Designation: C1931 – 23

Standard Test Method for Determination of Uranium Isotopic Composition by Gamma-Ray Spectrometry[1]

This standard is issued under the fixed designation C1931; 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 applies to the nondestructive determination of the isotopic abundances of uranium, typically ^{234}U, ^{235}U, ^{236}U, and ^{238}U, in isotopically homogeneous uranium-bearing materials using gamma spectrometry. The material is commonly inside a container and is measured without specimen preparation.

1.2 This test method is applicable to items containing sub-gram quantities of uranium to the maximum uranium mass allowed by criticality considerations.

1.3 Measurable gamma ray emissions from uranium cover the energy range from below 80 keV to above 1000 keV. K-X-ray emissions from the isotopes of uranium and their daughters are found in the energy region around 100 keV. This test method has been applied to all portions of this energy range.

1.4 The isotopic abundance of ^{236}U is usually not directly determined because its low-energy gamma rays are too weak (**1**)[2] to be detected under normal measurement conditions. Isotopic correlation techniques have been used to estimate its relative abundance (**2**).

1.5 This test method has been demonstrated in routine use for isotopic amount fraction (atom %) of ^{235}U from 0.2 % to 97 %.

1.6 This test method requires decay equilibrium (160 days for 99 %) between ^{238}U and its 24.1 d half-life ^{234}Th daughter. Corrections can be made if the date of chemical separation of the ^{234}Th daughter is known.

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

1.8 *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.*

1.9 *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:*[3]

C698 Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Mixed Oxides ($(U, Pu)O_2$)

C1030 Test Method for Determination of Plutonium Isotopic Composition by Gamma-Ray Spectrometry

C1133 Test Method for Nondestructive Assay of Special Nuclear Material in Low-Density Scrap and Waste by Segmented Passive Gamma-Ray Scanning

C1221 Test Method for Nondestructive Analysis of Special Nuclear Materials in Homogeneous Solutions by Gamma-Ray Spectrometry

C1316 Test Method for Nondestructive Assay of Nuclear Material in Scrap and Waste by Passive-Active Neutron Counting Using ^{252}Cf Shuffler

C1455 Test Method for Nondestructive Assay of Special Nuclear Material Holdup Using Gamma-Ray Spectroscopic Methods

C1458 Test Method for Nondestructive Assay of Plutonium, Tritium and ^{241}Am by Calorimetric Assay

C1493 Test Method for Non-Destructive Assay of Nuclear Material in Waste by Passive and Active Neutron Counting Using a Differential Die-Away System

C1514 Test Method for Measurement of ^{235}U Fraction Using Enrichment Meter Principle

C1673 Terminology of C26.10 Nondestructive Assay Methods

[1] This test method is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.10 on Non Destructive Assay.

Current edition approved June 1, 2023. Published November 2023. DOI: 10.1520/C1931-23.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[3] 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.

C1718 Test Method for Nondestructive Assay of Radioactive Material by Tomographic Gamma Scanning
E181 Guide for Detector Calibration and Analysis of Radionuclides in Radiation Metrology for Reactor Dosimetry
E267 Test Method for Uranium and Plutonium Concentrations and Isotopic Abundances

2.2 *ANSI Standards:*[4]

ANSI/IEEE Std 325-1996 IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors
ANSI N15.36 Measurement Control Program – Nondestructive Assay Measurement Control and Assurance

3. Summary of Test Method

3.1 The full-energy peak intensities of gamma-rays emitted from an uranium-bearing item are determined from a single gamma-ray spectrum obtained with a High-Purity Germanium (HPGe) detector. The method has also been developed for use with $LaBr_3$(Ce) and CZT detectors (**3**).

3.2 3.2 For isotopically homogeneous uranium the isotope amount ratio, N^i/N^k, for isotopes i and k is related to the net counts in the full energy peaks of interest, $C\ (E_j^i)$, for gamma ray j with energy E_j emitted from isotope i and $C\ (E_l^k)$ for gamma ray l with energy E_l from isotope k by:

$$\frac{N^i}{N^k} = \frac{C(E_j^i)}{C(E_l^k)} \cdot \frac{T_{1/2}^i}{T_{1/2}^k} \cdot \frac{BR_l^k}{BR_j^i} \cdot \frac{RE(E_l)}{RE(E_j)} \tag{1}$$

where:

$RE(E_i)$ = relative detection efficiency for a gamma-ray of energy E_i,
$T_{1/2}^i$ = half-life of isotope i, and
BR_j^i = gamma-ray branching ratio or branching intensity (usually expressed as gamma-rays per disintegration) of gamma ray j from isotope i.

Eq 1 applies to isotopically homogeneous uranium where the relative efficiency is only dependent on energy.

3.3 The half-lives $T_{1/2}$ and the branching ratios BR are known, published nuclear data. The full energy peak counting intensity $C(E)$ is determined from the gamma-ray spectrum of the measured item.

3.4 The relative detection efficiency, $RE(E)$, is a function of gamma-ray energy and arises from the combined effects of detector response, attenuation due to absorbers and container walls, and self-absorption within the measured item for gamma rays of differing energies. The relative detection efficiencies are determined for each measured item from the observed gamma-ray spectrum by considering a series of gamma rays from a single isotope. The quotient of the photopeak counting intensity for gamma ray j with energy E_j emitted from isotope i and the branching ratio of gamma ray j from isotope i is proportional to the relative detection efficiency at energy E_j. This quotient defines the shape of the relative efficiency as a function of energy.

$$\frac{C(E_j^i)}{BR_j^i} \propto \left(\frac{N^i}{T_{1/2}^i}\right) \cdot RE(E_j) \tag{2}$$

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

Relative efficiency data from different isotopes may be used to extend the relative efficiency curve. Data from different isotopes have the same shape but different normalization constants. It is customary to fit all the relative efficiency data to a mathematical function. The mathematical function is often chosen to represent the physical processes present in the measurement although simple polynomial functions have also been used. This process relies on the assumption that only a single isotopic composition is present.

3.5 All factors in Eq 1 are either determined from the gamma-ray spectrum of the measured item or are known, published nuclear constants. The isotope amount ratios are determined without recourse to standards or calibration by this so-called Intrinsic Calibration technique.

3.6 The measured isotope amount ratios can be converted to isotope amount fractions when the isotope amount ratios of all isotopes are measured with respect to a common isotope.

3.6.1 *Example*—Measuring isotope amount ratios (Eq 1) with respect to ^{238}U. Measure f_{234}/f_{238}, f_{235}/f_{238}, ...f_i/f_{238}, where f_i is the isotope amount fraction of isotope i in the measured item.

3.6.2 All isotope amount fractions must sum to unity.

$$1.0 = f_{234} + f_{235} + f_{236} + f_{238} \tag{3}$$

3.6.3 Dividing Eq 3 by the common isotope amount fraction, f_{238}, and rearranging gives an expression for the isotope amount fraction of the common isotope, ^{238}U here, in terms of the directly measured isotope amount ratios (see 3.6.1).

$$f_{238} = \left[\frac{f_{234}}{f_{238}} + \frac{f_{235}}{f_{238}} + \left(\frac{f_{236}}{f_{238}}\right) + 1\right]^{-1} \tag{4}$$

3.6.4 Compute the other isotope amount fractions from the measured isotope amount ratios and Eq 4.

$$f_i = \frac{f_i}{f_{238}} \times f_{238}, i \neq 236 \tag{5}$$

3.6.5 Compute f_{236} from an isotopic correlation or acceptable knowledge. (See 1.4 and Refs (**1 and 2**).)

3.6.6 Renormalize, if needed, so all isotope amount fractions sum to unity.

3.6.7 The directly measured isotope amount fractions may be converted to isotope mass fractions, if desired, using:

$$m_{xxx} = \frac{f_{xxx} \cdot A_{xxx}}{(f_{234} \cdot A_{234} + f_{235} \cdot A_{235} + f_{236} \cdot A_{236} + f_{238} \cdot A_{238})} \tag{6}$$

where:

m_{xxx} = isotope mass fraction of isotope xxx,
A_{xxx} = atomic mass of isotope xxx, and
f_{xxx} = directly measured isotope amount fraction of isotope xxx.

4. Significance and Use

4.1 The determination of uranium isotopic composition by gamma-ray spectrometry is a nondestructive technique and when used with other nondestructive techniques that quantify a single isotope, such as Test Methods C1133 (Segmented Gamma Scanning), C1221 (Solution Assay), C1455 (Holdup),