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Technical Evaluation of Tom Scurry Associates

Model PM-203 Doorway Monitor

July 1978

MASTER

U.S. Department of Energy
Assistant Secretary for Defense Programs
Office of Safeguards and Security

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TECHNICAL EVALUATION OF THE TOM SCURRY ASSOCIATES

MODEL PM-203 DOORWAY MONITOR

Technical Evaluation of the Tom Scurry Associates

Model PM-203 Doorway Monitor

Abstract

Under a basic assignment by the Office of Safeguards and Security, the Tom Scurry Associates Model PM-203 Personnel Doorway SNM Monitor manufactured by Tom Scurry Associates was evaluated by LASL Group Q-2 against the DOE Personnel Doorway Monitor standards. During the evaluation, a small change was required in detector shielding to eliminate low sensitivity areas at the portal sides. With the modified shielding described in this report, the PM-203 meets the Office of Safeguards and Security SNM doorway monitor specifications for detecting either ^{235}U or ^{239}Pu - ^{233}U . This system is also capable of monitoring ^{238}Pu .

The manufacturer is located at the following address:

Tom Scurry Associates
4599 North Broadway
Boulder, Colorado 80302

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Description of Monitor Operation

The Tom Scurry Associates (TSA) monitor, shown in Fig. 1, consists of two portal-forming cabinets that contain detectors, an occupancy indicating infrared light link, and a NIM bin, which contains the signal and logic electronics. The detector array consists of eight NaI scintillators, 5.08-cm diameter by 2.54-cm thick, with four placed in each cabinet. The scintillators, with integral photomultiplier, plug-on photomultiplier base, and lead shield are supported inside the cabinets with vertical spacing of about 55 cm between scintillators. The lowest detectors have the scintillator center 15 cm above the floor of the cabinet. Figure 2 shows the cabinet interior and detector supports. As received for testing, the cabinets were not self-supporting. The manufacturer intends that support be provided by an existing door frame. It is also necessary for the user to provide some means to route cables between the cabinets and limit the vertical extent of the portal. For the purpose of evaluation, the unistrut frame in Fig. 1 was constructed.

The occupancy sensor, also supported by unistrut in Fig. 1, consists of two infrared transmitters and two receivers on the approach side of the portal. This arrangement allows effective monitoring in one direction only, and an alternative occupancy sensor, such as the optional switchmat or ultrasonic monitor, must be requested if it is desired to monitor incoming traffic also.

The NIM bin, shown in Fig. 3, provides power for the signal conditioning, control, logic, and display functions. Detector high voltage and a signal conditioning unit are standard commercial NIM modules designed for scintillation spectroscopy. The logic

module, called an updating comparator, is manufactured by TSA and provides the logic and display functions. The last component, also manufactured by TSA, is the Personnel Detector that operates the infrared light link.

Light pulses from gamma events in the scintillators are converted to current pulses in the photomultipliers that are further conditioned in a pre-amplifier and amplifier. The amplifier output is processed by a single channel analyzer (SCA) that is set to discriminate against pulses from gamma interactions outside of an energy window of interest. The energy window is set to optimize sensitivity as will be described later. The logic pulse output of the SCA is counted by the updating comparator. During periods when the monitor is not occupied, the unit simply performs a series of end-to-end 20-s counts that are used to calculate a mean count rate (counts per second), which is stored and displayed on the front panel at the end of each 20-s count. Whenever the monitor is occupied, an alarm level is calculated by using the stored background count rate, B , to determine the alarm level by taking

$$B + N\sqrt{B}$$

where N is switch selectable on the front panel (called the N -SIGMA switch) after the convention

$$\sigma = \sqrt{B}$$

When occupancy occurs, a sequence of 1-s long signal counts is made and each signal count is compared to the alarm level. Should the signal count equal or exceed the alarm level, an alarm condition occurs that causes an audible and visual indication and a relay closure. The visual indicator is simply a display of the difference between count and alarm level that appears in place of the background

count rate. The alarm condition is latching and continues until a reset button on the front panel is pushed. Should no alarm occur, the 1-s signal counts continue for one second after occupancy ceases. Thus, for a normal pace walkthrough, two 1-s signal counts are made.

The background count rate itself is also monitored and should it fall outside of switch selectable upper and lower limits, another latching alarm condition occurs. Here, there is an individual relay closure for high and low background count rates and the numerical display is blanked. A separate reset button on the rear panel of the updating comparator must be used to restore normal operation. The purpose of this function is to indicate equipment failure or unusually high background that is high enough to reduce monitor sensitivity below an acceptable level.

Tests Conducted

The TSA monitor was received and set up in January 1977. Preliminary tests indicated that the detectors were too tightly collimated by lead shielding cones to view a source near the side of the portal at a position halfway between detectors. Figure 4 illustrates this at the left. The problem was corrected by shimming the lead shielding away from the cabinet surface and bending the shielding slightly to the shape shown in Fig. 4 at the right. Then sensitivity anywhere along the portal sides was slightly greater than at the top center of the portal. The evaluation period began and a single short interruption of the evaluation period occurred with a failure in one of the light link receivers.

Sensitivity tests for ^{235}U were carried out using a portal width of

76 cm and N-SIGMA switch setting of four. Preliminary testing indicated adequate sensitivity for ^{239}Pu - ^{233}U at the manufacturers advertised 112-cm width, but in the 21 $\mu\text{R/h}$ test background, adequate sensitivity for ^{235}U with a four-sigma alarm level setting was not achieved until the spacing was reduced to 76 cm. In addition, the SCA window setting had to be reset to optimize sensitivity for ^{235}U . The manufacturer's recommended window did not give adequate sensitivity at what was considered minimum portal width and the designer's¹⁾ window setting was also inadequate. To optimize the window, one can use the fact that the instrument's alarm level is a multiple of $\sqrt{B}$ or, in more general terms given by Evans²⁾, that one is searching for a signal among statistical fluctuations that vary as the $\sqrt{B}$.

To do this, one measures a signal as net source counts, S , from a particular source and background, B , with no source for a number of different SCA windows. That window where the ratio of S to $\sqrt{B}$ is greatest, is the optimum. In practice, the square of the ratio is used, S^2/B , and results of measurements with the three windows mentioned are shown in Table I. The optimum window clearly gives the maximum sensitivity.

The procedure used in sensitivity testing was to first determine the low sensitivity regions in the monitor by static source measurements. These are, with the lowest first: the top center of the portal at the height of the cabinet top; the bottom center at the floor; and the region halfway between detectors at the sides of the portal. The sensitivity for detection was then determined by a number of individuals walking through the monitor with the source positioned to pass through a region of lowest sensitivity. Thus, sources were carried on the head, on the inside of the

of the shoe near the ankle, or on the side of the body at the waist or calf. A normal walking pace was used, and for the foot region or when the source was attached to the leg, care was taken that the source was neither held stationary or swung rapidly through the sensitive region. The walker was instructed to plant the source foot on a marker just outside the sensitive area as he walked through. The effect then was for the source to accelerate from a standing start through the sensitive volume. Nine individuals were used in testing sensitivity so the results are averaged over a wide range of walking speed and body parameters. Walkthroughs were done in small groups to avoid building up source counts in the background and sigma determinations. Results of the sensitivity tests are given in Table II. The disparity in doorway widths for the uranium and plutonium sources in Table II is common to all doorway monitors. Static measurements on this monitor indicate that at 76 cm spacing, the ^{239}Pu sensitivity would be adequate to detect a 0.25-g ^{239}Pu sphere at the 4-sigma setting.

In order to estimate what increased portal widths might be used in lower background environments while maintaining the sensitivity achieved during this evaluation, a series of static measurements were made. It was determined that the ratio of the mean source counts accumulated during a walkthrough to a static count with the source in the same position was 0.57 for the head region of the portal. The factor 0.57 was used with static measurements of the source positioned in the head region at several portal widths to determine an equivalent walkthrough source count at each width. This source was used to calculate the maximum background count rate where the monitor would have the same sensitivity as measured in the evaluation. The results are shown in Fig. 5. To use Fig. 5 to estimate a maximum width for a new location, one can use 18.3 c/s per $\mu\text{R/h}$ background

if an accurate background measurement had been made.

False alarm testing was carried out during the night and on weekends when there should be little interference from changing background. The procedure used was to interrupt the light link with a rotating shutter for a period of time in which about 29 of the l-s counts were made, then about 24 seconds was allowed for the background update. The alarm relay closure was used to record false alarms and actuate an electro-mechanical device that operated the reset button. Results are given in Table III. The results agree with alarm rates calculated using the Poisson distribution and a truncated square root. The interval between alarms was also recorded and the distribution of intervals was consistent with the alarm probability determined. The three-sigma setting alarm rate is too high to meet the requirements of the portal monitor standard. At four sigma, the indicated alarm rate per passage is adequate to meet the standard requirement of one false alarm per 8-h period, even at a very high traffic rate. It should be noted that if the monitor were set up for two-way traffic, the occupied state would persist longer and more l-s samples would be collected. The alarm probability per passage increases directly with the number of samples made in one passage and one might expect a doubling of the alarm frequency with two-directional operation; the rate in this situation would still be acceptable.

Conclusions

The performance of this monitor during the evaluation period has been exceptionally good. The monitor functioned properly when set up and continued to operate with only one failure

in a light link sensor. Completing the evaluation on schedule indicates this was a thoroughly debugged instrument when received. The sensitivity and false alarm rate were not as good as advertised at 122-cm width, but both sensitivity and false alarm rate were acceptable at 76-cm width.

Mechanical setup of the monitor required about one man day. One must mount the detectors in the cabinets (they are shipped separately for mechanical and thermal protection) and then provide support for the cabinets, light link components, and cables. A barrier across the cabinet tops has to be provided in a working installation and was assumed to be there during this evaluation. The height of the barrier would be 188 cm with the cabinet resting on the floor. This barrier height seemed a bit low, but there was more sensitivity in the foot region compared to the head region so that the cabinet bottom was raised 7.6 cm above the floor and when sensitivity tests were repeated, results were acceptable. This puts the head barrier at 195 cm above the floor. With the barrier positioned, the unit was ready to be operated.

Calibration of the unit requires setting individual gain and focus adjustments on each of the eight detectors and then determining the optimum SCA window. The initial calibration can take an hour or two but thereafter checking the calibration is quite rapid. A preliminary setup at the factory can be a big help and presumably is done; however, none of the locking adjustments had been locked in the tested unit and the adjustments were changed in packing and shipping.

The utilization of eight small NaI detectors in this monitor has a number of important consequences. One effect of the individual detectors is that the sensitivity varies a great deal on the portal sides between detectors.

As a result, care must be taken that the discrete detector shielding is properly designed and is properly in place so that sensitivity is not lost.

A second point is that by using the small high efficiency NaI detectors, the background count rates are low enough that the four-sigma trip level is a large fraction of the background. For example, with a Scurry PM-203 background of 386 c/s, the four-sigma alarm point is 465 c/s or 20% above background. Another result of the low count rate is that the false alarm rate varies with count rate. One usually assumes that the normal distribution can be used to describe the distribution of sample counts in a doorway monitor in which case a constant false alarm rate with background results. Here, one must use the Poisson distribution to accurately calculate the frequency of four-sigma deviations. The result is a variation that corresponds to about a 25% increase over the test results in false alarm rate at a monitor background of 183 c/s (10 μ R/h) to a 25% reduction at 551 c/s (30 μ R/h).

Because the sensitivity and false alarm rates of the monitor depend quite strongly on some variable features of this monitor, the specifications as tested are given in Table IV.

Acceptable performance of the monitor during these tests demonstrates the adequacy of the basic design and gives some indication of its reliability. Each working installation has its unique environment and various detector spacings can be used to meet the requirements of higher or lower background situations. To insure proper performance and continued effectiveness, there is no substitute for testing at the time of installation and periodically thereafter. Such tests should include sensitivity tests made with actual walkthroughs

and false alarm tests that may be a simple record of false alarms experienced. Walkthrough testing should use a proper size and geometry source of the appropriate isotope (spheres of 10-g ^{235}U or 1-g ^{239}Pu metal as specified in the standards) carried on the body and located in the minimum sensitivity region. The number of walkthroughs should be sufficient to lend confidence to the results. For example, one would like to have 95% confidence that the detection probability for a walkthrough with a 10-g ^{235}U sphere on the head is 50% or greater. One makes a number of walkthroughs and records the number of detections. Then using Fig. 6, which is derived from confidence belts given by Dixon and Massey³⁾, one can determine whether or not the performance is acceptable by finding the point corresponding to the number of passages and the percentage of passages detected. If the point lies above the curve in Fig. 6, then one has 95% confidence of 50% or greater detection probability. As an example, if one makes 40 attempts and detects 26, the performance is acceptable. Similarly, 10 attempts with 9 detections would be acceptable. False alarm monitoring is particularly useful for early indication of malfunction.

3. Wilfrid J. Dixon and Frank J. Massey, Introduction to Statistical Analysis, McGraw-Hill Book Co., 1969.

References

1. Dana Ray Cartwright, Rockwell International, Rocky Flats Plant, "Request for ERDA Approval for the Rocky Flats Design Personnel Doorway Monitors Future Installations," March 15, 1976.
2. Robley D. Evans, The Atomic Nucleus, McGraw-Hill Book Co., Inc., 1955, page 771.

Table I

S^2/B Measurements Made with Three SCA Windows

Using a 10-g ^{235}U Sphere for the Source

and 21 $\mu\text{R/h}$ Background

^{235}U Mass Needed in a Spherical Source
to Give the Same Detection
Probability as the Optimum Window
(g)

SCA Window (Volts)	Energy Window (keV)	S^2/B (c/o)	
optimum 0.3 - 0.85	70 - 215	62	10
Rocky Flats Plant 0.21 - 1.5	46 - 385	48	12.2
TSA	70 - 1735	36	15.2

Table II

Sensitivity Tests in a Background of 21 $\mu\text{R/h}^*$
 (monitor count rate of 385 c/s using a SCA window optimized for ^{235}U)

<u>Source</u>	<u>Doorway width (cm)</u>	<u>N-Sigma switch</u>	<u>Observed False Alarm Rate (passages)</u>	<u>Minimum Detection Probability for Source Positions Used</u>
10 g ^{235}U sphere	76	4	1 per 3850	0.63
1 g ^{239}Pu sphere	122	4	1 per 3850	1.00

* Background measurements were carried out using a Reuter-Stokes RS-111 Environmental Monitor.

Table III

Observed Statistical False Alarm Rate

<u>N-Sigma Switch</u>	<u>False Alarm Rate*</u>	<u>Number of Hours Observed</u>
3	4.2×10^{-3} or 1 per 238 passages	15
4	2.60×10^{-4} or 1 per 3850 passages	725

* One passage includes two tests, i.e., two 1-s count intervals.

Table IV

The Components as Tested for the
Tom Scurry Associates PM-203 SNM Portal Monitor for
 ^{235}U or ^{239}Pu - ^{233}U

Scintillators:	Eight Bicron integral NaI scintillator/photomultiplier, Model 2M1/2. The crystal is 5.08-cm diameter by 2.54-cm thick. Four scintillators were on each side of the portal. Scintillator centers were located vertically 15 cm, 70 cm, 125 cm, and 180 cm above the bottom of the cabinet. The horizontal spacing between the scintillators was 76 cm for the combined ^{235}U and ^{239}Pu - ^{233}U monitoring and 122 cm for ^{239}Pu -only monitoring.
Scintillator Shielding:	0.32-cm Pb in the form of a cylinder wrapped around the photomultiplier tube and a 15-cm square sheet that is formed and spaced as in Fig. 4.
Updating Comparator:	N-SIGMA switch set to 4.
Occupancy Monitor:	Infrared light link.
High Voltage Power Supply:	ORTEC 456 set at 1100 volts.
Preamplifier:	ORTEC 113
Amplifier:	ORTEC 485
Single Channel Analyzer:	ORTEC 550

Fig. 1 The Tom Scurry Associates PM-203 as set up for evaluation. The unistrut frame was provided by us for support for the cabinets and light link components. The manufacturer expects to replace the cabinets with a more photogenic enclosure soon.

Fig. 2 The cabinets contain sheet metal supports for the detectors and the lead shielding.

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ORIGINAL SHIELDING

MODIFIED SHIELDING

The lead Shielding Cones have Been Moved Back 0.64 cm and the Top and Bottom Cone Edges are Bent Back an Additional 1.27cm to Allow Scintillator to View the Problem Region.

Modified Cone Top Edge
1.27cm Bend

The Original Lead Shielding is Shown At The Left. The Modifications Are Indicated At The Right.

Fig 4

Fig 5

Fig 6