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Historical Examination of the ASTM Standard E722 1-MeV Silicon Equivalent Fluence Metric

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ABSTRACT

ASTM Committee E10 on Nuclear Technology and Applications develops and maintains many standards that are relevant to the radiation metrology activities in Sandia National Laboratories' Radiation and Electrical Sciences Center. This is particularly true for the reactor facilities and Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices. In the past decade, Subcommittee E10.07 has been making substantive changes to the standard widely used to assess radiation hardness to neutron effects in electronics, *E722 – Standard Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics*. ASTM Standard E722 describes the method that defines the 1-MeV silicon and the 1-MeV gallium arsenide equivalent fluence radiation damage metrics. An evaluation of the impact of changes to the shape of the 1-MeV silicon equivalent fluence radiation damage metric from the 1985 version (E722-85) to the most recent version (E722-19) is performed.

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1. INTRODUCTION

ASTM Committee E10 on Nuclear Technology and Applications develops and maintains many standards that are relevant to the radiation metrology activities in Sandia National Laboratories' (SNL) Radiation and Electrical Sciences Center. This is particularly true for the SNL reactor facilities and Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices. In the past decade, Subcommittee E10.07 has been making substantive changes to the standard widely used to assess radiation hardness to neutron effects in electronics (*E722 – Standard Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics*). This ASTM standard addresses the method used to define the 1-MeV silicon equivalent fluence [1-MeV(Si) Damage Equivalent in Silicon (DES)] radiation damage metric. An examination of the changes to the 1-MeV(Si) DES from the 1985 version (E722-85) to the most recent version (E722-19) is performed in this report.

ASTM Standard E722 defines the equivalent monoenergetic neutron fluence (of a neutron fluence spectrum) for an irradiated material ($\Phi_{eq,E_{ref},mat}$) using the following methodology:

$$\Phi_{eq,E_{ref},mat} = \frac{\int_0^\infty \Phi(E) \cdot F_{D,mat}(E) dE}{F_{D,E_{ref},mat}} \tag{1}$$

where $\Phi(E)$ is the incident neutron fluence spectrum, $F_{D,mat}(E)$ is the neutron displacement damage function for the irradiated material, and $F_{D,E_{ref},mat}$ is the displacement damage reference value for the irradiated material and for the specified equivalent energy (E_{ref}). While the original E722 standard was published prior to 1985, the first use of 95 ± 4 MeV-mbarn for the displacement damage reference value for silicon at 1-MeV ($F_{D,1-MeV,Si}$) was found in E722-85 [1]. The value of $F_{D,1-MeV,Si}$ has been fixed at 95 MeV-mbarn within the E722 standard since that time. With the value of $F_{D,1-MeV,Si}$ fixed, the discussion in this report focuses upon the shape and methodology used to produce the neutron displacement damage function for silicon ($F_{D,Si}(E)$).

1.1. ASTM Standard E722-85

Comparisons of multiple reactor facilities in the 1970s showed inconsistent results when testing silicon electronic devices to the "same" neutron relative damage effectiveness [1] even when the reactors used for the irradiations were the same design. Experimental efforts were launched to use both reactor dosimetry for the neutron spectra and transistor damage measurements in the same irradiation [2]. The need for a consistent methodology in providing a characterized neutron spectrum in terms of an equivalent monoenergetic neutron fluence drove the initial publication of ASTM Standard E722. The initial efforts to provide silicon displacement damage kerma were limited to neutron energies between 10 keV – 18 MeV [1],[3] and were based on the ENDF/B-IV [4] (released 1974) or ENDF/B-V (released in 1978) nuclear data evaluations. The high energy limit corresponded to the upper energy of the most common fine-group energy structure in use at that time, the original 620-group SAND-II energy group structure. The lower energy bound was motivated by the fact that the displacement contributions from < 10 keV neutrons in most reactor test environments were considered to be negligible. Flanders and Sparks [1] confirm the rationale for this lower energy limit when they note that the initial tabulation for $F_{D,Si}(E)$ in the E722 standard

was provided only down to 10 keV, and this was believed to be adequate based on the majority of the work in the field being done at fast burst reactor facilities.

The 1-MeV silicon equivalent fluence function from E722-85 is found in Figure 1 below. The key features apparent in the figure are the energy cutoff for neutron energies below 10 keV and the upper energy bin as the response function from E722-85 ended at 18 MeV.

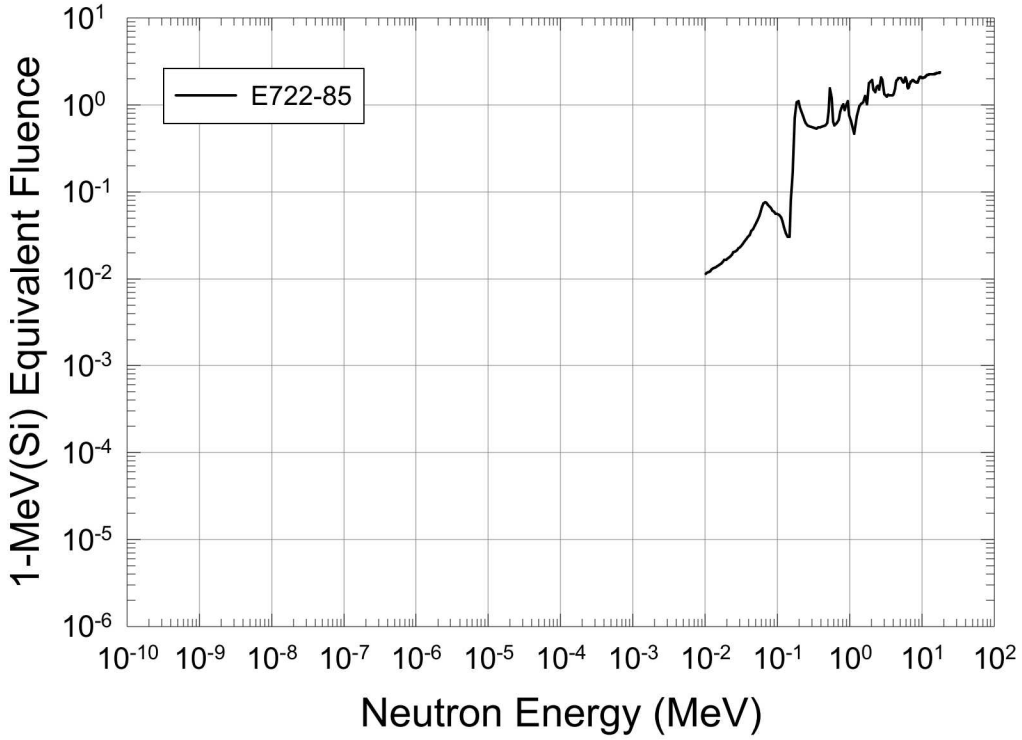

Figure 1 – 1-MeV Silicon Equivalent Neutron Fluence from E722-85 [5]

1.2. ASTM Standard E722-94 (04/09)

After the publication of E722-85, experiments were conducted at a variety of facilities including the MoLLY-G reactor at White Sands Missile Range, SPR-II reactor at SNL, and the RTNS-1 facility at Lawrence Livermore National Laboratory [1]. Discrepancies in the results of these experiments led to a modification of the shape of the $F_{D,Si}(E)$ function that was published as ASTM Standard E722-94 [6]. The methodology used to produce the shape of this function remained unchanged through the ASTM re-approval balloting process in 2004 and 2009. The $F_{D,Si}(E)$ function for E722-94 was processed from the ENDF/B-VI cross section for ^{28}Si, an update over the use of the ENDF/B-V cross sections that formed the basis of the recommended response in E722-85. In the E722-94 revision, the high energy portion of the response function was changed to reflect changes in the underlying ^{28}Si cross section and extended up to the modified SAND-II energy bound of 20-MeV, and the tabulation of the neutron displacement damage function was also extended down to neutron energies as low as 10^{-10} MeV.

The 1-MeV silicon equivalent fluence function from E722-94 is found in Figure 2. The function from E722-94 is shown on the same scale with the function from E722-85 in Figure 3. The comparison figure demonstrates the large changes that were required in the E722 standard in the

late 1980s and early 1990s in order to harmonize the predictions from the monoenergetic fluence function with the experimental results that were being published at various neutron test facilities. Additionally, the fact that the E722 damage function for silicon changed very little for over 15 years indicates that the methodology used to produce it had merit.

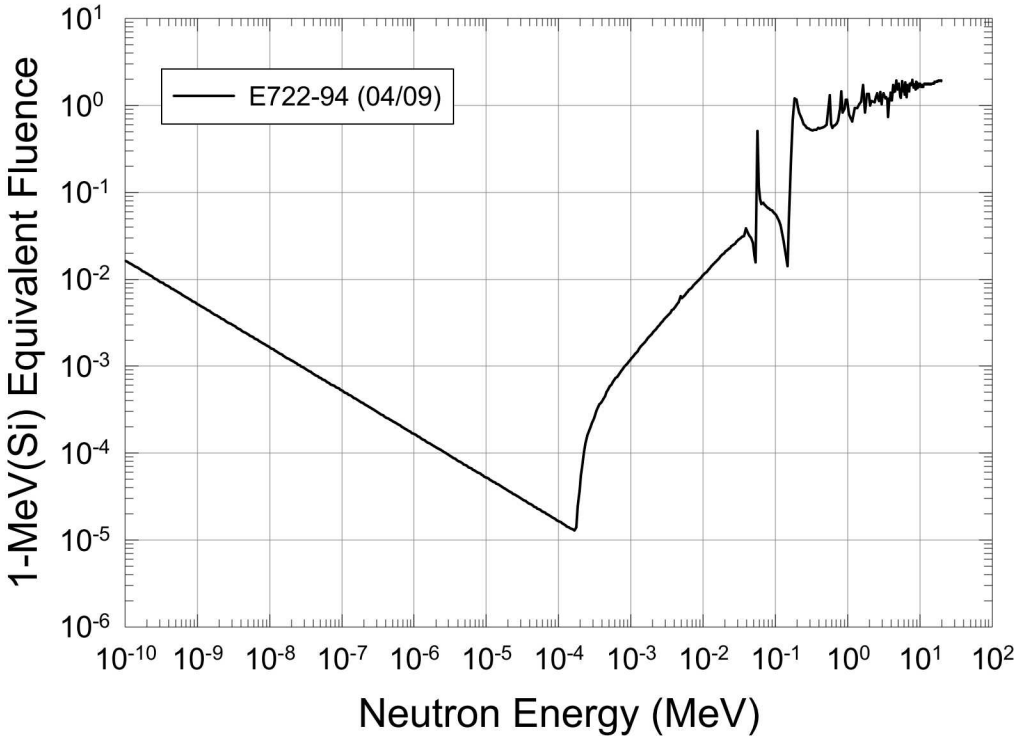

Figure 2 – 1- MeV Silicon Equivalent Neutron Fluence from E722-94 [6]-[8]

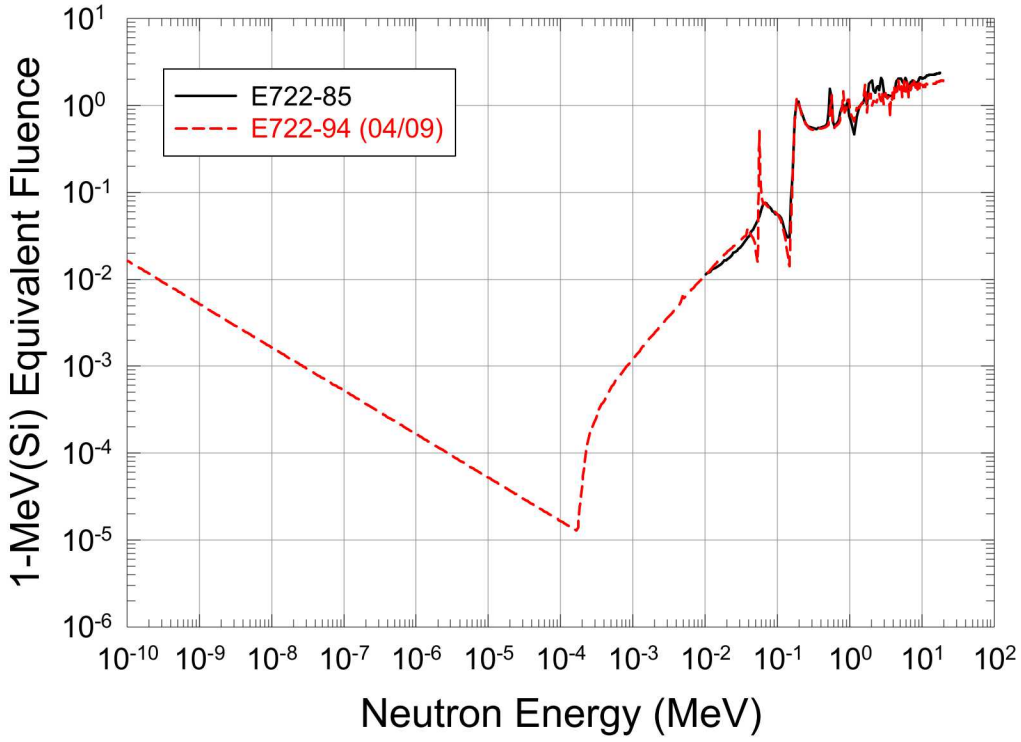

Figure 3 – 1-MeV Silicon Equivalent Fluence Function from E722-85 and E722-94

1.3. ASTM Standard E722-14

As mentioned in the previous section, Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices did not make technical changes to the E722 standard between 1994-2013. However, when the E722-14 [9] standard was published, it included several changes in the methodology used to produce the silicon displacement damage factors found in the standard's Appendix A.1. The overall impact to the actual computed displacement damage factors was minimal for most of the response range, but the changes were necessary to maintain a modern standard [10]. DePriest [10] outlined the following set of changes in E722-14 that differed from previous versions of the E722 standard:

- The database for silicon nuclear cross sections was updated from ENDF/B-VI to the ENDF/B-VII.1 nuclear data.
  - In the E722-09$^{\varepsilon 1}$ standard [8], the ENDF/B-VI cross section evaluation was utilized.
  - The E722-14 standard used the ENDF/B-VII, Revision 1 evaluation for the displacement kerma factors.
- Natural silicon was used for the displacement kerma factors rather than just isotopic ^{28}Si.
  - In all previous versions of E722, ^{28}Si was the only isotope considered when evaluating the displacement kerma factors.
  - The updated E722-14 standard included ^{29}Si and ^{30}Si with appropriate atomic abundances when evaluating the displacement kerma factors.
- Displacement threshold energy for the silicon lattice was reduced.

- The E722-09$^{\varepsilon 1}$ used a value for the displacement threshold energy of 25 eV when creating the displacement damage factors.
- The displacement threshold energy was reduced from 25 eV to 20.5 eV for the update to the E722-14 standard.
- A rigorous implementation of the Norgett-Robinson-Torrens (NRT) [11] treatment of the damage energy and displacement threshold was implemented. The earlier E722-94 version used the NJOY code [12] default treatment that was a sharp threshold Kinchin-Pease treatment [13].

The 1-MeV silicon equivalent fluence function from E722-14 is found in Figure 4. A comparison of the E722-94 and E722-14 functions is found in Figure 5. Since the curves in this figure are virtually indistinguishable, Figure 6 shows an enlarged comparison of the regions most impacted by the changes outlined above.

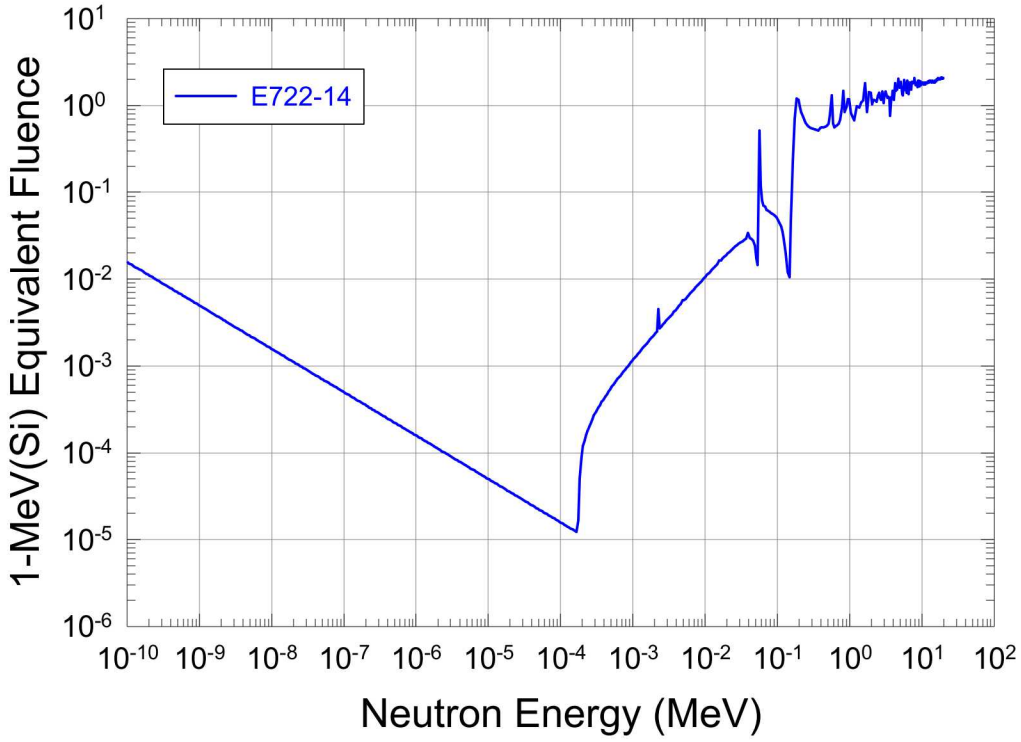

Figure 4 – 1-MeV Silicon Equivalent Neutron Fluence from E722-14 [9]

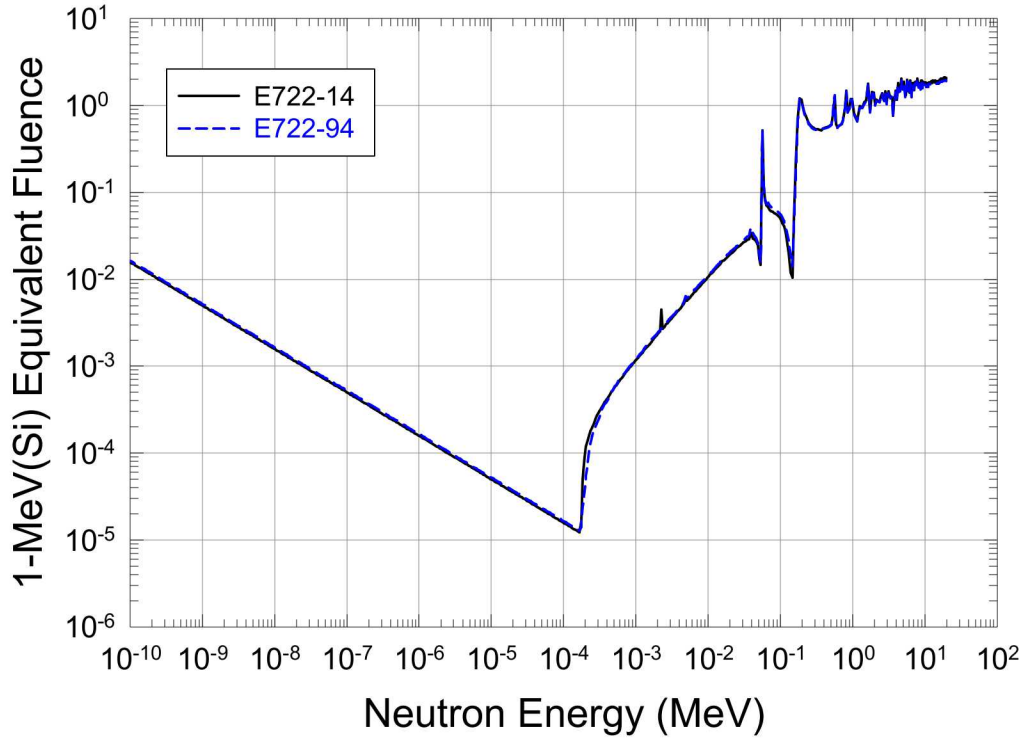

Figure 5 – 1-MeV Silicon Equivalent Fluence Function from E722-94 and E722-14

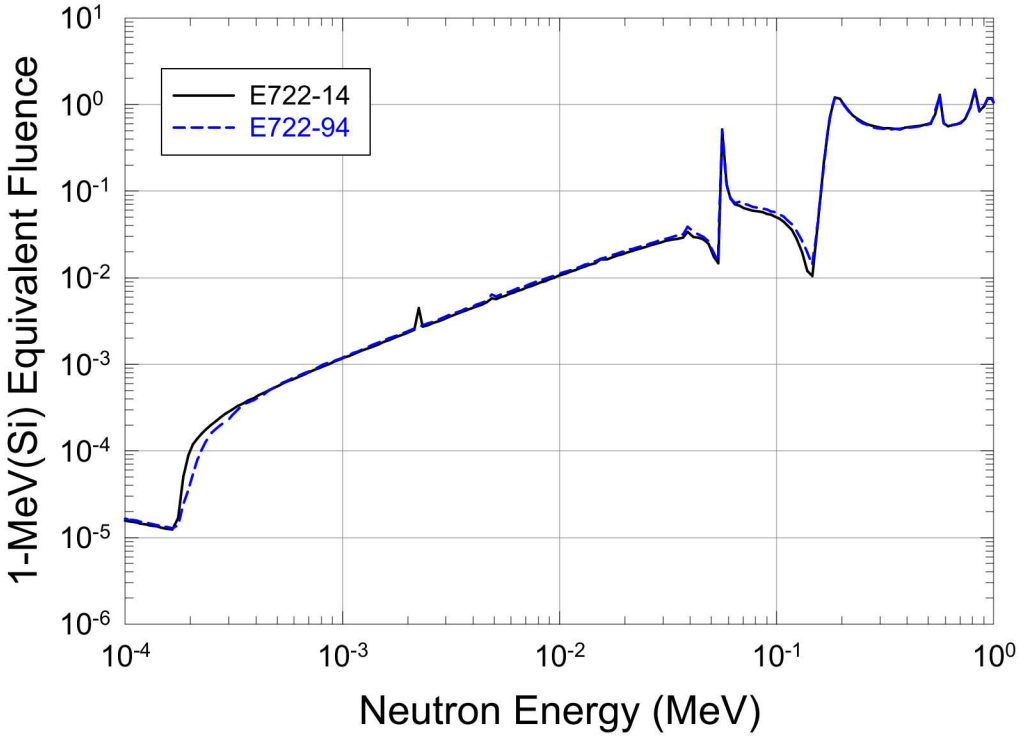

Figure 6 – 1-MeV Silicon Equivalent Fluence Function from E722-94 and E722-14: Expanded

1.4. ASTM Standard E722-19

Since 2014, Subcommittee E10.07 has reexamined the methodology used to produce the silicon damage function defined in the Annexes of the E722 standard. These are the changes in the methodology used to produce the silicon damage function found between E722-14 and E722-19 [14]:

- The ENDF/B-VIII, Revision 0 nuclear cross section evaluations for ^{28}Si, ^{29}Si, and ^{30}Si were used rather than the ENDF/B-VII, Revision 1 (as in E722-14).
- The silicon damage function was calculated by using a slightly modified version of the NJOY-2012 code [12].
  - The value of the total kerma was calculated from the nuclear data evaluations for elemental silicon.
  - The total kerma was partitioned into ionization and displacement fractions using the Robinson formalism of the damage partition function [15].
  - The displacement kerma component of the total kerma was established as the relevant neutron displacement damage function for silicon – without any NRT or Kinchin-Pease correction for the probability of creating an actual lattice displacement, i.e. Frenkel pair, near the displacement threshold energy. That is, $F_{D,Si}(E) = \kappa_{D,Si}(E)$ where $\kappa_{D,Si}(E)$ is the silicon microscopic displacement kerma factor (displacement kerma per target atom per unit neutron fluence).

The 1-MeV silicon equivalent fluence function from E722-19 is found in Figure 7. A comparison of the E722-14 and E722-19 functions is found in Figure 8.

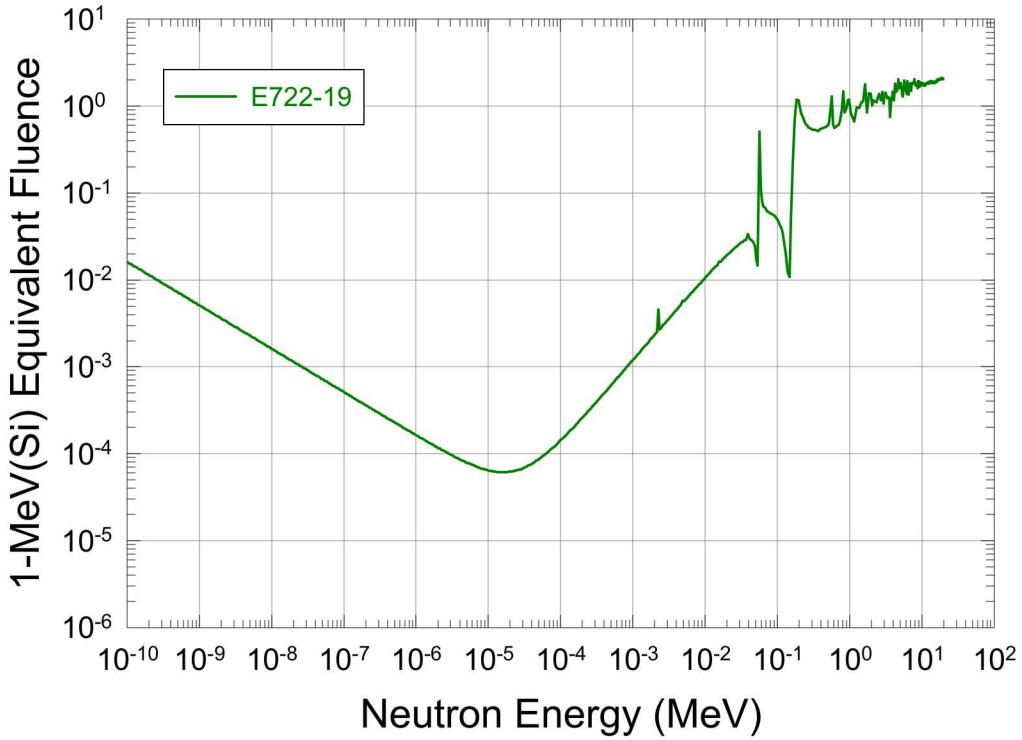

Figure 7 – 1-MeV Silicon Equivalent Neutron Fluence from E722-19 [14]

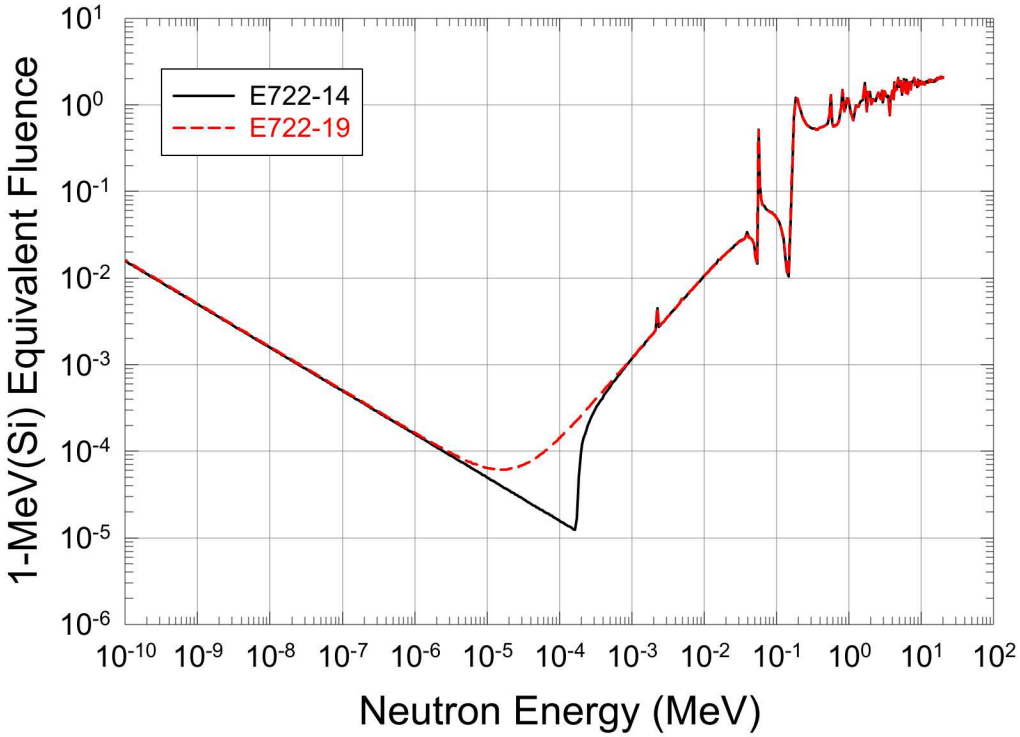

Figure 8 – 1-MeV Silicon Equivalent Fluence Function from E722-14 and E722-19

The changes described above the figures may seem relatively minor, but the discrepancy between is E722-14 and E722-19 is profound for neutrons energies in the range from 10^{-6} to 10^{-3} MeV – the energy region where lattice atom recoil energies from elastic scattering events are close to the angle-dependent displacement threshold energy. If a neutron test facility relies on a significant number of neutrons in this region, the integral silicon damage metric reported by the facility will increase tremendously. Fortunately, most neutron test facilities are likely to find little to change to their reported silicon damage metric.

1.5. Assessment of Impact

In the sections above, the changes to ASTM Standard E722 from 1985 to the present have been outlined. While the standard provides a method to report or calculate a silicon damage metric for electronic device testing in neutron environments, the discussion above merely demonstrated that the shape of the silicon damage response function changed over time. It did not include any assessment of the impact of the changes on the integral silicon damage metric that is reported for a neutron environment. In the next section, the silicon damage responses from the different eras of the ASTM Standard E722 will be used to produce integral 1-MeV(Si) equivalent fluences for neutron environments of interest to the SNL electronics testing community.

2. INTEGRAL COMPARISONS

The focus of this report is the assessment of the impact of changes to ASTM Standard E722 on reported integral neutron damage metrics for silicon. In other words, how does the reported integral 1-MeV(Si) equivalent fluence reported by a neutron test facility change when the silicon damage function is modified by ASTM Subcommittee E10.07? To examine the effects of these changes, the integral 1-MeV(Si) equivalent fluence will be calculated for 5 reactor environments and 2 fission spectra. The reactor environments are the following:

- The central cavity of the Annular Core Research Reactor (ACRR-CC)
- The lead-boron bucket in the central cavity of the Annular Core Research Reactor (ACRR-PbB)
- The central cavity of the Sandia Pulsed Reactor-III (SPRIII-CC)
- The 6-inch leakage using the tripod irradiation position at the White Sands Missile Range fast burst reactor (WSMR 6-inch)
- The 24-inch leakage irradiation position at the White Sands Missile Range fast burst reactor (WSMR 24-inch)

The two fission spectra that will be evaluated are the following:

- A Watt fission spectrum from the thermal neutron fission of ^{235}U (^{235}Watt Fission)
- A fission spectrum from the spontaneous fission of ^{252}Cf (^{252}Cf Spontaneous Fission) [16]

In these calculations, the normalization for the integral silicon damage metrics was based on 1 MJ of integrated reactor power for the reactor environments and 1 neutron emitted for the fission spectra environments. The integral 1-MeV(Si) equivalent fluence results from these various neutron test environments are found in Table 1. In the table, the reported integral values prior to 1994 would be higher by 6 – 12% when compared to values that were reported from 25 years ago and onward. As mentioned in previous work [10], the impact of changes since 2009 are minimal for common neutron testing environments, but the changes reflect increased fidelity in the processing of bulk silicon material with nuclear data codes.

Table 1 – Comparison of Integral Metrics for Various Neutron Sources

Neutron Spectrum	E722-85 (1-MeV DES)	E722-94 (1-MeV DES)	E722-14 (1-MeV DES)	E722-19 (1-MeV DES)
ACRR-CC	9.222255E+12	8.470833E+12	8.663239E+12	8.616283E+12
ACRR-PbB	5.711248E+12	5.283578E+12	5.399674E+12	5.370006E+12
SPRIII-CC	5.086745E+13	4.662770E+13	4.774663E+13	4.748669E+13
WSMR 6-inch	2.771505E+13	2.509018E+13	2.572614E+13	2.558743E+13
WSMR 24-inch	2.626465E+13	2.402825E+13	2.462404E+13	2.449036E+13
^{235}U Watt Fission	1.18472	1.04809	1.07892	1.07323
^{252}Cf Spontaneous Fission	1.22595	1.06781	1.09994	1.09421
The integrals for the reactor environments are normalized to a pulse of 1 MJ of reactor power. The integrals for the fission spectra are normalized to 1 fission neutron emitted.				

Since E722-19 represents the recommended shape of ASTM's silicon damage metric response function, the ratio of the historical integral metrics to the current recommendation was deemed

appropriate as a comparator. Table 2 contains the summary of those ratio calculations for the environments displayed in Table 1. The table displays the 6 – 12% change in the calculated integral metric for the various reactor environment from the 1985 publication to the present. It also shows that the recent change from 2014 to the present has little impact on the integral metrics in these environments. This contrasts with the significant changes that are seen in energy-dependent response shape found in Figure 8. Finally, the change from 1994 (2009) to the present is entirely consistent with the changes reported when E722-14 was published [10].

Table 2 – Ratio of Historical E722 Integrals to E722-19

Neutron Spectrum	E722-85 / E722-19 Ratio	E722-94 / E722-19 Ratio	E722-14 / E722-19 Ratio
ACRR-CC	1.0703	0.9831	1.0054
ACRR-PbB	1.0635	0.9839	1.0055
SPRIII-CC	1.0712	0.9819	1.0055
WSMR 6-inch	1.0832	0.9806	1.0054
WSMR 24-inch	1.0724	0.9811	1.0055
^{235}U Watt Fission	1.1039	0.9766	1.0053
^{252}Cf Spontaneous Fission	1.1204	0.9759	1.0052

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APPENDIX A. Template for 89-Group Response Function

```
E722-19 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  5e7
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
F192:N  100
FC192   1-MeV(Si) Equivalent Fluence (1-MeV DES) from E722-19
E192      1.000000E-10 1.050000E-10 1.100000E-10 1.150000E-10 1.200000E-10
          1.275000E-10 1.350000E-10 1.425000E-10 1.500000E-10 1.600000E-10
          1.700000E-10 1.800000E-10 1.900000E-10 2.000000E-10 2.100000E-10
          2.200000E-10 2.300000E-10 2.400000E-10 2.550000E-10 2.700000E-10
          2.800000E-10 3.000000E-10 3.200000E-10 3.400000E-10 3.600000E-10
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          5.000000E-10 5.250000E-10 5.500000E-10 5.750000E-10 6.000000E-10
          6.300000E-10 6.600000E-10 6.900000E-10 7.200000E-10 7.600000E-10
          8.000000E-10 8.400000E-10 8.800000E-10 9.200000E-10 9.600000E-10
          1.000000E-09 1.050000E-09 1.100000E-09 1.150000E-09 1.200000E-09
          1.275000E-09 1.350000E-09 1.425000E-09 1.500000E-09 1.600000E-09
          1.700000E-09 1.800000E-09 1.900000E-09 2.000000E-09 2.100000E-09
          2.200000E-09 2.300000E-09 2.400000E-09 2.550000E-09 2.700000E-09
          2.800000E-09 3.000000E-09 3.200000E-09 3.400000E-09 3.600000E-09
          3.800000E-09 4.000000E-09 4.250000E-09 4.500000E-09 4.750000E-09
          5.000000E-09 5.250000E-09 5.500000E-09 5.750000E-09 6.000000E-09
          6.300000E-09 6.600000E-09 6.900000E-09 7.200000E-09 7.600000E-09
          8.000000E-09 8.400000E-09 8.800000E-09 9.200000E-09 9.600000E-09
```

1.000000E-08 1.050000E-08 1.100000E-08 1.150000E-08 1.200000E-08
1.275000E-08 1.350000E-08 1.425000E-08 1.500000E-08 1.600000E-08
1.700000E-08 1.800000E-08 1.900000E-08 2.000000E-08 2.100000E-08
2.200000E-08 2.300000E-08 2.400000E-08 2.550000E-08 2.700000E-08
2.800000E-08 3.000000E-08 3.200000E-08 3.400000E-08 3.600000E-08
3.800000E-08 4.000000E-08 4.250000E-08 4.500000E-08 4.750000E-08
5.000000E-08 5.250000E-08 5.500000E-08 5.750000E-08 6.000000E-08
6.300000E-08 6.600000E-08 6.900000E-08 7.200000E-08 7.600000E-08
8.000000E-08 8.400000E-08 8.800000E-08 9.200000E-08 9.600000E-08
1.000000E-07 1.050000E-07 1.100000E-07 1.150000E-07 1.200000E-07
1.275000E-07 1.350000E-07 1.425000E-07 1.500000E-07 1.600000E-07
1.700000E-07 1.800000E-07 1.900000E-07 2.000000E-07 2.100000E-07
2.200000E-07 2.300000E-07 2.400000E-07 2.550000E-07 2.700000E-07
2.800000E-07 3.000000E-07 3.200000E-07 3.400000E-07 3.600000E-07
3.800000E-07 4.000000E-07 4.250000E-07 4.500000E-07 4.750000E-07
5.000000E-07 5.250000E-07 5.500000E-07 5.750000E-07 6.000000E-07
6.300000E-07 6.600000E-07 6.900000E-07 7.200000E-07 7.600000E-07
8.000000E-07 8.400000E-07 8.800000E-07 9.200000E-07 9.600000E-07
1.000000E-06 1.050000E-06 1.100000E-06 1.150000E-06 1.200000E-06
1.275000E-06 1.350000E-06 1.425000E-06 1.500000E-06 1.600000E-06
1.700000E-06 1.800000E-06 1.900000E-06 2.000000E-06 2.100000E-06
2.200000E-06 2.300000E-06 2.400000E-06 2.550000E-06 2.700000E-06
2.800000E-06 3.000000E-06 3.200000E-06 3.400000E-06 3.600000E-06
3.800000E-06 4.000000E-06 4.250000E-06 4.500000E-06 4.750000E-06
5.000000E-06 5.250000E-06 5.500000E-06 5.750000E-06 6.000000E-06
6.300000E-06 6.600000E-06 6.900000E-06 7.200000E-06 7.600000E-06
8.000000E-06 8.400000E-06 8.800000E-06 9.200000E-06 9.600000E-06
1.000000E-05 1.050000E-05 1.100000E-05 1.150000E-05 1.200000E-05
1.275000E-05 1.350000E-05 1.425000E-05 1.500000E-05 1.600000E-05
1.700000E-05 1.800000E-05 1.900000E-05 2.000000E-05 2.100000E-05
2.200000E-05 2.300000E-05 2.400000E-05 2.550000E-05 2.700000E-05
2.800000E-05 3.000000E-05 3.200000E-05 3.400000E-05 3.600000E-05
3.800000E-05 4.000000E-05 4.250000E-05 4.500000E-05 4.750000E-05
5.000000E-05 5.250000E-05 5.500000E-05 5.750000E-05 6.000000E-05
6.300000E-05 6.600000E-05 6.900000E-05 7.200000E-05 7.600000E-05
8.000000E-05 8.400000E-05 8.800000E-05 9.200000E-05 9.600000E-05
1.000000E-04 1.050000E-04 1.100000E-04 1.150000E-04 1.200000E-04
1.275000E-04 1.350000E-04 1.425000E-04 1.500000E-04 1.600000E-04
1.700000E-04 1.800000E-04 1.900000E-04 2.000000E-04 2.100000E-04
2.200000E-04 2.300000E-04 2.400000E-04 2.550000E-04 2.700000E-04
2.800000E-04 3.000000E-04 3.200000E-04 3.400000E-04 3.600000E-04
3.800000E-04 4.000000E-04 4.250000E-04 4.500000E-04 4.750000E-04
5.000000E-04 5.250000E-04 5.500000E-04 5.750000E-04 6.000000E-04
6.300000E-04 6.600000E-04 6.900000E-04 7.200000E-04 7.600000E-04
8.000000E-04 8.400000E-04 8.800000E-04 9.200000E-04 9.600000E-04
1.000000E-03 1.050000E-03 1.100000E-03 1.150000E-03 1.200000E-03
1.275000E-03 1.350000E-03 1.425000E-03 1.500000E-03 1.600000E-03
1.700000E-03 1.800000E-03 1.900000E-03 2.000000E-03 2.100000E-03
2.200000E-03 2.300000E-03 2.400000E-03 2.550000E-03 2.700000E-03
2.800000E-03 3.000000E-03 3.200000E-03 3.400000E-03 3.600000E-03
3.800000E-03 4.000000E-03 4.250000E-03 4.500000E-03 4.750000E-03
5.000000E-03 5.250000E-03 5.500000E-03 5.750000E-03 6.000000E-03
6.300000E-03 6.600000E-03 6.900000E-03 7.200000E-03 7.600000E-03
8.000000E-03 8.400000E-03 8.800000E-03 9.200000E-03 9.600000E-03
1.000000E-02 1.050000E-02 1.100000E-02 1.150000E-02 1.200000E-02
1.275000E-02 1.350000E-02 1.425000E-02 1.500000E-02 1.600000E-02
1.700000E-02 1.800000E-02 1.900000E-02 2.000000E-02 2.100000E-02
2.200000E-02 2.300000E-02 2.400000E-02 2.550000E-02 2.700000E-02
2.800000E-02 3.000000E-02 3.200000E-02 3.400000E-02 3.600000E-02
3.800000E-02 4.000000E-02 4.250000E-02 4.500000E-02 4.750000E-02
5.000000E-02 5.250000E-02 5.500000E-02 5.750000E-02 6.000000E-02
6.300000E-02 6.600000E-02 6.900000E-02 7.200000E-02 7.600000E-02
8.000000E-02 8.400000E-02 8.800000E-02 9.200000E-02 9.600000E-02

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          1.000000E-01 1.050000E-01 1.100000E-01 1.150000E-01 1.200000E-01
          1.275000E-01 1.350000E-01 1.425000E-01 1.500000E-01 1.600000E-01
          1.700000E-01 1.800000E-01 1.900000E-01 2.000000E-01 2.100000E-01
          2.200000E-01 2.300000E-01 2.400000E-01 2.550000E-01 2.700000E-01
          2.800000E-01 3.000000E-01 3.200000E-01 3.400000E-01 3.600000E-01
          3.800000E-01 4.000000E-01 4.250000E-01 4.500000E-01 4.750000E-01
          5.000000E-01 5.250000E-01 5.500000E-01 5.750000E-01 6.000000E-01
          6.300000E-01 6.600000E-01 6.900000E-01 7.200000E-01 7.600000E-01
          8.000000E-01 8.400000E-01 8.800000E-01 9.200000E-01 9.600000E-01
          1.000000E+00 1.100000E+00 1.200000E+00 1.300000E+00 1.400000E+00
          1.500000E+00 1.600000E+00 1.700000E+00 1.800000E+00 1.900000E+00
          2.000000E+00 2.100000E+00 2.200000E+00 2.300000E+00 2.400000E+00
          2.500000E+00 2.600000E+00 2.700000E+00 2.800000E+00 2.900000E+00
          3.000000E+00 3.100000E+00 3.200000E+00 3.300000E+00 3.400000E+00
          3.500000E+00 3.600000E+00 3.700000E+00 3.800000E+00 3.900000E+00
          4.000000E+00 4.100000E+00 4.200000E+00 4.300000E+00 4.400000E+00
          4.500000E+00 4.600000E+00 4.700000E+00 4.800000E+00 4.900000E+00
          5.000000E+00 5.100000E+00 5.200000E+00 5.300000E+00 5.400000E+00
          5.500000E+00 5.600000E+00 5.700000E+00 5.800000E+00 5.900000E+00
          6.000000E+00 6.100000E+00 6.200000E+00 6.300000E+00 6.400000E+00
          6.500000E+00 6.600000E+00 6.700000E+00 6.800000E+00 6.900000E+00
          7.000000E+00 7.100000E+00 7.200000E+00 7.300000E+00 7.400000E+00
          7.500000E+00 7.600000E+00 7.700000E+00 7.800000E+00 7.900000E+00
          8.000000E+00 8.100000E+00 8.200000E+00 8.300000E+00 8.400000E+00
          8.500000E+00 8.600000E+00 8.700000E+00 8.800000E+00 8.900000E+00
          9.000000E+00 9.100000E+00 9.200000E+00 9.300000E+00 9.400000E+00
          9.500000E+00 9.600000E+00 9.700000E+00 9.800000E+00 9.900000E+00
          1.000000E+01 1.010000E+01 1.020000E+01 1.030000E+01 1.040000E+01
          1.050000E+01 1.060000E+01 1.070000E+01 1.080000E+01 1.090000E+01
          1.100000E+01 1.110000E+01 1.120000E+01 1.130000E+01 1.140000E+01
          1.150000E+01 1.160000E+01 1.170000E+01 1.180000E+01 1.190000E+01
          1.200000E+01 1.210000E+01 1.220000E+01 1.230000E+01 1.240000E+01
          1.250000E+01 1.260000E+01 1.270000E+01 1.280000E+01 1.290000E+01
          1.300000E+01 1.310000E+01 1.320000E+01 1.330000E+01 1.340000E+01
          1.350000E+01 1.360000E+01 1.370000E+01 1.380000E+01 1.390000E+01
          1.400000E+01 1.410000E+01 1.420000E+01 1.430000E+01 1.440000E+01
          1.450000E+01 1.460000E+01 1.470000E+01 1.480000E+01 1.490000E+01
          1.500000E+01 1.510000E+01 1.520000E+01 1.530000E+01 1.540000E+01
          1.550000E+01 1.560000E+01 1.570000E+01 1.580000E+01 1.590000E+01
          1.600000E+01 1.610000E+01 1.620000E+01 1.630000E+01 1.640000E+01
          1.650000E+01 1.660000E+01 1.670000E+01 1.680000E+01 1.690000E+01
          1.700000E+01 1.710000E+01 1.720000E+01 1.730000E+01 1.740000E+01
          1.750000E+01 1.760000E+01 1.770000E+01 1.780000E+01 1.790000E+01
          1.800000E+01 1.810000E+01 1.820000E+01 1.830000E+01 1.840000E+01
          1.850000E+01 1.860000E+01 1.870000E+01 1.880000E+01 1.890000E+01
          1.900000E+01 1.910000E+01 1.920000E+01 1.930000E+01 1.940000E+01
          1.950000E+01 1.960000E+01 1.970000E+01 1.980000E+01 1.990000E+01
          2.000000E+01
C
C  Multipliers converted from E722-19 standard. The values were taken from
C   Table A.1.1 divided by 95 MeV-mb.
C
C  The first bin is a zero because the bin goes from 0.0 -- 1.0e-10 MeV
C   (i.e., below the table).
C
EM192     0.000000
          1.595282E-02 1.558306E-02 1.522148E-02 1.490198E-02 1.451471E-02
          1.409668E-02 1.370529E-02 1.335189E-02 1.296773E-02 1.256808E-02
          1.220451E-02 1.188299E-02 1.156761E-02 1.127695E-02 1.101085E-02
          1.076432E-02 1.053112E-02 1.026241E-02 9.963900E-03 9.734723E-03
          9.489117E-03 9.171704E-03 8.893324E-03 8.630347E-03 8.397176E-03
          8.175085E-03 7.950534E-03 7.719402E-03 7.506562E-03 7.312217E-03
          7.134199E-03 6.969120E-03 6.807333E-03 6.664544E-03 6.510981E-03
```

6.358844E-03 6.214722E-03 6.081285E-03 5.934804E-03 5.781439E-03
5.637423E-03 5.505012E-03 5.385029E-03 5.272246E-03 5.159555E-03
5.044712E-03 4.927919E-03 4.813487E-03 4.712512E-03 4.589856E-03
4.457961E-03 4.334183E-03 4.222111E-03 4.100999E-03 3.974343E-03
3.859500E-03 3.757803E-03 3.658161E-03 3.566225E-03 3.481995E-03
3.404028E-03 3.330168E-03 3.245319E-03 3.150920E-03 3.078394E-03
3.000836E-03 2.900377E-03 2.812441E-03 2.729239E-03 2.655487E-03
2.585222E-03 2.514240E-03 2.441106E-03 2.373822E-03 2.312394E-03
2.256100E-03 2.203916E-03 2.152659E-03 2.107561E-03 2.058977E-03
2.010897E-03 1.965289E-03 1.923075E-03 1.876844E-03 1.828260E-03
1.782751E-03 1.740845E-03 1.702937E-03 1.667294E-03 1.631645E-03
1.595288E-03 1.558408E-03 1.522148E-03 1.490301E-03 1.451574E-03
1.409767E-03 1.370633E-03 1.335191E-03 1.296978E-03 1.256912E-03
1.220554E-03 1.188403E-03 1.156865E-03 1.128205E-03 1.102214E-03
1.076534E-03 1.053834E-03 1.026684E-03 9.972135E-04 9.742449E-04
9.485122E-04 9.173569E-04 8.892626E-04 8.632116E-04 8.395656E-04
8.178086E-04 7.950972E-04 7.721073E-04 7.517277E-04 7.318199E-04
7.135971E-04 6.971000E-04 6.809112E-04 6.666334E-04 6.513581E-04
6.361248E-04 6.217233E-04 6.083695E-04 5.938242E-04 5.784673E-04
5.640348E-04 5.507835E-04 5.387556E-04 5.274865E-04 5.162080E-04
5.046618E-04 4.929933E-04 4.815499E-04 4.714628E-04 4.593011E-04
4.461119E-04 4.337341E-04 4.225374E-04 4.104582E-04 3.977728E-04
3.862888E-04 3.761195E-04 3.661763E-04 3.569836E-04 3.485711E-04
3.407749E-04 3.333996E-04 3.249669E-04 3.155175E-04 3.082251E-04
3.005624E-04 2.905281E-04 2.817564E-04 2.734780E-04 2.661447E-04
2.591503E-04 2.520946E-04 2.449979E-04 2.385995E-04 2.322015E-04
2.265946E-04 2.218086E-04 2.170232E-04 2.122377E-04 2.069904E-04
2.022257E-04 1.979847E-04 1.937443E-04 1.888561E-04 1.841233E-04
1.797698E-04 1.754169E-04 1.715873E-04 1.680866E-04 1.645759E-04
1.611573E-04 1.578013E-04 1.544453E-04 1.510893E-04 1.469936E-04
1.430019E-04 1.393186E-04 1.356349E-04 1.319109E-04 1.281462E-04
1.244643E-04 1.213475E-04 1.183324E-04 1.157599E-04 1.136494E-04
1.115489E-04 1.094383E-04 1.068154E-04 1.036498E-04 1.011009E-04
9.899512E-05 9.629942E-05 9.360375E-05 9.100968E-05 8.903300E-05
8.716113E-05 8.505946E-05 8.303008E-05 8.131906E-05 7.960709E-05
7.814875E-05 7.694828E-05 7.574777E-05 7.454727E-05 7.323512E-05
7.210408E-05 7.114048E-05 7.017596E-05 6.906608E-05 6.806888E-05
6.718673E-05 6.630663E-05 6.558987E-05 6.497880E-05 6.436676E-05
6.384162E-05 6.340443E-05 6.296631E-05 6.252912E-05 6.200716E-05
6.167695E-05 6.144127E-05 6.120657E-05 6.110787E-05 6.114748E-05
6.121686E-05 6.146287E-05 6.173961E-05 6.215604E-05 6.271522E-05
6.327531E-05 6.383443E-05 6.453198E-05 6.537166E-05 6.610253E-05
6.725783E-05 6.884911E-05 7.043941E-05 7.206144E-05 7.387020E-05
7.570974E-05 7.777599E-05 8.016993E-05 8.265818E-05 8.514542E-05
8.770744E-05 9.034600E-05 9.298425E-05 9.562204E-05 9.852118E-05
1.017758E-04 1.050774E-04 1.083779E-04 1.122293E-04 1.167034E-04
1.212176E-04 1.257322E-04 1.302873E-04 1.348733E-04 1.394592E-04
1.446453E-04 1.504540E-04 1.562625E-04 1.620707E-04 1.693099E-04
1.780936E-04 1.868972E-04 1.957109E-04 2.059852E-04 2.177932E-04
2.296017E-04 2.414294E-04 2.532673E-04 2.651143E-04 2.769703E-04
2.888261E-04 3.006818E-04 3.154577E-04 3.332421E-04 3.481045E-04
3.657664E-04 3.894618E-04 4.131469E-04 4.368315E-04 4.604606E-04
4.840797E-04 5.105968E-04 5.400768E-04 5.695026E-04 5.989385E-04
6.282997E-04 6.575963E-04 6.868833E-04 7.161804E-04 7.483546E-04
7.833852E-04 8.183411E-04 8.532954E-04 8.939846E-04 9.404321E-04
9.868007E-04 1.033171E-03 1.079366E-03 1.125536E-03 1.171703E-03
1.223355E-03 1.280597E-03 1.337942E-03 1.395178E-03 1.466483E-03
1.551874E-03 1.637151E-03 1.722327E-03 1.821154E-03 1.933869E-03
2.046589E-03 2.158735E-03 2.270884E-03 2.383094E-03 2.501046E-03
4.536044E-03 2.719080E-03 2.853275E-03 3.017743E-03 3.155322E-03
3.317421E-03 3.534495E-03 3.751669E-03 3.968331E-03 4.182436E-03
4.396116E-03 4.635933E-03 4.901031E-03 5.164181E-03 5.753520E-03
5.691502E-03 5.945687E-03 6.203513E-03 6.461395E-03 6.744584E-03

7.049484E-03 7.351842E-03 7.654252E-03 8.005832E-03 8.402534E-03
8.796512E-03 9.190572E-03 9.579157E-03 9.964328E-03 1.034951E-02
1.077419E-02 1.123916E-02 1.170486E-02 1.216963E-02 1.274803E-02
1.342056E-02 1.408717E-02 1.475729E-02 1.632405E-02 1.635029E-02
1.718813E-02 1.799371E-02 1.879214E-02 1.953606E-02 2.022343E-02
2.091087E-02 2.159676E-02 2.245113E-02 2.348076E-02 2.433925E-02
2.531638E-02 2.645437E-02 2.741201E-02 2.824512E-02 2.891606E-02
3.395438E-02 2.942629E-02 2.894861E-02 2.751292E-02 2.436986E-02
1.750108E-02 1.473833E-02 5.102557E-01 1.185633E-01 8.144701E-02
7.045904E-02 6.758741E-02 6.289855E-02 6.102315E-02 5.939214E-02
5.796759E-02 5.677964E-02 5.493674E-02 5.308755E-02 5.096747E-02
4.803102E-02 4.440468E-02 4.011263E-02 3.539297E-02 2.861901E-02
2.012582E-02 1.243200E-02 1.074729E-02 4.630531E-02 2.142965E-01
6.967900E-01 1.194928E+00 1.161856E+00 9.778891E-01 8.377525E-01
7.438071E-01 6.812343E-01 6.276306E-01 5.887208E-01 5.657171E-01
5.506482E-01 5.348051E-01 5.312571E-01 5.213859E-01 5.152831E-01
5.437318E-01 5.523169E-01 5.573879E-01 5.705596E-01 5.871536E-01
6.138774E-01 7.744636E-01 1.296565E+00 6.132445E-01 5.587832E-01
5.759743E-01 5.896165E-01 6.133580E-01 6.858127E-01 9.368014E-01
1.469640E+00 8.427217E-01 9.561049E-01 1.176541E+00 1.182003E+00
8.135916E-01 6.684232E-01 9.720252E-01 9.479468E-01 1.084496E+00
1.141592E+00 1.777233E+00 8.417834E-01 1.411149E+00 1.393433E+00
1.023096E+00 1.160121E+00 1.129225E+00 1.109264E+00 1.271437E+00
1.386657E+00 1.240826E+00 1.157051E+00 1.445751E+00 1.065752E+00
1.283887E+00 1.436759E+00 1.292818E+00 1.227415E+00 1.266966E+00
1.221972E+00 7.546353E-01 1.246506E+00 1.198444E+00 1.465315E+00
1.442463E+00 1.159672E+00 1.800248E+00 1.458281E+00 1.523816E+00
1.515252E+00 1.693085E+00 2.029166E+00 1.738562E+00 1.595993E+00
1.632913E+00 1.858567E+00 1.633226E+00 1.358886E+00 1.299443E+00
1.594589E+00 1.641383E+00 1.967071E+00 1.824894E+00 1.495868E+00
1.696385E+00 1.391118E+00 1.932004E+00 1.674469E+00 1.547359E+00
1.349243E+00 1.648753E+00 1.818252E+00 1.608449E+00 1.553214E+00
1.817931E+00 1.504771E+00 1.847023E+00 1.856516E+00 1.834001E+00
1.803728E+00 1.833604E+00 1.905894E+00 1.905185E+00 2.044466E+00
1.861281E+00 1.707379E+00 1.783114E+00 1.808011E+00 1.820524E+00
1.808893E+00 1.801489E+00 1.617148E+00 1.727797E+00 1.931886E+00
1.928078E+00 1.721164E+00 1.661349E+00 1.801621E+00 1.876169E+00
1.820580E+00 1.722271E+00 1.760512E+00 1.807682E+00 1.833345E+00
1.814499E+00 1.836591E+00 1.819473E+00 1.827609E+00 1.764359E+00
1.752134E+00 1.730145E+00 1.781554E+00 1.821468E+00 1.820691E+00
1.792563E+00 1.737453E+00 1.749869E+00 1.793672E+00 1.824792E+00
1.837900E+00 1.827524E+00 1.811996E+00 1.815523E+00 1.829263E+00
1.846797E+00 1.875485E+00 1.879095E+00 1.886394E+00 1.855277E+00
1.822445E+00 1.902617E+00 1.922516E+00 1.916385E+00 1.920161E+00
1.929426E+00 1.896027E+00 1.861993E+00 1.875164E+00 1.908675E+00
1.872325E+00 1.849779E+00 1.874974E+00 1.941365E+00 1.879609E+00
1.858465E+00 1.889256E+00 1.902334E+00 1.915307E+00 1.917209E+00
1.863380E+00 1.838768E+00 1.847998E+00 1.882414E+00 1.888709E+00
1.849368E+00 1.877775E+00 1.919879E+00 1.918785E+00 1.906633E+00
1.887307E+00 1.885586E+00 1.897034E+00 1.939152E+00 1.973056E+00
1.981568E+00 1.982081E+00 1.975939E+00 1.963486E+00 1.953779E+00
2.002760E+00 2.055754E+00 2.038253E+00 2.016018E+00 2.021813E+00
2.027933E+00 2.025303E+00 2.023206E+00 2.024696E+00 2.022501E+00
2.007919E+00 1.997078E+00 2.005203E+00 2.017861E+00 2.043682E+00
2.067293E+00 2.058768E+00 2.043898E+00 2.031998E+00 2.021352E+00
2.040740E+00 2.081724E+00 2.104486E+00 2.095945E+00 2.086034E+00
2.072433E+00 2.058534E+00 2.053780E+00 2.052407E+00 2.052711E+00
2.055340E+00 2.058595E+00 2.064598E+00 2.071225E+00 2.077756E+00

C

APPENDIX B. MCNP EM Cards for E722-19 Responses

```
C
C
FC192 1-MeV(Si) Equivalent Fluence (1-MeV DES [E722-19])
C
C 640 Groups
C
C
E192      1.000000E-10 1.050000E-10 1.100000E-10 1.150000E-10 1.200000E-10
          1.275000E-10 1.350000E-10 1.425000E-10 1.500000E-10 1.600000E-10
          1.700000E-10 1.800000E-10 1.900000E-10 2.000000E-10 2.100000E-10
          2.200000E-10 2.300000E-10 2.400000E-10 2.550000E-10 2.700000E-10
          2.800000E-10 3.000000E-10 3.200000E-10 3.400000E-10 3.600000E-10
          3.800000E-10 4.000000E-10 4.250000E-10 4.500000E-10 4.750000E-10
          5.000000E-10 5.250000E-10 5.500000E-10 5.750000E-10 6.000000E-10
          6.300000E-10 6.600000E-10 6.900000E-10 7.200000E-10 7.600000E-10
          8.000000E-10 8.400000E-10 8.800000E-10 9.200000E-10 9.600000E-10
          1.000000E-09 1.050000E-09 1.100000E-09 1.150000E-09 1.200000E-09
          1.275000E-09 1.350000E-09 1.425000E-09 1.500000E-09 1.600000E-09
          1.700000E-09 1.800000E-09 1.900000E-09 2.000000E-09 2.100000E-09
          2.200000E-09 2.300000E-09 2.400000E-09 2.550000E-09 2.700000E-09
          2.800000E-09 3.000000E-09 3.200000E-09 3.400000E-09 3.600000E-09
          3.800000E-09 4.000000E-09 4.250000E-09 4.500000E-09 4.750000E-09
          5.000000E-09 5.250000E-09 5.500000E-09 5.750000E-09 6.000000E-09
          6.300000E-09 6.600000E-09 6.900000E-09 7.200000E-09 7.600000E-09
          8.000000E-09 8.400000E-09 8.800000E-09 9.200000E-09 9.600000E-09
          1.000000E-08 1.050000E-08 1.100000E-08 1.150000E-08 1.200000E-08
          1.275000E-08 1.350000E-08 1.425000E-08 1.500000E-08 1.600000E-08
          1.700000E-08 1.800000E-08 1.900000E-08 2.000000E-08 2.100000E-08
          2.200000E-08 2.300000E-08 2.400000E-08 2.550000E-08 2.700000E-08
          2.800000E-08 3.000000E-08 3.200000E-08 3.400000E-08 3.600000E-08
          3.800000E-08 4.000000E-08 4.250000E-08 4.500000E-08 4.750000E-08
          5.000000E-08 5.250000E-08 5.500000E-08 5.750000E-08 6.000000E-08
          6.300000E-08 6.600000E-08 6.900000E-08 7.200000E-08 7.600000E-08
          8.000000E-08 8.400000E-08 8.800000E-08 9.200000E-08 9.600000E-08
          1.000000E-07 1.050000E-07 1.100000E-07 1.150000E-07 1.200000E-07
          1.275000E-07 1.350000E-07 1.425000E-07 1.500000E-07 1.600000E-07
          1.700000E-07 1.800000E-07 1.900000E-07 2.000000E-07 2.100000E-07
          2.200000E-07 2.300000E-07 2.400000E-07 2.550000E-07 2.700000E-07
          2.800000E-07 3.000000E-07 3.200000E-07 3.400000E-07 3.600000E-07
          3.800000E-07 4.000000E-07 4.250000E-07 4.500000E-07 4.750000E-07
          5.000000E-07 5.250000E-07 5.500000E-07 5.750000E-07 6.000000E-07
          6.300000E-07 6.600000E-07 6.900000E-07 7.200000E-07 7.600000E-07
          8.000000E-07 8.400000E-07 8.800000E-07 9.200000E-07 9.600000E-07
          1.000000E-06 1.050000E-06 1.100000E-06 1.150000E-06 1.200000E-06
          1.275000E-06 1.350000E-06 1.425000E-06 1.500000E-06 1.600000E-06
          1.700000E-06 1.800000E-06 1.900000E-06 2.000000E-06 2.100000E-06
          2.200000E-06 2.300000E-06 2.400000E-06 2.550000E-06 2.700000E-06
          2.800000E-06 3.000000E-06 3.200000E-06 3.400000E-06 3.600000E-06
          3.800000E-06 4.000000E-06 4.250000E-06 4.500000E-06 4.750000E-06
          5.000000E-06 5.250000E-06 5.500000E-06 5.750000E-06 6.000000E-06
          6.300000E-06 6.600000E-06 6.900000E-06 7.200000E-06 7.600000E-06
          8.000000E-06 8.400000E-06 8.800000E-06 9.200000E-06 9.600000E-06
          1.000000E-05 1.050000E-05 1.100000E-05 1.150000E-05 1.200000E-05
          1.275000E-05 1.350000E-05 1.425000E-05 1.500000E-05 1.600000E-05
          1.700000E-05 1.800000E-05 1.900000E-05 2.000000E-05 2.100000E-05
          2.200000E-05 2.300000E-05 2.400000E-05 2.550000E-05 2.700000E-05
          2.800000E-05 3.000000E-05 3.200000E-05 3.400000E-05 3.600000E-05
          3.800000E-05 4.000000E-05 4.250000E-05 4.500000E-05 4.750000E-05
          5.000000E-05 5.250000E-05 5.500000E-05 5.750000E-05 6.000000E-05
          6.300000E-05 6.600000E-05 6.900000E-05 7.200000E-05 7.600000E-05
```

8.000000E-05 8.400000E-05 8.800000E-05 9.200000E-05 9.600000E-05
1.000000E-04 1.050000E-04 1.100000E-04 1.150000E-04 1.200000E-04
1.275000E-04 1.350000E-04 1.425000E-04 1.500000E-04 1.600000E-04
1.700000E-04 1.800000E-04 1.900000E-04 2.000000E-04 2.100000E-04
2.200000E-04 2.300000E-04 2.400000E-04 2.550000E-04 2.700000E-04
2.800000E-04 3.000000E-04 3.200000E-04 3.400000E-04 3.600000E-04
3.800000E-04 4.000000E-04 4.250000E-04 4.500000E-04 4.750000E-04
5.000000E-04 5.250000E-04 5.500000E-04 5.750000E-04 6.000000E-04
6.300000E-04 6.600000E-04 6.900000E-04 7.200000E-04 7.600000E-04
8.000000E-04 8.400000E-04 8.800000E-04 9.200000E-04 9.600000E-04
1.000000E-03 1.050000E-03 1.100000E-03 1.150000E-03 1.200000E-03
1.275000E-03 1.350000E-03 1.425000E-03 1.500000E-03 1.600000E-03
1.700000E-03 1.800000E-03 1.900000E-03 2.000000E-03 2.100000E-03
2.200000E-03 2.300000E-03 2.400000E-03 2.550000E-03 2.700000E-03
2.800000E-03 3.000000E-03 3.200000E-03 3.400000E-03 3.600000E-03
3.800000E-03 4.000000E-03 4.250000E-03 4.500000E-03 4.750000E-03
5.000000E-03 5.250000E-03 5.500000E-03 5.750000E-03 6.000000E-03
6.300000E-03 6.600000E-03 6.900000E-03 7.200000E-03 7.600000E-03
8.000000E-03 8.400000E-03 8.800000E-03 9.200000E-03 9.600000E-03
1.000000E-02 1.050000E-02 1.100000E-02 1.150000E-02 1.200000E-02
1.275000E-02 1.350000E-02 1.425000E-02 1.500000E-02 1.600000E-02
1.700000E-02 1.800000E-02 1.900000E-02 2.000000E-02 2.100000E-02
2.200000E-02 2.300000E-02 2.400000E-02 2.550000E-02 2.700000E-02
2.800000E-02 3.000000E-02 3.200000E-02 3.400000E-02 3.600000E-02
3.800000E-02 4.000000E-02 4.250000E-02 4.500000E-02 4.750000E-02
5.000000E-02 5.250000E-02 5.500000E-02 5.750000E-02 6.000000E-02
6.300000E-02 6.600000E-02 6.900000E-02 7.200000E-02 7.600000E-02
8.000000E-02 8.400000E-02 8.800000E-02 9.200000E-02 9.600000E-02
1.000000E-01 1.050000E-01 1.100000E-01 1.150000E-01 1.200000E-01
1.275000E-01 1.350000E-01 1.425000E-01 1.500000E-01 1.600000E-01
1.700000E-01 1.800000E-01 1.900000E-01 2.000000E-01 2.100000E-01
2.200000E-01 2.300000E-01 2.400000E-01 2.550000E-01 2.700000E-01
2.800000E-01 3.000000E-01 3.200000E-01 3.400000E-01 3.600000E-01
3.800000E-01 4.000000E-01 4.250000E-01 4.500000E-01 4.750000E-01
5.000000E-01 5.250000E-01 5.500000E-01 5.750000E-01 6.000000E-01
6.300000E-01 6.600000E-01 6.900000E-01 7.200000E-01 7.600000E-01
8.000000E-01 8.400000E-01 8.800000E-01 9.200000E-01 9.600000E-01
1.000000E+00 1.100000E+00 1.200000E+00 1.300000E+00 1.400000E+00
1.500000E+00 1.600000E+00 1.700000E+00 1.800000E+00 1.900000E+00
2.000000E+00 2.100000E+00 2.200000E+00 2.300000E+00 2.400000E+00
2.500000E+00 2.600000E+00 2.700000E+00 2.800000E+00 2.900000E+00
3.000000E+00 3.100000E+00 3.200000E+00 3.300000E+00 3.400000E+00
3.500000E+00 3.600000E+00 3.700000E+00 3.800000E+00 3.900000E+00
4.000000E+00 4.100000E+00 4.200000E+00 4.300000E+00 4.400000E+00
4.500000E+00 4.600000E+00 4.700000E+00 4.800000E+00 4.900000E+00
5.000000E+00 5.100000E+00 5.200000E+00 5.300000E+00 5.400000E+00
5.500000E+00 5.600000E+00 5.700000E+00 5.800000E+00 5.900000E+00
6.000000E+00 6.100000E+00 6.200000E+00 6.300000E+00 6.400000E+00
6.500000E+00 6.600000E+00 6.700000E+00 6.800000E+00 6.900000E+00
7.000000E+00 7.100000E+00 7.200000E+00 7.300000E+00 7.400000E+00
7.500000E+00 7.600000E+00 7.700000E+00 7.800000E+00 7.900000E+00
8.000000E+00 8.100000E+00 8.200000E+00 8.300000E+00 8.400000E+00
8.500000E+00 8.600000E+00 8.700000E+00 8.800000E+00 8.900000E+00
9.000000E+00 9.100000E+00 9.200000E+00 9.300000E+00 9.400000E+00
9.500000E+00 9.600000E+00 9.700000E+00 9.800000E+00 9.900000E+00
1.000000E+01 1.010000E+01 1.020000E+01 1.030000E+01 1.040000E+01
1.050000E+01 1.060000E+01 1.070000E+01 1.080000E+01 1.090000E+01
1.100000E+01 1.110000E+01 1.120000E+01 1.130000E+01 1.140000E+01
1.150000E+01 1.160000E+01 1.170000E+01 1.180000E+01 1.190000E+01
1.200000E+01 1.210000E+01 1.220000E+01 1.230000E+01 1.240000E+01
1.250000E+01 1.260000E+01 1.270000E+01 1.280000E+01 1.290000E+01
1.300000E+01 1.310000E+01 1.320000E+01 1.330000E+01 1.340000E+01
1.350000E+01 1.360000E+01 1.370000E+01 1.380000E+01 1.390000E+01

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          1.400000E+01 1.410000E+01 1.420000E+01 1.430000E+01 1.440000E+01
          1.450000E+01 1.460000E+01 1.470000E+01 1.480000E+01 1.490000E+01
          1.500000E+01 1.510000E+01 1.520000E+01 1.530000E+01 1.540000E+01
          1.550000E+01 1.560000E+01 1.570000E+01 1.580000E+01 1.590000E+01
          1.600000E+01 1.610000E+01 1.620000E+01 1.630000E+01 1.640000E+01
          1.650000E+01 1.660000E+01 1.670000E+01 1.680000E+01 1.690000E+01
          1.700000E+01 1.710000E+01 1.720000E+01 1.730000E+01 1.740000E+01
          1.750000E+01 1.760000E+01 1.770000E+01 1.780000E+01 1.790000E+01
          1.800000E+01 1.810000E+01 1.820000E+01 1.830000E+01 1.840000E+01
          1.850000E+01 1.860000E+01 1.870000E+01 1.880000E+01 1.890000E+01
          1.900000E+01 1.910000E+01 1.920000E+01 1.930000E+01 1.940000E+01
          1.950000E+01 1.960000E+01 1.970000E+01 1.980000E+01 1.990000E+01
          2.000000E+01
C
C  Multipliers converted from E722-19 standard. The values were taken from
C   Table A.1.1 divided by 95 MeV-mb.
C
C  The first bin is a zero because the bin goes from 0.0 -- 1.0e-10 MeV
C   (i.e., below the table).
C
EM192     0.000000
          1.595282E-02 1.558306E-02 1.522148E-02 1.490198E-02 1.451471E-02
          1.409668E-02 1.370529E-02 1.335189E-02 1.296773E-02 1.256808E-02
          1.220451E-02 1.188299E-02 1.156761E-02 1.127695E-02 1.101085E-02
          1.076432E-02 1.053112E-02 1.026241E-02 9.963900E-03 9.734723E-03
          9.489117E-03 9.171704E-03 8.893324E-03 8.630347E-03 8.397176E-03
          8.175085E-03 7.950534E-03 7.719402E-03 7.506562E-03 7.312217E-03
          7.134199E-03 6.969120E-03 6.807333E-03 6.664544E-03 6.510981E-03
          6.358844E-03 6.214722E-03 6.081285E-03 5.934804E-03 5.781439E-03
          5.637423E-03 5.505012E-03 5.385029E-03 5.272246E-03 5.159555E-03
          5.044712E-03 4.927919E-03 4.813487E-03 4.712512E-03 4.589856E-03
          4.457961E-03 4.334183E-03 4.222111E-03 4.100999E-03 3.974343E-03
          3.859500E-03 3.757803E-03 3.658161E-03 3.566225E-03 3.481995E-03
          3.404028E-03 3.330168E-03 3.245319E-03 3.150920E-03 3.078394E-03
          3.000836E-03 2.900377E-03 2.812441E-03 2.729239E-03 2.655487E-03
          2.585222E-03 2.514240E-03 2.441106E-03 2.373822E-03 2.312394E-03
          2.256100E-03 2.203916E-03 2.152659E-03 2.107561E-03 2.058977E-03
          2.010897E-03 1.965289E-03 1.923075E-03 1.876844E-03 1.828260E-03
          1.782751E-03 1.740845E-03 1.702937E-03 1.667294E-03 1.631645E-03
          1.595288E-03 1.558408E-03 1.522148E-03 1.490301E-03 1.451574E-03
          1.409767E-03 1.370633E-03 1.335191E-03 1.296978E-03 1.256912E-03
          1.220554E-03 1.188403E-03 1.156865E-03 1.128205E-03 1.102214E-03
          1.076534E-03 1.053834E-03 1.026684E-03 9.972135E-04 9.742449E-04
          9.485122E-04 9.173569E-04 8.892626E-04 8.632116E-04 8.395656E-04
          8.178086E-04 7.950972E-04 7.721073E-04 7.517277E-04 7.318199E-04
          7.135971E-04 6.971000E-04 6.809112E-04 6.666334E-04 6.513581E-04
          6.361248E-04 6.217233E-04 6.083695E-04 5.938242E-04 5.784673E-04
          5.640348E-04 5.507835E-04 5.387556E-04 5.274865E-04 5.162080E-04
          5.046618E-04 4.929933E-04 4.815499E-04 4.714628E-04 4.593011E-04
          4.461119E-04 4.337341E-04 4.225374E-04 4.104582E-04 3.977728E-04
          3.862888E-04 3.761195E-04 3.661763E-04 3.569836E-04 3.485711E-04
          3.407749E-04 3.333996E-04 3.249669E-04 3.155175E-04 3.082251E-04
          3.005624E-04 2.905281E-04 2.817564E-04 2.734780E-04 2.661447E-04
          2.591503E-04 2.520946E-04 2.449979E-04 2.385995E-04 2.322015E-04
          2.265946E-04 2.218086E-04 2.170232E-04 2.122377E-04 2.069904E-04
          2.022257E-04 1.979847E-04 1.937443E-04 1.888561E-04 1.841233E-04
          1.797698E-04 1.754169E-04 1.715873E-04 1.680866E-04 1.645759E-04
          1.611573E-04 1.578013E-04 1.544453E-04 1.510893E-04 1.469936E-04
          1.430019E-04 1.393186E-04 1.356349E-04 1.319109E-04 1.281462E-04
          1.244643E-04 1.213475E-04 1.183324E-04 1.157599E-04 1.136494E-04
          1.115489E-04 1.094383E-04 1.068154E-04 1.036498E-04 1.011009E-04
          9.899512E-05 9.629942E-05 9.360375E-05 9.100968E-05 8.903300E-05
          8.716113E-05 8.505946E-05 8.303008E-05 8.131906E-05 7.960709E-05
```

7.814875E-05 7.694828E-05 7.574777E-05 7.454727E-05 7.323512E-05
7.210408E-05 7.114048E-05 7.017596E-05 6.906608E-05 6.806888E-05
6.718673E-05 6.630663E-05 6.558987E-05 6.497880E-05 6.436676E-05
6.384162E-05 6.340443E-05 6.296631E-05 6.252912E-05 6.200716E-05
6.167695E-05 6.144127E-05 6.120657E-05 6.110787E-05 6.114748E-05
6.121686E-05 6.146287E-05 6.173961E-05 6.215604E-05 6.271522E-05
6.327531E-05 6.383443E-05 6.453198E-05 6.537166E-05 6.610253E-05
6.725783E-05 6.884911E-05 7.043941E-05 7.206144E-05 7.387020E-05
7.570974E-05 7.777599E-05 8.016993E-05 8.265818E-05 8.514542E-05
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6.967900E-01 1.194928E+00 1.161856E+00 9.778891E-01 8.377525E-01
7.438071E-01 6.812343E-01 6.276306E-01 5.887208E-01 5.657171E-01
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1.221972E+00 7.546353E-01 1.246506E+00 1.198444E+00 1.465315E+00
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          1.752134E+00 1.730145E+00 1.781554E+00 1.821468E+00 1.820691E+00
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          2.055340E+00 2.058595E+00 2.064598E+00 2.071225E+00 2.077756E+00
C
C
C
C
FC12 1-MeV(Si) Equivalent Fluence (1-MeV DES [E722-19])
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
          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
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          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
C Description: This free field response was extracted from the E722-19.
C K. R. DePriest.
C
C Production: The data from Table A.1.1 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: E722-19_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
            7.44243E-03 3.15650E-03 1.89213E-03 1.18247E-03 7.37912E-04
            5.56521E-04 4.57195E-04 3.86261E-04 2.96518E-04 2.29093E-04
            1.94744E-04 1.66723E-04 1.18107E-04 8.63707E-05 7.18240E-05
            6.34384E-05 6.17099E-05 6.82414E-05 8.59796E-05 1.20652E-04
            1.81709E-04 2.84302E-04 3.95208E-04 5.00273E-04 6.35462E-04
            8.08117E-04 1.02623E-03 1.22511E-03 1.38355E-03 1.55573E-03
            1.75506E-03 1.97671E-03 2.23608E-03 3.22875E-03 2.84539E-03
            3.19544E-03 3.59791E-03 4.04335E-03 4.57170E-03 5.21018E-03
            5.82500E-03 6.48725E-03 7.29222E-03 8.17655E-03 9.17621E-03
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            1.77583E-02 1.95684E-02 2.15329E-02 2.29035E-02 2.39830E-02
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            5.27105E-01 5.51687E-01 5.74651E-01 8.19356E-01 6.85554E-01
            5.99625E-01 9.59231E-01 1.02508E+00 1.02010E+00 7.16095E-01
            9.53112E-01 1.23916E+00 1.18830E+00 1.24351E+00 1.21606E+00
            1.44932E+00 1.66214E+00 1.70001E+00 1.80739E+00 1.79807E+00
            1.88337E+00 1.88107E+00 1.94634E+00 2.04734E+00
```

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