Designation: E722 – 14

Standard Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics[1]

This standard is issued under the fixed designation E722; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This practice covers procedures for characterizing neutron fluence from a source in terms of an equivalent monoenergetic neutron fluence. It is applicable to neutron effects testing, to the development of test specifications, and to the characterization of neutron test environments. The sources may have a broad neutron-energy range, or may be mono-energetic neutron sources with energies up to 20 MeV. This practice is not applicable in cases where the predominant source of displacement damage is from neutrons of energy less than 10 keV. The relevant equivalence is in terms of a specified effect on certain physical properties of materials upon which the source spectrum is incident. In order to achieve this, knowledge of the effects of neutrons as a function of energy on the specific property of the material of interest is required. Sharp variations in the effects with neutron energy may limit the usefulness of this practice in the case of mono-energetic sources.

1.2 This practice is presented in a manner to be of general application to a variety of materials and sources. Correlation between displacements (**1-3**)[2] caused by different particles (electrons, neutrons, protons, and heavy ions) is beyond the scope of this practice. In radiation-hardness testing of electronic semiconductor devices, specific materials of interest include silicon and gallium arsenide, and the neutron sources generally are test and research reactors and californium-252 irradiators.

1.3 The technique involved relies on the following factors: *(1)* a detailed determination of the fluence spectrum of the neutron source, and *(2)* a knowledge of the degradation (damage) effects of neutrons as a function of energy on specific material properties.

1.4 The detailed determination of the neutron fluence spectrum referred to in 1.3 need not be performed afresh for each test exposure, provided the exposure conditions are repeatable. When the spectrum determination is not repeated, a neutron fluence monitor shall be used for each test exposure.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard, except for MeV, keV, eV, MeV·mbarn, rad(Si)·cm^2, rad(GaAs)·cm^2.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E265 Test Method for Measuring Reaction Rates and Fast-Neutron Fluences by Radioactivation of Sulfur-32

E693 Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements Per Atom (DPA), E 706(ID)

E720 Guide for Selection and Use of Neutron Sensors for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics

E721 Guide for Determining Neutron Energy Spectra from Neutron Sensors for Radiation-Hardness Testing of Electronics

[1] This practice is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applicationsand is the direct responsibility of Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this practice.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706 (IIC)

E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, E 706 (IIA)

2.2 *International Commission on Radiation Units and Measurements (ICRU) Reports:*[4]

ICRU Report 13 Neutron Fluence, Neutron Spectra, and Kerma

ICRU Report 60 Fundamental Quantities and Units for Ionizing Radiation

ICRU Report 85 Fundamental Quantities and Units for Ionizing Radiation (Revised)

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *displacement damage function*—($F_{D,mat}(E)$) an energy-dependent parameter proportional to the quotient of the observable displacement damage per target atom and the neutron fluence. Different displacement-related damage functions may exist, so the damage mode of interest and the observation procedure shall be identified when the specific damage function is defined. See, for example, Annexes A1.2.2 and A2.2.2.

3.1.1.1 *Discussion*—Observable changes in a material's properties attributable to the atomic displacement process are useful indices of displacement damage in that material. In cases where the observed displacement damage is not in linear proportion to the applied fluence, the displacement damage function represents the quotient d(observed damage)/dΦ in the limiting case of zero fluence. Examples of suitable representations of displacement damage functions are given in the annexes. In the case of silicon, damage mode of interest is the change in minority-carrier recombination lifetime in the bulk semiconductor material. While several procedures exist to directly measure the minority carrier lifetime in bulk material, since this lifetime is related to the gain of a bipolar junction transistor (BJT), one observable damage metric is the BJT gain degradation. For this damage mode, it has been shown that the displacement damage function may be successfully equated with the microscopic displacement kerma factor. This question is discussed further in the annexes.

3.1.2 *microscopic displacement kerma factor*—($\kappa_{D,mat}(E)$) the energy-dependent quotient of the displacement kerma per target atom and the neutron fluence. $\kappa_{D,mat}(E)$ is proportional to $K_{D,mat}\bar{A}/\Phi$, where $K_{D,mat}$ is the displacement kerma, $\bar{A}$ is the mean atomic mass of the material and Φ is the neutron fluence from a monoenergetic source of energy E.

3.1.2.1 *Discussion*—This quantity may be calculated from the microscopic neutron interaction cross sections, the kinematic relations for each reaction and from a suitable partition function which divides the total kerma into ionization and displacement kerma. The use of the term *microscopic* kerma factor in this standard is to indicate that energy times area per atom is used, instead of per unit mass, as in the term kerma factor defined in E170.

3.1.3 *fluence spectrum hardness parameter*—($H_{Eref,mat} = \Phi_{eq,Eref,mat}/\Phi$) this parameter is defined as the ratio of the equivalent monoenergetic neutron fluence to the total fluence, $\Phi_{eq,Eref,mat}/\Phi$. The numerical value of the hardness parameter is also equal to the fluence of monoenergetic neutrons at the specific energy, Eref, required to produce the same displacement damage in the specified material, mat, as unit fluence of neutrons of neutron spectrum Φ(E).

3.1.3.1 *Discussion*—For damage correlation, a convenient method of characterizing the shape of an incident neutron fluence spectrum Φ(E), is in terms of a fluence spectrum hardness parameter **(4)**. The hardness parameter in a particular neutron field depends on the displacement damage function used to compute the damage (see annexes) and is therefore different for different semiconductor materials.

3.1.4 *equivalent monoenergetic neutron fluence*—($\Phi_{eq,Eref,mat}$) an equivalent monoenergetic neutron fluence, $\Phi_{eq,Eref,mat}$, characterizes an incident fluence spectrum, Φ(E), in terms of the fluence of monoenergetic neutrons at a specific energy Eref required to produce the same displacement damage in a specified irradiated material, mat, as Φ(E).

3.1.4.1 *Discussion*—Note that $\Phi_{eq,Eref,mat}$ is equivalent to Φ(E) if, and only if, the specific device effect (for example, current gain degradation in silicon) being correlated is described by the displacement damage function used in the calculation.

3.1.5 *fluence* and *fluence spectrum*—see *neutron fluence* and *neutron fluence spectrum*.

3.1.6 *kerma factor*—($K_{mat}(E)$) the **kerma** per unit fluence of particles of energy E present in a specified material, mat. See Terminology E170 for the definition of **kerma**, and a formula for calculating the kerma factor.

3.1.6.1 *Discussion*—When a material is irradiated by a neutron field, the energy imparted to charged particles in the material may be described by the kerma. The kerma may be divided into two parts, ionization kerma and displacement kerma. See 3.1.2.1 for the distinction between kerma factor and microscopic kerma factor. Calculations of ionization and microscopic displacement kerma in silicon and gallium arsenide as a result of irradiation by neutrons with energies up to 20 MeV are described in Refs **5-8** and in the annexes.

3.1.7 *neutron fluence* and *neutron fluence spectrum* are used in this standard, and are special cases of **fluence** and **fluence spectrum** as defined in E170.

3.1.7.1 *Discussion*—In cases where the context makes clear that neutrons are referred to, the terms *fluence* and *fluence spectrum* are sometimes used.

4. Summary of Practice

4.1 The equivalent monoenergetic neutron fluence, $\Phi_{eq,Eref,mat}$, is given as follows:

$$\Phi_{eq,Eref,mat} = \frac{\int_0^\infty \Phi(E) F_{D,mat}(E)\,dE}{F_{D,Eref,mat}} \quad (1)$$

[4] Available from International Commission on Radiation Units and Measurements, 7910 Woodmont Avenue Suite 400 Bethesda, MD 20841-3095, http://www.icru.org/

where:

$\Phi(E)$ = incident neutron fluence spectrum,
$F_{D,mat}(E)$ = neutron displacement damage function for the irradiated material (displacement damage per unit fluence) as a function of energy, and
$F_{D,Eref,mat}$ = displacement damage reference value designated for the irradiated material and for the specified equivalent energy, Eref, as given in the annexes.

The energy limits on the integral are determined in practice by the incident neutron fluence spectrum and by the material being irradiated.

4.2 The neutron spectrum hardness parameter, $H_{Eref,mat}$, is given as follows:

$$H_{Eref,mat} = \frac{\int_0^\infty \Phi(E) F_{D,mat}(E) dE}{F_{D,Eref,mat} \int_0^\infty \Phi(E) dE} \quad (2)$$

4.3 Once the neutron fluence spectrum has been determined (for example, in accordance with Test Method E721) and the equivalent monoenergetic fluence calculated, then a monitor (such as an activation foil) can be used in subsequent irradiations at the same location to determine the fluence; that is, the neutron fluence is then described in terms of the equivalent monoenergetic neutron fluence per unit monitor response, $\Phi_{eq,Eref,mat}/M_r$. Use of a monitor foil to predict $\Phi_{eq,Eref,mat}$ is valid only if the neutron spectrum remains constant.

5. Significance and Use

5.1 This practice is important in characterizing the radiation hardness of electronic devices irradiated by neutrons. This characterization makes it feasible to predict some changes in operational properties of irradiated semiconductor devices or electronic systems. To facilitate uniformity of the interpretation and evaluation of results of irradiations by sources of different fluence spectra, it is convenient to reduce the incident neutron fluence from a source to a single parameter—an equivalent monoenergetic neutron fluence—applicable to a particular semiconductor material.

5.2 In order to determine an equivalent monoenergetic neutron fluence, it is necessary to evaluate the displacement damage of the particular semiconductor material. Ideally, this quantity is correlated to the degradation of a specific functional performance parameter (such as current gain) of the semiconductor device or system being tested. However, this correlation has not been established unequivocally for all device types and performance parameters since, in many instances, other effects also can be important. Ionization effects produced by the incident neutron fluence or by gamma rays in a mixed neutron fluence, short-term and long-term annealing, and other factors can contribute to observed performance degradation (damage). Thus, caution should be exercised in making a correlation between calculated displacement damage and performance degradation of a given electronic device. The types of devices for which this correlation is applicable, and numerical evaluation of displacement damage are discussed in the annexes.

5.3 The concept of 1-MeV equivalent fluence is widely used in the radiation-hardness testing community. It has merits and disadvantages that have been debated widely (**9-12**). For these reasons, specifics of a standard application of the 1-MeV equivalent fluence are presented in the annexes.

6. Procedure for Calculating $\Phi_{eq,Eref,mat}$

6.1 To evaluate Eq 1 and 2, determine the energy limits E_{min} and E_{max} to be used in place of zero and infinity in the integrals of (Eq 1) and (Eq 2) and the values of the displacement damage function $F_{D,mat}(E)$ for the irradiated material and perform the indicated integrations.

6.1.1 Choose the upper limit E_{max} to be at an energy above which the integral damage falls to an insignificant level. For Godiva- or TRIGA-type spectra, this limit is about 12 MeV.

6.1.2 Choose the lower-energy limit E_{min} to be at an energy below which the integral damage falls to an insignificant level. For silicon irradiated by Godiva-type spectra, this energy has been historically chosen to be about 0.01 MeV. More highly moderated spectra may require lower thresholds or specialized filtering requirements such as a boron shield, or both.

6.1.3 The values of the neutron displacement damage function used in Eq 1 and 2 obviously depend on the material and the equivalent energy chosen. For silicon, resonance effects cause large variations (by a factor of 20 or more) in the displacement damage function as a function of energy over the range from about 0.1 to 8 MeV (**4, 5**). Therefore, monoenergetic neutron sources with these energies may not be useful for effects testing. Also, for a selected equivalent energy, the value of $F_{D,Eref,mat}$ at that specific energy may not be representative of the displacement damage function at nearby energies. In such cases, a method of averaging the damage function over a range of energies around the chosen equivalent energy can be used. Such averaging is discussed in the annexes. Because the $F_{D,mat}(E)$ term is normalized by dividing by $F_{D,Eref,mat}$ in Eq 1 and 2, only the shape of the $F_{D,mat}(E)$ function versus energy is of primary importance. In such a case, precise knowledge of the absolute values of $F_{D,mat}(E)$ is not required in evaluating $\Phi_{eq,Eref,mat}$ and $H_{Eref,mat}$.

7. Determining $\Phi_{eq,Eref,mat}$ with a Monitor Foil

7.1 At the same time that the fluence spectrum, $\Phi(E)$, of the source is determined (for example, with an activation foil set in accordance with Guides E720 or E844, or both, and Test Method E721 or Practice E944, or both) place a fast-neutron monitor foil in the neutron field at an appropriate location. After $\Phi_{eq,Eref,mat}$ is determined and the monitor foil counted, calculate the ratio of the equivalent monoenergetic fluence to the unit monitor response, $\Phi_{eq,Eref,mat}/M_r$.

7.2 Use the response of the fast-neutron monitor foil, M_r, to predict $\Phi_{eq,Eref,mat}$ in subsequent routine device test irradiations. For this method to be valid, it is important to keep the source-foil geometry essentially identical to that used for calibrating the monitor foil. Moderate changes in source-to-foil distance are allowable. In addition, make sure the source location (of a Godiva-type reactor) with respect to scattering materials (walls, floor, etc.) is the same. Do not change or move nearby scattering materials or moderators.

7.3 Precautions in maintaining original calibration conditions are necessary to avoid altering the neutron fluence

spectrum significantly in subsequent irradiations. An appreciable change in the spectrum will invalidate the calibration of the monitor foil and, therefore, would necessitate a new measurement of Φ(E) and recalibration of the monitor foil. Whenever the neutron source configuration is changed, as for example, if the core fuel elements are replaced or rearranged in a nuclear reactor, the activation foil spectrum measurements and all quantities derived from them may need to be remeasured.

7.4 The choice of a monitor foil material depends on several factors:

7.4.1 The activation threshold should be high enough so as to make it insensitive to neutrons below the E_{min} value used in Eq 1 and 2. However, the threshold energy should be low enough to sample a significant fraction of the total fluence.

7.4.2 The monitor foil should have a high neutron sensitivity and a convenient half-life.

7.4.3 The detector system available for counting the monitor foil may dictate the choice of foil material. A germanium gamma-ray detector system can be used, and ^{54}Fe or ^{58}Ni foils utilized as monitors. However, if a beta particle detector system is available, then ^{32}S foils are suitable. Details of the use of sulfur foils are given in Test Method E265.

8. Report

8.1 In the report of the results of radiation-hardness tests in which an equivalent monoenergetic neutron fluence is calculated, the report should include at least the following information:

8.1.1 Semiconductor material and device performance parameter (for example, current gain in silicon bipolar transistors) degradation being correlated to displacement damage should be specified.

8.1.2 Neutron source as to type and mode of operation during tests (fast-pulse or steady state).

8.1.3 Neutron fluence spectrum and how it was determined.

8.1.4 Monitor foil employed and the detector system used for counting the foil. If an effective fission cross section for the monitor foil is used, its value should be stated.

8.1.5 The neutron displacement damage function should be given, or referenced. The specific material (for example, silicon) whose applicable damage function was used must be specified. The values cited in Annex A1 and Annex A2 shall be used for silicon and GaAs, respectively.

8.1.6 Methods used for determining the average value of $F_{D,Eref,mat}$ and the value of Eref selected. The values cited in Annex A1 and Annex A2 shall be used for silicon and GaAs, respectively.

8.1.7 Method used for evaluating the integrals of Eq 1 and 2 (for example, the energy bin width and number of bins in a numerical integration, and the limits of integration).

8.1.8 Values of $\Phi_{eq,Eref,mat}$, $H_{Eref,mat}$, and $\Phi_{eq,Eref,mat}/M_r$.

9. Precision and Bias

9.1 The precision in calculating $\Phi_{eq,Eref,mat}$ and $H_{Eref,mat}$ will depend on the method of evaluation of the integrals in Eq 1 and 2 (for example, the width of the energy bins used in a numerical integration).

9.2 The uncertainty of the calculated results depends on *(1)* knowledge of the neutron fluence spectrum, *(2)* knowledge of the displacement damage functions over that energy spectrum, and *(3)* knowledge of the value of the average displacement damage function at the specified equivalent energy.

9.3 A specific example of the uncertainty associated with the calculation of a 1-MeV equivalent fluence for silicon is given in Annex A1.

10. Keywords

10.1 displacement damage; electronic hardness; gallium arsenide; hardness parameter; silicon; silicon damage; silicon equivalent damage (SED); 1–MeV equivalent fluence

ANNEXES

(Mandatory Information)

A1. CALCULATION OF 1-MeV EQUIVALENT NEUTRON FLUENCE FOR SILICON

A1.1 Background

A1.1.1 The observable damage metric of interest in this annex is the change in gain of a silicon bipolar junction transistor (BJT) due to bulk displacement damage effects. The damage mechanism is the change in minority-carrier recombination lifetime in the bulk semiconductor material. While a BJT gain may also be degraded by oxide traps and interface states introduced by the ionizing dose to the oxide, this is a surface effect and is not within the scope of this standard. In interpreting measurements of this 1-MeV(Si) damage, efforts must be made to eliminate any interference from ionization-related surface effects.

A1.1.2 The choice of the specific energy for determining an equivalent fluence has been the subject of some controversy within the electronics hardness-testing community (**9**). Some workers (**10**) have proposed that 1 MeV be used while others (**11**, **12**) have suggested 14 MeV to be more appropriate. The concept of 1-MeV equivalent fluence has gained broad acceptance in practice, and procedures for applying it to silicon are described in this annex in some detail.

A1.1.3 An important basis of the practice is the correlation of radiation damage effects in a semiconductor device with the displacement kerma produced in bulk silicon by neutron irradiation. This correlation assumes that volume (versus

surface) effects are the dominant radiation damage mechanism. Experimental evidence indicates that displacement kerma is a valid measure of device performance degradation (for example, reduction in current gain) in bipolar transistors whose operation basically depends on volume mechanisms (**13, 14**). However, for device types governed by surface phenomena (such as MOSFET devices), it is clear that this correlation is not valid. Surface-effect devices are more sensitive than are volume-effect devices to ionization radiation effects produced either by a neutron field or a mixed neutron-gamma field. Therefore, the basic mechanism associated with device performance and the effect being correlated (for example, gain degradation) should be kept in mind before applying this practice at any equivalent energy.

A1.2 Calculation of $\Phi_{eq,1MeV,Si}$

A1.2.1 The displacement damage function, $F_{D,mat}(E)$, defined for silicon in this annex is the silicon microscopic displacement kerma factor, as tabulated in Table A1.1.

A1.2.2 A 1-MeV equivalent fluence in silicon is defined for an irradiation by neutrons of any neutron spectrum for which the predominant source of displacement damage is from neutrons of energy between 10 keV and 20 MeV. The neutron fluence spectrum, $\Phi(E)$, may be that determined from a neutron transport calculation, that determined from measurements, or that given in an environment specification document.

A1.2.3 The neutron fluence spectrum, $\Phi(E)$, may be determined experimentally by measuring a set of activation foils and then by application of a spectral adjustment computer code (see Guide E720 and Test Method E721 for details).

A1.2.4 Results of calculations of silicon microscopic displacement kerma factors (displacement kerma per target atom per unit neutron fluence), $\kappa_{D,Si}(E)$, are given in Table A1.1 as a function of neutron energy over the range from 10^{-10} to 20 MeV (**15**). The unit of the microscopic kerma factor is megaelectron volt times millibarns (MeV·mbarn). Each factor can be multiplied by 3.435×10^{-13} to convert to rad(Si)·cm^2, or by 3.435×10^{-19} to convert to J·m^2/kg or Gy(Si)·m^2. The silicon microscopic displacement kerma factor as given in Table A1.1 is the accepted silicon damage function to be used in the application of this standard: $F_{D,Si}(E) = \kappa_{D,Si}(E)$. This microscopic displacement kerma was computed by using the ENDF/B-VII cross sections (**16**) for ^{28}Si, ^{29}Si and ^{30}Si in their natural abundance composition, a displacement threshold energy of 20.5 eV, the Robinson fit to the Lindhard energy partition function (**17**), and the NJOY-2012 processing code (**18**). Fig. A1.1 shows the energy dependence of the silicon 1-MeV damage function.

A1.2.5 An average value of neutron microscopic displacement kerma factor near 1 MeV is difficult to determine because of sharp neutron cross-section resonances in that energy region. To avoid these difficulties, Namenson, Wolicki, and Messenger (**13**) fitted the function $AE(1 - \exp(-B/E))$ to various tabulations of $\kappa_D(E)$ versus energy. The values of A and B obtained by a least squares fit yielded an average value at 1 MeV of 95 ± 4 MeV·mbarn. A similar procedure applied to the data given in Table A1.1 also gives a value close to 95 MeV·mbarn. Accordingly, the designated value of $F_{D,1MeV,Si}$ to be used in Eq 1 and 2 to calculate a 1-MeV equivalent fluence is 95 MeV·mbarn.

A1.2.6 For purposes of intercomparison of hardness testing results from various laboratories, the value of $F_{D,1MeV,Si}$ used in obtaining such results is very important; therefore, reporting of results should include confirmation that the value of $F_{D,1MeV,Si}$ designated in A1.2.5 was used in any calculation.

A1.2.7 Once the neutron fluence spectrum $\Phi(E)$ has been determined for the energy range of interest, then use numerical integration to evaluate Eq 1 and 2, using values for $F_D(E)$ from Table A1.1 and $F_{D,1MeV,Si} = 95$ MeV·mbarn.

A1.3 Precision and Bias

A1.3.1 The values for $\kappa_{D,Si}(E)$ given in Table A1.1 are determined by calculating the total kerma and then partitioning it into ionization and displacement fractions. Because of the lack of adequate theory to partition the kerma and uncertainties in cross sections, the estimated uncertainty in the microscopic displacement kerma factor is about 10 % up to 3 MeV. Correlation of displacement kerma with measured damage in many neutron fields has been confirmed with uncertainties no larger than 10 % (**14**).

A1.3.2 Uncertainties in the neutron fluence spectrum, $\Phi(E)$, will vary based on the method used to obtain it. If neutron sensors such as activation foils were used, see Standard Guide E721.

A1.3.3 Since this mandatory annex requires the use of Table A1.1 and $F_{D,1MeV,Si} = 95$ MeV·mbarn, no uncertainty in the calculation of 1-MeV equivalent fluence is attributable to the consistent use of these data. Therefore only the uncertainty in the determination of $\Phi(E)$ need be considered in assigning an uncertainty to the 1-MeV equivalent fluence. An uncertainty in the spectrum in the range ±20 %, would most often lead to uncertainties no more than ±10 % in the integral quantity $\Phi_{eq,1MeV,Si}$. While no specific group structure for representing the neutron fluence spectrum is recommended, the choice of energy bin boundaries will affect the uncertainty in the 1-MeV equivalent fluence. The energy bin boundaries should be chosen with due consideration for the shape of both the neutron spectrum and the 1-MeV equivalent damage function. A poor choice of the energy group structure used to evaluate the integral in Eq 2 could increase this uncertainty (see 8.1.7).

TABLE A1.1 ^{nat}Silicon Damage Function

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
1	2.000000E+01	1.995000E+01	1.974223E+02
2	1.990000E+01	1.985000E+01	1.967937E+02
3	1.980000E+01	1.975000E+01	1.961647E+02
4	1.970000E+01	1.965000E+01	1.955857E+02
5	1.960000E+01	1.955000E+01	1.952768E+02
6	1.950000E+01	1.945000E+01	1.950267E+02
7	1.940000E+01	1.935000E+01	1.949968E+02
8	1.930000E+01	1.925000E+01	1.951260E+02
9	1.920000E+01	1.915000E+01	1.955842E+02
10	1.910000E+01	1.905000E+01	1.969098E+02
11	1.900000E+01	1.895000E+01	1.982156E+02
12	1.890000E+01	1.885000E+01	1.991628E+02
13	1.880000E+01	1.875000E+01	1.999799E+02
14	1.870000E+01	1.865000E+01	1.978047E+02
15	1.860000E+01	1.855000E+01	1.938940E+02
16	1.850000E+01	1.845000E+01	1.920378E+02
17	1.840000E+01	1.835000E+01	1.930547E+02
18	1.830000E+01	1.825000E+01	1.941904E+02
19	1.820000E+01	1.815000E+01	1.956167E+02
20	1.810000E+01	1.805000E+01	1.964416E+02
21	1.800000E+01	1.795000E+01	1.941766E+02
22	1.790000E+01	1.785000E+01	1.917115E+02
23	1.780000E+01	1.775000E+01	1.905113E+02
24	1.770000E+01	1.765000E+01	1.897319E+02
25	1.760000E+01	1.755000E+01	1.907675E+02
26	1.750000E+01	1.745000E+01	1.921653E+02
27	1.740000E+01	1.735000E+01	1.923810E+02
28	1.730000E+01	1.725000E+01	1.922374E+02
29	1.720000E+01	1.715000E+01	1.924440E+02
30	1.710000E+01	1.705000E+01	1.926999E+02
31	1.700000E+01	1.695000E+01	1.921279E+02
32	1.690000E+01	1.685000E+01	1.915772E+02
33	1.680000E+01	1.675000E+01	1.937092E+02
34	1.670000E+01	1.665000E+01	1.953922E+02
35	1.660000E+01	1.655000E+01	1.903341E+02
36	1.650000E+01	1.645000E+01	1.856649E+02
37	1.640000E+01	1.635000E+01	1.865918E+02
38	1.630000E+01	1.625000E+01	1.877974E+02
39	1.620000E+01	1.615000E+01	1.883864E+02
40	1.610000E+01	1.605000E+01	1.883452E+02
41	1.600000E+01	1.595000E+01	1.875458E+02
42	1.590000E+01	1.585000E+01	1.843038E+02
43	1.580000E+01	1.575000E+01	1.803025E+02
44	1.570000E+01	1.565000E+01	1.792159E+02
45	1.560000E+01	1.555000E+01	1.793850E+02
46	1.550000E+01	1.545000E+01	1.812501E+02
47	1.540000E+01	1.535000E+01	1.824167E+02
48	1.530000E+01	1.525000E+01	1.825359E+02
49	1.520000E+01	1.515000E+01	1.785266E+02
50	1.510000E+01	1.505000E+01	1.758240E+02
51	1.500000E+01	1.495000E+01	1.795943E+02
52	1.490000E+01	1.485000E+01	1.789953E+02
53	1.480000E+01	1.475000E+01	1.757235E+02
54	1.470000E+01	1.465000E+01	1.748468E+02
55	1.460000E+01	1.455000E+01	1.772119E+02
56	1.450000E+01	1.445000E+01	1.823635E+02
57	1.440000E+01	1.435000E+01	1.822088E+02
58	1.430000E+01	1.425000E+01	1.809770E+02
59	1.420000E+01	1.415000E+01	1.797454E+02
60	1.410000E+01	1.405000E+01	1.768178E+02
61	1.400000E+01	1.395000E+01	1.788456E+02
62	1.390000E+01	1.385000E+01	1.847664E+02
63	1.380000E+01	1.375000E+01	1.784289E+02
64	1.370000E+01	1.365000E+01	1.760411E+02
65	1.360000E+01	1.355000E+01	1.782104E+02
66	1.350000E+01	1.345000E+01	1.816978E+02
67	1.340000E+01	1.335000E+01	1.785120E+02
68	1.330000E+01	1.325000E+01	1.772619E+02
69	1.320000E+01	1.315000E+01	1.805299E+02
70	1.310000E+01	1.305000E+01	1.837276E+02
71	1.300000E+01	1.295000E+01	1.828576E+02
72	1.290000E+01	1.285000E+01	1.825162E+02

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
73	1.280000E+01	1.275000E+01	1.831141E+02
74	1.270000E+01	1.265000E+01	1.812270E+02
75	1.260000E+01	1.255000E+01	1.735857E+02
76	1.250000E+01	1.245000E+01	1.767395E+02
77	1.240000E+01	1.235000E+01	1.797322E+02
78	1.230000E+01	1.225000E+01	1.790482E+02
79	1.220000E+01	1.215000E+01	1.787140E+02
80	1.210000E+01	1.205000E+01	1.759861E+02
81	1.200000E+01	1.195000E+01	1.743238E+02
82	1.190000E+01	1.185000E+01	1.730297E+02
83	1.180000E+01	1.175000E+01	1.727131E+02
84	1.170000E+01	1.165000E+01	1.742102E+02
85	1.160000E+01	1.155000E+01	1.752101E+02
86	1.150000E+01	1.145000E+01	1.739761E+02
87	1.140000E+01	1.135000E+01	1.710272E+02
88	1.130000E+01	1.125000E+01	1.668493E+02
89	1.120000E+01	1.115000E+01	1.656722E+02
90	1.110000E+01	1.105000E+01	1.709562E+02
91	1.100000E+01	1.095000E+01	1.736557E+02
92	1.090000E+01	1.085000E+01	1.737472E+02
93	1.080000E+01	1.075000E+01	1.699377E+02
94	1.070000E+01	1.065000E+01	1.650493E+02
95	1.060000E+01	1.055000E+01	1.671501E+02
96	1.050000E+01	1.045000E+01	1.683353E+02
97	1.040000E+01	1.035000E+01	1.743913E+02
98	1.030000E+01	1.025000E+01	1.736199E+02
99	1.020000E+01	1.015000E+01	1.752688E+02
100	1.010000E+01	1.005000E+01	1.731668E+02
101	1.000000E+01	9.950000E+00	1.749790E+02
102	9.900000E+00	9.850000E+00	1.725378E+02
103	9.800000E+00	9.750000E+00	1.680329E+02
104	9.700000E+00	9.650000E+00	1.643838E+02
105	9.600000E+00	9.550000E+00	1.737880E+02
106	9.500000E+00	9.450000E+00	1.790983E+02
107	9.400000E+00	9.350000E+00	1.719788E+02
108	9.300000E+00	9.250000E+00	1.585817E+02
109	9.200000E+00	9.150000E+00	1.642940E+02
110	9.100000E+00	9.050000E+00	1.840511E+02
111	9.000000E+00	8.950000E+00	1.844116E+02
112	8.900000E+00	8.850000E+00	1.649178E+02
113	8.800000E+00	8.750000E+00	1.543472E+02
114	8.700000E+00	8.650000E+00	1.719501E+02
115	8.600000E+00	8.550000E+00	1.726602E+02
116	8.500000E+00	8.450000E+00	1.737737E+02
117	8.400000E+00	8.350000E+00	1.725798E+02
118	8.300000E+00	8.250000E+00	1.702067E+02
119	8.200000E+00	8.150000E+00	1.629746E+02
120	8.100000E+00	8.050000E+00	1.776760E+02
121	8.000000E+00	7.950000E+00	1.951620E+02
122	7.900000E+00	7.850000E+00	1.818550E+02
123	7.800000E+00	7.750000E+00	1.819305E+02
124	7.700000E+00	7.650000E+00	1.750185E+02
125	7.600000E+00	7.550000E+00	1.721660E+02
126	7.500000E+00	7.450000E+00	1.750415E+02
127	7.400000E+00	7.350000E+00	1.771959E+02
128	7.300000E+00	7.250000E+00	1.762695E+02
129	7.200000E+00	7.150000E+00	1.436002E+02
130	7.100000E+00	7.050000E+00	1.734795E+02
131	7.000000E+00	6.950000E+00	1.482196E+02
132	6.900000E+00	6.850000E+00	1.534783E+02
133	6.800000E+00	6.750000E+00	1.735103E+02
134	6.700000E+00	6.650000E+00	1.573224E+02
135	6.600000E+00	6.550000E+00	1.287192E+02
136	6.500000E+00	6.450000E+00	1.476404E+02
137	6.400000E+00	6.350000E+00	1.597855E+02
138	6.300000E+00	6.250000E+00	1.843861E+02
139	6.200000E+00	6.150000E+00	1.327218E+02
140	6.100000E+00	6.050000E+00	1.618680E+02
141	6.000000E+00	5.950000E+00	1.427187E+02
142	5.900000E+00	5.850000E+00	1.741425E+02
143	5.800000E+00	5.750000E+00	1.877007E+02
144	5.700000E+00	5.650000E+00	1.566230E+02

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
145	5.600000E+00	5.550000E+00	1.521489E+02
146	5.500000E+00	5.450000E+00	1.239832E+02
147	5.400000E+00	5.350000E+00	1.296535E+02
148	5.300000E+00	5.250000E+00	1.558386E+02
149	5.200000E+00	5.150000E+00	1.773568E+02
150	5.100000E+00	5.050000E+00	1.558377E+02
151	5.000000E+00	4.950000E+00	1.523304E+02
152	4.900000E+00	4.850000E+00	1.659307E+02
153	4.800000E+00	4.750000E+00	1.936596E+02
154	4.700000E+00	4.650000E+00	1.615820E+02
155	4.600000E+00	4.550000E+00	1.446275E+02
156	4.500000E+00	4.450000E+00	1.454466E+02
157	4.400000E+00	4.350000E+00	1.391803E+02
158	4.300000E+00	4.250000E+00	1.718335E+02
159	4.200000E+00	4.150000E+00	1.106764E+02
160	4.100000E+00	4.050000E+00	1.377047E+02
161	4.000000E+00	3.950000E+00	1.398655E+02
162	3.900000E+00	3.850000E+00	1.143880E+02
163	3.800000E+00	3.750000E+00	1.189786E+02
164	3.700000E+00	3.650000E+00	7.205235E+01
165	3.600000E+00	3.550000E+00	1.166491E+02
166	3.500000E+00	3.450000E+00	1.209489E+02
167	3.400000E+00	3.350000E+00	1.171509E+02
168	3.300000E+00	3.250000E+00	1.233782E+02
169	3.200000E+00	3.150000E+00	1.371566E+02
170	3.100000E+00	3.050000E+00	1.225885E+02
171	3.000000E+00	2.950000E+00	1.017558E+02
172	2.900000E+00	2.850000E+00	1.380089E+02
173	2.800000E+00	2.750000E+00	1.104907E+02
174	2.700000E+00	2.650000E+00	1.185021E+02
175	2.600000E+00	2.550000E+00	1.324304E+02
176	2.500000E+00	2.450000E+00	1.213907E+02
177	2.400000E+00	2.350000E+00	1.059031E+02
178	2.300000E+00	2.250000E+00	1.077988E+02
179	2.200000E+00	2.150000E+00	1.108041E+02
180	2.100000E+00	2.050000E+00	9.770454E+01
181	2.000000E+00	1.950000E+00	1.330953E+02
182	1.900000E+00	1.850000E+00	1.348081E+02
183	1.800000E+00	1.750000E+00	8.041240E+01
184	1.700000E+00	1.650000E+00	1.700470E+02
185	1.600000E+00	1.550000E+00	1.090791E+02
186	1.500000E+00	1.450000E+00	1.035514E+02
187	1.400000E+00	1.350000E+00	9.048161E+01
188	1.300000E+00	1.250000E+00	9.292444E+01
189	1.200000E+00	1.150000E+00	6.372608E+01
190	1.100000E+00	1.050000E+00	7.763185E+01
191	1.000000E+00	9.800000E-01	1.131754E+02
192	9.600000E-01	9.400000E-01	1.131017E+02
193	9.200000E-01	9.000000E-01	9.118594E+01
194	8.800000E-01	8.600000E-01	8.053426E+01
195	8.400000E-01	8.200000E-01	1.406037E+02
196	8.000000E-01	7.800000E-01	8.943636E+01
197	7.600000E-01	7.400000E-01	6.524542E+01
198	7.200000E-01	7.050000E-01	5.860863E+01
199	6.900000E-01	6.750000E-01	5.631161E+01
200	6.600000E-01	6.450000E-01	5.497674E+01
201	6.300000E-01	6.150000E-01	5.337400E+01
202	6.000000E-01	5.875000E-01	5.845961E+01
203	5.750000E-01	5.625000E-01	1.238521E+02
204	5.500000E-01	5.375000E-01	7.387514E+01
205	5.250000E-01	5.125000E-01	5.861309E+01
206	5.000000E-01	4.875000E-01	5.610784E+01
207	4.750000E-01	4.625000E-01	5.453479E+01
208	4.500000E-01	4.375000E-01	5.326508E+01
209	4.250000E-01	4.125000E-01	5.275325E+01
210	4.000000E-01	3.900000E-01	5.195346E+01
211	3.800000E-01	3.700000E-01	4.929888E+01
212	3.600000E-01	3.500000E-01	4.988140E+01
213	3.400000E-01	3.300000E-01	5.080230E+01
214	3.200000E-01	3.100000E-01	5.115308E+01
215	3.000000E-01	2.900000E-01	5.263600E+01
216	2.800000E-01	2.750000E-01	5.408311E+01

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
217	2.700000E-01	2.625000E-01	5.621729E+01
218	2.550000E-01	2.475000E-01	6.002709E+01
219	2.400000E-01	2.350000E-01	6.508627E+01
220	2.300000E-01	2.250000E-01	7.103450E+01
221	2.200000E-01	2.150000E-01	8.003430E+01
222	2.100000E-01	2.050000E-01	9.342780E+01
223	2.000000E-01	1.950000E-01	1.112661E+02
224	1.900000E-01	1.850000E-01	1.143433E+02
225	1.800000E-01	1.750000E-01	6.670408E+01
226	1.700000E-01	1.650000E-01	2.042371E+01
227	1.600000E-01	1.550000E-01	4.389965E+00
228	1.500000E-01	1.462500E-01	1.001896E+00
229	1.425000E-01	1.387500E-01	1.144801E+00
230	1.350000E-01	1.312500E-01	1.886640E+00
231	1.275000E-01	1.237500E-01	2.722165E+00
232	1.200000E-01	1.175000E-01	3.374691E+00
233	1.150000E-01	1.125000E-01	3.836533E+00
234	1.100000E-01	1.075000E-01	4.231811E+00
235	1.050000E-01	1.025000E-01	4.577435E+00
236	1.000000E-01	9.800000E-02	4.858211E+00
237	9.600000E-02	9.400000E-02	5.061763E+00
238	9.200000E-02	9.000000E-02	5.239306E+00
239	8.800000E-02	8.600000E-02	5.416013E+00
240	8.400000E-02	8.200000E-02	5.530739E+00
241	8.000000E-02	7.800000E-02	5.667758E+00
242	7.600000E-02	7.400000E-02	5.824413E+00
243	7.200000E-02	7.050000E-02	6.004439E+00
244	6.900000E-02	6.750000E-02	6.452232E+00
245	6.600000E-02	6.450000E-02	6.704520E+00
246	6.300000E-02	6.150001E-02	7.759747E+00
247	6.000000E-02	5.875000E-02	1.131117E+01
248	5.750000E-02	5.625000E-02	4.881800E+01
249	5.500000E-02	5.375000E-02	1.394853E+00
250	5.250000E-02	5.125000E-02	1.665855E+00
251	5.000000E-02	4.875000E-02	2.324566E+00
252	4.750000E-02	4.625000E-02	2.627535E+00
253	4.500000E-02	4.375000E-02	2.766006E+00
254	4.250000E-02	4.125000E-02	2.815044E+00
255	4.000000E-02	3.900000E-02	3.236911E+00
256	3.800000E-02	3.700000E-02	2.761191E+00
257	3.600000E-02	3.500000E-02	2.694322E+00
258	3.400000E-02	3.300000E-02	2.615048E+00
259	3.200000E-02	3.100000E-02	2.523839E+00
260	3.000000E-02	2.900000E-02	2.416137E+00
261	2.800000E-02	2.750000E-02	2.327857E+00
262	2.700000E-02	2.625000E-02	2.251406E+00
263	2.550000E-02	2.475000E-02	2.159320E+00
264	2.400000E-02	2.350000E-02	2.075862E+00
265	2.300000E-02	2.250000E-02	2.006089E+00
266	2.200000E-02	2.150000E-02	1.936267E+00
267	2.100000E-02	2.050000E-02	1.866401E+00
268	2.000000E-02	1.950000E-02	1.793231E+00
269	1.900000E-02	1.850000E-02	1.716946E+00
270	1.800000E-02	1.750000E-02	1.640070E+00
271	1.700000E-02	1.650000E-02	1.560138E+00
272	1.600000E-02	1.550000E-02	1.556516E+00
273	1.500000E-02	1.462500E-02	1.408101E+00
274	1.425000E-02	1.387500E-02	1.344240E+00
275	1.350000E-02	1.312500E-02	1.280620E+00
276	1.275000E-02	1.237500E-02	1.216535E+00
277	1.200000E-02	1.175000E-02	1.161918E+00
278	1.150000E-02	1.125000E-02	1.117882E+00
279	1.100000E-02	1.075000E-02	1.073083E+00
280	1.050000E-02	1.025000E-02	1.028187E+00
281	1.000000E-02	9.800000E-03	9.874197E-01
282	9.600000E-03	9.400000E-03	9.506696E-01
283	9.200000E-03	9.000000E-03	9.139211E-01
284	8.800000E-03	8.600000E-03	8.768218E-01
285	8.400000E-03	8.200000E-03	8.391631E-01
286	8.000000E-03	7.800000E-03	8.014963E-01
287	7.600000E-03	7.400000E-03	7.636029E-01
288	7.200000E-03	7.050000E-03	7.300621E-01

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
289	6.900000E-03	6.750000E-03	7.012189E-01
290	6.600000E-03	6.450000E-03	6.723806E-01
291	6.300000E-03	6.150000E-03	6.433160E-01
292	6.000000E-03	5.875000E-03	6.163418E-01
293	5.750000E-03	5.625000E-03	5.917502E-01
294	5.500000E-03	5.375000E-03	5.670536E-01
295	5.250000E-03	5.125000E-03	5.426664E-01
296	5.000000E-03	4.875000E-03	5.478224E-01
297	4.750000E-03	4.625000E-03	4.921758E-01
298	4.500000E-03	4.375000E-03	4.669758E-01
299	4.250000E-03	4.125000E-03	4.417112E-01
300	4.000000E-03	3.900000E-03	4.189391E-01
301	3.800000E-03	3.700000E-03	3.985144E-01
302	3.600000E-03	3.500000E-03	3.780234E-01
303	3.400000E-03	3.300000E-03	3.573080E-01
304	3.200000E-03	3.100000E-03	3.365366E-01
305	3.000000E-03	2.900000E-03	3.157687E-01
306	2.800000E-03	2.750000E-03	3.002674E-01
307	2.700000E-03	2.625000E-03	2.870274E-01
308	2.550000E-03	2.475000E-03	2.711862E-01
309	2.400000E-03	2.350000E-03	2.582637E-01
310	2.300000E-03	2.250000E-03	4.285303E-01
311	2.200000E-03	2.150000E-03	2.373112E-01
312	2.100000E-03	2.050000E-03	2.260708E-01
313	2.000000E-03	1.950000E-03	2.153233E-01
314	1.900000E-03	1.850000E-03	2.045339E-01
315	1.800000E-03	1.750000E-03	1.937540E-01
316	1.700000E-03	1.650000E-03	1.829727E-01
317	1.600000E-03	1.550000E-03	1.720326E-01
318	1.500000E-03	1.462500E-03	1.624055E-01
319	1.425000E-03	1.387500E-03	1.541113E-01
320	1.350000E-03	1.312500E-03	1.459994E-01
321	1.275000E-03	1.237500E-03	1.378551E-01
322	1.200000E-03	1.175000E-03	1.309130E-01
323	1.150000E-03	1.125000E-03	1.253166E-01
324	1.100000E-03	1.075000E-03	1.197011E-01
325	1.050000E-03	1.025000E-03	1.140764E-01
326	1.000000E-03	9.800000E-04	1.089957E-01
327	9.600000E-04	9.400000E-04	1.044395E-01
328	9.200000E-04	9.000000E-04	9.987921E-02
329	8.800000E-04	8.600000E-04	9.530343E-02
330	8.400000E-04	8.200000E-04	9.069958E-02
331	8.000000E-04	7.800000E-04	8.607882E-02
332	7.600000E-04	7.400000E-04	8.144432E-02
333	7.200000E-04	7.050000E-04	7.738508E-02
334	6.900000E-04	6.750000E-04	7.388832E-02
335	6.600000E-04	6.450000E-04	7.038044E-02
336	6.300000E-04	6.150000E-04	6.686015E-02
337	6.000000E-04	5.875000E-04	6.361766E-02
338	5.750000E-04	5.625000E-04	6.065090E-02
339	5.500000E-04	5.375000E-04	5.760463E-02
340	5.250000E-04	5.125000E-04	5.454441E-02
341	5.000000E-04	4.875000E-04	5.136848E-02
342	4.750000E-04	4.625000E-04	4.811422E-02
343	4.500000E-04	4.375000E-04	4.506059E-02
344	4.250000E-04	4.125000E-04	4.182278E-02
345	4.000000E-04	3.900000E-04	3.875193E-02
346	3.800000E-04	3.700000E-04	3.631544E-02
347	3.600000E-04	3.500000E-04	3.391288E-02
348	3.400000E-04	3.300000E-04	3.126043E-02
349	3.200000E-04	3.100000E-04	2.849958E-02
350	3.000000E-04	2.900000E-04	2.549538E-02
351	2.800000E-04	2.750000E-04	2.322776E-02
352	2.700000E-04	2.625000E-04	2.124416E-02
353	2.550000E-04	2.475000E-04	1.885846E-02
354	2.400000E-04	2.350000E-04	1.683389E-02
355	2.300000E-04	2.250000E-04	1.509236E-02
356	2.200000E-04	2.150000E-04	1.325680E-02
357	2.100000E-04	2.050000E-04	1.128237E-02
358	2.000000E-04	1.950000E-04	8.452462E-03
359	1.900000E-04	1.850000E-04	4.783556E-03
360	1.800000E-04	1.750000E-04	1.586685E-03

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
361	1.700000E-04	1.650000E-04	1.167438E-03
362	1.600000E-04	1.550000E-04	1.204608E-03
363	1.500000E-04	1.462500E-04	1.240012E-03
364	1.425000E-04	1.387500E-04	1.272877E-03
365	1.350000E-04	1.312500E-04	1.309168E-03
366	1.275000E-04	1.237500E-04	1.347998E-03
367	1.200000E-04	1.175000E-04	1.383702E-03
368	1.150000E-04	1.125000E-04	1.413338E-03
369	1.100000E-04	1.075000E-04	1.446982E-03
370	1.050000E-04	1.025000E-04	1.481218E-03
371	1.000000E-04	9.800000E-05	1.514867E-03
372	9.600000E-05	9.400000E-05	1.547929E-03
373	9.200000E-05	9.000000E-05	1.580986E-03
374	8.800000E-05	8.600000E-05	1.616201E-03
375	8.400000E-05	8.200000E-05	1.655033E-03
376	8.000000E-05	7.800000E-05	1.697291E-03
377	7.600000E-05	7.400000E-05	1.742383E-03
378	7.200000E-05	7.050000E-05	1.785130E-03
379	6.900000E-05	6.750000E-05	1.824350E-03
380	6.600000E-05	6.450000E-05	1.866705E-03
381	6.300000E-05	6.150000E-05	1.911406E-03
382	6.000000E-05	5.875000E-05	1.956307E-03
383	5.750000E-05	5.625000E-05	1.998267E-03
384	5.500000E-05	5.375000E-05	2.045805E-03
385	5.250000E-05	5.125000E-05	2.094225E-03
386	5.000000E-05	4.875000E-05	2.146551E-03
387	4.750000E-05	4.625000E-05	2.203487E-03
388	4.500000E-05	4.375000E-05	2.266084E-03
389	4.250000E-05	4.125000E-05	2.333973E-03
390	4.000000E-05	3.900000E-05	2.399704E-03
391	3.800000E-05	3.700000E-05	2.464949E-03
392	3.600000E-05	3.500000E-05	2.533518E-03
393	3.400000E-05	3.300000E-05	2.610886E-03
394	3.200000E-05	3.100000E-05	2.692761E-03
395	3.000000E-05	2.900000E-05	2.786080E-03
396	2.800000E-05	2.750000E-05	2.857781E-03
397	2.700000E-05	2.625000E-05	2.929086E-03
398	2.550000E-05	2.475000E-05	3.015857E-03
399	2.400000E-05	2.350000E-05	3.091072E-03
400	2.300000E-05	2.250000E-05	3.159446E-03
401	2.200000E-05	2.150000E-05	3.231838E-03
402	2.100000E-05	2.050000E-05	3.310186E-03
403	2.000000E-05	1.950000E-05	3.395679E-03
404	1.900000E-05	1.850000E-05	3.488208E-03
405	1.800000E-05	1.750000E-05	3.582607E-03
406	1.700000E-05	1.650000E-05	3.689127E-03
407	1.600000E-05	1.550000E-05	3.806803E-03
408	1.500000E-05	1.462500E-05	3.918904E-03
409	1.425000E-05	1.387500E-05	4.023078E-03
410	1.350000E-05	1.312500E-05	4.138113E-03
411	1.275000E-05	1.237500E-05	4.260872E-03
412	1.200000E-05	1.175000E-05	4.374144E-03
413	1.150000E-05	1.125000E-05	4.468050E-03
414	1.100000E-05	1.075000E-05	4.574474E-03
415	1.050000E-05	1.025000E-05	4.682956E-03
416	1.000000E-05	9.800000E-06	4.789381E-03
417	9.600000E-06	9.400000E-06	4.893946E-03
418	9.200000E-06	9.000000E-06	4.998510E-03
419	8.800000E-06	8.600000E-06	5.109738E-03
420	8.400000E-06	8.200000E-06	5.232397E-03
421	8.000000E-06	7.800000E-06	5.366212E-03
422	7.600000E-06	7.400000E-06	5.508929E-03
423	7.200000E-06	7.050000E-06	5.644404E-03
424	6.900000E-06	6.750000E-06	5.768537E-03
425	6.600000E-06	6.450000E-06	5.902450E-03
426	6.300000E-06	6.150000E-06	6.044184E-03
427	6.000000E-06	5.875000E-06	6.186510E-03
428	5.750000E-06	5.625000E-06	6.319249E-03
429	5.500000E-06	5.375000E-06	6.469495E-03
430	5.250000E-06	5.125000E-06	6.622585E-03
431	5.000000E-06	4.875000E-06	6.787799E-03
432	4.750000E-06	4.625000E-06	6.967975E-03

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
433	4.500000E-06	4.375000E-06	7.165866E-03
434	4.250000E-06	4.125000E-06	7.381066E-03
435	4.000000E-06	3.900000E-06	7.589120E-03
436	3.800000E-06	3.700000E-06	7.795908E-03
437	3.600000E-06	3.500000E-06	8.012963E-03
438	3.400000E-06	3.300000E-06	8.257901E-03
439	3.200000E-06	3.100000E-06	8.517317E-03
440	3.000000E-06	2.900000E-06	8.813118E-03
441	2.800000E-06	2.750000E-06	9.040438E-03
442	2.700000E-06	2.625000E-06	9.265617E-03
443	2.550000E-06	2.475000E-06	9.539902E-03
444	2.400000E-06	2.350000E-06	9.777302E-03
445	2.300000E-06	2.250000E-06	9.993087E-03
446	2.200000E-06	2.150000E-06	1.022198E-02
447	2.100000E-06	2.050000E-06	1.047045E-02
448	2.000000E-06	1.950000E-06	1.074139E-02
449	1.900000E-06	1.850000E-06	1.103385E-02
450	1.800000E-06	1.750000E-06	1.133219E-02
451	1.700000E-06	1.650000E-06	1.166773E-02
452	1.600000E-06	1.550000E-06	1.203943E-02
453	1.500000E-06	1.462500E-06	1.239454E-02
454	1.425000E-06	1.387500E-06	1.272416E-02
455	1.350000E-06	1.312500E-06	1.308900E-02
456	1.275000E-06	1.237500E-06	1.347740E-02
457	1.200000E-06	1.175000E-06	1.383637E-02
458	1.150000E-06	1.125000E-06	1.413373E-02
459	1.100000E-06	1.075000E-06	1.447118E-02
460	1.050000E-06	1.025000E-06	1.481547E-02
461	1.000000E-06	9.800000E-07	1.515198E-02
462	9.600000E-07	9.400000E-07	1.548165E-02
463	9.200000E-07	9.000000E-07	1.581131E-02
464	8.800000E-07	8.600000E-07	1.616246E-02
465	8.400000E-07	8.200000E-07	1.654791E-02
466	8.000000E-07	7.800000E-07	1.697144E-02
467	7.600000E-07	7.400000E-07	1.742238E-02
468	7.200000E-07	7.050000E-07	1.785178E-02
469	6.900000E-07	6.750000E-07	1.824409E-02
470	6.600000E-07	6.450000E-07	1.866859E-02
471	6.300000E-07	6.150000E-07	1.911752E-02
472	6.000000E-07	5.875000E-07	1.956753E-02
473	5.750000E-07	5.625000E-07	1.998813E-02
474	5.500000E-07	5.375000E-07	2.046260E-02
475	5.250000E-07	5.125000E-07	2.094677E-02
476	5.000000E-07	4.875000E-07	2.146813E-02
477	4.750000E-07	4.625000E-07	2.203446E-02
478	4.500000E-07	4.375000E-07	2.265366E-02
479	4.250000E-07	4.125000E-07	2.333158E-02
480	4.000000E-07	3.900000E-07	2.399477E-02
481	3.800000E-07	3.700000E-07	2.463545E-02
482	3.600000E-07	3.500000E-07	2.532800E-02
483	3.400000E-07	3.300000E-07	2.608315E-02
484	3.200000E-07	3.100000E-07	2.691166E-02
485	3.000000E-07	2.900000E-07	2.782141E-02
486	2.800000E-07	2.750000E-07	2.856286E-02
487	2.700000E-07	2.625000E-07	2.923981E-02
488	2.550000E-07	2.475000E-07	3.011623E-02
489	2.400000E-07	2.350000E-07	3.090363E-02
490	2.300000E-07	2.250000E-07	3.158349E-02
491	2.200000E-07	2.150000E-07	3.231033E-02
492	2.100000E-07	2.050000E-07	3.308987E-02
493	2.000000E-07	1.950000E-07	3.393308E-02
494	1.900000E-07	1.850000E-07	3.483104E-02
495	1.800000E-07	1.750000E-07	3.581313E-02
496	1.700000E-07	1.650000E-07	3.688423E-02
497	1.600000E-07	1.550000E-07	3.805904E-02
498	1.500000E-07	1.462500E-07	3.917710E-02
499	1.425000E-07	1.387500E-07	4.022379E-02
500	1.350000E-07	1.312500E-07	4.135840E-02
501	1.275000E-07	1.237500E-07	4.259292E-02
502	1.200000E-07	1.175000E-07	4.370313E-02
503	1.150000E-07	1.125000E-07	4.466368E-02
504	1.100000E-07	1.075000E-07	4.569173E-02

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
505	1.050000E-07	1.025000E-07	4.679612E-02
506	1.000000E-07	9.800000E-08	4.786527E-02
507	9.600000E-08	9.400000E-08	4.886697E-02
508	9.200000E-08	9.000000E-08	4.993907E-02
509	8.800000E-08	8.600000E-08	5.108839E-02
510	8.400000E-08	8.200000E-08	5.232287E-02
511	8.000000E-08	7.800000E-08	5.365028E-02
512	7.600000E-08	7.400000E-08	5.508232E-02
513	7.200000E-08	7.050000E-08	5.642636E-02
514	6.900000E-08	6.750000E-08	5.766764E-02
515	6.600000E-08	6.450000E-08	5.899406E-02
516	6.300000E-08	6.150000E-08	6.041631E-02
517	6.000000E-08	5.875000E-08	6.180925E-02
518	5.750000E-08	5.625000E-08	6.316698E-02
519	5.500000E-08	5.375000E-08	6.462054E-02
520	5.250000E-08	5.125000E-08	6.618267E-02
521	5.000000E-08	4.875000E-08	6.786122E-02
522	4.750000E-08	4.625000E-08	6.965723E-02
523	4.500000E-08	4.375000E-08	7.162239E-02
524	4.250000E-08	4.125000E-08	7.376266E-02
525	4.000000E-08	3.900000E-08	7.585885E-02
526	3.800000E-08	3.700000E-08	7.788274E-02
527	3.600000E-08	3.500000E-08	8.008070E-02
528	3.400000E-08	3.300000E-08	8.247525E-02
529	3.200000E-08	3.100000E-08	8.509391E-02
530	3.000000E-08	2.900000E-08	8.797951E-02
531	2.800000E-08	2.750000E-08	9.034182E-02
532	2.700000E-08	2.625000E-08	9.247034E-02
533	2.550000E-08	2.475000E-08	9.522581E-02
534	2.400000E-08	2.350000E-08	9.772314E-02
535	2.300000E-08	2.250000E-08	9.987204E-02
536	2.200000E-08	2.150000E-08	1.021615E-01
537	2.100000E-08	2.050000E-08	1.046359E-01
538	2.000000E-08	1.950000E-08	1.072865E-01
539	1.900000E-08	1.850000E-08	1.101236E-01
540	1.800000E-08	1.750000E-08	1.132245E-01
541	1.700000E-08	1.650000E-08	1.166087E-01
542	1.600000E-08	1.550000E-08	1.203159E-01
543	1.500000E-08	1.462500E-08	1.238572E-01
544	1.425000E-08	1.387500E-08	1.271636E-01
545	1.350000E-08	1.312500E-08	1.307534E-01
546	1.275000E-08	1.237500E-08	1.346564E-01
547	1.200000E-08	1.175000E-08	1.381875E-01
548	1.150000E-08	1.125000E-08	1.412296E-01
549	1.100000E-08	1.075000E-08	1.444773E-01
550	1.050000E-08	1.025000E-08	1.479692E-01
551	1.000000E-08	9.800000E-09	1.513343E-01
552	9.600000E-09	9.400000E-09	1.544939E-01
553	9.200000E-09	9.000000E-09	1.578786E-01
554	8.800000E-09	8.600000E-09	1.615075E-01
555	8.400000E-09	8.200000E-09	1.654100E-01
556	8.000000E-09	7.800000E-09	1.695969E-01
557	7.600000E-09	7.400002E-09	1.741161E-01
558	7.200000E-09	7.050000E-09	1.783910E-01
559	6.900000E-09	6.750000E-09	1.823136E-01
560	6.600000E-09	6.450000E-09	1.865097E-01
561	6.300000E-09	6.150000E-09	1.910093E-01
562	6.000000E-09	5.875000E-09	1.954305E-01
563	5.750000E-09	5.625000E-09	1.997245E-01
564	5.500000E-09	5.375000E-09	2.043220E-01
565	5.250000E-09	5.125000E-09	2.092620E-01
566	5.000000E-09	4.875000E-09	2.145153E-01
567	4.750000E-09	4.625000E-09	2.202472E-01
568	4.500000E-09	4.375000E-09	2.264489E-01
569	4.250000E-09	4.125000E-09	2.332174E-01
570	4.000000E-09	3.900000E-09	2.398503E-01
571	3.800000E-09	3.700000E-09	2.462570E-01
572	3.600000E-09	3.500000E-09	2.532017E-01
573	3.400000E-09	3.300000E-09	2.607635E-01
574	3.200000E-09	3.100000E-09	2.690486E-01
575	3.000000E-09	2.900000E-09	2.781358E-01
576	2.800000E-09	2.750000E-09	2.856188E-01

TABLE A1.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
577	2.700000E-09	2.625000E-09	2.923387E-01
578	2.550000E-09	2.475000E-09	3.010741E-01
579	2.400000E-09	2.350000E-09	3.089780E-01
580	2.300000E-09	2.250000E-09	3.157665E-01
581	2.200000E-09	2.150000E-09	3.230341E-01
582	2.100000E-09	2.050000E-09	3.308206E-01
583	2.000000E-09	1.950000E-09	3.392524E-01
584	1.900000E-09	1.850000E-09	3.482320E-01
585	1.800000E-09	1.750000E-09	3.580432E-01
586	1.700000E-09	1.650000E-09	3.687250E-01
587	1.600000E-09	1.550000E-09	3.804435E-01
588	1.500000E-09	1.462500E-09	3.916631E-01
589	1.425000E-09	1.387500E-09	4.021197E-01
590	1.350000E-09	1.312500E-09	4.134568E-01
591	1.275000E-09	1.237500E-09	4.258020E-01
592	1.200000E-09	1.175000E-09	4.369826E-01
593	1.150000E-09	1.125000E-09	4.465885E-01
594	1.100000E-09	1.075000E-09	4.568687E-01
595	1.050000E-09	1.025000E-09	4.679121E-01
596	1.000000E-09	9.800000E-10	4.785457E-01
597	9.600000E-10	9.400000E-10	4.885617E-01
598	9.200000E-10	9.000000E-10	4.992629E-01
599	8.800000E-10	8.600000E-10	5.107370E-01
600	8.400000E-10	8.200000E-10	5.230523E-01
601	8.000000E-10	7.800000E-10	5.363069E-01
602	7.600000E-10	7.400000E-10	5.506078E-01
603	7.200000E-10	7.050000E-10	5.641260E-01
604	6.900000E-10	6.750000E-10	5.765295E-01
605	6.600000E-10	6.450000E-10	5.897839E-01
606	6.300000E-10	6.150000E-10	6.040069E-01
607	6.000000E-10	5.875000E-10	6.179947E-01
608	5.750000E-10	5.625000E-10	6.315721E-01
609	5.500000E-10	5.375000E-10	6.461082E-01
610	5.250000E-10	5.125000E-10	6.617193E-01
611	5.000000E-10	4.875000E-10	6.783583E-01
612	4.750000E-10	4.625000E-10	6.964648E-01
613	4.500000E-10	4.375000E-10	7.160863E-01
614	4.250000E-10	4.125000E-10	7.374700E-01
615	4.000000E-10	3.900000E-10	7.584712E-01
616	3.800000E-10	3.700000E-10	7.787098E-01
617	3.600000E-10	3.500000E-10	8.006697E-01
618	3.400000E-10	3.300000E-10	8.245867E-01
619	3.200000E-10	3.100000E-10	8.507917E-01
620	3.000000E-10	2.900000E-10	8.795210E-01
621	2.800000E-10	2.750000E-10	9.031932E-01
622	2.700000E-10	2.625000E-10	9.244294E-01
623	2.550000E-10	2.475000E-10	9.520433E-01
624	2.400000E-10	2.350000E-10	9.770555E-01
625	2.300000E-10	2.250000E-10	9.985254E-01
626	2.200000E-10	2.150000E-10	1.021512E+00
627	2.100000E-10	2.050000E-10	1.046163E+00
628	2.000000E-10	1.950000E-10	1.072772E+00
629	1.900000E-10	1.850000E-10	1.101138E+00
630	1.800000E-10	1.750000E-10	1.132239E+00
631	1.700000E-10	1.650000E-10	1.165989E+00
632	1.600000E-10	1.550000E-10	1.203061E+00
633	1.500000E-10	1.462500E-10	1.238567E+00
634	1.425000E-10	1.387500E-10	1.271631E+00
635	1.350000E-10	1.312500E-10	1.307436E+00
636	1.275000E-10	1.237500E-10	1.346467E+00
637	1.200000E-10	1.175000E-10	1.381874E+00
638	1.150000E-10	1.125000E-10	1.412203E+00
639	1.100000E-10	1.075000E-10	1.444772E+00
640	1.050000E-10	1.025000E-10	1.479691E+00

This is the SAND-II energy bin structure. The upper energy boundary is 20 MeV. The lower energy boundary is 1.0E-10 MeV.

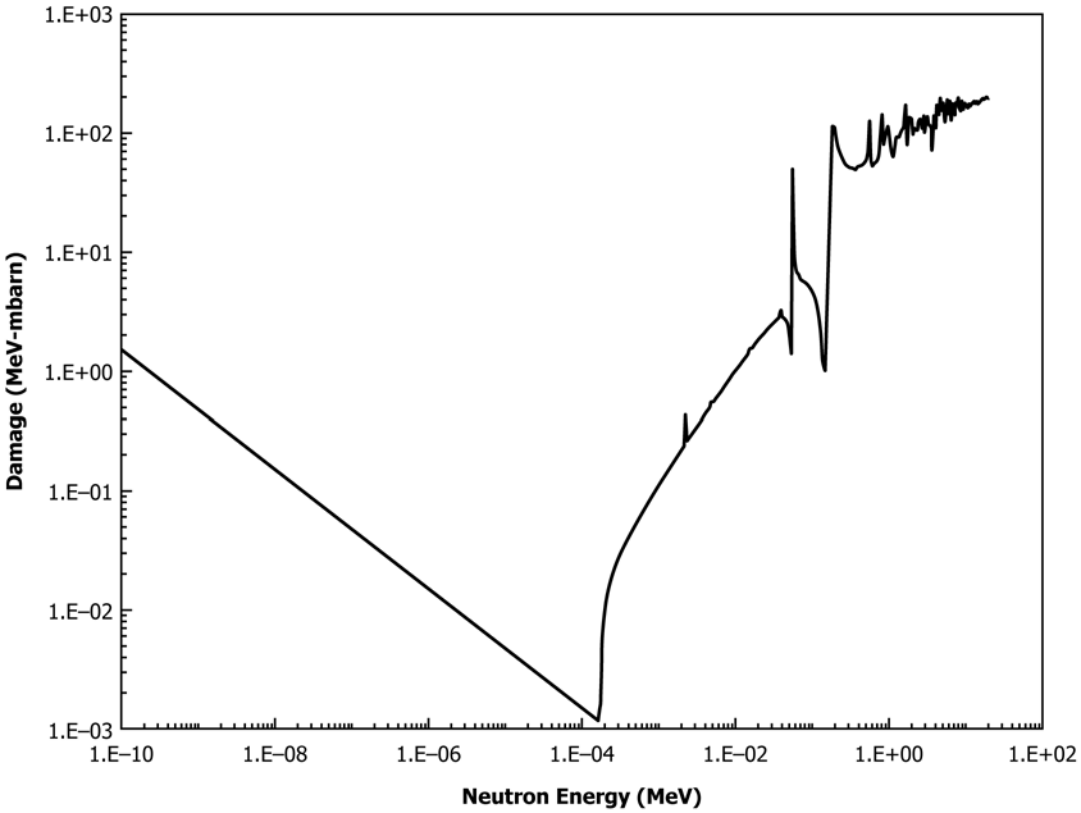

FIG. A1.1 Silicon Damage Function

A2. CALCULATION OF 1-MeV EQUIVALENT NEUTRON FLUENCE FOR GALLIUM ARSENIDE

A2.1 Background

A2.1.1 The observable damage metric of interest in this annex is the change in gain of a GaAs heterojunction transistor (HBT) and the change in the light output for a GaAs light-emitting diode (LED) due to bulk displacement damage effects. The damage mechanism is the change in minority-carrier recombination lifetime in the bulk semiconductor material. In interpreting measurements of this 1-MeV(GaAs) damage, efforts must be made to eliminate any interference from ionization-related effects.

A2.1.2 The choice of the specific energy for determining an equivalent fluence has been the subject of some controversy within the electronics hardness-testing community (**9**). The concept of 1-MeV equivalent fluence has gained broad acceptance in practice, and procedures for applying it to gallium arsenide are described in this annex in some detail.

A2.1.3 An important part of the practice is the correlation of radiation damage effects in a semiconductor device with the displacement kerma produced in bulk gallium arsenide by neutron irradiation. This correlation assumes that displacement effects are the dominant radiation damage mechanism and that equal numbers of initially displaced atoms produce equal changes in device performance. Experimental evidence (**8, 19**) indicates that displacement kerma is not a valid measure of changes in the fundamental properties (carrier concentration, mobility, and carrier lifetime) that determine device performance.

A2.1.4 The reason that displacement kerma does not correlate with property changes in gallium arsenide over the entire range of neutron energies of interest is attributed to variations in the defect production efficiency in displacement cascades of different sizes. This effect is also known to occur in other materials, including structural metals (**20**).

A2.1.5 Despite the deficiencies mentioned above, displacement kerma may still be useful as an exposure parameter, analogous to the use of displacements per atom (dpa) for exposures of ferritic steel (see Practice E693). When displacement kerma is used to compare property changes in gallium arsenide exposed to reactor neutrons in thermal and fast spectrum reactors, the discrepancies do not exceed ±10 % in reactors where careful comparisons have been made. When these reactor irradiations have been compared with accelerator irradiations with neutron energies of 3 and 14 MeV, however, much larger discrepancies have been observed (**8, 19**).

A2.1.6 Empirical efficiency factors that depend on the energies of the primary knock-on atoms (pka) have been

proposed (**8**) in order to remove the discrepancies described in A2.1.5. Fig. A2.1 shows the shape of the empirical damage efficiency factor for GaAs. This damage efficiency function can be fit with the following equation:

$$\zeta(r) = \begin{cases} 1.0 & r < 0.1 \text{ keV} \\ a_0 + a_1 \times \log(r) + a_2 \times r^2 \times \log(r) + a_3 \times [\log(r)]^2 & 0.1 \text{ keV} < r < 500.0 \text{ keV} \\ 0.01 & r > 500.0 \text{ keV} \end{cases}$$

where:

r = PKA recoil energy, keV,
$\zeta(r)$ = damage efficiency function,
a_0 = 0.872670,
a_1 = −0.187469,
a_2 = 1.237178E-7, and
a_3 = −0.060753.

As in Ref (**14**), this PKA-energy damage efficiency factor is used in conjunction with a normalization factor of 2.2 in order to match the damage reference value of 70 MeV·mbarn at 1 MeV.

A2.2 Calculation of $\Phi_{eq,1MeV,GaAs}$

A2.2.1 The displacement damage function, $F_{D,mat}(E)$, defined for gallium arsenide in this annex, is the integral over all PKA recoil energies of the gallium arsenide differential microscopic displacement kerma factor multiplied by the damage efficiency function, and is tabulated in Table A2.1.

$$F_{D,mat}(E) = 2.2 \int_0^{r_{max}} K_{D,mat}(E,r)\, \zeta(r)\, dr \qquad (A2.1)$$

where:

$K_{D,mat}(E,r)$ = differential microscopic displacement kerma factor per unit PKA recoil energy, at neutron energy E

A2.2.2 1-MeV equivalent fluence in a gallium arsenide is defined for an irradiation by neutrons of any neutron spectrum for which the predominant source of displacement damage is from neutrons of energy between 10 keV and 20 MeV. The neutron fluence spectrum, Φ(E), may be that determined from a neutron transport calculation, that determined from measurements, or that given in an environment specification document.

A2.2.3 The neutron fluence spectrum, Φ(E), may be determined experimentally by measuring a set of activation foils and then by application of a spectral adjustment computer code (see Guide E720 and Test Method E721 for details).

A2.2.4 Results of calculations of gallium arsenide microscopic displacement kerma factors (displacement kerma per target atom per unit neutron fluence), $\kappa_{D,GaAs}(E)$, are shown in Fig. A2.2 as a function of neutron energy (**7, 8**). The unit of the microscopic kerma factor is megaelectron volt times millibarns (MeV·mbarn). Each factor can be multiplied by 1.334×10^{-13} to convert to rad(GaAs)·cm^2 or by 1.334×10^{-19} to convert to J-m^2/kg or Gy(GaAs)·m^2. This microscopic displacement kerma factor was computed (8) by using the ENDF/B-VI ^{nat}Ga and ^{75}As cross section evaluation (21), a displacement threshold energy of 10 eV, the Robinson fit to the Lindhard energy partition function (17), and the NJOY97 processing code (22).

A2.2.5 The displacement damage reference value for GaAs was originally set to a value of 70 MeV·mbarn based on an inspection of the ENDF/B-VI microscopic displacement kerma for GaAs in the vicinity of 1 MeV. Improvements in the cross section evaluation for As-75 provided a better representation of the photon production and a lower displacement kerma. The current recommended average value of neutron microscopic displacement kerma factor near 1 MeV is ~60-63 MeV·mbarn. It is important that the whole radiation-hardness community use the same "reference damage value" in setting hardness specification and in testing electronic parts and that this value not change with every new cross section evaluation. Accordingly, the damage function for gallium arsenide is normalized to the original damage reference value: $F_{D,1MeV,}$

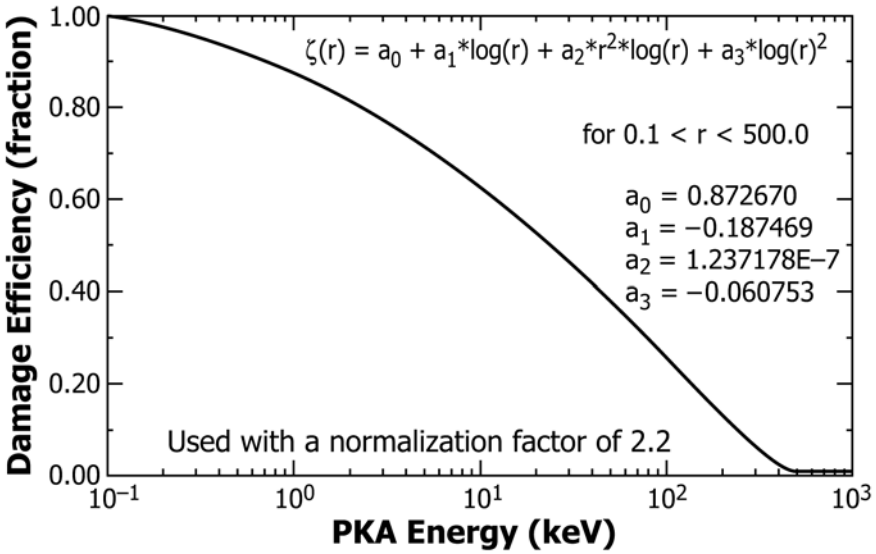

FIG. A2.1 GaAs Damage Efficiency Curve

TABLE A2.1 GaAs Damage Function

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
1	2.000000E+01	1.995000E+01	137.1559
2	1.990000E+01	1.985000E+01	137.2673
3	1.980000E+01	1.975000E+01	137.3787
4	1.970000E+01	1.965000E+01	137.4901
5	1.960000E+01	1.955000E+01	137.6015
6	1.950000E+01	1.945000E+01	137.7044
7	1.940000E+01	1.935000E+01	137.7994
8	1.930000E+01	1.925000E+01	137.8944
9	1.920000E+01	1.915000E+01	137.9892
10	1.910000E+01	1.905000E+01	138.0842
11	1.900000E+01	1.895000E+01	138.1766
12	1.890000E+01	1.885000E+01	138.2667
13	1.880000E+01	1.875000E+01	138.3568
14	1.870000E+01	1.865000E+01	138.4468
15	1.860000E+01	1.855000E+01	138.5368
16	1.850000E+01	1.845000E+01	138.6395
17	1.840000E+01	1.835000E+01	138.7767
18	1.830000E+01	1.825000E+01	138.9149
19	1.820000E+01	1.815000E+01	139.0533
20	1.810000E+01	1.805000E+01	139.1914
21	1.800000E+01	1.795000E+01	139.0089
22	1.790000E+01	1.785000E+01	138.5269
23	1.780000E+01	1.775000E+01	138.0448
24	1.770000E+01	1.765000E+01	137.5628
25	1.760000E+01	1.755000E+01	137.0808
26	1.750000E+01	1.745000E+01	136.9054
27	1.740000E+01	1.735000E+01	137.0164
28	1.730000E+01	1.725000E+01	137.1274
29	1.720000E+01	1.715000E+01	137.2384
30	1.710000E+01	1.705000E+01	137.3494
31	1.700000E+01	1.695000E+01	137.1862
32	1.690000E+01	1.685000E+01	136.7669
33	1.680000E+01	1.675000E+01	136.3476
34	1.670000E+01	1.665000E+01	135.9283
35	1.660000E+01	1.655000E+01	135.5089
36	1.650000E+01	1.645000E+01	135.0748
37	1.640000E+01	1.635000E+01	134.6265
38	1.630000E+01	1.625000E+01	134.1783
39	1.620000E+01	1.615000E+01	133.7302
40	1.610000E+01	1.605000E+01	133.2820
41	1.600000E+01	1.595000E+01	133.1028
42	1.590000E+01	1.585000E+01	133.1749
43	1.580000E+01	1.575000E+01	133.2471
44	1.570000E+01	1.565000E+01	133.3188
45	1.560000E+01	1.555000E+01	133.3914
46	1.550000E+01	1.545000E+01	133.4389
47	1.540000E+01	1.535000E+01	133.4642
48	1.530000E+01	1.525000E+01	133.4894
49	1.520000E+01	1.515000E+01	133.5145
50	1.510000E+01	1.505000E+01	133.5394
51	1.500000E+01	1.495000E+01	132.9427
52	1.490000E+01	1.485000E+01	131.9140
53	1.480000E+01	1.475000E+01	130.8872
54	1.470000E+01	1.465000E+01	129.8613
55	1.460000E+01	1.455000E+01	128.8357
56	1.450000E+01	1.445000E+01	128.3123
57	1.440000E+01	1.435000E+01	128.2097
58	1.430000E+01	1.425000E+01	128.1022
59	1.420000E+01	1.415000E+01	127.9740
60	1.410000E+01	1.405000E+01	127.8423
61	1.400000E+01	1.395000E+01	127.7934
62	1.390000E+01	1.385000E+01	127.8288
63	1.380000E+01	1.375000E+01	127.8575
64	1.370000E+01	1.365000E+01	127.8315
65	1.360000E+01	1.355000E+01	127.7969
66	1.350000E+01	1.345000E+01	127.7491
67	1.340000E+01	1.335000E+01	127.8355
68	1.330000E+01	1.325000E+01	128.1104
69	1.320000E+01	1.315000E+01	128.3626
70	1.310000E+01	1.305000E+01	128.6119
71	1.300000E+01	1.295000E+01	128.4289
72	1.290000E+01	1.285000E+01	127.7656

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
73	1.280000E+01	1.275000E+01	127.2168
74	1.270000E+01	1.265000E+01	127.3228
75	1.260000E+01	1.255000E+01	127.5358
76	1.250000E+01	1.245000E+01	127.7244
77	1.240000E+01	1.235000E+01	127.8873
78	1.230000E+01	1.225000E+01	128.0443
79	1.220000E+01	1.215000E+01	128.1685
80	1.210000E+01	1.205000E+01	128.2874
81	1.200000E+01	1.195000E+01	127.5901
82	1.190000E+01	1.185000E+01	126.5814
83	1.180000E+01	1.175000E+01	126.5332
84	1.170000E+01	1.165000E+01	126.4858
85	1.160000E+01	1.155000E+01	126.4938
86	1.150000E+01	1.145000E+01	126.4642
87	1.140000E+01	1.135000E+01	126.4172
88	1.130000E+01	1.125000E+01	126.4454
89	1.120000E+01	1.115000E+01	126.4621
90	1.110000E+01	1.105000E+01	126.5463
91	1.100000E+01	1.095000E+01	125.2593
92	1.090000E+01	1.085000E+01	123.5850
93	1.080000E+01	1.075000E+01	123.8293
94	1.070000E+01	1.065000E+01	124.1421
95	1.060000E+01	1.055000E+01	124.4976
96	1.050000E+01	1.045000E+01	124.8671
97	1.040000E+01	1.035000E+01	125.2962
98	1.030000E+01	1.025000E+01	125.8336
99	1.020000E+01	1.015000E+01	126.3516
100	1.010000E+01	1.005000E+01	126.8910
101	1.000000E+01	9.950000E+00	127.0425
102	9.900000E+00	9.850000E+00	126.9273
103	9.800000E+00	9.750000E+00	126.8053
104	9.700000E+00	9.650000E+00	126.6806
105	9.600000E+00	9.550000E+00	126.6502
106	9.500000E+00	9.450000E+00	126.5765
107	9.400000E+00	9.350000E+00	126.2807
108	9.300000E+00	9.250000E+00	125.9356
109	9.200000E+00	9.150000E+00	125.5770
110	9.100000E+00	9.050000E+00	125.2156
111	9.000000E+00	8.950000E+00	125.1276
112	8.900000E+00	8.850000E+00	125.2990
113	8.800000E+00	8.750000E+00	125.4694
114	8.700000E+00	8.650000E+00	125.6367
115	8.600000E+00	8.550000E+00	125.8031
116	8.500000E+00	8.450000E+00	125.9580
117	8.400000E+00	8.350000E+00	126.1020
118	8.300000E+00	8.250000E+00	126.2446
119	8.200000E+00	8.150000E+00	126.3802
120	8.100000E+00	8.050000E+00	126.5145
121	8.000000E+00	7.950000E+00	124.9300
122	7.900000E+00	7.850000E+00	121.7009
123	7.800000E+00	7.750000E+00	118.8325
124	7.700000E+00	7.650000E+00	118.0150
125	7.600000E+00	7.550000E+00	117.5293
126	7.500000E+00	7.450000E+00	117.0409
127	7.400000E+00	7.350000E+00	116.5500
128	7.300000E+00	7.250000E+00	116.0586
129	7.200000E+00	7.150000E+00	115.5648
130	7.100000E+00	7.050000E+00	115.0705
131	7.000000E+00	6.950000E+00	114.8306
132	6.900000E+00	6.850000E+00	114.8358
133	6.800000E+00	6.750000E+00	114.8405
134	6.700000E+00	6.650000E+00	114.8422
135	6.600000E+00	6.550000E+00	114.8434
136	6.500000E+00	6.450000E+00	114.8266
137	6.400000E+00	6.350000E+00	114.7922
138	6.300000E+00	6.250000E+00	114.7541
139	6.200000E+00	6.150000E+00	114.6941
140	6.100000E+00	6.050000E+00	114.6306
141	6.000000E+00	5.950000E+00	114.2725
142	5.900000E+00	5.850000E+00	113.6293
143	5.800000E+00	5.750000E+00	112.9814
144	5.700000E+00	5.650000E+00	112.3063

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
145	5.600000E+00	5.550000E+00	111.6268
146	5.500000E+00	5.450000E+00	110.9336
147	5.400000E+00	5.350000E+00	110.2271
148	5.300000E+00	5.250000E+00	109.5158
149	5.200000E+00	5.150000E+00	108.7766
150	5.100000E+00	5.050000E+00	108.0330
151	5.000000E+00	4.950000E+00	102.0466
152	4.900000E+00	4.850000E+00	99.23304
153	4.800000E+00	4.750000E+00	98.96036
154	4.700000E+00	4.650000E+00	98.66589
155	4.600000E+00	4.550000E+00	98.35501
156	4.500000E+00	4.450000E+00	98.02359
157	4.400000E+00	4.350000E+00	97.65742
158	4.300000E+00	4.250000E+00	97.25739
159	4.200000E+00	4.150000E+00	96.83241
160	4.100000E+00	4.050000E+00	96.38392
161	4.000000E+00	3.950000E+00	95.29969
162	3.900000E+00	3.850000E+00	93.60240
163	3.800000E+00	3.750000E+00	91.90091
164	3.700000E+00	3.650000E+00	90.19057
165	3.600000E+00	3.550000E+00	88.46346
166	3.500000E+00	3.450000E+00	87.28768
167	3.400000E+00	3.350000E+00	86.65953
168	3.300000E+00	3.250000E+00	86.02619
169	3.200000E+00	3.150000E+00	85.38896
170	3.100000E+00	3.050000E+00	84.75256
171	3.000000E+00	2.950000E+00	81.21822
172	2.900000E+00	2.850000E+00	78.03618
173	2.800000E+00	2.750000E+00	77.94052
174	2.700000E+00	2.650000E+00	77.78613
175	2.600000E+00	2.550000E+00	77.61927
176	2.500000E+00	2.450000E+00	77.45314
177	2.400000E+00	2.350000E+00	77.17774
178	2.300000E+00	2.250000E+00	77.12630
179	2.200000E+00	2.150000E+00	78.23370
180	2.100000E+00	2.050000E+00	79.77974
181	2.000000E+00	1.950000E+00	79.77537
182	1.900000E+00	1.850000E+00	76.39725
183	1.800000E+00	1.750000E+00	73.49136
184	1.700000E+00	1.650000E+00	72.47713
185	1.600000E+00	1.550000E+00	73.01718
186	1.500000E+00	1.450000E+00	71.02059
187	1.400000E+00	1.350000E+00	69.15923
188	1.300000E+00	1.250000E+00	69.89005
189	1.200000E+00	1.150000E+00	70.16261
190	1.100000E+00	1.050000E+00	69.97166
191	1.000000E+00	9.800000E-01	68.69471
192	9.600000E-01	9.400000E-01	66.38594
193	9.200000E-01	9.000000E-01	64.33213
194	8.800000E-01	8.600000E-01	63.91096
195	8.400000E-01	8.200000E-01	63.72685
196	8.000000E-01	7.800000E-01	63.43225
197	7.600000E-01	7.400000E-01	62.66481
198	7.200000E-01	7.050000E-01	61.24394
199	6.900000E-01	6.750000E-01	60.41233
200	6.600000E-01	6.450000E-01	59.68695
201	6.300000E-01	6.150000E-01	58.89531
202	6.000000E-01	5.875000E-01	58.23692
203	5.750000E-01	5.625000E-01	57.71369
204	5.500000E-01	5.375000E-01	57.12998
205	5.250000E-01	5.125000E-01	56.48677
206	5.000000E-01	4.875000E-01	55.66633
207	4.750000E-01	4.625000E-01	54.67182
208	4.500000E-01	4.375000E-01	53.63813
209	4.250000E-01	4.125000E-01	52.56604
210	4.000000E-01	3.900000E-01	51.54028
211	3.800000E-01	3.700000E-01	50.55792
212	3.600000E-01	3.500000E-01	49.54984
213	3.400000E-01	3.300000E-01	48.33731
214	3.200000E-01	3.100000E-01	47.06708
215	3.000000E-01	2.900000E-01	45.63056
216	2.800000E-01	2.750000E-01	44.43863

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
217	2.700000E-01	2.625000E-01	43.43638
218	2.550000E-01	2.475000E-01	42.16251
219	2.400000E-01	2.350000E-01	40.91005
220	2.300000E-01	2.250000E-01	39.89028
221	2.200000E-01	2.150000E-01	38.87049
222	2.100000E-01	2.050000E-01	37.85061
223	2.000000E-01	1.950000E-01	36.89561
224	1.900000E-01	1.850000E-01	36.00745
225	1.800000E-01	1.750000E-01	35.09917
226	1.700000E-01	1.650000E-01	34.05930
227	1.600000E-01	1.550000E-01	32.99495
228	1.500000E-01	1.462500E-01	31.87364
229	1.425000E-01	1.387500E-01	30.69371
230	1.350000E-01	1.312500E-01	29.51374
231	1.275000E-01	1.237500E-01	28.31557
232	1.200000E-01	1.175000E-01	27.26391
233	1.150000E-01	1.125000E-01	26.41328
234	1.100000E-01	1.075000E-01	25.56072
235	1.050000E-01	1.025000E-01	24.70057
236	1.000000E-01	9.800000E-02	23.85536
237	9.600000E-02	9.400000E-02	23.02436
238	9.200000E-02	9.000000E-02	22.19209
239	8.800000E-02	8.600000E-02	21.35164
240	8.400000E-02	8.200000E-02	20.50865
241	8.000000E-02	7.800000E-02	19.65873
242	7.600000E-02	7.400000E-02	18.79961
243	7.200000E-02	7.050000E-02	18.04391
244	6.900000E-02	6.750000E-02	17.38495
245	6.600000E-02	6.450000E-02	16.72312
246	6.300000E-02	6.150001E-02	16.06063
247	6.000000E-02	5.875000E-02	15.44457
248	5.750000E-02	5.625000E-02	14.87455
249	5.500000E-02	5.375000E-02	14.30452
250	5.250000E-02	5.125000E-02	13.73448
251	5.000000E-02	4.875000E-02	13.16471
252	4.750000E-02	4.625000E-02	12.59518
253	4.500000E-02	4.375000E-02	12.02353
254	4.250000E-02	4.125000E-02	11.44880
255	4.000000E-02	3.900000E-02	10.98796
256	3.800000E-02	3.700000E-02	10.63791
257	3.600000E-02	3.500000E-02	10.28706
258	3.400000E-02	3.300000E-02	9.930538
259	3.200000E-02	3.100000E-02	9.543841
260	3.000000E-02	2.900000E-02	9.139377
261	2.800000E-02	2.750000E-02	8.821269
262	2.700000E-02	2.625000E-02	8.546266
263	2.550000E-02	2.475000E-02	8.212161
264	2.400000E-02	2.350000E-02	7.919796
265	2.300000E-02	2.250000E-02	7.683573
266	2.200000E-02	2.150000E-02	7.446482
267	2.100000E-02	2.050000E-02	7.197344
268	2.000000E-02	1.950000E-02	6.939925
269	1.900000E-02	1.850000E-02	6.681116
270	1.800000E-02	1.750000E-02	6.421101
271	1.700000E-02	1.650000E-02	6.149005
272	1.600000E-02	1.550000E-02	5.871399
273	1.500000E-02	1.462500E-02	5.620331
274	1.425000E-02	1.387500E-02	5.399389
275	1.350000E-02	1.312500E-02	5.173678
276	1.275000E-02	1.237500E-02	4.943371
277	1.200000E-02	1.175000E-02	4.750016
278	1.150000E-02	1.125000E-02	4.589880
279	1.100000E-02	1.075000E-02	4.426621
280	1.050000E-02	1.025000E-02	4.263193
281	1.000000E-02	9.800000E-03	4.303217
282	9.600000E-03	9.400000E-03	4.466909
283	9.200000E-03	9.000000E-03	4.747111
284	8.800000E-03	8.600000E-03	3.853745
285	8.400000E-03	8.200000E-03	4.347416
286	8.000000E-03	7.800000E-03	3.681936
287	7.600000E-03	7.400000E-03	3.570645
288	7.200000E-03	7.050000E-03	4.099506

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
289	6.900000E-03	6.750000E-03	3.008282
290	6.600000E-03	6.450000E-03	5.091309
291	6.300000E-03	6.150000E-03	5.613547
292	6.000000E-03	5.875000E-03	4.520483
293	5.750000E-03	5.625000E-03	6.368707
294	5.500000E-03	5.375000E-03	2.619797
295	5.250000E-03	5.125000E-03	3.498544
296	5.000000E-03	4.875000E-03	3.661220
297	4.750000E-03	4.625000E-03	3.187647
298	4.500000E-03	4.375000E-03	2.123645
299	4.250000E-03	4.125000E-03	2.143989
300	4.000000E-03	3.900000E-03	4.579587
301	3.800000E-03	3.700000E-03	2.916783
302	3.600000E-03	3.500000E-03	4.351841
303	3.400000E-03	3.300000E-03	1.471401
304	3.200000E-03	3.100000E-03	2.006934
305	3.000000E-03	2.900000E-03	2.245155
306	2.800000E-03	2.750000E-03	4.212828
307	2.700000E-03	2.625000E-03	3.107141
308	2.550000E-03	2.475000E-03	1.521695
309	2.400000E-03	2.350000E-03	1.237342
310	2.300000E-03	2.250000E-03	1.152334
311	2.200000E-03	2.150000E-03	1.124852
312	2.100000E-03	2.050000E-03	1.463002
313	2.000000E-03	1.950000E-03	1.909435
314	1.900000E-03	1.850000E-03	3.035858
315	1.800000E-03	1.750000E-03	1.313788
316	1.700000E-03	1.650000E-03	3.652810
317	1.600000E-03	1.550000E-03	0.9715682
318	1.500000E-03	1.462500E-03	2.976944
319	1.425000E-03	1.387500E-03	1.058469
320	1.350000E-03	1.312500E-03	4.039089
321	1.275000E-03	1.237500E-03	0.6729786
322	1.200000E-03	1.175000E-03	0.6776407
323	1.150000E-03	1.125000E-03	1.379635
324	1.100000E-03	1.075000E-03	0.6787618
325	1.050000E-03	1.025000E-03	0.6751838
326	1.000000E-03	9.800000E-04	0.7052754
327	9.600000E-04	9.400000E-04	4.117430
328	9.200000E-04	9.000000E-04	0.7085687
329	8.800000E-04	8.600000E-04	0.7433070
330	8.400000E-04	8.200000E-04	1.908450
331	8.000000E-04	7.800000E-04	0.9723304
332	7.600000E-04	7.400000E-04	10.85853
333	7.200000E-04	7.050000E-04	0.8728912
334	6.900000E-04	6.750000E-04	3.919608
335	6.600000E-04	6.450000E-04	0.7984169
336	6.300000E-04	6.150000E-04	0.7578828
337	6.000000E-04	5.875000E-04	0.7991196
338	5.750000E-04	5.625000E-04	1.021199
339	5.500000E-04	5.375000E-04	14.05596
340	5.250000E-04	5.125000E-04	1.050040
341	5.000000E-04	4.875000E-04	0.9816861
342	4.750000E-04	4.625000E-04	1.814618
343	4.500000E-04	4.375000E-04	0.7590081
344	4.250000E-04	4.125000E-04	0.7195444
345	4.000000E-04	3.900000E-04	0.7715850
346	3.800000E-04	3.700000E-04	0.8270449
347	3.600000E-04	3.500000E-04	0.9752603
348	3.400000E-04	3.300000E-04	10.95681
349	3.200000E-04	3.100000E-04	11.93249
350	3.000000E-04	2.900000E-04	0.8039847
351	2.800000E-04	2.750000E-04	0.6671034
352	2.700000E-04	2.625000E-04	0.7201912
353	2.550000E-04	2.475000E-04	5.170911
354	2.400000E-04	2.350000E-04	0.5295004
355	2.300000E-04	2.250000E-04	0.4305282
356	2.200000E-04	2.150000E-04	0.4002900
357	2.100000E-04	2.050000E-04	0.3863766
358	2.000000E-04	1.950000E-04	0.3902313
359	1.900000E-04	1.850000E-04	0.4021000
360	1.800000E-04	1.750000E-04	0.4396242

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
361	1.700000E-04	1.650000E-04	0.5259843
362	1.600000E-04	1.550000E-04	0.6701467
363	1.500000E-04	1.462500E-04	0.8222943
364	1.425000E-04	1.387500E-04	0.9446481
365	1.350000E-04	1.312500E-04	1.104201
366	1.275000E-04	1.237500E-04	1.314697
367	1.200000E-04	1.175000E-04	1.464778
368	1.150000E-04	1.125000E-04	1.523553
369	1.100000E-04	1.075000E-04	1.662977
370	1.050000E-04	1.025000E-04	1.836706
371	1.000000E-04	9.800000E-05	1.958603
372	9.600000E-05	9.400000E-05	14.13184
373	9.200000E-05	9.000000E-05	3.572621
374	8.800000E-05	8.600000E-05	1.064388
375	8.400000E-05	8.200000E-05	0.7545328
376	8.000000E-05	7.800000E-05	0.5942491
377	7.600000E-05	7.400000E-05	0.4988076
378	7.200000E-05	7.050000E-05	0.4475922
379	6.900000E-05	6.750000E-05	0.4247919
380	6.600000E-05	6.450000E-05	0.4175343
381	6.300000E-05	6.150000E-05	0.4277524
382	6.000000E-05	5.875000E-05	0.4620370
383	5.750000E-05	5.625000E-05	0.5505592
384	5.500000E-05	5.375000E-05	0.8595088
385	5.250000E-05	5.125000E-05	1.599728
386	5.000000E-05	4.875000E-05	13.23834
387	4.750000E-05	4.625000E-05	101.9115
388	4.500000E-05	4.375000E-05	2.114861
389	4.250000E-05	4.125000E-05	0.8668850
390	4.000000E-05	3.900000E-05	0.3909836
391	3.800000E-05	3.700000E-05	0.3949136
392	3.600000E-05	3.500000E-05	0.3988437
393	3.400000E-05	3.300000E-05	0.4028142
394	3.200000E-05	3.100000E-05	0.4068260
395	3.000000E-05	2.900000E-05	0.4108446
396	2.800000E-05	2.750000E-05	0.4138921
397	2.700000E-05	2.625000E-05	0.4164736
398	2.550000E-05	2.475000E-05	0.4195617
399	2.400000E-05	2.350000E-05	0.4221645
400	2.300000E-05	2.250000E-05	0.4242919
401	2.200000E-05	2.150000E-05	0.4264191
402	2.100000E-05	2.050000E-05	0.4285465
403	2.000000E-05	1.950000E-05	0.4308486
404	1.900000E-05	1.850000E-05	0.4333223
405	1.800000E-05	1.750000E-05	0.4358479
406	1.700000E-05	1.650000E-05	0.4384445
407	1.600000E-05	1.550000E-05	0.4411159
408	1.500000E-05	1.462500E-05	0.4435087
409	1.425000E-05	1.387500E-05	0.4456379
410	1.350000E-05	1.312500E-05	0.4478301
411	1.275000E-05	1.237500E-05	0.4500898
412	1.200000E-05	1.175000E-05	0.4520449
413	1.150000E-05	1.125000E-05	0.4536326
414	1.100000E-05	1.075000E-05	0.4553187
415	1.050000E-05	1.025000E-05	0.4570198
416	1.000000E-05	9.800000E-06	0.4593957
417	9.600000E-06	9.400000E-06	0.4624639
418	9.200000E-06	9.000000E-06	0.4655328
419	8.800000E-06	8.600000E-06	0.4686785
420	8.400000E-06	8.200000E-06	0.4719080
421	8.000000E-06	7.800000E-06	0.4751475
422	7.600000E-06	7.400000E-06	0.4785279
423	7.200000E-06	7.050000E-06	0.4815185
424	6.900000E-06	6.750000E-06	0.4841248
425	6.600000E-06	6.450000E-06	0.4868641
426	6.300000E-06	6.150000E-06	0.4896156
427	6.000000E-06	5.875000E-06	0.4921912
428	5.750000E-06	5.625000E-06	0.4946683
429	5.500000E-06	5.375000E-06	0.4971502
430	5.250000E-06	5.125000E-06	0.4997018
431	5.000000E-06	4.875000E-06	0.5041212
432	4.750000E-06	4.625000E-06	0.5102257

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
433	4.500000E-06	4.375000E-06	0.5164981
434	4.250000E-06	4.125000E-06	0.5229010
435	4.000000E-06	3.900000E-06	0.5287051
436	3.800000E-06	3.700000E-06	0.5341017
437	3.600000E-06	3.500000E-06	0.5395223
438	3.400000E-06	3.300000E-06	0.5450680
439	3.200000E-06	3.100000E-06	0.5508251
440	3.000000E-06	2.900000E-06	0.5567760
441	2.800000E-06	2.750000E-06	0.5613497
442	2.700000E-06	2.625000E-06	0.5653187
443	2.550000E-06	2.475000E-06	0.5702257
444	2.400000E-06	2.350000E-06	0.5744995
445	2.300000E-06	2.250000E-06	0.5780208
446	2.200000E-06	2.150000E-06	0.5816858
447	2.100000E-06	2.050000E-06	0.5854434
448	2.000000E-06	1.950000E-06	0.5893638
449	1.900000E-06	1.850000E-06	0.5934480
450	1.800000E-06	1.750000E-06	0.5976869
451	1.700000E-06	1.650000E-06	0.6021605
452	1.600000E-06	1.550000E-06	0.6068507
453	1.500000E-06	1.462500E-06	0.6111978
454	1.425000E-06	1.387500E-06	0.6151050
455	1.350000E-06	1.312500E-06	0.6192380
456	1.275000E-06	1.237500E-06	0.6236259
457	1.200000E-06	1.175000E-06	0.6274282
458	1.150000E-06	1.125000E-06	0.6306947
459	1.100000E-06	1.075000E-06	0.6340853
460	1.050000E-06	1.025000E-06	0.6376522
461	1.000000E-06	9.800000E-07	0.6421335
462	9.600000E-07	9.400000E-07	0.6473066
463	9.200000E-07	9.000000E-07	0.6527138
464	8.800000E-07	8.600000E-07	0.6582779
465	8.400000E-07	8.200000E-07	0.6641567
466	8.000000E-07	7.800000E-07	0.6701603
467	7.600000E-07	7.400000E-07	0.6764001
468	7.200000E-07	7.050000E-07	0.6821381
469	6.900000E-07	6.750000E-07	0.6871272
470	6.600000E-07	6.450000E-07	0.6924125
471	6.300000E-07	6.150000E-07	0.6979194
472	6.000000E-07	5.875000E-07	0.7032928
473	5.750000E-07	5.625000E-07	0.7083228
474	5.500000E-07	5.375000E-07	0.7134417
475	5.250000E-07	5.125000E-07	0.7189181
476	5.000000E-07	4.875000E-07	0.7267829
477	4.750000E-07	4.625000E-07	0.7370012
478	4.500000E-07	4.375000E-07	0.7475832
479	4.250000E-07	4.125000E-07	0.7586753
480	4.000000E-07	3.900000E-07	0.7688796
481	3.800000E-07	3.700000E-07	0.7785481
482	3.600000E-07	3.500000E-07	0.7885520
483	3.400000E-07	3.300000E-07	0.7988138
484	3.200000E-07	3.100000E-07	0.8098748
485	3.000000E-07	2.900000E-07	0.8214272
486	2.800000E-07	2.750000E-07	0.8305146
487	2.700000E-07	2.625000E-07	0.8384903
488	2.550000E-07	2.475000E-07	0.8486955
489	2.400000E-07	2.350000E-07	0.8573889
490	2.300000E-07	2.250000E-07	0.8650002
491	2.200000E-07	2.150000E-07	0.8728340
492	2.100000E-07	2.050000E-07	0.8808779
493	2.000000E-07	1.950000E-07	0.8898087
494	1.900000E-07	1.850000E-07	0.8989656
495	1.800000E-07	1.750000E-07	0.9085490
496	1.700000E-07	1.650000E-07	0.9191540
497	1.600000E-07	1.550000E-07	0.9299974
498	1.500000E-07	1.462500E-07	0.9404176
499	1.425000E-07	1.387500E-07	0.9500903
500	1.350000E-07	1.312500E-07	0.9603268
501	1.275000E-07	1.237500E-07	0.9716213
502	1.200000E-07	1.175000E-07	0.9811401
503	1.150000E-07	1.125000E-07	0.9895244
504	1.100000E-07	1.075000E-07	0.9983672

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
505	1.050000E-07	1.025000E-07	1.007774
506	1.000000E-07	9.800000E-08	1.018910
507	9.600000E-08	9.400000E-08	1.031486
508	9.200000E-08	9.000000E-08	1.044724
509	8.800000E-08	8.600000E-08	1.058283
510	8.400000E-08	8.200000E-08	1.072606
511	8.000000E-08	7.800000E-08	1.087689
512	7.600000E-08	7.400000E-08	1.103361
513	7.200000E-08	7.050000E-08	1.117827
514	6.900000E-08	6.750000E-08	1.131091
515	6.600000E-08	6.450000E-08	1.144762
516	6.300000E-08	6.150000E-08	1.159280
517	6.000000E-08	5.875000E-08	1.173100
518	5.750000E-08	5.625000E-08	1.186418
519	5.500000E-08	5.375000E-08	1.200595
520	5.250000E-08	5.125000E-08	1.215826
521	5.000000E-08	4.875000E-08	1.231169
522	4.750000E-08	4.625000E-08	1.248158
523	4.500000E-08	4.375000E-08	1.266257
524	4.250000E-08	4.125000E-08	1.284803
525	4.000000E-08	3.900000E-08	1.303812
526	3.800000E-08	3.700000E-08	1.321313
527	3.600000E-08	3.500000E-08	1.340211
528	3.400000E-08	3.300000E-08	1.360443
529	3.200000E-08	3.100000E-08	1.382568
530	3.000000E-08	2.900000E-08	1.406710
531	2.800000E-08	2.750000E-08	1.426260
532	2.700000E-08	2.625000E-08	1.443849
533	2.550000E-08	2.475000E-08	1.468284
534	2.400000E-08	2.350000E-08	1.492531
535	2.300000E-08	2.250000E-08	1.513096
536	2.200000E-08	2.150000E-08	1.534934
537	2.100000E-08	2.050000E-08	1.558010
538	2.000000E-08	1.950000E-08	1.582237
539	1.900000E-08	1.850000E-08	1.608285
540	1.800000E-08	1.750000E-08	1.636128
541	1.700000E-08	1.650000E-08	1.666099
542	1.600000E-08	1.550000E-08	1.698255
543	1.500000E-08	1.462500E-08	1.728731
544	1.425000E-08	1.387500E-08	1.757004
545	1.350000E-08	1.312500E-08	1.787079
546	1.275000E-08	1.237500E-08	1.819693
547	1.200000E-08	1.175000E-08	1.849165
548	1.150000E-08	1.125000E-08	1.873784
549	1.100000E-08	1.075000E-08	1.900419
550	1.050000E-08	1.025000E-08	1.929170
551	1.000000E-08	9.800000E-09	1.957366
552	9.600000E-09	9.400000E-09	1.985813
553	9.200000E-09	9.000000E-09	2.015834
554	8.800000E-09	8.600000E-09	2.047956
555	8.400000E-09	8.200000E-09	2.081214
556	8.000000E-09	7.800000E-09	2.117132
557	7.600000E-09	7.400002E-09	2.155843
558	7.200000E-09	7.050000E-09	2.192089
559	6.900000E-09	6.750000E-09	2.224487
560	6.600000E-09	6.450000E-09	2.259289
561	6.300000E-09	6.150000E-09	2.296491
562	6.000000E-09	5.875000E-09	2.332987
563	5.750000E-09	5.625000E-09	2.367185
564	5.500000E-09	5.375000E-09	2.404750
565	5.250000E-09	5.125000E-09	2.444634
566	5.000000E-09	4.875000E-09	2.490470
567	4.750000E-09	4.625000E-09	2.542870
568	4.500000E-09	4.375000E-09	2.598317
569	4.250000E-09	4.125000E-09	2.658137
570	4.000000E-09	3.900000E-09	2.715810
571	3.800000E-09	3.700000E-09	2.771724
572	3.600000E-09	3.500000E-09	2.830851
573	3.400000E-09	3.300000E-09	2.894506
574	3.200000E-09	3.100000E-09	2.963683
575	3.000000E-09	2.900000E-09	3.039487
576	2.800000E-09	2.750000E-09	3.100623

TABLE A2.1 *Continued*

Bin Number	Upper Energy Bound (MeV)	Energy Mid-point (MeV)	Displacement Damage Function (MeV·mbarn)
577	2.700000E-09	2.625000E-09	3.157093
578	2.550000E-09	2.475000E-09	3.226965
579	2.400000E-09	2.350000E-09	3.290611
580	2.300000E-09	2.250000E-09	3.345073
581	2.200000E-09	2.150000E-09	3.404336
582	2.100000E-09	2.050000E-09	3.465674
583	2.000000E-09	1.950000E-09	3.531984
584	1.900000E-09	1.850000E-09	3.603455
585	1.800000E-09	1.750000E-09	3.681443
586	1.700000E-09	1.650000E-09	3.763800
587	1.600000E-09	1.550000E-09	3.855147
588	1.500000E-09	1.462500E-09	3.941984
589	1.425000E-09	1.387500E-09	4.022763
590	1.350000E-09	1.312500E-09	4.110997
591	1.275000E-09	1.237500E-09	4.206987
592	1.200000E-09	1.175000E-09	4.292010
593	1.150000E-09	1.125000E-09	4.368166
594	1.100000E-09	1.075000E-09	4.444819
595	1.050000E-09	1.025000E-09	4.528198
596	1.000000E-09	9.800000E-10	4.611351
597	9.600000E-10	9.400000E-10	4.693213
598	9.200000E-10	9.000000E-10	4.781856
599	8.800000E-10	8.600000E-10	4.871137
600	8.400000E-10	8.200000E-10	4.967869
601	8.000000E-10	7.800000E-10	5.072682
602	7.600000E-10	7.400000E-10	5.186074
603	7.200000E-10	7.050000E-10	5.291282
604	6.900000E-10	6.750000E-10	5.388422
605	6.600000E-10	6.450000E-10	5.494944
606	6.300000E-10	6.150000E-10	5.603578
607	6.000000E-10	5.875000E-10	5.712392
608	5.750000E-10	5.625000E-10	5.821317
609	5.500000E-10	5.375000E-10	5.930476
610	5.250000E-10	5.125000E-10	6.047915
611	5.000000E-10	4.875000E-10	6.182956
612	4.750000E-10	4.625000E-10	6.329957
613	4.500000E-10	4.375000E-10	6.492437
614	4.250000E-10	4.125000E-10	6.659180
615	4.000000E-10	3.900000E-10	6.831114
616	3.800000E-10	3.700000E-10	6.989074
617	3.600000E-10	3.500000E-10	7.163126
618	3.400000E-10	3.300000E-10	7.353035
619	3.200000E-10	3.100000E-10	7.553178
620	3.000000E-10	2.900000E-10	7.781979
621	2.800000E-10	2.750000E-10	7.962666
622	2.700000E-10	2.625000E-10	8.127457
623	2.550000E-10	2.475000E-10	8.341032
624	2.400000E-10	2.350000E-10	8.542303
625	2.300000E-10	2.250000E-10	8.710299
626	2.200000E-10	2.150000E-10	8.878578
627	2.100000E-10	2.050000E-10	9.068738
628	2.000000E-10	1.950000E-10	9.275459
629	1.900000E-10	1.850000E-10	9.486740
630	1.800000E-10	1.750000E-10	9.732625
631	1.700000E-10	1.650000E-10	9.986153
632	1.600000E-10	1.550000E-10	10.26194
633	1.500000E-10	1.462500E-10	10.53162
634	1.425000E-10	1.387500E-10	10.78174
635	1.350000E-10	1.312500E-10	11.05266
636	1.275000E-10	1.237500E-10	11.35017
637	1.200000E-10	1.175000E-10	11.61529
638	1.150000E-10	1.125000E-10	11.84453
639	1.100000E-10	1.075000E-10	12.09051
640	1.050000E-10	1.025000E-10	12.35521

This is the SAND-II energy bin structure. The upper energy boundary is 20 MeV. The lower energy boundary is 1.0E-10 MeV.

$_{GaAs}$ = 70 MeV·mbarn. This normalization results in the factor of 2.2 being used along with the damage efficiency function shown in Fig. A2.2. Thus, the designated value to be used in Eq

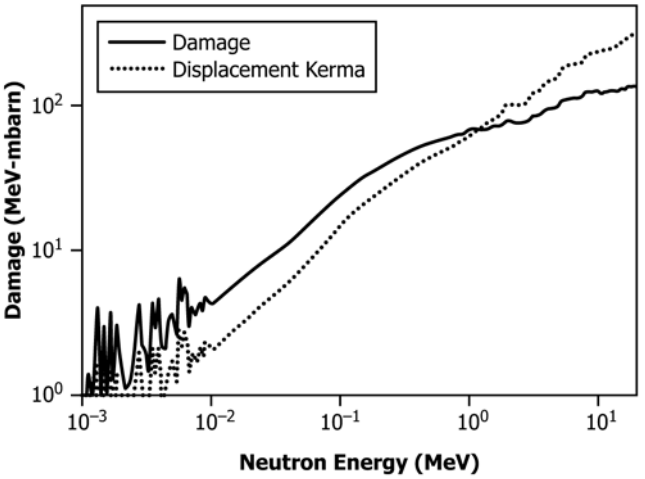

FIG. A2.2 Comparison of GaAs Microscopic Displacement Kerma and Damage Function

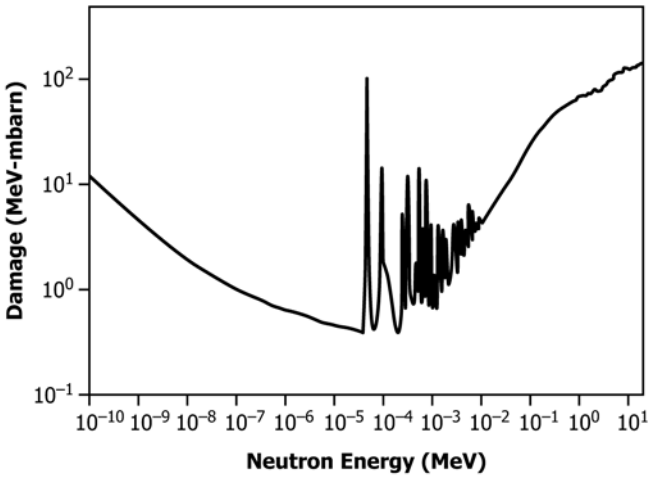

FIG. A2.3 GaAs Damage Function

1 and 2 to calculate a 1-MeV equivalent fluence in gallium arsenide is 70 MeV·mbarn.

A2.2.6 For purposes of intercomparison of hardness testing results from various laboratories, the value of $F_{D,1MeV,GaAs}$ used in obtaining such results is very important; therefore, reporting of results should include confirmation that the value of $F_{D,1MeV,GaAs}$ designated in A2.2.5 was used in any calculation.

A2.2.7 The empirical damage function derived from the efficiency factors, described in A2.1.6, are printed in Table A2.1 in the same energy structure as that used for the silicon damage factors of Table A1.1. The values are normalized to ∽70 MeV·mbarn at a neutron energy of 1 MeV. The values are also shown in Fig. A2.2, where they may be compared with the microscopic displacement kerma factors, and in Fig. A2.3.

A2.2.8 Once the neutron fluence spectrum Φ(E) has been determined for the energy range of interest, then use numerical integration to evaluate Eq 1 and 2, using values for the displacement damage function, F_D(E), from Table A2.1 and $F_{D,1MeV,GaAs}$ = 70 MeV·mbarn.

A2.3 Precision and Bias

A2.3.1 The values for $F_{D,GaAs}$(E) shown in Fig. A2.2 were determined by calculating the total kerma and then partitioning it into ionization and displacement fractions and applying the PKA-energy-dependent damage efficiency factors **(8)**. The estimated uncertainties in the values for total kerma is 5 to 10 %. Because of the lack of adequate theory to partition the kerma and uncertainties in cross sections, the estimated uncertainty in the microscopic displacement kerma factor is about 10 to 15 %.

A2.3.2 The uncertainties in the displacement damage function in Table A2.1 are at present quite large, ±20 % being a conservative figure.

A2.3.3 Comparisons between the calculations with the SAND II unfolding code (using activation-foil input data), neutron transport codes, and experimental spectrometry data give an estimated uncertainty in the determination of Φ(E) of about 20 % over the energy region of interest **(23)** (see Test Method E721).

A2.3.4 Since this mandatory annex requires the use of Table A2.1 and $F_{D,1MeV,GaAs}$ = 70 MeV·mbarn, no uncertainty in the calculation of 1-MeV equivalent fluence is attributable to the consistent use of these data. Therefore only the uncertainty in the determination of Φ(E) need be considered in assigning an uncertainty to the 1-MeV equivalent fluence. An uncertainty in the spectrum in the range± 20 %, would most often lead to uncertainties no more than ±10 % in the integral quantity $\Phi_{eq,1MeV,GaAs}$. While no specific group structure for representing the neutron fluence spectrum is recommended, the choice of energy bin boundaries will affect the uncertainty in the 1-MeV equivalent fluence. The energy bin boundaries should be chosen with due consideration for the shape of both the neutron spectrum and the 1-MeV equivalent damage function. A poor choice of the group structure used to evaluate the integral in Eq 2 could increase this uncertainty (see 8.1.7).

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