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Standard Guide for Neutron Irradiation of Unbiased Electronic Components¹

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1. Scope

1.1 This guide strictly applies only to the exposure of unbiased silicon (Si) or gallium arsenide (GaAs) semiconductor components (integrated circuits, transistors, and diodes) to neutron radiation to determine the permanent displacement damage in the components. Validated 1-MeV displacement damage functions codified in national standards, for example Practice E722, for silicon and GaAs are not currently standardized for other semiconductor materials.

1.2 Elements of this guide, with the deviations noted, may also be applicable to the exposure of semiconductors comprised of other materials, for example Ge, GaN, SiC, or AlN, except that validated 1-MeV displacement damage functions, codified in national standards, are not currently available.

1.3 Only the conditions of exposure are addressed in this guide. The effects of radiation on the test sample should be determined using appropriate electrical test methods.

1.4 This guide addresses those issues and concerns pertaining to irradiations with neutrons.

1.5 System and subsystem exposures and test methods are not included in this guide.

1.6 The range of interest for neutron fluence in displacement damage semiconductor testing ranges from approximately 10^9 to 10^{16} 1-MeV (Si)-Eqv.-n/cm².

1.7 This guide does not address neutron-induced single or multiple neutron event effects (nSEE) or transient annealing.

1.8 This guide provides an alternative to Test Method 1017, Neutron Displacement Testing, a component of MIL-STD-883 and MIL-STD-750.

1.9 *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 This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices.

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1.10 *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 Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

- 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
- E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices
- 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
- E722 Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics
- E1249 Practice for Minimizing Dosimetry Errors in Radiation Hardness Testing of Silicon Electronic Devices Using Co-60 Sources
- E1250 Test Method for Application of Ionization Chambers to Assess the Low Energy Gamma Component of Cobalt-60 Irradiators Used in Radiation-Hardness Testing of Silicon Electronic Devices
- E1854 Practice for Ensuring Test Consistency in Neutron-Induced Displacement Damage of Electronic Parts
- E1855 Test Method for Use of 2N2222A Silicon Bipolar Transistors as Neutron Spectrum Sensors and Displacement Damage Monitors
- E2450 Practice for Application of CaF₂(Mn) Thermoluminescence Dosimeters in Mixed Neutron-Photon Environments

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E3084 Practice for Characterizing Particle Irradiations of Materials in Terms of Non-Ionizing Energy Loss (NIEL)
F980 Guide for Measurement of Rapid Annealing of Neutron-Induced Displacement Damage in Silicon Semiconductor Devices

F1892 Guide for Ionizing Radiation (Total Dose) Effects Testing of Semiconductor Devices

2.2 *Military Standards:*³

MIL-STD-883 Test Method Standard Microcircuits

MIL-STD-750 Test Methods for Semiconductor Devices

2.3 *Other Documents:*

The Department of Defense publishes every few years a compendium of nuclear reactor facilities that may be suitable for neutron irradiation of electronic components:

Defense Threat Reduction Agency Guide to Nuclear Weapons Effects Simulation Facilities and Applications, July 31, 2014⁴

2.4 *U.S. Code of Federal Regulations:*

The Office of the Federal Register, National Archives and Records Administration publishes several documents that delineate the regulatory requirements for handling and transporting radioactive semiconductor components:

CFR Title 10, Part 20 Standards for Protection Against Radiation⁵

CFR Title 10, Part 30 Rules of General Applicability to Domestic Licensing of Byproduct Material⁵

CFR Title 49, Parts 100 to 177 Transportation⁵

3. Terminology

3.1 *Definitions:*

3.1.1 *1-MeV equivalent neutron fluence* ($\Phi_{\text{eq, 1 MeV, Matl}}$)—this expression is used by the radiation hardness testing community to characterize an incident energy-fluence spectrum, $\Phi(E)$, in terms of an equivalent monoenergetic neutrons fluence at a reference energy, $E_{\text{ref}} = 1 \text{ MeV}$, required to produce the same displacement damage in a specific irradiated material, denoted by the subscript as “Matl” (see Practice **E722** for details).

3.1.1.1 *Discussion*—Historically, the material has been assumed to be silicon (Si). Other materials such as gallium arsenide (GaAs), whose radiation damage effects mechanisms differ substantially from Si-based devices, require that use of the 1-MeV equivalent fluence expression include the explicit specification of the irradiation semiconductor material.

3.1.2 *equivalent monoenergetic neutron fluence* ($\Phi_{\text{eq, Eref, matl}}$)—an equivalent monoenergetic neutron fluence that characterizes an incident energy-fluence spectrum, $\Phi(E)$, in terms of the fluence of monoenergetic neutrons at a specific energy, E_{ref} , required to produce the same displacement damage in a specified irradiated material, matl (see Practice **E722** for details).

3.1.2.1 *Discussion*—The appropriate expressions for commonly used 1-MeV equivalent fluence are $\Phi_{\text{eq, 1 MeV, Si}}$ for silicon semiconductor devices and $\Phi_{\text{eq, 1 MeV, GaAs}}$ for gallium arsenide based devices. See Practice **E722** for a more thorough treatment of the meaning and significant limitations imposed on the use of these expressions.

3.1.3 *silicon damage equivalent (SDE)*—expression synonymous with “1-MeV(Si) equivalent fluence in silicon.”

4. Summary of Guide

4.1 Evaluation of neutron radiation-induced damage in semiconductor components and circuits requires that the following steps be taken:

4.1.1 Select a suitable neutron facility where the radiation environment and exposure geometry desired are both available and currently characterized (within the last 15 months per Practice **E1854** requirements). Practice **E1854** contains detailed guidance to assist the user in selecting a neutron facility that is certified to be adequately calibrated.

4.1.2 Prepare test plan and fixtures,

4.1.3 Conduct pre-irradiation electrical test of the test sample,

4.1.4 Expose test sample and associated neutron and photon dosimeters,

4.1.5 Retrieve irradiated test sample,

4.1.6 Read neutron and photon dosimeters,

4.1.7 Conduct post-irradiation electrical tests, and

4.1.8 Repeat 4.1.4 – 4.1.7 until the desired cumulative fluence is achieved or until degradation of the test device will not allow any further useful data to be taken.

4.2 Operations addressed in this guide are only those relating to facility selection, irradiation procedure and fixture development, positioning and exposure of the test sample, and shipment of the irradiated samples back to the parent facility. Dosimetry methods are covered in existing ASTM standards referenced in Section 2, and many pre- and post-exposure electrical measurement procedures are contained in the literature. Appropriate neutron and photon dosimetry is typically supplied by the neutron facility, see Practice **E1854**.

5. Significance and Use

5.1 Semiconductor devices can be permanently damaged by neutrons (**1, 2**).⁶ The effect of such damage on the performance of an electronic component can be determined by measuring the component’s electrical characteristics before and after exposure to fast neutrons in the neutron fluence range of interest. The resulting data can be utilized in the design of electronic circuits that are tolerant of the degradation exhibited by that component.

5.2 This guide provides a method by which the exposure of silicon and gallium arsenide semiconductor devices to neutron irradiation may be performed in a manner that is repeatable and which will allow comparison to be made of data taken at different facilities.

³ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

⁴ Available from Defense Special Weapons Agency, Washington, DC 20305-1000.

⁵ Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

⁶ The boldface numbers in parentheses refer to a list of references at the end of this standard.