Designation: C 1112 – 99

Standard Guide for Application of Radiation Monitors to the Control and Physical Security of Special Nuclear Material[1]

This standard is issued under the fixed designation C 1112; 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 briefly describes the state-of-the-art of radiation monitors for detecting special nuclear material (SNM) (see 3.1.11) in order to establish the context in which to write performance standards for the monitors. This guide extracts information from technical documentation to provide information for selecting, calibrating, testing, and operating such radiation monitors when they are used for the control and protection of SNM. This guide offers an unobtrusive means of searching pedestrians, packages, and motor vehicles for concealed SNM as one part of a nuclear material control or security plan for nuclear materials. The radiation monitors can provide an efficient, sensitive, and reliable means of detecting the theft of small quantities of SNM while maintaining a low likelihood of nuisance alarms.

1.2 Dependable operation of SNM radiation monitors rests on selecting appropriate monitors for the task, operating them in a hospitable environment, and conducting an effective program to test, calibrate, and maintain them. Effective operation also requires training in the use of monitors for the security inspectors who attend them. Training is particularly important for hand-held monitoring where the inspector plays an important role in the search by scanning the instrument over pedestrians and packages or throughout a motor vehicle.

1.3 SNM radiation monitors are commercially available in three forms:

1.3.1 *Small Hand-Held Monitors*—These monitors may be used by an inspector to manually search pedestrians and vehicles that stop for inspection.

1.3.2 *Automatic Pedestrian Monitors*—These monitors are doorway or portal monitors that search pedestrians in motion as they pass between radiation detectors, or wait-in monitoring booths that make extended measurements to search pedestrians while they stop to obtain exit clearance.

1.3.3 *Automatic Vehicle Monitors*—These monitors are portals that monitor vehicles as they pass between radiation detectors, or vehicle monitoring stations that make extended measurements to search vehicles while they stop to obtain exit clearance.

1.4 Guidance for applying SNM monitors is available as Atomic Energy Commission/Nuclear Regulatory Commission (AEC/NRC) regulatory guides, AEC/ERDA/DOE performance standards, and more recently as handbooks and applications guides published by national laboratories under DOE sponsorship. This broad information base covering the pertinent physics, engineering practice, and equipment available for monitoring has had no automatic mechanism for periodic review and revision. This ASTM series of guides and standards will consolidate the information in a form that is reexamined and updated on a fixed schedule.

1.5 Up-to-date information on monitoring allows both nuclear facilities and regulatory agencies to be aware of the current range of monitoring alternatives. Up-to-date information also allows manufacturers to be aware of the current goals of facilities and regulators, for example, to obtain particular sensitivities at a low nuisance alarm rate with instrumentation that is dependable and easy to maintain.

1.6 This guide updates and expands the scope of NRC regulatory guides and AEC/ERDA/DOE SNM monitor performance standards using the listed publications as a technical basis.[2]

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

1.8 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.*

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

Current edition approved June 10, 1999. Published July 1999. Originally published as C 1112 – 88. Last previous edition C 1112 – 93.

[2] Copies of out-of-print references may be available from Group NIS6, MS-J562, Los Alamos National Laboratory, Los Alamos, NM 87545.

2. Referenced Documents

2.1 *ASTM Standards:*

C 859 Terminology Relating to Nuclear Materials[3]

C 993 Guide for In-Plant Performance Evaluation of Automatic Pedestrian SNM Monitors[3]

C 1169 Guide for Laboratory Evaluation of Automatic Pedestrian SNM Monitor Performance[3]

C 1189 Guide to Procedures for Calibrating Automatic Pedestrian SNM Monitors[3]

C 1236 Guide for In-Plant Performance Evaluation of Automatic Vehicle SNM Monitors[3]

C 1237 Guide for In-Plant Performance Evaluation of Hand-Held SNM Monitors[3]

2.2 *Code of Federal Regulations:*

Title 10, Part 73, Physical Protection of Plants and Materials[4]

2.3 *AEC/NRC Regulatory Guides:*

5.27 Special Nuclear Material Monitors, June 1974[5]

5.7 Control of Personnel Access to Protected Areas, Vital Areas, and Material Access Areas, May 1980[5]

2.4 *AEC/ERDA/DOE SNM Monitor Standards:*

Personnel Doorway Monitor Standards, January 1974[6]

Standards for Hand-Held SNM Detection Instruments for Personnel, Package, and Vehicle Search, April 1974[6]

2.5 *NRC NUREG and NUREG/CR Reports:*

NUREG 1321, Testing Standards for Physical Security Systems at Category I Fuel Cycle Facilities, October 1991[5]

NUREG 1329, Entry/Exit Control at Fuel Fabrication Facilities Using or Possessing Formula Quantities of Strategic Special Nuclear Material, November 1985[5]

NUREG/CR 5899 (SAND 92-1339), Entry/Exit Control Components for Physical Protection Systems, 1992[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *alternative test sources*—there are no other radioactive isotopes that individually or together can duplicate the radioactive emissions of SNM. Hence, performance testing in a laboratory environment will use only SNM test sources. Operational testing at the recommended three-month interval can most often use SNM test sources, although sometimes a more readily available equivalent-intensity highly enriched uranium (HEU) source may be used in place of a very expensive and hard to obtain plutonium source. The more frequent daily or weekly operational testing will often substitute alternative isotopic sources. Often these are continuity tests that can use the cesium-137 (^{137}Cs) sources that are on hand for pulse height calibration. Also barium-133 (^{133}Ba) may be used when a gamma-ray spectrum similar to plutonium is needed to make a daily or weekly test that must roughly approximate testing with a particular plutonium test source. Gas lantern mantles containing thorium are radioactive and sometimes are used to test continuity in hand-held monitors.

3.1.2 *detection sensitivity*—specified in terms of the mass of SNM that will be detected 50 % or more of the time when carried through the monitor in a specified fashion. This convenient definition greatly simplifies SNM monitor performance testing and makes it possible to readily verify sensitivity by performing an experiment that mimics the monitor's normal use. The related masses that would be detected 95 % or 99 % of the time can be estimated from the 50 % mass but would be impractical to determine with high confidence by themselves. Experiments conducted to determine or verify sensitivity must be thorough enough to have an upper 95 % confidence coefficient so that repeating the experiment will probably give the same result.

3.1.3 *monitoring*—the process of detecting increased radiation intensity by making one or more measurements of the intensity in the vicinity of a pedestrian or motor vehicle for comparison with an alarm threshold derived from the expected background radiation intensity.

3.1.4 *NaI(Tl) detector*—an inorganic sodium iodide (thallium activated) (NaI(Tl)) scintillation detector that has inherently good gamma-ray sensitivity but poor neutron response.

3.1.5 *nuisance alarms*—an alarm not caused by SNM but by one of a number of other causes. For example, the statistical variation in the measurement process, natural or process-induced background intensity increases, or the presence of non-SNM radiation emitters, among other things, may increase a monitor's measurement result by enough to cause an alarm. Nuisance alarms from statistical variation, by design, are the only ones present during testing and are the ones of concern in designing and evaluating SNM monitors. These statistical alarms are expressed in terms of alarms per comparison (test) or, more importantly, alarms per passage, which may include a number of comparisons. A monitor's susceptibility to statistical alarms and its detection sensitivity are directly related.

3.1.6 *passthrough monitor*—a radiation monitor that allows free passage as it makes monitoring measurements and does not require the person or vehicle being monitored to stop unless it alarms.

3.1.7 *plastic scintillation detector*—a solid organic scintillator that responds to both gamma rays and energetic neutrons through scattering interactions between the incident radiation and electrons or protons in the scintillator.

3.1.8 *radiation detector*—(*1*) a detector consisting of a scintillating material and attached photomultiplier tube that produces light from neutron or gamma-ray interactions and converts the light to electrical signals. (*2*) a neutron proportional counter containing a converter gas to produce electrical signals from neutron interactions.

3.1.9 *standard SNM performance 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. Such minimum radioactive emission sources as described in 3.1.9.1 and 3.1.9.2 allow testing with the worst-case forms of SNM. As a result of worst-case testing, routine operation of a tested monitor in a plant achieves as good or

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

[4] Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[5] Available from the U.S. Nuclear Regulatory Commission, Washington, DC 20555.

[6] Chapter 4, *Entry-Control Systems Handbook*, SAND77-1033, Sandia National Laboratories, Albuquerque, NM 87185.

better performance and the monitor will detect the same or smaller masses of process SNM.

3.1.9.1 *special nuclear material (SNM)*—plutonium with an isotopic content of at least 93 % plutonium-239 (^{239}Pu) and less than 6.5 % plutonium-240 (^{240}Pu). The plutonium should contain less than 0.5 % impurities. The form of the material should be a metallic sphere or cube. The impact of americium-241 (^{241}Am), a plutonium decay product that will build up in time and emit increasing amounts of 60-keV gamma radiation, must be minimized by including a cadmium filter 0.04 to 0.08-cm thick as part of the source encapsulation. Protective encapsulation should be in as many layers as local rules require of a material such as aluminum (≤0.32-cm thickness) or thin (≤0.16-cm thickness) stainless steel or nickel that minimize unnecessary radiation absorption.

3.1.9.2 *standard uranium test source*—highly enriched uranium (HEU) containing at least 93 % uranium-235 (^{235}U) and less than 0.25 % impurities. The form of the material should be a metallic sphere or cube. Encapsulation should be thin plastic or thin aluminum (≤0.32-cm thickness) to minimize unnecessary radiation absorption in the encapsulation.

3.1.10 *special nuclear material (SNM)*—plutonium of any isotopic composition, ^{233}U, or enriched uranium as defined in Terminology C 859. This is the term normally used to describe monitors designed for monitoring SNM or strategic SNM, which is plutonium, uranium-233, and uranium enriched to 20 % or more in the ^{235}U isotope.

3.1.11 *special nuclear material (SNM) monitor*— a radiation detection system that measures ambient radiation intensity, determines an alarm threshold from the result, and then when it is monitoring, alarms if that threshold is exceeded.

3.1.12 *wait-in monitor*—a radiation monitor in which the person or vehicle being monitored is required to stop and remain stationary during monitoring measurement.

4. Significance and Use

4.1 SNM monitors are an efficient and sensitive means of unobtrusively (without a body search) meeting the requirements of 10 CFR (Code of Federal Regulations) Part 73 or DOE Order 5632.4 (May 1986) that individuals exiting nuclear material access areas (MAAs) be searched for concealed SNM. The monitors sense radiation emitted by SNM, which is an excellent but otherwise imperceptible clue to the presence of the material. Because the monitors operate in a natural radiation environment and must detect small intensity increases as clues, the monitors must be well designed and maintained to operate without unnecessary nuisance alarms.

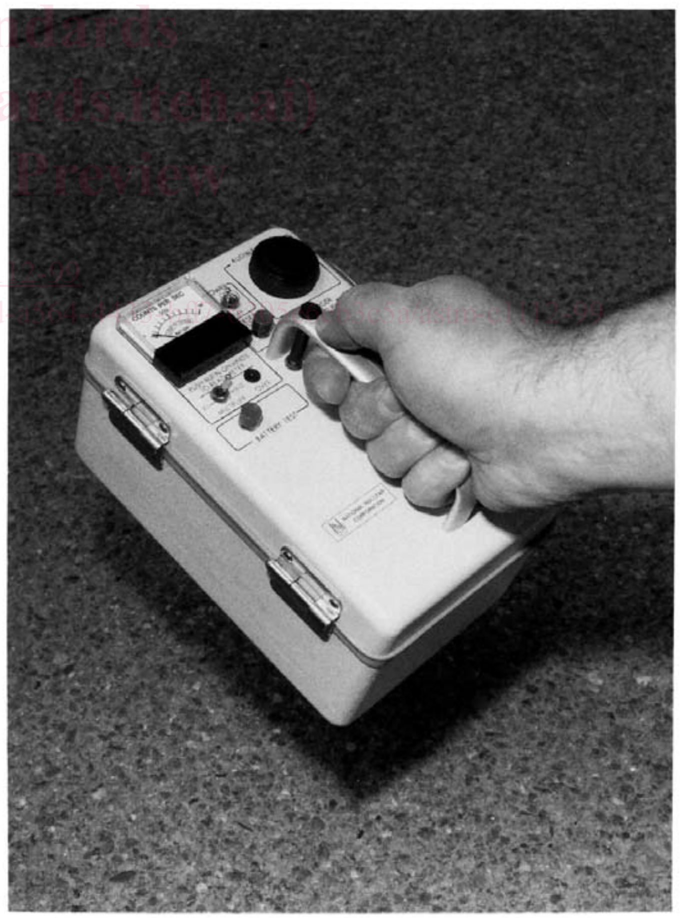
4.2 This guide provides information on different types of monitors for searching pedestrians and vehicles. Each monitor has an inherent sensitivity at a particular nuisance alarm rate that must be low enough to maintain the monitor's credibility. Sensitivity and nuisance alarm rates are both governed by the alarm threshold so it is very important that corresponding values for both be known when measured, estimated, or specified values are discussed. Fitting SNM monitors into a facility physical protection plan must not only consider adequate sensitivity but also a sufficiently low nuisance alarm rate.

5. Types of SNM Monitors

5.1 *Hand-Held Monitors*—These small, battery-powered, computer-operated instruments (Fig. 1) measure ambient background intensity (over 8 s or so) and then calculate an alarm threshold on power-up or push-button command. Otherwise, they continuously monitor, making short measurements (0.05 s long averaged over 0.4 s, for example) and then comparing the results to the alarm threshold. Hand-held monitor detectors may be gamma-ray sensitive NaI(Tl) detectors or, more commonly, plastic scintillation detectors that sense both gamma rays and neutrons **(1-3)**.[7] The operator of a hand-held monitor scans (at about 0.5 m/s) the instrument over every surface of a pedestrian or vehicle, coming within 5 to 15 cm (2 to 6 in.) of all possible locations for SNM **(4)**.

5.1.1 Frequent or continuous alarms in a particular region are clues that inform the operator of the presence and location of SNM. Occasional alarms from statistical variation in counting do not detract from searching so a very low alarm threshold

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



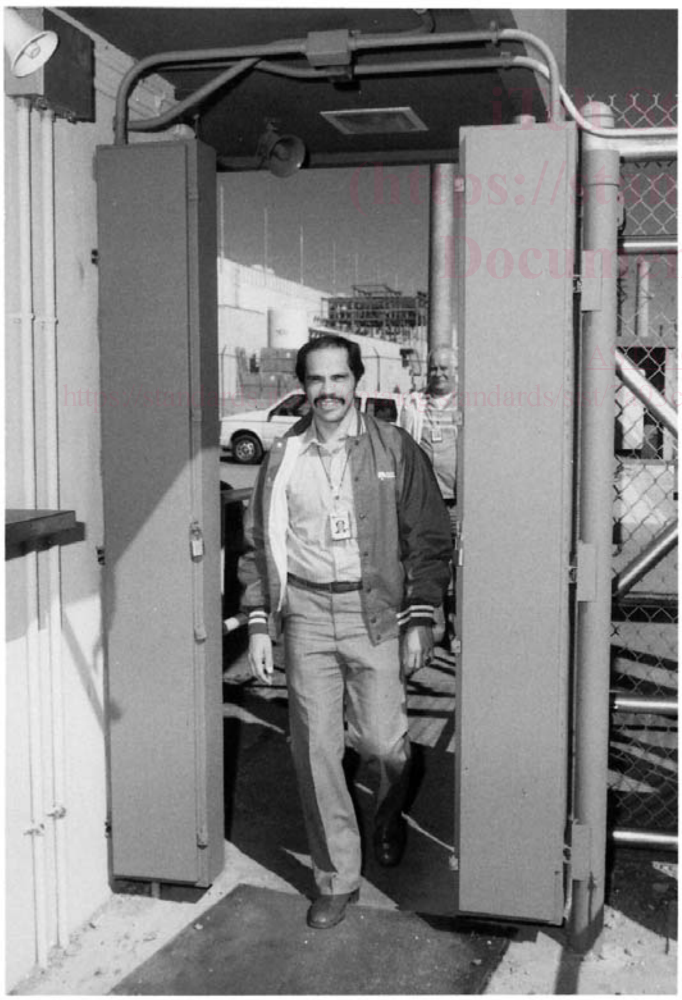
NOTE—Hand-held monitors are computer-based radiation detection systems that operate on battery power. The operator plays an important part in effective hand-held monitoring

FIG. 1 Hand-Held Monitors

and consequent high statistical alarm rate (1 per 100 comparisons, which corresponds to 1 or 2 alarms per minute) can be tolerated.

5.1.2 Hand-held monitor sensitivity in specific laboratory tests in the AEC performance Standard for Hand-Held SNM Detection Instruments for Personnel, Package, and Vehicle Search is required to be 10-g HEU or 1-g low-burnup plutonium in a 20 μR/h (5.16 nC/kg·h or 1.43 pA/kg) background. The applications guide to vehicle monitors **(5)** gives a sensitivity range of 3 to 9-g low-burnup plutonium and 100 to 300-g HEU for vehicle monitoring by routinely trained inspectors under specified worst-case conditions at 20 μR/h (5.16 nC/kg·h or 1.43 pA/kg) background intensity and a statistical nuisance alarm rate of 1/100. Sensitivity of the monitors under routine circumstances is equal or better in both cases.

5.2 *Automatic Pedestrian Monitors*—Pedestrian portal or doorway monitors search pedestrians as they walk through (Fig. 2). Few monitoring booths are operating at present. Automatic monitors usually have gamma-ray and neutron-sensitive plastic scintillation detectors. A few have either gamma-ray sensitive NaI(Tl) detectors or neutron-sensitive proportional counters.



NOTE—Pedestrian portal monitors automatically sense and monitor pedestrians as they pass through the portal. The monitors perform their task reliably without the need for operator action.

FIG. 2 Pedestrian Portal Monitors

5.2.1 Monitoring begins when a pedestrian is sensed at the portal threshold and a sequence of measurements (~0.25 s long and averaged over 0.75 to 1 s) made during passage (~0.75 to 1.5 s duration) are compared with an alarm threshold based on the current background intensity. Background is measured continuously when the monitor is unoccupied.

NOTE 1—Monitoring moving occupants is done most effectively using one of the transient signal detection methods described in Ref **(6)**.

5.2.2 Nuisance alarms must be minimized in automatic monitors because each alarm is significant and must be investigated. Alarms require further investigation with a hand-held monitor to find the cause. To avoid unnecessary nuisance alarms from counting statistics, alarm thresholds in automatic monitors are set high, as much as four standard deviations above the mean when six comparisons are made per passage as in the 1.5-s case above, and the background intensity is precisely determined.

5.2.3 Sensitivity of minimally qualifying automatic pedestrian monitors is specified in a draft revised AEC/NRC Regulatory Guide 5.27 **(7)** as 0.5-g low-burnup plutonium or 10-g HEU at normal passage through the monitor's minimum sensitivity region in a 20-μR/h (5.2 nC/kg·h or 1.43 pA/kg) background and with one or fewer statistical nuisance alarms per 1000 passages. The pedestrian monitor applications guide **(8)** establishes four sensitivity categories that range from 1 to 64-g ^{235}U and 0.03 to 1-g ^{239}Pu for normal passage through the least sensitive region of a portal under specific worst-case conditions that include 25-μR/h (6.5 nC/kg·h or 1.8 pA/kg) background intensity and a statistical nuisance alarm rate of 1 per 8 h of operation (as few as 1/4000 passages in laboratory tests). Sensitivity under routine circumstances is better.

5.3 *Automatic Vehicle Monitors*:

5.3.1 *Vehicle Portal Monitors*—These portals (Fig. 3) monitor vehicles in motion as they pass through the detectors on their approach to an entry control station. Almost all vehicle portal monitors are ones that use large plastic scintillation detectors to provide uniform monitoring with detectors on each side of the vehicle. During vehicle passage (lasting about 3 to 5 s at 2.2 m/s passage speed), six or more monitoring measurements (0.5 s long averaged over 2 s) will be made, about one for each metre of vehicle length. SNM anywhere in the vehicle will be near the detectors for at least one of these measurements, which is the one that offers the best chance for detection. The plastic scintillation detectors sense both gamma rays and neutrons; however, the distance between source and detector in a vehicle portal does not allow them to intercept many neutrons from SNM.

5.3.1.1 A new type of portal monitor obtains better neutron sensitivity by using very large neutron-chamber detectors that sense neutrons but not gamma rays (Fig. 4). It can be used alongside an existing gamma-ray vehicle portal to provide neutron monitoring to detect shielded plutonium.

5.3.1.2 The vehicle monitor applications guide **(5)** gives worst-case sensitivity estimates for existing portals as 10-g low-burnup plutonium or 1-kg HEU at a statistical nuisance