Designation: C 1189 – 02

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.

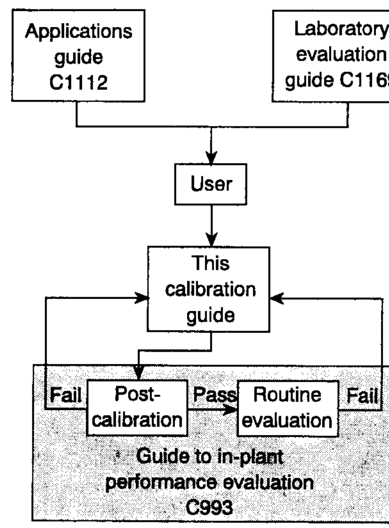

FIG. 1 The Relationship of Calibration to Other Procedures Described in Standard Guides for SNM Monitors

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]

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.

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

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

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

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 ^3He 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.

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

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

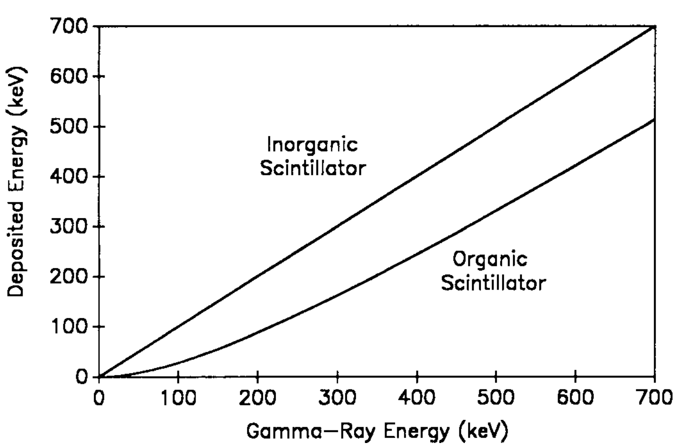

FIG. 2 The Relationship Between Incident Gamma-Ray Energy and Energy Deposited in NaI(Tl) and Plastic Scintillators

(*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.

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 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.

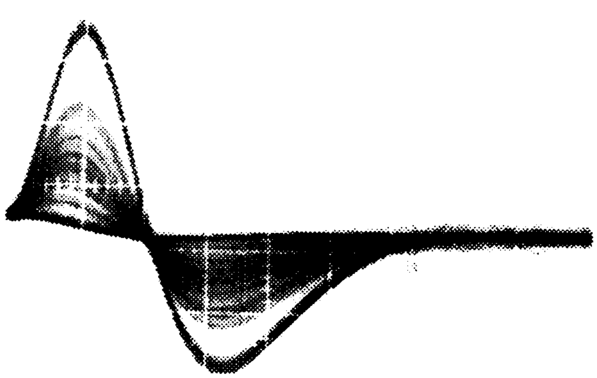

FIG. 3 The Gamma-Ray Spectrum of ^{137}Cs Detected by a NaI(Tl) Scintillator and Viewed with an Oscilloscope

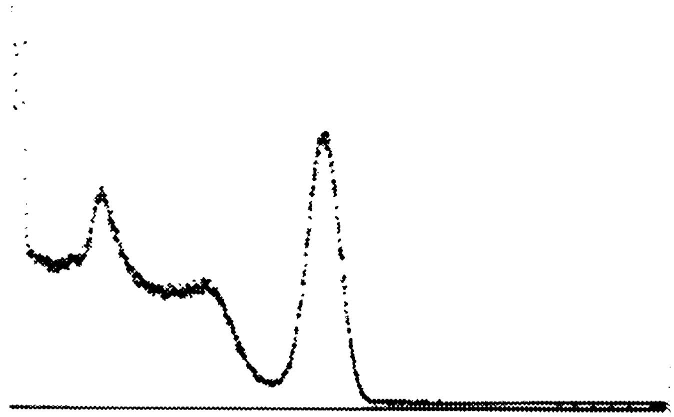

FIG. 4 The Gamma-Ray Spectrum of ^{137}Cs Detected by a NaI(Tl) Scintillator and Viewed with a Multi-Channel Analyzer

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.

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 oscillosocope, move the source away and then back repeatedly to emphasize the contrast.

10.3.3.3 Next, adjust the amplifier gain to place the mid-point of the knee in the cesium spectrum at the reference pulse height (usually 2 V, 3.3 V, or other pulse height).

10.3.3.4 Now attach the source to each remaining detector and adjust individual amplifiers if provided, or trimmer potentiometer, if provided, until the recommended pulse height is obtained.

10.3.4 In case of difficulty do as follows:

10.3.4.1 *Difficulty Seeing the Spectrum*—If the background intensity is intense enough that it is difficult to see the ^{137}Cs spectrum, it may help to isolate the individual detectors. Do

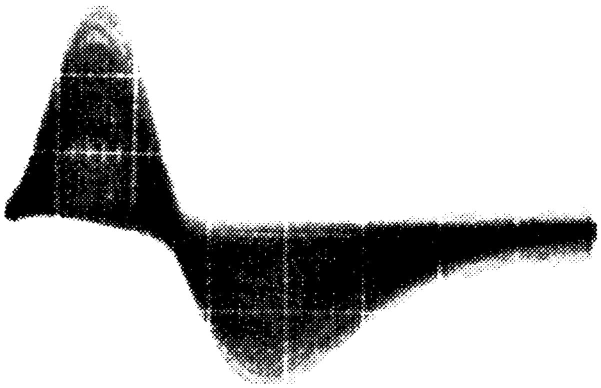

FIG. 5 The Gamma-Ray Spectrum of ^{137}Cs Detected by a Plastic Scintillator and Viewed with an Oscilloscope

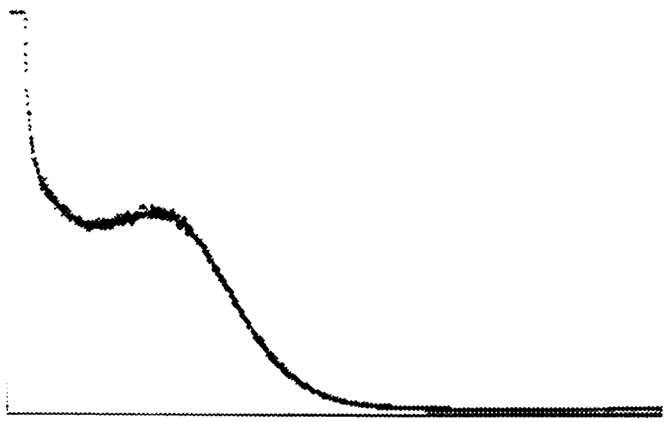

FIG. 6 The Gamma-Ray Spectrum of ^{137}Cs Detected by a Plastic Scintillator and Viewed with a Multi-Channel Analyzer

this using proper electrical safety practice (see 8.2), turning off the high voltage, and disconnecting the high voltage from all but the detector being calibrated. Leave all signal cables in place to avoid changing the total signal cable capacitance.

10.3.4.2 *Difficulty Adjusting Pulse Heights*—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. If this cannot be achieved, maintenance is needed to replace faulty resistors or photomultipliers or change component values so that all detectors can be set to the same pulse height.

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

10.4 *Neutron Proportional Counters*:

10.4.1 Neutron proportional counters absorb incident neutron energy by means of a conversion reaction that produces charged particles, which in turn cause ionization and detectable current pulses. The pulse-height spectrum has a peak or knee that characterizes the reaction and is used for calibration.

10.4.2 Before bringing the calibration source up to the detector, you should see a low-intensity background spectrum because neutron backgrounds are usually very low.

10.4.3 Adjusting the pulse height.

10.4.3.1 Safely hold or attach the californium (^{252}Cf) or other suitable neutron calibration source to one of the monitor's detectors at a reference point that can be used for each of the detectors.

10.4.3.2 Observe the pulse height spectrum on the oscilloscope or multichannel analyzer and verify that it looks like Fig. 7 or Fig. 8 for ^{3}He or Fig. 9 or Fig. 10 for BF_3 counters.

10.4.3.3 Adjust the amplifier gain to place the peak or knee in the californium spectrum at the reference pulse height (usually 2 V, 8 V, or other pulse height).

10.4.3.4 Now proceed through the remaining detectors, which should be well matched to the first one, and verify that they have the same pulse height.

10.4.4 In case of difficulty do as follows:

10.4.4.1 If the detectors are not well matched, check the manufacturer's manual to see if a means to balance the response of individual detectors is available. If not, consult the manufacturer about the problem and see if it is necessary to replace the unmatched proportional counters.

10.4.4.2 If a means to balance the response of detectors is provided and the limit of adjustment is reached, the high voltage or amplifier gain will have to be readjusted, as will all adjustments, until the detectors have uniform pulse height.

10.4.5 The detectors are now adjusted for uniform pulse height and the monitor is ready for calibration.

11. Setting the Lowest Practical Lower-Level Discriminator Value.

11.1 One of two methods is commonly used. The first looks at the monitor's signal to noise ratio and the second examines the variance and mean of a set of monitoring measurements. The discussion that follows uses the terms "average," "standard deviation," and" variance" as described in Practice E 876. The term "mean" is also used for "average" when it is common usage for the method described.

11.1.1 *Signal-to-Noise Ratio*—In SNM monitors, the measured signal is the monitor's net response to a SNM source, and the noise is taken to be the statistical variation in the measurement of pulses produced by radiation **(2)**. The signal-to-noise ratio for SNM monitors is a net SNM signal divided by the standard deviation of a routine background measurement, which for a Poisson distribution can be estimated with the square root of the monitor's average background. A net SNM source measurement divided by the square root of background is a useful figure of merit for optimizing a monitor's signal-to-noise ratio. Net SNM source and background measurements

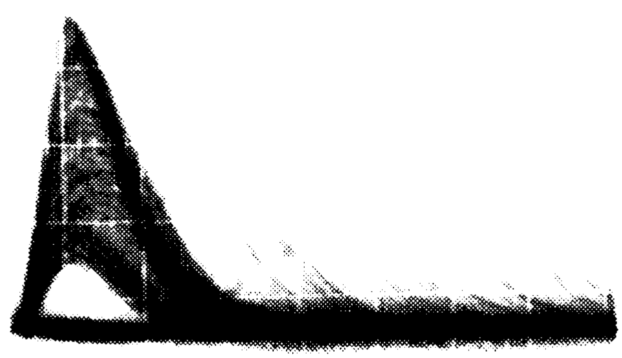

FIG. 7 The ^{252}Cf Neutron Spectrum Detected by a Moderated ^{3}He Proportional Counter and Viewed with an Oscilloscope

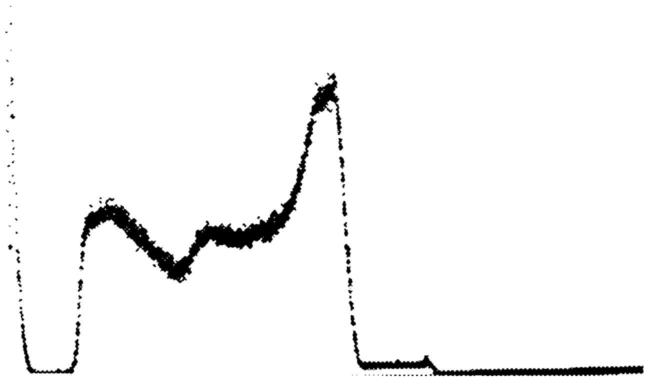

FIG. 8 The ^{252}Cf Neutron Spectrum Detected by a Moderated ^{3}He Proportional Counter and Viewed with a Multi-Channel Analyzer

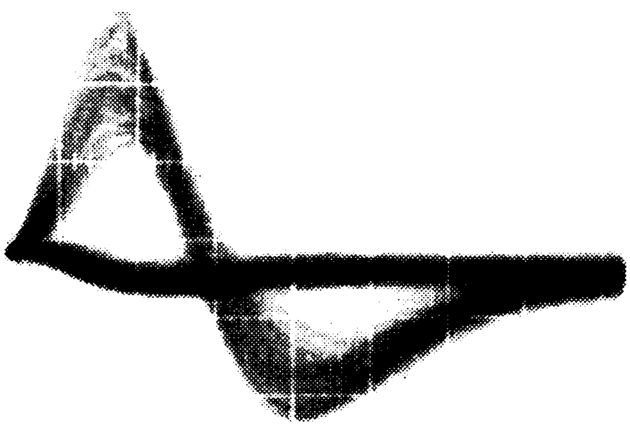

FIG. 9 The ^{252}Cf Neutron Spectrum Detected by a Moderated BF_3 Proportional Counter and Viewed with an Oscilloscope

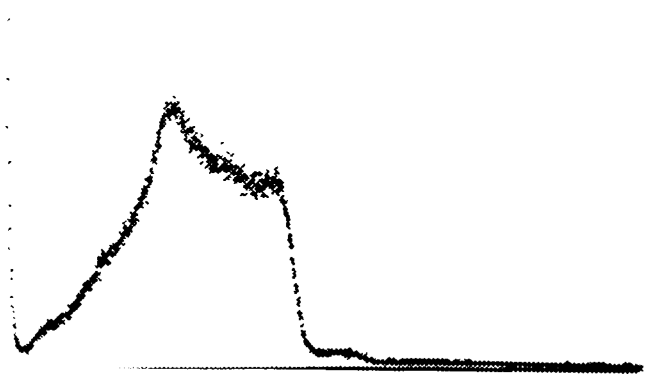

FIG. 10 The ^{252}Cf Neutron Spectrum Detected by a Moderated BF_3 Proportional Counter and Viewed with a Multi-Channel Analyzer

over a range of lower-level discriminator settings can be used to find the discriminator setting giving the greatest figure of merit, which would then be used for calibrating the monitor.

11.1.2 *Variance-to-Mean Ratio*—From the properties of a Poisson distribution, the variance and mean of sets of SNM monitor background measurements should be nearly identical for large measurement sets **(3)**. The variance and mean of sets of measurements for different lower-level discriminator settings can be used to determine the setting, if any, at which detectable electronic noise alters the statistical distribution of the measurements and introduces a significant difference between the variance and mean. The lowest practical lower-level discriminator setting can then be chosen to be just above the noise. Fine adjustment can be done later based on nuisance alarm experience.

11.2 *Optimum Detectability Method:* (See 11.3 for the Variance-to-Mean Method.)

11.2.1 *Measuring Instruments*—To measure SNM source and background intensity precisely, the monitor's SCA output must be measured over a much longer time interval than a normal monitoring interval. Two methods can be used as follows:

11.2.1.1 An external timer/scaler system can be attached to the monitor's SCA output connector, if present, to make measurements over time intervals of 50 to 100 s and

11.2.1.2 The monitor's background count display can be used for measurements. Several displayed values can be averaged, if necessary, to obtain an average from data for 50 to 100 s. Check the monitor's manual for the averaging time used for the display. Take care to be sure that constant intensities are measured because the beginning of a monitor background measurement will not necessarily coincide with placing or removing a radiation source.

11.2.2 *Measurement Protocol*—As with any radiation measurement technique, before proceeding with the following, make sure that there will be no interference from changing background, radioactive sources, or radiation-producing machinery.

11.2.2.1 Choose a position for the source that is readily reproducible so that the same radiation intensity will be present for each source measurement.

11.2.2.2 Set the lower-level discriminator to one end of the range to be covered, making sure to approach the setting using the same direction of rotation as will be used subsequently.

11.2.2.3 Make a background measurement and record it.

11.2.2.4 Put the source in position and measure and record the source plus background, or gross source, result.

11.2.2.5 Adjust the lower-level discriminator to the next value or, if the measurements are complete, go on to 11.2.3.

11.2.2.6 Measure and record the source plus background.

11.2.2.7 Remove the source and measure and record the background.

11.2.2.8 If the measurements are complete go to 11.2.3, otherwise adjust the lower-level discriminator and continue at 11.2.2.3.

11.2.3 *Calculating the Figure of Merit*:

11.2.3.1 For each lower-level discriminator value, calculate a net source count by subtracting the background measurement result from the gross source result.

11.2.3.2 Calculate the figure of merit at each level discriminator value by dividing the net source result by the square root of the corresponding background result.

11.2.4 *Picking the Lower-Level Discriminator Setting*—The level discriminator value giving the highest figure of merit is the choice for the lower-level discriminator setting. Proceed to 11.4.

11.3 *Variance-to-Mean Ratio Method*:

11.3.1 *Measurement Instruments*—The required measurements are sets of individual background measurements for an interval of time close to that used for monitoring measurements. This method uses the variance and mean of each set, and some means of determining them is required. Some monitor controllers have programs for the purpose. One hand-held instrument for the purpose, called a variance analyzer, is commercially available and can be used if the monitor has an external SCA output connector **(4)**.

11.3.2 *Description of the Method*:

11.3.2.1 Sets of background measurements, usually with at least 30 individual measurements per set, are made sequentially.

11.3.2.2 The mean and variance for a set is calculated as soon as its measurements are completed. For incident radiation of different energies having uniform effectiveness in the radiation detectors, the variance is approximately that for a single Poisson process **(5)**, and the variance-to-mean ratio for very large sets of measurements is approximately unity **(3)**.

11.3.2.3 Information on the variance-to-mean ratio is conveyed directly by the ratio, which should be a number close to 1. However, the commercially available equipment subtracts 1 from the ratio to extract the difference between the ratio and 1, so the result will be a number close to 0. A further difference in some commercial equipment is that the ratio of the standard deviation to the square root of the mean may be used instead of the variance-to-mean ratio.

11.3.2.4 The information on the variance-to-mean (or other) ratio for individual sets can be displayed. The running average for a number of sets can also be displayed to give a more precise result.

11.3.3 *Measurement Protocol*:

11.3.3.1 Make sure that the monitor's background count rate is steady and not influenced by sources of radiation or by people moving in the vicinity of the radiation monitors.

11.3.3.2 Set the lower-level discriminator to a chosen value and observe the variance analyzer display. The running average of 5 groups of measurements (150 total measurements) can be expected to have a relative standard deviation of about 12 % (500 counts or greater is a typical measurement). Hence, a variance-to-mean ratio greater than 1.2 might indicate the onset of electronic noise. Commerical variance analyzers that subtract 1 from the variance-to-mean ratio use results greater than 0.2 to indicate possible electronic noise **(6)**. Other instruments using the ratio of standard deviation to square root of the mean use results greater than 0.1 to indicate possible electronic noise **(7)**.

11.3.3.3 Vary the lower-level discriminator setting until the desired result averaged over five groups is obtained.

11.3.3.4 When the lowest practical setting is chosen, record the value and lock it in place.

11.4 *Readjustments*—Readjustment of the lower-level discriminator (LLD) may later be necessary. If experience shows that the nuisance alarm rate is too high, increase the LLD slightly. If the sensitivity is too low but the nuisance alarm rate acceptable, lowering the LLD may help. In any case, performance evaluation of detection sensitivity and nuisance alarm rate should follow any readjustment (see Guide C 993). This completes energy calibration.

12. Transient Signal Detection Methods Calibration

12.1 *Signal Detection Logic*—SNM monitors often match the response of their signal detection logic to the type of signal that is expected to be present while monitoring.

12.1.1 *Wait-In Monitors*—Wait-in monitors measure a relatively constant signal and a single measurement of a few seconds is usually sufficient.

12.1.2 *Walk-Through Monitors*—Walk-through monitors measure a signal that varies in amplitude as an individual walks through the detectors, and the signal is present for only a second or so. Methods for detecting short, time-variable signals by continuous or multiple measurements are used. These methods can be more sensitive than a single-measurement method even though the alarm threshold must be increased to obtain the same statistical nuisance alarm rate.

12.1.2.1 One analog method is described in Ref **(8)**.

12.1.2.2 A moving average scaler is described in Ref **(1)**.

12.1.2.3 A sequential probability ratio test (SPRT) method is described in Ref **(9)**.

12.2 *Occupancy Sensors*—Occupancy sensors are used to indicate when to measure background intensity and make monitoring measurements and apply (or respond to) signal detection logic.

12.2.1 Performance of occupancy sensors should trigger and start the monitoring process to analyze signals as a pedestrian, or other object that could transport SNM, approaches a walk-through monitor, perhaps using stored data, or when a pedestrian, or other object that could transport SNM, is positioned in a wait-in monitor. Occupancy sensors should not have excessive hold-in time that extends monitoring well beyond the time that monitoring signals are present.

12.3 *Adjusting the Detection Logic*:

12.3.1 Both the moving average and SPRT methods (see 12.1.2) allow users to select the length of monitoring measurements and the number of measurements analyzed together for monitoring. Ref **(1)** recommends that four subintervals of 0.2-s duration be used in a moving average scaler for a walk-through monitor with narrow radiation detectors and narrow portal width. Slowing pedestrians with turnstiles, using very wide detectors, or using very wide portals can justify using more or longer subintervals to extend the monitoring time.

12.4 *Adjusting Background Measurement Protocols*:

12.4.1 The precision of the expected background value used by a monitor to determine its alarm thresholds is a factor that can affect both the monitor's detection sensitivity and nuisance alarm rate. Ref **(10)** recommends using at least 20 background measurements to obtain a precise enough background estimate that its affect on the monitor's statistical nuisance alarm rate can be ignored in comparison to the contribution of statistical variation in monitoring measurements. On the other hand, a smaller number of background measurements may have to be used to obtain a timely background value if the background is highly variable or if the monitor is frequently used for monitoring and background measurement time is insufficient. Some monitors use a moving average scaler for background measurements to achieve both adequate precision and better response to changing background.

13. Adjusting Background Alarm Thresholds

13.1 *Purpose of Background Alarms*:

13.1.1 A low background alarm threshold detects complete failure of one or more radiation detectors. A high background alarm threshold detects high background intensity that may be caused by noisy detectors, by an artificially high background that could subvert the monitor's detection sensitivity, or by any other cause of high background that reduces sensitivity below that desired.

13.2 *Setting Background Alarms*:

13.2.1 *Background Intensity History*—The seasonal range of background indicated by the monitor is useful knowledge. Many factors can vary the background indication as follows:

13.2.1.1 Any variation in natural environmental radiation intensity may be sensed by a monitor,

13.2.1.2 Radiation from process activity may increase background in the monitoring area,

13.2.1.3 Seasonal variation in background radiation absorption, by snowfall for example, can change background intensity,

13.2.1.4 Weather changes can affect background intensity. Rain or snowfall can increase background until precipitated radon daughters decay. Later, the moisture may decrease the amount of radon entering the atmosphere, and

13.2.1.5 Temperature may change the performance of scintillators or photomultipliers and alter a monitor's background count rate.

13.3 *Setting the Background-Alarm Thresholds*:

13.3.1 *Lower Threshold*:

13.3.1.1 The monitor's average background and range of background is used in setting the lower threshold. The lower alarm threshold is set at the particular fraction of the average background that results if one detector is inoperative. If this value lies above the low point of the monitor's annual range, then the lower background alarm threshold will have to be reset seasonally.

13.3.2 *Upper Threshold*:

13.3.2.1 The results of a laboratory evaluation are needed for setting the upper threshold, the point at which the monitor no longer achieves the minimum required sensitivity. The manufacturer or organization conducting a laboratory evaluation can be consulted for information on upper threshold background intensities. In unattended monitoring, the upper background threshold may be used for another purpose, to provide a separate level of monitoring sensitivity when the occupancy sensor is not activated. In this case, an upper threshold is set and then tested and adjusted until the sensitivity is adequate and the nuisance alarm rate is tolerable.

13.4 *Response to Background Threshold Alarms*:

13.4.1 Low threshold alarms call for maintenance or repair. High threshold alarms call for investigation and repair unless high background from plant operations is expected. In that case, hand-held monitoring is substituted for automatic monitoring. One commercial monitor alerts a security inspector of the need to hand monitor during high background by vocal announcement each time the occupancy sensor is activated.

14. Application Notes

14.1 The lowest practical level-discriminator value determined in Section 11 may change with season. Similarly, the lower and upper background alarm thresholds may change as a result of seasonal temperature changes.

14.2 Success of the signal-to-noise method for setting lower-level discriminators depends on the measurements being free of variation caused by changing monitor count rate. Interference from radiation sources or radiation-producing machinery, changing monitor background from natural or plant activity, and variable shielding from movement of pedestrians or vehicles near the monitor must be avoided.

14.3 Success of the signal-to-noise method also depends on repositioning the source at the proper mark for each source measurement, storing the source well away from the detectors during background measurement, and using adequately long counting intervals as recommended in 11.2.1.2.

14.4 Variance analysis techniques for calibrating the lower-level discriminator depend on enough electronic noise being present to establish a set point. Some discriminators may not reach low enough bias levels to respond to noise, in which case the minimum setting would be used but the best possible performance may not be achieved.

14.5 Variance analysis depends on using groups of measurements during which the background intensity does not vary. Using very long counting times and very large groups may lead to interference from intensity variation or detector shielding from movement of nearby pedestrians. Introducing significant quantities of radioactive material or operating nearby radiation producing machinery during the measurements also leads to interference.

14.6 Analyzing a small group of measurments can produce an imprecise variance value that may be much larger or smaller than the mean (the fractional standard deviation of the variance is very large for a small number of measurements).

15. Keywords

15.1 gamma radiation; material control and accountability; neutron radiation; nuclear materials management; radiation detectors; radiation monitors; safeguards; security

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