Radiation Physics Note 43

RESPONSE MATRICES FOR POLYETHYLENE BONNER SPHERES OF DENSITY 0.92 g/cm^3

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Introduction

Sets of Bonner spheres are used at Fermilab to determine neutron energy spectra. The laboratory presently has two sets of spheres, one of "high density" (0.95 g/cm^3) and one of "low density" (0.92 g/cm^3).

It has been customary, with other experimenters, to use only high density polyethylene for Bonner spheres. Consequently, response functions for Bonner detectors have been calculated by Ref. 1 and others assuming 0.95 g/cm^3 density. There are no calculated response matrices available in the literature for 0.92 g/cm^3 spheres.

The purpose of this report is to obtain response matrices for 0.92 g/cm^3 density Bonner spheres. These matrices may be used in neutron spectra unfolding codes to analyze data taken with low density spheres.

Response Matrices for Bonner Detectors

Fermilab uses either 8x8 mm LiI phoswich detectors or stacks of LiF TLD's in measurements using Bonner spheres. The energy groups and response matrices (from Ref. 1) for 8x8 mm and 4x4 mm (approximate size of TLD stacks) detectors used in connection with 0.95 g/cm^3 density polyethylene are listed in Tables 1, 2 and 3 for easy reference. They are presently used in unfolding codes at Fermilab.

Reference 1 also contains response matrices corresponding to 0.5 x 0.5 inch LiI computed for 0.90, 0.95, and 1.0 g/cm^3 densities. Comparison is made there between a response matrix computed with transport codes for 0.95 g/cm^3 density and a matrix determined by linear interpolation between the .90 and 1.0 g/cm^3 density matrices. Interpolated and computed values generally differ by less than 1% but in some cases, notably at low energies with the 12 inch sphere, corresponding matrix elements differ by as much as 6%.

We obtained approximate response matrix elements for 0.92 g/cm^3 density by interpolating between the 0.90 and 0.95 g/cm^3 density 0.5 x 0.5 inch LiI matrix elements of Ref. 1 as follows:

$$R92_{ij} = R90_{ij} + 0.4\ (R95_{ij} - R90_{ij}) \qquad (1)$$

where $R90_{ij}$, $R92_{ij}$, and $R95_{ij}$ are the ij elements of the 0.90, 0.92, and 0.95 g/cm^3 matrices, respectively.

$$\text{Ratios } R_{ij} = R92_{ij}/R95_{ij} \qquad (2)$$

are used to calculate .92 g/cm^3 density matrix elements from 0.95 g/cm^3 elements for any detector size used with the spheres. Those ratios are listed in Table 4. A given element in the 0.92 g/cm^3 density matrix is obtained by multiplying the corresponding element in the 0.95 density matrix by the appropriate ratio factor in the array of Table 4.

The 0.92 g/cm^3 density response matrices for 4x4 mm and 8x8 mm LiI detectors obtained by the above interpolation method are shown in Tables 5 and 6. Errors in the matrix elements of Tables 5 and 6 are expected to be less than 3% at most.

A sample comparison plot of 0.92 and 0.95 g/cm^3 density response matrices for the 3 inch sphere and 8x8 mm detector are shown in Fig. 1. The difference in magnitude of the two curves varies noticeably over the energy range, as expected. It is evident, too, that the two response function curves cross at about 1 keV energy. This is consistent with Table 4 and the .5 x .5 inch response matrices of Ref. 1.

Summary

In the absence of available 0.92 g/cm^3 density response functions, approximate response matrices for 4x4 mm and 8x8 mm LiI corresponding to that density were calculated by linear interpolation from published 0.5 x 0.5 inch response functions.

References

1. Sanna, R.S., 1973, "Thirty One Group Response Matrices for the Multisphere Neutron Spectrometer Over the Energy Range Thermal to 400 GeV," U.S. AEC, HASL-267.

Table Titles

Table 1 Energies and Energy Increments Computed from HASL-267, Table 1.

Table 2 Response Matrix for 4x4 mm LiI detector and 0.95 gm/cm^3 density spheres.

Table 3 Response Matrix for 8x8 mm LiI detector and 0.95 gm/cm^3 density spheres.

Table 4 Ratios obtained from interpolation calculation. Ratio values times 0.95 g/cm^3 density matrix elements yield corresponding 0.92 g/cm^3 density matrix elements.

Table 5 Response Matrix for 4x4 mm LiI detector and 0.92 g/cm^3 density spheres.

Table 6 Response Matrix for 8x8 mm LiI detector and 0.92 g/cm^3 density spheres.

Figure Caption

Figure 1 Comparison of 0.92 and 0.95 g/cm^3 density response functions for 3 inch sphere and 8x8 mm LiI detector.

Table 1

ENERGY AND ENERGY INCREMENTS FOR
RESPONSE MATRICES. HASL-267.

GRP	ENERGY	DE
1	THERMAL	.4040E-06
2	.5316E-06	.2686E-06
3	.9932E-06	.7624E-06
4	.2102E-05	.1614E-05
5	.4451E-05	.3417E-05
6	.9423E-05	.7234E-05
7	.1995E-04	.1531E-04
8	.4223E-04	.3242E-04
9	.8941E-04	.6866E-04
10	.1893E-03	.1453E-03
11	.4041E-03	.3175E-03
12	.8554E-03	.6411E-03
13	.1796E-02	.1379E-02
14	.3802E-02	.2918E-02
15	.8048E-02	.6179E-02
16	.1704E-01	.1308E-01
17	.3607E-01	.2768E-01
18	.7635E-01	.5863E-01
19	.1576E+00	.1126E+00
20	.3176E+00	.2271E+00
21	.6395E+00	.4564E+00
22	.1287E+01	.9198E+00
23	.2593E+01	.1852E+01
24	.5221E+01	.3729E+01
25	.1051E+02	.7512E+01
26	.1962E+02	.1089E+02
27	.3395E+02	.1884E+02
28	.5873E+02	.3260E+02
29	.1016E+03	.5635E+02
30	.1758E+03	.9760E+02
31	.3041E+03	.1688E+03

1 Table 2

RESPONSE MATRIX TAKEN FROM HASL-267.

4X4 MM DETECTOR .95 DENSITY

GRP	BARE	2 INCH	3 INCH	5 INCH	8 INCH	10 INCH	12 INCH	18 INCH	CADMIUM
1	1.6854E-01	1.2852E-01	9.7515E-02	4.7543E-02	1.2653E-02	4.8054E-03	1.7332E-03	4.2525E-05	5.0000E-06
2	1.1327E-01	2.6279E-01	2.1168E-01	1.0261E-01	2.6903E-02	1.0161E-02	3.6564E-03	9.2207E-05	7.0280E-02
3	9.4778E-02	2.8930E-01	2.5294E-01	1.2606E-01	3.2995E-02	1.2442E-02	4.4758E-03	1.1514E-04	8.6417E-02
4	7.4135E-02	2.9784E-01	2.8439E-01	1.4762E-01	3.8738E-02	1.4594E-02	5.2508E-03	1.3778E-04	7.2117E-02
5	5.6322E-02	2.9081E-01	3.0303E-01	1.6529E-01	4.3653E-02	1.6441E-02	5.9170E-03	1.5819E-04	5.5264E-02
6	4.1793E-02	2.7498E-01	3.1239E-01	1.8023E-01	4.8075E-02	1.8107E-02	6.5193E-03	1.7746E-04	4.1098E-02
7	3.0286E-02	2.5451E-01	3.1486E-01	1.9308E-01	5.2201E-02	1.9669E-02	7.0849E-03	1.9626E-04	2.9232E-02
8	2.1592E-02	2.3206E-01	3.1219E-01	2.0421E-01	5.6152E-02	2.1176E-02	7.6313E-03	2.1502E-04	2.1219E-02
9	1.5240E-02	2.0928E-01	3.0564E-01	2.1382E-01	6.0000E-02	2.2657E-02	8.1696E-03	2.3401E-04	1.3879E-02
10	1.0811E-02	1.8717E-01	2.9629E-01	2.2211E-01	6.3817E-02	2.4144E-02	8.7115E-03	2.5357E-04	1.0500E-02
11	7.6454E-03	1.6634E-01	2.8493E-01	2.2916E-01	6.7632E-02	2.5652E-02	9.2632E-03	2.7387E-04	7.4290E-03
12	5.2735E-03	1.4707E-01	2.7216E-01	2.3497E-01	7.1450E-02	2.7190E-02	9.8278E-03	2.9500E-04	5.1560E-03
13	3.6579E-03	1.2949E-01	2.5862E-01	2.3989E-01	7.5388E-02	2.8809E-02	1.0425E-02	3.1762E-04	3.5750E-03
14	2.5750E-03	1.1357E-01	2.4477E-01	2.4427E-01	7.9611E-02	3.0582E-02	1.1083E-02	3.4271E-04	2.5150E-03
15	1.9348E-03	9.9158E-02	2.3095E-01	2.4873E-01	8.4475E-02	3.2668E-02	1.1862E-02	3.7243E-04	1.8900E-03
16	1.4500E-03	8.5947E-02	2.1740E-01	2.5440E-01	9.0743E-02	3.5413E-02	1.2893E-02	4.1165E-04	1.4150E-03
17	1.1018E-03	7.3447E-02	2.0392E-01	2.6292E-01	9.9956E-02	3.9555E-02	1.4468E-02	4.7145E-04	1.0750E-03
18	8.6945E-04	6.0893E-02	1.8931E-01	2.7627E-01	1.1537E-01	4.6842E-02	1.7308E-02	5.8120E-04	8.4700E-04
19	1.1751E-03	4.8106E-02	1.7119E-01	2.9329E-01	1.4143E-01	6.0500E-02	2.2973E-02	8.1618E-04	1.1460E-03
20	1.8542E-03	3.5256E-02	1.4577E-01	3.0607E-01	1.8344E-01	8.7274E-02	3.5767E-02	1.4869E-03	1.8080E-03
21	4.4492E-04	2.2515E-02	1.1167E-01	2.9930E-01	2.3996E-01	1.3148E-01	6.5539E-02	4.2358E-03	4.3400E-04
22	2.7026E-04	1.3117E-02	7.8327E-02	2.7672E-01	3.1410E-01	2.2464E-01	1.3709E-01	1.9273E-02	2.6400E-04
23	1.7899E-04	6.3270E-03	4.3506E-02	1.9417E-01	2.9716E-01	2.5929E-01	1.9443E-01	5.3320E-02	1.7600E-04
24	1.0212E-04	2.8111E-03	2.1791E-02	1.2033E-01	2.4234E-01	2.5271E-01	2.2732E-01	1.1088E-01	1.0100E-04
25	5.0065E-05	1.1240E-03	9.5620E-03	6.2602E-02	1.5676E-01	1.8753E-01	1.9337E-01	1.4300E-01	4.9000E-05
26	4.5946E-05	5.6625E-04	4.6141E-03	3.0087E-02	7.7386E-02	9.5157E-02	1.0138E-01	8.4305E-02	4.6000E-05
27	3.0015E-05	3.3619E-04	2.7406E-03	1.8369E-02	4.9672E-02	6.3345E-02	7.0151E-02	6.6262E-02	3.0000E-05
28	1.8732E-05	2.2399E-04	1.8495E-03	1.2700E-02	3.5823E-02	4.7160E-02	5.4066E-02	5.7515E-02	1.9000E-05
29	1.2187E-05	1.7340E-04	1.4579E-03	1.0216E-02	2.9912E-02	4.0501E-02	4.7852E-02	5.6262E-02	1.2000E-05
30	7.9545E-06	1.4230E-04	1.2418E-03	9.0718E-03	2.7837E-02	3.8754E-02	4.7023E-02	5.9752E-02	8.0000E-06
31	4.6976E-06	1.2274E-04	1.0990E-03	8.1887E-03	2.5791E-02	3.6530E-02	4.5101E-02	6.0432E-02	5.0000E-06

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Table 3

RESPONSE MATRIX TAKEN FROM HASL-267.

8X8 MM DETECTOR .95 DENSITY

GRP	BARE	2 INCH	3 INCH	5 INCH	8 INCH	10 INCH	12 INCH	18 INCH
1	7.2354E-01	4.4430E-01	3.3029E-01	1.5980E-01	4.2455E-02	1.6092E-02	5.8542E-03	1.9493E-04
2	6.0763E-01	9.1903E-01	7.1837E-01	3.4491E-01	9.0270E-02	3.4030E-02	1.2334E-02	4.1419E-04
3	5.4393E-01	1.0248E+00	8.6126E-01	4.2383E-01	1.1071E-01	4.1671E-02	1.5087E-02	5.1052E-04
4	4.5725E-01	1.0699E+00	9.7249E-01	4.9656E-01	1.2998E-01	4.8884E-02	1.7688E-02	6.0329E-04
5	3.8739E-01	1.0590E+00	1.0411E+00	5.5632E-01	1.4648E-01	5.5072E-02	1.9920E-02	6.8469E-04
6	2.8685E-01	1.0143E+00	1.0786E+00	6.0709E-01	1.6132E-01	6.0657E-02	2.1936E-02	7.5964E-04
7	2.1603E-01	9.4994E-01	1.0926E+00	6.5103E-01	1.7517E-01	6.5893E-02	2.3827E-02	8.3118E-04
8	1.5878E-01	8.7535E-01	1.0885E+00	6.8938E-01	1.8845E-01	7.0944E-02	2.5653E-02	9.0127E-04
9	1.1463E-01	7.9678E-01	1.0706E+00	7.2275E-01	2.0139E-01	7.5909E-02	2.7451E-02	9.7113E-04
10	8.2564E-02	7.1846E-01	1.0424E+00	7.5183E-01	2.1423E-01	8.0897E-02	2.9260E-02	1.0422E-03
11	5.8971E-02	6.4301E-01	1.0065E+00	7.7682E-01	2.2709E-01	8.5959E-02	3.1102E-02	1.1151E-03
12	4.1096E-02	5.7195E-01	9.6496E-01	7.9777E-01	2.3996E-01	9.1119E-02	3.2988E-02	1.1902E-03
13	2.8730E-02	5.0620E-01	9.2008E-01	8.1576E-01	2.5326E-01	9.6553E-02	3.4982E-02	1.2702E-03
14	2.0310E-02	4.4594E-01	8.7350E-01	8.3198E-01	2.6754E-01	1.0251E-01	3.7180E-02	1.3585E-03
15	1.5303E-02	3.9089E-01	8.2658E-01	8.4863E-01	2.8401E-01	1.0952E-01	3.9782E-02	1.4630E-03
16	1.1498E-02	3.4006E-01	7.8024E-01	8.6961E-01	3.0526E-01	1.1875E-01	4.3232E-02	1.6013E-03
17	8.7511E-03	2.9165E-01	7.3388E-01	9.0069E-01	3.3652E-01	1.3268E-01	4.8502E-02	1.8123E-03
18	6.9113E-03	2.4274E-01	6.8326E-01	9.4898E-01	3.8894E-01	1.5722E-01	5.8017E-02	2.1983E-03
19	9.3027E-03	1.9307E-01	6.1980E-01	1.0107E+00	4.7788E-01	2.0335E-01	7.7027E-02	3.0143E-03
20	1.4685E-02	1.4402E-01	5.3013E-01	1.0587E+00	6.2211E-01	2.9421E-01	1.2013E-01	5.3011E-03
21	3.5567E-03	9.2192E-02	4.0714E-01	1.0387E+00	8.1749E-01	4.6113E-01	2.2104E-01	1.4569E-03
22	2.1546E-03	5.4062E-02	2.8617E-01	9.6275E-01	1.0746E+00	7.6472E-01	4.6493E-01	6.5336E-03
23	1.4310E-03	2.6362E-02	1.5930E-01	6.7653E-01	1.0193E+00	8.8557E-01	6.6190E-01	1.8064E-01
24	8.1679E-04	1.1865E-02	7.9972E-02	4.1967E-01	8.3256E-01	8.6483E-01	7.7570E-01	3.7619E-01
25	4.0010E-04	4.8064E-03	3.5168E-02	2.1846E-01	5.3903E-01	6.4242E-01	6.6063E-01	4.8565E-01
26	3.6683E-04	2.4879E-03	1.7041E-02	1.0505E-01	2.6613E-01	3.2605E-01	3.4647E-01	2.8640E-01
27	2.4014E-04	1.4920E-03	1.0141E-02	6.4161E-02	1.7085E-01	2.1710E-01	2.3979E-01	2.2516E-01
28	1.5034E-04	9.9289E-04	6.8447E-03	4.4364E-02	1.2323E-01	1.6165E-01	1.8484E-01	1.9548E-01
29	9.7882E-05	7.6236E-04	5.3868E-03	3.5679E-02	1.0290E-01	1.3883E-01	1.6360E-01	1.9124E-01
30	6.3898E-05	6.1803E-04	4.5805E-03	3.1676E-02	9.5759E-02	1.3284E-01	1.6078E-01	2.0311E-01
31	3.7765E-05	5.2507E-04	4.0441E-03	2.8583E-02	8.8714E-02	1.2521E-01	1.5420E-01	2.0542E-01

Table 4 RESPONSE MATRIX ELEMENT RATIOS R92/R95

GRP	2 in.	3 in.	5 in.	8 in.	10 in.	12 in.	18 in.
1	1.0277E+00	1.0414E+00	1.0788E+00	1.1442E+00	1.1918E+00	1.2478E+00	1.5964E+00
2	1.0224E+00	1.0415E+00	1.0801E+00	1.1454E+00	1.1928E+00	1.2481E+00	1.5867E+00
3	1.0168E+00	1.0385E+00	1.0799E+00	1.1456E+00	1.1931E+00	1.2481E+00	1.5800E+00
4	1.0115E+00	1.0348E+00	1.0792E+00	1.1458E+00	1.1933E+00	1.2479E+00	1.5736E+00
5	1.0066E+00	1.0307E+00	1.0780E+00	1.1458E+00	1.1934E+00	1.2477E+00	1.5676E+00
6	1.0017E+00	1.0265E+00	1.0764E+00	1.1457E+00	1.1935E+00	1.2475E+00	1.5617E+00
7	9.9696E-01	1.0221E+00	1.0743E+00	1.1455E+00	1.1935E+00	1.2473E+00	1.5562E+00
8	9.9214E-01	1.0176E+00	1.0721E+00	1.1452E+00	1.1935E+00	1.2472E+00	1.5507E+00
9	9.8729E-01	1.0130E+00	1.0694E+00	1.1447E+00	1.1934E+00	1.2470E+00	1.5456E+00
10	9.8244E-01	1.0084E+00	1.0665E+00	1.1441E+00	1.1933E+00	1.2468E+00	1.5404E+00
11	9.7757E-01	1.0038E+00	1.0635E+00	1.1433E+00	1.1931E+00	1.2466E+00	1.5354E+00
12	9.7266E-01	9.9926E-01	1.0585E+00	1.1423E+00	1.1929E+00	1.2464E+00	1.5306E+00
13	9.6773E-01	9.9462E-01	1.0567E+00	1.1411E+00	1.1925E+00	1.2461E+00	1.5259E+00
14	9.6269E-01	9.8999E-01	1.0531E+00	1.1396E+00	1.1920E+00	1.2459E+00	1.5212E+00
15	9.5756E-01	9.8522E-01	1.0491E+00	1.1379E+00	1.1913E+00	1.2456E+00	1.5164E+00
16	9.5258E-01	9.8006E-01	1.0447E+00	1.1356E+00	1.1904E+00	1.2451E+00	1.5112E+00
17	9.4603E-01	9.7417E-01	1.0392E+00	1.1323E+00	1.1888E+00	1.2445E+00	1.5049E+00
18	9.3888E-01	9.6688E-01	1.0318E+00	1.1267E+00	1.1856E+00	1.2429E+00	1.4962E+00
19	9.3165E-01	9.5795E-01	1.0217E+00	1.1166E+00	1.1778E+00	1.2378E+00	1.4827E+00
20	9.2724E-01	9.4778E-01	1.0081E+00	1.0987E+00	1.1597E+00	1.2214E+00	1.4546E+00
21	9.1654E-01	9.3551E-01	9.9168E-01	1.0727E+00	1.1271E+00	1.1831E+00	1.3823E+00
22	9.0821E-01	9.2259E-01	9.7307E-01	1.0415E+00	1.0843E+00	1.1269E+00	1.2617E+00
23	9.0427E-01	9.1261E-01	9.5748E-01	1.0157E+00	1.0493E+00	1.0809E+00	1.1725E+00
24	9.0219E-01	9.0409E-01	9.4350E-01	9.9321E-01	1.0196E+00	1.0427E+00	1.1040E+00
25	9.0155E-01	8.9759E-01	9.3254E-01	9.7615E-01	9.9783E-01	1.0157E+00	1.0591E+00
26	9.0166E-01	8.9810E-01	9.3193E-01	9.7326E-01	9.9313E-01	1.0091E+00	1.0462E+00
27	9.0036E-01	8.9704E-01	9.2975E-01	9.6904E-01	9.8736E-01	1.0016E+00	1.0328E+00
28	9.0304E-01	8.9675E-01	9.2809E-01	9.6548E-01	9.8231E-01	9.9491E-01	1.0202E+00
29	9.1249E-01	8.9811E-01	9.2681E-01	9.6238E-01	9.7792E-01	9.8918E-01	1.0100E+00
30	9.2954E-01	9.0611E-01	9.2494E-01	9.5908E-01	9.7388E-01	9.8433E-01	1.0026E+00
31	9.5085E-01	9.0872E-01	9.2488E-01	9.5730E-01	9.7139E-01	9.8120E-01	9.9755E-01

Table 5 HASL-267 RESPONSE MATRIX MODIFIED FOR DIFFERENT SPHERE DENSITY.

4X4 MM DETECTOR .92 DENSITY

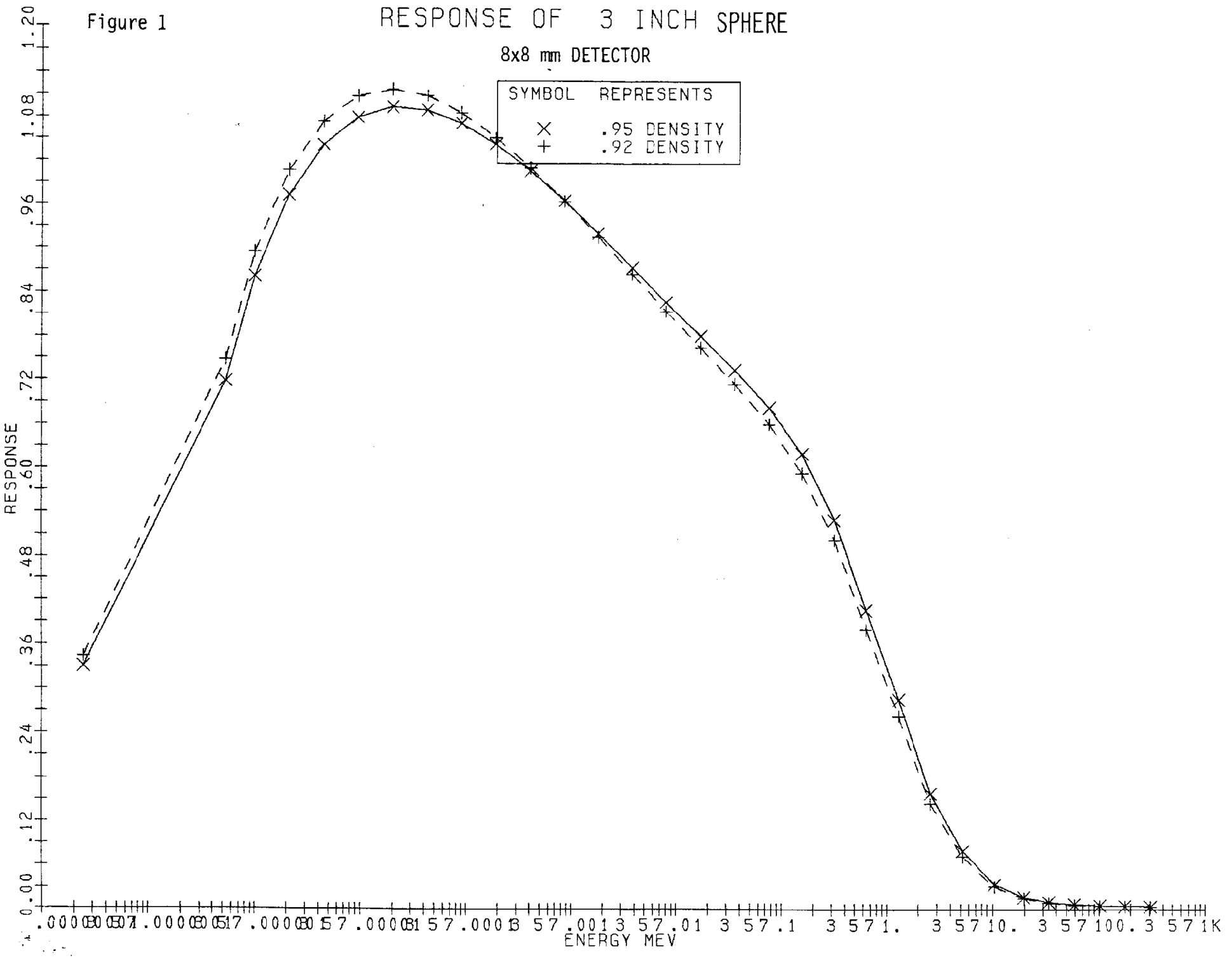
GRP	BARE	2 INCH	3 INCH	5 INCH	8 INCH	10 INCH	12 INCH	18 INCH
1	1.6854E-01	1.3208E-01	1.0156E-01	5.1290E-02	1.4478E-02	5.7272E-03	2.1627E-03	6.7886E-05
2	1.1327E-01	2.6867E-01	2.2047E-01	1.1083E-01	3.0814E-02	1.2120E-02	4.5636E-03	1.4630E-04
3	9.4778E-02	2.9417E-01	2.6267E-01	1.3614E-01	3.7800E-02	1.4845E-02	5.5860E-03	1.8192E-04
4	7.4135E-02	3.0126E-01	2.9428E-01	1.5931E-01	4.4387E-02	1.7416E-02	6.5525E-03	2.1681E-04
5	5.6322E-02	2.9272E-01	3.1234E-01	1.7818E-01	5.0017E-02	1.9621E-02	7.3828E-03	2.4798E-04
6	4.1793E-02	2.7546E-01	3.2066E-01	1.9399E-01	5.5078E-02	2.1610E-02	8.1330E-03	2.7715E-04
7	3.0286E-02	2.5374E-01	3.2182E-01	2.0743E-01	5.9796E-02	2.3475E-02	8.8372E-03	3.0541E-04
8	2.1592E-02	2.3024E-01	3.1768E-01	2.1893E-01	6.4304E-02	2.5273E-02	9.5175E-03	3.3343E-04
9	1.5240E-02	2.0662E-01	3.0961E-01	2.2866E-01	6.8682E-02	2.7039E-02	1.0187E-02	3.6167E-04
10	1.0811E-02	1.8388E-01	2.9879E-01	2.3688E-01	7.3010E-02	2.8811E-02	1.0861E-02	3.9060E-04
11	7.6454E-03	1.6261E-01	2.8602E-01	2.4371E-01	7.7321E-02	3.0606E-02	1.1547E-02	4.2050E-04
12	5.2735E-03	1.4305E-01	2.7196E-01	2.4871E-01	8.1614E-02	3.2434E-02	1.2249E-02	4.5153E-04
13	3.6579E-03	1.2531E-01	2.5723E-01	2.5350E-01	8.6024E-02	3.4354E-02	1.2991E-02	4.8465E-04
14	2.5755E-03	1.0933E-01	2.4232E-01	2.5725E-01	9.0727E-02	3.6454E-02	1.3808E-02	5.2134E-04
15	1.9348E-03	9.4949E-02	2.2754E-01	2.6095E-01	9.6123E-02	3.8919E-02	1.4775E-02	5.6476E-04
16	1.4500E-03	8.1871E-02	2.1306E-01	2.6577E-01	1.0305E-01	4.2155E-02	1.6053E-02	6.2207E-04
17	1.1018E-03	6.9483E-02	1.9865E-01	2.7323E-01	1.1318E-01	4.7024E-02	1.8005E-02	7.0948E-04
18	8.6945E-04	5.7171E-02	1.8304E-01	2.8506E-01	1.2998E-01	5.5534E-02	2.1511E-02	8.6957E-04
19	1.1751E-03	4.4818E-02	1.6399E-01	2.9964E-01	1.5791E-01	7.1258E-02	2.8436E-02	1.2102E-03
20	1.8542E-03	3.2691E-02	1.3816E-01	3.0856E-01	2.0155E-01	1.0121E-01	4.3685E-02	2.1628E-03
21	4.4492E-04	2.0636E-02	1.0447E-01	2.9681E-01	2.5742E-01	1.4820E-01	7.7541E-02	5.8552E-03
22	2.7026E-04	1.1913E-02	7.2263E-02	2.6927E-01	3.2712E-01	2.4359E-01	1.5448E-01	2.4317E-02
23	1.7899E-04	5.7213E-03	3.9704E-02	1.8591E-01	3.0182E-01	2.7208E-01	2.1016E-01	6.2516E-02
24	1.0212E-04	2.5362E-03	1.9701E-02	1.1353E-01	2.4069E-01	2.5766E-01	2.3704E-01	1.2241E-01
25	5.0065E-05	1.0133E-03	8.5828E-03	5.8379E-02	1.5302E-01	1.8712E-01	1.9641E-01	1.5145E-01
26	4.5946E-05	5.1056E-04	4.1439E-03	2.8039E-02	7.5317E-02	9.4504E-02	1.0230E-01	8.8199E-02
27	3.0015E-05	3.0269E-04	2.4584E-03	1.7079E-02	4.8134E-02	6.2544E-02	7.0263E-02	6.8432E-02
28	1.8732E-05	2.0227E-04	1.6585E-03	1.1787E-02	3.4587E-02	4.6326E-02	5.3791E-02	5.8676E-02
29	1.2187E-05	1.5823E-04	1.3094E-03	9.4682E-03	2.8787E-02	3.9607E-02	4.7334E-02	5.6824E-02
30	7.9545E-06	1.3227E-04	1.1252E-03	8.3909E-03	2.6698E-02	3.7742E-02	4.6286E-02	5.9907E-02
31	4.6976E-06	1.1671E-04	9.9868E-04	7.5736E-03	2.4690E-02	3.5485E-02	4.4253E-02	6.0284E-02

Table 6 HASL-267 RESPONSE MATRIX MODIFIED FOR DIFFERENT SPHERE DENSITY.

8X8 MM DETECTOR .92 DENSITY

GRP	BARE	2 INCH	3 INCH	5 INCH	8 INCH	10 INCH	12 INCH	18 INCH
1	7.2354E-01	4.5662E-01	3.4398E-01	1.7239E-01	4.8578E-02	1.9179E-02	7.3048E-03	3.1118E-04
2	6.0763E-01	9.3960E-01	7.4821E-01	3.7254E-01	1.0339E-01	4.0592E-02	1.5394E-02	6.5718E-04
3	5.4393E-01	1.0421E+00	8.9438E-01	4.5771E-01	1.2683E-01	4.9719E-02	1.8829E-02	8.0661E-04
4	4.5725E-01	1.0822E+00	1.0063E+00	5.3588E-01	1.4893E-01	5.8336E-02	2.2073E-02	9.4933E-04
5	3.8739E-01	1.0660E+00	1.0731E+00	5.9970E-01	1.6784E-01	6.5725E-02	2.4855E-02	1.0733E-03
6	2.8685E-01	1.0161E+00	1.1071E+00	6.5345E-01	1.8482E-01	7.2392E-02	2.7366E-02	1.1864E-03
7	2.1603E-01	9.4705E-01	1.1167E+00	6.9942E-01	2.0066E-01	7.8645E-02	2.9720E-02	1.2935E-03
8	1.5878E-01	8.6847E-01	1.1077E+00	7.3906E-01	2.1581E-01	8.4670E-02	3.1994E-02	1.3976E-03
9	1.1463E-01	7.8665E-01	1.0845E+00	7.7292E-01	2.3053E-01	9.0590E-02	3.4231E-02	1.5009E-03
10	8.2564E-02	7.0584E-01	1.0512E+00	8.0182E-01	2.4509E-01	9.6534E-02	3.6481E-02	1.6054E-03
11	5.8971E-02	6.2859E-01	1.0104E+00	8.2615E-01	2.5962E-01	1.0256E-01	3.8771E-02	1.7121E-03
12	4.1096E-02	5.5631E-01	9.6424E-01	8.4441E-01	2.7410E-01	1.0869E-01	4.1115E-02	1.8217E-03
13	2.8730E-02	4.8986E-01	9.1513E-01	8.6204E-01	2.8899E-01	1.1514E-01	4.3592E-02	1.9382E-03
14	2.0310E-02	4.2930E-01	8.6475E-01	8.7617E-01	3.0490E-01	1.2219E-01	4.6322E-02	2.0666E-03
15	1.5303E-02	3.7430E-01	8.1436E-01	8.9033E-01	3.2317E-01	1.3048E-01	4.9551E-02	2.2185E-03
16	1.1498E-02	3.2393E-01	7.6468E-01	9.0847E-01	3.4665E-01	1.4136E-01	5.3829E-02	2.4198E-03
17	8.7511E-03	2.7591E-01	7.1492E-01	9.3603E-01	3.8103E-01	1.5773E-01	6.0359E-02	2.7273E-03
18	6.9113E-03	2.2790E-01	6.6063E-01	9.7919E-01	4.3821E-01	1.8639E-01	7.2107E-02	3.2890E-03
19	9.3027E-03	1.7987E-01	5.9374E-01	1.0326E+00	5.3358E-01	2.3951E-01	9.5346E-02	4.4693E-03
20	1.4685E-02	1.3354E-01	5.0245E-01	1.0673E+00	6.8354E-01	3.4119E-01	1.4672E-01	7.7110E-03
21	3.5567E-03	8.4498E-02	3.8088E-01	1.0301E+00	8.7696E-01	5.1976E-01	2.6152E-01	2.0139E-03
22	2.1546E-03	4.9099E-02	2.6402E-01	9.3682E-01	1.1192E+00	8.2922E-01	5.2391E-01	8.2437E-03
23	1.4310E-03	2.3838E-02	1.4538E-01	6.4776E-01	1.0353E+00	9.2925E-01	7.1543E-01	2.1179E-01
24	8.1679E-04	1.0705E-02	7.2302E-02	3.9596E-01	8.2690E-01	8.8177E-01	8.0886E-01	4.1531E-01
25	4.0010E-04	4.3332E-03	3.1567E-02	2.0372E-01	5.2617E-01	6.4103E-01	6.7101E-01	5.1433E-01
26	3.6683E-04	2.2432E-03	1.5304E-02	9.7900E-02	2.5901E-01	3.2381E-01	3.4963E-01	2.9963E-01
27	2.4014E-04	1.3433E-03	9.0969E-03	5.9654E-02	1.6556E-01	2.1435E-01	2.4017E-01	2.3253E-01
28	1.5034E-04	8.9662E-04	6.1380E-03	4.1174E-02	1.1898E-01	1.5879E-01	1.8390E-01	1.9943E-01
29	9.7882E-05	6.9564E-04	4.8379E-03	3.3067E-02	9.9029E-02	1.3577E-01	1.6183E-01	1.9315E-01
30	6.3898E-05	5.7448E-04	4.1504E-03	2.9298E-02	9.1841E-02	1.2937E-01	1.5826E-01	2.0364E-01
31	3.7765E-05	4.9927E-04	3.6749E-03	2.6436E-02	8.4926E-02	1.2163E-01	1.5130E-01	2.0492E-01

Figure 1


RESPONSE OF 3 INCH SPHERE
8x8 mm DETECTOR
SYMBOL REPRESENTS
× .95 DENSITY
+ .92 DENSITY
RESPONSE
0.00
.12
.24
.36
.48
.60
.72
.84
.96
1.08
1.20
ENERGY MEV