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Standard Guide to Procedures for Calibrating Automatic Pedestrian SNM Monitors[1]

This standard is issued under the fixed designation C 1189; 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 covers calibrating the energy response of the radiation detectors and setting the discriminator and alarm thresholds used in automatic pedestrian special nuclear material (SNM) monitors.

1.2 Automatic pedestrian SNM Monitors and their application are described in Guide C 1112, which suggests that the monitors be calibrated and tested when installed and that, thereafter, the calibration should be checked and the monitor tested with SNM at three-month intervals.

1.3 Dependable operation of SNM monitors rests, in part, on an effective program to test, calibrate, and maintain them. The procedures and methods described in this guide may help both to achieve dependable operation and obtain timely warning of misoperation.

1.4 This guide can be used in conjunction with other ASTM standards. Fig. 1 illustrates the relationship between calibration and other procedures described in standard guides, and it also shows how the guides relate to an SNM monitor user. The guides below the user in the figure deal with routine procedures for operational monitors. Note that Guide C 993 is an in-plant performance evaluation that is used to verify acceptable detection of SNM after a monitor is calibrated. The guides shown above the user in Fig. 1 give information on applying SNM monitors (C 1112) and on evaluating SNM monitors (C 1169) to provide comparative information on monitor performance.

2. Referenced Documents

2.1 *ASTM Standards:*

C 859 Terminology Relating to Nuclear Materials[2]

C 993 Guide for In-Plant Performance Evaluation of Automatic Pedestrian SNM Monitors[2]

C 1112 Guide for Application of Radiation Monitors to the Control and Physical Security of Special Nuclear Material[2]

C 1169 Guide for Laboratory Evaluation of Automatic Pedestrian SNM Monitor Performance[2]

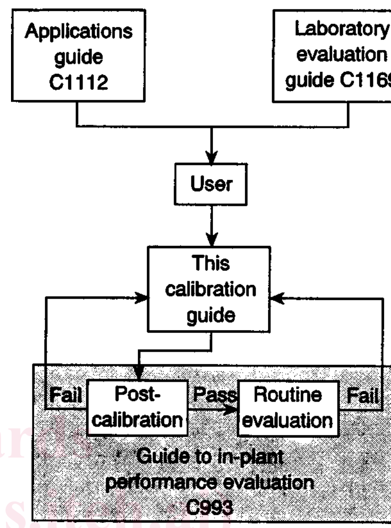

FIG. 1 The Relationship of Calibration to Other Procedures Described in Standard Guides for SNM Monitors

E 876 Practice for Use of Statistics in the Evaluation of Spectrometric Data[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *calibration*—a multistep procedure that uniformly adjusts the energy response of a monitor's detector array and sets the operating parameters of its detection circuits for optimum performance. In a few monitors, an additional analog adjustment of a signal detection circuit is required.

3.1.2 *SNM*—special nuclear material: plutonium of any isotopic composition, ^{233}U, or enriched uranium as defined in Terminology C 859.

3.1.2.1 *Discussion*—This term is used here to describe both SNM and strategic SNM, which is plutonium, uranium-233, and uranium enriched to 20% or more in the ^{235}U isotope.

3.1.3 *SNM Monitor*—a radiation detection system that measures ambient radiation intensity, determines an alarm threshold from the result, and then when it monitors, sounds an alarm if its measured radiation intensity exceeds the threshold.

3.1.3.1 *Discussion*—The automatic pedestrian SNM monitor discussed here is a walk-through or wait-in portal or monitoring booth.

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[1] This guide is under the jurisdiction of ASTM Committee C–26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.12 on Safeguard Applications.

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[2] *Annual Book of ASTM Standards*, Vol 12.01.

[3] *Annual Book of ASTM Standards*, Vol 03.06.

4. Summary of Guide

4.1 This guide covers various instructions for calibrating SNM pedestrian monitors for optimum performance in normal operation. The order of procedures is as follows.

4.1.1 The energy response of inorganic or organic scintillation detectors or of neutron proportional counters, is calibrated to produce appropriate signal pulse heights for SNM radiation (see Section 10).

4.1.2 The monitor's pulse height discriminators are calibrated to form a region of interest containing SNM radiation from highly enriched uranium or low-burnup plutonium (see Sections 9 and 11), or for detecting neutrons in proportional counters (see Section 9).

4.1.3 The monitor's transient signal detection logic is adjusted for appropriate response to walk-through or wait-in monitoring (see Section 12).

4.2 This guide covers adjusting various thresholds used in SNM monitors.

4.2.1 This guide describes setting background alarm thresholds that may be used to announce loss of detection sensitivity or detector failure (see Section 13).

4.2.2 This guide discusses setting the lowest practical discriminator levels for the radiation detectors (see Section 11).

4.3 When calibration is complete, the monitor should be tested using in-plant evaluation procedures described in Guide C 993.

5. Significance and Use

5.1 SNM monitors are an effective means to search pedestrians for concealed SNM. Maintaining monitor effectiveness rests on appropriate calibration and adjustment being part of a continuing maintenance program.

5.2 The significance of this guide for monitor users who must detect SNM is to describe calibration and adjustment procedures for the purpose.

5.3 The significance of this guide for monitor manufacturers is to describe calibration procedures, particularly for detecting forms of SNM that may not be readily available to them.

6. Interferences

6.1 The monitor should be in proper operating condition when calibrated. Any indication that the monitor does not stay in calibration or that it drifts substantially during the interval between calibration checks is cause for repair or renovation and then recalibration.

7. Apparatus

7.1 *SNM Automatic Pedestrian Monitors*, having arrays of radiation detectors that form a portal through which pedestrians pass or that surround a pedestrian as he waits in a booth for clearance to pass.

7.2 *Radiation Detectors*, used in SNM monitors may detect gamma rays, neutrons, or both. One of three types of detector listed is usually used. All of types of detector operate in a pulse-counting mode to obtain good sensitivity for detecting small changes in radiation intensity.

7.2.1 *Inorganic Scintillation Detectors*, such as sodium iodide [NaI(T1)], detect gamma rays but have little response to neutrons from SNM. This detector is useful for detecting unshielded SNM.

7.2.2 *Neutron Proportional Counters*, containing BF_3 or ^{3}He as a converter gas, detect thermal neutrons and are used with a moderator to thermalize fast neutrons from SNM. This detector is useful for detecting unshielded or shielded plutonium.

7.2.3 *Organic Scintillators*, detect both gamma rays and fast neutrons from SNM. This detector is useful for detecting unshielded SNM and shielded plutonium.

7.3 *Oscilloscope or Multi-Channel Analyzer*, for viewing reference detector pulses produced by a specific radiation source during energy calibration.

7.3.1 *Gamma-Ray Detectors*, reference pulses from 662-keV gamma rays emitted by a ^{137}Cs source with a nominal 8-microCurie (0.3-kBq) activity are used for calibration.

7.3.2 *Neutron Proportional Counters*, reference pulses from neutrons emitted by a ^{252}Cf neutron source with less than 2×10^4 neutron/s (0.009-µg) source strength can be used for calibration.

NOTE 1—Acquisition, storage, and use of sources should be under the guidance of a responsible radiation safety officer (see Section 8 on hazards).

7.4 *Manufacturer's or Designer's Operation and Maintenance Manual*, essential for quick and efficient monitor calibration. The manufacturer's suggested calibration scheme is a good starting place, if not the best approach to calibration. Calibration requires knowledge of test point and adjustment locations that should be described in the manuals.

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8. Hazards

8.1 Make sure that the use of radioactive materials is under the guidance of a responsible radiation safety officer who can provide any needed radiation safety training, personnel dosimetry, and handling procedures for radiation sources.

8.2 The radiation detectors in SNM monitors all operate at high voltages that may be hazardous. Although a person is not usually exposed to high voltage during calibration, make sure that the work is performed with the approval of a responsible safety officer with proper attention given to electrical safety training and reading any warnings of high voltage exposure in manuals or posted on equipment.

9. Pulse-Height Analysis Calibration

9.1 Once a monitor's detector array is adjusted to uniform pulse height, the pulse-height analysis circuitry can be adjusted. The point is to set a lower-level discriminator to exclude electronic noise and pulses from radiation below the SNM energy range. Most often a second-level discriminator or window is also set to discriminate energy above the SNM radiation, thus forming an SNM energy region of interest.

9.2 *Discriminator Settings for SNM*—The lower-level discriminator setting and the window or upper-level discriminator setting, if used, may depend on the type of SNM to be detected and the type of detector used for the following reasons.

9.2.1 The two types of SNM, highly enriched uranium (HEU) and low-burnup plutonium, differ in their intrinsic gamma-ray spectra.

9.2.2 Inorganic and organic scintillators respond differently to gamma rays. Inorganic scintillators produce pulse heights that are proportional to the detected gamma-ray energy. However, organic scintillators do not, as Fig. 2 illustrates. At low gamma-ray energies, a smaller fraction of the incident gamma-ray energy is deposited in an organic scintillator, and it produces a proportionately smaller pulse height. Hence, inorganic and organic scintillators calibrated to the same reference pulse height will have different upper and lower discriminator voltage levels for an SNM region of interest. The examples following illustrate the differences.

9.3 *Gamma-Ray Regions of Interest for SNM*:

9.3.1 *HEU*—The HEU gamma-ray region extends from 60 to 220 keV **(1)**.[4] The corresponding deposited energy range in an organic scintillator is 11.4 to 102 keV. The resulting discriminator levels for calibrations using 2 and 3.3 V for ^{137}Cs pulse height are as follows:

(*a*) Calibration using 2 V in a NaI(Tl) detector: 0.18 to 0.66 V,

(*b*) Calibration using 3.3 V in a NaI(Tl) detector: 0.3 to 1.10 V,

(*c*) Calibration using 2 V in a plastic detector: 0.05 to 0.43 V, and

(*d*) Calibration using 3.3 V in a plastic detector: 0.08 to 0.70 V.

9.3.2 *Low-Burnup Plutonium*—The optimum region of interest for low-burnup plutonium extends from 0 to 450 keV **(1)**. The value 0 means the lowest practical value achieved by one of the means discussed in Section 11. The corresponding deposited energy range in an organic scintillator is 0 to 287 keV. The resulting discriminator levels for calibrations using 2 and 3.3 V for ^{137}Cs pulse height are as follows:

(*a*) Calibration using 2 V in a NaI(Tl) detector: 0 to 1.36 V,

(*b*) Calibration using 3.3 V in a NaI(Tl) detector: 0 to 2.24 V,

(*c*) Calibration using 2 V in a plastic detector: 0 to 1.20 V, and

(*d*) Calibration using 3.3 V in a plastic detector: 0 to 1.97 V.

9.3.3 In case of other gamma-ray pulse-height calibrations for ^{137}Cs gamma rays than are given here, use values directly scaled from the listed values for the same type of detector.

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

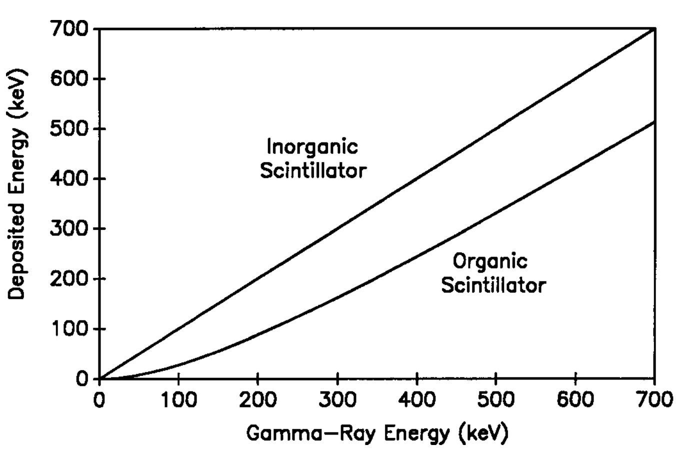

FIG. 2 The Relationship Between Incident Gamma-Ray Energy and Energy Deposited in NaI(Tl) and Plastic Scintillators

9.4 *Optimum Neutron Analysis Windows*, for proportional counters are given here.

NOTE 2—For organic scintillators, adequate fast neutron response for present-day SNM monitoring applications is usually achieved using the plastic detector discriminator levels for gamma rays given in 9.3.2.

9.4.1 Neutron proportional counters detect moderated neutrons from plutonium and each type of proportional counter has its own pulse-height spectrum for detected neutrons.

9.4.2 The upper level is unimportant in this case because there is no high level background. Only a lower-level discriminator may be available in some monitors. Suggested operating ranges are as follows:

(*a*) For BF_3 calibrated to 2 V, from 0.3 to 10 V;

(*b*) For ^{3}He calibrated to 2 V, from 0.4 to 10 V;

(*c*) For BF_3 calibrated to 8 V, from 1.2 to 10 V; and

(*d*) For ^{3}He calibrated to 8 V, from 1.6 to 10 V.

9.4.3 In case another neutron pulse height than given here is used, the values can be directly scaled from the listed values for the same type of detector.

9.5 *Setting the Discriminators*:

9.5.1 Set the appropriate values in the monitor's discriminators or single-channel analyzers (SCA) noting the following special cases:

9.5.1.1 *Interpreting Window Discriminator Voltage Levels*—Monitors having both a level discriminator and a window discriminator float the window voltage level on top of the level-discriminator voltage level. Hence, the upper discriminator value, which is the upper limit of the operating ranges just tabulated, is the sum of the monitor's level discriminator and window values.

9.5.1.2 *Zero Discriminator Values*—The value 0 means the lowest practical value. It will be determined later using a procedure described in Section 11.

9.5.1.3 *Backlash in Potentiometer Adjustments*—When setting multiturn potentiometers, adopt a convention for the direction of rotation so that settings can be made reproducibly.

9.5.1.4 *Uncalibrated Adjustments*—If a calibrated multiturn potentiometer dial is not provided, the designer or manufacturer will have to indicate how to make these adjustments with the aid of a voltmeter or oscilloscope.

10. Procedures

10.1 *Detector Energy Calibration*:

10.1.1 Detector energy calibration sets the SNM detector response to a particular reference pulse height for gamma rays or neutrons from a calibration source. The reference pulse height recommendations of designers and manufacturers for different detectors range from 2 to 8 V. Particular values for each detector type are provided, and the corresponding energy regions for different types of SNM are listed in the following procedures.

10.1.2 Put the monitor into operation using the manufacturer's instructions. Pay particular attention to checking or setting the detector high voltage to the recommended value using proper electrical safety practice (see 8.2).

10.1.3 With the detectors operating at an appropriate high voltage, proceed with energy calibration by varying amplifier

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gain or individual detector voltage dividers or both to balance the response of each detector. This is done using the pulse-height spectrum of a reference source as viewed on an oscilloscope or multichannel analyzer coupled to the monitor's amplifier analog output. Procedures for each type of detector follow.

10.2 *Inorganic Scintillators:* (See 10.3 for organic (plastic) scintillators and 10.4 for neutron detectors.)

10.2.1 Inorganic scintillators, such as NaI(T1), absorb gamma-ray energy both by photoelectric absorption and Compton scattering. Photoelectric absorption leads to peaks in the pulse-height spectrum that are characteristic of the incident gamma-ray energy, and one gamma-ray peak is used as a reference pulse height for calibration.

10.2.2 Before bringing the reference source up to the detector, look at the background pulse-height spectrum on the oscilloscope or multichannel analyzer so that you are familiar with it and will recognize the peak in the reference source spectrum.

10.2.3 Adjusting the pulse height.

10.2.3.1 Safely hold or attach the cesium (^{137}Cs) reference source to one of the monitor's detectors at a reference point that can be used for each detector, for example, at its center or at a manufacturer's specified location.

10.2.3.2 Observe the pulse height spectrum and verify that it looks like Fig. 3 or Fig. 4.

10.2.3.3 Adjust the amplifier gain to place the peak in the cesium spectrum at the reference pulse height (usually 2 V, 3.3 V, or other pulse height).

10.2.3.4 Now attach the source to each remaining detector and adjust individual amplifiers, if provided, or trimmer potentiometers on detector voltage dividers, if provided, to obtain the same pulse height.

10.2.4 In case of difficulty do as follows.

10.2.4.1 If the limit of adjustment is reached on a trimmer, the amplifier gain will have to be readjusted, as will all trimmer adjustments, until the detectors have uniform pulse height, and

10.2.4.2 If uniform pulse height cannot be achieved, maintenance is needed to replace faulty resistors or photomultipliers, or to change component values so that all detectors can be set to the same pulse height.

10.2.5 The detector array is now adjusted for uniform pulse height and is ready for the next calibration step. Proceed with Section 10.

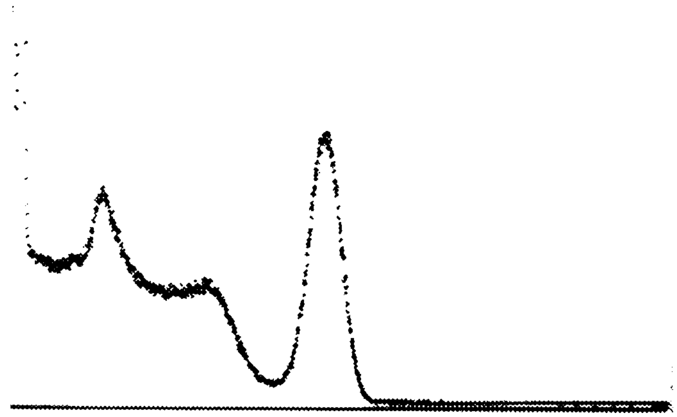

FIG. 4 The Gamma-Ray Spectrum of ^{137}Cs Detected by a NaI(Tl) Scintillator and Viewed with a Multi-Channel Analyzer

10.3 *Organic Scintillators*:

10.3.1 Organic scintillators, such as plastic scintillators or liquid scintillators, absorb incident gamma-ray or neutron energy by Compton scattering from electrons or protons present in the scintillator. Only the gamma-ray energy response is calibrated in this procedure. Compton scattering does not lead to peaks but to a distribution of pulse heights that is characteristic of the incident gamma-ray energy at its end point, a knee shape in the spectrum. The half-height of the slope of the knee is used for calibration.

NOTE 3—Adequate fast neutron response in organic scintillators for present-day SNM monitoring applications is achieved by the gamma-ray energy calibration procedure.

10.3.2 Before bringing the calibration source up to the detector, carefully look at the background pulse-height spectrum on the oscilloscope or multichannel analyzer so that you are familiar with it and will recognize the difference when the calibration source is added.

10.3.3 *Adjusting the pulse height*:

10.3.3.1 Safely hold or attach the cesium (^{137}Cs) calibration source to one of the monitor's detectors at a reference point that can be used for each detector, for example, at its center or the manufacturer's specified location.

10.3.3.2 Observe the pulse-height spectrum on the oscilloscope or multichannel analyzer and verify that it looks like Fig. 5 or Fig. 6. If you want to verify the position of the knee on an

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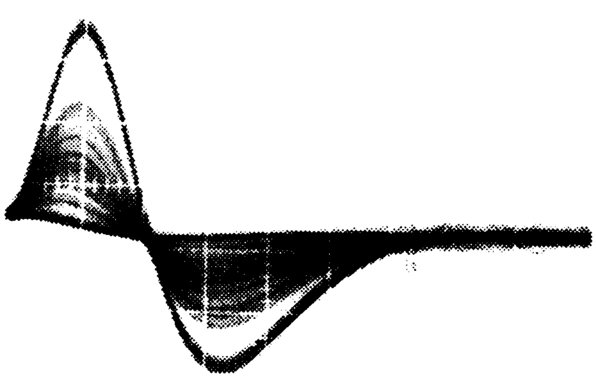

FIG. 3 The Gamma-Ray Spectrum of ^{137}Cs Detected by a NaI(Tl) Scintillator and Viewed with an Oscilloscope

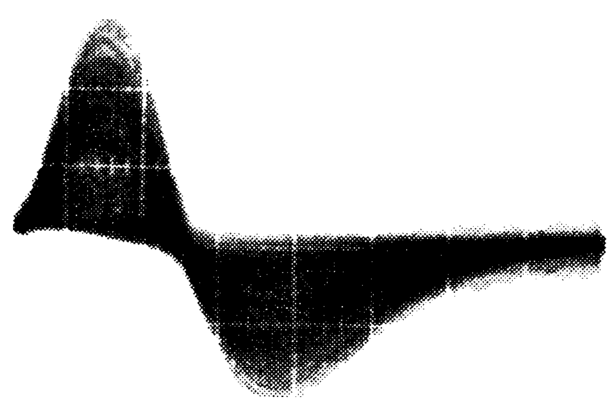

FIG. 5 The Gamma-Ray Spectrum of ^{137}Cs Detected by a Plastic Scintillator and Viewed with an Oscilloscope