Designation: E1854 – 13

Standard Practice for Ensuring Test Consistency in Neutron-Induced Displacement Damage of Electronic Parts[1]

This standard is issued under the fixed designation E1854; 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.

1. Scope

1.1 This practice sets forth requirements to ensure consistency in neutron-induced displacement damage testing of silicon and gallium arsenide electronic piece parts. This requires controls on facility, dosimetry, tester, and communications processes that affect the accuracy and reproducibility of these tests. It provides background information on the technical basis for the requirements and additional recommendations on neutron testing.

1.2 Methods are presented for ensuring and validating consistency in neutron displacement damage testing of electronic parts such as integrated circuits, transistors, and diodes. The issues identified and the controls set forth in this practice address the characterization and suitability of the radiation environments. They generally apply to reactor sources, accelerator-based neutron sources, such as 14-MeV DT sources, and ^{252}Cf sources. Facility and environment characteristics that introduce complications or problems are identified, and recommendations are offered to recognize, minimize or eliminate these problems. This practice may be used by facility users, test personnel, facility operators, and independent process validators to determine the suitability of a specific environment within a facility and of the testing process as a whole. Electrical measurements are addressed in other standards, such as Guide F980. Additional information on conducting irradiations can be found in Practices E798 and F1190. This practice also may be of use to test sponsors (organizations that establish test specifications or otherwise have a vested interest in the performance of electronics in neutron environments).

1.3 Methods for the evaluation and control of undesired contributions to damage are discussed in this practice. References to relevant ASTM standards and technical reports are provided. Processes and methods used to arrive at the appropriate test environments and specification levels for electronics systems are beyond the scope of this practice; however, the process for determining the 1-MeV equivalent displacement specifications from operational environment neutron spectra should employ the methods and parameters described herein. Some important considerations and recommendations are addressed in Appendix X1 (Nonmandatory information).

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

2. Referenced Documents

2.1 The ASTM standards listed below present methods for ensuring proper determination of neutron spectra and fluences, gamma-ray doses, and damage in silicon and gallium arsenide devices. The proper use of these standards is the responsibility of the radiation metrology or dosimetry organization affiliated with facility operations. The references listed in each standard are also relevant to all participants as background material for testing consistency.

2.2 *ASTM Standards:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry
E181 Test Methods for Detector Calibration and Analysis of Radionuclides
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

[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] 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.

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
E393 Test Method for Measuring Reaction Rates by Analysis of Barium-140 From Fission Dosimeters
E481 Test Method for Measuring Neutron Fluence Rates by Radioactivation of Cobalt and Silver
E482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance, E706 (IID)
E496 Test Method for Measuring Neutron Fluence and Average Energy from $^{3}H(d,n)^{4}He$ Neutron Generators by Radioactivation Techniques
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
E666 Practice for Calculating Absorbed Dose From Gamma or X Radiation
E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices
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
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
E798 Practice for Conducting Irradiations at Accelerator-Based Neutron Sources
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)
E1018 Guide for Application of ASTM Evaluated Cross Section Data File, Matrix E706 (IIB)
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
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
E2005 Guide for Benchmark Testing of Reactor Dosimetry in Standard and Reference Neutron Fields
E2450 Practice for Application of $CaF_2(Mn)$ Thermoluminescence Dosimeters in Mixed Neutron-Photon Environments
F980 Guide for Measurement of Rapid Annealing of Neutron-Induced Displacement Damage in Silicon Semiconductor Devices
F1190 Guide for Neutron Irradiation of Unbiased Electronic Components

3. Functional Responsibilities

3.1 The following terms are used to identify key roles and responsibilities in the process of reactor testing of electronics. Some participants may perform more than one role, and the relationship among the participants may differ from test program to test program and from facility to facility.

3.2 *Sponsor*—Individual or organization requiring the test results and ultimately responsible for the test specifications and use of the results (for example, a system developer or procuring activity). Test sponsors should consider the objectives of the test and the issues raised in this practice. They shall clearly communicate to the user the test requirements, including specific test methods.

3.3 *User*—Generally, the individual or team who contracts for the use of the facility, specifies the characteristics needed to accomplish the test objectives, and makes sure that the documentation of the test parameters is complete. If the test sponsor does not communicate clear requirements and sufficient information to fully interpret them, the user shall communicate to the sponsor, prior to the test, the assumptions made and any limitations of applicability of test data because of these assumptions. This may require consultation with a test specialist, who may be internal or external to the user organization. Facility users also should consider the objectives of their tests and the issues raised in this practice. The user may also conduct the tests. The user shall communicate the environmental, procedural (including specific test methods, if any) and reporting requirements to the other participants including the tester, the facility operators, and the test specialist.

3.4 *Facility Organization*—The group responsible for providing the radiation environment. The facility organization shall provide pre-test communication to the user on facility capabilities, cautions, and limitations, as well as dosimetry capabilities, characteristics of the test environment, and test consistency issues unique to the facility and/or test station within the facility. If there is no independent validator, the facility shall also be required to provide the user with documentation on the controls, calibrations, and validation tests, which verify its suitability for the proposed tests. Post-test, the facility shall report dosimetry results, relevant operational parameters, and any occurrences that might affect the test results. The radiation facility and test station used in the test shall meet the criteria specified in Section 5.

3.5 *Dosimetry Group*—Individual or team providing data of record on dose, dose rate, neutron fluence, and spectra.

3.6 *Test Specialist*—Individual providing radiation test expertise. This individual may identify the appropriate damage function(s) and may fold them with neutron spectra to determine/predict damage and damage ratios. This individual may also provide information on experiment limitations, custom configurations that are advantageous, and interpretation of dosimetry results.

3.7 *Validator*—Independent person who may be responsible for verifying either the suitability of the radiation environment, the quality of the radiation test including the electrical measurements, or the radiation hardness of the electronic part production line.

4. Significance and Use

4.1 This practice was written primarily to guide test participants in establishing, identifying, maintaining, and using suitable environments for conducting high quality neutron tests. Its development was motivated, in large measure, because inadequate controls in the neutron-effects-test process have in some past instances resulted in exposures that have differed by factors of three or more from irradiation specifications. A radiation test environment generally differs from the environment in which the electronics must operate (the operational environment); therefore, a high quality test requires not only the use of a suitable radiation environment, but also control and compensation for contributions to damage that differ from those in the operational environment. In general, the responsibility for identifying suitable test environments to accomplish test objectives lies with the sponsor/user/tester and test specialist part of the team, with the assistance of an independent validator, if available. The responsibility for the establishment and maintenance of suitable environments lies with the facility operator/dosimetrist and test specialist, again with the possible assistance of an independent validator. Additional guidance on the selection of an irradiation facility is provided in Practice F1190.

4.2 This practice identifies the tasks that must be accomplished to ensure a successful high quality test. It is the overall responsibility of the sponsor or user to ensure that all of the required tasks are complete and conditions are met. Other participants provide appropriate documentation to enable the sponsor or user to make that determination.

4.3 The principal determinants of a properly conducted test are: (*1*) the radiation test environment shall be well characterized, controlled, and correlated with the specified irradiation levels; (*2*) damage produced in the electronic materials and devices is caused by the desired, specified component of the environment and can be reproduced at any other suitable facility; and (*3*) the damage corresponding to the specification level derived from radiation environments in which the electronics must operate can be predicted from the damage produced by the test environment. In order to ensure that these requirements are met, system developers, procurers, users, facility operators, and test personnel must collectively meet all of the essential requirements and effectively communicate to each other the tasks that must be accomplished and the conditions that must be met. Criteria for determining and maintaining the suitability of neutron radiation environments for 1-MeV equivalent displacement damage testing of electronics parts are presented in Section 5. Mandatory requirements for test consistency in neutron displacement damage testing of electronic parts are presented in Section 5. Additional background material on neutron testing and important considerations for gamma dose and dose rate effects are presented in (non-mandatory) Appendix X1 and Appendix X2, but compliance is not required.

4.4 Some neutron tests are performed with a specific end application for the electronics in mind. Others are performed merely to ensure that a 1-MeV-equivalent-displacement-damage-specification level is met. The issues and controls presented in this practice are necessary and sufficient to ensure consistency in the latter case. They are necessary but may not be sufficient when the objective is to determine device performance in an operational environment. In either case, a corollary consistency requirement is that test results obtained at a suitable facility can be replicated within suitable precision at any other suitable facility.

4.4.1 An objective of radiation effects testing of electronic devices is often to predict device performance in operational environments from the data that is obtained in the test environments. If the operational and test environments differ materially from each other, then damage equivalence methodologies are required in order to make the required correspondences. This process is shown schematically in Fig. 1. The part of the process (A, in Fig. 1) that establishes the operational neutron environments required to select the appropriate 1-MeV-equivalent specification level, or levels, is beyond the scope of this practice. However, if a neutron spectrum is used to set a 1 MeV equivalent fluence specification level, it is important that the process (B, in Fig. 1) be consistent with this practice. Damage equivalence methodologies must address all of the important contributors to damage in the operational and test environments or the objectives of the test may not be met. In the mixed neutron-gamma radiation fields produced by nuclear reactors, most of the permanent damage in solid-state semiconductor devices results from displacement damage produced by fast neutrons through primary knock-on atoms and their associated damage cascades. The same damage functions must be used by all test participants to ensure damage equivalence. Damage functions for silicon and gallium arsenide are provided in the current edition of Practice E722 (see

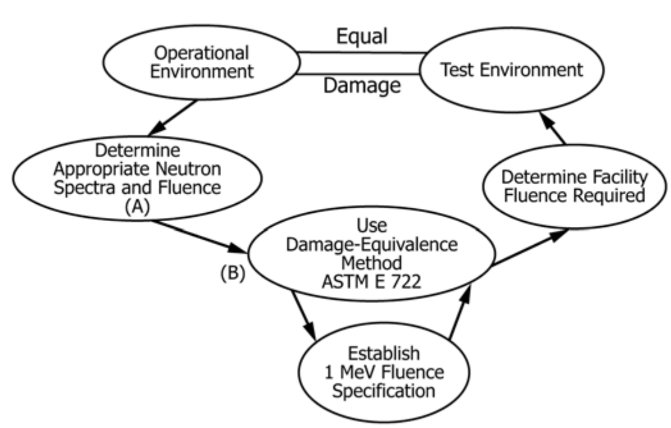

FIG. 1 Process for Damage Equivalence