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Standard Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238¹

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1. Scope

1.1 This test method covers procedures for measuring reaction rates by assaying a fission product (F.P.) from the fission reaction $^{238}\text{U}(n,f)\text{F.P.}$

1.2 The reaction is useful for measuring neutrons with energies from approximately 1.5 to 7 MeV and for irradiation times up to 30 to 40 years.

1.3 Equivalent fission neutron fluence rates as defined in Practice E261 can be determined.

1.4 Detailed procedures for other fast-neutron detectors are referenced in Practice E261.

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

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

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* volume information, refer to the standard's Document Summary page on the ASTM website.

E320 Test Method for Cesium-137 in Nuclear Fuel Solutions by Radiochemical Analysis (Withdrawn 1993)³

E393 Test Method for Measuring Reaction Rates by Analysis of Barium-140 From Fission Dosimeters

E705 Test Method for Measuring Reaction Rates by Radioactivation of Neptunium-237

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)

E1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance, E 706 (IIIA)

E1018 Guide for Application of ASTM Evaluated Cross Section Data File, Matrix E706 (IIB)

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology E170.

4. Summary of Test Method

4.1 High-purity ^{238}U (<40 ppm ^{235}U) is irradiated in a fast-neutron field, thereby producing radioactive fission products from the reaction $^{238}\text{U}(n,f)\text{F.P.}$

4.2 Various fission products such as ^{137}Cs – $^{137\text{m}}\text{Ba}$, ^{140}Ba – ^{140}La , ^{95}Zr , and ^{144}Ce can be assayed depending on the length of irradiation, purpose of the experiment, etc.

4.3 The gamma rays emitted through radioactive decay are counted, and the reaction rate, as defined in Practice E261, is calculated from the decay rate and the irradiation conditions.

4.4 The neutron fluence rate for neutrons with energies from approximately 1.5 to 7 MeV can then be calculated from the spectral-weighted neutron activation cross section as defined in Practice E261.

4.5 A parallel procedure that uses ^{237}Np instead of ^{238}U is given in Test Method E705.

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

5. Significance and Use

5.1 Refer to Practice E261 for a general discussion of the determination of fast-neutron fluence rate with fission detectors.

5.2 ²³⁸U is available as metal foil, wire, or oxide powder (see Guide E844). It is usually encapsulated in a suitable container to prevent loss of, and contamination by, the ²³⁸U and its fission products.

5.3 One or more fission products can be assayed. Pertinent data for relevant fission products are given in Table 1 and Table 2.

5.3.1 ¹³⁷Cs-^{137m}Ba is chosen frequently for long irradiations. Radioactive products ¹³⁴Cs and ¹³⁶Cs may be present, which can interfere with the counting of the 0.662 MeV ¹³⁷Cs-¹³⁷Ba gamma rays (see Test Methods E320).

5.3.2 ¹⁴⁰Ba-¹⁴⁰La is chosen frequently for short irradiations (see Test Method E393).

5.3.3 ⁹⁵Zr can be counted directly, following chemical separation, or with its daughter ⁹⁵Nb using a high-resolution gamma detector system.

5.3.4 ¹⁴⁴Ce is a high-yield fission product applicable to 2- to 3-year irradiations.

5.4 It is necessary to surround the ²³⁸U monitor with a thermal neutron absorber to minimize fission product production from a quantity of ²³⁵U in the ²³⁸U target and from ²³⁹Pu from (n,γ) reactions in the ²³⁸U material. Assay of the ²³⁹Pu concentration when a significant contribution is expected.

5.4.1 Fission product production in a light-water reactor by neutron activation product ²³⁹Pu has been calculated to be insignificant (<2 %), compared to that from ²³⁸U(n,f), for an irradiation period of 12 years at a fast-neutron ($E > 1$ MeV) fluence rate of $1 \times 10^{11} \text{ cm}^{-2} \cdot \text{s}^{-1}$ provided the ²³⁸U is shielded from thermal neutrons (see Fig. 2 of Guide E844).

TABLE 2 Recommended Fission Yields for Certain Fission Products^A

Fissile Isotope	Neutron Energy	Reaction Product	Type Yield	ENDF/B-VII ^{A,B} Fission Yield %
²³⁸ U(n,f)	0.5 MeV	⁹⁵ Zr	RC	6.01736 ± 4 %
		⁹⁹ Mo	RC	6.16825 ± 1.4 %
		¹⁰³ Ru	RC	6.27532 ± 1.4 %
		¹³⁷ Cs	RC	6.05254 ± 1 %
		^{137m} Ba	RI	6.56004e-6 ± 64 %
		¹⁴⁰ Ba	RC	5.81523 ± 0.7 %
		¹⁴⁰ La	RI	2.48002e-5 ± 64 %
		¹⁴⁴ Ce	RC	4.54797 ± 1.4 %

^A “Special Issue on Evaluated Nuclear Data File ENDF/B-VII.0,” *Nuclear Data Sheets*, J. K. Tuli, editor, Vol 107, December 2006. Data available on the ENDF/B-VII, Online, <http://www.nndc.bnl.gov/exfor/endl00.htm>, July 1, 2008.

^B All yield data given as a %; RC represents a cumulative yield; RI represents an independent yield.

5.4.2 Fission product production from photonuclear reactions, that is, (γ,f) reactions, while negligible near-power and research-reactor cores, can be large for deep-water penetrations (1).⁴

5.5 Good agreement between neutron fluence measured by ²³⁸U fission and the ⁵⁴Fe(n,p)⁵⁴Mn reaction has been demonstrated (2). The reaction ²³⁸U(n,f) F.P. is useful since it is responsive to a broader range of neutron energies than most threshold detectors.

5.6 The ²³⁸U fission neutron spectrum-averaged cross section in several benchmark neutron fields is given in Table 3 of Practice E261. Sources for the latest recommended cross sections are given in Guide E1018. In the case of the ²³⁸U(n,f)F.P. reaction, the recommended cross section source is the ENDF/B-VI release 8 cross section (MAT = 9237) (3). Fig. 1 shows a plot of the recommended cross section versus neutron energy for the fast-neutron reaction ²³⁸U(n,f)F.P.

NOTE 1—The data is taken from the Evaluated Nuclear Data File, ENDF/B-VI, rather than the later ENDF/B-VII. This is in accordance with Guide E1018, Section 6.1, since the later ENDF/B-VII data files do not include covariance information. Some covariance information exists for ²³⁸U in the standard sublibrary, but this is only for energies greater than 1 MeV. For more details, see Section H of Ref 4.

6. Apparatus

6.1 *Gamma-Ray Detection Equipment* that can be used to accurately measure the decay rate of fission product activity are the following two types (5):

6.1.1 *NaI(Tl) Gamma-Ray Scintillation Spectrometer* (see Test Methods E181 and E1005).

6.1.2 *Germanium Gamma-Ray Spectrometer* (see Test Methods E181 and E1005)—Because of its high resolution, the germanium detector is useful when contaminant activities are present.

⁴ The boldface numbers in parentheses refer to the list of references appended to this test method.

TABLE 1 Recommended Nuclear Parameters for Certain Fission Products

Fission Product	Parent Half-Life ^A (6)	Primary Radiation ^A (7) (keV)	γ Probability of Decay ^A (7)	Maximum Useful Irradiation Duration
⁹⁵ Zr	64.032 (6) d	724.192 (4)	0.4427 (22)	6 months
		756.725 (12)	0.5438	
⁹⁹ Mo	2.7489 (6) d	739.500 (17)	0.1213 (22)	300 hours
		777.921 (20)	0.0426 (8)	
¹⁰³ Ru	39.26 (2) d	497.084 (6)	0.910 (12)	4 months
¹³⁷ Cs	30.03 (5) yr	661.657 (3) ^B	0.8510 ^B	30–40 years
¹⁴⁰ Ba – ¹⁴⁰ La	12.752 (3) d	537.261 (4)	0.2439 (23)	1–1.5 months
		1596.21 (4)	0.954 (14) ^C	
¹⁴⁴ Ce	289.91 (5) d	133.515 (2)	0.1109 (10)	2–3 years

^A The lightface numbers in parentheses are the magnitude of plus or minus uncertainties in the last digit(s) listed.

^B With ^{137m}Ba (2.552 min) in equilibrium.

^C Probability of daughter ¹⁴⁰La decay.

^D With ¹⁴⁰La (1.6781 d) in transient equilibrium.