Designation: E704 – 19

Standard Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238[1]

This standard is issued under the fixed designation E704; 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 covers procedures for measuring reaction rates by assaying a fission product (F.P.) from the fission reaction ^{238}U(n,f)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, provided that the analysis methods described in Practice E261 are followed.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *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

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

E320 Test Method for Cesium-137 in Nuclear Fuel Solutions by Radiochemical Analysis (Withdrawn 1993)[3]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

E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance

E1005 Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance

E1018 Guide for Application of ASTM Evaluated Cross Section Data File

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}U(n,f)F.P.

4.2 Various fission products such as ^{137}Cs-^{137m}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.

[1] This test method is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applicationsand 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] The last approved version of this historical standard is referenced on www.astm.org.

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.

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 ^{238}U 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 ^{238}U 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 ^{137}Cs-^{137m}Ba is chosen frequently for long irradiations. Radioactive products ^{134}Cs and ^{136}Cs may be present, which can interfere with the counting of the 0.662 MeV ^{137}Cs-^{137m}Ba gamma rays (see Test Method E320).

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

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

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

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

TABLE 1 Recommended Nuclear Parameters for Certain Fission Products

Fission Product	Parent Half-Life[A] **(1,2,3)**	Primary Radiation[A] **(2,3)** (keV)	γ Probability of Decay[A] **(4,2,3)**	Maximum Useful Irradiation Duration
^{95}Zr	64.032 (6) d	724.193 (3)	0.4427 (22)	6 months
		756.729 (12)	0.5438 (22)	
^{99}Mo	2.7479 (6) d	739.500 (17)	0.1212 (15)	300 hours
		777.921 (20)	0.0428 (8)	
^{103}Ru	39.247 (13) d	497.085 (10)	0.910 (12)	4 months
^{137}Cs	30.05 (8) yr	661.657 (3)[B]	0.8499 (20)[B]	30 – 40 years
^{140}Ba – ^{140}La	12.753 (4) d	537.303 (6)[C]	0.2439 (22)[C]	1–1.5 months
		1596.203 (13)	0.9540 (5)[D]	
^{140}La/^{140}Ba			1.1516 (5)[E]	
^{144}Ce	284.89 (6) d	133.5152 (20)	0.1083 (12)	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] The recommended half-life and gamma emission probabilities have been taken from the Reference **(3)** data that was recommended at the time that the recommended fission yields were set.
[D] Probability of daughter ^{140}La decay.
[E] This is the activity ratio of ^{140}La/^{140}Ba after reached transient equilibrium (t ≥ 19 days).

TABLE 2 Recommended Fission Yields for Certain Fission Products[A]

Fissile Isotope	Neutron Energy	Reaction Product	Type Yield	JEFF-3.1.1[A,B] Fission Yield %
^{238}U(n,f)	0.5 MeV	^{95}Zr	RC	5.19 ± 1.714 %
		^{99}Mo	RC	6.18 ± 1.6 %
		^{103}Ru	RC	6.03 ± 1.6 %
		^{137}Cs	RC	6.02 ± 2.52 %
		^{137m}Ba	RI	1.0169e-2 ± 36.5 %
		^{140}Ba	RC	5.68 ± 2.67 %
		^{140}La	RI	6.8165e-6 ± 64 %
		^{144}Ce	RC	4.67 ± 2.46 %

[A] The JEFF-3.1/3.1.1 radioactive decay data and fission yields sub-libraries, JEFF Report 20, OECD 2009, Nuclear Energy Agency **(5)**.
[B] All yield data given as a %; RC represents a cumulative yield; RI represents an independent yield.

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

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 **(6)**.[4]

5.5 Good agreement between neutron fluence measured by ^{238}U fission and the ^{54}Fe(n,p)^{54}Mn reaction has been demonstrated **(7)**. The reaction ^{238}U(n,f) F.P. is useful since it is responsive to a broader range of neutron energies than most threshold detectors.

5.6 The ^{238}U 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 ^{238}U(n, f)F.P. reaction, the recommended cross section source is the ENDF/B-VI release 8 cross section (MAT = 9237) **(8)**. Fig. 1 shows a plot of the recommended cross section versus neutron energy for the fast-neutron reaction ^{238}U(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 ^{238}U in the standard sublibrary, but this is only for energies greater than 1 MeV. For more details, see Section H of Ref **9**.

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 **(10)**:

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.