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Impact of ASTM Standard E722 Update on Radiation Damage Metrics

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Abstract

The impact of recent changes to the ASTM Standard E722 is investigated. The methodological changes in the production of the displacement kerma factors for silicon has significant impact for some energy regions of the 1-MeV(Si) equivalent fluence response function. When evaluating the integral over all neutrons energies in various spectra important to the SNL electronics testing community, the change in the response results in an increase in the total 1-MeV(Si) equivalent fluence of 2 – 7%. Response functions have been produced and are available for users of both the NuGET and MCNP codes.

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NOMENCLATURE

ACRR	Annular Core Research Reactor
ENDF	Evaluated Nuclear Data File
MCNP	Monte Carlo N-Particle
NuGET	<u>N</u> eutron <u>G</u> amma <u>E</u> nergy <u>T</u> ransport
SNL	Sandia National Laboratories
SPR-III	Sandia Pulse Reactor – III
WSMR FBR	White Sands Missile Range Fast Burst Reactor

1. INTRODUCTION

Recently, ASTM Committee E10 completed an update to E722-09^{ε1} – Standard Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics [1]. This ASTM standard is the method used to define the 1-MeV(Si) equivalent fluence radiation damage metric. The E10.07 sub-committee (Radiation Dosimetry for Radiation Effects on Materials and Devices) had not made technical changes to the standard since 1994. However, when the E722-14 standard is formally published later this year, it will include changes to the silicon displacement kerma factors found in the standard's Appendix A.1.

The underlying changes to the methodology used to produce the displacement kerma factors for silicon were substantial while the overall impact to the actual computed displacement kerma factors was minimal for most of the response range. Here is a list of the changes that the E10.07 sub-committee recommended in the updated E722 standard:

- Cross section database was updated to the ENDF/B-VII.1 set
 - In the E722-09^{ε1} standard, the ENDF/B-VI cross section evaluation was utilized.
 - The updated E722 standard uses the most recent cross section evaluation from ENDF (Release VII, Revision 1).
- Use of natural (i.e., the proper combination of isotopic cross section evaluations) silicon for the displacement kerma factors
 - In all previous versions of E722, ²⁸Si was the only isotope considered when evaluating the displacement kerma factors.
 - The updated E722 standard includes ²⁹Si and ³⁰Si with appropriate atomic abundances when evaluating the displacement kerma factors.
- Displacement threshold energy for the silicon lattice reduced
 - The E722-09^{ε1} used a value for the displacement threshold energy of 25 eV when creating the displacement kerma factors.
 - The displacement threshold energy has been reduced to 20.5 eV for the update to the E722 standard.

This document attempts to provide some guidance on how the updated E722 standard will impact the radiation damage metric [that is, the 1-MeV(Si) equivalent neutron fluence] used by the electronics testing community for neutron test environments when compared to the values from the E722-09^{ε1} version of the standard. In addition, this document provides users of the NuGET code [2] and the MCNP code [3] with free-field radiation response functions for the 1-MeV(Si) equivalent fluence based on E722-14 that can be utilized for radiation damage calculations with those codes.

2. DATA PROCESSING

The relevant data for the electronics testing community for neutron test environments is identified in Appendix A.1 of the E722 standard. The data found in that appendix is provided as a silicon displacement kerma factor with units of MeV-mbarn. In order to use the tabular data for equivalent monoenergetic fluence calculations, one must select a displacement damage reference value designated for the irradiated material and for the specified equivalent energy. The E10.07 sub-committee decided that the historical displacement damage reference value for 1-MeV equivalent fluence in silicon of 95 MeV-mbarn should continue to be used. The values in Table A1.1 of the E722 standard must be divided by 95 MeV-mbarn to produce the 1-MeV(Si) equivalent fluence response function typically used by neutron environment testing community.

Once the values in Table A1.1 have been converted from displacement kerma factors to 1-MeV(Si) equivalent fluence values, an analyst has a 640-group neutron response function. Typically, MCNP users are able to utilize the response function in this form to compute the relevant radiation damage metrics. However, NuGET users must have the response function re-binned into the NuGET 89-groups (neutrons) to match the multi-group radiation transport structure of the code. The re-binning of the 640-group response was performed using MCNP. The re-binning used a fold of the 640-group response with sources that represent each of the NuGET neutron energy groups. The result of each source fold is a 1-MeV(Si) equivalent fluence value corresponding to the NuGET response value for that energy group. The template file for producing the NuGET re-binned response is found in Appendix A.

A comparison of the 640-group response extracted from Table A1.1 with the re-binned NuGET response is found below in Figure 1. The figure displays the response histograms for each of the responses, but the bin structure of the 640-group response tends to make the response look as if it is plotted as a point-wise response function. As one would expect, there are more detailed features in the 640-group response that are averaged away in the 89-group structure. A set of EM cards for use with MCNP is provided in Appendix B for both of these response functions.

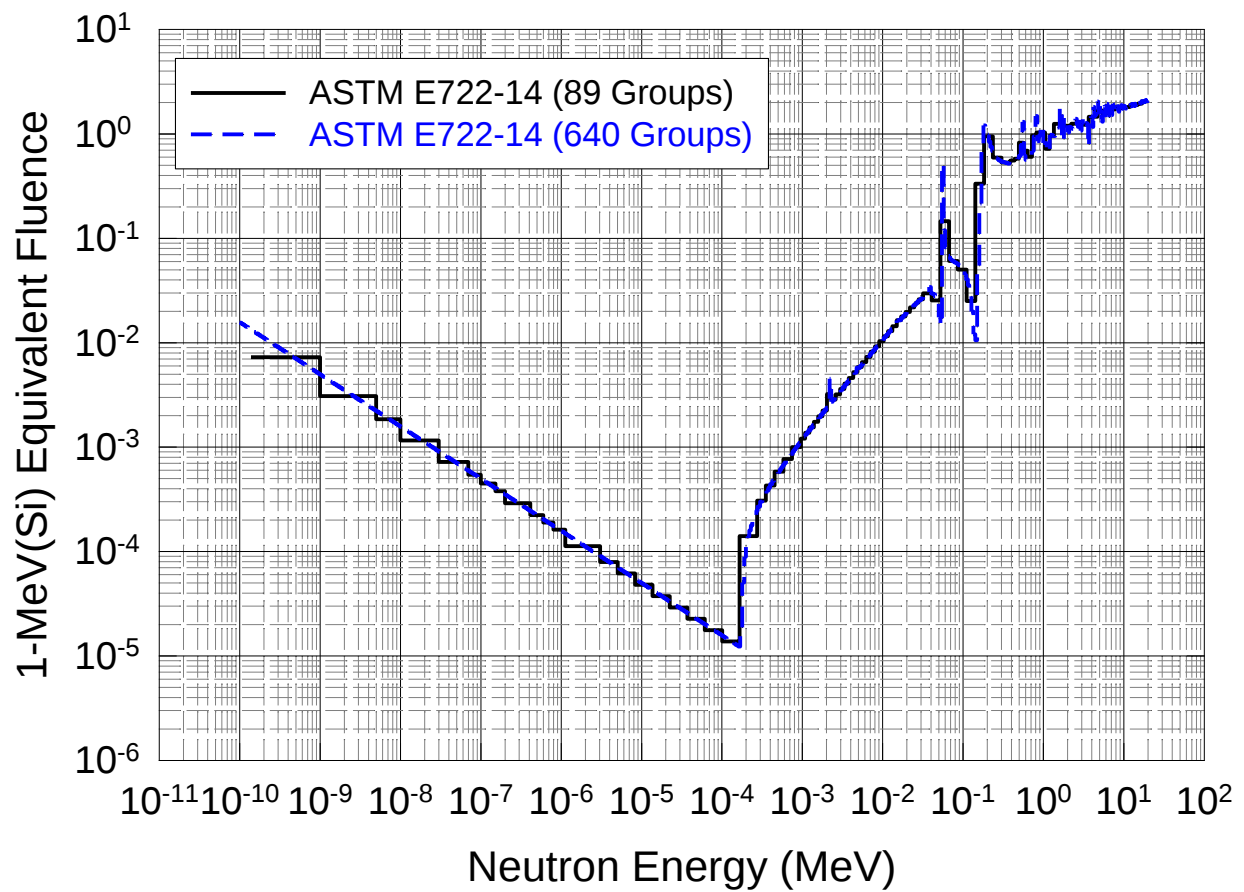


Figure 1 – 1-MeV(Si) Equivalent Fluence from E722-14 in 640- and 89-groups.

3. RESPONSE FUNCTION COMPARISONS

In order to assess the effect of the updated 1-MeV(Si) equivalent fluence response on radiation environment characterizations, the E722-09 response function was extracted from the NuGET source code and placed into a NuGET compatible external response function. In addition to the E722-09 response, the E722-14 response was incorporated into a NuGET external response function. Both of these response functions are found in Appendix C. The NuGET code has a little known (and undocumented) feature that produces 89-group histograms for each response in a calculation. So, the histograms were produced for the E722-09 and E722-14 response functions by including them in a NuGET calculation. A plot of those response function histograms is shown in Figure 2. A cursory examination of the figure shows that there does not appear to be significant changes to the response function. However, the figure is provided in a log-log scale that can hide many differences. A different approach is required to find out how the update changes the responses calculated by NuGET and MCNP users.

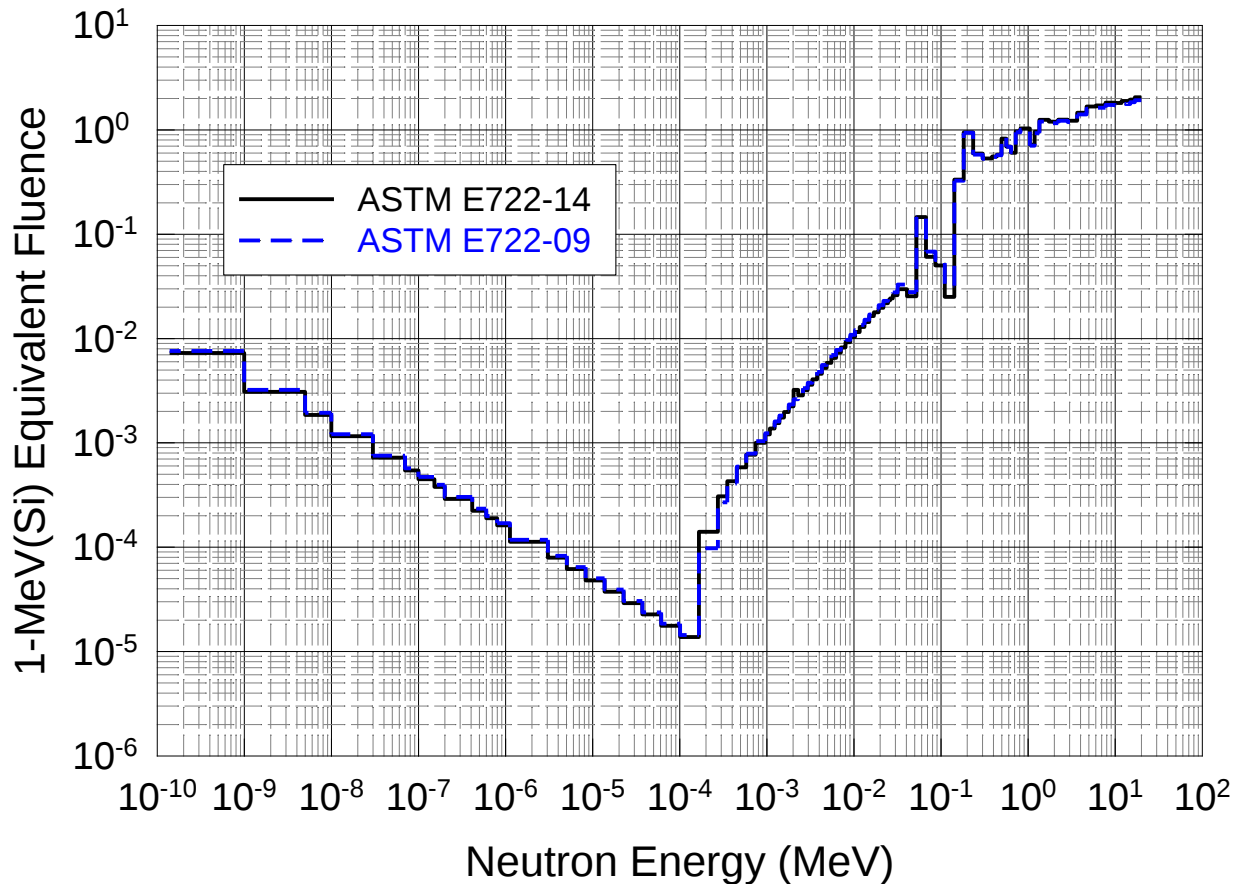


Figure 2 – NuGET Response Histograms for E722-09 and E722-14

Since the log-log plot minimizes the details visible to users, a Δ of the new response versus the old was computed for each energy bin ($R_{i,X}$ is the 1-MeV(Si) equivalent response of the i^{th} energy bin for the E722 vintage given by X):

$$\Delta_i = R_{i,E722-14} - R_{i,E722-09} \quad \text{where } i = 1, 2, \dots, 89 \quad (1)$$

The resulting Δ values are plotted as a histogram below in Figure 3. Again, in the figure we seem to find that most of the changes made by the E10.07 sub-committee did not significantly alter the monoenergetic neutron fluence equivalent response metric. (*NOTE: For reference, the Δ values for energies greater than 100 keV are generally less than a 10% change from the E722-09 standard. See below for details.*)

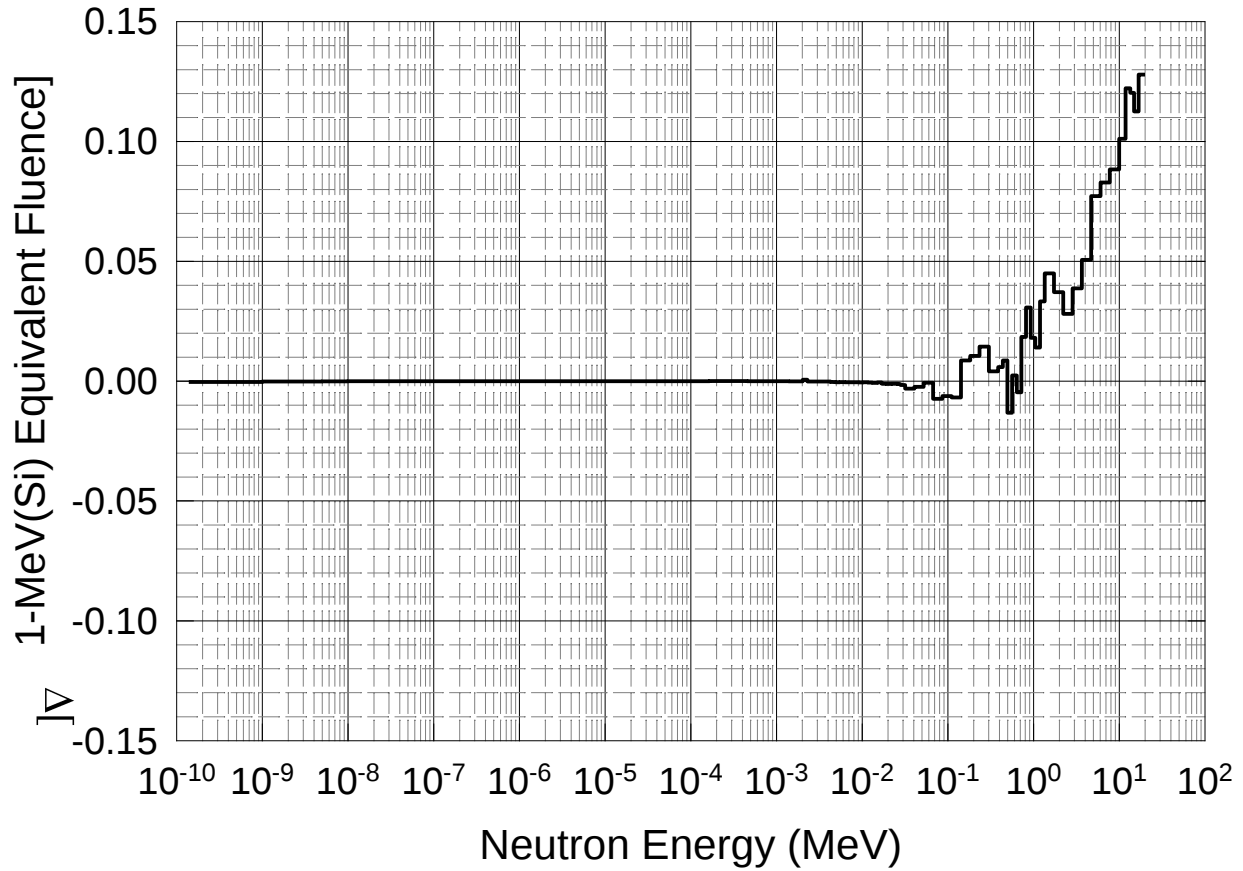


Figure 3 – Histogram of Δ 's of E722 Responses

As a final check on the difference between the versions of the E722 standard, the percent difference between the two standards was evaluated using this equation:

$$(\% \text{ Difference})_i = \left(\frac{R_{i,E722-14} - R_{i,E722-09}}{R_{i,E722-09}} \right) \times 100 \quad \text{where } i = 1, 2, \dots, 89 \quad (2)$$

The resulting percent difference values are plotted as a histogram below in Figure 4. The figure finally allows one to examine where the three changes discussed in the introduction had the most significant effect on the 1-MeV(Si) equivalent fluence response. Differences greater than 20% are concentrated in the 0.1 keV – 200 keV regions. The response function differs by less than 10% in the rest of the energy ranges. The large difference found in the 100 – 200 eV range is a consequence of the reduction in the displacement threshold energy from 25 eV to 20.5 eV. The increase in that region coincides with the minimum of the trough in the kerma function (see Figure 1). The minimum is the point at which the recoil energy from elastic scattering reaches the displacement threshold energy. Since the threshold was decreased, neutron energies producing an atomic recoil distribution with a significant fraction of recoils in the vicinity of 20.5 eV – 25 eV will experience an enhanced displacement kerma.

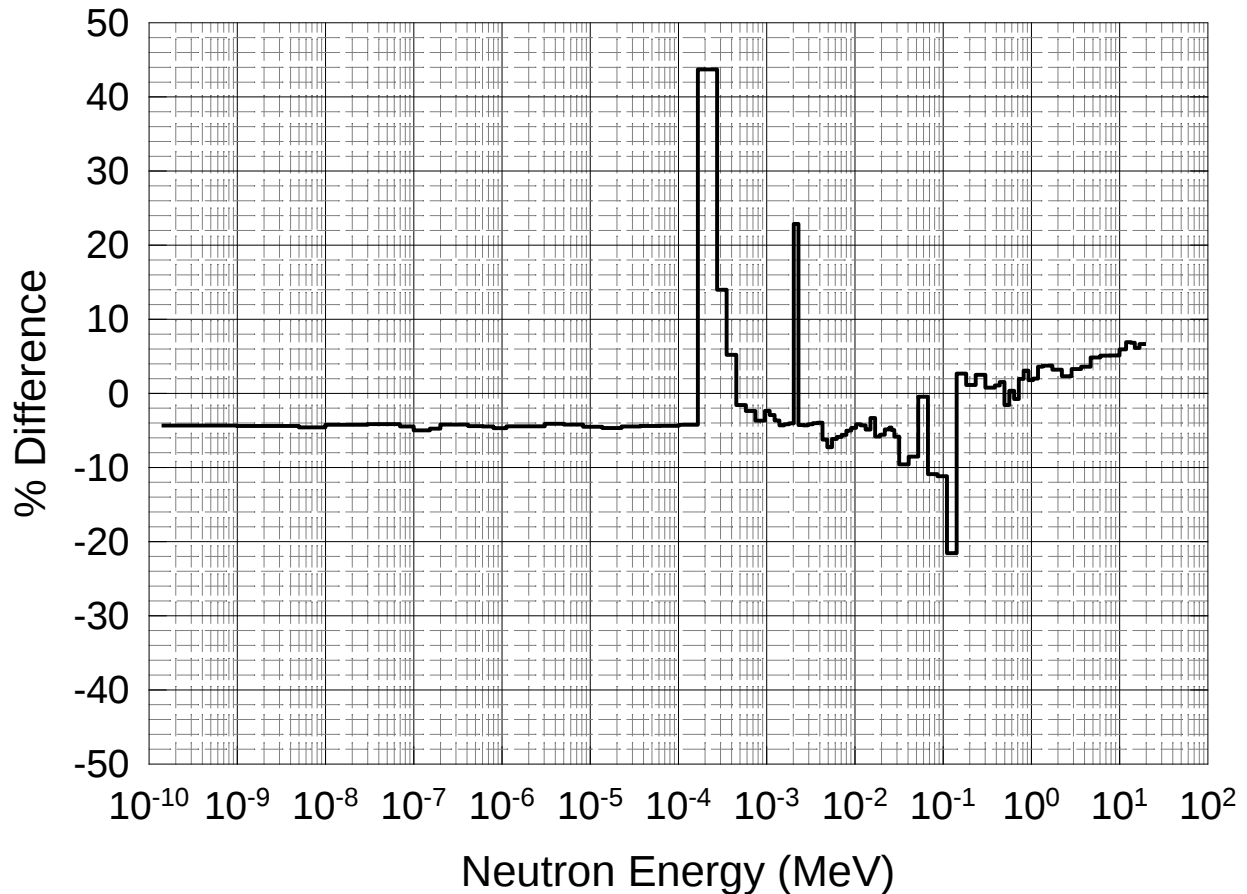


Figure 4 – Histogram of Percent Difference of E722 Responses

The small changes in the region below 0.1 keV are most likely due to the change to a complete elemental description of the silicon instead of simply using the ^{28}Si cross section. There are also small changes throughout the response function that are the result of the use of the ENDF/B-VII release 1 cross sections rather than the ENDF/B-VI vintage cross section.

4. INTEGRAL METRIC COMPARISONS

In the previous section, the changes to the actual neutron displacement kerma response function from the E722 standard were examined. While those comparisons place in context the scope and magnitude of the E722 methodology changes, they provide very little information about how the integral radiation damage metric will change in a given neutron spectrum. Therefore, the changes in the integral metric for different radiation environments that utilize this response must be understood. As a first approach, the response functions were folded with three different reactor spectra of interest to the Sandia National Laboratories electronics testing community (ACRR Pb-B₄C bucket, WSMR FBR at 6" from the reactor, and SPR-III Central Cavity). The source / response folding was performed using MCNP. Both the 640-group and 89-group response for E722-14 were included to show that the re-binning process did not alter integral metrics for a given spectrum. The results of these source / response fold calculations are found in Table 1. The metrics in the table show that the updated response will result in an increase of 2 – 3% for the reactor spectra studied.

Table 1 – Integral Metrics from Source / Response Folding

Spectrum	E722-14 (640)	E722-14 (89)	Ratio 640/89	E722-09	Ratio E722-14 / E722-09
ACRR-PbB	5.52881E-01	5.52866E-01	1.0000	5.40978E-01	1.0220
SPR3-CC	8.62301E-01	8.62282E-01	1.0000	8.42353E-01	1.0237
WSMR-FBR	9.14830E-01	9.14821E-01	1.0000	8.92206E-01	1.0253
The values in the table are normalized to 1.0 n/cm ² from the specified spectrum.					
The units for the integral metric are 1-MeV(Si) equivalent fluence per n/cm ² in the specified spectrum.					

While the metrics for the reactor show that the changes are not really significant, it is not clear how the metrics for a transported spectrum (i.e., a source with a great deal of scattered radiation) would change. To examine this effect, the NuGET 4 π R² ratio mode was utilized for the unclassified thermonuclear (TN), fission, and 14-MeV sources. This calculation computes the time integral of the two 1-MeV equivalent responses as a function of the areal density in air and then produces a ratio of the responses. The updated E722 is the numerator for these calculations that are shown in Figure 5 (i.e., $R_{E722-14}(\rho R) / R_{E722-09}(\rho R)$ is plotted in the figure). The figure makes it clear that the updated E722 response will be 2 – 7% higher than the E722-09 response for all sources (transported or folded).

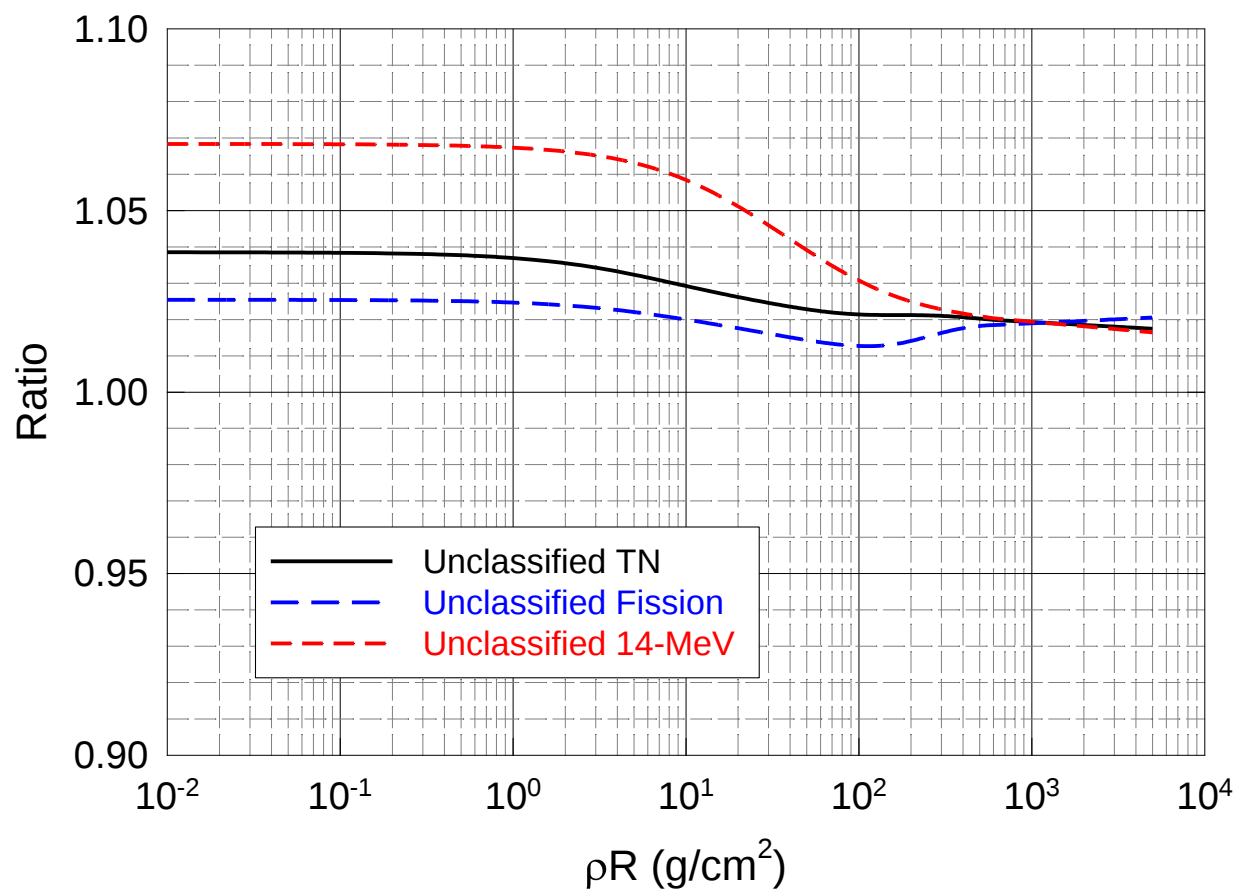


Figure 5 – $4\pi R^2$ Ratios for Different Unclassified NuGET Sources

4. SUMMARY AND CONCLUSIONS

Recent changes to the ASTM E722-14 required an examination of the effect of the significant methodological changes in producing neutron kerma factors on the integral metric used by SNL's electronics testing community. The updated neutron response from ASTM E722-14 was extracted and processed for use by radiation environment analysts. Thus, the response function based on the displacement kerma factors for silicon in E722-14 has been produced for users of NuGET and MCNP. Some energy regions of the updated response function have significant differences from the past responses derived from the E722 standard.

Integral metrics obtained using E722-14 from neutron sources with a wide energy range will result in values 2 – 7% greater than the E722-09 based responses. Some increase in the integral metric of 1-MeV(Si) equivalent neutron fluence was expected given that the displacement threshold energy recommended by the E10.07 sub-committee was reduced from 25 eV to 20.5 eV (an 18% reduction in the threshold energy). However, the large change in the threshold energy did not result in integral metrics as large as its threshold shift. It is likely that the majority of the difference in the integral metrics is due to the change in the cross section evaluation and inclusion of all the silicon isotopes in the response. The NuGET free-field responses and MCNP EM cards are available to users upon request.

5. REFERENCES

1. ASTM E722 – Standard Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics, ASTM International, West Conshohocken, PA, 2014.
2. K. R. DePriest and P. J. Griffin. NuGET User's Guide: Revision 0. SAND Report, SAND2004-1567 (OUO/ECI), Sandia National Laboratories, Albuquerque, NM, April 2004.
3. T. Goorley, M. James, T. Booth, F. Brown, J. Bull, L.J. Cox, J. Durkee, J. Elson, M. Fensin, R.A. Forster, J. Hendricks, H.G. Hughes, R. Johns, B. Kiedrowski, R. Martz, S. Mashnik, G. McKinney, D. Pelowitz, R. Prael, J. Sweezy, L. Waters, T. Wilcox, and T. Zukaitis, "Initial MCNP 6 Release Overview", LA-UR-11-07082, Los Alamos National Laboratory, also *Nuclear Technology*, **180**, pg 298-315 (Dec 2012).

APPENDIX A: MCNP TEMPLATE FOR 89-GROUP RESPONSE FUNCTION

```

Rebin E722-14 Response from 640 groups to NuGET 89-groups (Template)
C
C *****
C *
C CELL CARDS
C *****
C
  1    0   -100      IMP:N=1  $Scoring sphere
900    0    100      IMP:N=0  $Void

C
C *****
C *
C SURFACE CARDS
C *****
C
100    SO    0.2820948  $Sphere with surface area of 1 cm^2
C

C          1          2          3          4          5          6          7          8
C 34567890123456789012345678901234567890123456789012345678901234567890
C *****
C *
C DATA CARDS
C *****
C
MODE N
NPS 1e7
PRINT 10
C
C *****
C * SOURCE CARDS
C *****
C
SDEF ERG=D2
C
SI2 E low E high
SP2 0 1
C *****
C * NEUTRON TALLIES
C *****
C
F2:N 100
FC2 1-MeV(Si) Equivalent Fluence (1-MeV DES)
E2 1.000E-10 1.050E-10 1.100E-10 1.150E-10 1.200E-10 1.275E-10
1.350E-10 1.425E-10 1.500E-10 1.600E-10 1.700E-10 1.800E-10
1.900E-10 2.000E-10 2.100E-10 2.200E-10 2.300E-10 2.400E-10
2.550E-10 2.700E-10 2.800E-10 3.000E-10 3.200E-10 3.400E-10
3.600E-10 3.800E-10 4.000E-10 4.250E-10 4.500E-10 4.750E-10
5.000E-10 5.250E-10 5.500E-10 5.750E-10 6.000E-10 6.300E-10
6.600E-10 6.900E-10 7.200E-10 7.600E-10 8.000E-10 8.400E-10
8.800E-10 9.200E-10 9.600E-10 1.000E-09 1.050E-09 1.100E-09
1.150E-09 1.200E-09 1.275E-09 1.350E-09 1.425E-09 1.500E-09
1.600E-09 1.700E-09 1.800E-09 1.900E-09 2.000E-09 2.100E-09
2.200E-09 2.300E-09 2.400E-09 2.550E-09 2.700E-09 2.800E-09
3.000E-09 3.200E-09 3.400E-09 3.600E-09 3.800E-09 4.000E-09
4.250E-09 4.500E-09 4.750E-09 5.000E-09 5.250E-09 5.500E-09
5.750E-09 6.000E-09 6.300E-09 6.600E-09 6.900E-09 7.200E-09
7.600E-09 8.000E-09 8.400E-09 8.800E-09 9.200E-09 9.600E-09
1.000E-08 1.050E-08 1.100E-08 1.150E-08 1.200E-08 1.275E-08
1.350E-08 1.425E-08 1.500E-08 1.600E-08 1.700E-08 1.800E-08
1.900E-08 2.000E-08 2.100E-08 2.200E-08 2.300E-08 2.400E-08

```

22

4.600E+00	4.700E+00	4.800E+00	4.900E+00	5.000E+00	5.100E+00
5.200E+00	5.300E+00	5.400E+00	5.500E+00	5.600E+00	5.700E+00
5.800E+00	5.900E+00	6.000E+00	6.100E+00	6.200E+00	6.300E+00
6.400E+00	6.500E+00	6.600E+00	6.700E+00	6.800E+00	6.900E+00
7.000E+00	7.100E+00	7.200E+00	7.300E+00	7.400E+00	7.500E+00
7.600E+00	7.700E+00	7.800E+00	7.900E+00	8.000E+00	8.100E+00
8.200E+00	8.300E+00	8.400E+00	8.500E+00	8.600E+00	8.700E+00
8.800E+00	8.900E+00	9.000E+00	9.100E+00	9.200E+00	9.300E+00
9.400E+00	9.500E+00	9.600E+00	9.700E+00	9.800E+00	9.900E+00
1.000E+01	1.010E+01	1.020E+01	1.030E+01	1.040E+01	1.050E+01
1.060E+01	1.070E+01	1.080E+01	1.090E+01	1.100E+01	1.110E+01
1.120E+01	1.130E+01	1.140E+01	1.150E+01	1.160E+01	1.170E+01
1.180E+01	1.190E+01	1.200E+01	1.210E+01	1.220E+01	1.230E+01
1.240E+01	1.250E+01	1.260E+01	1.270E+01	1.280E+01	1.290E+01
1.300E+01	1.310E+01	1.320E+01	1.330E+01	1.340E+01	1.350E+01
1.360E+01	1.370E+01	1.380E+01	1.390E+01	1.400E+01	1.410E+01
1.420E+01	1.430E+01	1.440E+01	1.450E+01	1.460E+01	1.470E+01
1.480E+01	1.490E+01	1.500E+01	1.510E+01	1.520E+01	1.530E+01
1.540E+01	1.550E+01	1.560E+01	1.570E+01	1.580E+01	1.590E+01
1.600E+01	1.610E+01	1.620E+01	1.630E+01	1.640E+01	1.650E+01
1.660E+01	1.670E+01	1.680E+01	1.690E+01	1.700E+01	1.710E+01
1.720E+01	1.730E+01	1.740E+01	1.750E+01	1.760E+01	1.770E+01
1.780E+01	1.790E+01	1.800E+01	1.810E+01	1.820E+01	1.830E+01
1.840E+01	1.850E+01	1.860E+01	1.870E+01	1.880E+01	1.890E+01
1.900E+01	1.910E+01	1.920E+01	1.930E+01	1.940E+01	1.950E+01
1.960E+01	1.970E+01	1.980E+01	1.990E+01	2.000E+01	

C

C Multipliers converted from E722-14. The values were taken from the table
C divided by 95 MeV-mb. The first bin is a zero because the bin goes from
C 0.0 -- 1.0e-10 Mev (i.e., below the table).

C

EM2

0.000000					
1.55757E-02	1.52081E-02	1.48653E-02	1.45460E-02	1.41733E-02	1.37625E-02
1.33856E-02	1.30375E-02	1.26638E-02	1.22736E-02	1.19183E-02	1.15909E-02
1.12923E-02	1.10122E-02	1.07528E-02	1.05108E-02	1.02848E-02	1.00215E-02
9.73084E-03	9.50730E-03	9.25812E-03	8.95570E-03	8.67986E-03	8.42810E-03
8.19695E-03	7.98391E-03	7.76284E-03	7.53775E-03	7.33121E-03	7.14061E-03
6.96547E-03	6.80114E-03	6.64813E-03	6.50521E-03	6.35797E-03	6.20825E-03
6.06873E-03	5.93817E-03	5.79587E-03	5.64534E-03	5.50581E-03	5.37618E-03
5.25540E-03	5.14275E-03	5.03732E-03	4.92539E-03	4.80914E-03	4.70093E-03
4.59982E-03	4.48213E-03	4.35218E-03	4.23284E-03	4.12277E-03	4.00467E-03
3.88132E-03	3.76888E-03	3.66560E-03	3.57108E-03	3.48232E-03	3.40036E-03
3.32386E-03	3.25240E-03	3.16920E-03	3.07725E-03	3.00651E-03	2.92775E-03
2.83209E-03	2.74488E-03	2.66528E-03	2.59218E-03	2.52474E-03	2.45492E-03
2.38367E-03	2.31839E-03	2.25806E-03	2.20276E-03	2.15076E-03	2.10236E-03
2.05716E-03	2.01062E-03	1.96326E-03	1.91909E-03	1.87780E-03	1.83280E-03
1.78523E-03	1.74116E-03	1.70008E-03	1.66188E-03	1.62625E-03	1.59299E-03
1.55757E-03	1.52081E-03	1.48663E-03	1.45461E-03	1.41744E-03	1.37635E-03
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1.12933E-03	1.10143E-03	1.07538E-03	1.05128E-03	1.02866E-03	1.00238E-03
9.73372E-04	9.50967E-04	9.26100E-04	8.95725E-04	8.68161E-04	8.42955E-04
8.19818E-04	7.98514E-04	7.76449E-04	7.53920E-04	7.33234E-04	7.14329E-04
6.96660E-04	6.80216E-04	6.64916E-04	6.50624E-04	6.35961E-04	6.20990E-04
6.07028E-04	5.93962E-04	5.79814E-04	5.64740E-04	5.50767E-04	5.37773E-04
5.25674E-04	5.14389E-04	5.03845E-04	4.92591E-04	4.80966E-04	4.70144E-04
4.60033E-04	4.48347E-04	4.35352E-04	4.23408E-04	4.12391E-04	4.00621E-04
3.88255E-04	3.76980E-04	3.66643E-04	3.57190E-04	3.48314E-04	3.40109E-04
3.32458E-04	3.25301E-04	3.17013E-04	3.07787E-04	3.00662E-04	2.92857E-04
2.83281E-04	2.74559E-04	2.66611E-04	2.59321E-04	2.52577E-04	2.45596E-04
2.38460E-04	2.31942E-04	2.25980E-04	2.20492E-04	2.15396E-04	2.10401E-04
2.05974E-04	2.01237E-04	1.96511E-04	1.92043E-04	1.87913E-04	1.83393E-04
1.78647E-04	1.74189E-04	1.70131E-04	1.66435E-04	1.62965E-04	1.59495E-04
1.55952E-04	1.52328E-04	1.48776E-04	1.45646E-04	1.41867E-04	1.37779E-04

1.33939E-04	1.30469E-04	1.26731E-04	1.22818E-04	1.19286E-04	1.16146E-04
1.13067E-04	1.10215E-04	1.07600E-04	1.05190E-04	1.02919E-04	1.00420E-04
9.75328E-05	9.51625E-05	9.27697E-05	8.96560E-05	8.69253E-05	8.43470E-05
8.20622E-05	7.98855E-05	7.76954E-05	7.54302E-05	7.33471E-05	7.14505E-05
6.97114E-05	6.80999E-05	6.65184E-05	6.51212E-05	6.36230E-05	6.21311E-05
6.07214E-05	5.94148E-05	5.79887E-05	5.64864E-05	5.50779E-05	5.37867E-05
5.26159E-05	5.15152E-05	5.04145E-05	4.92943E-05	4.81524E-05	4.70321E-05
4.60436E-05	4.48513E-05	4.35591E-05	4.23482E-05	4.12516E-05	4.00716E-05
3.88329E-05	3.77117E-05	3.67180E-05	3.57440E-05	3.48441E-05	3.40193E-05
3.32573E-05	3.25376E-05	3.17459E-05	3.08325E-05	3.00819E-05	2.93272E-05
2.83449E-05	2.74830E-05	2.66686E-05	2.59468E-05	2.52600E-05	2.45681E-05
2.38535E-05	2.31946E-05	2.25953E-05	2.20445E-05	2.15348E-05	2.10344E-05
2.05927E-05	2.01201E-05	1.96495E-05	1.92037E-05	1.87908E-05	1.83409E-05
1.78662E-05	1.74214E-05	1.70126E-05	1.66420E-05	1.62940E-05	1.59460E-05
1.55918E-05	1.52314E-05	1.48772E-05	1.45653E-05	1.41895E-05	1.37807E-05
1.33987E-05	1.30528E-05	1.26801E-05	1.22888E-05	1.167019E-05	5.03532E-05
8.89733E-05	1.18762E-04	1.39545E-04	1.58867E-04	1.77199E-04	1.98510E-04
2.23623E-04	2.44503E-04	2.68372E-04	2.99996E-04	3.29057E-04	3.56978E-04
3.82268E-04	4.07915E-04	4.40240E-04	4.74322E-04	5.06465E-04	5.40721E-04
5.74152E-04	6.06365E-04	6.38431E-04	6.69660E-04	7.03791E-04	7.40847E-04
7.77772E-04	8.14580E-04	8.57309E-04	9.06093E-04	9.54732E-04	1.00319E-03
1.05136E-03	1.09936E-03	1.14732E-03	1.20080E-03	1.26001E-03	1.31912E-03
1.37803E-03	1.45111E-03	1.53684E-03	1.62222E-03	1.70953E-03	1.81087E-03
1.92603E-03	2.03952E-03	2.15299E-03	2.26656E-03	2.37969E-03	2.49801E-03
4.51085E-03	2.71857E-03	2.85459E-03	3.02134E-03	3.16071E-03	3.32388E-03
3.54249E-03	3.76114E-03	3.97919E-03	4.19489E-03	4.40989E-03	4.64959E-03
4.91553E-03	5.18080E-03	5.76655E-03	5.71228E-03	5.96899E-03	6.22895E-03
6.48781E-03	6.77175E-03	7.07769E-03	7.38125E-03	7.68486E-03	8.03793E-03
8.43680E-03	8.83330E-03	9.22970E-03	9.62022E-03	1.00070E-02	1.03939E-02
1.08230E-02	1.12956E-02	1.17672E-02	1.22307E-02	1.28056E-02	1.34802E-02
1.41499E-02	1.48221E-02	1.63844E-02	1.64225E-02	1.72639E-02	1.80731E-02
1.88761E-02	1.96463E-02	2.03818E-02	2.11167E-02	2.18512E-02	2.27297E-02
2.36990E-02	2.45038E-02	2.54330E-02	2.65667E-02	2.75268E-02	2.83613E-02
2.90652E-02	3.40727E-02	2.96320E-02	2.91159E-02	2.76583E-02	2.44691E-02
1.75353E-02	1.46827E-02	5.13874E-01	1.19065E-01	8.16815E-02	7.05739E-02
6.79182E-02	6.32046E-02	6.13096E-02	5.96606E-02	5.82183E-02	5.70107E-02
5.51506E-02	5.32817E-02	5.11391E-02	4.81835E-02	4.45454E-02	4.03846E-02
3.55231E-02	2.86544E-02	1.98594E-02	1.20505E-02	1.05463E-02	4.62102E-02
2.14986E-01	7.02148E-01	1.20361E+00	1.17122E+00	9.83451E-01	8.42466E-01
7.47732E-01	6.85119E-01	6.31864E-01	5.91761E-01	5.69296E-01	5.54063E-01
5.38453E-01	5.34761E-01	5.25067E-01	5.18936E-01	5.46879E-01	5.55297E-01
5.60685E-01	5.74050E-01	5.90609E-01	6.16980E-01	7.77633E-01	1.30371E+00
6.15364E-01	5.61832E-01	5.78703E-01	5.92754E-01	6.16933E-01	6.86794E-01
9.41435E-01	1.48004E+00	8.47729E-01	9.59852E-01	1.19054E+00	1.19132E+00
8.17177E-01	6.70801E-01	9.78152E-01	9.52438E-01	1.09001E+00	1.14820E+00
1.78997E+00	8.46446E-01	1.41903E+00	1.40100E+00	1.02847E+00	1.16636E+00
1.13472E+00	1.11477E+00	1.27780E+00	1.39400E+00	1.24739E+00	1.16306E+00
1.45273E+00	1.07111E+00	1.29041E+00	1.44375E+00	1.29872E+00	1.23317E+00
1.27315E+00	1.22789E+00	7.58446E-01	1.25241E+00	1.20408E+00	1.47227E+00
1.44952E+00	1.16501E+00	1.80877E+00	1.46506E+00	1.53102E+00	1.52239E+00
1.70086E+00	2.03852E+00	1.74664E+00	1.60348E+00	1.64040E+00	1.86691E+00
1.64041E+00	1.36477E+00	1.30509E+00	1.60157E+00	1.64866E+00	1.97580E+00
1.83308E+00	1.50230E+00	1.70387E+00	1.39707E+00	1.94091E+00	1.68195E+00
1.55411E+00	1.35494E+00	1.65603E+00	1.82642E+00	1.61556E+00	1.56021E+00
1.82610E+00	1.51158E+00	1.85547E+00	1.86522E+00	1.84254E+00	1.81227E+00
1.84230E+00	1.91506E+00	1.91426E+00	2.05434E+00	1.87027E+00	1.71552E+00
1.79165E+00	1.81663E+00	1.82920E+00	1.81748E+00	1.81000E+00	1.62471E+00
1.73598E+00	1.94117E+00	1.93738E+00	1.72941E+00	1.66928E+00	1.81030E+00
1.88525E+00	1.82935E+00	1.73036E+00	1.76877E+00	1.81619E+00	1.84188E+00
1.82281E+00	1.84493E+00	1.82758E+00	1.83570E+00	1.77195E+00	1.75947E+00
1.73736E+00	1.78882E+00	1.82892E+00	1.82795E+00	1.79954E+00	1.74392E+00
1.75631E+00	1.80029E+00	1.83133E+00	1.84432E+00	1.83379E+00	1.81803E+00
1.82137E+00	1.83499E+00	1.85249E+00	1.88120E+00	1.88472E+00	1.89192E+00

1.86042E+00	1.82722E+00	1.90765E+00	1.92752E+00	1.92122E+00	1.92482E+00
1.93397E+00	1.90031E+00	1.86591E+00	1.87907E+00	1.91261E+00	1.87590E+00
1.85306E+00	1.87820E+00	1.94491E+00	1.88259E+00	1.86124E+00	1.89206E+00
1.90502E+00	1.91799E+00	1.91962E+00	1.86539E+00	1.84049E+00	1.84972E+00
1.88416E+00	1.89047E+00	1.85078E+00	1.87923E+00	1.92143E+00	1.92018E+00
1.90790E+00	1.88826E+00	1.88648E+00	1.89792E+00	1.94004E+00	1.97417E+00
1.98258E+00	1.98301E+00	1.97681E+00	1.96412E+00	1.95437E+00	2.00352E+00
2.05676E+00	2.03904E+00	2.01660E+00	2.02240E+00	2.02842E+00	2.02573E+00
2.02355E+00	2.02506E+00	2.02279E+00	2.00808E+00	1.99718E+00	2.00538E+00
2.01802E+00	2.04396E+00	2.06781E+00	2.05912E+00	2.04411E+00	2.03215E+00
2.02145E+00	2.04099E+00	2.08215E+00	2.10505E+00	2.09645E+00	2.08648E+00
2.07273E+00	2.05878E+00	2.05396E+00	2.05260E+00	2.05291E+00	2.05555E+00
2.05880E+00	2.06489E+00	2.07151E+00	2.07813E+00		

C

APPENDIX B: MCNP EM CARDS FOR E722-14 RESPONSES

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C
C
FC2  1-MeV(Si) Equivalent Fluence (1-MeV DES [E722-14])
C
C    640 Groups
C
E2   1.000E-10 1.050E-10 1.100E-10 1.150E-10 1.200E-10 1.275E-10
      1.350E-10 1.425E-10 1.500E-10 1.600E-10 1.700E-10 1.800E-10
      1.900E-10 2.000E-10 2.100E-10 2.200E-10 2.300E-10 2.400E-10
      2.550E-10 2.700E-10 2.800E-10 3.000E-10 3.200E-10 3.400E-10
      3.600E-10 3.800E-10 4.000E-10 4.250E-10 4.500E-10 4.750E-10
      5.000E-10 5.250E-10 5.500E-10 5.750E-10 6.000E-10 6.300E-10
      6.600E-10 6.900E-10 7.200E-10 7.600E-10 8.000E-10 8.400E-10
      8.800E-10 9.200E-10 9.600E-10 1.000E-09 1.050E-09 1.100E-09
      1.150E-09 1.200E-09 1.275E-09 1.350E-09 1.425E-09 1.500E-09
      1.600E-09 1.700E-09 1.800E-09 1.900E-09 2.000E-09 2.100E-09
      2.200E-09 2.300E-09 2.400E-09 2.550E-09 2.700E-09 2.800E-09
      3.000E-09 3.200E-09 3.400E-09 3.600E-09 3.800E-09 4.000E-09
      4.250E-09 4.500E-09 4.750E-09 5.000E-09 5.250E-09 5.500E-09
      5.750E-09 6.000E-09 6.300E-09 6.600E-09 6.900E-09 7.200E-09
      7.600E-09 8.000E-09 8.400E-09 8.800E-09 9.200E-09 9.600E-09
      1.000E-08 1.050E-08 1.100E-08 1.150E-08 1.200E-08 1.275E-08
      1.350E-08 1.425E-08 1.500E-08 1.600E-08 1.700E-08 1.800E-08
      1.900E-08 2.000E-08 2.100E-08 2.200E-08 2.300E-08 2.400E-08
      2.550E-08 2.700E-08 2.800E-08 3.000E-08 3.200E-08 3.400E-08
      3.600E-08 3.800E-08 4.000E-08 4.250E-08 4.500E-08 4.750E-08
      5.000E-08 5.250E-08 5.500E-08 5.750E-08 6.000E-08 6.300E-08
      6.600E-08 6.900E-08 7.200E-08 7.600E-08 8.000E-08 8.400E-08
      8.800E-08 9.200E-08 9.600E-08 1.000E-07 1.050E-07 1.100E-07
      1.150E-07 1.200E-07 1.275E-07 1.350E-07 1.425E-07 1.500E-07
      1.600E-07 1.700E-07 1.800E-07 1.900E-07 2.000E-07 2.100E-07
      2.200E-07 2.300E-07 2.400E-07 2.550E-07 2.700E-07 2.800E-07
      3.000E-07 3.200E-07 3.400E-07 3.600E-07 3.800E-07 4.000E-07
      4.250E-07 4.500E-07 4.750E-07 5.000E-07 5.250E-07 5.500E-07
      5.750E-07 6.000E-07 6.300E-07 6.600E-07 6.900E-07 7.200E-07
      7.600E-07 8.000E-07 8.400E-07 8.800E-07 9.200E-07 9.600E-07
      1.000E-06 1.050E-06 1.100E-06 1.150E-06 1.200E-06 1.275E-06
      1.350E-06 1.425E-06 1.500E-06 1.600E-06 1.700E-06 1.800E-06
      1.900E-06 2.000E-06 2.100E-06 2.200E-06 2.300E-06 2.400E-06
      2.550E-06 2.700E-06 2.800E-06 3.000E-06 3.200E-06 3.400E-06
      3.600E-06 3.800E-06 4.000E-06 4.250E-06 4.500E-06 4.750E-06
      5.000E-06 5.250E-06 5.500E-06 5.750E-06 6.000E-06 6.300E-06
      6.600E-06 6.900E-06 7.200E-06 7.600E-06 8.000E-06 8.400E-06
      8.800E-06 9.200E-06 9.600E-06 1.000E-05 1.050E-05 1.100E-05
      1.150E-05 1.200E-05 1.275E-05 1.350E-05 1.425E-05 1.500E-05
      1.600E-05 1.700E-05 1.800E-05 1.900E-05 2.000E-05 2.100E-05
      2.200E-05 2.300E-05 2.400E-05 2.550E-05 2.700E-05 2.800E-05
      3.000E-05 3.200E-05 3.400E-05 3.600E-05 3.800E-05 4.000E-05
      4.250E-05 4.500E-05 4.750E-05 5.000E-05 5.250E-05 5.500E-05
      5.750E-05 6.000E-05 6.300E-05 6.600E-05 6.900E-05 7.200E-05
      7.600E-05 8.000E-05 8.400E-05 8.800E-05 9.200E-05 9.600E-05
      1.000E-04 1.050E-04 1.100E-04 1.150E-04 1.200E-04 1.275E-04
      1.350E-04 1.425E-04 1.500E-04 1.600E-04 1.700E-04 1.800E-04
      1.900E-04 2.000E-04 2.100E-04 2.200E-04 2.300E-04 2.400E-04
      2.550E-04 2.700E-04 2.800E-04 3.000E-04 3.200E-04 3.400E-04
      3.600E-04 3.800E-04 4.000E-04 4.250E-04 4.500E-04 4.750E-04
      5.000E-04 5.250E-04 5.500E-04 5.750E-04 6.000E-04 6.300E-04
      6.600E-04 6.900E-04 7.200E-04 7.600E-04 8.000E-04 8.400E-04
      8.800E-04 9.200E-04 9.600E-04 1.000E-03 1.050E-03 1.100E-03
      1.150E-03 1.200E-03 1.275E-03 1.350E-03 1.425E-03 1.500E-03

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1.600E-03	1.700E-03	1.800E-03	1.900E-03	2.000E-03	2.100E-03
2.200E-03	2.300E-03	2.400E-03	2.550E-03	2.700E-03	2.800E-03
3.000E-03	3.200E-03	3.400E-03	3.600E-03	3.800E-03	4.000E-03
4.250E-03	4.500E-03	4.750E-03	5.000E-03	5.250E-03	5.500E-03
5.750E-03	6.000E-03	6.300E-03	6.600E-03	6.900E-03	7.200E-03
7.600E-03	8.000E-03	8.400E-03	8.800E-03	9.200E-03	9.600E-03
1.000E-02	1.050E-02	1.100E-02	1.150E-02	1.200E-02	1.275E-02
1.350E-02	1.425E-02	1.500E-02	1.600E-02	1.700E-02	1.800E-02
1.900E-02	2.000E-02	2.100E-02	2.200E-02	2.300E-02	2.400E-02
2.550E-02	2.700E-02	2.800E-02	3.000E-02	3.200E-02	3.400E-02
3.600E-02	3.800E-02	4.000E-02	4.250E-02	4.500E-02	4.750E-02
5.000E-02	5.250E-02	5.500E-02	5.750E-02	6.000E-02	6.300E-02
6.600E-02	6.900E-02	7.200E-02	7.600E-02	8.000E-02	8.400E-02
8.800E-02	9.200E-02	9.600E-02	1.000E-01	1.050E-01	1.100E-01
1.150E-01	1.200E-01	1.275E-01	1.350E-01	1.425E-01	1.500E-01
1.600E-01	1.700E-01	1.800E-01	1.900E-01	2.000E-01	2.100E-01
2.200E-01	2.300E-01	2.400E-01	2.550E-01	2.700E-01	2.800E-01
3.000E-01	3.200E-01	3.400E-01	3.600E-01	3.800E-01	4.000E-01
4.250E-01	4.500E-01	4.750E-01	5.000E-01	5.250E-01	5.500E-01
5.750E-01	6.000E-01	6.300E-01	6.600E-01	6.900E-01	7.200E-01
7.600E-01	8.000E-01	8.400E-01	8.800E-01	9.200E-01	9.600E-01
1.000E+00	1.100E+00	1.200E+00	1.300E+00	1.400E+00	1.500E+00
1.600E+00	1.700E+00	1.800E+00	1.900E+00	2.000E+00	2.100E+00
2.200E+00	2.300E+00	2.400E+00	2.500E+00	2.600E+00	2.700E+00
2.800E+00	2.900E+00	3.000E+00	3.100E+00	3.200E+00	3.300E+00
3.400E+00	3.500E+00	3.600E+00	3.700E+00	3.800E+00	3.900E+00
4.000E+00	4.100E+00	4.200E+00	4.300E+00	4.400E+00	4.500E+00
4.600E+00	4.700E+00	4.800E+00	4.900E+00	5.000E+00	5.100E+00
5.200E+00	5.300E+00	5.400E+00	5.500E+00	5.600E+00	5.700E+00
5.800E+00	5.900E+00	6.000E+00	6.100E+00	6.200E+00	6.300E+00
6.400E+00	6.500E+00	6.600E+00	6.700E+00	6.800E+00	6.900E+00
7.000E+00	7.100E+00	7.200E+00	7.300E+00	7.400E+00	7.500E+00
7.600E+00	7.700E+00	7.800E+00	7.900E+00	8.000E+00	8.100E+00
8.200E+00	8.300E+00	8.400E+00	8.500E+00	8.600E+00	8.700E+00
8.800E+00	8.900E+00	9.000E+00	9.100E+00	9.200E+00	9.300E+00
9.400E+00	9.500E+00	9.600E+00	9.700E+00	9.800E+00	9.900E+00
1.000E+01	1.010E+01	1.020E+01	1.030E+01	1.040E+01	1.050E+01
1.060E+01	1.070E+01	1.080E+01	1.090E+01	1.100E+01	1.110E+01
1.120E+01	1.130E+01	1.140E+01	1.150E+01	1.160E+01	1.170E+01
1.180E+01	1.190E+01	1.200E+01	1.210E+01	1.220E+01	1.230E+01
1.240E+01	1.250E+01	1.260E+01	1.270E+01	1.280E+01	1.290E+01
1.300E+01	1.310E+01	1.320E+01	1.330E+01	1.340E+01	1.350E+01
1.360E+01	1.370E+01	1.380E+01	1.390E+01	1.400E+01	1.410E+01
1.420E+01	1.430E+01	1.440E+01	1.450E+01	1.460E+01	1.470E+01
1.480E+01	1.490E+01	1.500E+01	1.510E+01	1.520E+01	1.530E+01
1.540E+01	1.550E+01	1.560E+01	1.570E+01	1.580E+01	1.590E+01
1.600E+01	1.610E+01	1.620E+01	1.630E+01	1.640E+01	1.650E+01
1.660E+01	1.670E+01	1.680E+01	1.690E+01	1.700E+01	1.710E+01
1.720E+01	1.730E+01	1.740E+01	1.750E+01	1.760E+01	1.770E+01
1.780E+01	1.790E+01	1.800E+01	1.810E+01	1.820E+01	1.830E+01
1.840E+01	1.850E+01	1.860E+01	1.870E+01	1.880E+01	1.890E+01
1.900E+01	1.910E+01	1.920E+01	1.930E+01	1.940E+01	1.950E+01
1.960E+01	1.970E+01	1.980E+01	1.990E+01	2.000E+01	

C

C Multipliers converted from E722-14. The values were taken from the table
 C divided by 95 MeV-mb. The first bin is a zero because the bin goes from
 C 0.0 -- 1.0e-10 Mev (i.e., below the table).

C

EM2 0.000000

1.55757E-02	1.52081E-02	1.48653E-02	1.45460E-02	1.41733E-02	1.37625E-02
1.33856E-02	1.30375E-02	1.26638E-02	1.22736E-02	1.19183E-02	1.15909E-02
1.12923E-02	1.10122E-02	1.07528E-02	1.05108E-02	1.02848E-02	1.00215E-02
9.73084E-03	9.50730E-03	9.25812E-03	8.95570E-03	8.67986E-03	8.42810E-03

8.19695E-03	7.98391E-03	7.76284E-03	7.53775E-03	7.33121E-03	7.14061E-03
6.96547E-03	6.80114E-03	6.64813E-03	6.50521E-03	6.35797E-03	6.20825E-03
6.06873E-03	5.93817E-03	5.79587E-03	5.64534E-03	5.50581E-03	5.37618E-03
5.25540E-03	5.14275E-03	5.03732E-03	4.92539E-03	4.80914E-03	4.70093E-03
4.59982E-03	4.48213E-03	4.35218E-03	4.23284E-03	4.12277E-03	4.00467E-03
3.88132E-03	3.76888E-03	3.66560E-03	3.57108E-03	3.48232E-03	3.40036E-03
3.32386E-03	3.25240E-03	3.16920E-03	3.07725E-03	3.00651E-03	2.92775E-03
2.83209E-03	2.74488E-03	2.66528E-03	2.59218E-03	2.52474E-03	2.45492E-03
2.38367E-03	2.31839E-03	2.25806E-03	2.20276E-03	2.15076E-03	2.10236E-03
2.05716E-03	2.01062E-03	1.96326E-03	1.91909E-03	1.87780E-03	1.83280E-03
1.78523E-03	1.74116E-03	1.70008E-03	1.66188E-03	1.62625E-03	1.59299E-03
1.55757E-03	1.52081E-03	1.48663E-03	1.45461E-03	1.41744E-03	1.37635E-03
1.33856E-03	1.30376E-03	1.26648E-03	1.22746E-03	1.19184E-03	1.15920E-03
1.12933E-03	1.10143E-03	1.07538E-03	1.05128E-03	1.02866E-03	1.00238E-03
9.73372E-04	9.50967E-04	9.26100E-04	8.95725E-04	8.68161E-04	8.42955E-04
8.19818E-04	7.98514E-04	7.76449E-04	7.53920E-04	7.33234E-04	7.14329E-04
6.96660E-04	6.80216E-04	6.64916E-04	6.50624E-04	6.35961E-04	6.20990E-04
6.07028E-04	5.93962E-04	5.79814E-04	5.64740E-04	5.50767E-04	5.37773E-04
5.25674E-04	5.14389E-04	5.03845E-04	4.92591E-04	4.80966E-04	4.70144E-04
4.60033E-04	4.48347E-04	4.35352E-04	4.23408E-04	4.12391E-04	4.00621E-04
3.88255E-04	3.76980E-04	3.66643E-04	3.57190E-04	3.48314E-04	3.40109E-04
3.32458E-04	3.25301E-04	3.17013E-04	3.07787E-04	3.00662E-04	2.92857E-04
2.83281E-04	2.74559E-04	2.66611E-04	2.59321E-04	2.52577E-04	2.45596E-04
2.38460E-04	2.31942E-04	2.25980E-04	2.20492E-04	2.15396E-04	2.10401E-04
2.05974E-04	2.01237E-04	1.96511E-04	1.92043E-04	1.87913E-04	1.83393E-04
1.78647E-04	1.74189E-04	1.70131E-04	1.66435E-04	1.62965E-04	1.59495E-04
1.55952E-04	1.52328E-04	1.48776E-04	1.45646E-04	1.41867E-04	1.37779E-04
1.33939E-04	1.30469E-04	1.26731E-04	1.22818E-04	1.19286E-04	1.16146E-04
1.13067E-04	1.10215E-04	1.07600E-04	1.05190E-04	1.02919E-04	1.00420E-04
9.75328E-05	9.51625E-05	9.27697E-05	8.96560E-05	8.69253E-05	8.43470E-05
8.20622E-05	7.98855E-05	7.76954E-05	7.54302E-05	7.33471E-05	7.14505E-05
6.97114E-05	6.80999E-05	6.65184E-05	6.51212E-05	6.36230E-05	6.21311E-05
6.07214E-05	5.94148E-05	5.79887E-05	5.64864E-05	5.50779E-05	5.37867E-05
5.26159E-05	5.15152E-05	5.04145E-05	4.92943E-05	4.81524E-05	4.70321E-05
4.60436E-05	4.48513E-05	4.35591E-05	4.23482E-05	4.12516E-05	4.00716E-05
3.88329E-05	3.77117E-05	3.67180E-05	3.57440E-05	3.48441E-05	3.40193E-05
3.32573E-05	3.25376E-05	3.17459E-05	3.08325E-05	3.00819E-05	2.93272E-05
2.83449E-05	2.74830E-05	2.66686E-05	2.59468E-05	2.52600E-05	2.45681E-05
2.38535E-05	2.31946E-05	2.25953E-05	2.20445E-05	2.15348E-05	2.10344E-05
2.05927E-05	2.01201E-05	1.96495E-05	1.92037E-05	1.87908E-05	1.83409E-05
1.78662E-05	1.74214E-05	1.70126E-05	1.66420E-05	1.62940E-05	1.59460E-05
1.55918E-05	1.52314E-05	1.48772E-05	1.45653E-05	1.41895E-05	1.37807E-05
1.33987E-05	1.30528E-05	1.26801E-05	1.22888E-05	1.167019E-05	5.03532E-05
8.89733E-05	1.18762E-04	1.39545E-04	1.58867E-04	1.77199E-04	1.98510E-04
2.23623E-04	2.44503E-04	2.68372E-04	2.99996E-04	3.29057E-04	3.56978E-04
3.82268E-04	4.07915E-04	4.40240E-04	4.74322E-04	5.06465E-04	5.40721E-04
5.74152E-04	6.06365E-04	6.38431E-04	6.69660E-04	7.03791E-04	7.40847E-04
7.77772E-04	8.14580E-04	8.57309E-04	9.06093E-04	9.54732E-04	1.00319E-03
1.05136E-03	1.09936E-03	1.14732E-03	1.20080E-03	1.26001E-03	1.31912E-03
1.37803E-03	1.45111E-03	1.53684E-03	1.62222E-03	1.70953E-03	1.81087E-03
1.92603E-03	2.03952E-03	2.15299E-03	2.26656E-03	2.37969E-03	2.49801E-03
4.51085E-03	2.71857E-03	2.85459E-03	3.02134E-03	3.16071E-03	3.32388E-03
3.54249E-03	3.76114E-03	3.97919E-03	4.19489E-03	4.40989E-03	4.64959E-03
4.91553E-03	5.18080E-03	5.76655E-03	5.71228E-03	5.96899E-03	6.22895E-03
6.48781E-03	6.77175E-03	7.07769E-03	7.38125E-03	7.68486E-03	8.03793E-03
8.43680E-03	8.83330E-03	9.22970E-03	9.62022E-03	1.00070E-02	1.03939E-02
1.08230E-02	1.12956E-02	1.17672E-02	1.22307E-02	1.28056E-02	1.34802E-02
1.41499E-02	1.48221E-02	1.63844E-02	1.64225E-02	1.72639E-02	1.80731E-02
1.88761E-02	1.96463E-02	2.03818E-02	2.11167E-02	2.18512E-02	2.27297E-02
2.36990E-02	2.45038E-02	2.54330E-02	2.65667E-02	2.75268E-02	2.83613E-02
2.90652E-02	3.40727E-02	2.96320E-02	2.91159E-02	2.76583E-02	2.44691E-02
1.75353E-02	1.46827E-02	5.13874E-01	1.19065E-01	8.16815E-02	7.05739E-02
6.79182E-02	6.32046E-02	6.13096E-02	5.96606E-02	5.82183E-02	5.70107E-02

5.51506E-02	5.32817E-02	5.11391E-02	4.81835E-02	4.45454E-02	4.03846E-02
3.55231E-02	2.86544E-02	1.98594E-02	1.20505E-02	1.05463E-02	4.62102E-02
2.14986E-01	7.02148E-01	1.20361E+00	1.17122E+00	9.83451E-01	8.42466E-01
7.47732E-01	6.85119E-01	6.31864E-01	5.91761E-01	5.69296E-01	5.54063E-01
5.38453E-01	5.34761E-01	5.25067E-01	5.18936E-01	5.46879E-01	5.55297E-01
5.60685E-01	5.74050E-01	5.90609E-01	6.16980E-01	7.77633E-01	1.30371E+00
6.15364E-01	5.61832E-01	5.78703E-01	5.92754E-01	6.16933E-01	6.86794E-01
9.41435E-01	1.48004E+00	8.47729E-01	9.59852E-01	1.19054E+00	1.19132E+00
8.17177E-01	6.70801E-01	9.78152E-01	9.52438E-01	1.09001E+00	1.14820E+00
1.78997E+00	8.46446E-01	1.41903E+00	1.40100E+00	1.02847E+00	1.16636E+00
1.13472E+00	1.11477E+00	1.27780E+00	1.39400E+00	1.24739E+00	1.16306E+00
1.45273E+00	1.07111E+00	1.29041E+00	1.44375E+00	1.29872E+00	1.23317E+00
1.27315E+00	1.22789E+00	7.58446E-01	1.25241E+00	1.20408E+00	1.47227E+00
1.44952E+00	1.16501E+00	1.80877E+00	1.46506E+00	1.53102E+00	1.52239E+00
1.70086E+00	2.03852E+00	1.74664E+00	1.60348E+00	1.64040E+00	1.86691E+00
1.64041E+00	1.36477E+00	1.30509E+00	1.60157E+00	1.64866E+00	1.97580E+00
1.83308E+00	1.50230E+00	1.70387E+00	1.39707E+00	1.94091E+00	1.68195E+00
1.55411E+00	1.35494E+00	1.65603E+00	1.82642E+00	1.61556E+00	1.56021E+00
1.82610E+00	1.51158E+00	1.85547E+00	1.86522E+00	1.84254E+00	1.81227E+00
1.84230E+00	1.91506E+00	1.91426E+00	2.05434E+00	1.87027E+00	1.71552E+00
1.79165E+00	1.81663E+00	1.82920E+00	1.81748E+00	1.81000E+00	1.62471E+00
1.73598E+00	1.94117E+00	1.93738E+00	1.72941E+00	1.66928E+00	1.81030E+00
1.88525E+00	1.82935E+00	1.73036E+00	1.76877E+00	1.81619E+00	1.84188E+00
1.82281E+00	1.84493E+00	1.82758E+00	1.83570E+00	1.77195E+00	1.75947E+00
1.73736E+00	1.78882E+00	1.82892E+00	1.82795E+00	1.79954E+00	1.74392E+00
1.75631E+00	1.80029E+00	1.83133E+00	1.84432E+00	1.83379E+00	1.81803E+00
1.82137E+00	1.83499E+00	1.85249E+00	1.88120E+00	1.88472E+00	1.89192E+00
1.86042E+00	1.82722E+00	1.90765E+00	1.92752E+00	1.92122E+00	1.92482E+00
1.93397E+00	1.90031E+00	1.86591E+00	1.87907E+00	1.91261E+00	1.87590E+00
1.85306E+00	1.87820E+00	1.94491E+00	1.88259E+00	1.86124E+00	1.89206E+00
1.90502E+00	1.91799E+00	1.91962E+00	1.86539E+00	1.84049E+00	1.84972E+00
1.88416E+00	1.89047E+00	1.85078E+00	1.87923E+00	1.92143E+00	1.92018E+00
1.90790E+00	1.88826E+00	1.88648E+00	1.89792E+00	1.94004E+00	1.97417E+00
1.98258E+00	1.98301E+00	1.97681E+00	1.96412E+00	1.95437E+00	2.00352E+00
2.05676E+00	2.03904E+00	2.01660E+00	2.02240E+00	2.02842E+00	2.02573E+00
2.02355E+00	2.02506E+00	2.02279E+00	2.00808E+00	1.99718E+00	2.00538E+00
2.01802E+00	2.04396E+00	2.06781E+00	2.05912E+00	2.04411E+00	2.03215E+00
2.02145E+00	2.04099E+00	2.08215E+00	2.10505E+00	2.09645E+00	2.08648E+00
2.07273E+00	2.05878E+00	2.05396E+00	2.05260E+00	2.05291E+00	2.05555E+00
2.05880E+00	2.06489E+00	2.07151E+00	2.07813E+00		

C

C

C

FC12 1-MeV(Si) Equivalent Fluence (1-MeV DES [E722-14])

C

C

C

E12

89 Groups

1.38880e-10	1.00000e-09	5.00000e-09	1.00000e-08	3.00000e-08
7.00000e-08	1.00000e-07	1.52300e-07	2.00000e-07	4.13990e-07
6.00000e-07	8.00000e-07	1.12530e-06	3.05900e-06	5.04350e-06
8.31530e-06	1.37100e-05	2.26030e-05	3.72660e-05	6.14420e-05
1.01300e-04	1.67020e-04	2.75360e-04	3.53580e-04	4.54000e-04
5.82950e-04	7.48520e-04	9.61120e-04	1.08910e-03	1.23410e-03
1.39840e-03	1.58460e-03	1.79560e-03	2.03470e-03	2.30560e-03
2.61260e-03	2.96040e-03	3.35460e-03	3.80130e-03	4.30740e-03
4.88100e-03	5.53080e-03	6.26730e-03	7.10170e-03	8.04730e-03
9.11880e-03	1.03330e-02	1.17090e-02	1.32680e-02	1.50340e-02
1.70360e-02	1.93040e-02	2.18750e-02	2.47880e-02	2.60580e-02
2.80880e-02	3.18280e-02	4.08680e-02	5.24750e-02	6.73790e-02
8.65170e-02	1.11090e-01	1.42640e-01	1.83160e-01	2.35180e-01
3.01970e-01	3.87740e-01	4.39370e-01	4.97870e-01	5.64160e-01
6.39280e-01	7.24400e-01	8.20850e-01	9.30140e-01	1.05400e+00
1.19430e+00	1.35340e+00	1.73770e+00	2.23130e+00	2.86510e+00

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3.67880e+00 4.72370e+00 6.06530e+00 7.78800e+00 1.00000e+01
1.19120e+01 1.34990e+01 1.49180e+01 1.69050e+01 2.00000e+01
C
C Description: This free field response was extracted from the draft
C SAND report by P. J. Griffin that documents the relationship
C between displacement damage in materials and the metrics that
C attempt to describe the damage. The values in Table 3 of the
C SAND report for energies below 20 MeV were divided by 95 Mev-mbarn.
C The reference value of 95 +/- 4 MeV-mbarn was determined by fitting
C the ASTM E722 displacement kerma data over 0.01 - 15 MeV.
C
C Production: The data from Table 3 was divided by 95 MeV-mbarn and
C an MCNP EM card was produced using 640 groups (SAND-II format see
C above). The response function below is a response re-binning
C produced by folding the 640 group response bin-by-bin (89 bins).
C
C MCNP Template File: E722-14_fold-template.inp
C
C The first bin is a zero because the bin goes from
C 0.0 -- 1.38880e-10 Mev (i.e., below the table).
C
EM12 0.000000
7.26563E-03 3.08163E-03 1.84723E-03 1.15434E-03 7.20352E-04
5.43212E-04 4.46214E-04 3.76850E-04 2.89097E-04 2.22682E-04
1.89067E-04 1.61412E-04 1.12337E-04 7.90144E-05 6.15139E-05
4.79121E-05 3.73121E-05 2.90663E-05 2.26316E-05 1.76292E-05
1.37299E-05 1.40102E-04 3.05925E-04 4.28032E-04 5.81219E-04
7.66884E-04 9.95812E-04 1.20261E-03 1.36601E-03 1.54063E-03
1.74309E-03 1.96903E-03 2.23127E-03 3.21693E-03 2.84672E-03
3.20089E-03 3.60630E-03 4.05482E-03 4.58558E-03 5.22541E-03
5.84547E-03 6.51372E-03 7.32151E-03 8.20967E-03 9.21528E-03
1.03322E-02 1.15514E-02 1.29221E-02 1.43905E-02 1.64193E-02
1.78369E-02 1.96880E-02 2.17731E-02 2.31555E-02 2.41704E-02
2.59869E-02 2.96832E-02 2.54049E-02 1.45665E-01 6.06114E-02
5.00769E-02 2.50824E-02 3.33327E-01 9.46508E-01 5.91308E-01
5.30683E-01 5.54795E-01 5.78093E-01 8.23389E-01 6.88925E-01
6.02708E-01 9.63792E-01 1.03145E+00 1.02806E+00 7.18846E-01
9.58555E-01 1.24661E+00 1.19467E+00 1.24988E+00 1.22195E+00
1.45608E+00 1.66953E+00 1.70773E+00 1.81600E+00 1.80517E+00
1.88826E+00 1.88371E+00 1.94737E+00 2.04764E+00
C

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APPENDIX C: NUGET FREE-FIELD E722 RESPONSES

```

23  1  0
    '1-MeV[Si] from ASTM E722-14 (1-MeV[Si])'  1      0.00
    '(1-MeV[Si])'
    '1-MeV[Si] from ASTM E722-14'
*****
*
* Response: Free-Field 1-MeV(Si) Equivalent Fluence from E722-14
*
* Description: This free field response was extracted from the draft
* SAND report by P. J. Griffin that documents the relationship
* between displacement damage in materials and the metrics that
* attempt to describe the damage. The values in Table 3 of the
* SAND report for energies below 20 MeV were divided by 95 Mev-mb.
* The reference value of 95 +/- 4 MeV-mb was determined by fitting
* the ASTM E722 displacement kerma data over 0.01 - 15 MeV.
*
* Production: The data from Table 3 was divided by 95 MeV-mb and
* an MCNP EM card was produced using 640 groups (SAND-II format).
* The response function below is a response re-binning produced by
* folding the 640 group response bin-by-bin (89 bins).
*
* MCNP Template File:  E722-14_fold-template.inp
*
* NOTES: This response will have equivalent EM cards for MCNP in
* both 640 and 89 groups.
*
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1.70773E+00  1.66953E+00  1.45608E+00  1.22195E+00  1.24988E+00  1.19467E+00
1.24661E+00  9.58555E-01  7.18846E-01  1.02806E+00  1.03145E+00  9.63792E-01
6.02708E-01  6.88925E-01  8.23389E-01  5.78093E-01  5.54795E-01  5.30683E-01
5.91308E-01  9.46508E-01  3.33327E-01  2.50824E-02  5.00769E-02  6.06114E-02
1.45665E-01  2.54049E-02  2.96832E-02  2.59869E-02  2.41704E-02  2.31555E-02
2.17731E-02  1.96880E-02  1.78369E-02  1.64193E-02  1.43905E-02  1.29221E-02
1.15514E-02  1.03322E-02  9.21528E-03  8.20967E-03  7.32151E-03  6.51372E-03
5.84547E-03  5.22541E-03  4.58558E-03  4.05482E-03  3.60630E-03  3.20089E-03
2.84672E-03  3.21693E-03  2.23127E-03  1.96903E-03  1.74309E-03  1.54063E-03
1.36601E-03  1.20261E-03  9.95812E-04  7.66884E-04  5.81219E-04  4.28032E-04
3.05925E-04  1.40102E-04  1.37299E-05  1.76292E-05  2.26316E-05  2.90663E-05
3.73121E-05  4.79121E-05  6.15139E-05  7.90144E-05  1.12337E-04  1.61412E-04
1.89067E-04  2.22682E-04  2.89097E-04  3.76850E-04  4.46214E-04  5.43212E-04
7.20352E-04  1.15434E-03  1.84723E-03  3.08163E-03  7.26563E-03

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