



Designation: C1295 – 13

# Standard Test Method for Gamma Energy Emission from Fission and Decay Products in Uranium Hexafluoride and Uranyl Nitrate Solution<sup>1</sup>

This standard is issued under the fixed designation C1295; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the measurement of gamma energy emitted from fission and decay products in uranium hexafluoride ( $UF_6$ ) and uranyl nitrate solution. It is intended to provide a method for demonstrating compliance with  $UF_6$  specifications C787 and C996 and uranyl nitrate specification C788.

1.2 The lower limit of detection is 5000 MeV Bq/kg (MeV/kg per second) of uranium and is the square root of the sum of the squares of the individual reporting limits of the nuclides to be measured. The limit of detection was determined on a pure, aged natural uranium (ANU) solution. The value is dependent upon detector efficiency and background.

1.3 The nuclides to be measured are  $^{106}Ru/^{106}Rh$ ,  $^{103}Ru$ ,  $^{137}Cs$ ,  $^{144}Ce$ ,  $^{144}Pr$ ,  $^{141}Ce$ ,  $^{95}Zr$ ,  $^{95}Nb$ , and  $^{125}Sb$ . Other gamma energy-emitting fission nuclides present in the spectrum at detectable levels should be identified and quantified as required by the data quality objectives.

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

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.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

C761 Test Methods for Chemical, Mass Spectrometric, Spectrochemical, Nuclear, and Radiochemical Analysis of

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.05 on Methods of Test.

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<sup>2</sup> 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.

Uranium Hexafluoride

C787 Specification for Uranium Hexafluoride for Enrichment

C788 Specification for Nuclear-Grade Uranyl Nitrate Solution or Crystals

C996 Specification for Uranium Hexafluoride Enriched to Less Than 5 %  $^{235}U$

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

## 3. Summary of Test Method

3.1 A solution of the uranium sample is counted on a high-resolution gamma-ray spectrometry system. The resulting spectrum is analyzed to determine the identity and activity of the gamma-ray-emitting radioactive fission and decay products. The number of counts recorded from one or more of the peaks identified with each fission nuclide is converted to disintegrations of that nuclide per second (Bq). The gamma-ray energy for a fission nuclide is calculated by multiplying the number of disintegrations per second of the nuclide by the mean gamma-ray energy emission rate of the nuclide. The calculated gamma-ray energy emission rates for all observed fission nuclides are summed, then divided by the mass of the uranium in the sample to calculate the overall rate of gamma energy production in units of million electron volts per second per kilogram of uranium. Decay product nuclides will be separately quantified and reported based on specific needs.

## 4. Significance and Use

4.1 Specific gamma-ray emitting radionuclides in  $UF_6$  are identified and quantified using a high-resolution gamma-ray energy analysis system, which includes a high-resolution germanium detector. This test method shall be used to meet the health and safety specifications of C787, C788, and C996 regarding applicable fission products in reprocessed uranium solutions. This test method may also be used to provide information to parties such as conversion facilities on the level of uranium decay products in such materials.

## 5. Apparatus

5.1 *High-Resolution Gamma-Ray Spectrometry System*, as specified in Practice D3649.

5.2 *Sample Container with Fitted Cap*—A leak-proof plastic container capable of holding the required sample volume. The dimensions must be consistent between containers used for samples and standard to keep the counting geometry constant. The greatest detection efficiency will be achieved with a low-height sample container with a diameter slightly smaller than the detector being used.

5.3 *Sample Holder*, shall be used to position the sample container such that the detector view of the sample is reproducible. To reduce the effects of coincident summing, the sample holder shall provide a minimum separation of 5 mm between the sample container and the detector end cap.

## 6. Calibration and Standardization of Detector

6.1 Prepare a mixed radionuclide calibration standard stock solution covering the energy range of approximately 50 to 2000 keV.

6.1.1 Commercial calibration standards are available which are traceable to NIST or other national standards laboratories.

6.2 Prepare a solution of ANU at 6.74 gU/100 g. The uranium and its progeny's relationship must not have been altered for at least eight months.

6.3 Transfer a known, suitable activity of the mixed nuclide calibration standard stock solution (40 to 50 kBq) to a container identical to that used for the sample measurement. Add ANU solution to the mixed nuclide standard so that the final volume and uranium concentration match those expected in the sample measurement. Practice D3649 provides information on calibration of detector energy, efficiency, resolution, and other parameters.

6.4 The detector energy scale and efficiency are calibrated by placing the container with the mixed nuclide calibration standard in a sample holder that provides a reproducible geometry relative to the detector. Collect a spectrum over a period up to 1 h that includes all the gamma photopeaks in the energy range up to ~2000 keV. All counting conditions (except count duration) must be identical to those that will be used for analysis of the actual sample.

6.5 Determine the net counts under each peak of every nuclide in the mixed radionuclide standard, then divide by the

count duration (live time) to determine the rate in counts per second for each radionuclide. If a background count on the detector shows any net peak area for the peaks of interest, these must be subtracted from the standard counts per second.

6.6 Divide the observed count rate determined for each gamma peak by the calculated emission rate of the gamma ray that produced the peak in the mixed calibration standard (gammas per second).

6.6.1 Calculation of the gamma emission rate for each peak from the mixed calibration standard must account for the following:

6.6.1.1 Activity of the nuclide that produces the peak in its original standard (disintegrations/second/unit volume). This is taken from the standard certificate of measurement supplied with the standard.

6.6.1.2 Volume of each isotopic standard taken for the mixed standard and the final volume of the mixed standard.

6.6.1.3 Fraction of the volume of the mixed standard taken for counting.

6.6.1.4 Decay of the activity of each isotope in the standard between its date of standardization and the date of counting according to the equation:

$$A_i = A_{i_0} e^{-\lambda_i t} \quad (1)$$

where:

$A_i$  = activity of isotope  $i$  on the date of counting in Bq,

$A_{i_0}$  = activity of isotope  $i$  on the date of standard characterization in Bq,

$\lambda_i$  = decay constant of isotope  $i$  in units of inverse time (values for some isotopes of interest may be found in column 3 of Table 1), and

$t$  = elapsed time between the calibration reference date and the date of counting. Time units must be the same as in the decay constant.

6.6.1.5 The abundance of gamma rays of the energy of interest emitted by each disintegration (see Table 1).

6.7 Plot a detector efficiency curve of counts/gamma versus gamma energy. Most multichannel analyzers and associated software are able to store individual values from this curve or the equation of the curve for later use.

**TABLE 1 Gamma-Ray-Emitting Fission Products Found in UF<sub>6</sub>**

| Nuclide                              | Half-Life | Decay Constant ( $\lambda_i$ ) | Measurement Peaks, MeV | Abundance Gamma/Disintegration ( $G_i$ ) | Mean Gamma Energy Disintegration, MeV Bq ( $E_i$ ) |
|--------------------------------------|-----------|--------------------------------|------------------------|--|--|
| <sup>103</sup> Ru/ <sup>103</sup> Rh | 39.35d    | 0.01761/d                      | 0.4971<br>0.6103       | 0.889<br>0.056                           | 0.484  |
| <sup>106</sup> Ru/ <sup>106</sup> Rh | 366.5d    | 0.001891/d                     | 0.5119<br>0.6222       | 0.207<br>0.0981                          | 0.209  |
| <sup>141</sup> Ce                    | 32.55d    | 0.02129/d                      | 0.1454                 | 0.484                                    | 0.0718   |
| <sup>144</sup> Ce/ <sup>144</sup> Pr | 284.5d    | 0.002436/d                     | 0.1335                 | 0.1110                                   | 0.0518   |
| <sup>137</sup> Cs/ <sup>137</sup> Ba | 30.17y    | 0.02297/y                      | 0.6616                 | 0.851                                    | 0.5655   |
| <sup>95</sup> Nb                     | 34.97d    | 0.01982/d                      | 0.7658                 | 1.000                                    | 0.766  |
| <sup>95</sup> Zr                     | 63.98d    | 0.01083/d                      | 0.7242<br>0.7567       | 0.444<br>0.549                           | 0.737  |
| <sup>125</sup> Sb                    | 2.71y     | 0.256/y                        | 0.4279<br>0.6008       | 0.294<br>0.178                           | 0.433  |