Designation: C1807 – 15

Standard Guide for Nondestructive Assay of Special Nuclear Material (SNM) Holdup Using Passive Neutron Measurement Methods[1]

This standard is issued under the fixed designation C1807; 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 guide describes passive neutron measurement methods used to nondestructively estimate the amount of neutron-emitting special nuclear material compounds remaining as holdup in nuclear facilities. Holdup occurs in all facilities in which nuclear material is processed. Material may exist, for example, in process equipment, in exhaust ventilation systems, and in building walls and floors.

1.1.1 The most frequent uses of passive neutron holdup techniques are for the measurement of uranium or plutonium deposits in processing facilities.

1.2 This guide includes information useful for management, planning, selection of equipment, consideration of interferences, measurement program definition, and the utilization of resources.

1.3 Counting modes include both singles (totals) or gross counting and neutron coincidence techniques.

1.3.1 Neutron holdup measurements of uranium are typically performed on neutrons emitted during (α, n) reactions and spontaneous fission using singles (totals) or gross counting. While the method does not preclude measurement using coincidence or multiplicity counting for uranium, measurement efficiency is generally not sufficient to permit assays in reasonable counting times.

1.3.2 For measurement of plutonium in gloveboxes, installed measurement equipment may provide sufficient efficiency for performing counting using neutron coincidence techniques in reasonable counting times.

1.4 The measurement of nuclear material holdup in process equipment requires a scientific knowledge of radiation sources and detectors, radiation transport, modeling methods, calibration, facility operations, and uncertainty analysis. It is subject to the constraints of the facility, management, budget, and schedule, plus health and safety requirements, as well as the laws of physics. This guide does not purport to instruct the NDA practitioner on these principles.

1.5 The measurement process includes defining measurement uncertainties and is sensitive to the chemical composition, isotopic composition, distribution of the material, various backgrounds, and interferences. The work includes investigation of material distributions within a facility, which could include potentially large holdup surface areas. Nuclear material held up in pipes, ductwork, gloveboxes, and heavy equipment is usually distributed in a diffuse and irregular manner. It is difficult to define the measurement geometry, identify the form of the material, and measure it.

1.6 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.7 *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:*[2]

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

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

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

C1592/C1592M Guide for Making Quality Nondestructive Assay Measurements

C1673 Terminology of C26.10 Nondestructive Assay Methods

2.2 *NRC Standard:*

NRC Regulatory Guide 5.23 In-Situ Assay of Plutonium Residual Holdup[3]

[1] This guide 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 Jan. 1, 2015. Published January 2015. DOI: 10.1520/C1807-15.

[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 U. S. Nuclear Regulatory Commission (NRC), One White Flint North, 11555 Rockville Pk., Rockville, MD 20852-2738, http://www.nrc.gov.

2.3 *ANSI Standard:*
ANSI N15.20 Guide to Calibrating Nondestructive Assay Systems[4]

3. Terminology

3.1 *Definitions*—Refer to Terminology C1673 for definitions used in this guide.

4. Summary of Guide

4.1 *Introduction*—Holdup measurements using neutron methods typically measure the (α, n) or spontaneous fission production of neutrons, or both. Neutrons generated in items that do not include significant masses of neutron moderators, such as hydrogenous materials, typically have an escape fraction of nearly one. The isotopic distribution and, for (α, n) production, the chemical composition of the measured material affect assay results and shall be determined by process knowledge or an alternative measurement technique. Ref **(1)**[5] provides an example of a holdup campaign using neutron measurements.

4.2 *Choice of Measurement Method*—Passive neutron measurement methods are typically used for holdup when other methods of measurement (for example, gamma-ray assay) are not practical or would produce large biases. In some cases, neutron measurements are performed in conjunction with gamma-ray measurements for defense in depth or to obtain isotopic information, or both. Neutron measurement instrumentation is typically heavier, more difficult to shield, and has more difficult data interpretation than other NDA measurement methods. Neutrons, though, are very penetrating and less influenced by lumps than gamma rays, and the instrumentation has a very stable response. Examples of when neutron measurements are preferred include containers that severely attenuate gamma rays of interest for the nuclides measured or when sufficient nuclear material is present that self-attenuation of gamma rays of interest is severe (see Test Method C1455 and Guide C1592/C1592M).

4.3 *Specific Neutron Yield*—The number of neutrons generated per unit time per unit mass of the nuclide(s) of interest is an important parameter that is affected by conditions (for example, chemical composition and isotopic distribution) not detectable by passive neutron holdup measurement methods. Information used to estimate specific neutron yield shall be determined using process knowledge or alternate analysis methods (for example, sampling and X-ray fluorescence to determine chemical composition and high-resolution gamma-ray spectroscopy to determine isotopic composition). Both the chemical and isotopic distribution have significant effects on specific neutron yield.

4.4 *Definition of Requirements*—Definition of the holdup measurement requirements should include, as a minimum, the measurement objectives (that is, nuclear criticality safety, special nuclear material (SNM) accountability, radiological safety, or combinations thereof); time and resource constraints; the desired measurement sensitivity, accuracy, and uncertainty; and available resources (schedule, funds, and subject matter experts). Specific data quality objectives should be provided when available.

4.5 *Information Gathering and Initial Evaluation*—Information shall be gathered concerning the item or items to be assayed, and an initial evaluation should be made of the measurement techniques and level of effort needed to meet the holdup measurement requirements. Preliminary radiation measurements may be needed to define the location and extent of the holdup. Additional information should be collected prior to commencement of measurements. This information includes, but is not limited to, the geometric configuration of the item or process equipment to be assayed, location of the equipment in the facility, the presence of neutron moderators and absorbers, neutron leakage multiplication, factors affecting specific neutron yield, sources of background or interferences, facility processing status, radiological and industrial safety considerations, plus the personnel and equipment needed to complete the assay. Sources of information may include a visual survey, engineering drawings, process knowledge, process operators, results of sampling and wet chemical analysis, and prior assay documentation.

4.6 *Measurement Plan*—A measurement plan shall be developed. The initial evaluation provides a basis for choosing the quantitative method and assay model and, subsequently, leads to the determination of the detection system and calibration method to be used. Appropriate reference materials and support equipment are developed or assembled for the specific measurement technique. The plan will include measurement locations and geometries or guidance for their selection. In the plan, required documentation; operating procedures; background measurement methods and frequencies; plus training, quality, and measurement control requirements (Guide C1009) are typically outlined. Necessary procedures, including those for measurement control, shall be developed, documented, and approved.

4.7 *Calibration*—Calibration and initialization of measurement control is completed before measurements of unknowns. Calibration requires reference materials traceable to a National Measurement Institute to establish detection efficiency and modeling detector response to neutron sources. If modeling is used for calibration (for example, Monte Carlo n-Partical (MCNP) modeling), detailed specifications for the detector package will be required. If modeling is used, validation of the calibration shall include validation of each model developed. Familiarity with the facility on which assays will be performed is required to ensure that calibration is sufficiently robust to encompass all reasonable measurement situations.

4.7.1 *Calibration Using ^{252}Cf*—^{252}Cf is commonly used for calibrating neutron detectors. ^{252}Cf is convenient in that it provides a point source of neutron emissions with a strong signal so that calibrations can be completed using relatively short measurement times. Corrections for the difference in detection efficiency between neutrons from ^{252}Cf and neutrons from assayed items may be significant because of the difference in average energy from the two sources. For example, the

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

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

average energy of neutrons from ^{252}Cf is 2.14 MeV and the average energy of neutrons from holdup is 1.2 MeV for (α, n) with Fluorine as a target and an alpha energy of 5.2 MeV (**2**). An additional issue is that ^{252}Cf standards are typically certified for total neutron activity, and isotopes present in the standards produce an increasing number of neutrons as the mass of ^{252}Cf decreases relative to the mass of longer-lived isotopes as time passes. As the time since separation of the ^{252}Cf increases, this may become a significant source of bias unless appropriate corrections are made.

4.7.2 *Calibration Using Surrogate Materials*—Surrogate materials, typically created using the same materials that will be subsequently measured, may also be used for calibration, provided sufficient characterization is performed to establish traceability. These sources typically produce fewer neutrons per unit time than ^{252}Cf and require longer measurement times for equivalent calibration uncertainty. In addition, surrogate materials are typically significantly larger than point sources, which may complicate the process of evaluating calibration data. Calibration using surrogate materials reduces the number of corrections (for example, for energy difference between neutrons produced by the calibration source and measured materials) and may result in a lower total measurement uncertainty.

4.7.3 *Calibration Confirmation*—A calibration confirmation is needed to produce objective evidence demonstrating the applicability and correctness of the calibration relative to the items in which holdup is to be measured. The recommended method is to assemble test item(s) consisting of source/matrix and radioactive material configuration(s) nominally representative of the items to be characterized. The test item(s) should contain known and, preferably, traceable quantity of radioactive material in a known and representative configuration. If practical, the range of expected materials should be spanned. Acceptance criteria for the calibration confirmation measurements should be established in the measurement plan.

4.8 *Measurements*—Perform measurements and measurement control as detailed in the measurement plan or procedure.

4.9 *Evaluation of Measurement Data*—As appropriate, corrections are estimated and made for factors that may bias the measurement. Examples include neutron scattering; cosmic ray induced spallation; leakage multiplication; neutron moderators, absorbers, and poisons; and the presence of targets that produce (α, n) neutrons. These corrections are applied in the calculation of the assay value. Measurement uncertainties are established based on factors affecting the assay.

4.9.1 Converting measurement data to estimates of the quantity of nuclear material holdup requires careful evaluation of the measurement parameters against calibration and modeling assumptions. Depending on the calibration, models, and measurement methods used, corrections may be necessary for geometric effects (differences between holdup measurement and calibration geometries); neutron moderators, absorbers, or poisons; scattering from nearby process equipment; the influence (scattering and shielding) of and holdup in nearby process equipment that is in the detector field of view; background; and interferences. Measurement uncertainties (random and item-specific bias) are estimated based on uncertainties in assay parameters. A comprehensive total measurement uncertainty analysis must accompany every measurement result.

4.9.2 Results should be evaluated against previous results or clean-out data, if either are available. This evaluation provides a cross-check between measurement techniques. The results of this evaluation can be used to provide feedback to measurement personnel, to refine the measurement and analysis techniques, and to evaluate the measurement uncertainty against estimates. If a discrepancy is evident, an evaluation should be made. Modeling errors or other sources of bias can be identified using this technique. Additional measurements with subsequent evaluation may be required. This can be used as a step in a phased approach.

4.9.3 If practical, measurements should be made of clean process equipment or, ideally, a plant that has not yet had nuclear material introduced. This provides a baseline for future measurement of holdup.

4.10 *Documentation*—Measurement documentation should include the plans and procedures, a description of measurement parameters considered important to the calibration and for each measurement location, the measurement techniques used, the raw data, assumptions and correction factors used in the analysis, a thorough description of the models used, the results with estimated precision and bias, and comparison to other measurement techniques when available.

5. Significance and Use

5.1 This guide assists in satisfying requirements in such areas as safeguards, SNM inventory control, nuclear criticality safety, waste disposal, and decontamination and decommissioning (D&D). This guide can apply to the measurement of holdup in process equipment or discrete items whose neutron production properties may be measured or estimated. These methods may meet target accuracy for items with complex distributions of SNM in the presence of moderators, absorbers, and neutron poisons; however, the results are subject to larger measurement uncertainties than measurements of less complex items.

5.2 *Quantitative Measurements*—These measurements result in quantification of the mass of SNM in the holdup. They include all the corrections and descriptive information, such as isotopic composition, that are available.

5.2.1 High-quality results require detailed knowledge of radiation sources and detectors, radiation transport, calibration, facility operations, and error analysis. Consultation with qualified NDA personnel is recommended (Guide C1490).

5.2.2 Holdup estimates for a single piece of process equipment or piping often include some compilation of multiple measurements. The holdup estimate must appropriately combine the results of each individual measurement. In addition, uncertainty estimates for each individual measurement must be made and appropriately combined.

5.3 *Scan*—Radiation scanning, typically gamma, may be used to provide a qualitative description of the extent, location, and the relative quantity of holdup. It can be used to plan or supplement the quantitative neutron measurements. Other indicators (for example, visual) may also indicate a need for a holdup measurement.