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GAMMA-RAY DETECTORS
FOR INTELLIGENT, HAND-HELD RADIATION MONITORS*

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Abstract

Small radiation detectors based on HgI_2, bismuth germanate (BGO), plastic, or NaI(Tℓ) detector materials were evaluated for use in small, lightweight radiation monitors. The two denser materials, HgI_2 and BGO, had poor resolution at low-energy and thus performed less well than NaI(Tℓ) in detecting low-energy gamma rays from bare, enriched uranium. The plastic scintillator, a Compton recoil detector, also performed less well at low gamma-ray energy. Two small NaI(Tℓ) detectors were suitable for detecting bare uranium and shielded plutonium. One became part of a new lightweight hand-held monitor and the other found use as a pole-mounted detector for monitoring hard-to-reach locations.

Introduction

Intelligent, hand-held radiation monitors are battery-powered instruments that comprise radiation detectors, signal-conditioning electronics, discrete-component or microprocessor decision circuits, and communicating devices. The purpose of the monitors is to detect local increases in ambient radiation intensity. The monitors determine an alarm level from ambient background intensity and then, as the operator moves the monitor about, they compare present radiation intensity to the alarm level. Response to a significant increase in radiation intensity is an audible sound.

Intelligent monitors were developed to free operators from having to watch and interpret an analog or digital display so that they can visually conduct a search. Intelligent, hand-held monitors permit even unskilled operators to conduct highly effective searches for low-intensity radioactive objects that may be unauthorized materials, lost radioactive items, slightly contaminated objects, radioactive waste leakage, and hold-up material in radioactive process lines. Although the operators must be instructed to look in the proper places, they need not be experienced health physics surveyors to detect environmental-level sources of radiation. However, trained health physics surveyors also find intelligent monitors quite useful.

Hand-Held Radiation Monitors

Lightweight, rugged, intelligent, hand-held monitors were developed at the Los Alamos National Laboratory[1] for the DOE Protective Force. The monitors allow guards to search personnel and vehicles quickly for the presence of special nuclear material (SNM) at the perimeter of material access areas. The capability of the monitors to detect very low levels of radiation convinced Los Alamos officials to furnish health physics surveyors with the instruments for general-purpose monitoring, such as examining salvage material for unknown types of contamination.

Further development of intelligent hand-held monitors continues at Los Alamos. In particular, we are investigating alternative detectors, monitoring algorithms, power supplies, and electronics that can make the instruments lighter, more sensitive, and more useful. This paper describes the investigation of alternative gamma-ray detectors.

Our investigation is directed toward making hand-held monitors more lightweight and versatile. This can be done by replacing the original, relatively heavy detectors--3.8-cm-diam by 3.8-cm-long NaI(Tℓ) scintillators and 3.8-cm-diam photomultiplier tubes (PMTs)--with smaller, lighter detectors. The choices are a solid state detector[2] or one of the small scintillation detectors that have become practical with the recent introduction of much smaller PMTs. Our goal is to reduce the size and weight of the detector without significantly decreasing its detection sensitivity, particularly for SNM radiation sources.

The detection sensitivity of intelligent monitors is basically determined by the magnitude of the detector's net signal compared to the standard deviation of its expected background. However, simply examining the ratio of measured signal to standard deviation of background is not as informative as analyzing candidate detector response to sources moving by as they would during a search. To perform an operational evaluation of alternative detectors, we analyzed each detector's response to particular radiation sources moving past the detector. An energy window starting at 60 keV was used for measuring both background and source response. Precisely determined source-intensity profiles were scaled to a typical monitor counting time and analyzed with a specific detection algorithm to determine the detectors' performance.

Measurements and Comparisons

The scanning sources were typical of those encountered in SNM security monitoring, such as bare uranium enriched in ^{235}U, mixed isotopes of plutonium with ^{239}Pu as the principal constituent, and plutonium inside a lead container. The "bare" plutonium was lightly shielded by cadmium to attenuate time-varying 60 keV radiation. The quantity of material in each case was near the threshold for detection. Scanning took place at an average distance of closest approach of 46 cm and at a height 1 m above the floor. Counting

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positions were spaced 15 cm apart corresponding to 0.3-s intervals in a continuous 0.5-m/s scan. These positions correspond to the monitor's decision points during use.

The procedure for comparing scanning and background data from individual detectors began by calculating an alarm level for 0.3-s monitoring counts. The alarm level was chosen to give less than 3% false alarms under Poisson statistics for a detector's expected background count in a 22-μR/h background intensity. The seemingly high false-alarm rate is acceptable in hand-held monitors because false alarms do not detract from operation, which requires motion to locate sources. In fact, the audible false alarms assure the operator that the monitor is operating with an appropriate stored background. At each counting position, the gross count during that counting interval is a mean value for calculating the Poisson probability, Pd_i, of exceeding the alarm level. From each detection probability, Pd_i, the miss probability, $1 - Pd_i$, at each point is determined. The product of the miss probabilities for the entire scan determines the overall detection probability, PD, as follows.

$$PD = 1 - \prod_{i=1}^{n} \left(1 - Pd_i\right) \quad .$$

The detectors we compared include the newer ones with improved stopping power, HgI_2 and BGO, as well as the established detectors, NaI(Tℓ) and the solid organic scintillator NE 102 (plastic). In most cases, different detector shapes were tested and, in addition to the conventional cylindrical scintillator with a coaxial PMT, some scintillators were disk-shaped with a side-mounted PMT. This unusual geometry, introduced at Los Alamos to make a 12.7-cm-diam detector fit into a briefcase, originally had a 3.8-cm PMT and was called a flapjack because of its skillet shape. The flapjack spawned a series of similar but smaller detectors. These slab-like detectors offer excellent response normal to the slab and poor response parallel to the slab.

Our original hand-held monitor detector, a 3.8-cm-diam cylinder 3.8 cm high, offered uniform spatial response. However, in a lighter scintillator with improved sensitivity in one direction, detection area must be sacrificed in other directions. Alternative detector shapes in Table I are either disks or extended cylinders that are evaluated in their most sensitive orientation. The different PMT sizes listed in Table I may also affect performance. Even when PMT sizes are identical, integral detector assemblies often prevent moving the PMT from one scintillator to another. Hence, the evaluation results may be slightly influenced by parameter variation among the different PMTs.

Results and Applications

The tabulated results in Table II offer no superior alternatives to the original detector except for the larger, heavier ones, but several smaller, lighter alternative detectors perform nearly as well. Poor energy resolution at low energy in the dense materials HgI_2 and BGO limits detection of plutonium and bare, enriched uranium by small detectors; this result is most significant for uranium because it is a low-intensity gamma-ray emitter. The plastic scintillator performs similarly because it is a Compton-recoil detector

TABLE I
RADIATION DETECTOR PARAMETERS

Radiation Detector Components					Detector Parameters		
Scintillator			Photomultiplier Tube		Total Weight (g)	Active Area (cm^2)	Active Thickness (cm)
Type	Diameter (cm)	Length (cm)	Type	Diameter (cm)			
HgI_2	2.5[a]	1.1	---	---	130	14.4	3.8
BGO	3.8	3.8	R980	3.8	494	14.4	3.8
BGO	2.5	1.3	R1635	1.0[b]	115	4.9	1.3
Plastic	10.2x12.7[a]	3.8	R580	3.8	1008	129.5	3.8
NaI(Tℓ)	12.7	3.8	4441	3.8[b]	2510	126.7	3.8
NaI(Tℓ)	12.7	2.5	R1288	2.5[b]	1580	126.7	2.5
NaI(Tℓ)	5.7	1.9	R1635	1.0[b]	370	25.5	1.9
NaI(Tℓ)	5.7	1.3	R1635	1.0[b]	260	25.5	1.3
NaI(Tℓ)	3.8	3.8	R980	3.8	343	14.4	3.8
NaI(Tℓ)	2.5	5.0	R1288	2.5	170	12.5	2.5
NaI(Tℓ)	2.5	2.5	R1288	2.5	125	6.3	2.5

[a]The cross section is rectangular.
[b]These PMTs are mounted on the edge of the scintillator.

TABLE II
PROBABILITY OF DETECTING SOURCES

Radiation Detectors				Probability of Detection[a]		
	Dimensions		PMT	Plutonium		Enriched Uranium
Type	Diameter (cm)	Length (cm)	Diameter (cm)	(cadmium shield)	(lead shield)	(bare)
HgI_2	2.5[b]	1.1	---	0.48±0.05	1.0	0.65
BGO	3.8	3.8	3.8	0.72	0.99	0.89
BGO	2.5	1.3	1.0[c]	0.55	---	0.67
Plastic	10.2x12.7[b]	3.8	3.8	0.77	0.96	0.72
NaI(Tℓ)	12.7	3.8	3.8[c]	1.0	1.0	1.0
NaI(Tℓ)	12.7	2.5	2.5[c]	1.0	0.84	1.0
NaI(Tℓ)	5.7	1.9	1.0[c]	0.78	0.45	0.98
NaI(Tℓ)	5.7	1.3	1.0[c]	0.87	0.43	0.92
NaI(Tℓ)	3.8	3.8	3.8	0.74	0.98	0.93
NaI(Tℓ)	2.5	5.0	2.5	0.84	0.97	0.80±0.07
NaI(Tℓ)	2.5	2.5	2.5	0.84±0.02	0.61	0.74

[a]Probability of detecting one source passage at 0.5 m/s and 0.46-m distance of closest approach. Typical 1σ errors are indicated.

[b]The cross section is rectangular.

[c]These PMTs are mounted on the edge of the scintillator.

and has inherently poor low-energy response.[3] Plastic requires a large area to compensate for its poor low-energy detection efficiency and the large area permits it to perform very well at the higher energies characteristic of shielded plutonium. On the other hand NaI(Tℓ) has good resolution and good performance for the bare materials, even with 1-cm-diam PMTs. NaI(Tℓ) also detects the shielded plutonium well when the detector has adequate thickness, 2.5 cm or so. Our first application of alternate detectors made use of the last two entries in Table II, which are 2.5-cm-thick NaI(Tℓ) cylinders, 5- and 2.5-cm long.

The longer of the two alternate detectors performed about as well as the original heavy detector but weighed half as much. We combined this detector with a high-voltage supply that provides individual dynode voltages and needs no power consuming voltage divider (Fig. 1). Low power CMOS electronics further reduced the power requirement to a total of 11 mA for the entire instrument. A lightweight, 242-g, rechargable battery pack can supply sufficient energy for 45 h of operation. The entire hand-held monitor (Fig. 2) called a Programmable Rate Monitor[4] weighs only 1115 g compared to 1955 g for a typical commercial version of our original hand-held monitor.

A second detector, the last entry in Table II, was applied to searching areas normally out of a person's reach. The light weight (335 g) of the packaged 2.5-cm-diam by 2.5-cm thick detector and its high-voltage power supply made it ideal for mounting on the end of a pole. Low voltage power and signal wires along the pole lead to the monitor's instrument case near the operator (Fig. 3). Operating this type of monitor is much like operating any other hand-held monitor, but manipulating the long pole can be tiring. The lightweight detector helps reduce the operator's effort and makes overhead monitoring more practical.

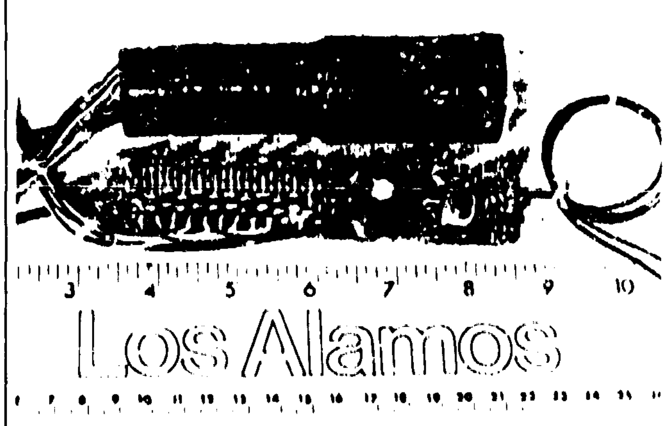

Figure 1
The 2.5-cm-diam by 5-cm-long NaI(Tℓ) scintillator with attached 2.5-cm-diam by 5-cm-long PMT is powered by a high-voltage supply having about the same cross sectional area. The high-voltage supply provides individual dynode voltages to eliminate unnecessary power loss in a voltage divider.

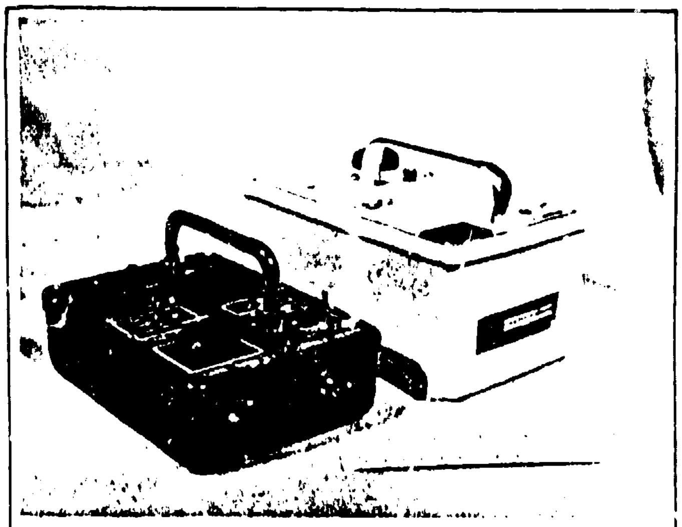

Figure 2
The prototype PRM on the left is about half the size and half the weight but provides the same performance as the monitor on the right, a commercial version of the original hand-held monitor developed at Los Alamos. The CMS, Inc., version of the earlier Los Alamos design replicates the original 3.8- by 3.8-cm detector but the National Nuclear Corp. version has a smaller, 3.8-cm-diam by 1.25-cm-long detector.

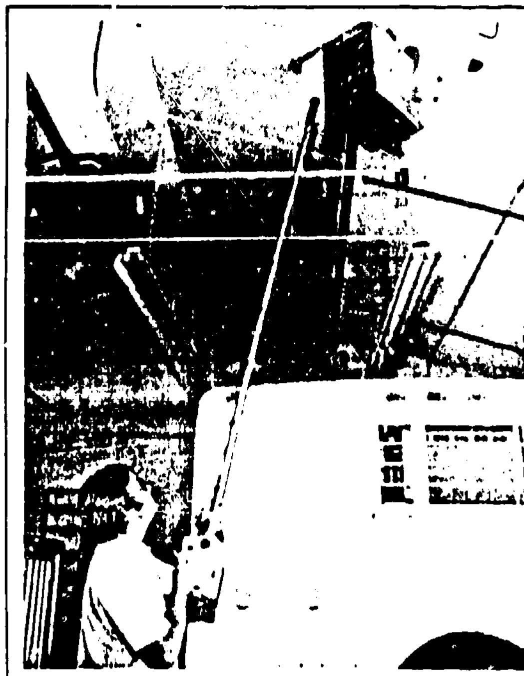

Figure 3
A lightweight 2.5-cm-diam by 2.5-cm-long NaI(Tℓ) scintillator with a 2.5-cm-diam by 5-cm-long PMT and a lightweight high-voltage supply are mounted at the end of the pole. The lightweight detector performs almost as well as the detector in our original hand-held monitor but is much easier to manipulate when it is suspended at the end of the long pole.

None of the alternative detectors with 1-cm-diam PMTs have yet been incorporated in instruments. The smaller forms of the flapjack have lower sensitivity for detecting shielded plutonium. A slightly thicker scintillator might improve sensitivity but would also make a 2.5-cm-diam photomultiplier more appropriate. At present, the first applications of scintillators with the smaller PMTs will probably be in small instruments for characterizing the ambient radiation from the environment at monitoring locations. In this application, monitor size and weight is important to ease transport while high detector efficiency is important to quickly determine background. The combination of requirements can easily be met by an instrument having a small NaI(Tℓ) scintillator and 1-cm photomultiplier.

Equipment Manufacturers

The equipment used for this study was manufactured* by Bicron Corporation, in Newbury, Ohio; CMS, Inc., in Goleta, California; Harshaw Crystal and Electronic Products in Solon, Ohio; National Nuclear Corporation in Mountain View, California; and TSA Systems, Inc., in Boulder, Colorado.

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*Reference herein to any specific commercial product, process, or service by trade name, trademark, or manufacturer does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or agency thereof.

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References

[1] W. E. Kunz, W. H. Chambers, C. N. Henry, S. W. France, D. R. Millegan, R. D. Hastings, and G. M. Worth, "Hand-Held Personnel and Vehicle Monitors," Los Alamos Scientific Laboratory report LA-6359 (1976).

[2] J. L. Warren, "Larger Volumes of HgI$_2$ Used as Portable Gamma-Ray Counters," Nuclear Instruments and Methods 213, 103 (1983).

[3] P. E. Fehlau and G. S. Brunson, "Coping with Plastic Scintillators in Nuclear Safeguards," IEEE Trans. on Nucl. Sci. NS-30, 158 (1983).

[4] D. R. Millegan and K. V. Nixon, "Modular Gamma Systems," IEEE Trans. on Nucl. Sci. NS-30, 536 (1983).