INTERNATIONAL

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Standard Test Method for Non-Destructive Assay of Nuclear Material in Waste by Passive and Active Neutron Counting Using a Differential Die-Away System[1]

This standard is issued under the fixed designation C1493; 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 a system that performs nondestructive assay (NDA) of uranium or plutonium, or both, using the active, differential die-away technique (DDT), and passive neutron coincidence counting. Results from the active and passive measurements are combined to determine the total amount of fissile and spontaneously-fissioning material in drums of scrap or waste. Corrections are made to the measurements for the effects of neutron moderation and absorption, assuming that the effects are averaged over the volume of the drum and that no significant lumps of nuclear material are present. These systems are most widely used to assay low-level and transuranic waste, but may also be used for the measurement of scrap materials. The examples given within this test method are specific to the second-generation Los Alamos National Laboratory (LANL) passive-active neutron assay system.

1.1.1 In the active mode, the system measures fissile isotopes such as ^{235}U and ^{239}Pu. The neutrons from a pulsed, 14-MeV neutron generator are thermalized to induce fission in the assay item. Between generator pulses, the system detects prompt-fission neutrons emitted from the fissile material. The number of detected neutrons between pulses is proportional to the mass of fissile material. This method is called the differential die-away technique.

1.1.2 In the passive mode, the system detects time-coincident neutrons emitted from spontaneously fissioning isotopes. The primary isotopes measured are ^{238}Pu, ^{240}Pu, and ^{242}Pu; however, the system may be adapted for use on other spontaneously-fissioning isotopes as well, such as kilogram quantities of ^{238}U. The number of coincident neutrons detected is proportional to the mass of spontaneously-fissioning material.

1.2 The active mode is used to assay fissile material in the following ranges.

1.2.1 For uranium-only bearing items, the DDT can measure the ^{235}U content in the range from about 0.02 to over 100 g. Small mass uranium-bearing items are typically measured using the active mode and only large mass items are measured in passive mode.

1.2.2 For plutonium-only bearing items, the DDT method measures the ^{239}Pu content in the range between about 0.01 and 20 g.

1.3 The passive mode is capable of assaying spontaneously-fissioning nuclei, over a nominal range from 0.05 to 15 g ^{240}Pu equivalent.

1.4 This test method requires knowledge of the relative abundances of the plutonium or uranium isotopes to determine the total plutonium or uranium mass.

1.5 This test method will give biased results when the waste form does not meet the calibration specifications and the measurement assumptions presented in this test method regarding the requirements for a homogeneous matrix, uniform source distribution, and the absence of nuclear material lumps, to the extent that they effect the measurement.

1.6 The complete active and passive assay of a 208 L drum is nominally 10 min or less but either mode can be extended to meet data quality objectives.

1.7 Some improvements to this test method have been reported (**1**, **2**, **3**, **4**).[2] Discussions of these improvements are not included in this test method although improvements continue to occur.

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

1.9 *This standard may involve hazardous materials, operations, and equipment. 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*

[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.

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[2] The boldface numbers given in parentheses refer to a list of references at the end of the text.

establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 8.

1.10 *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]

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

C1207 Test Method for Nondestructive Assay of Plutonium in Scrap and Waste by Passive Neutron Coincidence Counting

C1215 Guide for Preparing and Interpreting Precision and Bias Statements in Test Method Standards Used in the Nuclear Industry

C1490 Guide for the Selection, Training and Qualification of Nondestructive Assay (NDA) Personnel

C1592 Guide for Making Quality Nondestructive Assay Measurements

C1673 Terminology of C26.10 Nondestructive Assay Methods

2.2 *ANSI Standard:*[4]

ANSI N15.20 Guide to Calibrating Nondestructive Assay Systems

2.3 *U.S. Government Documents:*[5]

DOE Order 435.1 (supersedes DOE Order 5820.2A) Radioactive Waste Management

DOE Order 474.1 (supersedes DOE Order 5633.3B) Control and Accountability of Nuclear Materials

DOE Order 5630.2 Control and Accountability of Nuclear Materials, Basic Principles

DOE /WIPP-069 Waste Acceptance Criteria for the Waste Isolation Pilot Plant

10 CFR Part 71 Packaging and Transport of Radioactive Materials

40 CFR Part 191 Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Waste

USNRC Regulatory Guide 5.11 Nondestructive Assay of Special Nuclear Materials Contained in Scrap and Waste

USNRC Regulatory Guide 5.53 Qualification, Calibration, and Error Estimation Methods for Nondestructive Assay

3. Terminology

3.1 *Definitions:*

3.1.1 The following definitions are needed in addition to those presented in C26.10 Terminology C1673.

3.1.2 *active mode, n*—determines total fissile mass of the assayed item through thermal neutron interrogation and subsequent detection of prompt-fission neutrons released from induced fission. A 14-MeV neutron generator is pulsed at a nominal rate of 50 Hz. The pulsed neutrons rapidly thermalize in the chamber and in the assay item. Thermal neutrons are captured by fissile material which then fissions and immediately releases more neutrons which are detected prior to the initiation of the next pulse. The prompt-neutron count rate is proportional to the mass of fissile material. This mode is called the differential die-away technique (DDT). Refer to Fig. 1.

3.1.3 *bare detector package, n*—neutron detectors surrounded by polyethylene, but not shielded with cadmium. These packages provide a better efficiency for thermal neutrons, thus providing a better passive sensitivity when a small amount of nuclear material is present.

3.1.3.1 *bare totals, n*—is the sum of neutrons detected from all bare detector packages.

3.1.4 *early gate, n*—the time interval during which the thermal-neutron induced prompt-fission neutrons are measured.

3.1.4.1 *Discussion*—Typically, this time interval begins 0.4 to 0.9 ms after the initiating neutron generator pulse and is 2 to 4 ms in duration. This gate is used only during the active mode. Fig. 1 indicates the approximate delay and length of the early gate in reference to a generator pulse.

3.1.5 *late gate, n*—the time interval during which the active neutron background is measured. Typically, this time interval begins 8 to 18 ms after the initiating neutron generator pulse. Refer to Fig. 1.

4. Summary of Test Method

4.1 This test method addresses a system that performs active differential die-away and passive neutron coincidence counting. Examples of the apparatus, data acquisition, and calculations contained in this test method are specific to the second-generation LANL passive-active neutron assay system (**5**) but the principle applies to other DDT systems.

4.1.1 Typically, the active mode is performed prior to the passive mode. A 208 L drum is placed inside the chamber and rotated continuously during the measurement. The active mode is performed by interrogating the drum with neutrons from a pulsed neutron generator for 40 to 200 s. The passive mode is performed using a counting interval of 200 to 1000 s (**5, 6, 7**). If the isotopic ratios as well as the relative responses are known for individual radionuclides, the active and passive modes can be used to give independent measurements of the total plutonium mass.

4.1.2 The system can also be operated only in the passive mode to measure the plutonium content of scrap or waste, or only in the active mode for measurement of uranium.

[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.

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

[5] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

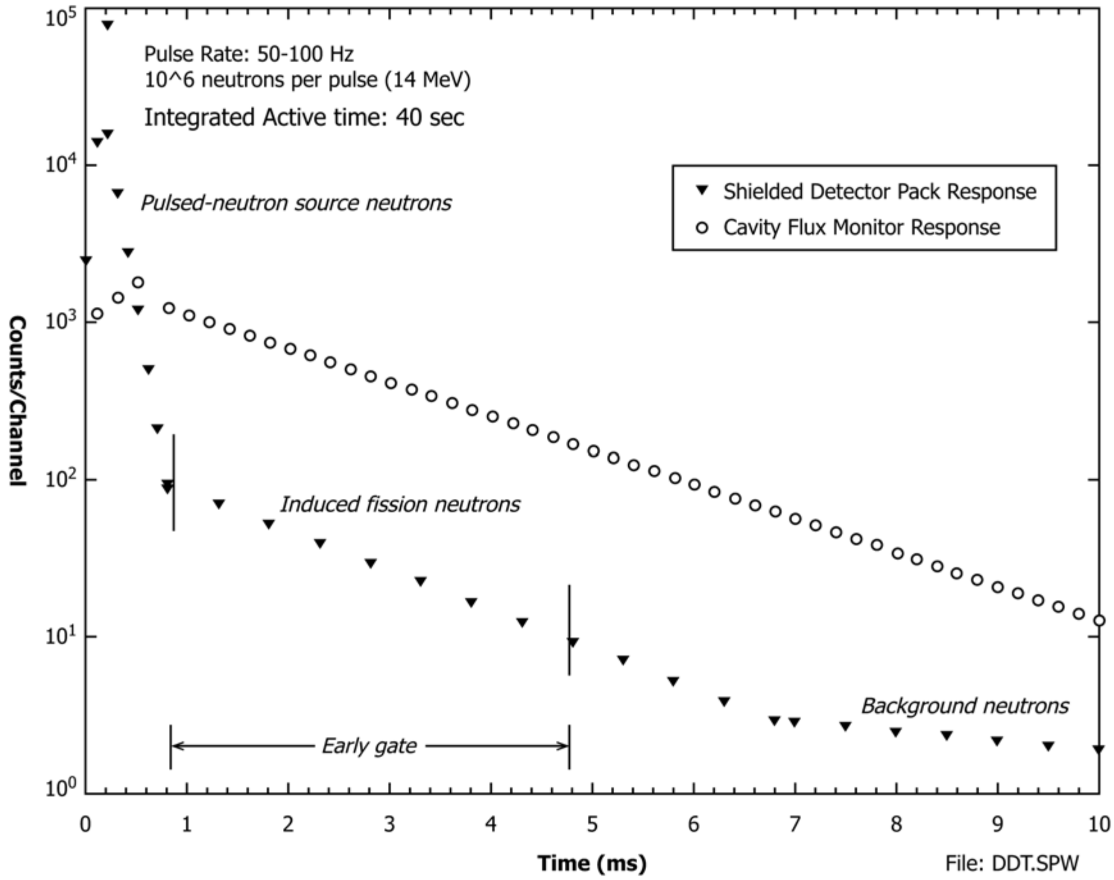

FIG. 1 Time History of an Active Assay of Plutonium Using the Differential Die-Away Technique

4.1.3 In all modes, the relative abundances of the plutonium and uranium isotopes are required to determine the total plutonium mass, uranium mass, or both.

4.2 The active assay is performed using the differential die-away technique (**5**, **6**, **7**). The technique is described below and in Fig. 1.

4.2.1 A 14-MeV neutron generator is pulsed periodically, with a pulse width of 10 to 20 µs, usually at a frequency of 50 or 100 Hz.

4.2.2 After each pulse, the neutrons are quickly moderated to thermal energies in the polyethylene walls, graphite walls, or both, of the cavity and ultimately, in the waste matrix of the drum where they induce fission in fissile material.

4.2.3 The high energy neutrons from the generator that enter the Cd-shielded detector packages decrease in number exponentially (due to capture or escape). After about 600 to 900 µs, essentially all of the high energy interrogating neutrons have been cleared from the detector packages and the remaining interrogating flux of neutrons is at thermal energies.

4.2.4 Fissions induced by the interrogating neutron flux in the fissile material in the drum produce prompt high-energy neutrons, which are thermalized by the waste matrix and the walls of the measurement chamber before being measured by the shielded detector packages during the early gate. Typically, the prompt neutrons are counted in this gate, nominally between 0.7 to 4.7 ms after each generator pulse (see Fig. 1, Region A). The temporal difference between the fission neutron signal and the tail of the interrogation neutron signal gives rise to the name of the technique - differential die-away.

4.2.5 A background count is also made during the late gate (typically 8 to 18 ms after each pulse after the moderated interrogating and induced fission neutrons have been cleared from the system (see Fig. 1, Region B). The late gate count is used to correct the early gate count for background neutrons, which are those neutrons, including delayed fission neutrons, that are not prompt fission neutrons.

4.2.6 The net number of prompt neutrons detected, normalized to the interrogating neutron flux as measured by the cavity flux monitor, is correlated to the quantity of fissile material in the drum.

4.2.7 The total nuclide mass is determined from the known relative abundances of the isotopes (Test Method C1030) and the measured fissile mass.

4.3 The passive assay uses both shielded and bare detector packages to count accidentals and coincident neutrons from spontaneously-fissioning nuclei. Corrections are made to the counting data to account for background coincident neutrons. The number of coincident neutrons detected by the system is correlated to the mass of spontaneously-fissioning isotopes (for example, the even mass isotopes of plutonium) in the assay item (Test Method C1207). The total plutonium mass is determined from the corrected coincidence count rates, the calibration curve correlating the corrected coincidence count