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ENDF/B based 27-Group Cross-Sections for some Rare-Earth and Concrete Elements

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by

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BHABHA ATOMIC RESEARCH CENTRE
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INIS Subject Category : A34

Descriptors :

NEUTRON REACTIONS

GROUP CONSTANTS

SAMARIUM 149 TARGET

EUROPIUM 151 TARGET

EUROPIUM 153 TARGET

GADOLINIUM

MAGNESIUM

ALUMINIUM

SILICON

POTASSIUM

CALCIUM

EV RANGE

KEV RANGE

MEV RANGE 01-10

MEV RANGE 10-100

CONCRETES

SHIELDING MATERIALS

EVALUATED DATA

ABSTRACT

27-group cross-sections have been generated for some rare-earth and concrete elements using their basic cross-sections from the ENDF/B library. The rare-earth elements are ^{149}Sm, Gd, ^{151}Eu and ^{153}Eu and the concrete-elements are Mg, Al, Si, K and Ca. Concrete mixed with the rare-earth elements can act as an effective neutron shield in nuclear reactors. This cross-section set will serve as a useful tool in carrying out such safety and shielding studies.

ENDF/B BASED 27-GROUP CROSS-SECTIONS FOR SOME RARE-EARTH AND CONCRETE ELEMENTS

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S.B. Garg

1. INTRODUCTION

Recently a 27-group cross-sections set[1] had been derived from ENDF/B library for several elements of interest in reactor technology. The multigroup resonance self-shielding factors[2] and the Pg-elastic scattering matrices[3] have also been generated for some of these elements. These newly generated data resulted in improved criticality predictions[4,5] of fast critical assemblies of different sizes and compositions when compared to the modified ABBN set[6]. To carry out the safety and shielding studies of nuclear reactors ^{149}Sm, Gd, ^{151}Eu, ^{153}Eu, Mg, Al, Si, K and Ca have now been included in the Garg-set. The first four of these elements belong to the rare-earth class and act as poison for neutrons. The remaining five elements are the constituents of concrete.

Concrete mixed with the rare-earth elements can act as an effective neutron shield in nuclear reactors.

2. GROUP CROSS-SECTIONS

Formulations and procedures of obtaining multigroup cross-sections from the basic ENDF/B library are explained in ref.(1) and therefore these are not repeated in this report. However, it can be briefly stated that the energy point cross-sections of these elements have been generated

in the resolved and unresolved resonance regions with RESEND code[7] and they have then been combined with the floor corrections of ENDF/B library to obtain smooth cross-sections in the entire energy range varying from 10^{-5} ev to 20 MeV.

Cross-sections at any energy point lying in the energy-range 10^{-5} ev to 20 MeV have been obtained using the appropriate combination of the following three interpolation schemes.

1. $\ln E$ vs $\ln \sigma$
2. $\ln E$ vs σ , and
3. E vs σ

27-group cross-sections have been obtained with FIGERO code[8] using 1/E weighting spectrum. Group-to-group scattering matrices have been computed using the discrete level and evaporation models in INSCAT code[8]. The total group-to-group scattering cross-section is obtained as

$$\sigma_{i\to i+1} = \sigma^{d}_{i\to i+1} + \sigma^{in}_{i\to i+1} + 2\,\sigma^{n,2n}_{i\to i+1}$$

where

$\sigma^{d}_{i\to i+1}$ = discrete level group-to-group scattering cross-section

$\sigma^{in}_{i\to i+1}$ = inelastic group-to-group scattering cross-section

$\sigma^{n,2n}_{i\to i+1}$ = (n,2n) group-to-group scattering cross-section

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Table 1 gives the energy structure of the 27-groups and the calculated group cross-sections are listed in Tables 2 to 28.

3. ACKNOWLEDGEMENTS

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Table - 1

Energy Structure of 27-Group Cross-Section Set

Group	Energy Range	Lethargy Width
1	10.5 Mev - 15.0 Mev	0.3567
2	6.5 " - 10.5 "	0.4796
3	4.0 " - 6.5 "	0.4855
4	2.5 " - 4.0 "	0.4700
5	1.4 " - 2.5 "	0.5798
6	0.8 " - 1.4 "	0.5596
7	0.4 " - 0.8 "	0.6931
8	0.2 " - 0.4 "	0.6931
9	0.1 " - 0.2 "	0.6931
10	46.5 Kev - 0.1 "	0.7657
11	21.5 " - 46.5 Kev	0.7714
12	10.0 " - 21.5 "	0.7655
13	4.65 " - 10.0 "	0.7657
14	2.15 " - 4.65 "	0.7714
15	1.0 " - 2.15 "	0.7655
16	465 ev - 1.0 "	0.7657
17	215 " - 465 ev	0.7714
18	100 " - 215 "	0.7655
19	46.5 " - 100 "	0.7657
20	21.5 " - 46.5 "	0.7714
21	10.0 " - 21.5 "	0.7655
22	4.65 " - 10.0 "	0.7657
23	2.15 " - 4.65 "	0.7714
24	1.0 " - 2.15 "	0.7655
25	0.465" - 1.0 "	0.7657
26	0.215" - 0.465 "	0.7714
27	0.025 ev	-

Table - 2

^{149}Sm

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	3.0034	0.3931	1.7007	0.0014	0.0123	0.0123	5.1232	0.0143	2.4951	0.8750
2	2.6626	1.1988	0.8864	0.0032	0.0042	0.0042	4.7594	0.0179	2.7288	0.7624
3	2.9043	2.1502	0.0066	0.0081	0.0010	0.0010	5.0712	0.0241	3.0260	0.7022
4	3.8938	2.2489	0.0	0.0191	0.0	0.0	6.1618	0.0326	3.3937	0.7094
5	4.6149	2.3847	0.0	0.0455	0.0	0.0	7.0451	0.0410	4.1824	0.6200
6	4.4498	2.8453	0.0	0.1030	0.0	0.0	7.3981	0.0637	5.5768	0.4087
7	4.3762	2.8967	0.0	0.2221	0.0	0.0	7.4950	0.0762	7.0140	0.1085
8	5.4011	1.8713	0.0	0.4531	0.0	0.0	7.7255	0.1020	7.5092	0.0340
9	7.1300	0.9594	0.0	0.7470	0.0	0.0	8.8364	0.1378	8.7049	0.0114
10	9.5504	0.4702	0.0	1.0234	0.0	0.0	11.0440	0.1682	10.9418	0.0045
11	11.3993	0.0895	0.0	1.5729	0.0	0.0	13.0617	0.1993	12.9994	0.0045
12	11.7200	0.0	0.0	2.4661	0.0	0.0	14.1861	0.2065	14.1291	0.0045
13	16.2829	0.0	0.0	3.0609	0.0	0.0	19.3438	0.2868	19.1349	0.0045
14	21.3441	0.0	0.0	5.6693	0.0	0.0	27.0134	0.3731	26.6883	0.0045
15	27.7569	0.0	0.0	10.435	0.0	0.0	38.1919	0.4890	37.8630	0.0045
16	35.6485	0.0	0.0	18.938	0.0	0.0	54.5865	0.6278	54.1750	0.0045
17	44.9902	0.0	0.0	33.635	0.0	0.0	78.6252	0.7865	78.1580	0.0045
18	55.5740	0.0	0.0	58.5600	0.0	0.0	114.1340	0.9791	113.5660	0.0045
19	322.138	0.0	0.0	178.8300	0.0	0.0	500.9680	5.6734	499.5184	0.0045
20	65.2040	0.0	0.0	160.4600	0.0	0.0	225.6640	1.1399	225.3706	0.0045
21	11.3581	0.0	0.0	123.5500	0.0	0.0	134.9081	0.2001	134.8570	0.0045
22	55.0094	0.0	0.0	580.9200	0.0	0.0	635.9294	0.9688	635.6819	0.0045
23	5.7061	0.0	0.0	18.5060	0.0	0.0	23.5821	0.0887	23.5593	0.0045
24	17.1500	0.0	0.0	159.3500	0.0	0.0	176.5000	0.3021	176.4228	0.0045
25	41.8907	0.0	0.0	2860.200	0.0	0.0	2902.0907	0.7378	2901.9022	0.0045
26	45.5773	0.0	0.0	2188.800	0.0	0.0	2234.3775	0.7967	2234.1722	0.0045
27	165.060	0.0	0.0	41191.0	0.0	0.0	41356.0	0.0	41355.3172	0.0045

Table - 3

^{149}Sm

Discrete Level Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ / k →	0	1	2	3	4	5	6	7
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	.8739	1.0205	.0726	0.0	0.0	0.0	0.0	0.0
6	.9685	1.5487	.2987	.0285	.0025	.0002	0.0	0.0
7	1.3644	.8285	.4384	.1964	.0523	.0138	.0020	0.0
8	1.3636	.2448	.1232	.0930	.0364	.0084	.0011	0.0
9	.7521	.2079	0.0	0.0	0.0	0.0	0.0	0.0
10	.2581	.1496	0.0	0.0	0.0	0.0	0.0	0.0
11	.0173	.0556	.0171	.0045	.0011	.0003	0.0	0.0

Table - 4

^{149}Sm

Statistical Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	.00007	.0030	.0261	.0714	.1205	.0905	.0559	.0194	.0057	.0021
2	.0022	.0372	.1545	.3512	.3209	.2233	.0833	.0255	.0074	.0021
3	.0201	.1500	.5216	.6284	.5194	.2155	.0696	.0207	.0048	.0013
4	.0660	.3879	.6546	.6701	.3173	.1097	.0339	.0080	.0018	.0005
5	.0004	.0132	.0096	.1507	.0993	.0431	.0122	.0029	.0007	.0002

n-2n Scattering Matrices

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	.0003	.0129	.1125	.3077	.5192	.3902	.2409	.0835	.0246	.0092
2	.0016	.0273	.1134	.2578	.2355	.1639	.0611	.0187	.0054	.0015
3	0.0	0.0	0.0	.0001	.0012	.0023	.0018	.0008	.0002	.0001

Table - 5

Gd

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_e	σ_t	σ_{er}	σ_{tr}	μ
1	3.4123	0.2013	1.9879	0.0013	5.6028	0.0192	2.7246	0.8433
2	2.6084	1.8146	0.6723	0.0034	5.0987	0.0176	3.1424	0.7475
3	2.7610	2.6347	0.0	0.0104	5.4061	0.0181	3.3271	0.7518
4	3.4839	2.6699	0.0	0.0305	6.1843	0.0236	3.5608	0.7523
5	4.0160	2.7553	0.0	0.0838	6.8551	0.0276	4.0853	0.6893
6	4.2665	2.8335	0.0	0.1131	7.2131	0.0416	4.7613	0.5744
7	5.0533	2.1392	0.0	0.1048	7.2973	0.0541	4.6521	0.4216
8	6.2431	1.2023	0.0	0.1689	7.6143	0.0829	5.8371	0.2823
9	7.3307	0.5370	0.0	0.3646	8.2323	0.1142	7.0577	0.1586
10	8.4129	0.0896	0.0	0.6544	9.1569	0.1295	8.4638	0.0811
11	9.2379	0.0	0.0	1.1258	10.3637	0.1478	10.0070	0.0382
12	9.8870	0.0	0.0	1.7099	11.5969	0.1628	11.4205	0.0173
13	10.4070	0.0	0.0	3.6840	14.0910	0.1731	13.8000	0.0071
14	10.8830	0.0	0.0	8.0941	16.9771	0.1802	16.9131	0.00428
15	10.6983	0.0	0.0	8.1815	18.8798	0.1785	18.3005	0.00428
16	11.7631	0.0	0.0	14.2870	26.0501	0.1962	25.8170	0.00428
17	11.2336	0.0	0.0	17.6570	28.8906	0.1860	28.5690	0.00428
18	11.6302	0.0	0.0	27.6120	39.2422	0.1941	38.8130	0.00428
19	10.2925	0.0	0.0	24.8260	35.1185	0.1717	33.2977	0.00428
20	5.7374	0.0	0.0	28.5920	34.3294	0.0950	31.6030	0.00428
21	10.4016	0.0	0.0	50.1540	60.5556	0.1736	52.2652	0.00428
22	2.9289	0.0	0.0	39.0430	41.9719	0.0489	41.3604	0.00428
23	4.5844	0.0	0.0	147.1400	151.7244	0.0759	150.2920	0.00428
24	2.6692	0.0	0.0	43.7550	46.4242	0.0445	46.3260	0.00428
25	5.1147	0.0	0.0	79.0350	84.1497	0.0853	83.8931	0.00428
26	13.1268	0.0	0.0	564.690	577.8168	0.2174	576.524	0.00428
27	167.00	0.0	0.0	49050.0	49217.0	0.0	49216.3	0.00428

Table - 6

Gd

Statistical Scattering Matrices

$\sigma_i \longrightarrow i + k$

i ↓ k →	0	1	2	3	4	5	6	7	8	9
1	.00003	.0013	.0122	.0351	.0614	.0472	.0296	.0103	.0031	.0011
2	.0027	.0498	.2194	.5207	.4894	.3466	.1307	.0402	.0117	.0034
3	.0211	.1689	.6197	.7731	.6532	.2749	.0894	.0267	.0062	.0017
4	.0696	.4375	.7705	.8107	.3903	.1362	.0422	.0100	.0022	.0006
5	.2422	.6786	.9660	.5606	.2156	.0703	.0171	.0038	.0009	.0002
6	.4829	1.0492	.7902	.3489	.1223	.0309	.0071	.0016	.0003	.0001
7	.7169	.7808	.4207	.1638	.0438	.0103	.0023	.0007	.0001	0.0
8	.5500	.3996	.1827	.0531	.0130	.0030	.0007	.0001	0.0	0.0
9	.2948	.1684	.0552	.0143	.0034	.0008	.0002	0.0	0.0	0.0
10	.0509	.0250	.0079	.0020	.0005	.0001	0.0	0.0	0.0	0.0

Table - 7

Gd

n-2n Scattering Matrices

$\sigma_i \longrightarrow i + k$

i ↓ k →	0	1	2	3	4	5	6	7	8	9
1	.0786	3112	.5027	.4594	.3642	.1661	.0760	.0219	.0059	.0019
2	.0010	0.181	.0805	.1924	11818	.1291	.0488	.0150	.0044	.0012

Table - 8

^{151}Eu

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	2.9454	0.2628	1.8109	0.0037	0.0197	0.0044	5.0469	0.0135	2.4617	0.8777
2	2.8162	1.3185	0.3721	0.0073	0.0060	0.0012	4.6213	0.0183	2.4615	0.7669
3	3.1185	2.0351	0.0	0.0163	0.0015	0.0002	5.1716	0.0270	3.0273	0.6857
4	4.0859	2.1266	0.0	0.0345	0.0004	0.0	6.2474	0.0363	3.4299	0.6879
5	4.8668	2.2883	0.0	0.0797	0.0	0.0	7.2348	0.0427	4.2181	0.6197
6	4.6174	2.6965	0.0	0.1951	0.0	0.0	7.5090	0.0650	5.6102	0.4108
7	4.8031	2.7139	0.0	0.2769	0.0	0.0	7.7939	0.0837	7.3161	0.0968
8	5.9784	1.9536	0.0	0.5846	0.0	0.0	8.5166	0.1139	8.4164	0.0123
9	7.1024	1.2201	0.0	1.2283	0.0	0.0	9.5508	0.1361	9.4955	0.0063
10	8.1590	0.7364	0.0	2.1629	0.0	0.0	11.0583	0.1418	11.0012	0.00446
11	9.3133	0.1530	0.0	3.6732	0.0	0.0	13.1395	0.1607	13.0920	0.00446
12	11.1906	0.0	0.0	5.5756	0.0	0.0	16.7662	0.1946	16.6166	0.00446
13	14.1207	0.0	0.0	8.2298	0.0	0.0	22.3505	0.2454	22.2478	0.00446
14	16.1893	0.0	0.0	13.9130	0.0	0.0	30.1023	0.2793	29.9910	0.00446
15	18.2487	0.0	0.0	23.1090	0.0	0.0	41.3577	0.3172	41.2230	0.00446
16	20.1971	0.0	0.0	37.5100	0.0	0.0	57.7071	0.3510	57.5210	0.00446
17	21.9588	0.0	0.0	59.8050	0.0	0.0	81.7638	0.3788	81.6470	0.00446
18	23.4631	0.0	0.0	93.7760	0.0	0.0	117.2391	0.4079	117.1170	0.00446
19	24.6740	0.0	0.0	143.980	0.0	0.0	168.6540	0.4288	168.535	0.00446
20	23.5639	0.0	0.0	222.580	0.0	0.0	246.1439	0.4065	246.0388	0.00446
21	10.0512	0.0	0.0	206.460	0.0	0.0	216.5112	0.1747	216.4662	0.00446
22	9.7936	0.0	0.0	297.290	0.0	0.0	307.0836	0.1702	307.0399	0.00446
23	14.8240	0.0	0.0	649.010	0.0	0.0	663.8340	0.2557	663.7679	0.00446
24	6.9064	0.0	0.0	479.380	0.0	0.0	486.2864	0.1201	486.2556	0.00446
25	43.0839	0.0	0.0	3699.30	0.0	0.0	3742.3839	0.7488	3742.1917	0.00446
26	35.4174	0.0	0.0	7622.60	0.0	0.0	7658.0174	0.6110	7657.8594	0.00446
27	3.3786	0.0	0.0	9348.10	0.0	0.0	9351.50	0.0	9351.4635	0.00446

Table - 9

^{151}Eu

Statistical Level Scattering Matrices

$\sigma_{i \rightarrow i \leftarrow k}$

i ↓ / k →	0	1	2	3	4	5	6	7
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	.0676	.1552	0.0	0.0	0.0	0.0	0.0	0.0
5	1.2772	.8021	.0097	0.0	0.0	0.0	0.0	0.0
6	1.2488	1.1641	.2748	.0096	0.0	0.0	0.0	0.0
7	1.6692	.6831	.2353	.0769	.0311	.0136	.0040	0.0
8	1.4501	.3170	.1057	.0477	.0209	.0082	.0008	0.0
9	.9061	.3014	0.0	0.0	.0009	.0009	0.0	0.0
10	.4387	.2984	0.0	0.0	0.0	0.0	0.0	0.0
11	.0346	.0992	.0223	.0059	.0016	.0003	.0002	0.0

Table - 10

^{151}Eu

Statistical Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	.00004	.0020	.0176	.0488	.0832	.0629	.0389	.0135	.0040	.0015
2	.0029	.0497	.2092	.4806	.4422	.3091	.1156	.0354	.0103	.0030
3	.0185	.1403	.4942	.6005	.4991	.2077	.0672	.0201	.0047	.0012
4	.0543	.3254	.5535	.5704	.2712	.0940	.0290	.0069	.0015	.0004
5	.0002	.0061	.0449	.0712	.0472	.0205	.0058	.0014	.0003	.0001

n-2n Scattering Matrices

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	.0003	.0132	.1173	.3246	.5527	.4178	.2589	.0899	.0265	.0097
2	0.0	.0004	.0073	.0538	.1047	.1175	.0589	.0210	.0066	.0020

Table - 11

^{153}Eu

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	2.8503	0.4603	1.7790	0.0026	0.0055	0.0055	5.1032	0.0129	2.6015	0.8777
2	2.6144	2.0378	0.1940	0.0052	0.0016	0.0016	4.8546	0.0168	2.8495	0.7668
3	2.9259	2.2505	0.0	0.0119	0.0003	0.0003	5.1889	0.0237	3.1300	0.7014
4	3.9546	2.2671	0.0	0.0249	0.0	0.0	6.2466	0.0322	3.4332	0.7097
5	4.7325	2.4447	0.0	0.0583	0.0	0.0	7.2355	0.0387	4.2034	0.6404
6	4.4467	2.9162	0.0	0.1402	0.0	0.0	7.5031	0.0598	5.5897	0.4298
7	4.4787	3.2149	0.0	0.1989	0.0	0.0	7.8925	0.0763	7.4157	0.1054
8	5.2870	2.8449	0.0	0.4219	0.0	0.0	8.5538	0.0993	8.4650	0.0134
9	6.5709	2.1179	0.0	0.9700	0.0	0.0	9.6588	0.1242	9.5798	0.0652
10	9.2707	0.2011	0.0	1.5572	0.0	0.0	11.0290	0.1590	10.9259	0.0044
11	10.5305	0.0	0.0	2.6445	0.0	0.0	13.1750	0.1793	12.7615	0.0044
12	11.4588	0.0	0.0	4.7610	0.0	0.0	16.2198	0.1966	16.1630	0.0044
13	12.4167	0.0	0.0	5.8061	0.0	0.0	18.2228	0.2130	18.1381	0.0044
14	14.0890	0.0	0.0	9.8350	0.0	0.0	23.9240	0.2399	23.8310	0.0044
15	15.7864	0.0	0.0	16.4190	0.0	0.0	32.2054	0.2709	32.1090	0.0044
16	17.4250	0.0	0.0	26.8240	0.0	0.0	44.2490	0.2989	44.1510	0.0044
17	18.9361	0.0	0.0	43.0340	0.0	0.0	61.9701	0.3224	61.8700	0.0044
18	20.2506	0.0	0.0	67.8650	0.0	0.0	88.1156	0.3475	87.9810	0.0044
19	21.3255	0.0	0.0	104.6900	0.0	0.0	126.0155	0.3658	125.9130	0.0044
20	20.3561	0.0	0.0	152.0500	0.0	0.0	172.4061	0.3466	169.0930	0.0044
21	17.7910	0.0	0.0	217.430	0.0	0.0	235.2210	0.3053	222.0190	0.0044
22	9.3471	0.0	0.0	191.8500	0.0	0.0	201.1971	0.1603	196.4602	0.0044
23	15.3718	0.0	0.0	970.9300	0.0	0.0	986.3018	0.2617	973.9593	0.0044
24	2.0914	0.0	0.0	104.3300	0.0	0.0	106.4214	0.0359	106.0339	0.0044
25	3.6317	0.0	0.0	80.5000	0.0	0.0	84.1317	0.0623	84.0877	0.0044
26	3.8810	0.0	0.0	147.5600	0.0	0.0	151.4410	0.0661	151.4135	0.0044
27	4.7563	0.0	0.0	452.620	0.0	0.0	457.380	0.0	457.3554	0.0044

Table - 12

^{153}Eu

Discrete Level Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1.0926	.8274	.0978	0.0	0.0	0.0	0.0	0.0
6	1.3928	1.1287	.2978	.0958	.0028	0.0	0.0	0.0
7	1.7839	1.3110	.0249	.0574	.0258	.0095	.0023	0.0
8	.8570	1.3055	.4426	.1992	.0375	0.0	0.0	0.0
9	.1639	1.1259	.6232	.1689	.0283	.0061	.0004	0.0
10	0.0	0.0	.1349	.0753	.0167	.0033	.0003	0.0

Table - 13

^{153}Eu

Statistical Scattering Matrices

$\sigma_i \longrightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	0.0	.00009	.0039	.0309	.1118	.1382	.1161	.0486	.0158	.0061
2	0.0	.00009	.0066	.1258	.4429	.7336	.4673	.1888	.0632	.0201
3	0.0	0.0	.0025	.0733	.5218	.8093	.5299	.2290	.0647	.0201
4	0.0	0.0	.0006	.0676	.5054	.8172	.5837	.2155	.0591	.0186
5	0.0	0.0	0.0	0.0	.0078	.0938	.1701	.1050	.0378	.0136

n-2n Scattering Matrices

E ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	.0003	.0124	.1128	.3161	.5429	.4127	.2565	.0893	.0264	.0096
2	0.0	0.0	.0006	.0118	.0418	.0695	.0444	.0180	.0060	.0019

Table - 14

Mg

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	.719	.6324	.0223	.00030	.1543	.1757	1.703	.0431	1.169	.7428
2	.829	.7345	.0027	.00030	.0814	.0698	1.717	.0495	1.174	.6547
3	1.028	.8580	0.0	.00031	.0011	.0168	1.904	.0904	1.426	.4653
4	1.485	.6501	0.0	.00036	0.0	.0035	2.139	.1757	1.649	.3301
5	2.162	.3204	0.0	.00056	0.0	0.0	2.483	.1918	1.660	.3807
6	3.251	.0154	0.0	.00099	0.0	0.0	3.267	.2854	1.939	.4084
7	5.467	.0013	0.0	.00143	0.0	0.0	5.470	.4149	3.466	.3666
8	6.940	0.0	0.0	0.0	0.0	0.0	6.940	.6958	5.807	.1633
9	4.627	0.0	0.0	.00013	0.0	0.0	4.627	.5358	4.472	.0335
10	11.363	0.0	0.0	.00173	0.0	0.0	11.365	1.232	11.362	.0003
11	3.557	0.0	0.0	.00041	0.0	0.0	3.557	.3936	3.656	- .0277
12	4.090	0.0	0.0	.00094	0.0	0.0	4.091	.4314	3.978	.0277
13	3.334	0.0	0.0	.00016	0.0	0.0	3.334	.3516	3.242	.0277
14	3.367	0.0	0.0	.00020	0.0	0.0	3.367	.3524	3.274	.0277
15	3.385	0.0	0.0	.00028	0.0	0.0	3.385	.3570	3.291	.0277
16	3.393	0.0	0.0	.00039	0.0	0.0	3.393	.3578	3.299	.0277
17	3.399	0.0	0.0	.00056	0.0	0.0	3.400	.3558	3.306	.0277
18	3.400	0.0	0.0	.00083	0.0	0.0	3.401	.3586	3.307	.0277
19	3.399	0.0	0.0	.00122	0.0	0.0	3.400	.3584	3.306	.0277
20	3.398	0.0	0.0	.00179	0.0	0.0	3.400	.3557	3.306	.0277
21	3.398	0.0	0.0	.00264	0.0	0.0	3.401	.3584	3.307	.0277
22	3.396	0.0	0.0	.00390	0.0	0.0	3.400	.3581	3.306	.0277
23	3.394	0.0	0.0	.00574	0.0	0.0	3.400	.3552	3.306	.0277
24	3.392	0.0	0.0	.00841	0.0	0.0	3.400	.3578	3.306	.0277
25	3.384	0.0	0.0	.01229	0.0	0.0	3.396	.3569	3.302	.0277
26	3.373	0.0	0.0	.01803	0.0	0.0	3.390	.3531	3.297	.0277
27	3.337	0.0	0.0	.0630	0.0	0.0	3.400	0.0	3.308	.0277

Table - 15

Mg

Discrete Level Scattering Matrices

$\sigma_i \longrightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8
1	.0940	.1280	.0631	.0352	.0085	0.0	0.0	0.0	0.0
2	.1209	.2340	.1579	.0956	.0339	.0102	0.0	0.0	0.0
3	.1832	.3767	.1385	.0993	.0482	.0084	0.0	0.0	0.0
4	.0439	.4247	.1610	.0183	.0027	0.0	0.0	0.0	0.0
5	.0060	.1147	.1221	.0561	.0191	.0023	0.0	0.0	0.0
6	.0002	.0070	.0070	.0011	0.0	0.0	0.0	0.0	0.0
7	0.0	.0002	.0010	.0001	0.0	0.0	0.0	0.0	0.0

Table - 16

Mg

Statistical Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ \ k →	0	1	2	3	4	5	6	7	8	9	10
1	.0008	.0113	.0444	.0723	.0849	.0502	.0268	.0085	.0024	.0007	.0002
2	.0070	.0015	.0004	.0001	.0001	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	.0001	.0007	.0009	.0009	.0004	.0001	0.0	0.0	0.0	0.0

n, 2n Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ \ k →	0	1	2	3	4	5	6	7	8	9	10
1	0.0	0.0	0.0	0.0	.0010	.0042	.0081	.0056	.0024	.0008	.0002
2	0.0	0.0	0.0	0.0	0.0	.0002	.0008	.0009	.0005	.0002	0.0

Table - 17

Al

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	.6397	.8571	.0150	.00043	.0878	.1191	1.719	.0428	1.283	.6813
2	.8259	.8356	0.0	.00021	.0867	.0506	1.800	.0525	1.311	.5926
3	1.3675	.7668	0.0	0.0	.0283	.00072	2.163	.0949	1.412	.5495
4	2.1061	.5534	0.0	0.0	.0035	0.0	3.663	.1731	2.645	.4835
5	2.711	.2879	0.0	.00014	0.0	0.0	2.999	.2115	1.928	.3951
6	3.289	.0781	0.0	.00016	0.0	0.0	3.367	.2933	2.272	.3328
7	4.032	0.0	0.0	.00045	0.0	0.0	4.032	.3426	3.175	.2125
8	3.809	0.0	0.0	.00081	0.0	0.0	3.810	.3731	3.459	.0922
9	5.190	0.0	0.0	.00208	0.0	0.0	5.192	.5382	4.989	.0391
10	5.191	0.0	0.0	.00184	0.0	0.0	5.193	.4944	5.063	.02496
11	6.788	0.0	0.0	.00787	0.0	0.0	6.796	.6418	6.627	.02496
12	1.064	0.0	0.0	.00304	0.0	0.0	1.067	.1014	1.040	.02496
13	1.753	0.0	0.0	.01535	0.0	0.0	1.768	.1670	1.724	.02496
14	1.335	0.0	0.0	.00394	0.0	0.0	1.339	.1262	1.306	.02496
15	1.346	0.0	0.0	.00228	0.0	0.0	1.348	.1283	1.314	.02496
16	1.347	0.0	0.0	.00203	0.0	0.0	1.349	.1283	1.315	.02496
17	1.347	0.0	0.0	.00258	0.0	0.0	1.349	.1274	1.315	0.2496
18	1.347	0.0	0.0	.00328	0.0	0.0	1.350	.1284	1.316	.02496
19	1.347	0.0	0.0	.00450	0.0	0.0	1.351	.1283	1.317	.02496
20	1.347	0.0	0.0	.00661	0.0	0.0	1.354	.1274	1.320	.02496
21	1.347	0.0	0.0	.00972	0.0	0.0	1.357	.1284	1.323	.02496
22	1.347	0.0	0.0	.01425	0.0	0.0	1.361	.1283	1.327	.02496
23	1.347	0.0	0.0	.02091	0.0	0.0	1.368	.1274	1.334	.02496
24	1.347	0.0	0.0	.03068	0.0	0.0	1.378	.1284	1.344	.02496
25	1.347	0.0	0.0	.04498	0.0	0.0	1.392	.1283	1.358	.02496
26	1.347	0.0	0.0	.06612	0.0	0.0	1.413	.1274	1.379	.02496
27	1.511	0.0	0.0	0.232	0.0	0.0	1.743	0.0	1.705	.02496

Table - 18

Al

Discrete Level Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ / k →	0	1	2	3	4	5	6	7
1	.0179	.1645	.1953	.1826	.1924	.0780	.0170	.0094
2	.0090	.2344	.1803	.1837	.1034	.0403	.0031	0.0
3	.1223	.2819	.2299	.0959	.0318	.0049	0.0	0.0
4	.0810	.2375	.1219	.0893	.0219	.0017	0.0	0.0
5	.0274	.1524	.0990	.0064	.0026	0.0	0.0	0.0
6	0.0	.0179	.0469	.0110	.0021	0.0	0.0	0.0

Table - 19

Al

n, 2n Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8
1	0.0	0.0	.0002	.0013	.0039	.0043	.0034	.0014	.0005

Table - 20

Si

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	.722	.5903	.0321	.00052	.2474	.1768	1.768	.0388	1.239	.7333
2	.808	.6875	.0017	.00057	.2555	.1464	1.899	.0433	1.380	.6423
3	1.465	.7463	0.0	.00061	.0398	.0104	2.262	.1064	1.916	.5091
4	1.834	.5301	0.0	.00064	0.0	.00038	2.365	.1571	1.559	.4397
5	2.888	.1457	0.0	.00065	0.0	0.0	3.035	.2375	2.064	.3362
6	3.622	.00029	0.0	.00066	0.0	0.0	3.623	.2824	2.200	.3928
7	3.242	0.0	0.0	.00067	0.0	0.0	3.243	.2887	2.786	.1409
8	5.541	0.0	0.0	.00067	0.0	0.0	5.542	.5277	5.092	.0213
9	2.765	0.0	0.0	.00068	0.0	0.0	2.766	.2816	2.717	.0178
10	1.697	0.0	0.0	.00214	0.0	0.0	1.699	.1555	1.658	.0240
11	1.427	0.0	0.0	.00729	0.0	0.0	1.434	.1297	1.400	.0240
12	1.710	0.0	0.0	.00028	0.0	0.0	1.710	.1567	1.669	.0240
13	2.099	0.0	0.0	.00032	0.0	0.0	2.099	.1923	2.049	.0240
14	2.15	0.0	0.0	.00046	0.0	0.0	2.150	.1955	2.098	.0240
15	2.15	0.0	0.0	.00068	0.0	0.0	2.151	.1970	2.099	.0240
16	2.15	0.0	0.0	.00098	0.0	0.0	2.151	.1969	2.099	.0240
17	2.15	0.0	0.0	.00145	0.0	0.0	2.151	.1955	2.099	.0240
18	2.15	0.0	0.0	.00212	0.0	0.0	2.152	.1970	2.100	.0240
19	2.15	0.0	0.0	.00312	0.0	0.0	2.153	.1969	2.101	.0240
20	2.15	0.0	0.0	.00458	0.0	0.0	2.155	.1955	2.103	.0240
21	2.15	0.0	0.0	.00674	0.0	0.0	2.157	.1970	2.105	.0240
22	2.15	0.0	0.0	.00983	0.0	0.0	2.160	.1969	2.108	.0240
23	2.15	0.0	0.0	.01446	0.0	0.0	2.164	.1955	2.112	.0240
24	2.15	0.0	0.0	.02123	0.0	0.0	2.171	.1970	2.119	.0240
25	2.15	0.0	0.0	.03119	0.0	0.0	2.181	.1969	2.121	.0240
26	2.15	0.0	0.0	.04577	0.0	0.0	2.196	.1955	2.136	.0240
27	2.15	0.0	0.0	0.160	0.0	0.0	2.310	0.0	2.258	.0240

Table - 21

S1

Discrete Level Scattering Matrices

$$\sigma_{i \rightarrow i + k}$$

i ↓ \ k →	0	1	2	3	4	5	6	7
1	.0686	.1099	.0662	.0218	.0110	0.0	0.0	0.0
2	.0991	.2336	.0920	.0985	.0405	.0194	.0020	0.0
3	.1445	.4065	.1231	.0390	.0184	.0034	0.0	0.0
4	.0016	.2781	.2141	.0339	.0022	0.0	0.0	0.0
5	0.0	.0064	.0814	.0449	.0122	.0009	0.0	0.0

Table - 22

Si

Statistical Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9	10
1	0.0	.0001	.0043	.0266	.0811	.0898	.0704	.0282	.0090	.0026	.0007
2	0.0	.0004	.0040	.0186	.0270	.0252	.0113	.0038	.0011	.0003	.0001
3	0.0	.0002	.0014	.0030	.0036	.0019	.0007	.0002	.0001	0.0	0.0

n, 2n Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9	10
1	0.0	0.0	.0004	.0026	.0082	.0092	.0073	.0029	.0009	.0003	.0001
2	0.0	0.0	0.0	0.0	.0002	.0005	.0005	.0003	.0001	0.0	0.0

Table - 23

K

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	1.042	.424	.0012	0.0	.3746	.1285	1.971	.0578	1.328	.6168
2	1.402	.634	0.0	0.0	.3578	.1578	2.552	.0509	1.623	.6629
3	2.117	.615	0.0	0.0	.2999	.1360	3.168	.0817	1.820	.6367
4	3.015	.179	0.0	.00016	.1736	.0380	3.406	.1839	2.066	.4444
5	2.855	.028	0.0	.00027	.0561	.0021	2.941	.1705	2.001	.3291
6	2.419	.003	0.0	.00048	.00417	0.0	2.426	.1590	1.732	.2869
7	2.186	0.0	0.0	.00090	0.0	0.0	2.187	.1272	1.683	.2308
8	1.957	0.0	0.0	.00180	0.0	0.0	1.959	.1276	1.689	.1379
9	2.120	0.0	0.0	.00361	0.0	0.0	2.124	.1442	1.940	.0867
10	2.855	0.0	0.0	.00751	0.0	0.0	2.862	.1815	2.700	.0568
11	2.607	0.0	0.0	.01621	0.0	0.0	2.623	.1698	2.525	.0376
12	1.782	0.0	0.0	.01223	0.0	0.0	1.794	.1195	1.755	.0219
13	3.315	0.0	0.0	.03975	0.0	0.0	3.355	.2196	3.298	.0172
14	5.184	0.0	0.0	.2814	.00015	0.0	5.465	.3408	5.376	.0172
15	1.177	0.0	0.0	.00874	.00021	0.0	1.186	.0780	1.166	.0172
16	1.323	0.0	0.0	.01287	.00031	0.0	1.336	.0876	1.313	.0172
17	1.438	0.0	0.0	.01890	.00046	0.0	1.457	.0945	1.432	.0172
18	1.569	0.0	0.0	.02776	.00067	0.0	1.597	.1039	1.570	.0172
19	1.717	0.0	0.0	.04070	.00099	0.0	1.758	.1137	1.729	.0172
20	1.828	0.0	0.0	.05977	.00145	.00013	1.889	.1202	1.858	.0172
21	1.919	0.0	0.0	.08778	.00213	.00019	2.009	.1291	1.976	.0172
22	2.001	0.0	0.0	.1287	.00313	.00028	2.133	.1345	2.099	.0172
23	2.051	0.0	0.0	.1890	.00459	.00041	2.245	.1348	2.210	.0172
24	2.036	0.0	0.0	.2776	.00674	.00061	2.320	.1349	2.285	.0172
25	2.023	0.0	0.0	.4070	.0099	.00089	2.440	.1340	2.405	.0172
26	2.041	0.0	0.0	.5977	.01452	.00131	2.653	.1342	2.618	.0172
27	2.200	0.0	0.0	2.100	.0510	.0046	4.356	0.0	4.318	.0172

Table - 24

K

Discrete Level Scattering Matrices

$\sigma_i \rightarrow i + k$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	.0040	.0434	.0079	.0076	.0022	.0006	0.0	0.0	0.0
3	0.0	.1505	.2596	.1028	.0459	.0105	.0012	0.0	0.0	0.0
4	0.0	.0031	.0590	.0500	.0211	.0047	.0001	0.0	0.0	0.0

Table - 25

K

Statistical Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9	10
1	.0021	.0221	.0725	.1046	.1130	.0632	.0327	.0101	.0028	.0008	.0002
2	.0128	.0657	.1270	.1678	.1073	.0601	.0196	.0056	.0016	.0003	.0001
3	.0026	.0077	.0136	.0105	.0066	.0023	.0007	.0002	.0001	0.0	0.0
4	.0047	.0118	.0115	.0083	.0032	.0010	.0003	.0001	0.0	0.0	0.0
5	.0066	.0089	.0079	.0034	.0011	.0003	.0001	0.0	0.0	0.0	0.0
6	.0005	.0011	.0008	.0004	.0001	.0001	0.00	0.0	0.0	0.0	0.0

n, 2n Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9	10
1	0.0	0.0	.0001	.0002	.0004	.0003	.0002	.0001	—	—	—

Table - 26

C_8

Group	σ_e	σ_{in}	$\sigma_{n,2n}$	σ_c	$\sigma_{n,p}$	$\sigma_{n,\alpha}$	σ_t	σ_{er}	σ_{tr}	μ
1	.989	.3415	.00104	0.0	.3776	.18195	1.890	.0405	1.188	.7097
2	1.465	.4687	0.0	0.0	.6315	.24858	2.814	.0397	1.728	.7415
3	2.281	.3565	0.0	0.0	.5171	.21607	3.371	.0865	1.925	.6339
4	3.211	.0268	0.0	0.0	.2537	.09738	3.589	.2061	2.302	.4008
5	2.918	.0088	0.0	.00015	.0255	.01150	2.964	.1935	2.275	.2362
6	2.305	.0011	0.0	.00025	.0011	.00286	2.310	.1569	1.749	.2434
7	1.877	0.0	0.0	.00031	.00015	.00269	1.880	.1051	1.451	.2288
8	2.891	0.0	0.0	.00098	0.0	.00260	2.894	.1819	2.507	.1338
9	2.393	0.0	0.0	.00332	0.0	.00255	2.399	.1716	2.091	.1268
10	1.487	0.0	0.0	.00217	0.0	.00252	1.492	.0989	1.509	- .0117
11	1.800	0.0	0.0	.01764	0.0	.00251	1.820	.1193	1.848	- .0158
12	2.157	0.0	0.0	.01041	0.0	.0025	2.170	.1443	2.208	- .0176
13	2.384	0.0	0.0	.00164	0.0	.0025	2.388	.1599	2.406	- .0076
14	2.519	0.0	0.0	.00179	0.0	.0025	2.524	.1635	2.510	.0055
15	2.566	0.0	0.0	.00300	0.0	.0025	2.572	.1668	2.543	.0115
16	2.568	0.0	0.0	.00279	0.0	.0025	2.574	.1664	2.537	.0143
17	2.568	0.0	0.0	.00394	0.0	.0025	2.575	.1649	2.535	.0156
18	2.568	0.0	0.0	.00573	0.0	.0025	2.577	.1661	2.532	.0163
19	2.568	0.0	0.0	.00839	0.0	.0025	2.579	.1660	2.537	.0165
20	2.568	0.0	0.0	.01229	0.0	.0025	2.583	.1648	2.541	.0167
21	2.568	0.0	0.0	.01843	0.0	.0025	2.589	.1661	2.546	.0167
22	2.618	0.0	0.0	.02728	0.0	.0025	2.648	.1692	2.608	.0168
23	2.698	0.0	0.0	.03900	0.0	.0025	2.740	.1731	2.695	.0168
24	2.778	0.0	0.0	.05699	0.0	.0025	2.838	.1797	2.791	.0168
25	2.856	0.0	0.0	.0837	0.0	.0025	2.943	.1846	2.895	.0168
26	2.919	0.0	0.0	.1234	0.0	.0025	3.045	.1893	2.996	.0168
27	2.987	0.0	0.0	.430	0.0	.0025	3.420	0.0	3.370	.0168

Table - 27

Ca

Discrete Level Scattering Matrices

$\sigma_{i \rightarrow i+k}$

i ↓ / k →	0	1	2	3	4	5	6	7
1	.0100	.0998	.0871	.0476	.0125	0.0	0.0	0.0
2	.0048	.0764	.1466	.1270	.0633	.0253	.0037	0.0
3	.0016	.0214	.1282	.1091	.0721	.0219	.0019	0.0
4	.0012	.0056	.0004	.0088	.0079	.0029	0.0	0.0
5	0.0	.0037	.0037	.0014	0.0	0.0	0.0	0.0
6	0.0	0.0	.0003	.0006	.0002	0.0	0.0	0.0

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2 .1 .78

Table - 28

Ca

Statistical Scattering Matrices

$\sigma_{i \rightarrow i + k}$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	.0005	.0055	.0179	.0026	.0279	.0156	.0081	.0025	.0007	.0002
2	.0005	.0025	.0081	.0064	.0041	.0023	.0007	.0002	0.0	0.0

n, 2n Scattering Matrices

$\sigma_{i \rightarrow i + k}$

i ↓ / k →	0	1	2	3	4	5	6	7	8	9
1	0.0	0.0	.0001	.0002	.0003	.0002	.0002	0.0	0.0	0.0