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Standard Guide for Determining Neutron Energy Spectra from Neutron Sensors for Radiation-Hardness Testing of Electronics¹

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

1. Scope

1.1 This guide covers procedures for determining the energy-differential fluence spectra of neutrons used in radiation-hardness testing of electronic semiconductor devices. The types of neutron sources specifically covered by this guide are fission or degraded energy fission sources used in either a steady-state or pulse mode.

1.2 This guide provides guidance and criteria that can be applied during the process of choosing the spectrum adjustment methodology that is best suited to the available data and relevant for the environment being investigated.

1.3 This guide is to be used in conjunction with Guide E720 to characterize neutron spectra and is used in conjunction with Practice E722 to characterize damage-related parameters normally associated with radiation-hardness testing of electronic semiconductor devices.

NOTE 1—Although Guide E720 only discusses activation foil sensors, any energy-dependent neutron-responding sensor for which a response function is known may be used (1).²

NOTE 2—For terminology used in this guide, see Terminology E170.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recom-*

mendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:³

- E170 Terminology Relating to Radiation Measurements and Dosimetry
- E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques
- E262 Test Method for Determining Thermal Neutron Reaction Rates and Thermal Neutron Fluence Rates by Radioactivation Techniques
- E263 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Iron
- E264 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Nickel
- E265 Test Method for Measuring Reaction Rates and Fast-Neutron Fluences by Radioactivation of Sulfur-32
- E266 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Aluminum
- E393 Test Method for Measuring Reaction Rates by Analysis of Barium-140 From Fission Dosimeters
- E523 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Copper
- E526 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Titanium
- E704 Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238
- E705 Test Method for Measuring Reaction Rates by Radioactivation of Neptunium-237
- E720 Guide for Selection and Use of Neutron Sensors for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics
- E722 Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics

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² The boldface numbers in parentheses refer to the list of references at the end of this guide.

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
- E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance
- E1018 Guide for Application of ASTM Evaluated Cross Section Data File
- E1297 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Niobium
- E1855 Test Method for Use of 2N2222A Silicon Bipolar Transistors as Neutron Spectrum Sensors and Displacement Damage Monitors

3. Terminology

3.1 *Definitions*: The following list defines some of the special terms used in this guide:

3.1.1 *effect*—the characteristic which changes in the sensor when it is subjected to the neutron irradiation. The effect may be the reactions in an activation foil.

3.1.2 *prior spectrum*—an estimate of the neutron spectrum obtained by transport calculation or otherwise and used as input to a least-squares adjustment.

3.1.3 *response*—the magnitude of the effect. It can be the measured value or that calculated by integrating the response function over the neutron fluence spectrum. The response is an integral parameter mathematically approximated by a discrete summation, $R = \sum_i R_i$, where R_i is the response in each differential energy region at E_i of width ΔE_i .

3.1.4 *response function*—the set of values of R_i in each differential energy region divided by the neutron fluence in that differential energy region, that is, the set $f_i = R_i/(\Phi(E_i)\Delta E_i)$.

3.1.5 *sensor*—an object or material (sensitive to neutrons) the response of which is used to help define the neutron environment. A sensor may be an activation foil.

3.1.6 *spectrum adjustment*—the process of changing the shape and magnitude of the neutron energy spectrum so that quantities integrated over the spectrum agree more closely with their measured values. Other physical constraints on the spectrum may be applied.

3.1.7 *trial function*—a neutron spectrum which, when integrated over sensor response functions, yields calculated responses that can be compared to the corresponding measured responses.

3.2 *Abbreviations*:

3.2.1 *DUT*—device under test.

3.2.2 *ENDF*—evaluated nuclear data file.

3.2.3 *NNDC*—National Nuclear Data Center (at Brookhaven National Laboratory).

3.2.4 *RSICC*—Radiation Safety Information Computation Center (at Oak Ridge National Laboratory).

3.2.5 *TREE*—transient radiation effects on electronics.

4. Significance and Use

4.1 It is important to know the energy spectrum of the particular neutron source employed in radiation-hardness test-

ing of electronic devices in order to relate radiation effects with device performance degradation.

4.2 This guide describes the factors which must be considered when the spectrum adjustment methodology is chosen and implemented. Although the selection of sensors (foils) and the determination of responses (activities) is discussed in Guide E720, the experiment should not be divorced from the analysis. In fact, it is advantageous for the analyst conducting the spectrum determination to be closely involved with the design of the experiment to ensure that the data obtained will provide the most accurate spectrum possible. These data include the following: (1) measured responses such as the activities of foils exposed in the environment and their uncertainties, (2) response functions such as reaction cross sections along with appropriate correlations and uncertainties, (3) the geometry and materials in the test environment, and (4) a trial function or prior spectrum and its uncertainties obtained from a transport calculation or from previous experience.

5. Spectrum Determination with Neutron Sensors

5.1 *Experiment Design*:

5.1.1 The primary objective of the spectrum characterization experiment should be the acquisition of a set of response values (activities) from effects (reactions) with well-characterized response functions (cross sections) with responses which adequately define (as a set) the fluence values at energies to which the device to be tested is sensitive. For silicon devices in fission-driven environments the significant neutron energy range is usually from 10 keV to 15 MeV. Lists of suitable reactions along with approximate sensitivity ranges are included in Guide E720. Reactor sensor set design is also discussed in Guide E844. The foil set may include the use of responses with sensitivities outside the energy ranges needed for the DUT to aid in interpolation to other regions of the spectrum. For example, knowledge of the spectrum below 10 keV aids in the determination of the spectrum fraction above that energy.

5.1.2 An example of the difficulty encountered in ensuring response coverage (over the energy range of interest) is the following: If fission foils cannot be used in an experiment because of licensing problems, cost, or radiological handling difficulties (especially with ^{235}U , ^{237}Np , or ^{239}Pu), a large gap may be left in the foil set response between 100 keV and 2 MeV—a region important for silicon and gallium arsenide damage (see Figs. A1.1 and A2.3 of Practice E722). In this case two options are available. First, seek other sensors to fill the gap (such as silicon devices sensitive to displacement effects (see Test Method E1855)), $^{93}\text{Nb}(n,n')^{93\text{m}}\text{Nb}$ (see Test Method E1297) or $^{103}\text{Rh}(n,n')^{103\text{m}}\text{Rh}$. Second, devote the necessary resources to determine a trial function that is close to the real spectrum. In the latter case it may be necessary to carry out transport calculations to generate a prior spectrum which incorporates the use of uncertainty and covariance information.

5.1.3 Other considerations that affect the process of planning an experiment are the following:

5.1.3.1 Are the fluence levels low and of long duration so that only long half-life reactions are useful? This circumstance can severely reduce the response coverage of the foil set.