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Standard Guide for Benchmark Testing of Reactor Dosimetry in Standard and Reference Neutron Fields[1]

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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.

2. Referenced Documents

2.1 *ASTM Standards:*

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

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

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

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

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

E 266 Test Methods for Measuring Fast-Neutron Reaction Rates by Radioactivation of Aluminum[2]

E 343 Test Methods for Measuring Reaction Rates by Analysis of Molybdenum 99 Activity from Fission Dosimeters[2]

E 393 Test Methods for Measuring Reaction Rates by Analysis of Barium-140 from Fission Dosimeters[2]

E 482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance, E 706 (IID)[2]

E 523 Test Methods for Measuring Fast-Neutron Reaction Rates by Radioactivation of Copper[2]

E 526 Test Methods for Measuring Fast-Neutron Reaction Rates by Radioactivation of Titanium[2]

E 704 Test Methods for Measuring Fast-Neutron Reaction Rates by Radioactivation of Uranium-238[2]

E 705 Test Methods for Measuring Fast-Neutron Reaction Rates by Radioactivation of Neptunium-237[2]

E 706 Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards[2]

E 706 (IIE2) Guide for Benchmark Testing of Light Water Reactor Calculations[2]

E 844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E 706 (IIC)[2]

E 854 Test Method for Application and Analysis of Solid State Track Recorder (SSTR) Monitors for Reactor Surveillance, E 706 (IIIB)[2]

E 910 Test Method for Application and Analysis of Helium Accumulation Fluence Monitors for Reactor Vessel Surveillance, E 706 (IIIC)[2]

E 1297 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Niobium[2]

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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 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 are neutron source environments that closely approximate the unscattered neutron spectra from ^{252}Cf spontaneous fission and ^{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 reference field considered in detail is the Materials Dosimetry Reference Facility, which has a spectral shape similar to the neutrons impinging on a pressurized water reactor vessel. The various categories of benchmark fields are defined in Terminology E 170.

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

[1] This practice is under the jurisdiction of ASTM Committee E-10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.05 on Nuclear Radiation Metrology.

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

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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 E 706 (IIE2), and in Refs. **(1)**[3] 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 presently existing facilities.

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}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 available, 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}Ni(n,p) ^{58}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 *Materials Dosimetry Reference Facility (MDRF)—Reference Neutron Field*:

5.4.1 A new, high-intensity reference-neutron field for reactor dosimetry has been placed into operation, by NIST, in the pool adjacent to the Ford Nuclear Reactor (FNR) at the University of Michigan. Neutron spectrum characterization has been accomplished by measurement of spectral indexes (see Section 7.) and DORT neutron transport calculations. The fast neutron fluence rate has been determined by means of the fluence transfer procedure (see 6.2) from a NIST ^{252}Cf standard neutron field and by other means (Ref.**(10)**). MDRF certified neutron fluences are monitored with the ^{58}Ni(n,p) ^{58}Co activation reaction. The fast neutron spectrum is similar to that at the inside surface of the pressure vessel in a PWR reactor with a thermal shield. Spectral monitoring measurements during changes in nearest neighbors in the pool and fuel element changes at the nearest edge of the core indicated fluence rate level variations but very small (< 5 %) changes in the spectrum (for example, no significant changes in various reaction rate ratios).

5.4.2 The MDRF is employed for calibration and validation experiments in support of materials neutron dosimetry for the

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