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Standard Guide for Laboratory Evaluation of Automatic Pedestrian SNM Monitor Performance¹

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1. Scope

1.1 The requirement to search pedestrians for special nuclear material (SNM) to prevent its theft has long been a part of both United States Department of Energy and United States Nuclear Regulatory Commission rules for the physical protection of SNM. Information on the application of SNM monitors to perform such searches is provided in Guide C1112. This guide establishes a means to compare the performance of different SNM pedestrian monitors operating in a specific laboratory environment.² The goal is to provide relative information on the capability of monitors to search pedestrians for small quantities of concealed SNM under characterized conditions. The outcome of testing assigns a sensitivity category to a monitor related to its SNM mass-detection probability; the monitor's corresponding nuisance-alarm probability for that sensitivity category is also determined and reported.

1.2 The evaluation uses a practical set of worst-case environmental, radiation emission, and radiation response factors so that a monitor's lowest level of performance in a practical operating environment for detecting small quantities of SNM is evaluated. As a result, when that monitor is moved from laboratory to routine operation, its performance will likely improve. This worst-case procedure leads to unclassified evaluation results that understate rather than overstate the performance of a properly used SNM monitor in operational use.

1.3 The evaluation applies to two types of SNM monitors that are used to detect small quantities of SNM. Both are automatic monitors; one monitors pedestrians as they walk through a portal formed by the monitor's radiation detectors (walkthrough or portal monitor), and the other monitors pedestrians who are stationary for a short period of time while they are monitored (wait-in monitor). The latter can be a portal monitor with a delay mechanism to halt a pedestrian for a few

seconds or it can be an access-control booth or room that contains radiation detectors to monitor a pedestrian waiting for clearance to pass.

1.4 The values stated in SI units are to be regarded as standard.

1.5 *This standard does not purport to address 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:³

C859 Terminology Relating to Nuclear Materials

C993 Guide for In-Plant Performance Evaluation of Automatic Pedestrian SNM Monitors

C1112 Guide for Application of Radiation Monitors to the Control and Physical Security of Special Nuclear Material

C1189 Guide to Procedures for Calibrating Automatic Pedestrian SNM Monitors

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *confidence coefficient*—the theoretical proportion of confidence intervals from an infinite number of repetitions of an evaluation that would contain the true result.

3.1.1.1 *Discussion*—In a demonstration, if the true result were known the theoretical confidence coefficient would be the approximate proportion of confidence intervals, from a large number of repetitions of an evaluation, that contain the true result. Typical confidence coefficients are 0.90, 0.95 and 0.99.

3.1.2 *Confidence Interval for a Detection Probability*—An interval, based on an actual evaluation situation, so constructed that it contains the (true) detection probability with a stated confidence.

3.1.2.1 *Discussion*—Confidence is often expressed as 100*the confidence coefficient. Thus, typical confidence levels are 90, 95 and 99 %.

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² Note that this is a laboratory evaluation and is not designed for routine in-plant use. A separate guide, C993, is available for verifying routine in-plant performance.

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.

3.1.3 *detection probability*—the proportion of passages for which the monitor is expected to alarm during passages of a particular test source.

3.1.3.1 *Discussion*—Although probabilities are properly expressed as proportions, performance requirements for detection probability in regulatory guidance have sometimes been expressed in percentage. In that case, the detection probability as a proportion can be obtained by dividing the percentage by 100.

3.1.4 *detection sensitivity category*—specified in terms of a test source mass for which the monitor has a 0.50 or greater detection probability, as measured by a test procedure having a 95 % confidence coefficient for its result. The specified 0.50 or greater detection probability is a very convenient one for testing. The limited number of test source masses used to define sensitivity categories (see Table 1 and Table 2) adequately describe the performance of SNM monitors that can detect small quantities of SNM.

3.1.5 *nuisance alarm*—a monitoring alarm not caused by SNM but by one of two other causes, which are statistical variation in the measurement process or natural background intensity variation. Other contributors to nuisance alarms, such as interfering radiation sources and equipment malfunction, should not be present during testing.

3.1.6 *radiation intensity*—expressed as the number of photons or neutrons emitted by a material per second or as the environmental background radiation dose rate.

3.1.7 *SNM (special nuclear material)*—plutonium of any isotopic composition, ^{233}U , or enriched uranium as defined in Terminology C859. 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.

3.1.8 *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.

3.1.9 *standard SNM test source*—a metallic sphere or cube of SNM having maximum self attenuation of its emitted radiation and an isotopic composition to minimize that emission as described below. Encapsulation and filtering also affect radiation intensity, and particular details are listed for each source.

3.1.9.1 *standard plutonium source*—a metallic sphere or cube of low-burnup plutonium containing at least 93 % ^{239}Pu , less than 6.5 % ^{240}Pu , and less than 0.5 % impurities.

3.1.9.2 *Discussion*—A cadmium filter can reduce the impact of ^{241}Am , a plutonium decay product that will slowly build up in time and emit increasing amounts of 60-keV radiation.

TABLE 1 Mass Detection Sensitivities of SNM Monitors^A

Category	Description	Uranium ^B (g)	Plutonium ^C (g)
I	Standard Plutonium	64	1
II	Standard Uranium	10	0.29
III	Improved Sensitivity	3	0.08
IV	High Sensitivity	1	0.03

^A In a nominal 20 $\mu\text{R/h}$ background intensity using standard metallic test sources and procedures described in 11.2.

^B HEU as described in 8.4.

^C Low-burnup plutonium as described in 8.5.

TABLE 2 Mass Detection Sensitivities in Pedestrian Neutron Monitors^A

Category	Description	Plutonium ^B (g)
NI	Standard Neutron	250
NIJ	Improved Neutron	100
NIJJ	High Sensitivity Neutron	30

^A In a nominal 20 $\mu\text{R/h}$ background intensity using standard metallic test sources and procedures described in 11.2.

^B Low-burnup plutonium as described in 8.5. For monitors having gamma-ray sensitivity in addition to neutron sensitivity the plutonium must be shielded in 5-cm thick lead.

Begin use of 0.04-cm-thick cadmium filter when three or more years have elapsed since separation of plutonium decay products. If ten or more years have elapsed since separation, use a cadmium filter 0.08-cm thick. The protective encapsulation should be in as many layers as local rules require of a non-radioactive material such as aluminum (≤ 0.32 -cm thick) or thin (≤ 0.16 -cm thick) stainless steel or nickel to reduce unnecessary radiation absorption.

3.1.9.3 *standard uranium source*—a metallic sphere or cube of highly-enriched uranium (HEU) containing at least 93 % ^{235}U and less than 0.25 % impurities. Protective encapsulation should be thin plastic or thin aluminum (≤ 0.32 -cm thick) to reduce unnecessary radiation absorption in the encapsulation. No additional filter is needed.

4. Summary of Guide

4.1 Evaluation follows a sequence of steps, each of which should reach an acceptable outcome before the next is begun. The steps are: placing the monitor into operation; determining nuisance alarm probability; determining detection probability; and categorizing the results.

4.2 The monitor is put into operation in a nominal 20 $\mu\text{R/h}$ (5.2 nC/kg h or 1.43 pA/kg) background environment. The manufacturer's instructions are followed to assemble, calibrate (see Section 10), and begin using the monitor.

4.3 Nuisance alarm probability is determined (see Section 11) by automatic data collection with a system that cycles the monitor alternately through a group of simulated pedestrian passages and a background update while recording the background intensity and each of its alarms.

4.4 Detection probability is determined (see Section 12) by transporting SNM test sources through the monitor's least sensitive region, which is determined as part of the evaluation. Different individuals transport the SNM at their accustomed pace but in a specified manner. Results (number of detections and passages) are analyzed as a binomial experiment to give a confidence interval for the probability of detection that may place the monitor in a sensitivity category. If the monitor can be operated in different modes or at more than one spacing between its detectors, it should be evaluated in each mode and at each spacing that is expected to be used operationally.

4.5 The sensitivity category of a monitor is determined (see Section 13) by the smallest test source for which the monitor has a 0.50 or greater detection probability with 95 % confidence at an acceptable nuisance alarm probability.

5. Significance and Use

5.1 SNM monitors are an effective and unobtrusive means to search pedestrians for concealed SNM. Nuclear facility security plans often include SNM monitors as one means to help prevent theft or unauthorized removal of designated quantities of SNM from access areas. This guide describes a way to evaluate and categorize the relative performance of available SNM monitors that might be considered for use in a security plan.

5.2 The significance of the evaluation for monitor users is that evaluated monitoring equipment has a verified capability. Unexpected deficiencies such as low sensitivity for highly self-absorbing forms of SNM, lower than expected sensitivity in areas having high natural background intensity, or a high nuisance-alarm probability from electronic noise or faulty alarm logic often can be detected during evaluation and corrected before a monitor is placed in operation or further marketed.

5.3 The significance of the evaluation for monitor manufacturers is that it may disclose deficiencies in design or construction that, when corrected, will improve the product. A monitor verified to be in a particular sensitivity category will be a product that customers who need that level of performance can purchase in good faith.

5.4 The established sensitivity categories for evaluated monitors will provide information to regulatory agencies on the performance range of monitoring equipment for detecting small quantities of SNM.

5.5 Independent monitor evaluation will encourage monitor manufacturers to provide appropriate documentation for calibrating and operating their monitors to obtain the best possible performance for detecting SNM.

5.6 The underlying assumptions in this guide are that SNM monitors are applied in a wide range of background environments at facilities that process a variety of chemical and physical forms of SNM. The operational experience with a monitor at one facility provides little comparative information for a user of SNM monitors at another facility where the environment and materials are different. A laboratory evaluation in a characterized environment using characterized test sources and providing information on both SNM detection probability and nuisance alarm probability does provide useful comparative information on different monitors.

5.7 The user of evaluation results is warned that the results are comparative ones for selection of monitoring equipment used to detect small quantities of SNM. Obtaining equivalent or better results for monitoring small quantities of SNM at any facility rests on properly installing the monitor at an appropriate location, maintaining monitor calibration, keeping the monitor in good repair with a testing and maintenance program, and providing proper training for operating personnel.

5.8 The evaluation uses essentially unshielded test sources; hence, results are based on detecting the entire gamma-ray or neutron spectrum of the sources. The effect of deliberate use of shielding materials on the performance of SNM monitors is beyond the scope of this guide.

6. Interferences

6.1 The evaluation requires a nominal natural background environment that has an intensity in the range of the highest found in the continental United States [nominal 20 $\mu\text{R/h}$ (5.2 nC/kg h or 1.43 pA/kg)] and has only natural variation. Locations having low backgrounds are not suitable for testing; other locations are unsuitable as well when variable backgrounds from other than natural causes are present. A simulated high intensity background produced by point sources is unsuitable.

6.2 Parts of the evaluation use specific values or measurements that can alter the testing outcome if not done properly. For example, an improperly measured background intensity (see 7.1) that is actually much higher or lower than stated in 6.1 will bias the results toward a lower or higher sensitivity category. Similarly, inattention to test source specification, method of carrying test sources through the monitor, and improper interpretation and reporting of results will bias the outcome. Other possible errors and biases in the evaluation results are discussed in Section 13.

7. Apparatus

7.1 Measuring the gamma-ray background intensity requires a precision ion chamber or similar environmental radiation measurement device that is calibrated to provide gamma-ray dose rate. For neutron monitors, the background intensity is inferred from the more readily measured gamma-ray intensity because the cosmic-ray and terrestrial factors that lead to high natural gamma-ray intensity are the same ones that produce high natural neutron background intensity.

7.2 The presence of unnatural sources of background during nuisance alarm testing can be discovered by recording the output of a background monitor or the output of the monitor's radiation detection circuits. A strip-chart recorder, data logger, and computer-generated display are convenient ways to record background data.

7.3 Alarms also must be recorded during nuisance alarm testing. For example, an event marker could record alarms on a background strip-chart record or a data logger, scaler, or computer could record alarms.

7.4 A scaler or other form of pulse counter may be necessary to average monitor signals to determine the monitor's least sensitive region. Net signals from a test source placed in different regions indicate the monitor's relative response there.

7.5 A timing device that provides a sequence of periodic or random (but not overlapping) occupancy signals and background update periods is needed for nuisance alarm determination. Appendix X1 gives one example of a timing circuit for the purpose.

7.6 Automatically cycling the monitor for nuisance alarm testing requires the monitor's alarm to automatically reset itself. If it does not, a means to generate an alarm reset signal is usually easy to provide. For example, the alarm signal can operate a solenoid that depresses the alarm reset pushbutton.

8. Test Materials

8.1 The materials required for this guide are recommended SNM test sources (see 3.1.9). These have been limited