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*

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

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

appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 859 Terminology Relating to Nuclear Materials

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

C 1189 Guide to Procedures for Calibrating Automatic Pedestrian SNM Monitors

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

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

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

[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.

operation of a tested monitor in a plant achieves as good or 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.

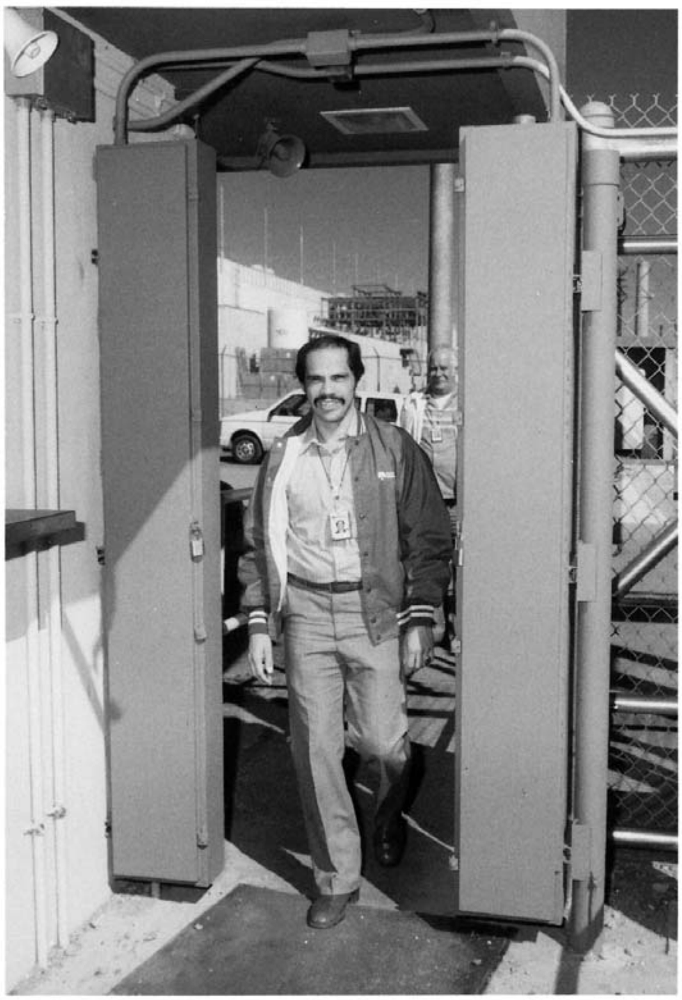
NOTE—Hand-held monitors are computer-based radiation detection systems that operate on battery power. The operator plays an important part in effective hand-held monitoring

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*:

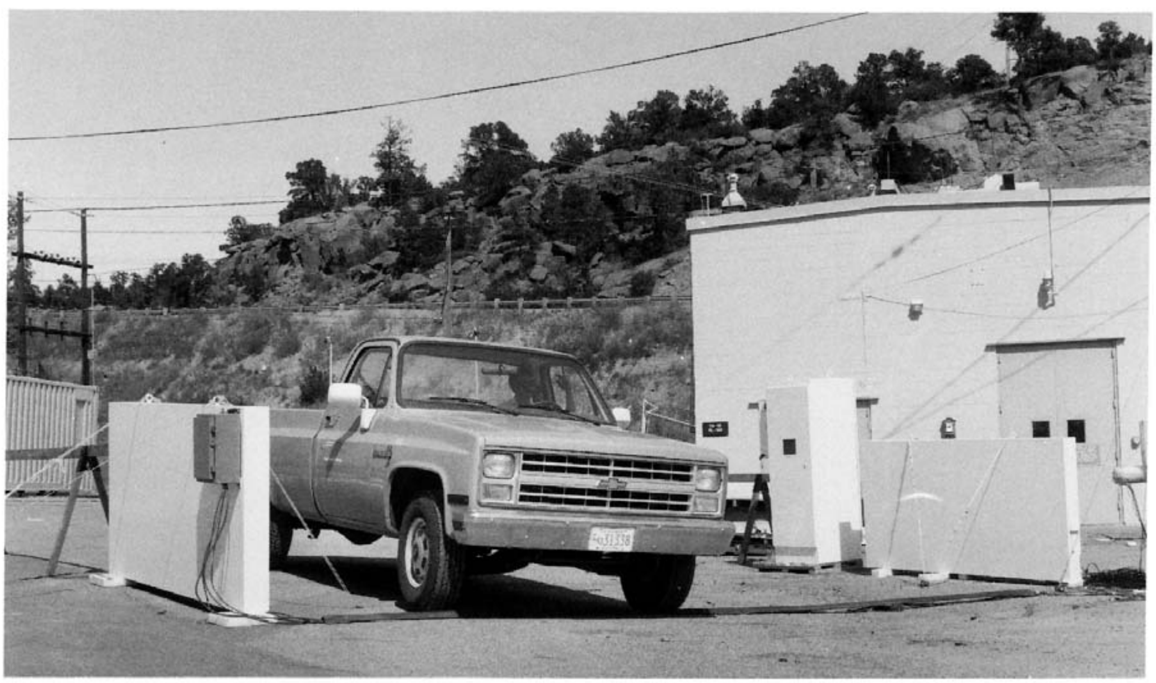
5.3.1 *Vehicle Portal Monitors*—These portals (Fig. 3) monitor vehicles in motion as they pass through the detectors on their approach to an entry control station. Almost all vehicle portal monitors are ones that use large plastic scintillation detectors to provide uniform monitoring with detectors on 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

NOTE—Vehicle portals automatically sense and monitor vehicles passing between the detectors. Attenuation by vehicle structure or contents and the larger distance between detectors make vehicle portals less sensitive than other types of monitor.

FIG. 3 Vehicle Portal



NOTE—Neutron vehicle portal monitors can outperform other vehicle portals for detecting shielded plutonium, but gamma-ray vehicle portals provide the best unshielded SNM sensitivity.

FIG. 4 Neutron Vehicle Portal Monitor

alarm rate of 1/4000 passages and passage speed of 8 km/h. Sensitivity under routine circumstances is better.

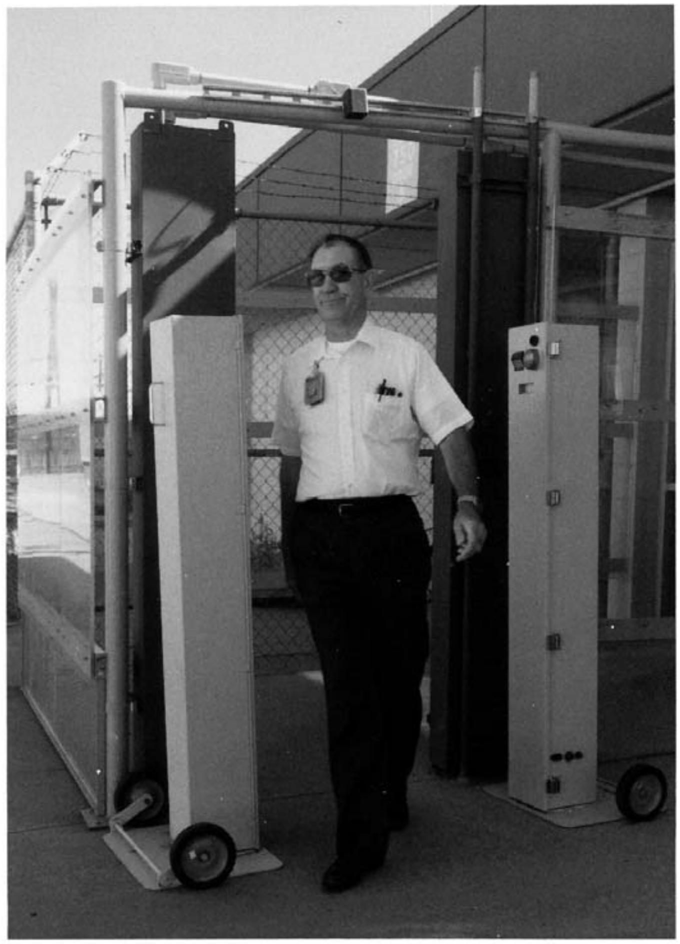
5.3.2 *Vehicle Monitoring Stations*—These monitors (Fig. 5) are located near an entry control station and monitor vehicles while they stop and wait for exit clearance. In this case, the monitoring time can be long enough (20 to 60 s) to achieve sensitivity close to that obtained in pedestrian portals. Many plastic scintillators (16 or more) are used, and most of them are underground in trenches below the vehicle. The number and proximity of detectors allows them to detect many neutrons and gamma rays from SNM located in a vehicle. A monitoring station makes only one measurement, but its detectors are distributed around the vehicle so that one of them is near SNM placed anywhere in the vehicle. The vehicle monitor applications guide (**5**) gives worst-case sensitivity estimates for a monitoring station as detecting 0.3-g low-burnup plutonium of 40-g HEU at a statistical nuisance alarm rate of 3/1000. Sensitivity under routine circumstances is better.

5.4 *Multipurpose Portable Radiation Scanner*[8]—This newly developed type of SNM monitor (Fig. 6) fills a temporary need for automatic monitoring. For example, it may be used for a few days when a permanent monitor is being repaired or modified. Another use could be at a construction area or other temporary gate when monitoring is temporarily required. This monitor is easily portable (wheels are provided), may meet temporary monitoring requirements, and is self-powered (20 to 140-h batteries) except for battery charging power. The monitor provides local status and alarm signals and also may be interfaced to facility alarm networks.

[8] Information on these new monitors is available from the manufacturer, TSA Systems, Ltd., 1830 Boston Ave., Longmont, CO 80501, under the designation PRS-1.

NOTE—Vehicle monitoring stations use an extended measurement time and have close proximity between detectors and vehicles, which makes them the most sensitive type of vehicle monitor.

FIG. 5 Vehicle Monitoring Stations



NOTE—Portable radiometric scanners are a new type of SNM monitor designed for temporary use. They are self-contained except for battery charging power and have wheels to make them portable.

FIG. 6 Portable Radiometric Scanners

6. Operational Considerations

6.1 *Background Radiation Intensity*—SNM monitors detect signals from SNM against a natural background plus perhaps an additional facility-related background from materials in process or storage. The statistics of the measurement process at constant statistical nuisance alarm probability cause sensitivity to decrease as background intensity increases. Hence, best performance is obtained when the background intensity is as low as possible. Neutron backgrounds are inherently very much lower than gamma-ray backgrounds, but SNM neutron source strengths are also relatively low. Usually, gamma-ray detection is the most effective form of monitoring, and neutron detection is used only to improve monitoring for plutonium in thick gamma-ray shielding.

6.2 *SNM Shielding*— Some amount of SNM self-shielding is usually present, and SNM encapsulation and packaging may also provide shielding. Vehicles may have structural materials or contents that can shield SNM, making it more difficult to detect. A related factor is that a pedestrian or vehicle coming between a radiation detector and terrestrial sources of background radiation will lower a monitor's background count rate. As a result, whenever a monitor is occupied, a higher count rate from SNM will be needed to alarm the monitor than that needed when it is unoccupied. This phenomena is most significant in vehicle monitors.

6.3 *Reducing the Impact of SNM Shielding*:

6.3.1 SNM shielding is most effective for the gamma radiation from HEU. Pedestrian monitoring for uranium may be made more effective if shielding can be detected independently by a very sensitive metal detector located next to an SNM monitor. Perhaps 100 or 200 g of solid lead shielding can be detected with a walkthrough metal detector; however, many innocent metallic items will also be detected and could cause an intolerable nuisance alarm rate for pedestrians in street clothing. Pedestrians suited in work clothing with nonmetallic fasteners and not carrying unnecessary metallic items may not cause alarms. Providing changing rooms with lockers so that pedestrians can change into nonmetallic attire before passing through a monitor should make high-sensitivity metal detection a useful technique for improving HEU monitoring.

6.3.2 Shielding has a smaller impact on radiation from low-burnup plutonium. With plutonium, the plastic scintillators sense both gamma rays and neutrons, and shielding is not effective unless both heavy gamma-ray shielding and bulky neutron shielding are present. Because the plastic scintillator monitors are so effective at detecting shielded plutonium, metal detectors add little to the overall effectiveness. The pedestrian monitor applications guide (**8**) estimates that quantities of 100 g or more of low-burnup, metallic plutonium are impractical to hide from a monitor by using very thick gamma-ray shielding if the monitor meets the Category II requirement to detect 0.3-g unshielded plutonium (or 10-g unshielded HEU).

7. Applying SNM Monitors

7.1 Pedestrian and vehicle monitors should be used at the boundary of MAAs or protected areas as required by a facility physical protection plan for SNM. Monitor locations should be in areas of low background and low background variation. The monitor's detectors should be collimated with lead shielding to limit their view to the area that will be occupied during monitoring. Traffic flow speed should match a monitor's optimal performance speed (easily adjustable in some monitors). An extended measurement time in a monitor located where a person must stand during identification and badge inspection for exit clearance can improve the monitor's sensitivity over walkthrough monitoring. Turnstiles can slow pedestrians, and speed bumps can slow vehicles to increase the available monitoring time in a portal. Automatic monitors are most reliable but hand-held monitors more easily adapt to high and variable background. In some cases, hand-held monitors can more closely approach SNM, increasing the SNM signal relative to background and making it easier to detect.

7.2 Background updating should be on push-button command in hand-held monitors and should be continuous in unoccupied automatic monitors. Background measurement times should be at least 20 times as long as monitoring measurement periods to minimize the influence of background precision on a monitor's statistical nuisance alarm rate. However, shorter background measurements may occasionally be necessary to cope with a variable background. Occupancy sensors (visible or infrared light beam or magnetic vehicle sensor, for example) should be used to inform automatic monitors when to monitor (occupied) and when to measure background (unoccupied).

7.3 Ideally, only one pedestrian or vehicle at a time should be in the monitoring area to keep bystanders from altering the true background, providing shielding, or causing confusion about which person or vehicle triggered an alarm. Where prevailing circumstances allow multiple occupancy, photographic or video records of monitor occupants triggered by an alarm may help find the cause.

7.4 Background limit alarms should be provided in automatic monitors. Backgrounds outside the limits may indicate a need for repair or simply an unusually high background that lowers the monitor's sensitivity enough that hand-held monitoring is called for. An upper limit should be set at the point that the sensitivity becomes inadequate (**5**). For example, if sensitivity is insufficient above a background of 35 μR/h (9 nC/kg·h or 2.5 pA/kg) and the normal background is 25 μR/h (6.5 nC/kg·h or 1.8 pA/kg) and produces 5000 counts/s in the monitor, its upper limit would be set at 7000 counts/s. The same monitor operated in a 10 μR/h (2.6 nC/kg·h or 0.72 pA/kg) background displays a lower count rate but has the same upper limit. Lower limits are set to detect one nonfunctioning detector. In the example above, with four detectors, the lower limit would be set at 3900 counts/s at 25 μR/h background and 1600 counts/s at 10 μR/h background. Background alarms are signaled with indicator lamps, and in some cases, for example, Part 3, Sec. VI of the vehicle monitor applications guide (**5**), the monitor is taken out of service except for making a vocal announcement to hand monitor each time the monitor is occupied.

7.5 All monitor wiring, controls, and adjustments should be protected from harm and accidental or unauthorized changes. Wiring can be protected in conduit or supervised to detect tampering. Separate information and control modules having the necessary indicators and switches for security inspectors can be provided. Tamper switches can be used on all cabinets containing monitor or occupancy sensor hardware to detect inadvertent or unauthorized access to the monitor that may subvert it.

7.6 Bypass barriers for portal monitors should be used to prevent passage outside the monitor's sensitive region. Barrier panels are used for pedestrian monitors and vehicle trap fencing for vehicles. Monitoring stations for vehicles also have trap fencing and in monitoring booths, the booth walls prevent bypass.

7.7 A chime or other pleasant sound can be used in automatic monitors to inform the inspector that an occupant has been sensed and is being monitored, a positive indication that the monitor is operating. Where traffic flow is high, making the chime a nuisance, a readily visible indicator lamp may be more appropriate.

7.8 A sound that readily demands attention should be used to announce alarms. Visual alarm signals also help. But the alarm announcement should not be severe enough to unnecessarily distract the inspector at a time when he or she should closely observe the vehicle or pedestrian causing the alarm.

8. Testing and Calibration

8.1 A monitor should be calibrated and then tested with SNM at the time of installation. Written records of calibration, including all parameter settings and observations, should be kept on file to aid any future repair and troubleshooting effort and to provide evidence of a well-run maintenance program.

8.2 Daily testing to verify that a monitor is in good working order and is capable of reporting an alarm often can be done by protective force inspectors, either once a day or at the start of each work shift. If repair is needed, a hand-held monitor or portable monitor can be used in the interim. An isotopic source such as ^{137}Cs normally used for calibration or a ^{133}Ba with 3.7×10^4 to 1.1×10^5 Bq (1 to 3 μCurie) activity would be suitable for the purpose. Written records of daily tests signed by the security inspector will provide good supporting documentation.

8.3 At MAA boundaries where an SNM test source can be stored near the monitors, testing with SNM is usually practical, and a schedule of testing with SNM by authorized personnel can be established to verify that the monitors meet the sensitivity required by the facility physical protection plan. Testing with SNM could be done at weekly, monthly, or at longer intervals, but, in any case, at no less than a three-month interval.

8.4 At protected area boundaries where SNM is not readily available, isotopic source tests can substitute for SNM source tests, particularly if testing is more frequent than three-month intervals. The substitute source suggested in the pedestrian monitor applications guide (**8**) is ^{133}Ba, and Table V in that guide lists an appropriate source activity for pedestrian monitors in each performance category. The vehicle monitor applications guide (**5**) suggests substitute sources and activities for each type of vehicle monitor in Part 1, Sec. V.

8.5 At three-month intervals, each monitor's calibration should be checked, and then the monitor should be tested with SNM. Testing and recalibration as needed should also follow any repair, even repairs that are not expected to affect performance. Moving an automatic monitor to another location also calls for recalibration and testing.

8.6 Monitor calibration and maintenance is most easily done if the manufacturer provides designated and protected (but readily accessible for maintenance) test points, test signal connectors, and adjustments that externally provide everything that needs to be observed or adjusted during calibration. A clear, complete, and easily read calibration and maintenance manual is essential for proper monitor upkeep. Guide C 1189 further explains the process of calibrating the radiation detectors and detection logic used in SNM monitors.

8.7 Test procedures and test sources for monitors are described in this series of ASTM standards; Guide C 993 for pedestrian portals, Guide C 1236 for vehicle monitors, Guide C 1237 for hand-held monitors. Standard test sources are forms of SNM that emit less radiation than common process materials in order to make test performance the worst case. Least emission is from metallic SNM having high self-attenuation of emitted radiation, isotopic compositions for least emission, and, in the case of plutonium, a thin cadmium absorber to remove 60-keV gamma rays from ^{241}Am that builds up over time, making any form of unfiltered plutonium unsuitable as a standard test source (see 3.1.9.2).

9. Evolution of Monitoring Technology

9.1 This guide concentrates on the technology that is now available for operational use at regulated facilities. Some of the SNM monitors discussed are relatively new, but all are in service. New monitoring concepts such as neutron pedestrian portals that are not yet commercially available are not discussed here but eventually will be. Although such equipment addresses the same basic needs discussed in this guide, it is not likely to make existing technology obsolete and will have similar guidelines for its proper use.

10. Keywords

10.1 material control and accountability; nuclear materials management; radiation monitors; safeguards; security; SNM

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