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*A Portable, Automatic SNM Monitor for
Nuclear Safeguards: Development,
Evaluation, and Applications*

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A PORTABLE, AUTOMATIC SNM MONITOR FOR NUCLEAR SAFEGUARDS: DEVELOPMENT, EVALUATION, AND APPLICATIONS

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ABSTRACT

The portable SNM monitor is a lightweight, full-size, automatic monitor, suitable for temporary service (such as demonstrations or for use during maintenance) or as a permanent replacement for hand-held monitors. We based the monitor on the TSA Systems, Ltd., modular SNM monitor design and, through evaluation and improvement of the commercial modules, obtained adequate sensitivity in a single-cabinet monitor that is easily portable. Complete monitoring of pedestrians with a single detector cabinet is achieved by requiring the pedestrian to stand in front of the detectors and turn around through 360 deg while being observed by a security inspector. The monitor is available commercially as the TSA Systems Model PMD-701, and it is beginning to be used in both temporary and permanent applications.

I. INTRODUCTION

A special-nuclear-material (SNM) monitor is a radiation detection system designed to respond to the radiations emitted by SNM by sounding an alarm when the materials are present. The portable SNM monitor is a full-size, automatic monitor suitable for temporary or permanent service. The monitor stems from our work during the 1980s to develop SNM monitors for the Nevada Test Site (NTS). The stimulus for developing the monitor was a need for a portable, vehicle SNM monitor for use at ground-zero locations, as outlined in our 1987 technical assistance plan.¹ Although the priority for the NTS application soon died away, other applications for a portable monitor appeared. One prospective application was to provide temporary SNM monitoring, for instance, in place of a portal monitor being repaired or recalibrated. Another possible application was to replace hand-held monitoring at locations where the portable monitor would be more compatible than a conventional portal monitor, making automatic monitoring possible. A third, serendipitous application

for the portable monitor, now that it is available, is as a demonstration unit for illustrating the nature and capabilities of SNM monitors.

For a monitor to be portable, it must be lightweight and easily handled. The most important steps toward obtaining light weight in a portable monitor were; (1) being able to contain everything needed in a single cabinet; and (2) being able to monitor by having the person stand in front of the cabinet while turning around through at least 360 deg. This mode of operation gives the single-cabinet design the best chance for thorough monitoring and acceptable sensitivity. However, obtaining acceptable sensitivity also requires getting the best from each of the monitor's commercial components. This involved modifying the cabinet material and evaluating and modifying the commercial system controller to obtain better sensitivity.

The portable monitor is commercially available and is being used in some applications; this report describes the monitor, its development (including the measures taken to obtain adequate sensitivity at an acceptable weight), and its capabilities.

II. DEVELOPMENT OF THE PORTABLE PORTAL

A. An Overview

Transportable SNM monitors are not entirely new; arrays of hand-held monitors and one commercial monitor on wheels have been used for temporary monitoring in the past. However, these have not provided head-to-toe sensitivity equivalent to permanently installed portal monitors. Our task, then, was to find a way to reduce the size and weight of an automatic portal monitor to make it portable while, at the same time, maintaining adequate sensitivity. As a starting point, we chose the *TSA Systems' line of SNM monitors for three reasons: (1) their low-power system controller can be housed together with the detectors; (2) their modular approach to building different types of monitor; and (3) our experience from previous evaluations² suggested that detector sizes could be greatly reduced without sensitivity loss if the system controller were modified to reduce the low-level noise in the signal-processing electronics.

Figure 1 illustrates the portable portal monitor, designated PMD-701 by TSA Systems. The exterior view at the right shows the front door of the detector cabinet and the four important items mounted on it. Mounted at the top of the door are a red strobe light and a sounder for announcing alarms, a yellow lamp to indicate out-of-service status, and a passive-infrared sensor that is used to tell when a person is present to be monitored. A short distance below, the slot-shaped window in the door allows viewing the system controller's liquid-crystal display (LCD) showing the monitor's count rate. The system controller itself can be seen in the open-door view at the left. The system controller serves several purposes; it provides appropriate power for the monitor and signal conditioning for the detectors, and it carries out the microprocessor functions for controlling the monitor and analyzing detector signals. The two black objects above and below the controller are plastic scintillators, the radiation detectors used by the monitor. They are oriented to place their photomultipliers, which convert scintillation light to electrical pulses, behind the system controller. Also in the cabinet, at the bottom, are a battery and trickle charger that provide the primary power for the monitor.

B. Design for the Portable Portal

We based the initial design for the portable portal on our NTS vehicle portal monitors³ with two important

modifications. One was to change from using steel cabinets to aluminum ones; this reduced weight and increased transmission of low-energy gamma rays and x rays, allowing us to use smaller radiation detectors. The second modification was to adopt the TSA system controller, which eliminated the need for a separate electronics cabinet and provided a small, low-power, lightweight electronics package for the monitor. We asked TSA Systems to modify their standard PM-701 portal design, as indicated in Table I, to produce our custom prototype portable portal.

C. Improving the System Controller

Our first experience with the TSA Systems compact system-controller unit was in 1985, when the company sent us a VMC-250 control unit as a possible replacement for the controller in a TSA Systems PM600 portal monitor that we were evaluating for Rocky Flats. We found that the new controller was not yet a viable product because its nuisance-alarm** rate was "so high as to be almost continuous"⁴ when its single-channel analyzer (SCA) [†]was adjusted for best detection of highly enriched uranium (HEU). We recommended a consultant who could help correct the problem, and we had an opportunity, in 1987, to evaluate TSA Systems' later edition of the controller, designated model PMC-750. Its performance was much improved, but residual noise prevented us from adjusting the SCA for the very best possible HEU detection.⁶ The SC-750 controller provided in our prototype portable monitor performed in the same manner, except that TSA Systems had limited the SCA adjustment, at about 160 mV, so that users could not adjust the SCA into the noisy region.

The SCA adjustment is particularly important for detecting low-energy radiation with plastic scintillators that depend on collision reactions to detect radiation. For example, gamma rays are detected when they collide with an electron, sharing part of their energy with it, and the electron then loses that energy in a process that produces light that can be converted to electrical pulses by a photomultiplier tube. The amount of shared energy will vary from a good fraction of the gamma-ray energy to very little, so there will be a broad spectrum of

**A nuisance alarm "is a monitoring alarm not caused by SNM but by other causes that may be statistical variation in the measurement process, background intensity variation, or equipment malfunction."⁵

[†]An SCA is used to select signal pulses that fall within a selected pulse-height range for further processing; in this case, the range would contain the radiations from SNM.

* TSA Systems, Ltd., 1820 Delaware, Longmont, CO 80501

(a)

(b)

Fig. 1. Interior (a) and exterior (b) views of the portable portal monitor illustrate the basic components used in the TSA Systems' NMM monitors.

Table I. Modifications to the PM-701 Design	
Modification	Description of the modification (in manufacturer's measurement units)
Light, transparent cabinet material	Aluminum, 0.080 in. thick with a 0.125-in.-thick back plate and a 0.250-in.-thick base (Exterior should be painted white.) ^a
Cabinet sealing ^a	Foam gasket on door and silastic sealing material around door-mounted components
Rain shield ^a	Aluminum deflector above the top edge of the door
Handles	Two sets of handles on the cabinet sides to aid in transporting the monitor
Smaller radiation detectors	3-in. by 1.5-in. by 31-in. plastic scintillators with 5-in. light pipes
Thinner detector collimation	0.125-in.-thick lead collimators instead of the standard 0.375 in.
Battery	12 V, 12.5 Ah, providing at least 12 h of operation after power failure
Chime ^a	To signal that monitoring is in progress
System controller	Use lowest-noise version available
^a Afterthoughts introduced during or after the evaluation.	

electrical pulse heights emerging from plastic scintillation detectors. For relatively low-energy radiation, as from HEU, small pulses predominate and are very important to detect. Because the SCA should begin accepting pulses at about 80 mV, instead of at the 160-mV lower limit of the SC-750, we took it upon ourselves to try to reduce the noise levels in the unit.

We purchased a second SC-750 for study and modification; D. W. McArthur and K. S. Allander (LANL, N-2) worked on the problem. They found ground loops, insufficient bypassing, an inadequate low-voltage power supply, complex cable routing, and lack of a ground plane between digital and analog circuits to be significant problems⁷; and they made modifications

to the second controller to improve its performance wherever possible. Their renovation reduced noise levels enough to allow setting an SCA lower limit of 100 mV (without increasing nuisance alarms), which is significantly below the original 160 mV.⁸ Figure 2 illustrates the increase in detection efficiency, as a function of gamma-ray energy, that was brought on by the renovation. The efficiency is much greater in the region below 200 keV, where the gamma rays and x rays from HEU lie. The corresponding increase in sensitivity approximately doubled the monitor's count-rate response to HEU,⁸ as shown in Table II.

After reviewing our suggestions for reducing the noise in the SC-750, the manufacturer conducted their

Fig. 2. A lower SCA threshold, made possible by reducing noise, greatly increases detection efficiency at low energy, providing greater sensitivity for detecting HEU.

own evaluation⁹ and then produced a new, low-noise version of the unit. We purchased one of them for the portable monitor, and its performance compared well to our renovated unit. The low-noise SC-750 had noise levels low enough to allow setting a SCA threshold at 80 mV, and its response to HEU more than doubled the rate for the original SC-750. The low-noise design is now standard in TSA monitors.

III. LABORATORY PERFORMANCE EVALUATION

We conducted a laboratory evaluation of the portable portal monitor with the low-noise control unit installed. The response to the HEU sphere was higher than we had achieved with our renovation, but the nuisance-alarm rate was slightly higher as well, as indicated in Table III.

Table II. Comparison of the SC-750 Performance Before and After Renovation^a

Controller status	SCA lower threshold (mV)	Nuisance alarms, range per passage	10.7-g HEU sphere count rate (counts/s)
As received	160	1/990 to 1/1025	187
Renovated	100	1/894 to 1/1078	375

^aData are from simulated passages that included five monitoring comparisons for each passage. The nuisance-alarm range corresponds to ± 1 std dev. The HEU sphere, containing 10 g of ^{235}U , was positioned 38 cm from the plane of the detector front surfaces at 61 cm above the floor.

Table III. Comparison of the SC-750 Performance^a

Controller status	SCA lower level (mV)	Nuisance alarms, range per passage	10.7-g HEU sphere count rate (counts/s)
As received	160	1/990 to 1/1025	187
Renovated	100	1/894 to 1/1078	375
Low-noise version	80	1/654 to 1/821	462

^aData are from simulated passages that included five monitoring comparisons for each passage. The nuisance-alarm range corresponds to ± 1 std dev. The HEU sphere, containing 10 g of ^{235}U , was positioned 38 cm from the plane of the detector front surfaces at 61 cm above the floor.

For performance testing, we used the procedures outlined in ASTM standard C 1169,¹⁰ which uses the least-sensitive location for performance testing. We established that the foot region was least sensitive by scanning a 10.7-g HEU sphere from floor level to the cabinet height of 7 ft* (213 cm) above the floor at a short distance from the cabinet door. The data for the as-received and renovated portals in Fig. 3 illustrate the least-sensitive region, and also graphically demonstrate the HEU-sensitivity improvement brought about by being able to lower the SCA threshold. Another indication of improved sensitivity to low-energy radiation is that there is a difference between the doors-open and doors-closed curves for the renovated portal, but not for the as-received portal. After renovation, the portal is detecting gamma rays from HEU with low enough energy that they are being attenuated by the relatively thin aluminum door. Before renovation, only the most energetic gamma rays were detected, and they readily passed through the closed door.

We used the step-up and rotate method of monitoring in our detection sensitivity evaluation, where each passage involved an individual walking up to the monitor and stopping in front of it, turning completely around until again facing the monitor, then turning and walking away. Four individuals each made two groups of five passages with a 10.7-g HEU sphere attached to an interior ankle. Background was allowed to update between groups of five passages. The overall result was 36 detections for 40 passages, qualifying the portable portal monitor as a Category II, standard uranium monitor, under the ASTM mass-detection sensitivity criteria** given in Table 1 of ASTM C 1169. The ASTM laboratory evaluation summary report for the portable monitor is reproduced in the Appendix.

IV. IN-PLANT EVALUATION

A DOE user need, designated AL024-92, gave us the opportunity to conduct an in-plant evaluation of the portable portal monitor. The user need asked for an automatic monitoring system to replace hand-held monitors in material access areas (MAAs) with highly variable background intensity. The areas are part of the Los Alamos Critical Experiments Facility (LACEF),

*Manufacturer's units.

**The criteria require detecting the 10.7-g standard HEU source with 0.50 probability, as determined with a method having a 95% confidence coefficient for its result.

Fig. 3. The HEU vertical source-scan data determine the least-sensitive region.

where critical assembly operation can elevate background intensity during operation and for a period of time thereafter. Standard portal monitors are generally not adaptable to elevated background areas because a portal with opposing detectors is difficult to collimate. However, the single-cabinet portable monitor seemed to have a chance for adapting to the environment.

The aspects of the portable monitor design that might allow it to perform well, where a conventional SNM portal monitor might not, are the following.

- (1) The portable monitor is not a walk-through monitor where the radiation signal from SNM may have to be detected during a second or so of monitoring as an individual passes through. It is a wait-in monitor where the individual stands close to the detectors for an extended monitoring time, which can both increase the signal and extend the time that the signal may be present for detection. Hence, the detected signal may be larger.
- (2) The portable monitor does not have to monitor an individual predominantly from the sides. Instead the individual stands on a position mark in front of the monitor cabinet, then turns completely around (360 deg). This act allows a better chance of exposing to the detectors any uranium attached to the individual's body, hence, the detected signal may be larger.
- (3) The third aspect is that the portable monitor's background and, therefore, its alarm threshold may be lower because it has fewer detectors, two instead of four, and its detectors are smaller.

So, there is a good possibility that, with the portable monitor, signals from uranium could be larger, relative to background, giving the portable monitor better sensitivity.

We evaluated the monitor at one of the LACEF kivas, which are the remote buildings where critical assemblies are operated. The portable monitor was installed outside the kiva in a location where a thick concrete shield was between it and the critical assemblies. In this application, a security inspector is always present when the kiva, which is a MAA, is opened, so there is always an inspector present when SNM monitoring takes place. The security inspector conducts a search for metal; and had this been a routine installation, he would also closely observe the SNM monitoring process to be sure that each individual stands and turns as prescribed (Fig. 4). During the evaluation, the inspector continued to use the hand-held monitor, and individuals were given the opportunity to try the portable portal and provide comments.

We experienced two failures during installation of the portal: a failed battery and a failed photomultiplier dynode voltage divider. These were the only failures that we have had, and they do not seem to be evidence for a continuing problem. Once the monitor was installed, we recorded its detector count rate to assess the influence of critical assembly operation on SNM monitoring. The monitor's displayed background count rate was about 1700 counts/s at the beginning of the evaluation, and the background had increased to about 2150 counts/s at the

end. The increase was caused by temporarily stored radioactive material in a nearby warehouse. Final sensitivity testing of the monitor took place at the higher background, so that value was used as an estimate of when monitoring could resume after critical assembly operation. For the types of critical assembly operation that took place during the evaluation, background intensities decreased to SNM monitoring levels within a few hours. Figure 5 illustrates the background time history for one critical assembly operation.

In Fig. 5, the background intensity decreases to monitoring levels after about 4 h, hence, monitoring could resume at that point with adequate sensitivity. In many cases, such as the tune-up spike at the right (earlier) side of Fig. 5, there would be no delay before resuming monitoring. In other operations with different critical assemblies or power levels, it is possible that recovery would take longer.

The point of resumption simply depends on a successful outcome for routine, in-plant sensitivity testing of the monitor. Testing took place at a background of 2150 counts/s during our evaluation, and, since each trial was detected, it may be possible to operate at even higher backgrounds by conducting additional in-plant sensitivity tests when higher backgrounds occur.

V. APPLICATIONS FOR THE PORTABLE MONITOR

At the completion of the in-plant evaluation, the monitor was in good working order and showed no evidence of environmental damage. It was returned to our laboratory, where we checked its calibration and source response. We saw no changes from when the monitor was removed from the laboratory more than 6 months earlier. A limited amount of moving the monitor to different locations for demonstrations also produced no change in calibration or response.

The first permanent application of the portable portal will be at the LACEF. Los Alamos operational security funds were allocated for purchasing and installing this type of monitor to replace hand monitoring at four locations. We assisted with purchase specification for the monitors, and the manufacturer has delivered them to the site. The monitors should be installed at four MAAs in the near future. At that time, this project will have completed addressing user need AL024-92.

Fig. 4. Monitoring requires the individual to rotate through 360 deg.

Fig. 5. Strip-chart record of a Flattop critical assembly free run that was conducted for a criticality safety class. Time increases from right to left at 1 h per division. The vertical scale approximately reflects 1000 counts/s per major division.

ACKNOWLEDGMENTS

The author acknowledges the work of Duncan MacArthur and Krag Allander in troubleshooting and reworking the monitor's control unit and for providing assistance on other occasions. Joe Lujan and Debra Rutherford (Group N-2) were instrumental in facilitating the evaluation at LACEF. Jose Gutierrez and Perry Hewlett (Group OS-2) conducted the in-plant sensitivity tests that were required for operational security approval of the portable monitor for routine use.

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APPENDIX

LABORATORY EVALUATION SUMMARY REPORT

Evaluated monitor: TSA Systems PMD-701 with low-noise SC-750 controller.

Manufacturer: TSA Systems, Inc., 1820 Delaware Place, Longmont, CO 80501. (303) 651-6147.

Mode of operation: Wait in front of the monitor and turn completely around during monitoring.

Mechanical factors:

Cabinet: Aluminum cabinet is 0.080 in. thick.

Detectors: Plastic scintillation detectors are 3 in. wide by 31 in. long and 1.5 in. thick. Detector encapsulation is black plastic electrical tape.

Calibration factors:

Gamma-ray (^{137}Cs) pulse height is adjusted to 3.3 V at amplifier analog output.

SCA range is adjusted to 0.080-2.0 V.

Selectable options:

Occupancy hold-in: 2 s

Alarm comparison intervals: 5

N sigma: 4.0

Test environment:

Monitor indicates a background count rate of about 1150 counts/s.

Background intensity is measured to be 21.8 $\mu\text{rad/h}$.

Instrument used is a Kimmel MAB 605 integrating dose-rate meter.

Method used 86.25 h of integration.

Nuisance-alarm results:

Nuisance alarm rate per passage is 1 per 759 passages.

Number of alarms recorded was 176. Number of passages was 133,650.

Method used had multiple timing circuits to regulate background update and occupancies and a strip-chart recorder to record alarms.

Performance-Test Protocol:

Source: Test source is a 10-g ^{235}U (10.7-g HEU) metallic sphere.

Method of carrying: Source is carried inside a shoe at an interior ankle.

Procedure: Test procedure has the individual carrying the source approach the monitor, stop in front of it, turn around through 360 deg, then turn and depart.

Passage speed: The individual was stationary except for rotation.

Sensitivity Test Results:

HEU Category: II, Standard uranium. This category of monitor detects standard 10-g ^{235}U and 0.3-g ^{239}Pu test sources with at least 0.5 probability.

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