{u_{th}} \frac{D(u')}{\xi \Sigma_T(u')} du'}{\int_0^{u_{th}} Z(u) du} \quad (1)$$

where τ = Fermi Age to thermal energy, cm^2
 u = lethargy, $\ln(10^7/E)$ where E is energy in electron volts
 u_{th} = thermal lethargy
 $Z(u)du$ = the number of neutrons born in the lethargy interval between u and $u + du$
 $D(u)$ = the diffusion constant corresponding to a lethargy u
 ξ = average logarithmic energy decrement/collision for a mixture
 $\Sigma_T(u)$ = total macroscopic cross section corresponding to lethargy u ,

The integral $\int_0^{u_{th}} Z(u)du$ is normalized to unity, so that Z becomes the fraction of fission neutrons born with lethargies lying between u and $u + du$.

It is convenient to reverse the order of integration before transforming to the form:

$$\tau = \int_0^{u_{th}} \frac{D(u)du}{\xi \Sigma_T(u)} \int_0^u Z(u')du' \quad (2)$$

Equation (2) may be approximated as the following sum:

$$\tau = \sum_{i=1}^{i=i_{th}} \left(\frac{D}{\xi \Sigma_T} \right)_i \Delta u_i \left\{ \frac{Z_i \Delta u_i}{2} + \sum_{j=1}^{j=i-1} Z_j \Delta u_j \right\} \quad (3)$$

where $(D/\xi \Sigma_T)_i$ and Z_i are the average values of these quantities within the lethargy interval Δu_i . Given a particular division of the lethargy interval between 0 and u_{th} , and a fission spectrum, one may make the substitution:

$$F_i = \Delta u_i \left\{ \frac{Z_i \Delta u_i}{2} + \sum_{j=1}^{j=i-1} Z_j \Delta u_j \right\} \quad (4)$$

and write

$$\tau = \sum_{i=1}^{i=i_{th}} F_i \left(\frac{D}{\xi \Sigma_T} \right)_i \quad (5)$$

For calculation purposes, it was assumed that the average value of $\frac{D}{\xi \Sigma_T}$ over an interval could be obtained from the average values of each of these quantities in the interval and further, for the case of mixtures, that the values of D , ξ and Σ_T might be obtained from the average values for the individual elements in the interval. Equations (6), (7) and (8) were employed to calculate $D/\xi \Sigma_T$ for each interval:

$$D = \frac{1}{3 \Sigma_{Tr}} = \frac{1}{3 \sum_j N_j \sigma_{sj} (1-\mu_j)} \quad (6)$$

(where N_j is the number of atoms of element j per barn-cm, σ_{sj} is the microscopic scattering cross section in barns, and μ_j is the average cosine of the scattering angle.) This same formula is used to compute thermal diffusion constants.

$$\xi \Sigma_T = \sum_j \xi_j N_j \sigma_{Tj} \quad (7)$$

where ξ_j , N_j , and σ_{Tj} are, respectively, the average logarithmic energy decrement per collision, concentration in atoms per barn-cm., and microscopic total cross section in barns of the j_{th} element. It follows that:

$$\left(\frac{D}{\xi \Sigma_T} \right)_i = \frac{1}{3 \sum_j N_j \sigma_{sj}(1 - \mu_j) \left(\sum_j \xi_j N_j \sigma_{Tj} \right)} \quad (8)$$

The cross sections in the code are given, except where otherwise noted, as $3 \sigma_{Tr}$ and $\xi \sigma_T$. There is, however, no difficulty in using separate values of σ_s , $1 - \mu$, ξ , and σ_T , since the code actually carries out the operations $(3 \sigma_s)(1 - \mu)$ and $(\xi)(\sigma_T)$. At the present time the cells which are supposed to contain $1 - \mu$ and ξ all contain unity, with some exceptions noted.

To calculate the fast diffusion constant for two-group reactor calculations, the formula (9) was used:

$$D_1 = \frac{\sum_{i=1}^{th} F_i \left(\frac{D}{\xi \Sigma_T} \right)_i}{\sum_{i=1}^{th} \left(\frac{F_i}{\xi \Sigma_T} \right)_i} \quad (9)$$

PRACTICAL USE OF THE CODE TAPES

Output of the Code

1. The output of the Oracle code under discussion consists of the following results printed in the following order

1. Identification Word	(contained in cell 310)
2. τ	Cell 251
3. D_1	Cell 252
4. D_{th}	Cell 26E

If the user desires, it is also easy to print out values of $\Delta\tau$, i.e., the increment of age corresponding to lethargy interval Δu . (The sum of these $\Delta\tau$ values is τ itself.) These values would be printed out after items 1-4 listed above. All results are printed out in the following ten digit form:

XXXXXXXXZZ

which is equivalent to

(0.XXXXXX) $10^{\pm ZZ}$

If Y is 0, the exponent of 10 is +. If Y is F, the exponent is -.

Thus an answer printed as

0234567017

would mean 0.234567×10^{17} . An answer printed as

0765432F08

would mean 0.765432×10^{-8}

2. Input Data. Normally, the input data would be typed as follows:

Item 1. Identification Word - Any 10 digit word to identify the case under study. (contained in cell 310)

Item 2. Instruction word - 0000000000 or 0300000000. (contained in cell 311) If the first, the output will be the four quantities listed above. If the second, the output will also contain ΔT values.

Items 3 - 17. The concentrations of the elements of the mixture in atoms per barn centimeter in the following order:

Deuterium	(Cell 300)
Oxygen	(301)
Thorium - I	(302)
U-238	(303)
Hydrogen	(304)
Sulfur	(305)
Lithium	(306)
U-235	(307)
Pu-239	(308)
U-233-I	(309)
Zirconium	(30A)
Stainless steel	(30B)
Iron	(30C)
Aluminium	(30D)
Thorium - II	(30E)
Uranium-233-II	(30F)

(The meaning of the Roman numerals appended to the names of the elements Th and U-233 is explained in the notes to Appendix II.) These concentrations must be typed in the same 10 digit form (OXXXXXXYYZ) described above. The list of input quantities should end with a single space, and each number must be separated from its successor by a single space.

To perform the calculation for a single case, the input tape is placed under the reader (after the code tape has been loaded in the manner to be described below) and the command

43 18D

is given to the operator. The break point switch should be in the up position. The machine will load the input numbers, calculate for about 15 seconds, punch out the answers and stop. If another case is to be loaded individually, the command is changed to

43 18F

with the break point up.

If several cases are to be run, the input numbers may be typed in succession on a single tape, each set of numbers containing the entire set of data required above. The code will run all the cases on the single command 43 18D. The break point switch should be in the continuous position until the last case, when it is placed up. The machine then stops in cell 15A, ready for further computation when the 43 18F order is given.

Should a succession of cases be under study such that the change in input numbers from one case to the next involves only a few changes, and these changes involve consecutive cells, the amount of typing required may be considerably reduced by either of two simple procedures, one of

which involves loss of ability to punch out values of ΔT and the other of which does not. In either case, the other numbers which it is not desired to change must already be in their assigned cells. The first procedure is as follows: At the beginning of the input tape, the following word should be typed:

94 161 43 15F

followed by a double space. On loading the input tape the command 90:18B is given. To load the remainder of the tape and perform the calculation, the usual 43 18D order is used, (or 43 18F if a calculation has already been performed with the machine stopping on the break point in 15A.) The input data is typed as follows:

Item 1. Identification Word

Item 2. 00 XXX 00 YYY where XXX and YYY denote the initial and final numbers of those cells which it is desired to change. For example, if one wished to change only cells 306 and 307 (which contain Li and U-235 concentrations) this word would read 0030600307. If only one concentration were to be changed (say 306) it would read 0030600306.

Item 3. The new concentrations in atoms per barn-centimeter to be placed in the cells to be changed, ending with a single space.

If it is desired to retain the ability to punch out ΔT values, the alternative procedure which follows is used. At the beginning of the input tape, the words

94 311 43 199//

94 161 43 15F//

are typed, separated and followed by double spaces as shown. To load such a tape, the orders 90:18B, 90:199 are given. The input numbers will then be ready to be used on the 43 18D order. The input numbers are then given in the form:

Item 1. Identification word

Item 2. The instruction word 0000000000 or 0300000000

Item 3. The initial and final numbers of the cells to be changed 00 XXX 00 YYY

Item 4. The new concentrations

3. Loading the Code Tape and Changing Cross Sections.

The present code must be used on the single Oracle memory. The code tape contains floating point subroutines, the code itself, F_i values, $3\sigma_{Tr}$ (thermal) values, ξ values, $1-\mu$ values, and values of $\xi\sigma_T$ and $3\sigma_{Tr}$ for the 27 lethargy groups used between 10^7 e.v. and a thermal energy corresponding to 250°C . To load it give the orders:

1. 90 3FA

The tape stops loading about half way through its length.

2. 43 163, with break point switch up. The remainder of the tape is loaded (except for a short section at the end.) The machine stops on a break point in cell 105, and is now ready for the age computation, i.e., the loading of input data tapes on the command 43:18D. If a sum check is desired, give the order 43:169.

The user may desire to use different cross sections than those printed on the tapes. (For the cross sections presently used, see Appendix II). To change the group cross sections, one loads the entire

Oracle tape as previously described. Then a tape bearing the following information is placed under the reader, and loaded with the command 43:1A0 (Break Point up):

1. A key word, either 0000000 XXX or 00 800 00 XXX. If the first word is used the machine will load another group of new cross sections. If the second word is used, the machine will stop on a break point in 1B1 ready for either further cross section changes on repeating the 43 1A0 order or for computing ages. The number XXX denotes the element whose cross section is to be changed. The numbers to be used are:

Element	Set of $3\sigma_{Tr}$ values	Set of $\xi\sigma_T$ values
D	000	010
O	001	011
Th-I	002	012
U-238	003	013
H	004	014
S	005	015
Li	006	016
U-235	007	017
Pu-239	008	018
U-233-I	009	019
Zr	00A	01A
Stainless Steel	00B	01B
Fe	00C	01C
Al	00D	01D
Th-II	00E	01E
U-233-II	00F	01F

974 011

Thus, if one wished to change the set of ξ_T values given for sulfur and then stop, the key word would be 0080000015.

2. A series of 27 values of cross sections to replace those already recorded for the element in question. The values are typed in the 0 XXX XX YZZ form previously described. The series of values ends with a single space. If more than one set of cross sections is to be changed, the changes are typed in succession on the tape, each set of 27 values being preceded by a key word. The last set of changes should bear a key word of the 0080000XXX form. After loading the changes, the machine is ready to receive ordinary input data for computation.

Changing values of ξ , $1-\mu$, and $3\sigma_{Tr}$ (thermal) is done by inserting new values in converted floating point form in the appropriate cells. One may insert them by loading previously converted numbers into the cells, or by writing a short code which would use the floating point input conversion routine already present. The latter procedure is preferable. The storage cell numbers for these quantities are given in Appendix I. Suitable places for inserting such a routing would be cells 196 - 19F, 1B2-1CE, or 1D2-21A. After having loaded in the code normally, one would load the short routine into the cells desired. For example, if it were inserted starting in cell 19A, it would read

```
24 19A 43 03C
00 XXX 00 YYY
00 000 00 000//
```

On placing a tape containing changes to be inserted in consecutive cells from XXX to YYY inclusive and giving the order 43 19A, the numbers would

be converted and stored in cells XXX to YYY. The machine would then idle in cell 19C ready for further use in ordinary computations. If one wished changes in non-consecutive cells, the short routine would read:

19A	24	19A	43	03C
B	00	XXX	00	XXX
C	24	19C	43	03C
D	00	YYY	00	YYY
E	00	000	00	000//

This routine would enable changes to be made in non-consecutive cells XXX and YYY.

Changing Magnetic Tape Drives Used in the Code

It sometimes happens that one of the magnetic tape drives is not functioning properly. Provision is made in the code for changing the drives used in the event of such an emergency. The code normally employs drives 0 and 1. Drive 0 is used to contain the 27 group cross sections and drive 1 is used to contain a part of the code. At the start of a new case, drive 0 should be on block 020 and drive 1 should be on block 001.

The procedure for changing the drives is as follows. The code is partially loaded with the usual 90:3FA order. Before loading and converting cross sections on magnetic tape (accomplished by the 43:163 order) the following orders are given:

1. To Use Drives 1 and 2

- a. 43:180

b. Change Orders 18E to A2 OF7 43 18F
18F to 60 18F AE 001
191 to B2 OF7 43 193
192 to 60 105 AD 020

2. To Use Drives 2 and 3

a. 43:183

b. Change orders 18E to A3 OF7 43 18F
18F to 60 18F AF 001
191 to B3 OF7 43 193
192 to 60 105 AE 020

The remainder of the tape is then loaded with a 43:163 order. Other emergencies which these shifts will not meet are best treated by inspecting those cells containing magnetic tape orders. Those normally involving drive 0 are 192,101,105, and 107. Those involving drive 1 are 18E, 18F, and 191. An important feature of changing from drive 0 is that changes must be made before trying to load the cross section portion of the code tape, i.e., before giving the 43:163 order. If a drive is found defective during operations, it is best to start the entire loading procedure from the beginning, using different drives as needed.

APPENDIX I

The Code for Calculating Ages

A. Memory Locations of the Code Components

1. Floating Point Arithmetic, 000 - 03B
2. Input Floating Point Conversion, 03C - 06C
3. Output Floating Point Conversion, 06D - 0B3
4. Floating Point Temporaries, 3F0 - 3F9
5. Universal Constants, 3FA - 3FF
6. Age Code, 0F7 - 195, ICF - 1D1
7. F_i , 0B4 - 0E2
8. ξ_i , 0CF-0E2
9. $1-\mu_i$, 0E3 - 0F6
10. $3\sigma_{Tr}(\text{thermal})$, 320 - 32F
11. N_i , 300 - 30F
12. Identification Word for Case, 310
13. Key word for instruction to punch out ΔT values, 311
14. Temporaries used in age code, 200 - 250
15. Storage of T , 251
16. Storage of D_1 , 252
17. Storage of D_{th} , 26E
18. Sum check routine, 169 - 171
19. Routine for cross section changes, 1A0 - 1B1

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17.

AGE CODE

OF7	24	7FD	5F	21B
8	24	OF7	20	7FF
9	5F	OF7	43	OFB
A	24	7FD	5F	251
B	22	OFA	4B	OF7
C	24	OFC	43	03C
D	00	200	00	21A
E	43	100	00	000
F	00	000	00	01B
100	60	OFF	40	000
1	A0	200	43	103
2	00	000	00	01F
3	24	102	22	7FF
4	5F	102	4A	OFC
5	60	905	AC	020
6	60	OFF	40	000
7	B0	200	43	108
8	24	108	43	001
9	200	2	OE3	200
A	200	2	300	200
B	A00	8	21B	21B
C	43	110	00	000
D	01B	0	01B	01B
E	001	0	000	001
F	001	0	001	001

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974 016

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18.

AGE CODE (Cont'd)

110	24	10A	20	10E
1	5F	10A	24	10B
2	20	10F	5F	10B
3	24	109	20	10E
4	5F	109	22	116
115	4B	108	43	119
6	21B	2	0E3	21B
7	01B	0	000	01B
8	000	0	001	000
9	24	109	22	117
A	20	118	5F	109
B	24	10A	22	117
C	20	118	5F	10A
D	24	10B	22	10D
E	5F	10B	24	116
F	20	118	5F	116
120	40	000	24	109
1	22	123	4B	106
2	43	12A	00	000
3	200	2	0F3	200
4	200	2	OCF	200
5	200	2	300	200
6	A00	8	236	236
7	21B	2	OCF	21B
8	200	2	ODF	200
9	43	133	00	000
A	24	124	5F	109

974 017

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AGE CODE (Cont'd)

B	24	125	5F	10A
C	24	126	5F	10B
D	24	127	5F	116
E	24	128	5F	123
F	24	129	5F	122
130	43	106	00	000
1	02	5FF	FF	FFF
2	00	7FF	FF	FFF
3	24	7FD	5F	251
4	5F	252	43	138
135	000	0	000	000
6	A6E	8	251	251
7	001	0	000	000
8	24	138	43	001
9	0B4	1	236	253
A	253	8	252	252
B	253	1	132	253
C	253	1	21B	253
D	A53	8	251	251
E	24	139	20	10F
F	5F	139	24	13A
140	20	137	5F	13A
1	24	13B	20	10E
2	5F	13B	24	13C
3	20	10F	5F	13C

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20.

AGE CODE (Cont'd)

4	24	13D	20	137
5	5F	13D	22	136
6	4B	138	40	000
7	24	147	43	001
8	251	1	252	252
9	300	2	320	26F
A	A6F	8	26E	26E
B	40	000	40	000
C	24	149	20	10F
D	5F	149	24	14A
E	20	137	5F	14A
F	22	151	4B	1CF
150	43	176	00	000
1	A7F	8	26E	26E
2	60	310	84	310
3	24	153	43	06D
4	00	251	00	252
5	24	155	43	06D
6	00	26E	00	26E
7	43	15C	00	000
8	24	158	43	06D
9	00	253	00	26D
A	43	98F	00	000
B	40	158	43	15A
C	24	311	20	15B
D	5F	15B	43	15B

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974 019

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21.

AGE CODE (Cont'd)

E	43	105	00	000
F	24	15E	5F	OFC
160	24	160	43	03C
1	00	300	00	30F
2	43	OF7	00	000
3	24	163	43	03C
4	00	OB4	00	OF6
5	24	165	43	03C
6	00	320	00	32F
7	24	7FD	5F	26E
8	43	OFC	00	000
9	24	000	20	189
16A	5F	189	20	001
B	3A	189	7F	189
C	24	169	20	16E
D	5F	169	43	171
E	00	001	00	000
F	00	000	00	001
170	5F	189	20	189
1	24	16A	20	16F
2	5F	16A	22	170
3	4B	169	60	189
4	84	000	24	7FD
5	5F	189	00	000
6	24	176	43	001

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974 020

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22.

AGE CODE (Cont'd)

7	26E	2	132	26E
8	932	1	26E	26E
9	43	152	00	000
17A	A1	000	AD	000
B	B1	000	00	000
C	A2	000	AE	000
D	B2	000	00	000
E	A3	000	AF	000
F	B3	000	00	000
180	24	17A	58	101
1	52	105	24	17B
2	58	107	00	000
3	24	17C	58	101
4	52	105	24	17D
5	58	107	00	000
6	24	17E	58	101
7	52	105	24	175
8	58	107	00	000
9	00	000	00	000
18A	94	310	43	18B
B	94	311	43	15F
C	00	000	00	083
D	60	18C	40	000
E	A1	OF7	43	18F
F	60	18F	AD	001

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23.

AGE CODE (Cont'd)

190	60	18C	40	000
1	B1	OF7	43	193
2	60	105	AC	020
3	24	192	5F	105
4	24	7FD	5F	26E
5	43	18A	00	000
1CF	24	1D0	51	148
1D0	43	147	00	1D1
1	00	000	00	000

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APPENDIX

CROSS SECTIONS AND RELATED DATA

- A. Energy Division. The lethargy groups and their limits are the same as those used in the Univac Eyewash Code. The top 27 groups are used, so that the lowest energy considered corresponds to a temperature of 250°C while the upper limit is 10 Mev. The reader is referred to p. 31, ORNL Report 1925 for a listing of these energy and lethargy increments.
- B. Values of F_1 . These values are based upon the fission spectrum assumed in ORNL 1925. They are contained in converted form in cells OB4 - OCE during computations.

Cell Number	F_1
OB4	5.25×10^{-3}
OB5	3.607×10^{-2}
OB6	0.1134
OB7	0.223005
OB8	0.326825
OB9	1.28272
OBA	2.94735
OBB	3.
OBC	1.4
OB D	1.2
OBE	0.8
OB F	0.4
OC0	0.8
OC1	1.2
OC2-OC5	0.4
OC6-OCE	0.2

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25.

C. Values of ξ : These are contained in converted form in cells OCF-OE2. Since most of the group cross sections are in the form of $\xi \sigma_T$, the value of ξ placed in cells for these elements is unity.

Element	Cell Number	ξ
D	OCF	1
O	ODO	1
Th-I	OD1	1
U-238	OD2	1
H	OD3	1
S	OD4	1
Li	OD5	1
U-235	OD6	8.4865×10^{-3}
Pu-239	OD7	8.345×10^{-3}
U-233-I	OD8	1
Zr	OD9	2.1766×10^{-2}
Stainless Steel	ODA	1
Fe	ODB	3.539×10^{-2}
Al	ODC	7.237×10^{-2}
Th-II	ODD	1
U-233-II	ODE	1
-----	ODF	0
-----	OEO	0
-----	OE1	0
-----	OE2	0

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D. Values of $1 - \mu$. These are contained in converted form in cells OE3-OF6 in the same order with respect to elements as the values of ξ . At the present time, no group scattering cross sections are used and the values of $3\sigma_{Tr}$ are used directly. The contents of these cells are therefore all unity.

E. Values of $3\sigma_{Tr}(\text{thermal})$. These are contained in converted form in cells 320-32F. Caution must be exercised in the use of these numbers, which are preliminary in character and have not been critically examined. They have been used until now primarily to check the procedure used for calculating the thermal diffusion constant. In general, they are based upon scattering cross sections corresponding to 250°C .

Element	Cell Number	$3\sigma_{Tr}(\text{thermal})$
D	320	9.49335
O	1	11.49
Th-I	2	52.8 (based on total cross section)
U-238	3	24.591
H	4	40.149
S	5	2.426
Li	6	6.841
U-235	7	24.594
Pu-239	8	2.88
U-233-I	9	1272 (based on total cross section)
Zr	A	44.271
S.S.	B	2.8994 (macroscopic cross section)

(Cont'd)

Element	Cell Number	$3\sigma_{Tr}$ (thermal)
Fe	C	32.64
Al	D	4.065
Th-II	E	24.6 (based on scattering cross section only)
U-233-II	F	24 (based on scattering cross section)

F. Group Cross Sections. These cross sections are placed on magnetic tape drive 0 and are loaded into the fast memory according to the requirements of the code. Values of $3\sigma_{Tr}$ are listed first, followed by $\xi\sigma_T$ (or σ_T as noted) values. Each of these major groups is subdivided into 16 sets of 27 numbers, each set corresponding to an element, and each number corresponding to one of the 27 lethargy intervals used. The numbers are given here in the OXXXXXXYYZ form previously described. Except for cases specifically noted, the values listed are based upon cross sections presently employed in the Eyewash Univac Code.

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$3\sigma_{Tr}$ Values

Group No.	D	O	Th-I (3)	U-238	H
1	0235697001	0287400001	0861000001	0861581001	0894000000
2	0326771001	0463700001	0982000001	0981949001	0155950001
3	0437693001	0403900001	0112500002	0112480002	0236700001
4	0540621001	0467900001	0127000002	0126980002	0321850001
5	0619232001	0129330002	0143000002	0143110002	0419900001
6	0689628001	0115862002	0181000002	0181090002	0734383001
7	0697511001	0107190002	0282600002	0282640002	0160140002
8	0697511001	0107190002	0287500002	0292010002	0204870002
9	0697511001	0112900002	0321000002	0275800002	0207720002
10	0697511001	0107190002	0321000002	0262510002	0207720002
11	0697511001	0107190002	0321000002	0260270002	0207720002
12	0697511001	0107190002	0321000002	0260270002	0207720002
13	0697511001	0107190002	0348000002	0260280002	0207720000
14	0697511001	0107190002	0360000002	0273720002	0208380002
15	0697511001	0107190002	0369000002	0273100002	0213400002
16	0705240001	0107190002	0372000002	0270270002	0217800002
17	0723120001	0107190002	0375000002	0266780002	0228280002
18	0735790001	0107468002	0375000002	0263980002	0244850002
19	0752470001	0108585002	0375000002	0261740002	0261500002
20	0771140001	0109205002	0375000002	0259200002	0273800002
21	0797290001	0109845002	0373500002	0257920002	0289780002
22	0812740001	0110645002	0373500002	0254830002	0307100002
23	0821750001	0111415002	0372000002	0252440002	0329240002
24	0849410001	0112080002	0369000002	0249600002	0342560002
25	0885400001	0112750002	0367500002	0248200002	0358210002
26	0903680001	0117300002	0366000002	0245810002	0379010002
27	0923350001	0115435002	0363000002	0245860002	0398160002

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3_σ Tr Values

Group No.	S	Li	U-235	Pu-239 ⁽¹⁾	U-233-I ⁽²⁾
1	0852000001	0575000001	0186355002	0132000001	0265000002
2	0852000001	0568666001	0200415002	0162000001	0294000002
3	0852000001	0524783001	0203935002	0165000001	0294600002
4	0728400001	0450137001	0200415002	0156000001	0296700002
5	0737400001	0415302001	0178380002	0162000001	0300000002
6	0772500001	0666140001	0241447002	0222000001	0303900002
7	0119550002	0304025001	0370000002	0300000001	0342300002
8	0323100001	0382246001	0291618002	0297000001	0636000002
9	0317700001	0445717001	0247124002	0297000001	0132900003
10	0317700001	0475909001	0239940002	0288000001	0248400003
11	0312900001	0502044001	0239940002	0288000001	0334200003
12	0312900001	0515657001	0239940002	0288000001	0370500003
13	0302400001	0538541001	0239940002	0288000001	0321000003
14	0303900001	0567653001	0239940002	0288000001	0648000003
15	0296900001	0587698001	0239940002	0288000001	0594000003
16	0286900001	0597144001	0239940002	0288000001	0441000003
17	0280100001	0609584001	0239940002	0288000001	0445300003
18	0271900001	0621841001	0239940002	0288000001	0507000003
19	0272900001	0632508001	0239940002	0288000001	0588000003
20	0269400001	0637898001	0239940002	0288000001	0648000003
21	0266000001	0643295001	0239940002	0288000001	0711000003
22	0262700001	0650949001	0242440002	0288000001	0771000003
23	0259600001	0656948001	0245440002	0288000001	0855000003
24	0252800001	0662304001	0245940002	0288000001	0927000003
25	0250700001	0668249001	0245940002	0288000001	0104700004
26	0246500001	0675949001	0245940002	0288000001	0113400004
27	0242600001	0681377001	0245940002	0288000001	0127200004

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30.

3σ Tr Values

Group No.	Zr	Stainless Steel (macroscopic)	Fe	Al
1	0997064001	0849291000	0854600001	0662500001
2	0101493002	0876230000	0886750001	0733200001
3	0111568002	0846630000	0844700001	0791700001
4	0137435002	0743244000	0696450001	0818450001
5	0189586002	0758378000	0691600001	0713900001
6	0248314002	0961154000	0932800001	0120678002
7	0264937002	0154986001	0141941002	0118102002
8	0289810002	0209521001	0198503002	0462020001
9	0345936002	0277120001	0296290002	0451200001
10	0384688002	0288331001	0325625002	0451200001
11	0410630002	0293944001	0333738002	0451138001
12	0416649002	0291383001	0329526002	0450600001
13	0416564002	0290296001	0329302002	0449546001
14	0419854002	0298306001	0336246002	0446883001
15	0422049002	0304636001	0344345002	0443900001
16	0423109002	0291382001	0327250002	0441625001
17	0424626002	0290040001	0323425002	0439350001
18	0424356002	0290438001	0323985002	0436175001
19	0424126002	0289530001	0323050002	0433400001
20	0423948002	0290106001	0323100002	0431100001
21	0423740002	0289986001	0322150002	0428950001
22	0423530002	0290388001	0322650002	0426300001
23	0423292002	0289087001	0322150002	0423450001
24	0423522002	0287376001	0321550002	0419950001
25	0428453002	0288977001	0324600002	0416650001
26	0433568002	0290956001	0326900002	0412550001
27	0442040002	0290947001	0327250002	0408350001

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31.

$3\sigma_{Tr}$ Values

Group No.	Th-II (4)	U-233-II (4)
1	0861000001	0600000001
2	0982000001	0600000001
3	0112500002	0600000001
4	0127000002	0650000001
5	0143000002	0900000001
6	0181000002	0158300002
7	0282600002	0234200002
8	0287500002	0240000002
9	0275700002	0240000002
10	0262500002	0240000002
11	0260400002	0240000002
12	0260400002	0240000002
13	0260400002	0240000002
14	0276600002	0240000002
15	0273000002	0240000002
16	0270200002	0240000002
17	0266700002	0240000002
18	0264000002	0240000002
19	0261600002	0240000002
20	0259100002	0240000002
21	0259500002	0240000002
22	0264800002	0240000002
23	0254000002	0240000002
24	0249700002	0240000002
25	0248300002	0240000002
26	0245900002	0240000002
27	0246000002	0240000002

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32.

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5 σ_T Value

Group No.	D	O	Th-I ⁽⁵⁾	U-238	H
1	0846800000	0120900000	0626000F01	0313200F01	0894000000
2	0118460001	0195000000	0626000F01	0330700F01	0156000001
3	0158630001	0169900000	0626000F01	0359500F01	0236700001
4	0195970001	0196800000	0574200F01	0387400F01	0321800001
5	0224460001	0544000000	0593300F01	0410500F01	0419900001
6	0249980001	0487300000	0759800F01	0520900F01	0734400001
7	0252880001	0451000000	0932800F01	0828600F01	0160140002
8	0252880001	0451000000	0107700000	0994000F01	0204870002
9	0252880001	0414900000	0113100000	0108500000	0207720002
10	0252880001	0451000000	0108200000	0115500000	0207720002
11	0252880001	0451000000	0117900000	0131700000	0207720002
12	0252880001	0451000000	0992300F01	0800600F01	0207720002
13	0252880001	0451000000	0103800000	0164700000	0207720002
14	0252880001	0451000000	0110800000	0800300F01	0208380002
15	0252880001	0451000000	0117300000	0800300F01	0213700002
16	0255650001	0451000000	0120000000	0800300F01	0218360002
17	0262160001	0451000000	0123500000	0800300F01	0228980002
18	0266730001	0452000000	0127000000	0804500F01	0245690002
19	0272740001	0456800000	0129600000	0808600F01	0262480002
20	0279560001	0459400000	0131500000	0809400F01	0274880002
21	0288980001	0462100000	0134000000	0813600F01	0290980002
22	0294640001	0465500000	0136000000	0813500F01	0308420002
23	0297900001	0468700000	0139200000	0817700F01	0330720002
24	0307910001	0471500000	0141800000	0821900F01	0344160002
25	0320960001	0474300000	0144600000	0829500F01	0359940002
26	0327560001	0493400000	0148000000	0838800F01	0380990002
27	0334730001	0485500000	0151600000	0854800F01	0400330002

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$\xi \sigma_T$ Value

Group No.	S	Li	U-235 ⁽⁹⁾	Pu-239 ⁽⁹⁾	U-233-I ⁽⁶⁾
1	0178600000	0568700000	0754980001	0681300001	0430000F01
2	0178600000	0562800000	0802820001	0746600001	0430000F01
3	0178600000	0519100000	0815750001	0751600001	0430000F01
4	0152800000	0445100000	0806830001	0721500001	0445000F01
5	0154700000	0410800000	0735490001	0726600001	0520000F01
6	0162000000	0672400000	0967000001	0922100001	0705600F01
7	0250700000	0300700000	0151373002	0130300002	0149800000
8	0678000F01	0378100000	0186321002	0169290002	0307900000
9	0673000F01	0440900000	0329594002	0319290002	0493400000
10	0673000F01	0470600000	0526072002	0576280002	0685200000
11	0668000F01	0496900000	0678152002	0496280002	0117500001
12	0668000F01	0510400000	0723542002	0132628003	0137000001
13	0659000F01	0533300000	0956462002	0846280002	0152400001
14	0674000F01	0562300000	0323982002	0296280002	0311600001
15	0672000F01	0582500000	0887632002	0506280002	0259100001
16	0663000F01	0592100000	0711882002	0114628003	0150100001
17	0662000F01	0604800000	0970212002	0489628003	0156600001
18	0663000F01	0617300000	0192691003	0273963004	0179000001
19	0671000F01	0628100000	0238351003	0334963004	0199000001
20	0676000F01	0633800000	0229521003	0173963004	0211000001
21	0681000F01	0639400000	0238021003	0109963004	0225200001
22	0686000F01	0647500000	0254435003	0839628003	0244300001
23	0692000F01	0653500000	0276035003	0737628003	0269000001
24	0697000F01	0659300000	0306552003	0716628003	0293800001
25	0711000F01	0665600000	0345892003	0729628003	0320200001
26	0720000F01	0673900000	0388822003	0759628003	0352800001
27	0730000F01	0679800000	0436555003	0809628003	0391800001

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34.

$\xi \sigma_T$ Value

Group No.	Zr ⁽⁹⁾	Stainless Steel (macroscopic)	Fe ⁽⁹⁾	Al ⁽⁹⁾
1	0334810001	0104431F01	0293340001	0226640001
2	0340810001	0108148F01	0304190001	0250810001
3	0374640001	0102499F01	0290000001	0270800001
4	0461470001	0952968F02	0239980001	0279950001
5	0636630001	0980785F02	0238340001	0244140001
6	0833840001	0116968F01	0319730001	0412640001
7	0889660001	0197109F01	0483910001	0404200001
8	0973280001	0277753F01	0674750001	0158670001
9	0116184002	0320988F01	0100500002	0154990001
10	0129215002	0347114F01	0110399002	0154990001
11	0137950002	0352602F01	0113407002	0155000001
12	0139993002	0355022F01	0112249002	0155020001
13	0139992002	0359358F01	0112572002	0155000001
14	0141170002	0372332F01	0115881002	0154980001
15	0141992002	0374521F01	0119769002	0154960001
16	0142409002	0369397F01	0114781002	0154950001
17	0142992002	0370633F01	0114516002	0155030001
18	0142992002	0376527F01	0115850002	0154990001
19	0142993002	0379868F01	0116597002	0154970001
20	0142992002	0382903F01	0117431002	0154950001
21	0142992002	0386762F01	0118010002	0154950001
22	0142992002	0391426F01	0119095002	0155010001
23	0142992002	0394517F01	0120093002	0154990001
24	0143159002	0397462F01	0121091002	0154957001
25	0144908002	0403930F01	0123437002	0155010001
26	0146742002	0411948F01	0125863002	0154993001
27	0149692002	0418739F01	0127447002	0154953001

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ξ σ_T Value

Group No.	Th - II (7)	U-233-II (8)
1	0626000F01	0430000F01
2	0626000F01	0430000F01
3	0626000F01	0430000F01
4	0604500F01	0445000F01
5	0596000F01	0520000F01
6	0740500F01	0705600F01
7	0939500F01	0149800000
8	0115600000	0307900000
9	0132300000	0493400000
10	0119200000	0685200000
11	0102300000	0117500001
12	0101800000	0137000001
13	0105300000	0152400001
14	0111400000	0311600001
15	0117000000	0259100001
16	0120100000	0150100001
17	0123600000	0156600001
18	0127100000	0179000001
19	0129600000	0199000001
20	0131800000	0211000001
21	0134000000	0225200001
22	0136600000	0244300001
23	0139200000	0269000001
24	0141800000	0293800001
25	0144900000	0320200001
26	0148300000	0352800001
27	0151800000	0391800001

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36.

NOTES:

- (1) Values reported low by a factor of 10. Can be adjusted by placing a 10 in $l-\mu$.
- (2) Based on total cross section.
- (3) Based on improved scattering cross sections obtained by C. W. Nestor.
- (4) Based on scattering cross sections obtained from report CW 413 by C. B. Mills.
- (5) Based upon values reported by C. B. Mills in report CW-413.
(A slightly different set of values has been obtained by C. W. Nestor and can be applied with the use of the cross section change procedure.)
- (6) Based upon values reported by C. B. Mills in report CW-413.
- (7) Same cross sections as Th-I.
- (8) Same cross sections as U-233-I.
- (9) Values listed are σ_T values only. $\xi \sigma_T$ calculated by the code.

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