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Silicon Damage Response Function Derivation and Verification: Assessment of Impact on ASTM Standard E722

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Prepared by
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Abstract

Unsuccessful attempts by members of the radiation effects community to independently derive the Norgett-Robinson-Torrens (NRT) damage energy factors for silicon in ASTM standard E722-14 led to an investigation of the software coding and data that produced those damage energy factors. The ad hoc collaboration to discover the reason for lack of agreement revealed a coding error and resulted in a report documenting the methodology to produce the response function for the standard. The recommended changes in the NRT damage energy factors for silicon are shown to have significant impact for a narrow energy region of the 1-MeV(Si) equivalent fluence response function. However, when evaluating integral metrics over all neutrons energies in various spectra important to the SNL electronics testing community, the change in the response results in a small decrease in the total 1-MeV(Si) equivalent fluence of ~0.6% compared to the E722-14 response. Response functions based on the newly recommended NRT damage energy factors 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
MCNP	Monte Carlo N-Particle
NRT	Norgett-Robinson-Torrens
NuGET	Neutron Gamma Energy Transport
SNL	Sandia National Laboratories
SPR-III	Sandia Pulse Reactor – III
WSMR FBR	White Sands Missile Range Fast Burst Reactor

1. INTRODUCTION

In 2014, ASTM Committee E10 completed the revision of E722 – 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. Shortly after the publication of the new 1-MeV(Si) equivalent fluence metric, an evaluation of the impact on radiation damage metrics used by the electronics testing community for neutron test environments was performed [2]. In addition to the SNL evaluation, others in the radiation effects community attempted to derive the Norgett-Robinson-Torrens (NRT) damage energy factors found in ASTM E722 Appendix A.1 without success [3].

The attempt to reconcile the published NRT damage energy factors for silicon between researchers identified a software coding mistake that resulted in erroneous data being published as part of the 2014 changes to E722 [4]. As part of the correspondence to reconcile data differences [3], Griffin produced a new set of NRT damage energy factors for silicon that were verified by Frisoni. The result of the correspondence and collaboration to identify the proper treatment and coding was a SAND report that provides a detailed description of the process used in the production of the NRT damage energy factors for silicon that eventually make their way in the E722 publication [4].

This document will evaluate the difference between the NRT damage energy factors for silicon published by Griffin [4] and the values found in E722-14 [1]. Although ASTM produces consensus standards that must be evaluated by the appropriate interested parties, this document assumes that the new damage energy factors will become part of the E722 document in the not too distant future (perhaps by the end of 2016). As part of the evaluation in this document, there will be some guidance on how an updated E722 standard using the values from Griffin [4] will impact the radiation damage metric used by the electronics testing community for neutron test environments when compared to the values from the E722-14 version of the standard. In addition, this document provides users of the NuGET code [5] and the MCNP code [6] with free-field radiation response functions for the 1-MeV(Si) equivalent fluence based on newly published silicon NRT damage energy factors that can be utilized for radiation damage calculations with those codes.

2. DATA PROCESSING

In SAND2016-2269, Griffin produced the relevant data for the electronics testing community for neutron test environments in Table 6 of the SAND report. The data found in that table is provided as a ^{nat}Si NRT damage energy 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. Therefore, the values in Table 6 of SAND2016-2269 must be divided by 95 MeV-mbarn to produce the 1-MeV(Si) equivalent fluence response function typically used by the neutron environment testing community.

Once the values in Table 6 have been converted from NRT damage energy 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 6 of SAND2016-2269 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.

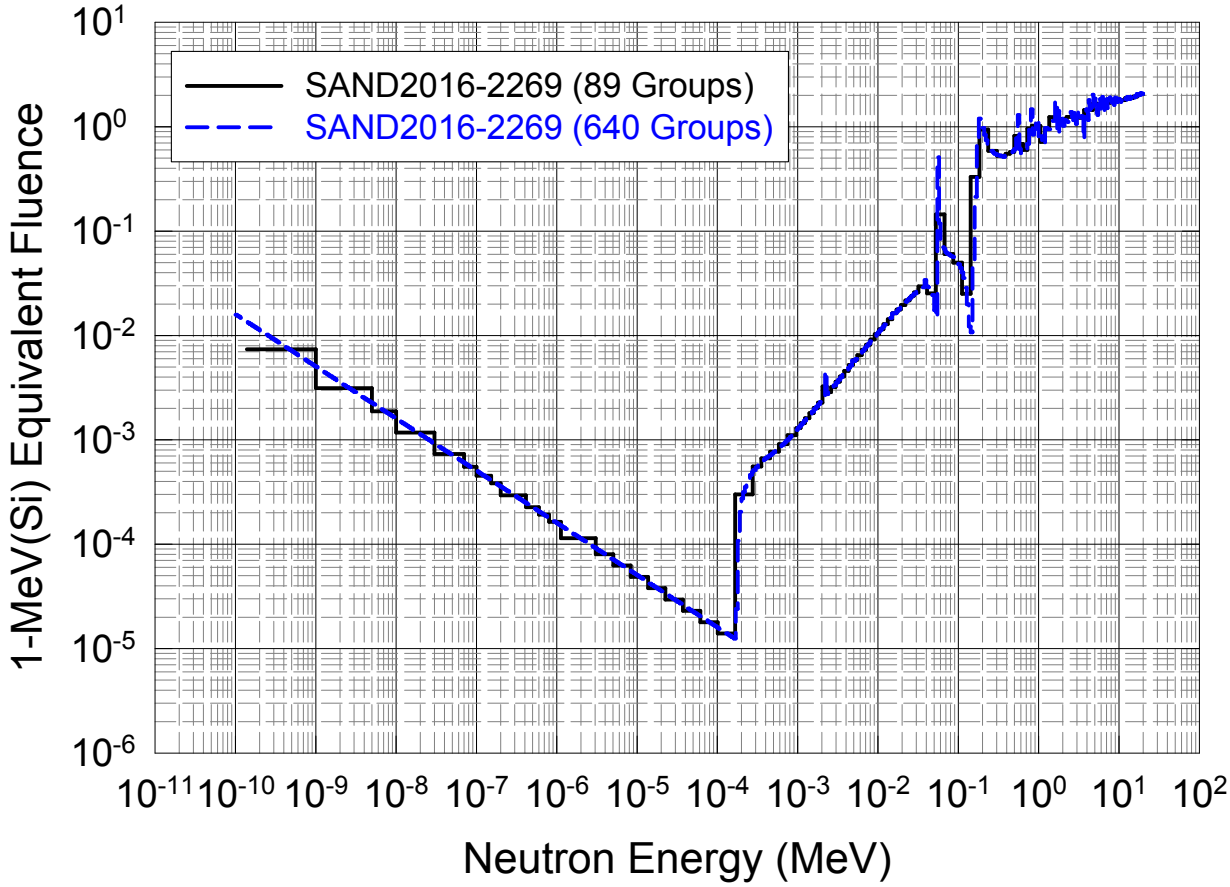

Figure 1 – 1-MeV(Si) Equivalent Fluence from SAND2016-2269 in 640- and 89-groups.

3. RESPONSE FUNCTION COMPARISONS

In order to assess the effect of the updated 1-MeV(Si) equivalent fluence response on radiation environment characterizations, the E722-14 response function was extracted and placed into a NuGET compatible external response function. In addition to the E722-14 response, the proposed E722 response from Griffin [4] 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 feature that produces 89-group histograms for each response in a calculation. So, the histograms were produced for the E722-14 and the proposed E722 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 are significant changes to the response function in region between ~0.15 - 2.0 keV. 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 proposed change modifies the current standard over the full energy range.

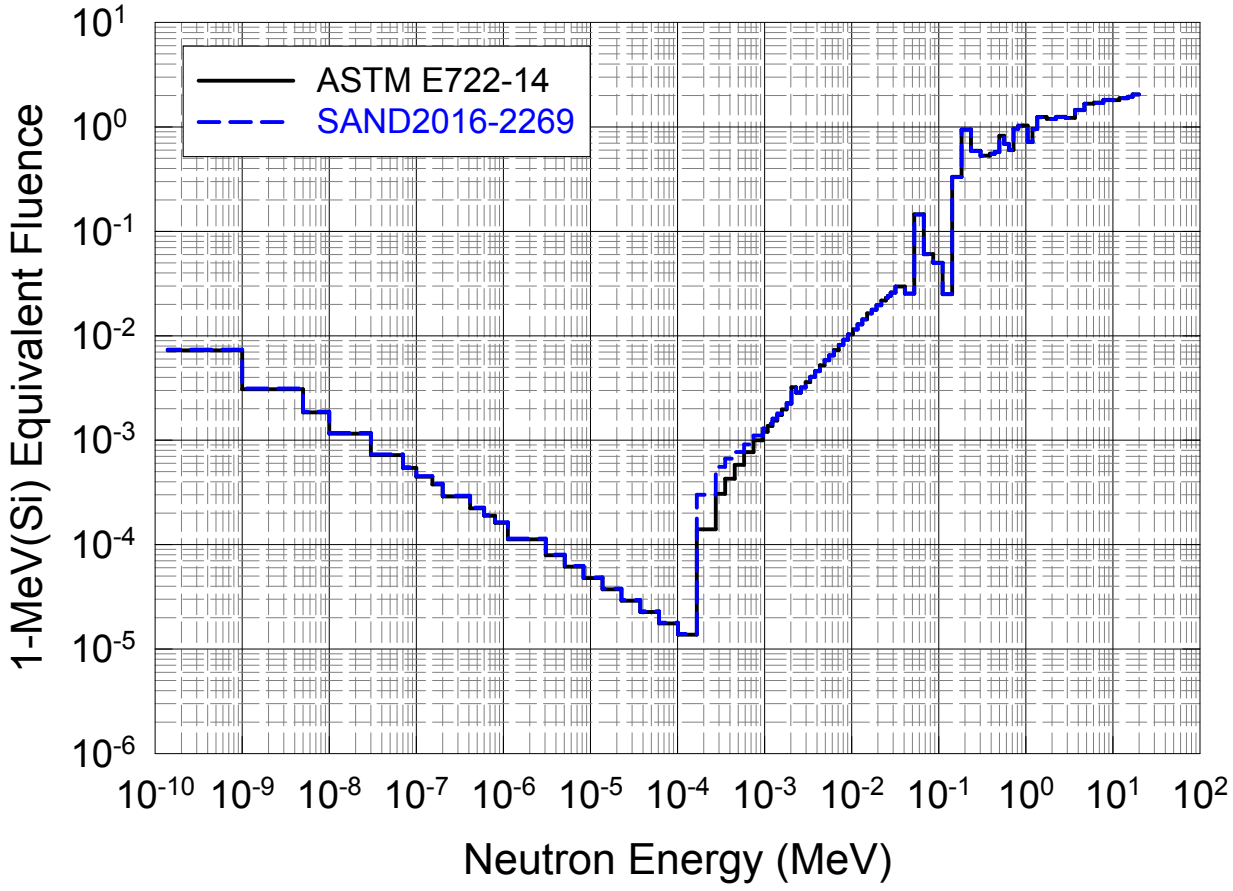

Figure 2 – NuGET Response Histograms for E722-14 and SAND2016-2269 Response

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 response given by X):

$$\Delta_i = R_{i,SAND2016-2269} - R_{i,E722-14} \quad \text{where } i = 1,\ 2, \text{K}\ ,89 \text{ * MERGEFORMAT (1)}$$

The resulting Δ values are plotted as a histogram below in Figure 3. In Figure 3, the changes noticed in Figure 2 are obscured because the weight of neutrons in the energy region near the threshold is much less than the neutrons at higher energies. Therefore, another method of examining the differences between E722-14 and SAND2016-2269 responses is needed.

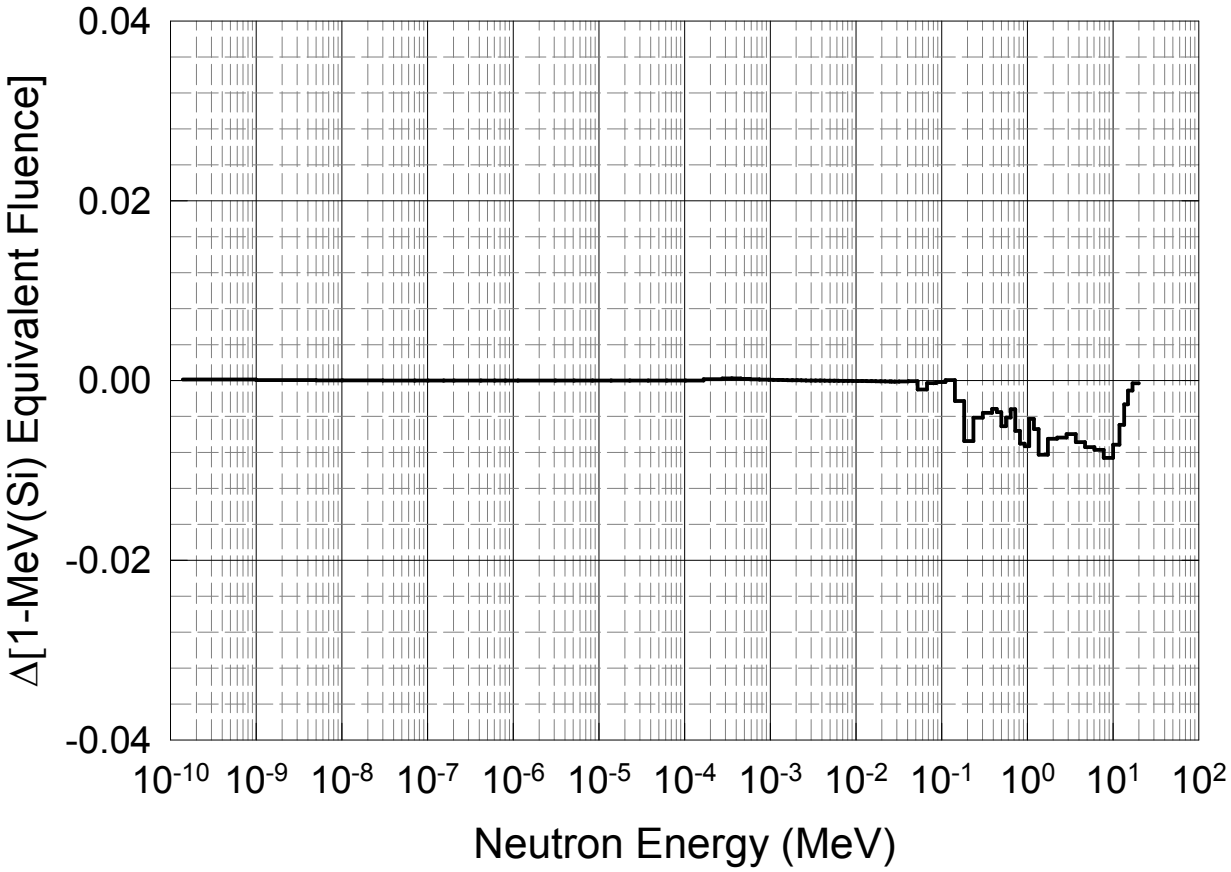

Figure 3 – Histogram of Δ's of E722 Responses

The percent difference method was utilized to demonstrate the difference between E722-14 and SAND2016-2269 responses. The percent difference between the two responses was evaluated using this equation:

$$\left(\%\ Difference\right)_i = \left(\frac{R_{i,SAND2016-2269} - R_{i,E722-14}}{R_{i,E722-14}}\right) \times 100 \quad \text{where } i = 1,\ 2, \text{K}\ ,89 \text{* MERGEFORM}$$

The resulting percent difference values are plotted as a histogram below in Figure 4. The figure finally allows one to examine where the changes discussed in SAND2016-2269 had the most significant effect on the 1-MeV(Si) equivalent fluence response. The figure shows differences greater than 100% in the region between 0.15 keV – 0.3 keV. It also shows the large differences in the region between 0.15 – 2.0 keV observed above in Figure 2. The response function differs by less than 10% in the rest of the energy ranges. The large difference found in this region is a consequence of the proper software coding for the silicon damage function near the silicon displacement threshold energy.

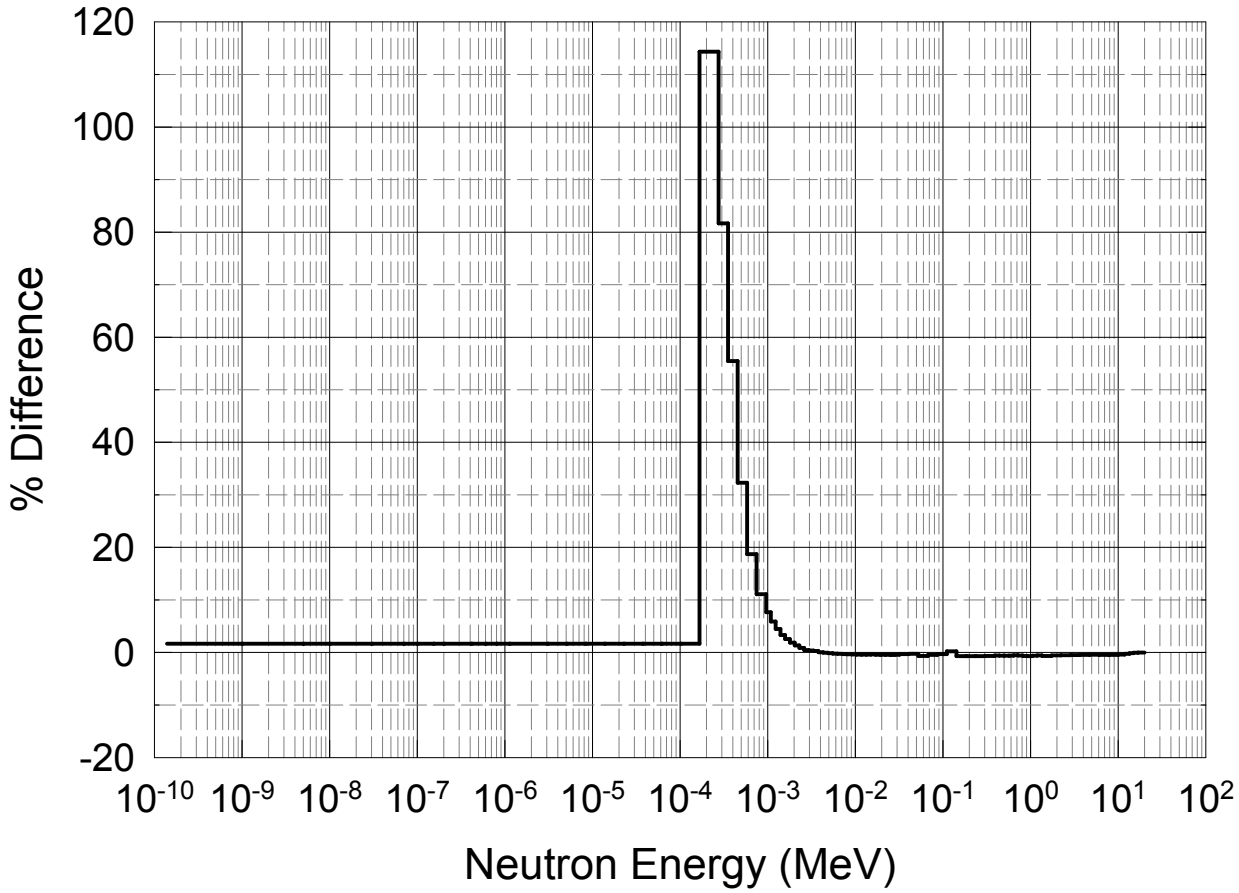

Figure 4 – Histogram of Percent Difference of E722 Responses

As one final look at the differences between SAND2016-2269 and E722-14, the ratio of the two responses was computed and plotted as a histogram. The histograms of the ratios are found in Figure 5.

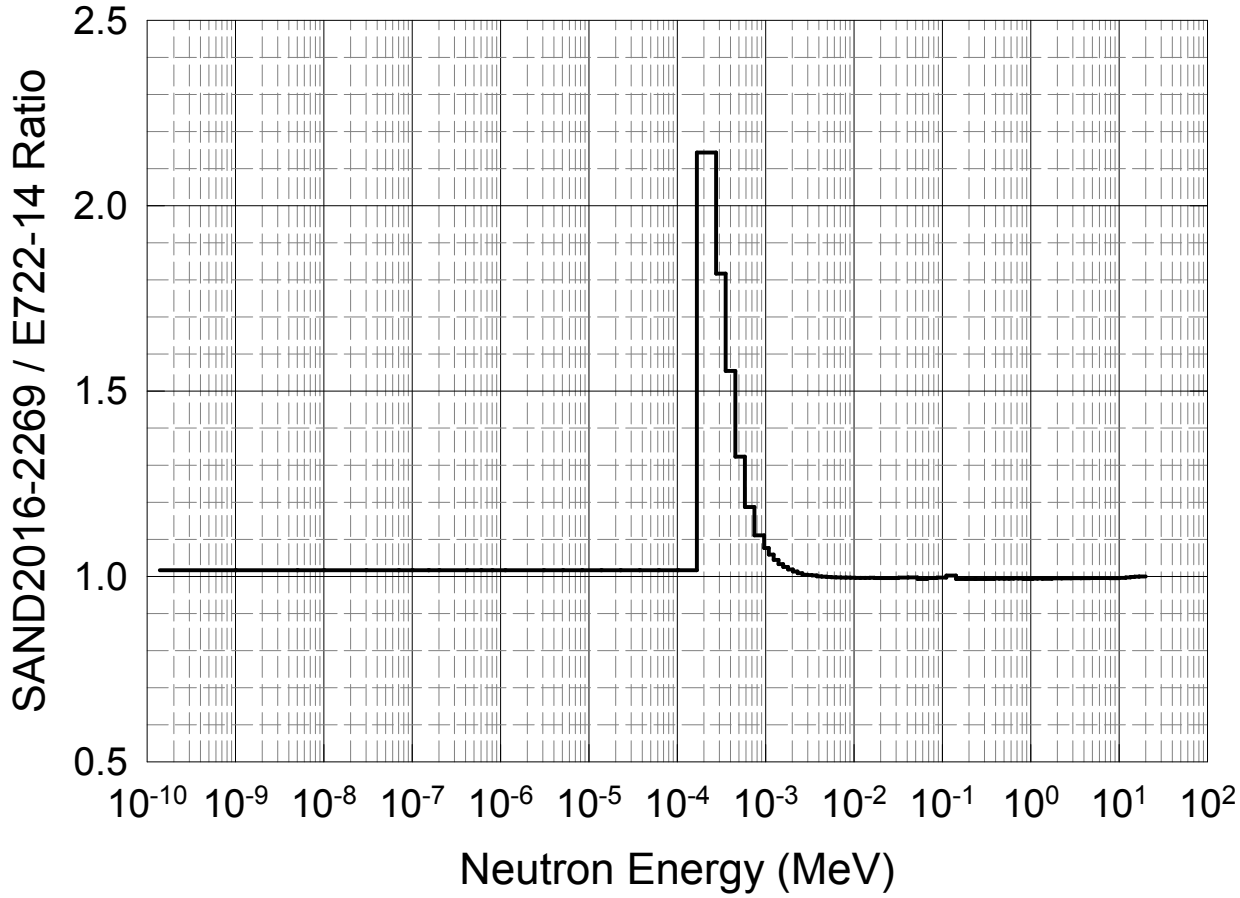

Figure 5 – Histogram of Ratios of E722 Responses

4. INTEGRAL METRIC COMPARISONS

The previous section documented how the recommended neutron NRT damage energy factors for silicon from SAND2016-2269 would modify the 1-MeV(Si) equivalent fluence response function that is generated from ASTM E722-14. With only the data in Figure 4 and Figure 5, one would expect that radiation damage metrics would change a great deal if ASTM E10 adopted the recommended damage energy factors. In order to put those changes into context of actual neutron irradiations, the integral radiation damage metric was evaluated for a few neutron spectra using the E722-09, E722-14, and SAND2016-2269 1-MeV(Si) equivalent fluence response functions. First, the response functions were folded with three different reactor spectra of interest to the Sandia National Laboratories electronics testing community (ACRR Pb-B_4C bucket, WSMR FBR at 6" from the reactor, and SPR-III Central Cavity). The source / response folding was performed using MCNP. The results of these source / response fold calculations are found in Table 1.

Table 1 – Integral Metrics from Source / Response Folding

Spectrum	E722-09	E722-14	SAND2016-2269	SAND Ratio to E722-09	SAND Ratio to E722-14
ACRR-PbB	5.40978E-01	5.52866E-01	5.49599E-01	1.0159	0.9941
SPR3-CC	8.42353E-01	8.62282E-01	8.57232E-01	1.0177	0.9941
WSMR-FBR	8.92206E-01	9.14821E-01	9.09561E-01	1.0195	0.9943

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.

A similar evaluation was performed to examine the change in the damage response methodology when E722-14 was published [2]. The previous work showed that the integral metrics for reactor spectra were 2 – 3% higher when the E722-14 response was used versus E722-09. Those differences can be extracted from the table. It is informative to note that, although the changes to the kerma factors recommended by SAND2016-2269 appear dramatic, the overall effect on the integral metrics is less than 0.6% for three of the environments of interests to the radiation effects community.

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 the effect of spectrum moderation on the integral metrics, the NuGET $4\pi R^2$ 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 recommended 1-MeV(Si) equivalent fluence response from SAND2016-2269 is the numerator for these calculations that are shown in Figure 6 (i.e., $R_{SAND2016-2269}(\rho R) \Big/ R_{E722-14}(\rho R)$ is plotted in the figure).

Figure 6 shows that the integral metric for the recommended response in SAND2016-2269 will be smaller than the E722-14 by less than 0.6% for the full range of areal densities covered by the $4\pi R^2$ calculation mode. Figure 6 and Table 1 also demonstrates that the recommended NRT damage energy factors in SAND2016-2269 will have little effect on the integral metrics for most (if not all) folded or transported sources.

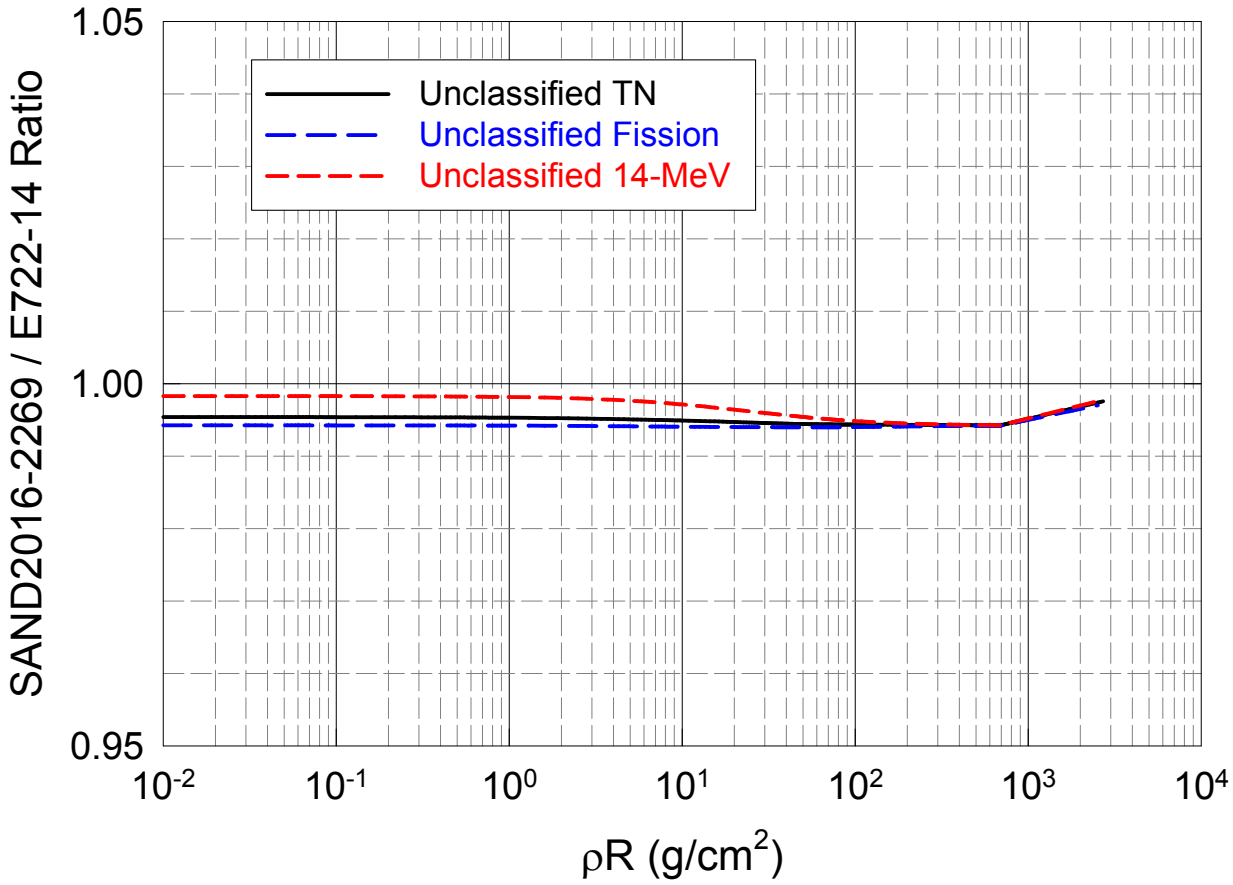

Figure 6 – $4\pi R^2$ Ratios for Different Unclassified NuGET Sources

4. SUMMARY AND CONCLUSIONS

Unsuccessful attempts by members of the radiation effects community to independently derive the NRT damage energy factors for silicon in ASTM standard E722-14 led to an investigation of the software coding and data that produced those damage energy factors. The collaboration revealed a coding error and resulted in a SAND report documenting the methodology to produce the response function for the standard [4]. The collaboration to understand the differences led to an independent verification of the silicon NRT damage energy factors [3].

The recommended silicon NRT damage energy factors from SAND2016-2269 were extracted and processed so that comparisons with previous and current versions of E722 could be made. Thus, the response function based on the NRT damage energy factors for silicon in SAND2016-2269 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. A cursory examination of the percent difference and ratios might lead users to expect a significant impact on integral metrics. However, the integral metrics obtained using SAND2016-2269 from neutron sources with a wide energy range will result in values ~0.6% less than the E722-14 based responses. The NuGET free-field responses and MCNP EM cards are available to users upon request.

5. REFERENCES

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APPENDIX A: MCNP TEMPLATE FOR 89-GROUP RESPONSE FUNCTION

```
Rebin Griffin SAND2016-2269 Response from 640 groups to NuGET 89-groups
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 *                               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 34567890123456789012345678901234567890123456789012345678901234567890123456789
C ******************************************************************************
C *                                 DATA CARDS                                 *
C ******************************************************************************
C
MODE N
NPS  2e6
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
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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
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5.750E-07 6.000E-07 6.300E-07 6.600E-07 6.900E-07 7.200E-07
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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
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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
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

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      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 SAND2016-2269. The values were taken from the
C   table divided by 95 MeV-mb. The first bin is a zero because the bin goes
C   from 0.0 -- 1.0e-10 Mev (i.e., below the table).
C
EM2   0.000000
      1.58357E-02 1.54626E-02 1.51142E-02 1.47894E-02 1.44102E-02 1.39929E-02
      1.36085E-02 1.32550E-02 1.28757E-02 1.24790E-02 1.21173E-02 1.17853E-02
      1.14811E-02 1.11963E-02 1.09323E-02 1.06866E-02 1.04564E-02 1.01892E-02
      9.89360E-03 9.66626E-03 9.41292E-03 9.10551E-03 8.82504E-03 8.56903E-03
      8.33408E-03 8.11743E-03 7.89266E-03 7.66378E-03 7.45390E-03 7.26007E-03
      7.08197E-03 6.91495E-03 6.75935E-03 6.61393E-03 6.46438E-03 6.31217E-03
      6.17024E-03 6.03745E-03 5.89275E-03 5.73971E-03 5.59789E-03 5.46603E-03
      5.34330E-03 5.22871E-03 5.12162E-03 5.00774E-03 4.88965E-03 4.77959E-03
      4.67680E-03 4.55708E-03 4.42491E-03 4.30363E-03 4.19170E-03 4.07166E-03
      3.94627E-03 3.83189E-03 3.72685E-03 3.63076E-03 3.54052E-03 3.45717E-03
      3.37947E-03 3.30681E-03 3.22212E-03 3.12870E-03 3.05676E-03 2.97669E-03
      2.87947E-03 2.79077E-03 2.70979E-03 2.63548E-03 2.56703E-03 2.49591E-03
      2.42355E-03 2.35716E-03 2.29591E-03 2.23958E-03 2.18675E-03 2.13753E-03
      2.09158E-03 2.04421E-03 1.99611E-03 1.95119E-03 1.90926E-03 1.86353E-03
      1.81512E-03 1.77021E-03 1.72858E-03 1.68973E-03 1.65345E-03 1.61964E-03
      1.58357E-03 1.54626E-03 1.51142E-03 1.47894E-03 1.44112E-03 1.39930E-03
      1.36096E-03 1.32560E-03 1.28768E-03 1.24800E-03 1.21183E-03 1.17863E-03
      1.14821E-03 1.11985E-03 1.09343E-03 1.06886E-03 1.04585E-03 1.01914E-03
      9.89657E-04 9.66872E-04 9.41590E-04 9.10706E-04 8.82679E-04 8.57047E-04
      8.33531E-04 8.11867E-04 7.89440E-04 7.66532E-04 7.45504E-04 7.26275E-04
      7.08309E-04 6.91598E-04 6.76038E-04 6.61505E-04 6.46593E-04 6.31372E-04
      6.17179E-04 6.03900E-04 5.89511E-04 5.74187E-04 5.59974E-04 5.46767E-04
      5.34464E-04 5.22995E-04 5.12274E-04 5.00826E-04 4.89006E-04 4.78010E-04
      4.67732E-04 4.55851E-04 4.42634E-04 4.30496E-04 4.19284E-04 4.07320E-04
      3.94751E-04 3.83291E-04 3.72777E-04 3.63168E-04 3.54135E-04 3.45799E-04
      3.38019E-04 3.30742E-04 3.22315E-04 3.12942E-04 3.05696E-04 2.97762E-04
      2.88019E-04 2.79149E-04 2.71071E-04 2.63660E-04 2.56806E-04 2.49704E-04
      2.42448E-04 2.35819E-04 2.29765E-04 2.24175E-04 2.19005E-04 2.13918E-04
      2.09426E-04 2.04596E-04 1.99796E-04 1.95263E-04 1.91050E-04 1.86466E-04
      1.81635E-04 1.77103E-04 1.72972E-04 1.69220E-04 1.65695E-04 1.62159E-04
      1.58552E-04 1.54873E-04 1.51265E-04 1.48079E-04 1.44245E-04 1.40083E-04
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1.36178E-04 1.32653E-04 1.28850E-04 1.24872E-04 1.21276E-04 1.18089E-04
1.14955E-04 1.12056E-04 1.09394E-04 1.06948E-04 1.04636E-04 1.02099E-04
9.91641E-05 9.67541E-05 9.43214E-05 9.11559E-05 8.83789E-05 8.57571E-05
8.34344E-05 8.12217E-05 7.89955E-05 7.66923E-05 7.45741E-05 7.26460E-05
7.08773E-05 6.92390E-05 6.76316E-05 6.62103E-05 6.46871E-05 6.31702E-05
6.17364E-05 6.04086E-05 5.89585E-05 5.74312E-05 5.59995E-05 5.46870E-05
5.34959E-05 5.23767E-05 5.12585E-05 5.01197E-05 4.89583E-05 4.78186E-05
4.68145E-05 4.56017E-05 4.42882E-05 4.30560E-05 4.19419E-05 4.07415E-05
3.94825E-05 3.83427E-05 3.73315E-05 3.63427E-05 3.54270E-05 3.45884E-05
3.38134E-05 3.30817E-05 3.22770E-05 3.13479E-05 3.05853E-05 2.98175E-05
2.88186E-05 2.79419E-05 2.71146E-05 2.63808E-05 2.56829E-05 2.49790E-05
2.42523E-05 2.35832E-05 2.29728E-05 2.24127E-05 2.18947E-05 2.13860E-05
2.09379E-05 2.04569E-05 1.99779E-05 1.95248E-05 1.91054E-05 1.86481E-05
1.81651E-05 1.77128E-05 1.72967E-05 1.69205E-05 1.65660E-05 1.62124E-05
1.58527E-05 1.54858E-05 1.51261E-05 1.48096E-05 1.44263E-05 1.40111E-05
1.36226E-05 1.32711E-05 1.28919E-05 1.24942E-05 2.39614E-05 1.07906E-04
2.04171E-04 2.73780E-04 3.16175E-04 3.53253E-04 3.86681E-04 4.21170E-04
4.60042E-04 4.91117E-04 5.14163E-04 5.43885E-04 5.81825E-04 6.18763E-04
6.35884E-04 6.51111E-04 6.74614E-04 6.95993E-04 7.13274E-04 7.39202E-04
7.64459E-04 7.87526E-04 8.10705E-04 8.34522E-04 8.60803E-04 8.89317E-04
9.17708E-04 9.47591E-04 9.83668E-04 1.02564E-03 1.06827E-03 1.11212E-03
1.15618E-03 1.20028E-03 1.24439E-03 1.29334E-03 1.34721E-03 1.40146E-03
1.45760E-03 1.52747E-03 1.60580E-03 1.68407E-03 1.76793E-03 1.86644E-03
1.97811E-03 2.08664E-03 2.19695E-03 2.30756E-03 2.41684E-03 2.53068E-03
4.56796E-03 2.74719E-03 2.87888E-03 3.03919E-03 3.17402E-03 3.33698E-03
3.55588E-03 3.77412E-03 3.99133E-03 4.20347E-03 4.41457E-03 4.65001E-03
4.91279E-03 5.17641E-03 5.76545E-03 5.70429E-03 5.95838E-03 6.21612E-03
6.47393E-03 6.75702E-03 7.06091E-03 7.36187E-03 7.66266E-03 8.01261E-03
8.40925E-03 8.80409E-03 9.19871E-03 9.58707E-03 9.97145E-03 1.03559E-02
1.07816E-02 1.12515E-02 1.17193E-02 1.21822E-02 1.27556E-02 1.34271E-02
1.40926E-02 1.47606E-02 1.63288E-02 1.63535E-02 1.71903E-02 1.79960E-02
1.87965E-02 1.95631E-02 2.02949E-02 2.10271E-02 2.17589E-02 2.26333E-02
2.35981E-02 2.43997E-02 2.53244E-02 2.64545E-02 2.74129E-02 2.82468E-02
2.89515E-02 3.40326E-02 2.95229E-02 2.90156E-02 2.75750E-02 2.44144E-02
1.75433E-02 1.47213E-02 5.09988E-01 1.18291E-01 8.12102E-02 7.01960E-02
6.75751E-02 6.28961E-02 6.10219E-02 5.93929E-02 5.79674E-02 5.67785E-02
5.49375E-02 5.30882E-02 5.09672E-02 4.80407E-02 4.44351E-02 4.03126E-02
3.54918E-02 2.86813E-02 1.99581E-02 1.22170E-02 1.07511E-02 4.62761E-02
2.13542E-01 6.96699E-01 1.19547E+00 1.16288E+00 9.76306E-01 8.36354E-01
7.42356E-01 6.80283E-01 6.27390E-01 5.87603E-01 5.65322E-01 5.50207E-01
5.34792E-01 5.31207E-01 5.21362E-01 5.15275E-01 5.43760E-01 5.52250E-01
5.57285E-01 5.70527E-01 5.87016E-01 6.13337E-01 7.73060E-01 1.29491E+00
6.11788E-01 5.58567E-01 5.75790E-01 5.89492E-01 6.13494E-01 6.84314E-01
9.35907E-01 1.46893E+00 8.42410E-01 9.53569E-01 1.18210E+00 1.18260E+00
8.11590E-01 6.67168E-01 9.72439E-01 9.47373E-01 1.08329E+00 1.14072E+00
1.77656E+00 8.41483E-01 1.41115E+00 1.39343E+00 1.02309E+00 1.16012E+00
1.12922E+00 1.10917E+00 1.27143E+00 1.38666E+00 1.24083E+00 1.15705E+00
1.44575E+00 1.06565E+00 1.28388E+00 1.43676E+00 1.29282E+00 1.22741E+00
1.26697E+00 1.22197E+00 7.54634E-01 1.24651E+00 1.19844E+00 1.46531E+00
1.44246E+00 1.15967E+00 1.80025E+00 1.45818E+00 1.52381E+00 1.51525E+00
1.69309E+00 2.02917E+00 1.73856E+00 1.59599E+00 1.63291E+00 1.85857E+00
1.63323E+00 1.35889E+00 1.29944E+00 1.59459E+00 1.64138E+00 1.96707E+00
1.82489E+00 1.49587E+00 1.69639E+00 1.39112E+00 1.93191E+00 1.67437E+00
1.54735E+00 1.34915E+00 1.64875E+00 1.81825E+00 1.60845E+00 1.55311E+00
1.81783E+00 1.50477E+00 1.84692E+00 1.85651E+00 1.83400E+00 1.80373E+00
1.83351E+00 1.90589E+00 1.90519E+00 2.04447E+00 1.86128E+00 1.70738E+00
1.78311E+00 1.80801E+00 1.82052E+00 1.80889E+00 1.80149E+00 1.61715E+00
1.72780E+00 1.93189E+00 1.92808E+00 1.72116E+00 1.66134E+00 1.80162E+00
1.87617E+00 1.82058E+00 1.72227E+00 1.76051E+00 1.80767E+00 1.83335E+00
1.81440E+00 1.83649E+00 1.81937E+00 1.82761E+00 1.76436E+00 1.75203E+00
1.73014E+00 1.78155E+00 1.82147E+00 1.82069E+00 1.79256E+00 1.73735E+00
1.74987E+00 1.79367E+00 1.82479E+00 1.83780E+00 1.82752E+00 1.81199E+00
1.81552E+00 1.82926E+00 1.84679E+00 1.87548E+00 1.87909E+00 1.88639E+00

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      1.85527E+00 1.82244E+00 1.90261E+00 1.92251E+00 1.91638E+00 1.92016E+00
      1.92932E+00 1.89603E+00 1.86199E+00 1.87516E+00 1.90867E+00 1.87232E+00
      1.84978E+00 1.87497E+00 1.94136E+00 1.87961E+00 1.85846E+00 1.88925E+00
      1.90233E+00 1.91531E+00 1.91721E+00 1.86328E+00 1.83876E+00 1.84800E+00
      1.88231E+00 1.88871E+00 1.84936E+00 1.87777E+00 1.91977E+00 1.91878E+00
      1.90663E+00 1.88720E+00 1.88558E+00 1.89703E+00 1.93905E+00 1.97305E+00
      1.98157E+00 1.98208E+00 1.97594E+00 1.96339E+00 1.95377E+00 2.00266E+00
      2.05575E+00 2.03815E+00 2.01602E+00 2.02181E+00 2.02783E+00 2.02521E+00
      2.02311E+00 2.02460E+00 2.02250E+00 2.00792E+00 1.99708E+00 2.00520E+00
      2.01776E+00 2.04368E+00 2.06729E+00 2.05877E+00 2.04380E+00 2.03199E+00
      2.02125E+00 2.04074E+00 2.08172E+00 2.10449E+00 2.09594E+00 2.08593E+00
      2.07233E+00 2.05852E+00 2.05368E+00 2.05240E+00 2.05270E+00 2.05534E+00
      2.05849E+00 2.06460E+00 2.07122E+00 2.07775E+00
C
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APPENDIX B: MCNP EM CARDS FOR PROPOSED E722 RESPONSES

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C
C
FC2   1-MeV(Si) Equivalent Fluence (1-MeV DES [E722])
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
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      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 SAND2016-2269. The values were taken from the
C   table divided by 95 MeV-mb. The first bin is a zero because the bin goes
C   from 0.0 -- 1.0e-10 Mev (i.e., below the table).
C
EM2   0.000000
      1.58357E-02 1.54626E-02 1.51142E-02 1.47894E-02 1.44102E-02 1.39929E-02
      1.36085E-02 1.32550E-02 1.28757E-02 1.24790E-02 1.21173E-02 1.17853E-02
      1.14811E-02 1.11963E-02 1.09323E-02 1.06866E-02 1.04564E-02 1.01892E-02
      9.89360E-03 9.66626E-03 9.41292E-03 9.10551E-03 8.82504E-03 8.56903E-03
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8.33408E-03 8.11743E-03 7.89266E-03 7.66378E-03 7.45390E-03 7.26007E-03
7.08197E-03 6.91495E-03 6.75935E-03 6.61393E-03 6.46438E-03 6.31217E-03
6.17024E-03 6.03745E-03 5.89275E-03 5.73971E-03 5.59789E-03 5.46603E-03
5.34330E-03 5.22871E-03 5.12162E-03 5.00774E-03 4.88965E-03 4.77959E-03
4.67680E-03 4.55708E-03 4.42491E-03 4.30363E-03 4.19170E-03 4.07166E-03
3.94627E-03 3.83189E-03 3.72685E-03 3.63076E-03 3.54052E-03 3.45717E-03
3.37947E-03 3.30681E-03 3.22212E-03 3.12870E-03 3.05676E-03 2.97669E-03
2.87947E-03 2.79077E-03 2.70979E-03 2.63548E-03 2.56703E-03 2.49591E-03
2.42355E-03 2.35716E-03 2.29591E-03 2.23958E-03 2.18675E-03 2.13753E-03
2.09158E-03 2.04421E-03 1.99611E-03 1.95119E-03 1.90926E-03 1.86353E-03
1.81512E-03 1.77021E-03 1.72858E-03 1.68973E-03 1.65345E-03 1.61964E-03
1.58357E-03 1.54626E-03 1.51142E-03 1.47894E-03 1.44112E-03 1.39930E-03
1.36096E-03 1.32560E-03 1.28768E-03 1.24800E-03 1.21183E-03 1.17863E-03
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9.89657E-04 9.66872E-04 9.41590E-04 9.10706E-04 8.82679E-04 8.57047E-04
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7.08309E-04 6.91598E-04 6.76038E-04 6.61505E-04 6.46593E-04 6.31372E-04
6.17179E-04 6.03900E-04 5.89511E-04 5.74187E-04 5.59974E-04 5.46767E-04
5.34464E-04 5.22995E-04 5.12274E-04 5.00826E-04 4.89006E-04 4.78010E-04
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4.91279E-03 5.17641E-03 5.76545E-03 5.70429E-03 5.95838E-03 6.21612E-03
6.47393E-03 6.75702E-03 7.06091E-03 7.36187E-03 7.66266E-03 8.01261E-03
8.40925E-03 8.80409E-03 9.19871E-03 9.58707E-03 9.97145E-03 1.03559E-02
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1.40926E-02 1.47606E-02 1.63288E-02 1.63535E-02 1.71903E-02 1.79960E-02
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2.89515E-02 3.40326E-02 2.95229E-02 2.90156E-02 2.75750E-02 2.44144E-02
1.75433E-02 1.47213E-02 5.09988E-01 1.18291E-01 8.12102E-02 7.01960E-02
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      7.42356E-01 6.80283E-01 6.27390E-01 5.87603E-01 5.65322E-01 5.50207E-01
      5.34792E-01 5.31207E-01 5.21362E-01 5.15275E-01 5.43760E-01 5.52250E-01
      5.57285E-01 5.70527E-01 5.87016E-01 6.13337E-01 7.73060E-01 1.29491E+00
      6.11788E-01 5.58567E-01 5.75790E-01 5.89492E-01 6.13494E-01 6.84314E-01
      9.35907E-01 1.46893E+00 8.42410E-01 9.53569E-01 1.18210E+00 1.18260E+00
      8.11590E-01 6.67168E-01 9.72439E-01 9.47373E-01 1.08329E+00 1.14072E+00
      1.77656E+00 8.41483E-01 1.41115E+00 1.39343E+00 1.02309E+00 1.16012E+00
      1.12922E+00 1.10917E+00 1.27143E+00 1.38666E+00 1.24083E+00 1.15705E+00
      1.44575E+00 1.06565E+00 1.28388E+00 1.43676E+00 1.29282E+00 1.22741E+00
      1.26697E+00 1.22197E+00 7.54634E-01 1.24651E+00 1.19844E+00 1.46531E+00
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      1.92932E+00 1.89603E+00 1.86199E+00 1.87516E+00 1.90867E+00 1.87232E+00
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      2.07233E+00 2.05852E+00 2.05368E+00 2.05240E+00 2.05270E+00 2.05534E+00
      2.05849E+00 2.06460E+00 2.07122E+00 2.07775E+00
C
C
C
FC12   1-MeV(Si) Equivalent Fluence (1-MeV DES [E722])
C
C     89 Groups
C
E12    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
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       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
```

```
       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 SAND2016-2269
C  by P. J. Griffin. The values in Table 6 of the SAND report for
C  energies below 20 MeV were divided by 95 Mev-mbarn. The reference
C  value of 95 +/- 4 MeV-mbarn was determined by fitting the ASTM E722
C  displacement kerma data over 0.01 - 15 MeV.
C
C Production: The data from Table 6 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-MOD_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
      7.38697E-03 3.13312E-03 1.87815E-03 1.17364E-03 7.32402E-04
      5.52298E-04 4.53680E-04 3.83152E-04 2.93933E-04 2.26408E-04
      1.92229E-04 1.64111E-04 1.14214E-04 8.03363E-05 6.25425E-05
      4.87135E-05 3.79357E-05 2.95522E-05 2.30102E-05 1.79240E-05
      1.39594E-05 3.00309E-04 5.55850E-04 6.65494E-04 7.68969E-04
      9.10440E-04 1.10621E-03 1.29490E-03 1.44634E-03 1.60935E-03
      1.80074E-03 2.01916E-03 2.27304E-03 3.26010E-03 2.87101E-03
      3.21528E-03 3.61954E-03 4.06547E-03 4.58726E-03 5.22228E-03
      5.83754E-03 6.49984E-03 7.30252E-03 8.18355E-03 9.18417E-03
      1.02944E-02 1.15055E-02 1.28715E-02 1.43322E-02 1.63567E-02
      1.77608E-02 1.96045E-02 2.16808E-02 2.30574E-02 2.40674E-02
      2.58766E-02 2.95862E-02 2.53388E-02 1.44824E-01 6.03347E-02
      4.99138E-02 2.51383E-02 3.30996E-01 9.39793E-01 5.87161E-01
      5.27088E-01 5.51634E-01 5.74569E-01 8.18293E-01 6.84671E-01
      5.99507E-01 9.58147E-01 1.02449E+00 1.02066E+00 7.14611E-01
      9.53149E-01 1.23834E+00 1.18819E+00 1.24346E+00 1.21600E+00
      1.44917E+00 1.66224E+00 1.69987E+00 1.80733E+00 1.79803E+00
      1.88335E+00 1.88105E+00 1.94630E+00 2.04731E+00
C
```

APPENDIX C: NUGET FREE-FIELD FOR 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     *
*                                                               *
* Decription: This free field response was extracted from the draft  *
*  SAND report by P. J. Griffin that documents the relationship      *
*  between displacemnt 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.                                           *
*                                                               *
*****************************************************************
 2.04764E+00  1.94737E+00  1.88371E+00  1.88826E+00  1.80517E+00  1.81600E+00
 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

 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

    100.  100.  100.

  0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
  0.0000      0.0000      0.0001      0.0000      0.0000      0.0001
  0.0001      0.0000      0.0000      0.0001      0.0001      0.0001
  0.0000      0.0001      0.0001      0.0000      0.0000      0.0000
  0.0000      0.0001      0.0003      0.0001      0.0000      0.0000
  0.0004      0.0001      0.0000      0.0000      0.0000      0.0000
```

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0001	0.0001	

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

```
23   1  0
   '1-MeV[Si] from ASTM E722-Mod (1-MeV[Si])'   1     0.00
   '(1-MeV[Si])'
   '1-MeV[Si] from ASTM E722-Mod'
*
*******************************************************************
*                                                                 *
* Response: Free-Field 1-MeV(Si) Eq. Fluence from SAND2016-2269   *
*                                                                 *
* Description: This free field response was extracted from        *
*  SAND2016-2269 by P. J. Griffin. The values in Table 6 of the SAND *
*  report for energies below 20 MeV were divided by 95 Mev-mbarn.  *
*  The reference value of 95 +/- 4 MeV-mbarn was determined by     *
*  fitting the ASTM E722 displacement kerma data over 0.01 - 15 MeV. *
*                                                                 *
* Production: The data from Table 6 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-Mod_fold-template.inp                 *
*                                                                 *
* NOTES: This response will have equivalent EM cards for MCNP in  *
*  both 640 and 89 groups.                                        *
*                                                                 *
*******************************************************************
*
 2.04730E+00  1.94630E+00  1.88105E+00  1.88336E+00  1.79806E+00  1.80738E+00
 1.69998E+00  1.66209E+00  1.44924E+00  1.21603E+00  1.24354E+00  1.18821E+00
 1.23833E+00  9.53133E-01  7.14572E-01  1.02078E+00  1.02447E+00  9.58183E-01
 5.99509E-01  6.84801E-01  8.18296E-01  5.74565E-01  5.51633E-01  5.27085E-01
 5.87162E-01  9.39771E-01  3.31046E-01  2.51388E-02  4.99140E-02  6.03349E-02
 1.44686E-01  2.53399E-02  2.95860E-02  2.58766E-02  2.40676E-02  2.30571E-02
 2.16809E-02  1.96045E-02  1.77610E-02  1.63567E-02  1.43320E-02  1.28714E-02
 1.15055E-02  1.02944E-02  9.18423E-03  8.18353E-03  7.30257E-03  6.49984E-03
 5.83751E-03  5.22232E-03  4.58731E-03  4.06543E-03  3.61950E-03  3.21524E-03
 2.87101E-03  3.26010E-03  2.27304E-03  2.01916E-03  1.80074E-03  1.60935E-03
 1.44634E-03  1.29490E-03  1.10621E-03  9.10440E-04  7.68969E-04  6.65494E-04
 5.55850E-04  3.00309E-04  1.39594E-05  1.79240E-05  2.30102E-05  2.95522E-05
 3.79357E-05  4.87135E-05  6.25425E-05  8.03363E-05  1.14214E-04  1.64111E-04
 1.92229E-04  2.26408E-04  2.93933E-04  3.83152E-04  4.53680E-04  5.52298E-04
 7.32402E-04  1.17364E-03  1.87815E-03  3.13312E-03  7.38697E-03

 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

    100.  100.  100.

  0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
  0.0000      0.0000      0.0001      0.0000      0.0000      0.0001
  0.0001      0.0000      0.0000      0.0001      0.0001      0.0001
  0.0000      0.0001      0.0001      0.0000      0.0000      0.0000
  0.0000      0.0001      0.0003      0.0001      0.0000      0.0000
  0.0004      0.0001      0.0000      0.0000      0.0000      0.0000
  0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
  0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
  0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
```

0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0001	0.0001	

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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