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Standard Guide for Benchmark Testing of Reactor Dosimetry in Standard and Reference Neutron Fields¹

This standard is issued under the fixed designation E2005; 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 guide covers facilities and procedures for benchmarking neutron measurements and calculations. Particular sections of the guide discuss: the use of well-characterized benchmark neutron fields to calibrate integral neutron sensors; the use of certified-neutron-fluence standards to calibrate radiometric counting equipment or to determine interlaboratory measurement consistency; development of special benchmark fields to test neutron transport calculations; use of well-known fission spectra to benchmark spectrum-averaged cross sections; and the use of benchmarked data and calculations to determine the uncertainties in derived neutron dosimetry results.

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

1.3 *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.*

1.4 *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

- E170 Terminology Relating to Radiation Measurements and Dosimetry
- E261 Practice for Determining Neutron Fluence, Fluence

- Rate, and Spectra 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
- E343 Test Method for Measuring Reaction Rates by Analysis of Molybdenum-99 Radioactivity From Fission Dosimeters (Withdrawn 2002)³
- E393 Test Method for Measuring Reaction Rates by Analysis of Barium-140 From Fission Dosimeters
- E482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance
- 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
- E854 Test Method for Application and Analysis of Solid State Track Recorder (SSTR) Monitors for Reactor Surveillance
- E910 Test Method for Application and Analysis of Helium Accumulation Fluence Monitors for Reactor Vessel Surveillance
- E1297 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Niobium
- E2006 Guide for Benchmark Testing of Light Water Reactor Calculations

¹ This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.05 on Nuclear Radiation Metrology.

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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.

3. Significance and Use

3.1 This guide describes approaches for using neutron fields with well known characteristics to perform calibrations of neutron sensors, to intercompare different methods of

³ The last approved version of this historical standard is referenced on www.astm.org.

dosimetry, and to corroborate procedures used to derive neutron field information from measurements of neutron sensor response.

3.2 This guide discusses only selected standard and reference neutron fields which are appropriate for benchmark testing of light-water reactor dosimetry. The Standard Fields considered here include neutron source environments that closely approximate: *a*) the unscattered neutron spectra from ^{252}Cf spontaneous fission; and *b*) the ^{235}U thermal neutron induced fission. These standard fields were chosen for their spectral similarity to the high energy region ($E > 2$ MeV) of reactor spectra. The various categories of benchmark fields are defined in Terminology E170.

3.3 There are other well known neutron fields that have been designed to mockup special environments, such as pressure vessel mockups in which it is possible to make dosimetry measurements inside of the steel volume of the “vessel.” When such mockups are suitably characterized, they are also referred to as benchmark fields. A variety of these engineering benchmark fields have been developed, or pressed into service, to improve the accuracy of neutron dosimetry measurement techniques. These special benchmark experiments are discussed in Guide E2006, and in Refs (1)⁴ and (2).

4. Neutron Field Benchmarking

4.1 To accomplish neutron field “benchmarking,” one must perform irradiations in a well-characterized neutron environment, with the required level of accuracy established by a sufficient quantity and quality of results supported by a rigorous uncertainty analysis. What constitutes sufficient results and their required accuracy level frequently depends upon the situation. For example:

4.1.1 Benchmarking to test the capabilities of a new dosimeter;

4.1.2 Benchmarking to ensure long-term stability, or continuity, of procedures that are influenced by changes of personnel and equipment;

4.1.3 Benchmarking measurements that will serve as the basis of intercomparison of results from different laboratories;

4.1.4 Benchmarking to determine the accuracy of newly established benchmark fields; and

4.1.5 Benchmarking to validate certain ASTM standard methods or practices which derive exposure parameters (for example, fluence > 1 MeV or dpa) from dosimetry measurements and calculations.

5. Description of Standard and Reference Fields

5.1 There are a few facilities which can provide certified “free field” fluence irradiations. The following provides a list of such facilities. The emphasis is on facilities that have a long-lived commitment to development, maintenance, research, and international interlaboratory comparison calibrations. As such, discussion is limited to recently existing facilities.

⁴ The boldface numbers given in parentheses refer to a list of references at the end of the text.

5.2 ^{252}Cf Fission Spectrum—Standard Neutron Field:

5.2.1 The standard fission-spectrum fluence from a suitably encapsulated ^{252}Cf source is characterized by its source strength, the distance from the source, and the irradiation time. In the U.S., neutron source emission rate calibrations are all referenced to source calibrations at the National Institute of Standards and Technology (NIST) accomplished by the MnSO_4 technique (3). Corrections for neutron absorption, scattering, and other than point-geometry conditions may, by careful experimental design, be held to less than 3 %. Associated uncertainties for the NIST ^{252}Cf irradiation facility are discussed in Ref (4). The principal uncertainties, which only total about 2.5 %, come from the source strength determination, scattering corrections, and distance measurements. Extensive details of standard field characteristics and values of measured and calculated spectrum-averaged cross sections are all given in a compendium, see Ref (5).

5.2.2 The NIST ^{252}Cf sources have a very nearly unperturbed spontaneous fission spectrum, because of the light-weight encapsulations, fabricated at the Oak Ridge National Laboratory (ORNL), see Ref (6).

5.2.3 For a comprehensive view of the calibration and use of a special (32 mg) ^{252}Cf source employed to measure the spectrum-averaged cross section of the $^{93}\text{Nb}(n,n')$ reaction, see Ref (7).

5.3 ^{235}U Fission Spectrum—Standard Neutron Field:

5.3.1 Because ^{235}U fission is the principal source of neutrons in present nuclear reactors, the ^{235}U fission spectrum is a fundamental neutron field for benchmark referencing or dosimetry accomplished in reactor environments. This remains true even for low-enrichment cores which have up to 30 % burnup.

5.3.2 There are currently two ^{235}U standard fission spectrum facilities, one in the thermal column of the NIST Research Reactor (8) and one at CEN/SCK, Mol, Belgium (9).

5.3.3 A standard ^{235}U neutron field is obtained by driving (fissioning) ^{235}U in a field of thermal neutrons. Therefore, the fluence rate depends upon the power level of the driving reactor, which is frequently not well known or particularly stable. Time dependent fluence rate, or total fluence, monitoring is necessary in the ^{235}U field. Certified fluence irradiations are monitored with the $^{58}\text{Ni}(n,p)^{58}\text{Co}$ activation reaction. The fluence-monitor calibration must be benchmarked.

5.3.4 For ^{235}U , as for ^{252}Cf irradiations, small (nominally < 3 %) scattering and absorption corrections are necessary. In addition, for ^{235}U , gradient corrections of the measured fluence which do not simply depend upon distance are necessary. The scattering and gradient corrections are determined by Monte Carlo calculations. Field characteristics of the NIST ^{235}U Fission Spectrum Facility and associated measured and calculated cross sections are given in Ref (5).

5.4 There are several additional facilities that can provide free field fluence irradiations that qualify as reference fields (10, 11). The following is a list of some of the facilities that have characterized reference fields:

5.4.1 Annular Core Research Reactor (ACRR) Central Cavity – Reference Neutron Field (12, 13)