Abstract 233

False Positive Probability as a Function of Background for Short Data Collection Times in a Germanium Detector Portal Monitor

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ABSTRACT

The interdiction of illicit radioactive materials relies on detecting the emissions from the material when passed in front of or through a radiation monitor. These portal monitors must be sensitive enough to detect and identify a specified (ANSI N42.38) quantity of material. The ability to identify, rather than just detect changes in activity, is important in order to differentiate between benign materials and threat materials. Clearing benign materials has a high cost in time and money. The identification depends on the signal-to-noise ratio, not the gross efficiency, of the detector. In low- or no-resolution detectors the background (noise) is high resulting in a low signal-to-noise ratio and the actual background can be affected by the object in the portal causing real increases in the background to go undetected. In a high-resolution monitor, the background is determined on the actual object spectrum, avoiding this problem. Portal monitors typically have 5 to 45 seconds to collect the gamma-ray spectrum and then 2 to 5 seconds to analyze the spectrum and give a result. The determination if a gamma-ray peak is present in the spectrum is usually done by calculating a quality factor and then comparing this quality factor with a threshold. The quality factor depends on the net peak area and the background under the peak in some way. The net peak area and the background depend on the full-energy peak efficiency and the detector resolution. The short collection time means there are few counts in the spectrum and the variation in the calculated values is high. The quality factor threshold for positive identification must be set so that the number of false identifications is less than 1 in 1000 measurements (ANSI N42.38). This threshold value also determines the minimum identifiable activity for the given background level. To measure this threshold, a pedestrian portal was constructed and the quality factor was measured for 10000 occupancies for several different background levels. The quality factor was also measured for 10000 occupancies with a small ^{133}Ba source. The results show the expected distribution for high background, but have some granularity at the lowest background. The results also show that the threshold must be set higher than expected for the lowest backgrounds in order to accomplish the 1 in 1000 false rate. The minimum identifiable activity for ^{133}Ba in the different backgrounds at the 1:1000 FAR (False alarm rate) setting is shown and is significantly lower than the limit defined in the standard. It is clear from these results that the high signal-to-noise ratio is more important than gross efficiency for radiation portal monitors required to interdict one group of radionuclides while clearing a second group for onward transportation.

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

INTRODUCTION

The interdiction of illicit radioactive materials relies on detecting the emissions, primarily gamma rays, and in some cases neutrons, from the material passed in front of or through a radiation monitor. These portal monitors must be sensitive enough to detect and identify a specified (ANSI N42.38) quantity of material. The time available to collect the gamma ray data is short because the flow of people, packages, or cargo cannot be significantly disrupted.

The ability to identify the nuclides in the object rather than just detect changes in activity is important in order to differentiate between benign materials and threat materials. If a benign material (such as ceramic tiles, kitty litter, or medical isotopes) causes an alarm, the material must be investigated. This clearing of benign materials has the potential to disrupt the efficient flow of commerce resulting in a high cost both in time and money. The nuclide identification depends on the recognition of the gamma ray signature of the nuclide, which means the full energy peak areas must be quantified. The ability to detect this signature depends on the signal-to-noise ratio, not the gross efficiency, of the detector. In low- or no-resolution detectors the background (noise) is high resulting in a low signal-to-noise ratio and the actual background can be affected by the object in the portal causing real increases in the background to go undetected. In a high-resolution monitor, the background is determined on the actual object spectrum, avoiding this problem.

Depending on the concept of operations (CONOPS), package portal monitors typically have 2 to 45 seconds to collect the gamma-ray spectrum and then 2 to 5 seconds to analyze the spectrum and give a result. The determination if a gamma-ray peak is present in the spectrum is usually done by calculating a quality factor and then comparing this quality factor with a threshold. The quality factor depends on the net peak area and the background under the peak in some way. From the detector perspective, the net peak area and the background depend on the full-energy peak efficiency and the detector resolution. The short collection time means there are few counts in the spectrum. The small number of counts in the net peak area means that the variation in the calculated values is high. The quality factor threshold for positive identification must be set so that the number of false identifications is minimized. This threshold value also determines the minimum identifiable activity for the given background level.

EQUIPMENT

The data were collected using an integrated HPGe detector, Stirling cooler, MCA and communications link (Interchangeable Detector Module or IDM). The IDM and portal have been described in earlier work [1]. The spectra were collected in 16k channels with an energy range of 0 to 3 MeV. Comparison data were also collected on a 4 x 4 x 16 inch sodium iodide (NaI) detector. The NaI data were collected in 1024 channels for the same energy range. The background data were collected inside a building with concrete floors and minimal internal walls. Various backgrounds were measured by increasing the background using zircon sand. This would simulate increases in NORM.

Data were collected continuously to obtain 10000 data sets or occupancies of clean or “null” packages. The signal-to-noise ratio for peaks in a spectrum depends on the spectral data collected, not the time of collection, although the minimum activity (decays per second) that can be detected depends on the data collection time. Figure 1 shows a sample HPGe spectrum with 6000 counts in the range from 30 keV to 3 MeV. The two insets are the 370 keV energy and the ^{40}K peak regions. The ^{40}K value was used in the calculations as an actual peak in the spectrum. The 370 keV region was selected because it is free of peaks from naturally occurring radionuclides and is near the plutonium energies.

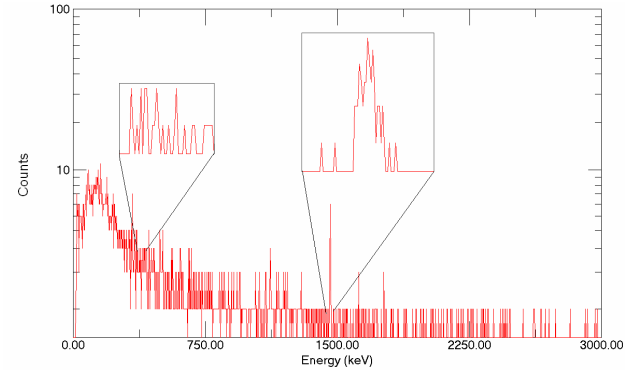

Figure 1. HPGe Spectrum with 6000 Total Counts

The total counts in the 370 keV region are shown in Fig. 2 for 2000 spectra. The minimum and maximum counts are indicated, showing the wide range of possible values (17 to 57).

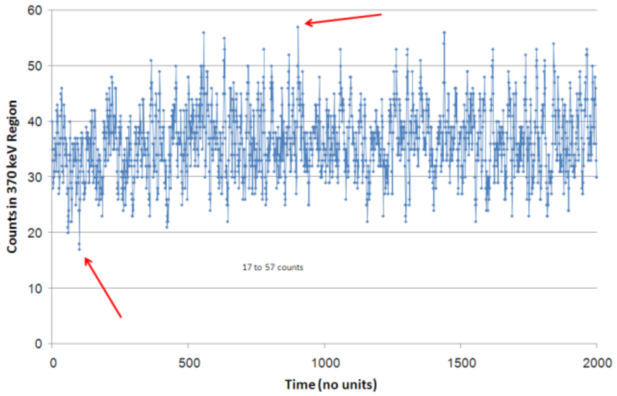

Figure 2. Natural Variation in Background

In addition to the natural variation in the background, other workers [2] have reported on the problem of background suppression by the actual object being scanned, such as a large empty container, as shown in Fig. 3. This illustrates the problem of any background subtraction method in determining the net peak area if the method does not use the data in the individual sample spectrum.

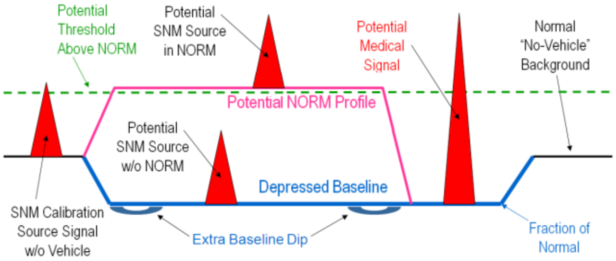

Figure 3. Background Changes with Object in Detection Zone

The determination of data collection time (often called occupancy time) for a portal is based on the time that a source would contribute meaningful data to the spectrum as it passed through the portal. Increasing the time beyond this has the adverse effect of reducing the signal-to-noise ratio because the background component is being increased with no increase in signal. In other words, the goal is to maximize the time the detectors are “seeing” the actual source and minimize the time they are summing background into the analysis The field of view (FOV) of the small portal was previously reported [3] and is shown in Fig. 4. At the given transit speed of 1.2 m/s, for the section of the FOV where 90% of the 383 keV peak data are collected, the data collection time is about 1.7 s. For optimal sensitivity, at a transit speed of 1.2m/s the identification must be based on spectra collected in 2 s or less.

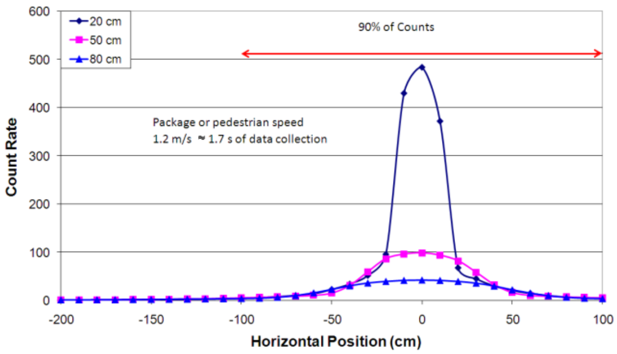

Figure 4. Field of View of IDM

CALCULATIONS

The figure of merit used here to determine if a peak is present or not is the peak quality factor, Q, in Eq. 1.

$$Q \equiv \frac{G-B}{\sigma_N}$$

Where

G is the gross counts
B is the background counts
σ_N is the uncertainty in the net peak area

The expected distribution of an ideal Q for a specific situation is shown in Fig. 5. [4] The shape of the distribution is Gaussian and for the null case, the expectation value for the blank would be 0.

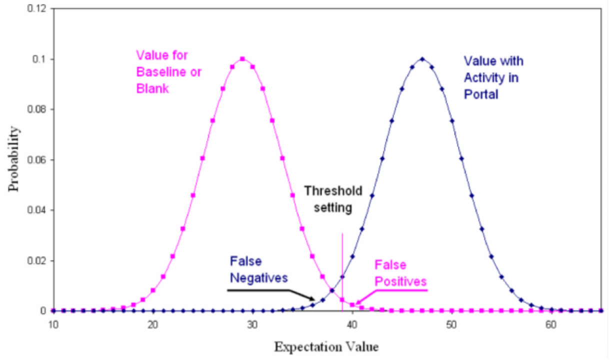

Figure 5. Idealized Q Distribution for Null and Positive Cases

The actual distribution of Q for 10000 null cases of the 370 keV background region is shown in Fig. 6. Note that, while the distribution has the general shape of a Gaussian, there are significant high and low tails on the null case. The large tails will require an increase in the threshold value to meet the false positive rate. The large variation from value-to-value is due to the small numbers in the null case and is reduced in the case of the peak of ^{40}K.

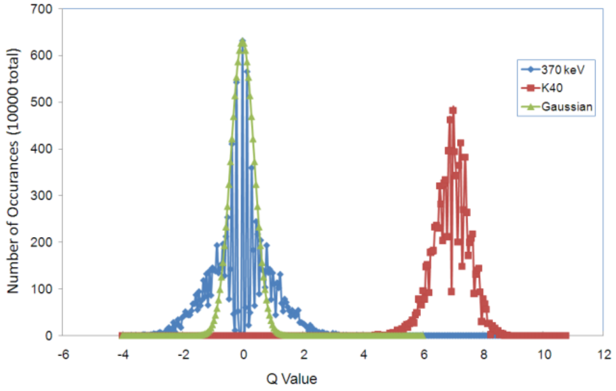

Figure 6. Actual Q Distribution for 10000 Cases

RESULTS

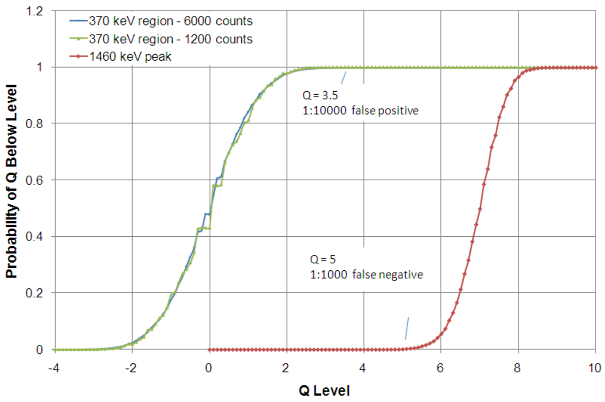

Figure 7. Integral of Q for Null and Positive Cases

An easier way to show (in relation to the 1:10000 FP value) the Q value is to use the integral or cumulative sum of Q, as shown in Fig. 7. This is a plot of Q calculated for a series of spectra like Fig. 1 for the two peaks shown and for two different values of the total counts in the 370 keV region. While the 370 keV region in the spectrum is "flat" background, the Q value can still be calculated using the expected FWHM of a peak at this energy. The value is symmetric around 0. Note that the different total count situations have nearly the same distribution. The discontinuities in the 370 keV curves, seen as small "bumps" on the line, are due to the fact that the channel counts must be integer values, some values are not possible when Q is near 0. Note that the Q value for a 1:10000 false positive rate is 3.5 for the background case and for the 1:1000 false negative rate for the peak of ^{40}K, Q is 5. With the Q threshold set at 3.5, ^{40}K would be detected in this background.

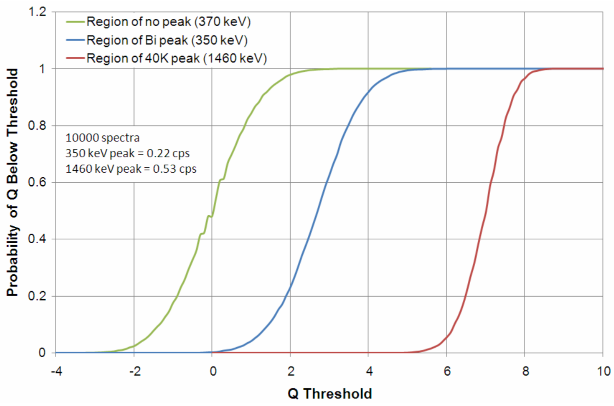

Figure 8. Integral of Q for Small Peak at 350 keV

The background contains a peak from ^{211}Bi at 350 keV and this can be used to show the Q value for small peaks with background similar to the 370 keV region. This is shown in Fig. 8. If the Q threshold was set at 3.5 for the 1:10000 false positive rate, then this peak would be positively identified about 20% of the time for those cases with this number of counts in the spectrum. Note that the shape of the curve has a higher slope with increasing count rate. Thus, in a situation where the peak count rate is higher than 0.60 cps on this background, the peak would be positively located.

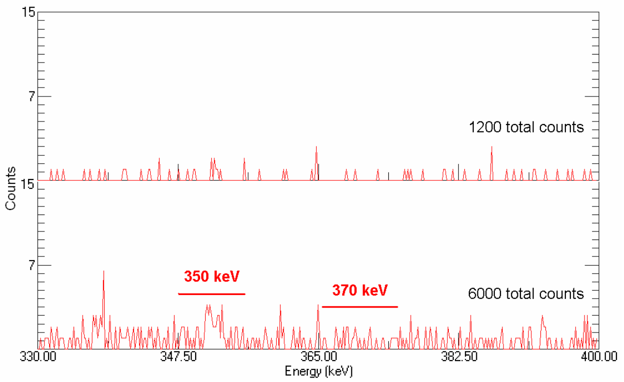

Figure 9. HPGE Spectra for Different Total Count

With the short collection time and subsequent low number of counts in the spectrum, detection will depend on the ability to recognize a peak in the data. Figure 9 shows the spectra for two different total count situations of natural background. The maximum vertical scale in each of the parts is 15 counts. The spectra from the NaI detector for the same background flux and energy region are shown in Fig. 10. The maximum vertical scale is

250 for the “equivalent to 1200 HPGe total count data” and 1500 for the “equivalent to 6000 HPGe total count” data. The 350 keV peak is clearly visible in the “6000 total count HPGe spectrum.” Even with more total counts, the peak is not visible in the NaI spectrum even at the high count situation.

The HPGe Q value depends on the net peak area and its uncertainty. The uncertainty depends on the background calculated on the sample spectrum itself. The total counts in the 370 keV region range from 0 to 13 counts for HPGe as shown in Fig. 11 and are uniform with time. Figure 12 shows the NaI data for the same collection parameters as Fig. 11. For NaI spectra, the integration energy range is taken as 3 times the FWHM and is represented by as the blue “box” in Fig. 10. Note that the NaI background varies dramatically with time. The figure covers about 28 hours and a large increase occurred over an hour at about 9 AM. An explanation for the change in background by much more than would have been caused due to statistics alone has not been found. This variation shows clearly why backgrounds should be determined dynamically and not based on historical data.

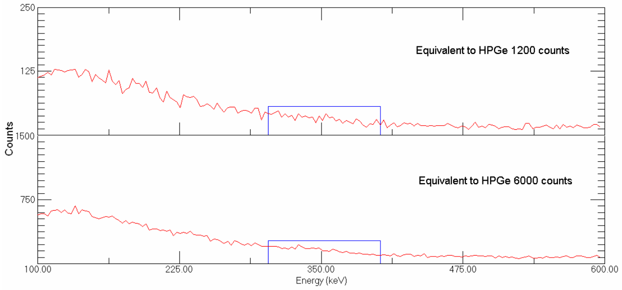

Figure 10. NaI Spectra for Same Conditions as HPGe in Fig. 9

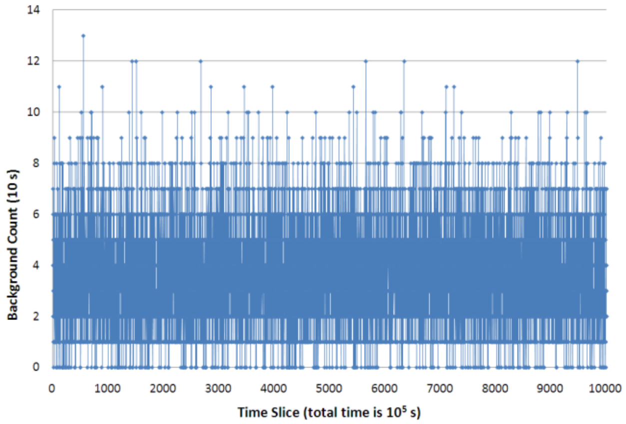

Figure 11. Variation in HPGe Background for Low Count Situation

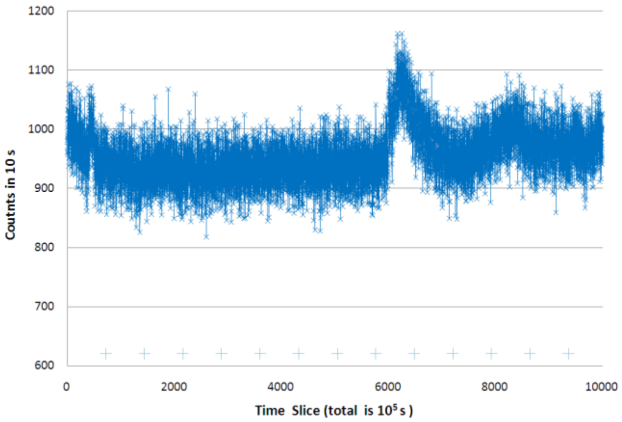

Figure 12. Variation in NaI Background for Low Count Situation

CONCLUSION

The desired short collection times for a vehicle, pedestrian or package portal monitor pose significant problems for the detection and identification of radionuclides. The natural variation and the object-related suppression or increase in the background gamma ray flux means the threshold for accurate identification must be set higher than one would wish in order to meet the 1:1000 or 1:10000 false positive rate. Background suppression due to the object of interest shielding the detector while transiting through the portal and natural variation in the background, mean that the background should be calculated from the actual sample spectrum itself. While this is readily possible with high resolution (HPGe) detectors, it is not always possible in the case of low resolution detectors. In addition, for the high resolution detector the expected nearby dynamic background variation can uniquely be used to set the identification threshold for the peaks in question. This then determines the minimum identifiable activity (MIA) for that nuclide and allows the threshold to be set at lower values than in an "equivalent" low resolution system with no increase in False Alarm Rates (FAR).

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