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.

Designation: C1316 – 08 (Reapproved 2017)

Standard Test Method for Nondestructive Assay of Nuclear Material in Scrap and Waste by Passive-Active Neutron Counting Using ^{252}Cf Shuffler[1]

This standard is issued under the fixed designation C1316; 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 the nondestructive assay of scrap and waste items for U, Pu, or both, using a ^{252} Cf shuffler. Shuffler measurements have been applied to a variety of matrix materials in containers of up to several 100 L. Corrections are made for the effects of matrix material. Applications of this test method include measurements for safeguards, accountability, TRU, and U waste segregation, disposal, and process control purposes (**1**, **2**, **3**).[2]

1.1.1 This test method uses passive neutron coincidence counting (**4**) to measure the ^{240}Pu-effective mass. It has been used to assay items with total Pu contents between 0.03 g and 1000 g. It could be used to measure other spontaneously fissioning isotopes such as Cm and Cf. It specifically describes the approach used with shift register electronics; however, it can be adapted to other electronics.

1.1.2 This test method uses neutron irradiation with a moveable Cf source and counting of the delayed neutrons from the induced fissions to measure the ^{235}U equivalent fissile mass. It has been used to assay items with ^{235}U contents between 0.1 g and 1000 g. It could be used to assay other fissile and fissionable isotopes.

1.2 This test method requires knowledge of the relative isotopic composition (See Test Method C1030) of the special nuclear material to determine the mass of the different elements from the measurable quantities.

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

1.4 The techniques described in this test method have been applied to materials other than scrap and waste. These other applications are not addressed in this test method.

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.* Specific precautionary statements are given in Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C1009 Guide for Establishing and Maintaining a Quality Assurance Program for Analytical Laboratories Within the Nuclear Industry

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

C1068 Guide for Qualification of Measurement Methods by a Laboratory Within the Nuclear Industry

C1128 Guide for Preparation of Working Reference Materials for Use in Analysis of Nuclear Fuel Cycle Materials

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

C1156 Guide for Establishing Calibration for a Measurement Method Used to Analyze Nuclear Fuel Cycle Materials

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

C1210 Guide for Establishing a Measurement System Quality Control Program for Analytical Chemistry Laboratories Within the Nuclear Industry

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 Nondestructive Assay Measurements

[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 in parentheses refer to a list of references at the end of this test method.

[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.

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2.2 *ANSI Documents:*

ANSI 15.20 Guide to Calibrating Nondestructive Assay Systems[4]

ANSI N15.36 Nondestructive Assay Measurement Control and Assurance[4]

3. Terminology

3.1 *Definitions*—Terms shall be defined in accordance with Terminology C1673.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *active mode, n*—determines total fissile mass in the assayed item through neutron interrogation and counting of the delayed neutrons from induced fissions.

4. Summary of Test Method

4.1 This test method consists of two distinct modes of operation: passive and active. The instrument that performs the active mode measurement is referred to as a shuffler due to the cyclic motion of the ^{252}Cf source. This test method usually relies on passive neutron coincidence counting to determine the Pu content of the item, and active neutron irradiation followed by delayed neutron counting to determine the U content.

4.1.1 *Passive Neutron Coincidence Counting Mode*—The even mass isotopes of Pu fission spontaneously. On average approximately 2.2 prompt neutrons are emitted per fission. The number of coincident fission neutrons detected by the instrument is correlated to the quantity of even mass isotopes of Pu. The total Pu mass is determined from the known isotopic ratios and the measured quantity of even mass isotopes. This test method refers specifically to the shift register coincidence counting electronics (see **(4)** and Test Method C1207).

4.1.2 *Active Neutron (Shuffler) Mode*—Fissions in ^{235}U, ^{239}Pu and other fissile nuclides can be induced by bombarding them with neutrons. Approximately 1 % of the neutrons emitted per fission are delayed in time, being emitted from the fission products over the time range from μs to several minutes after the fission event. Roberts et. al **(5)** were the first to observe delayed neutron emission. We now know that over 270 delayed neutron precursors contribute to the yield although the time behavior can be adequately described for most purposes using a few (six to eight) effective groups each with a characteristic time constant. The idea of detecting delayed neutrons for the analysis of ^{235}U has been attributed to Echo and Turk **(6)**. The active shuffler mode consists of several irradiate-count cycles, or shuffles, of the ^{252}Cf neutron source between the positions illustrated in Fig. 1. ^{252}Cf emits a fission neutron spectrum. During each shuffle, the ^{252}Cf source is moved close to the item for a short irradiation, then moved to a shielded position while the delayed neutrons are counted. The number of delayed neutrons detected is correlated with the quantity of fissile and fissionable material. The total U mass is determined from the known relative isotopic compostion and the measured quantity of ^{235}U equivalent **(7)**.

4.2 Either corrections are made for the effects of neutron absorbers and moderators in the matrix, or a matrix-specific calibration is used. The effect that needs correction is the increase or decrease in the specific neutron signal caused by the matrix.

4.3 Corrections are made for deadtime, neutron background, and the Cf source decay.

4.4 The active mode also induces fissions in Pu if it is present in the assay item. The passive measurement of Pu can be used to correct the active measurement of ^{235}U effective for the presence of Pu.

4.5 Calibrations are generally based on measurements of well documented reference materials **(8)** and may be extended by calculation **(9-11)**. The method includes measurement control tests to verify reliable and stable performance of the instrument.

5. Significance and Use

5.1 This test method is used to determine the U and Pu content of scrap and waste in containers. Active measurement times have typically been 100 to 1000 s. Passive measurement times have typically been 400 s to several hours. The following limits may be further restricted depending upon specific matrix, calibration material, criticality safety, or counting equipment considerations.

5.1.1 The passive measurement has been applied to benign matrices in 208 L drums with Pu content ranging from 30 mg to 1 kg.

5.1.2 The active measurement has been applied to waste drums with ^{235}U content ranging from about 100 mg to 1 kg.

5.2 This test method can be used to demonstrate compliance with the radioactivity levels specified in safeguards, waste, disposal, and environmental regulations (for example, see NRC regulatory guides 5.11, 5.53, DOE Order 5820.2a, and 10CFR61 sections 61.55 and sections 61.56, 40CFR191, and DOE/WIPP-069).

5.3 This test method could be used to detect diversion attempts that use shielding to encapsulate nuclear material.

5.4 The bias of the measurement results is related to the item size and density, the homogeneity and composition of the matrix, and the quantity and distribution of the nuclear material. The precision of the measurement results is related to the quantity of nuclear material and the count time of the measurement.

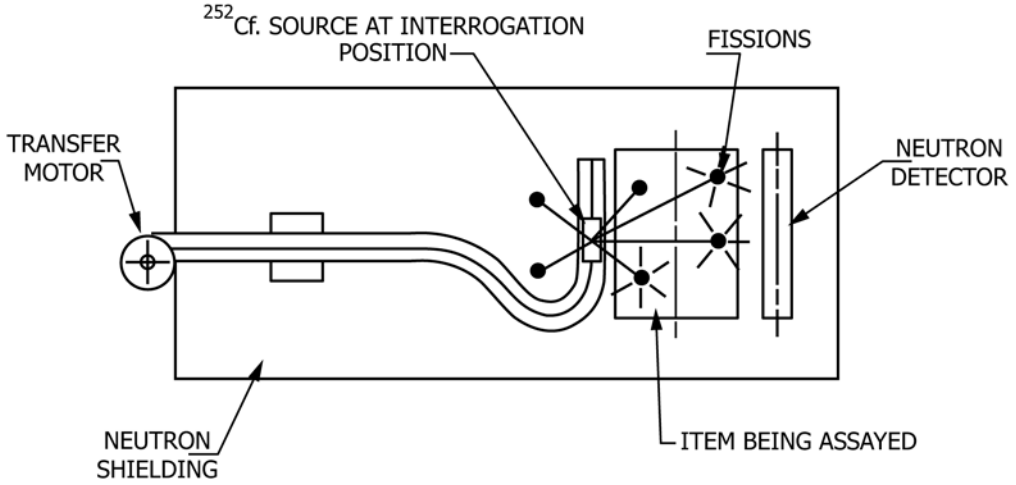
5.4.1 For both the matrix-specific and the matrix-correction approaches, the method assumes the calibration materials match the items to be measured with respect to the homogeneity and composition of the matrix, the neutron moderator and absorber content, and the quantity of nuclear material, to the extent they affect the measurement.

5.4.2 It is recommended that measurements be made on small containers of scrap and waste before they are combined in large containers. Special arrangement may be required to assay small containers to best effect in a large cavity general purpose shuffer.

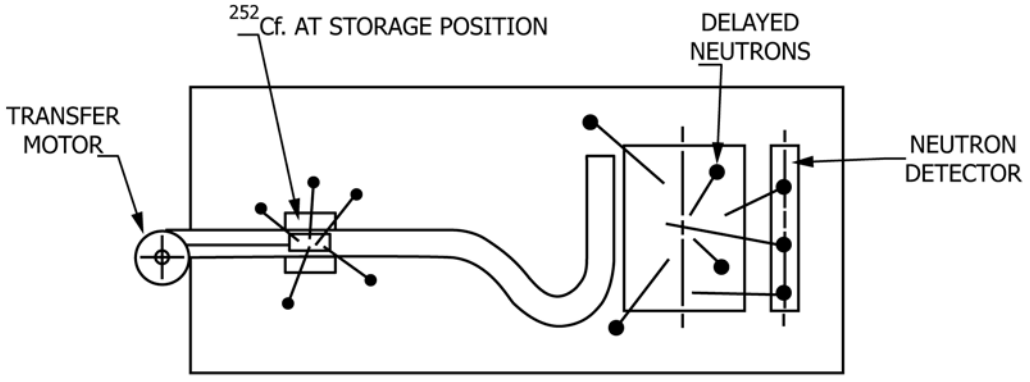
[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

^{252}Cf. SHUFFLER MEASUREMENT PRINCIPLE

A ^{252}Cf. NEUTRON SOURCE IS USED TO INDUCE FISSIONS IN THE SAMPLE.



DELAYED NEUTRONS ARE COUNTED WITH THE SOURCE STORED



NOTE 1—The shuffler measurement consists of several cycles. Each cycle includes the movement of the ^{252}Cf source from the storage (or home) position to the irradiation position close to the item, irradiation of the item for a period of about 10 s, return of the source to the shield followed by a counting period of about 10 s. In obvious notation this cycle structure may be succinctly described by the four time periods involved (t_{in}, t_{irr}, t_{out}, t_{cnt}). Typically the one-way transit times are less than 1 s.

FIG. 1 Cf Shuffler Measurement Principle