



Designation: F 1190 – 93

Standard Practice for Neutron Irradiation of Unbiased Electronic Components¹

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1. Scope

1.1 This practice applies to the exposure of unbiased silicon (Si) or gallium arsenide (GaAs) semiconductor components to neutron radiation from a nuclear reactor source. Only the conditions of exposure are addressed in this practice. The effects of radiation on the test sample should be determined using appropriate electrical test methods.

1.2 System and subsystem exposures and test methods are not included in this practice.

1.3 This practice is applicable to irradiations conducted with the reactor operating in either the pulsed or steady-state mode. The practical limits for neutron fluence ($\Phi_{\text{eq, 1 MeV, Si}}$ or $\Phi_{\text{eq, 1 MeV, GaAs}}$) in semiconductor testing range from approximately 10^9 to 10^{16} n/cm².

1.4 This practice addresses those issues and concerns pertaining to irradiations with neutrons of energies greater than 10 keV.

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

2. Referenced Documents

2.1 ASTM Standards:

- E 170 Terminology Relating to Radiation Measurements and Dosimetry²
- E 264 Test Method for Determining Fast-Neutron Reaction Rates by Radioactivation of Nickel²
- E 265 Test Method for Measuring Reaction Rates and Fast-Neutron Fluences by Radioactivation of Sulfur-32²
- E 668 Practice for Application of Thermoluminescence Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices²
- E 720 Guide for Selection and Use of Neutron-Activation Foils for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics²
- E 721 Method for Determining Neutron Energy Spectra with Neutron-Activation Foils for Radiation-Hardness

Testing of Electronics²

- E 722 Practice for Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics²
- F 867M Guide for Ionizing Radiation Effects Testing of Semiconductor Devices³
- F 980 Guide for the Measurement of Rapid Annealing of Neutron-Induced Displacement Damage in Semiconductor Devices.³

2.2 Other Documents:

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

DASIAC SR-94-009, April 1996, Guide to Nuclear Weapons Effects Simulation Facilities and Techniques⁴

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

Code of Federal Regulations: Title 10 (Energy), Part 20, Standards for Protection Against Radiation⁵

Code of Federal Regulations: Title 10 (Energy), Part 30, Rules of General Applicability to Domestic Licensing of Byproduct Material⁵

Code of Federal Regulations: Title 49 (Transportation), Parts 100 to 177⁵

3. Terminology

3.1 *1 MeV equivalent fluence*—this expression is used by the radiation-hardness testing community to refer to the characterization of an incident neutron energy fluence spectrum, $\Phi(E)$, in terms of the fluence of monoenergetic neutrons at 1 MeV energy required to produce the same displacement damage in a specified irradiated material as $\Phi(E)$ (see Practice E 722 for details).

3.1.1 *Discussion*—Historically, the material has been assumed to be silicon (Si). The emergence of gallium arsenide (GaAs) as a significant alternate semiconductor material, whose radiation damage effects mechanisms differ substantially from Si based devices, requires that future use of the 1

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² *Annual Book of ASTM Standards*, Vol 12.02.

³ *Annual Book of ASTM Standards*, Vol 10.04.

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.

MeV equivalent fluence expression include the explicit specification of the irradiation semiconductor material.

3.2 *silicon damage equivalent (SDE)*—archaic expression synonymous with “1 MeV equivalent fluence in silicon.”

3.3 *equivalent monoenergetic neutron fluence* ($\Phi_{\text{eq}, E_{\text{ref}}, \text{mat}}$)—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, mat .

3.3.1 *Discussion*—The appropriate expressions for commonly used 1 MeV equivalent fluence are $\Phi_{\text{eq}, 1 \text{ MeV}, \text{Si}}$ for silicon semiconductor devices and $\Phi_{\text{eq}, 1 \text{ MeV}, \text{GaAs}}$ for gallium arsenide based devices. See Practice E 722 for a much more thorough treatment of the meaning and significant limitations imposed on the use of these expressions.

4. Summary of Practice

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 reactor facility where the radiation environment and exposure geometry desired are both available and currently characterized. A reasonably complete list is contained in DASIAC SR-94-009.

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 dosimeters,

4.1.5 Retrieve irradiated test sample,

4.1.6 Read dosimeters,

4.1.7 Conduct post-irradiation electrical tests, and

4.1.8 Repeat 4.1.4 through 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 practice are only those relating to reactor facility selection, test procedure and fixture development, positioning and exposure of the test sample, and shipment of the irradiated samples 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.⁴ Dosimetry is usually supplied by the reactor facility.

5. Significance and Use

5.1 Semiconductor devices are permanently damaged by fast neutrons ($E > 10 \text{ keV}$). The effect of such damage on the performance of an electronic component can be determined by measuring the component 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 which are tolerant of the degradation exhibited by that component.

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

6. Interferences

6.1 *Gamma Effects:*

6.1.1 All nuclear reactors produce gamma radiation coincident with the production of neutrons. If a separation of neutron (n) and gamma ray (γ) degradation is desired, either the n/γ ratio must be increased to the point at which gamma effects are negligible or the test sample degradation must first be characterized in a “pure” gamma ray environment under zero bias conditions. The use of such data from a gamma ray exposure to separate neutron and gamma effects obtained in a neutron exposure may be a complex task. If this approach is used, Guide F 867 should be used as a reference.

6.1.2 TRIGA-type reactors (Training Research and Isotope production reactor manufactured by General Atomics) deliver gamma dose during neutron irradiations that can vary considerably depending on the immediately preceding operating history of the reactor. A TRIGA-type reactor that has been operating at a high power level for an extended period prior to the semiconductor component neutron irradiation will contain a larger fission product inventory that will contribute significantly higher gamma dose than a reactor that has had no recent high level operations.

6.2 *Temperature Effects*—Annealing of neutron damage is enhanced at elevated temperatures. Elevated temperatures may occur during irradiation, transportation, storage, or electrical characterization of the test devices.

6.3 *Dosimetry Errors*—Neutron fluence is typically reported in terms of an equivalent 1 MeV monoenergetic neutron fluence in the specified irradiated material ($\Phi_{\text{eq}, 1 \text{ MeV}, \text{Si}}$ or $\Phi_{\text{eq}, 1 \text{ MeV}, \text{GaAs}}$) in units of neutrons per square centimeter. ASTM guidelines and standards exist for calculating this value from measured reactor characteristics. However, reactor facilities may not routinely remeasure the neutron spectrum, (using Guide E 720 and Method E 721) at the test sample exposure sites. A currently valid determination of the neutron spectrum provides essential data needed to accurately ascertain the equivalent 1 MeV monoenergetic neutron fluence in the specified irradiated material. Lack of this critical data can result in substantial error. Therefore the experimenter must accept responsibility for obtaining a current valid determination of the 1 MeV equivalent fluence in silicon or GaAs, as needed, from the reactor facility operator. This may require a recharacterization of the reactor test facility, or the particular test configuration.

6.4 *Recoil Ionization Effects*—Ionization effects from neutron recoils within a semiconductor device may be significant for some device types at very high neutron fluences, although under normal conditions, ionization due to the gamma radiation from the source will be much greater than the ionization from recoils.

6.5 *Test Configuration Effects*—Extraneous materials in the vicinity of the test specimens can modify the environment at the test sample location. Both the neutron spectrum and the gamma field can be altered by the introduction of such material even if these materials are not interposed between the reactor core and the test devices.

6.6 *Thermal Neutron Effects*—Thermal neutrons ($\sim 0.04 \text{ eV}$) interact with the materials of the devices being irradiated causing them to become radioactive. As this means that irradiated parts cannot be handled or measured in a normal