Performance of a Radiation Portal Freight Monitor based on Integrated Germanium Detector Modules

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ABSTRACT
Portal monitors, container scanners, and mobile search systems, constructed with high resolution germanium (HPGe) detectors, are currently being installed at locations world-wide. This reflects a general desire for improved performance and a reduction in the time to make a good decision in interdiction cases. An integrated gamma-ray spectrometer, incorporating a mechanically-cooled HPGe detector, digital signal processing electronics, MCA, and communications has been developed to meet the detection and environmental needs of these systems. Specially developed software allows these spectrometers to be configured in a variety of portal monitoring applications. The HPGe detectors are designed to have good low- and medium-energy detection efficiency and excellent spectral peak resolution in order to eliminate peak overlaps and thereby remove problems of masking of SNM by common industrial and medical radionuclides found in all types of monitors. Systems using detectors with inferior resolution, regardless of efficiency, are unable to separate the radiation signals from NORM and illicit nuclides. In portal monitoring or in freight scanning, the Field of View (FOV) of a detector and transit speed determine the time the radioactive material contribute data to the spectrum. The absolute full-energy peak efficiency of the detector and background count-rate in the peak energy region determine the signal-to-noise ratio, and thus the minimum detectable (or identifiable) amount of material passing through the FOV. The performance of the integrated spectrometers and their performance in pedestrian portal configurations have been previously reported. A freight portal monitor was constructed with 8 HPGe detectors in cooperation with Thermo Fisher and the performance measured using ^{133}Ba, with and without high NORM background and with varying amounts of shielding. Test sources were moved through the portal at 8 km/h on a commercial truck and the response was recorded. Measurements presented show the impact of shielding and masking on the performance of the portal. The results illustrate applicability of the design to a variety of monitoring situations for the detection of illicit material.

Keywords: radioisotope; integrated systems; germanium detectors; HPGe; illicit trafficking; monitoring

INTRODUCTION

The performance of portal monitors for the detection of illicit radioactive materials is of great importance in determining the efficacy of these devices in stopping trafficking of nuclear materials. Many designs have been proposed and some have been tested to one or more of the existing standards for portal monitoring [1, 2, 3, 4] with varying results. In response to the need for high performance portal monitors, ORTEC has developed a monitor based on HPGe detectors. The high resolution of HPGe detectors is necessary for reliable detection and identification in real-world situations [5]. One monitor has been installed at the Anthony, New Mexico Port of Entry and a second one is installed at the Thermo-Fisher facility in Oak Wood, Ohio. Both portals have been in operation for more than six months. The New Mexico portal has been in continuous (24 hours per day) operation on commercial truck traffic on Interstate 10 as a secondary portal since October 2009. The Thermo portal is in operation as a test facility with controlled sources, shielding, and NORM. The following discussion applies to both units, but the results are only from the test facility.

The tests consisted of three different nuclides (^{57}Co, ^{133}Ba, and ^{137}Cs) mounted, one at a time, in a standard 14 ft box body truck, with and without shielding and NORM. The truck was driven at 8 kph through the portal. The ability to identify ^{133}Ba with various shielding thicknesses, with and without NORM is shown.

EQUIPMENT AND SETUP

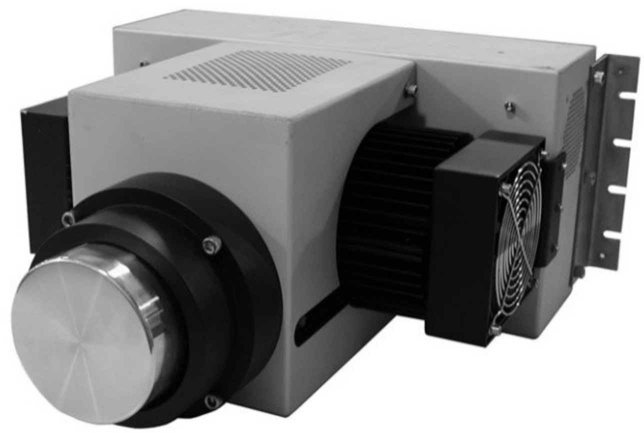

Figure 1 Interchangeable Detector Module (IDM)

HPGe Detectors

The HPGe detectors are IDMs, as shown in Fig. 1. Each IDM is a fully integrated gamma spectrometry subsystem consisting of an 85 mm diameter x 30 mm deep HPGe crystal. A complete description is given in [6]. The MCA uses the 1460 keV peak of ^{40}K for gain stabilization. The large diameter detector is optimized for energies from 100 keV to 400 keV with sufficient response up to 3 MeV, which is the necessary energy range for detection of SNM.

The detectors and electronics are controlled by computers mounted with the IDMs and communicate with the control computer by Ethernet.

Figure 2 Installed HPGe Portal at Anthony, New Mexico

Mounting

The 8 IDMs are mounted in environmentally controlled cabinets. The cabinets and shielding define the detection zone to be from 0.1 m to 2 m above the ground and are positioned 5 m apart. Four IDMs are mounted on each side of the detection zone at vertical positions of 0.25, 0.75, 1.25, and 1.75 m above ground level. Each cabinet includes an HVAC system and controller to maintain temperature inside the cabinet at a satisfactory level as well as a UPS power backup supply. The front of each cabinet has a plastic window to minimize the attenuation of gamma rays to the detector. Figure 2 shows the New Mexico installation.

Shielding

The IDM includes some steel shielding (the black ring around the detector endcap in Fig. 1 or the red ring in Fig. 3). The steel shielding extends from just behind the detector crystal for a distance of 10 cm. It is 12 mm thick for 4 cm and 25 mm thick for the remaining length. To reduce the general background and radiation from adjacent containers, side shields were added to the existing back shield as shown in Fig. 3. The additional shielding is 2.5 cm of steel as a vertical side shield from the bottom of the mounting rack to the 2 m height. The side shield extends from the steel shield outer diameter to 13 cm in front of the detector endcap. The Field of View (FOV) is the area in front of the detectors where a source of gamma rays (NORM or other source) could contribute to the spectrum. The side shields limit the FOV to about 120º for low-energy gamma rays.

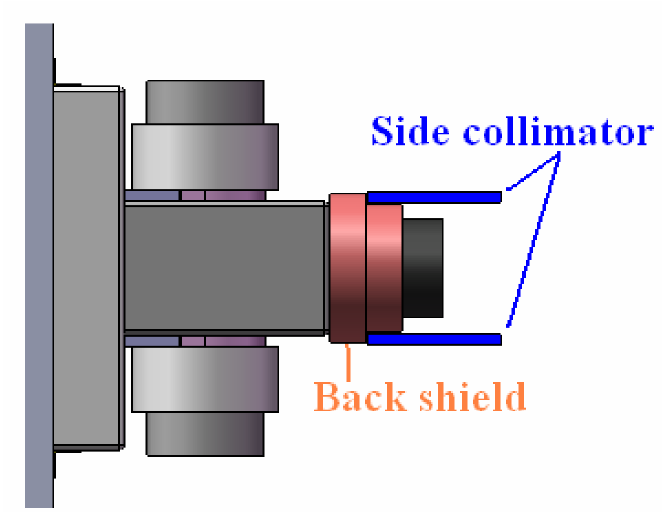

Figure 3 Schmatic of IDM Showing Shielding

The truck occupancies for this testing were determined by optical entry and exit sensors positioned about 4 m apart and centered on the detector position. Magnetic sensors in the pavement are used in the State of New Mexico installation.

Source and attenuators

The sources used were point sources. The sources were mounted in a wooden frame. The attenuators were 3.2 mm thick steel plates which could be combined to give total thicknesses of 0.32 to 10 cm. The attenuators were placed so as to shield the complete FOV on both sides of the portal from the source.

The NORM was placed on the sides of the source-attenuator assembly to give an increased background, but did not block the direct path for gamma rays between the sources and the detectors. The NORM was commercial water softener salt substitute or potassium chloride. About 3 tonne of KCl in 18 kg bags on pallets were in the truck.

ANALYSIS

Peak Quality Factor

The identification of the nuclide is based on the presence in the spectrum of selected intense gamma rays from that nuclide. The gamma rays used for each nuclide are given in a table stored in the analysis software. The gamma rays in the table are given in several sources[1, 4, 7, and 8]. The peak

is present in the spectrum if a measured parameter of the peak is above a threshold. For this work, the peak parameter used is the peak quality factor (Q) and is defined as the net peak area divided by the uncertainty in the net peak value [9]. The Q value depends on the peak signal and the background under the peak. The threshold is based on the desired false positive rate and false negative rate [10]. There is a threshold specified for each gamma ray in the analysis table. The identification is based on the full energy gamma ray signal and not on gross counting.
The background is determined dynamically from the same spectrum as the gamma ray net peak area is determined, so there is no stored background or background history. This avoids the problem of background suppression by high density shipments and variations in the background by natural causes, such as the weather.

Multiple detectors can be used to improve the detection ability by calculating the gross and net area for each peak in each detector spectrum and combining these gross and net values into a composite Q value. Combining detector responses in this manner and not by summing spectra avoids the problem of differing energy responses and differing peak widths (resolution) of the different detectors. This gives the Q for the portal of up to 8 times the efficiency of a single IDM. In addition, different groupings of detector responses can be combined and the grouping with the best signal-to-noise ratio is used for the identification.

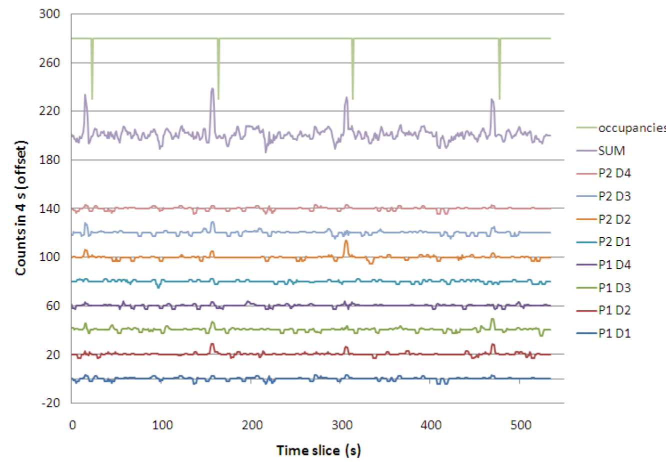

Figure 4 Contributions from Individual IDMs and the Composite Signal for ^{133}Ba (88 µCi) with 2.5 cm Steel Shielding

Figure 4 shows the individual net count responses from 8 IDMs for the situation of 88 µCi ^{133}Ba with NORM and shielded by 2.5 cm of steel as a function of time. Also shown is the aggregate or sum of the responses and the time of the end of the occupancy. There are 4 occupancies shown over the total time of 9 minutes. The source signal is clearly visible in the sum, but not in any one detector signal.

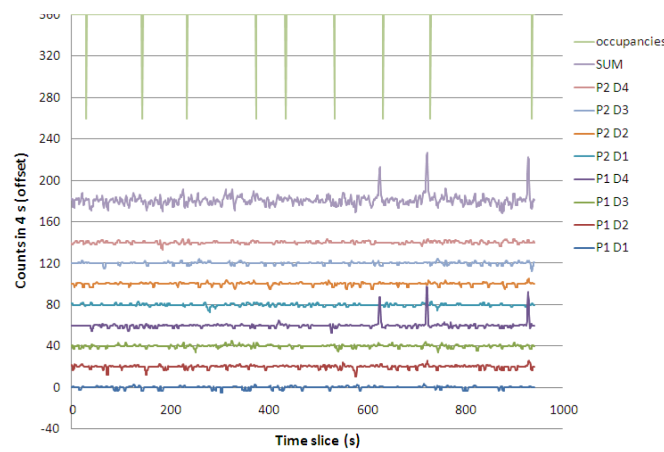

Figure 5 Contributions from Individual IDMs Showing Failure in the Test Fixture

Figure 5 shows a similar test run, but with 4.2 cm of steel which completely absorbs the ^{133}Ba gamma rays and without NORM. Note that for the last three occupancies, the top detector of panel 1 shows a strong signal. This anomaly was traced to the steel shield on the panel 1 side having fallen over slightly exposing only the top detector to the unshielded source.

RESULTS

The tests were conducted with and without NORM for shielding thickness from 4 mm to 7.5 cm. For each test situation, the number of identified nuclides was calculated as a percentage of the number of occupancies. The value ranges from 100% identification for the smaller thickness of steel to no identifications at higher thicknesses. The results for 88 µCi ^{133}Ba are shown in Fig. 6. As expected, the addition of NORM increases the background over much of the energy range and especially below 400 keV where the ^{133}Ba peaks are. The increased background increases the net peak area uncertainty which reduces the Q value and the maximum shielding thickness where identification is made.

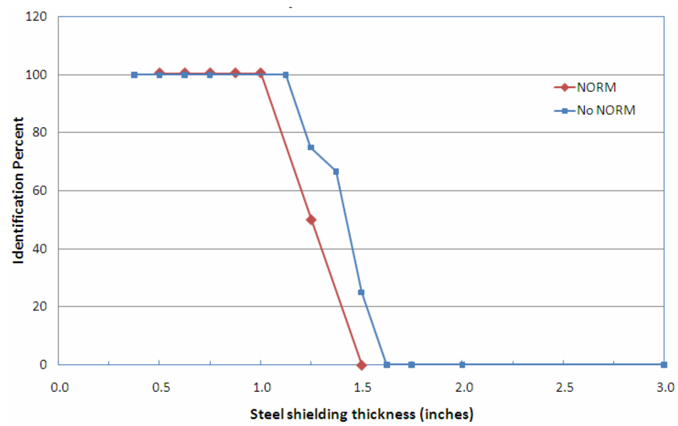

Figure 6 Percent Identification for ^{133}Ba for Different Thickness Steel Shielding with and without NORM

CONCLUSION

The testing of the portals with one of the nuclides specified in ANSI N42.38 (^{133}Ba) and various thickness of steel shielding shows the HPGe portal can meet the requirements as specified in the standard for identification of radionuclides being transported in cargo containers with and without shielding and at the vehicle speeds specified (8 kph). Operation as a secondary portal with the vehicle speed reduced to about 3.5 kph will improve the MIAs further. The portal uses a practical number (4 per panel) of detectors and relies on the high resolution in the spectrum for the superior performance. The operation of the two portals in an operational setting for more than 6 months demonstrates the reliability of the IDM hardware and the spectrum analysis software.

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