



Designation: E 1005 – 97

Standard Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance, E 706(IIIA)¹

This standard is issued under the fixed designation E 1005; 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 method describes general procedures for measuring the specific activities of radioactive nuclides produced in radiometric monitors (RMs) by nuclear reactions induced during surveillance exposures for reactor vessels and support structures. More detailed procedures for individual RMs are provided in separate standards identified in 2.1 and in Refs **11, 24-27**. The measurement results can be used to define corresponding neutron induced reaction rates which can in turn be used to characterize the irradiation environment of the reactor vessel and support structure. The principal measurement technique is high resolution gamma-ray spectrometry, although X-ray photon spectrometry and Beta particle counting are used to a lesser degree for specific RMs **(1-29)**.²

1.1.1 The measurement procedures include corrections for detector background radiation, random and true coincidence summing losses, differences in geometry between calibration source standards and the RMs, self absorption of radiation by the RM, other absorption effects, and radioactive decay corrections **(1-10, 12-22)**.

1.1.2 Specific activities are calculated by taking into account the time duration of the count, the elapsed time between start of count and the end of the irradiation, the half life, the mass of the target nuclide in the RM, and the branching intensities of the radiation of interest. Using the appropriate half life and known conditions of the irradiation, the specific activities may be converted into corresponding reaction rates **(24-30)**.

1.1.3 Procedures for calculation of reaction rates from the radioactivity measurements and the irradiation power time history are included. A reaction rate can be converted to neutron fluence rate (flux density) and fluence using the appropriate integral cross section and effective irradiation time values, and, with other reaction rates can be used to define the neutron spectrum through the use of suitable computer programs **(24-30)**.

1.1.4 The use of benchmark neutron fields for calibration of RMs can reduce significantly or eliminate systematic errors

since many parameters, and their respective uncertainties, required for calculation of absolute reaction rates are common to both the benchmark and test measurements and therefore are self cancelling. The benchmark equivalent fluence rates, for the environment tested, can be calculated from a direct ratio of the measured saturated activities in the two environments and the certified benchmark fluence rate **(24-30)**.

1.2 This method is intended to be used in conjunction with ASTM Guide E 844, also referred to as E 706 (IIC)³. The following existing or proposed ASTM practices, guides, and methods are also directly involved in the physics-dosimetry evaluation of reactor vessel and support structure surveillance measurements:

E 706 (O) Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards³

E 706 (IA), E 853 Analysis and Interpretation of Light-Water Reactor Surveillance Results³

E 706 (IC), E 560 Practice for Extrapolating Reactor Vessel Surveillance Dosimetry Results³

E 706 (ID), E 693 Practice for Characterizing Neutron Exposures in Ferritic Steels in Terms of Displacements Per Atom (DPA)³

E 706 (IE) Damage Correlation for Reactor Vessel Surveillance³

E 706 (IF), E 185 Practice for Conducting Surveillance Tests for Light-Water Nuclear Power Reactor Vessels³

E 706 (IG) Surveillance Tests for Nuclear Reactor Support Structures³

E 706 (IH), E 636 Practice for Conducting Supplemental Surveillance Tests for Nuclear Power Reactor Vessels³

E 706 (IIA), E 944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance³

E 706 (IIB), E 1018 Guide for Application of ASTM Evaluated Cross Section and Data File³

E 706 (IID), E 482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance³

E 706 (IIE) Benchmark Testing of Reactor Vessel Dosimetry³

E 706 (IIIB), E 854 Test Method for Application and Analysis of Solid State Track Recorder (SSTR) Monitors for Reactor Vessel Surveillance³

¹ This method 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 The boldface numbers in parentheses refer to the list of references appended to this method.

³ The reference in parentheses refers to Section 5 as well as Figs. 1 and 2 of Matrix E 706.

E 1005

E 706 (IIIC), E 910 Test Method for Application and Analysis of Helium Accumulation Fluence Monitors for Reactor Vessel Surveillance³

E 706 (IIID) Application and Analysis of Damage Monitors for Reactor Vessel Surveillance³

E 706 (IIIE) Application and Analysis of Temperature Monitors for Reactor Vessel Surveillance³

1.3 The general procedures in this method are applicable to the measurement of radioactivity in RMs which satisfy the specific constraints and conditions imposed for their analysis. More detailed procedures for individual RM monitors are identified in 2.1 and in Refs **11, 24-27** (see Table 1).

1.4 This method, along with the individual RM monitor standard methods, are intended for use by knowledgeable persons who are intimately familiar with the procedures, equipment, and techniques necessary to achieve high precision and accuracy in radioactivity measurements.

1.5 *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.*

TABLE 1 Radiometric Monitors Proposed for Reactor Vessel Surveillance

Dosimetry Reactions	Residual Nucleus			Target Atom Natural Abundance ^A [31]	Detector Response ^B	ASTM Standard or Ref.
	Half-life ^{C,A,D}	E _γ ^D (keV)	Yield ^D (%) γ/Reaction			
²³ Na(n,γ) ²⁴ Na	0.62356 (17) d	1368.633 2754.030	99.9936 99.855	1.00	NTR	(24-30)
²⁷ Al(n,α) ²⁴ Na	0.62356 (17) d	1368.633 2754.030	99.9936 99.855	1.00	TR	E 266
³² S(n,p) ³² P	14.262 (14) d	<E _β >=694.9	100.	0.9502 (9)	TR	E 265
⁴⁵ Sc(n,γ) ⁴⁶ Sc	83.79 (4) d	889.277 1120.545	99.9844 99.9874	1.00	NTR	(24-30)
⁴⁶ Ti(n,p) ⁴⁶ Sc	83.79 (4) d	889.277 1120.545	99.9844 99.9874	0.0825 (3)	TR	E 526
⁴⁷ Ti(n,p) ⁴⁷ Sc	3.3492 (16) d	159.381	68.3	0.0744 (2)	TR	E 526
⁴⁸ Ti(n,p) ⁴⁸ Sc	43.67 (9) h	983.526 1037.522 1312.120	100.0 97.5 100.0	0.7372 (3)	TR	E 526
⁵⁵ Mn(n,2n) ⁵⁴ Mn	312.3 (4) d	834.843	99.9758	1.00	TR	E 261, E 263 (24-30)
⁵⁴ Fe(n,p) ⁵⁴ Mn	312.3 (4) d	834.843	99.9758	0.05845 (35)	TR	E 263
⁵⁴ Fe(n,γ) ⁵⁵ Fe	2.73 (3) y	5.888 5.899 6.490	8.2 16.2 2.86	0.05845 (35)	NTR	(24-30)
⁵⁶ Fe(n,p) ⁵⁶ Mn	2.5785 (2) hr	846.754 1810.72 2113.05	98.87 27.18925 14.33615	0.91754 (36)	TR	(24-30)
⁵⁸ Fe(n,γ) ⁵⁹ Fe	44.503 (6) d	1099.251 1291.596 1481.7	56.5 43.2 0.059	0.00282 (4)	NTR	(24-30)
⁵⁹ Co(n,γ) ⁶⁰ Co	1925.5 (5) d 10.467 (6) m (meta)	1173.238 1332.502 58.603 826.28 1332.501 2158.77	99.857 99.983 2.01 0.00768 0.24 0.00072	1.00	NTR	E 262, E 481
⁵⁸ Ni(n,p) ⁵⁸ Co	70.82 (3) d 9.15 (10) h (meta)	810.775 863.959 1674.730 24.889	99.45 0.69 0.519 0.0369	0.68077 (9)	TR	E 264
⁶⁰ Ni(n,p) ⁶⁰ Co	1925.5 (5) d 10.467 (6) m (meta)	1173.238 1332.502 58.603 826.28	99.857 99.983 2.01 0.00768	0.26223 (8)	TR	(24-30)

E 1005

TABLE 1 *Continued*

Dosimetry Reactions	Residual Nucleus			Target Atom Natural Abundance ^A [31]	Detector Response ^B	ASTM Standard or Ref.
	Half-life ^{C,A,D}	E _γ ^D (keV)	Yield ^D (%) γ/Reaction			
		1332.501 2158.77	0.24 0.00072			
⁶³ Cu(n,γ) ⁶⁴ Cu	12.701 (2) h	1345.77	0.47336	0.6917 (3)	NTR	(24-30)
⁶³ Cu(n,α) ⁶⁰ Co	1925.5 (5) d	1173.238	99.857	0.6917 (3)	TR	E 523
		1332.502	99.983			
	10.467 (6) m	58.603	2.01			
	(meta)	826.33	0.0058			
		1332.501 2158.86	0.25 0.00088			
⁹³ Nb(n,n') ^{93m} Nb	5.89 (5) × 10 ³ d	30.77 16.52 (K _{α1,2})	0.000549 9.25	1.00	TR	(11, 24-30)
¹⁰³ Rh(n,n') ^{103m} Rh	56.12 (1) m	39.755	0.0684	1.00	TR	(24-30)
¹⁰⁹ Ag(n,γ) ^{110m} Ag	249.76 (20) d	116.48	0.00799	0.48161 (7)	NTR	E 481
		884.685	72.192			
		937.493	34.1314			
		1384.300	24.1204			
		1505.040	12.9532			
		1475.788	3.96868			
¹¹⁵ In(n,γ) ^{116m} In	54.41 (17) m	1293.54	84.4	0.9571 (2)	NTR	E 261, E 262
		1097.3	56.2104			
		818.7	11.4784			
		2112.1	15.5296			
¹¹⁵ In(n,n') ^{115m} In	4.486 (4) h	336.241	45.9	0.9571 (2)	TR	(24-30)
		497.370	0.047			
¹⁸¹ Ta(n,γ) ¹⁸² Ta	114.43 (3) d	1121.3008	34.9	0.99988 (2)	NTR	E 262
		1189.0503	16.225			
		1221.4066	26.9777			
¹⁹⁷ Au(n,γ) ¹⁹⁸ Au	2.6943 (8) d	1087.6904	0.159045	1.00	NTR	E 261, E 262 (24-30)
		675.8874	0.8038278			
		411.804	95.57			
²³² Th(n,γ) ²³³ Th	22.3 (1) m	890.1	0.14	1.00	NTR	(24-30)
		490.80	0.17			
		499.02	0.21			
		699.901	0.68			
		764.4	0.120			
... → ²³³ Pa	26.967 (2) d	312.17	38.6			
FM(n,f) ¹⁴⁴ Ce	284.893 (8) d	133.515 80.120	11.09 1.36407 (see Table 2)	— ^E	NTR, TR	E 704, E 705 (24-30)
FM(n,f) ¹⁴⁰ Ba	12.752 (3) d	537.261	24.4 (see Table 2)	— ^E	NTR, TR	E 393, E 704, E 705
¹⁴⁰ Ba → ¹⁴⁰ La	1.6781 (3) d	1596.21 815.772 487.021	95.4 23.2776 45.5058 (see Table 2)			(24-30)
FM(n,f) ¹³⁷ Cs	30.07 (16) y	661.660	85.1 (see Table 2)	— ^E	NTR, TR	E 320, E 704, E 705
¹³⁷ Cs → ^{137m} Ba	2.552 (1) m	661.660	90.11 (see Table 2)			(24-30)
FM(n,f) ¹⁰⁶ Ru	373.59 (15) d	—	— (see Table 2)	— ^E	NTR, TR	E 704, E 705 (24-30)
¹⁰⁶ Ru → ¹⁰⁶ Rh	29.80 (8) s	511.8605	20.4			