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Designation: E 1854 – 96

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

This standard is issued under the fixed designation E 1854; 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 Nuclear reactors are used to provide neutron and gamma-ray radiation environments for the testing of electronic piece parts, components, and systems. In these applications, reactor environments are most commonly used to determine the degradation in performance of the electronics caused by neutron-induced displacement damage. 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. In addition to neutrons, reactors are used to provide gamma-ray pulses of intensities and durations that are not achievable elsewhere. This practice also provides background information and recommendations on gamma-ray testing of electronics using nuclear reactors.

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 and 14-MeV neutron sources when used for displacement damage testing, and apply to ^{252}Cf testing when this source is used for this application. Facility and environment characteristics that introduce complications or problems are identified, and recommendations are offered as to how problems can be recognized and minimized or solved. 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, with the exception of the electrical measurements, which are addressed in other standards. Additional information on conducting irradiations can be found in Practices E 798 and F 1190. This practice also may be of use to test sponsors (that is, organizations that establish test specifications or otherwise have a vested interest in the performance of electronics in neutron environments).

1.3 Methods for evaluation and control of undesired contributors to damage are discussed in this practice, and 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 are addressed in Appendix X1.

1.4 *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 that is often closely 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:*

E 170 Terminology Relating to Radiation Measurements and Dosimetry[2]

E 181 Test Methods for Detector Calibration and Analysis of Radionuclides[2]

E 261 Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques[2]

E 262 Test Method for Determining Thermal Neutron Reaction and Fluence Rates by Radioactivation Techniques[2]

E 263 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Iron[2]

E 264 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Nickel[2]

E 265 Test Method for Measuring Reaction Rates and Fast-Neutron Fluences by Radioactivation of Sulfur-32[2]

[1] This practice is under the jurisdiction of ASTM Committee E-10 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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[2] *Annual Book of ASTM Standards*, Vol 12.02.

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E 393 Test Method for Measuring Reaction Rates by Analysis of Barium-140 from Fission Dosimeters[2]
E 481 Test Method for Measuring Neutron Fluence Rate by Radioactivation of Cobalt and Silver[2]
E 482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance, E 706 (IID)[2]
E 523 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Copper[2]
E 526 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Titanium[2]
E 665 Practice for Determining Absorbed Dose Versus Depth in Materials Exposed to the X-ray Output of Flash X-ray Machines[2]
E 666 Practice for Calculating Absorbed Dose From Gamma or X Radiation[2]
E 668 Practice for the Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[2]
E 704 Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238[2]
E 705 Test Method for Measuring Reaction Rates by Radioactivation of Neptunium-237[2]
E 720 Guide for Selection and Use of Neutron-Activation Foils for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics[2]
E 721 Guide for Determining Neutron Energy Spectra from Neutron Sensors for Radiation-Hardness Testing of Electronics[2]
E 722 Practice for Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics[2]
E 798 Practice for Conducting Irradiations at Accelerator-Based Neutron Sources[2]
E 844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706 (IIC)[2]
E 944 Practice for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, (IIA)[2]
E 1018 Guide for Application of ASTM Evaluated Cross Section Data File, E 706 (IIB)[2]
E 1249 Practice for Minimizing Dosimetry Errors in Radiation Hardness Testing of Silicon Electronic Devices Using Co-60 Sources[2]
E 1250 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[2]
E 1297 Test Method for Measuring Fast Neutron Reaction Rates by Radioactivation of Niobium[2]
F 1190 Practice for Neutron Irradiation of Unbiased Electronic Components[3]

3. The Roles of the Participants

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 that 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 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 minimum quality assurance criteria specified in Section 5.

3.5 *Dosimetry Group*—Individual or team providing definitive data 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 that 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.

3.8 At the beginning of many of the paragraphs that discuss tasks to be carried out, a label is added in parentheses to designate the participant who usually has the primary responsibility for this task.

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

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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; 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 F 1190.

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 in 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 use of a reactor facility for gamma dose and dose rate testing are presented in Appendixes Appendix X2 and Appendix X3, but compliance is not required.

4.4 Some neutron tests are performed with an end application of 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 not necessarily 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. If a facility user is not aware of the detailed characteristics of the operational radiation environment, it is prudent to select a test facility and test location in which contributors to damage by other than fast neutrons (E_n > 100 keV) are minimized.

4.4.1 An objective of radiation effects testing of electronic devices is often to predict device performance in operational environments from data obtained in test environments. If these environments differ materially from each other, then damage equivalence methodologies are required in order to make the required correspondences. The process is shown schematically in Fig. 1. The part of the process (A, in Fig. 1) that establishes the 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 specification level (B, in Fig. 1), it is important that this process 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 reactor test are not ensured. 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 E 722 (see Note 1). At present, no damage equivalence methodologies for neutron displacement damage have been developed and validated for semiconductors other than silicon and gallium arsenide.

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NOTE 1—Pre-1993 editions of Practice E 722 reference outdated versions of the silicon damage function and do not include GaAs damage functions.

4.4.2 If a 1-MeV equivalent neutron fluence specification, or a neutron spectrum, is provided, the damage equivalence methodology, shown schematically in Fig. 1, is used to ensure that the correct neutron fluence is provided and that the damage in devices placed in the exposure position correlates with the

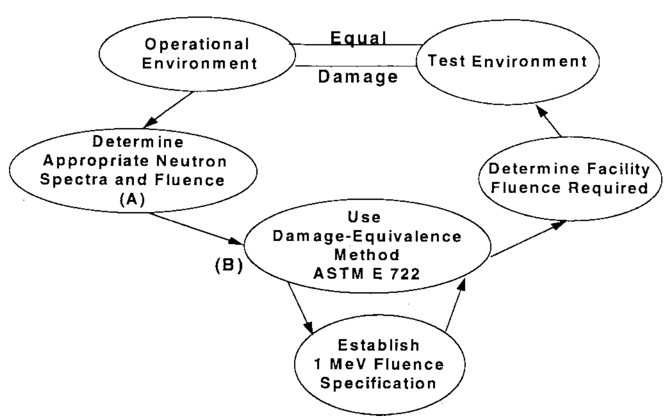

FIG. 1 Process for Damage Equivalence

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displacement energy from the neutrons at that location.

5. Requirements for Neutron Displacement Damage Testing

5.1 This section identifies the requirements that must be met to ensure consistency in neutron displacement damage testing of electronics. The following is not intended to dictate who will be responsible for individual tasks, as this may vary from program to program and is subject to negotiation. The user, supported by the other participants, shall ensure that all of the required tasks are accomplished.

5.2 *Test Specification* (Sponsor/User)—The sponsor or procuring group specifies the radiation test levels. Frequently, 1-MeV equivalent (Si) fluence levels are specified. The damage equivalence methodology and parameters used to determine the 1-MeV fluence shall be in accordance with Practice E 722.

5.2.1 (Optional) If desired by the sponsor/user/tester, together they determine if the test specifications are adequate to obtain the sponsor's test objectives. The first steps are to examine the characteristics of the operational environment where the devices are to perform, to choose the devices to be tested, and to determine the important damage parameters to be evaluated. Next, a radiation environment must be chosen that can meet the sponsor's test objectives and be effectively used to evaluate the responses of the required device parameters to the radiation environment. This step may require the support of a test specialist and facility operators.

5.3 *Sources*—The test station may be in or near a fast-burst reactor or a pool-type reactor (such as a TRIGA). A 14-MeV or ^{252}Cf neutron source also may be used. Operation may be in either pulse or steady state mode, as appropriate. The source shall be one that is acceptable to the sponsor. Preferred sources and test locations are those in which device damage contributions from anything other than fast neutrons are negligible (see Appendix X2).

5.4 *Environment Characterization* (Facility Operator and Test Specialist)—It is assumed in this section that the primary damage mechanism being investigated is the neutron displacement damage. If secondary effects (such as those caused be ionizing radiation) contribute to the response of the device, these processes must be taken into account in interpreting the test results. These issues are discussed in 5.11.1 and 5.11.2. The neutron environment is characterized by a neutron spectrum measurement.

5.4.1 (Dosimetry Group) At a minimum, the facility shall provide the experimenter with a neutron spectrum representing the free-field environment at the "Device Under Test" (DUT) location. This spectrum determination shall be derived with a methodology that gives appropriate weight to experimental measurements. These methodologies may include use of activation sensors within an iterative or least-squares spectrum adjustment code. (See Guides E 720 and E 721.) A free-field spectrum based solely upon neutron transport calculations is not acceptable. If the fixtures used by the experimenter significantly perturb the free-field environment, the appropriate spectrum in the proper relationship to those fixtures shall be determined.

NOTE 2—The determination of the spectrum at a location within or near an experimental fixture that perturbs the free-field spectrum is often best accomplished by calculations. Calculations alone may be sufficient in these cases as long as the calculational methodology and modeling have been validated by comparison with measurements for the free-field (unperturbed) case. Experimental validation of any calculations is always desirable, but is not always practical. The use of dosimetry sensors is discussed in Test Methods E 181, E 262, E 393, E 481, E 523, E 526, E 704, E 705, and E 1297, Practice E 261, and Guide E 844.

5.4.2 (Dosimetry Group) For the determination of the spectrum, the sensor set must be sensitive over the energy range within which the device under test is sensitive. In particular, the sensor set shall include a sensor with significant response in the 10-keV to 1-MeV energy region. Sensors with energy responses in this region include the fission foils, ^{235}U, ^{239}Pu, and ^{237}Np. In addition, niobium through the reaction ^{93}Nb(n,n′)^{93m}Nb can be useful, although its very long half-life of about 16 years usually results in a very low activity. In the absence of fission foils, silicon devices can be used effectively as spectrum sensors. It is suggested that both fission foils and silicon devices be used for mutual confirmation **(1,2)**.[4]

5.4.3 (Dosimetry Group) To provide information needed to account for possible gamma-ray effects on the DUT, the facility shall provide a measure of the gamma-ray dose to the silicon or gallium arsenide device. The selected gamma-ray sensor shall have been demonstrated to have a low neutron sensitivity. The gamma-ray detector response shall be traceable to NIST standards. One common gamma dose sensor with low neutron sensitivity is a CaF_2:Mn thermoluminescent detector (TLD). LiF TLDs (even LiF TLDs with a low enriched ^{7}Li component) are more sensitive to thermal neutrons than CaF_2 and should only be used with care in fast burst reactors and should be avoided in reactors with a significant thermal neutron flux. Both radiochromic films and alanine show a high neutron sensitivity due to proton recoil in the hydrogeneous dosimeter material, and are thus not recommended as gamma sensors for mixed neutron/gamma reactor environments.

5.5 *Damage Equivalence* (Facility operator, Validator)—The facility shall provide, at 15-month intervals or less, experimental confirmation that the equivalent fluence is equal to that predicted by the spectrum. This may be done by demonstrating that the damage measured in a standardized and calibrated silicon (or GaAs) device is equal to that calculated from the spectrum that is attributed to the test environment. The standardized device is denoted as the PHI1 monitor to distinguish it from the DUT. Two devices appropriate to this application, because of extensive investigations of their responses, are 2N2222A transistors **(1)** and DN-156 diodes **(3)**. The neutron-induced displacement damage degrades the gain of the transistors in amounts proportional to the 1-MeV equivalent fluence, Φ_1. In the diodes, the forward voltage increases with fluence in a reproducible, but nonlinear, way (The shape of the calibration curve is the same for all of the diodes.) (see 5.9 and Practice E 722). Thus, 2N2222A transistors and DN-156 diodes are appropriate PHI1 monitors if they

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

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are calibrated in the environments whose spectra (and consequently Φ_1) are well established. The environment is considered to be satisfactorily characterized for electronic parts testing if the Φ_1, measured with the pHI1 monitors, is within 10 % of that predicted using the spectrum and fluence reported by the test facility for that location (see Note 3).

5.6 *Reference Sources*—Special importance is being given here to the role of reference sources used in the process of ensuring reproducibility of the displacement damage measured in all facilities used for the neutron parts testing task. This practice defines the three Fast Burst Reactors (FBR) in the United States as being the appropriate reference sources for the calibration of PHI1 monitors. The three reactors are the SPR-III central cavity at Sandia National Laboratories **(4)**, the 29-cm leakage APRF environment at Aberdeen Proving ground **(5)**, and the 24-in. leakage environment at the White Sands Missile Range FBR **(6)**. The reasons for this designation as reference sources for the testing of electronic parts are the following. First, they inherently produce high neutron-to-gamma ray ratio environments without the need for special shielding (that modifies the spectrum). Second, the three laboratories regularly intercompare neutron metrology and gamma dosimetry results to verify that the measurements made by the separate laboratories in each of their reference environments agree with each other. Third, calculations of the spectra and device damage at the reference locations at all three FBRs agree closely with the measured spectra and with the measured ratios of silicon damage between the three reference facilities. Mutual agreements have been made between the laboratories to exchange limited dosimetry sets (including foil ratios that sample the spectrum shape and the PHI1 monitors) to verify that the spectra shapes and magnitudes have not changed. Annex A1 provides details on the reference source locations and provides references for an energy-dependent characterization of the neutron spectrum. This designation as reference sources requires the facilities to make such sensor exchanges at intervals no greater than two years.

NOTE 3—It must be pointed out that the damage measurements discussed here are all ratio measurements in reference and test environments taken with the same PHI1 monitor. Therefore the damage constant that relates the change in reciprocal gain for 2N2222 transistors (or forward voltage for DN-156 diodes) to displacement damage cancels out.

5.7 *Delivery of the Characterization Information*—The user is responsible for ensuring that he receives the information about the test environment needed to evaluate the response of his DUT. The facility shall be prepared to supply a validated neutron spectrum and associated gamma-ray dose for each test environment. The user or facility operator may contract out this task to others, if desired. The identification and characterization of secondary effects and conditions that affect the DUT are also necessary. The facility should be prepared to provide uncertainty information about spectrum, fluence, and dose so that the user can evaluate the effect of these uncertainties on the response of the DUT. This information generally reduces to an evaluation of uncertainties in the integral parameters such as Φ_1, the neutron fluence-to-gamma-ray dose ratio, the fluence greater than 3 MeV, the silicon hardness parameter (defined in Practice E 722), the ratio of the fluence greater than 10 keV to the fluence greater than 3 MeV, and the ratio of the total fluence to the fluence greater than 3 MeV.

5.8 *Controls and Auditability* (Facility Operator)—The facility (including the reference source FBRs) must provide written assurance that an adequate environment characterization has been performed, that it meets the environment characterization requirements in 5.4 and 5.5, and that the environment has not changed (except for the possible alteration by the test object itself) between the time of the most recent characterization (which was used in the supporting documentation) and the test time. To guard against unaccounted for changes:

5.8.1 The facility shall have adequate in-house procedures for monitoring changes in the reactor configuration between the time at which the experiment takes place and the time the environment characterization took place.

5.8.2 The facility shall confirm in writing that the current environment delivered to the user/tester does not deviate significantly from the environment at which the damage verification and spectral determination were performed.

5.8.3 The facility shall employ a process to inform facility staff responsible for interfacing with users/testers, internal test specialists, and dosimetry specialists of changes that may impact test consistency.

5.8.4 Appropriate neutron and gamma ray monitors shall be included with the DUT on each exposure.

5.9 *Dosimetry Equipment* (Dosimetry Group)—The dosimetry group shall have at a minimum:

5.9.1 Appropriate activation foil counting and gamma dose readout equipment with calibrations traceable to NIST.

5.9.2 Fast neutron threshold activation reactions such as $^{32}S(n,p)$, $^{54}Fe(n,p)$, or $^{58}Ni(n,p)$ shall be used to monitor the neutron fluence. These reactions are recommended because of their relatively high cross sections and long half-lives.

5.9.3 Suitable gamma dose sensors shall be used to monitor the gamma-ray dose. If thermoluminescence dosimeters are selected as the gamma sensor, Practice E 668 provides useful information on the calibration and use of TLDs in gamma environments. In mixed neutron and gamma ray fields, the gamma sensor should have a demonstrated low neutron sensitivity. CaF_2:Mn TLDs are an appropriate sensor for most applications.

5.9.4 Calibrated silicon devices may be used as spectrum sensors and 1-MeV equivalent fluence monitors. If silicon devices are used as monitors, then an appropriate device parameter reader must be available along with an oven for annealing treatments.

NOTE 4—Although the dosimetry group is usually associated with the facility in order to ensure continuity of environment characterization, it is often advantageous for the user to add his own dosimetry so that he can more readily monitor consistency with the local dosimetry and the results obtained at other test facilities.

5.10 *Damage Correlations* (Facility Operator)—For neutron displacement damage equivalence, either the 1-MeV(Si) equivalent fluence or the 1-MeV(GaAs) equivalent fluence must be provided. Alternatively, a neutron spectrum may be provided and the corresponding 1-MeV equivalent fluence specification can be determined using Practice E 722. The damage equivalence methodology in this practice has been

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validated for both silicon and gallium arsenide by demonstrating that equal damage is achieved for the same 1-MeV equivalent fluence even in neutron environments having very different energy distributions **(7,8)**. The spectrum at the test facility exposure location must also be parameterized into a 1-MeV equivalent fluence, Φ_1, using the same practice. By providing the specified Φ_1 in the test environment, the desired damage is produced and test consistency is achieved if all other contributions to the damage are accounted for or are negligible. The damage equivalence methodology is fully described in Practice E 722, and a brief outline is provided in Appendix X1. It is essential that the proper damage function for the device be used, and accurate spectra for the environments be determined. Usually the responsibility for providing and measuring the spectrum falls to the facility operator, the test specialist, or the dosimetry group.

5.11 *Test Device Response Function* (User/Test Specialist)—Decisions must be made to determine the appropriate response mechanisms in the DUT. After the damage mechanisms have been determined, the correct response functions can be used to calculate the delivered damage level. If the primary device damage mode is neutron displacement damage in the silicon or gallium arsenide, then the latest functions from Practice E 722 should be used. Validated damage functions for other semiconductor materials are likely to become available later. If the DUT responds to other components of the environment, these responses must also be characterized for the delivered environment. Secondary effects are discussed in subsection 5.12.

5.11.1 It is recommended that the tester use a test environment that approximates the operational environment to avoid surprises, especially if a new semiconductor technology is being tested. Alternatively, a free-field or neutron-enhanced fast burst reactor environment may be used to minimize unwanted contributors to damage in a neutron displacement damage test. A neutron-enhanced environment is produced by shielding the DUT from gamma-rays with a high-Z shield. If environment-modifying materials are used, then separate gamma-ray tests may be called for so that the contributing damage factors can be determined. If filters such as lead or bismuth surround the test object, the neutron spectrum will be modified and must be determined for that configuration.

5.11.2 It is the user/tester's responsibility to make certain that the proper response functions are used for the DUT, but it is the responsibility of the facility or test specialist to make certain that the correct 1-MeV fluence is ascribed to the free-field environment.

5.12 *Device Testing*—This subsection deals primarily with the testing of the DUTs and with the considerations that must be made beyond the basic characterization and maintenance of the test environment.

5.12.1 *Secondary Gamma-Ray Effects* (Sponsor/User)—It is the primary responsibility of the user (with assistance of a test specialist, if desired) to account for the secondary effects that influence his device performance. The most important potential contributor to secondary-damage effects is the prompt gamma-ray flux associated with the fission neutron-generation process. The inclusion of gamma sensors in the dosimeter packages allows the potential gamma-ray effects to be evaluated, provided the response of the DUT to gamma rays is determined separately. The response of the DUT to gamma dose shall be determined separately using a pure gamma calibrated source such as ^{60}Co or ^{137}Cs. Frequently encountered gamma-ray effects are discussed further in Appendix X2. The contribution of gamma rays is usually not significant for fast burst reactor tests, unless something that enhances the gamma field is nearby. Guidance for the use of TLDs in gamma fields is found in Practice E 668. Details on gamma sources can be found in Practices E 665 and E 666.

5.12.2 *Other Secondary Effects*—Other potential contributors to measured DUT performance include displacement damage annealing (which can actually aid in device performance recovery), the temperature at which the device performance is tested, and displacements caused by thermal neutron capture in trace contaminants and dopants in the electronic parts. For example, boron is frequently used as a dopant in silicon parts and high energy recoil particles can result from thermal neutron interactions. Gamma dose enhancement effects can be induced in devices at interfaces between materials with dissimilar atomic number. Dose enhancement effects are discussed in Practice E 1249 and Test Method E 1250.

5.12.3 *Measurements for the DUT Environment* (Dosimetry Group)—The neutron fluence used for device irradiation shall be obtained by measuring the amount of radioactivity induced by a fast-neutron threshold activation reaction such as ^{32}S(n,p), ^{54}Fe(n,p), or ^{58}Ni(n,p) in a monitor foil which is irradiated at the same time and colocated with the device. A standard method for converting the measured radioactivity to fluence in the specific monitor foil employed in a neutron environment is given in Test Methods E 263, E 264, and E 265.

5.12.3.1 As discussed in 5.4, the conversion of the foil radioactivity into a neutron fluence requires a knowledge of the neutron spectrum incident on the foil. If the spectrum is not known, it shall be determined by use of Guide E 720 or E 721 or Practice E 722 or their equivalent.

5.12.4 The determination of (*1*) the spectrum shape from the environment characterization, and (*2*) the magnitude of the 1-MeV fluence (derived form the spectrum) with the fluence monitor, completes the characterization of the neutron environment for the test. The user is cautioned that if the neutron spectrum is perturbed, the fluence monitor may no longer provide an accurate measure of the 1-MeV fluence. Additional guidance on the determination of a neutron spectrum by the foil activation method can be found in Guides E 482 and E 1018, and Practice E 944.

NOTE 5—There are cases in which a spectrum cannot be obtained and yet a good estimate of the 1-MeV equivalent fluence is needed. In that case the fluence transfer method, discussed in Appendix X1, may be the only option available. In that case the derived equivalent fluence is not independently verified. This subject is discussed further in Appendix X2.

5.13 *Test Documentation*—The user, with the assistance of the other participants, is responsible for making certain that all the tasks listed above (in 5.1-5.11) are accomplished and documented. The additional user tasks that must be carried out and documented are DUT performance measurements. If necessary, the sponsor may require the prediction of the device