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Standard Test Method for Measuring Reaction Rates by Analysis of Barium-140 From Fission Dosimeters[1]

This standard is issued under the fixed designation E 393; 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 test method describes two procedures for the measurement of reaction rates by determining the amount of the fission product ^{140}Ba produced by the non-threshold reactions ^{235}U(n,f), ^{241}Am(n,f), and ^{239}Pu(n,f), and by the threshold reactions $_{238}$U(n,f), ^{237}Np(n,f), and ^{232}Th(n,f).

1.2 These reactions produce many fission products, among which is ^{140}Ba, having a half-life of 12.752 days. ^{140}Ba emits gamma rays of several energies; however, these are not easily detected in the presence of other fission products. Competing activity from other fission products requires that a chemical separation be employed or that the ^{140}Ba activity be determined indirectly by counting its daughter product ^{140}La. This test method describes both procedure (*a*), the nondestructive determination of ^{140} Ba by the direct counting of ^{140}La several days after irradiation, and procedure (*b*), the chemical separation of ^{140}Ba and the subsequent counting of ^{140}Ba or its daughter ^{140}La.

1.3 With suitable techniques, fission neutron fluence rates can be measured in the range from 10^7 n (neutrons) · cm^{-2}· s^{-1} to approximately 10 ^{15} n · cm^{-2} · s^{-1}.

1.4 The measurement of time-integrated reaction rates with fission dosimeters by ^{140}Ba analysis is limited by the half-life of $_{140}$Ba to irradiation times up to about six weeks.

~~1.5The values stated in SI units are to be regarded as standard.~~

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

1.6 *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:* [2]

C 697 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Plutonium Dioxide Powders and Pellets

D 1193 Specification for Reagent Water

E 170 Terminology Relating to Radiation Measurements and Dosimetry

E 181 Test Methods for Detector Calibration and Analysis of Radionuclides

E 261 Practice for Determining Neutron Fluence, Fluence Rate, ~~Fluence,~~ and Spectra by Radioactivation Techniques

E 704 Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238

E 705 Test Method for Measuring Reaction Rates ~~By~~by Radioactivation of Neptunium-237

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

E 944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance, E 706 (IIA)

E 1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance, E 706(IIIA)

E 1018 Guide for Application of ASTM Evaluated Cross Section Data File, Matrix E 706 (IIB)

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology E 170.

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[1] This test method 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* ~~, Vol 12.01.~~volume information, refer to the standard's Document Summary page on the ASTM website.

4. Summary of Test Method

4.1 For nondestructive analysis, the fission dosimeter is allowed to cool for five days or more. The 1.596-MeV gamma energy peak of ^{140}La, which is the daughter product of the ^{140}Ba, is then counted. This information, combined with the decay constants for the La and the Ba, and the fission yield of the ^{140}Ba gives the reaction fission rate. When the proper cross section is used with the reaction rate, the equivalent fission fluence rate can be determined.

4.2 For destructive analysis, the fission product ^{140}Ba is separated from the irradiated fission dosimeter. The activity of the ^{140}Ba is determined by counting the 0.537 MeV gamma energy peak. This information is then used as in 4.1 ~~to give the reaction rate or the equivalent fission fluence rate.~~ to give the reaction rate.

5. Significance and Use

5.1 Refer to Guide E 844 for the selection, irradiation, and quality control of neutron dosimeters.

5.2 Refer to Practice E 261 for a general discussion of the measurement of neutron fluence rate and fluence. The neutron spectrum must be known in order to measure neutron fluence rates with a single detector. Also it is noted that cross sections are continuously being reevaluated. The latest recommended cross sections and details on how they can be obtained are discussed in Guide E 1018.

5.3 The reaction rate of a detector nuclide of known cross section, when combined with information about the neutron spectrum, permits the determination of the magnitude of the fluence rate impinging on the detector. Furthermore, if results from other detectors are available, the neutron spectrum can be defined more accurately. The techniques for fluence rate and fluence determinations are explained in Practice E 261.

5.4 ^{140}Ba is a radioactive nuclide formed as a result of uranium fission. Although it is formed in fission of any heavy atom, the relative yield will differ. Recommended fission yields for ^{140}Ba production are given in Table 1. The direct (independent) fission yield of the daughter product ^{140}La, which is counted, is given in Table 2. These independent fission yields are relatively low compared to the ^{140}Ba cumulative fission yield and will not significantly affect the accuracy of the nondestructive procedure and need not be considered.

5.5 The half-life of ^{140}Ba is 12.752 days. Its daughter ^{140}La has a half-life of 1.6781 days.[3] The comparatively long half-life of^{140}Ba allows the counting to be delayed several weeks after irradiation in a high-neutron field. However, to achieve maximum sensitivity the daughter product ^{140}La should be counted five to six days after the irradiation during nondestructive analysis or five to six days after chemical separation if the latter technique is used. An alternative method after chemical separation is to count the ^{140}Ba directly.

5.6 Because of its 12.752 day half-life and substantial fission yield, ^{140}Ba is useful for irradiation times up to about six weeks in moderate intensity fields. ~~One irradiation criterion is that the~~ The number of fissions produced should be approximately 10^9 or greater for good counting statistics. Also, if the irradiation time is substantially longer than six weeks, the neutron fluence rate determined will apply mainly to the neutron field existing during the latter part of the irradiation. The ^{140}Ba decay constant and yield are known more accurately than those of many fission products, so it is sometimes used as a standard or base reaction with which other measurements can be normalized.

6. Apparatus

6.1 For nondestructive analysis the chemical separation equipment, materials, and reagents are not required.

6.2 *A NaI(Tl) or Germanium Gamma-Ray Spectrometer*, see Test Methods E 181 and E 1005.

6.3 *Balance*, providing the accuracy and precision required by the experiment.

6.4 *Centrifuge*, clinical type, accommodating 50-mL centrifuge tubes.

6.5 *Steam Bath.*

6.6 *Ice Bath.*

6.7 *Drying Oven.*

6.8 *Filter Cones.*

6.9 *Fiberglass Filter Circles* for filter cone.

6.10 *Centrifuge Tubes*, 50-mL capacity.

6.11 *Fine Sintered-Glass Crucibles* .

7. Reagents and Materials

7.1 *Purity of Fission Dosimeters* —High purity uranium plutonium, neptunium, and thorium in the form of alloy wire, foil, or oxide powder are available.

7.1.1 *Target material* shall be furnished with a certificate of analysis indicating any impurity concentrations.

7.1.2 *Fission dosimeters* shall be encapsulated in hermetically sealed containers to avoid loss of materials and for health-hazard requirements.[4]

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[3] ~~*Annual Book of ASTM Standards*, Vol 11.01.~~ Nuclear Wallet Cards, compiled by J. K. Tuli, National Nuclear Data Center, April 2005.

[4] ~~Annual Book of ASTM Standards, Vol 12.02.~~

TABLE 1 Recommended Cumulative Fission Yields for ^{140}Ba Production

Fission Dosimeter	Thermal or Fast Neutron Field	Fission Yield,%[A,B]
^{235}U	T	5.84596 ± 1 %
	F	5.98741 ± 1 %
^{235}U	T	6.21448 ± 1 %
	F	5.977730 ± 1 %
^{238}U	F	5.84596± 1 %
^{238}U	F	5.81523± 1 %
^{239}Pu	T	5.31538± 1 %
	F	5.37475 ±2 %
^{239}Pu	T	5.35451± 1.4 %
	F	5.32323 ± 1.4 %
^{237}Np	F	5.47246 ± 1.4 %
^{237}Np	F	5.48848 ± 2 %
^{232}Th	F	7.87647 ± 2.8 %
^{232}Th	F	7.87767 ± 2.8 %
^{241}Am	T	5.95468 ± 2.8 %
	F	4.99172 ± 6 %
^{241}Am	T	5.92114 ± 2.8 %
	F	4.92101 ± 4 %

[A] These ENDF/B-VI values are considered the best available data. The uncertainties are expressed as a percentage of the fission yield.

[B] England, T. R., and Rider, B. F., *ENDF-349 Evaluation and Compilation of Fission Product Yields*, Los Alamos National Laboratory, Los Alamos, NM, report LA-UR-94-3106, ENDF-349, October 1994.

TABLE 2 Independent Fission Yields for ^{140}La Production

Fission Dosimeter	Thermal or Fast Neutron Field	Fission Yield, %[A,B]
^{235}U	T	5.25214×10^{-3} ± 64 %
	F	1.31401×10^{-3} ± 64 %
^{235}U	T	5.25630×10^{-3} ± 64 %
	F	2.03998×10^{-3} ± 64 %
^{238}U	F	1.38004×10^{-5} ± 64 %
^{238}U	F	2.48002×10^{-5} ± 64 %
^{239}Pu	T	8.11109×10^{-3} ± 64 %
	F	1.17572×10^{-2} ± 64 %
^{239}Pu	T	1.01969×10^{-3} ± 64 %
	F	9.86983×10^{-2} ± 64 %
^{237}Np	F	4.421×10^{-3} ± 64 %
^{232}Th	F	2.71003×10^{-5} ± 64 %
^{232}Th	F	4.84989×10^{-5} ± 64 %
^{241}Am	T	2.5758×10^{-2} ± 64 %
	F	2.07034×10^{-2} ± 32 %

[A] These ENDF/B-VI values are considered the best available data. The uncertainties are expressed as a percentage of the fission yield.

[B] England, T. R., and Rider, B. F., *ENDF-349 Evaluation and Compilation of Fission Product Yields*, Los Alamos National Laboratory, Los Alamos, NM, report LA-UR-94-3106, ENDF-349, October 1994.

7.1.3 In *thermal reactors threshold reaction dosimeters* (for example, ^{238}U, ^{237}Np, ^{232}Th) shall be shielded from thermal neutrons with elemental, or compounds of, cadmium, gadolinium, or boron to prevent fission production from trace quantities (>40 ppm) of ^{235}U, and ^{239}Pu and to suppress buildup of interfering fissionable nuclides, for example, ^{239}Pu in the ^{238}U dosimeter,^{238}Np and ^{238}Pu in the ^{237}Np dosimeter, and ^{233}U in the ^{232}Th dosimeter (see Guide E 844).

7.2 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[5] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.3 *Purity of Water*— Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II of Specification D 1193.

7.4 *Acetic Acid (36 %)*—Dilute 360 mL of glacial acetic acid to 1 L with water.

[4] Vanadium-encapsulated monitors of high purity are available from Isotope Sales Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830.

[5] Nuclear Wallet Cards, compiled by J. K. Tuli, National Nuclear Data Center, July 1990.

[5] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, NY, and the "United States Pharmacopeia."