Designation: D7784 – 20

Standard Practice for the Rapid Assessment of Gamma-ray Emitting Radionuclides in Environmental Media by Gamma Spectrometry[1]

This standard is issued under the fixed designation D7784; 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 practice covers the quantification of radionuclides in environmental media (for example, water, soil, vegetation, food) by means of simple preparation and counting with a high-resolution gamma ray detector. Because the practice is designed for rapid analysis, extensive efforts to ensure homogeneity or ideal sample counting conditions are not taken.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.3 *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.*

1.4 *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]

C998 Practice for Sampling Surface Soil for Radionuclides

D1129 Terminology Relating to Water

D3370 Practices for Sampling Water from Flowing Process Streams

D3649 Practice for High-Resolution Gamma-Ray Spectrometry of Water

D7282 Practice for Set-up, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements

D7902 Terminology for Radiochemical Analyses

2.2 *Other Documents:*

BIPM-5 Decay Data Evaluation Project (DDEP)[3]

NUDAT2[4]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this standard, refer to Terminologies D1129 and D7902.

4. Summary of Practice

4.1 Following sample collection, sample material is placed in a suitable container for analysis by a gamma spectrometry system. A suitable container is defined as a container which will both hold the sample in a fixed geometry and for which the gamma spectrometry system has been calibrated. For solid samples, the samples may be ground, sieved, or otherwise prepared for the purpose of volume reduction, homogenization, or conformance to the calibration standard, as desired.

5. Significance and Use

5.1 This practice was developed for the rapid determination of gamma-emitting radionuclides in environmental media. The results of the test may be used to determine if the activity of these radionuclides in the sample exceeds the action level for the relevant incident or emergency response. The detection limits will be dependent on sample size, counting configuration, and the detector system in use.

5.2 In most cases, a sample container which is large in diameter and short in height relative to the detector will provide the best gamma-ray detection efficiency. For samples of water or other low-Z materials (for example, vegetation), the re-entrant or Marinelli-style beaker may yield the best gamma-ray detection efficiency.

5.3 The density of the sample material and physical parameters of the sample container (for example, diameter, height, material) may have significant consequences for the accuracy of the sample analysis as compared to the calibration. For this

[1] This practice is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.04 on Methods of Radiochemical Analysis.

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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] Available from BIPM, Sèvres Cedex, France, https://www.bipm.org.

[4] Available from National Nuclear Data Center at Brookhaven National Laboratory, W Princeton Ave, Yaphank, NY 11980, http://www.nndc.bnl.gov.

reason, the ideal calibration material and container (often referred to as 'geometry') will be exactly the same as the samples to be analyzed. Differences in sample container or sample matrix may introduce significant errors in detector response, especially at low gamma-ray energies. Every effort should be made to account for these differences if the exact calibration geometry is not available.

5.4 This practice establishes an empirical gamma-ray spectrometer calibration using standards traceable to the SI via a national metrology institute (NMI) such as the National Institute of Standards and Technology (NIST) in the United States and the National Physical Laboratory (NPL) in the United Kingdom in a specific geometry selected to ensure that the container, density, and composition of the standard matches that of the samples as closely as possible. However, in some cases it may be beneficial to modify such initial calibrations using mathematical modeling or extrapolations to an alternate geometry. Use of such a model may be acceptable, depending on the measurement quality objectives of the analysis process, and provided that appropriate compensation to uncertainty estimates are included. The use of such calibration models is best supported by the successful analysis of a method validation reference material (MVRM).

5.5 This practice addresses the analysis of numerous gamma-emitting radionuclides in environmental media. This practice should be applicable to non-environmental media (for example, urine, debris, or rubble) that have similar physical properties. The key determination of *similar physical properties* is the ability to demonstrate that the gamma spectrometry system response to the sample configuration is suitably similar to that for which the system is calibrated.

5.6 For the analysis of radionuclides with low gamma-ray emission energies (<100 keV), self-absorption of the gamma-rays in the sample matrix can have a significant adverse effect on detection and quantification. The user should verify that instrument calibrations appropriately account for any self-absorption that may result from the sample matrix.

5.7 Commonly available energy and efficiency calibration standards cover the energy range of approximately 60 keV to 1836 keV. Results obtained using gamma-ray peaks outside the efficiency calibrated energy range will have greater uncertainty not accounted for in the uncertainty calculations of this practice. Great care should be taken to review the efficiency calibration values and the shape of the efficiency curve outside this range. For greater accuracy in the analysis of radionuclides whose gamma-ray energies are outside this range, a calibration standard which includes radionuclide(s) whose gamma-ray energies span the energy range of radionuclides of interest is advised.

6. Interferences

6.1 A list of some gamma-ray emitting radionuclides with relevant data is provided, for information only, in Table 1. This list includes radionuclides which may be of interest to agencies responding to a large scale radiological event. Through inspection of the list, it becomes apparent that there are numerous opportunities for interferences based on the gamma energy

TABLE 1 Example of Most Likely Radionuclides for Emergency Response

Nuclide	Gamma Energy (keV)	Gamma Fraction	Half-Life (d)
Ac-227	100	3.17E-04	7.96E+03
Ac-227	83.96	2.21E-04	7.96E+03
Ag-110m	657.75	9.47E-01	2.50E+02
Ag-110m	884.67	7.29E-01	2.50E+02
Am-241	59.54	3.63E-01	1.58E+05
Am-242m	49.3	1.90E-03	5.55E+04
Am-243	74.67	6.60E-01	2.70E+06
Au-198	411.80	9.55E-01	2.70E+00
Au-198	70.82	1.38E-02	2.70E+00
Ba-133	30.97	6.29E-01	3.91E+03
Ba-133	355.86	6.23E-01	3.91E+03
Ba-137m	661.62	9.00E-01	1.77E-03
Ba-137m	32.19	3.82E-02	1.77E-03
Ba-140	537.38	1.99E-01	1.28E+01
Ba-140	29.96	1.43E-01	1.28E+01
Bi-207	569.67	9.80E-01	1.39E+04
Bi-207	1063.62	7.70E-01	1.39E+04
Cd-109	24.95	1.43E-01	4.53E+02
Cd-113m	263.7	6.00E-05	5.33E+03
Cd-113m	23.17	6.00E-05	5.33E+03
Ce-141	145.45	4.80E-01	3.24E+01
Ce-141	36.03	8.88E-02	3.24E+01
Ce-143	293.3	4.34E-01	1.40E+00
Ce-143	36.03	3.23E-01	1.40E+00
Ce-144	133.53	1.08E-01	2.84E+02
Ce-144	36.03	4.80E-02	2.84E+02
Cf-252	43.4	1.30E-04	8.99E+02
Cm-242	44.03	3.25E-04	1.63E+02
Cm-243	103.75	2.08E-01	1.04E+04
Cm-244	42.82	2.55E-04	6.61E+03
Cm-245	103.76	2.30E-01	3.11E+06
Co-58	810.75	9.95E-01	7.08E+01
Co-58	511	3.00E-01	7.08E+01
Co-60	1332.51	1.00E+00	1.93E+03
Co-60	1173.23	9.99E-01	1.93E+03
Co-60	2158.7	8.00E-06	1.93E+03
Cr-51	320.07	9.83E-02	2.77E+01
Cs-134	604.66	9.76E-01	7.53E+02
Cs-134	795.76	8.54E-01	7.53E+02
Cs-136	818.5	1.00E+00	1.30E+01
Cs-136	1048.07	8.00E-01	1.30E+01
Cs-137	661.62	8.46E-01	1.10E+04
Cs-137	32.19	3.70E-02	1.10E+04
Eu-152	40.12	3.00E-01	4.64E+03
Eu-152	121.78	2.92E-01	4.64E+03
Eu-154	123.1	4.05E-01	3.11E+03
Eu-154	1274.8	3.55E-01	3.11E+03
Eu-155	86.45	3.27E-01	1.81E+03
Eu-155	105.31	2.18E-01	1.81E+03
Fe-59	1099.22	5.65E-01	4.51E+01
Fe-59	1291.56	4.32E-01	4.51E+01
Gd-153	41.54	6.00E-01	2.42E+02
Gd-153	40.9	3.20E-01	2.42E+02
Hf-181	482.16	8.60E-01	4.25E+01
Hf-181	133.05	4.30E-01	4.25E+01
Hg-203	279.17	8.15E-01	4.66E+01
Hg-203	72.87	6.40E-02	4.66E+01
Ho-166m	184.41	7.39E-01	4.38E+05
Ho-166m	810.31	5.97E-01	4.38E+05
I-125	27.47	7.30E-01	6.01E+01
I-125	27.2	3.92E-01	6.01E+01
I-129	29.78	3.60E-01	5.73E+09
I-129	29.46	1.90E-01	5.73E+09
I-131	364.48	8.12E-01	8.04E+00
I-131	636.97	7.27E-02	8.04E+00
I-131	284.29	6.06E-02	8.04E+00
I-131	80.18	2.62E-02	8.04E+00
I-131	29.78	2.59E-02	8.04E+00
I-132	667.69	9.87E-01	9.92E-02
I-132	772.61	7.62E-01	9.92E-02
In-114m	24.21	2.00E-01	4.95E+01
In-114m	189.9	1.77E-01	4.95E+01
Ir-192	316.49	8.70E-01	7.40E+01

TABLE 1 *Continued*

Nuclide	Gamma Energy (keV)	Gamma Fraction	Half-Life (d)
Ir-192	468.06	5.18E-01	7.40E+01
K-40	1460.75	1.07E-01	4.68E+11
La-140	1596.2	9.55E-01	1.68E+00
La-140	487.03	4.30E-01	1.68E+00
Mn-54	834.81	1.00E+00	3.12E+02
Mo-99	140.51	9.09E-01	2.76E+00
Mo-99	739.47	1.30E-01	2.76E+00
Na-22	511	1.80E+00	9.50E+02
Na-22	1274.54	9.99E-01	9.50E+02
Nb-94	871.1	1.00E+00	7.42E+06
Nb-94	702.5	1.00E+00	7.42E+06
Nb-95	765.82	9.90E-01	3.52E+01
Nd-147	91.1	2.83E-01	1.11E+01
Nd-147	38.72	2.30E-01	1.11E+01
Nd-147	531	1.35E-01	1.11E+01
Np-237	86.49	1.31E-01	7.82E+08
Np-237	29.38	9.80E-02	7.82E+08
Np-237	95.87	2.96E-02	7.82E+08
Np-239	103.7	2.40E-01	2.36E+00
Np-239	106.13	2.27E-01	2.36E+00
Pa–234m	1001.03	5.90E-03	8.13E-04
Pa-234m	766.6	2.07E-03	8.13E-04
Pb-210	46.52	4.00E-02	7.45E+03
Pm-145	37.36	3.86E-01	6.47E+03
Pm-145	36.85	2.11E-01	6.47E+03
Pm-147	121.2	4.00E-05	9.58E+02
Pm-149	285.9	3.10E-02	2.21E+00
Pm-149	859.4	1.00E-03	2.21E+00
Pm-151	340.08	2.24E-01	1.18E+00
Pm-151	40.12	1.66E-01	1.18E+00
Po-210	803	1.10E-05	1.38E+02
Pr-144	696.49	1.49E-02	1.20E-02
Pr-144	2185.61	7.70E-03	1.20E-02
Pu-236	47.6	6.90E-04	1.04E+03
Pu-236	109	1.20E-04	1.04E+03
Pu-238	43.45	3.80E-04	3.21E+04
Pu-238	99.86	7.24E-05	3.21E+04
Pu-239	51.62	2.08E-04	8.81E+06
Pu-239	129.28	6.20E-05	8.81E+06
Pu-240	45.24	4.50E-04	2.39E+06
Pu-240	104.23	7.00E-05	2.39E+06
Pu-241	98.44	2.20E-05	5.54E+03
Pu-241	94.66	1.20E-05	5.54E+03
Pu-241	111	8.40E-06	5.54E+03
Pu-242	44.7	3.60E-02	1.41E+08
Pu-242	103.5	7.80E-03	1.41E+08
Ra-226	185.99	3.28E-02	5.84E+05
Ra-226	83.78	3.10E-03	5.84E+05
Rb-86	1076.63	8.76E-02	1.86E+01
Rh-106	511.8	2.06E-01	3.46E-04
Rh-106	621.8	9.81E-02	3.46E-04
Ru-103	497.08	8.64E-01	3.94E+01
Ru-103	610.33	5.30E-02	3.94E+01
Sb-124	602.71	9.81E-01	6.02E+01
Sb-124	1691.04	5.00E-01	6.02E+01
Sb-126	695.1	9.97E-01	1.25E+01
Sb-126	666.2	9.97E-01	1.25E+01
Sb-127	685.5	3.57E-01	3.85E+00
Sb-127	473	2.50E-01	3.85E+00
Sc-46	1120.52	1.00E+00	8.39E+01
Sc-46	889.26	1.00E+00	8.39E+01
Se-75	264.65	5.86E-01	1.20E+02
Se-75	136	5.60E-01	1.20E+02
Sn-113	391.71	6.42E-01	1.15E+02
Sn-113	24.21	3.90E-01	1.15E+02
Sn-123	1089	6.00E-03	1.29E+02
Sn-123	1032	4.00E-04	1.29E+02
Sn-125	1066.6	9.00E-02	9.62E+00
Sn-125	915.5	4.25E-02	9.62E+00
Sn-126	87.57	3.75E-01	3.65E+07
Sn-126	26.11	1.89E-01	3.65E+07
Sr-89	909.2	9.50E-04	5.05E+01
Ta-182	67.75	4.13E-01	1.15E+02
Ta-182	1121.28	3.50E-01	1.15E+02
Tb-160	876.37	3.00E-01	7.21E+01

TABLE 1 *Continued*

Nuclide	Gamma Energy (keV)	Gamma Fraction	Half-Life (d)
Tb-160	298.57	2.74E-01	7.21E+01
Tc-99	89.6	6.50E-06	7.82E+07
Te-127	417.9	9.93E-03	3.90E-01
Te-127	360.3	1.35E-03	3.90E-01
Te-129	27.77	1.64E-01	4.83E-02
Te-129	459.5	7.14E-02	4.83E-02
Te-129m	27.47	1.53E-01	3.36E+01
Te-129m	27.2	7.80E-02	3.36E+01
Te-131m	773.67	3.81E-01	1.25E+00
Te-131m	852.21	2.06E-01	1.25E+00
Te-132	228.16	8.85E-01	3.25E+00
Te-132	28.5	5.40E-01	3.25E+00
Th-227	236	1.12E-01	1.85E+01
Th-227	50.2	8.50E-02	1.85E+01
Th-227	256.25	6.80E-02	1.85E+01
Ti-44	78.4	9.47E-01	1.73E+04
Ti-44	67.8	8.77E-01	1.73E+04
Tl-204	70.82	7.40E-03	1.38E+03
Tl-204	68.89	4.00E-03	1.38E+03
Tm-170	84.26	1.00E-01	1.29E+02
Tm-170	52.39	6.80E-02	1.29E+02
Tm-170	51.35	3.60E-02	1.29E+02
U-235	185.72	5.40E-01	2.57E+11
U-235	143.76	1.05E-01	2.57E+11
U-235	163.35	4.70E-02	2.57E+11
U-238	48	7.50E-04	1.72E+12
V-48	983.5	1.00E+00	1.61E+01
V-48	1311.6	9.80E-01	1.61E+01
V-48	511	9.80E-01	1.61E+01
W-187	685.74	2.92E-01	9.96E-01
W-187	479.57	2.34E-01	9.96E-01
Y-90	1760.7	1.15E-04	2.67E+00
Y-91	1204.9	3.00E-03	5.85E+01
Yb-169	50.74	7.81E-01	3.07E+01
Yb-169	63.12	4.50E-01	3.07E+01
Yb-169	49.77	4.22E-01	3.07E+01
Zn-65	1115.52	5.08E-01	2.44E+02
Zn-65	511	2.83E-02	2.44E+02
Zr-95	756.72	5.48E-01	6.44E+01
Zr-95	724.18	4.42E-01	6.44E+01

emissions. For this reason, it is important that the determination of the presence of a given radionuclide be supported by all available evidence (for example, additional gamma-ray emissions).

6.2 The data provided in Table 1, Table 2, and Table 3 are not mandatory and are provided for information only. The composition of the nuclide library used by the laboratory should be matched to the analytical need and the data should be validated using a current reference source such as BIPM-5 and

TABLE 2 Example of Most Likely Radionuclides for Emergency Response Subsequent To an Incident Involving a Radiological Dispersal Device

Alpha Emitters		Beta/Gamma Emitters	
Am-241	Ra-226	Ac-227	P-32
Cm-242	Th-228	Bi-210	Pd-103
Cm-243	Th-230	Bi-212	Pb-210
Cm-244	Th-232	Bi-214	Pb-212
Np-237	U-234	Co-57	Pb-214
Po-210	U-235	Co-60	Pu-241
Pu-238	U-238	I-125	Ra-228
Pu-239	U-Nat	I-129	Se-75
Pu-240		Ir-192	

TABLE 3 Example of Most Likely Radionuclides for Emergency Response Subsequent To an Incident Involving an Improvised Nuclear Device

Alpha Emitters	Beta/Gamma Emitters		
Am-241	Ba-140/ La-140	Nd-147/Pr-147	Sb-125
U-234	Ce-141	Eu-155	Sr-89
U-235	Ce-143/Pr-143	H-3	Sr-90/Y-90
U-238	Ce-144/Pr-144	I-131/Xe-131	Tc-99
Pu-238	Cs-134	I-133	Te-132/I-32
Pu-239	Cs-137	Np-239	Zr-95/Nb-95
Pu-240	Eu-154	Ru-103/Rh-103	Zr-97/Nb-97
	Mo-99/ Tc-99m	Ru-106/Rh-106	
	Activation Products		
	Ag-110m	Cr-51	Mn-54
	Co-60	Fe-59	Na-24

NUDAT2. Other sources of nuclear data may be used at the user's discretion. In all cases, the source should be clearly documented.

6.3 Several of the radionuclides listed in Table 1, Table 2, and Table 3 have X-ray emissions which may interfere with gamma-ray emissions, particularly below approximately 40 keV. It is the responsibility of the laboratory to ensure that X-ray and gamma-ray interferences are accounted for in the analytical process.

7. Apparatus

7.1 *Analytical Balance,* readable to 0.1 g.

7.2 *Sample Container*—a container suitable for holding the sample material to be analyzed. The container may be of any suitable configuration, but should be reproducible in its dimensions and capacity. This should be the same container design for which the counting system is calibrated. An ideal container is smaller in diameter than the detector to be used for analysis (7.3) and should be as short in the vertical dimension as is practical. A re-entrant beaker (for example, Marinelli-style) may be used to improve the counting efficiency for low Z-value materials. The container should be durable and sealable to prevent content loss during handling.

7.3 *Gamma-Ray Spectrometry System*—high resolution high purity germanium gamma spectrometer with an energy range of approximately 20 keV to 2200 keV (see Practice D3649). Note: The useable energy range of the gamma spectrometer will be determined by the efficiency calibration. Further guidance on the use of high purity germanium systems may be found in Practice D3649.

8. Reagents and Materials

8.1 *Radioactive Purity*—Radioactive purity should be such that the measured radioactivity of blank samples does not compromise the applicable measurement quality objectives.

8.2 *Calibration standard*—Known amounts of specific radionuclides whose gamma-ray emission energies cover a wide energy range should be used for calibration, provided that they have gamma ray energies covering the energy range of the radionuclides of interest. The known activity of the radionuclides should be traceable to a NMI.

9. Calibration of High-resolution Gamma-ray Spectroscopy System

9.1 Accumulate an energy spectrum using a calibration standard (8.2) traceable to a national standards body, in the geometrical position representing that of the samples to be analyzed. Accumulate sufficient net counts (total counts minus the Compton) in each full-energy gamma-ray peak of interest to obtain a one-sigma relative counting uncertainty of ≤1 %.

9.2 Using the gamma emission data from the calibration standard and the peak location data from the calibration spectrum establish the energy per channel relationship (energy calibration) as:

$$En = \text{Offset} + (Ch \times \text{Slope}) \quad (1)$$

where:

En = peak energy (keV),
Offset = energy offset for the energy calibration equation (keV),
Ch = peak location channel number, and
Slope = energy calibration equation slope (keV/channel).

NOTE 1—Most modern spectroscopy software packages perform this calculation, and may include higher-order polynomial terms to account for minor non-linearity in the energy calibration.

9.3 Using the gamma emission data from the calibration standard and the peak resolution data from the calibration spectrum establish the resolution versus energy relationship (resolution calibration) as:

$$FWHM = \text{Offset} + (En \times \text{Slope}) \quad (2)$$

where:

$FWHM$ = full width of the peak at one-half the maximum counts in the centroid channel (keV),
Offset = width offset for the resolution calibration equation (keV),
En = peak energy (keV), and
Slope = resolution calibration equation slope (keV/keV).

NOTE 2—Most modern spectroscopy software packages perform this calculation, and may include higher-order polynomial terms to account for non-linearity in the resolution calibration.

9.4 Calculate the full-energy peak efficiency, ϵ_f, using the equation defined in the laboratory quality manual or with example Eq 3:

$$\epsilon_f = \frac{R_n}{A_g \times DF} \quad (3)$$

where:

ϵ_f = full-energy peak efficiency (counts per gamma ray emitted),
R_n = net gamma-ray count in the full-energy peak of interest counts per second (s^{-1}),
A_g = gamma-ray emission rate (gamma rays per second),
DF = decay factor for the calibrating radionuclide:

$$DF = e^{-\lambda \times (t_1 - t_0)} \quad (4)$$

where:

λ = $0.693 / t_{1/2}$,
$t_{1/2}$ = half-life of calibrating radionuclide (half-life units must match those used for the difference $t_1 - t_0$),