Characterization of Room Temperature Detectors using the Proposed IEEE Standard

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Abstract – The availability and quality of room temperature detectors such as cadmium-zinc-teluride (CZT) has improved in recent years. There are many applications for these, but at present there are inconsistencies among manufacturers and users in the methods of testing and describing them. To overcome this deficiency, a standard is being developed similar to the ones that apply to NaI, HPGe and other detectors. The standard will describe methods of measuring efficiency, resolution and noise, and will provide details of the test apparatus necessary to perform the tests. It will also take into account the differences between the newer semiconductor detectors and those developed earlier. It furnishes definitions for specialized terms. Tutorial material is included.

I. INTRODUCTION

The draft standard, "IEEE Standard Test Procedures for CdZnTe and other Wide-Bandgap Semiconductor Detectors of ionizing Radiation," was written to provide a consistent means of describing the important features of these detectors. This will give manufacturers and users of these detectors a meaningful way to test and describe the detectors needed.

The existing standards for other detectors, such as sodium iodide (NaI) and germanium (HPGe) are not applicable for detectors such as cadmium-zinc-teluride (CZT) for several reasons. The resolution of CZT is much better than NaI. The crystal size is much smaller than the currently available HPGe, so the medium- and high-energy efficiency is much lower. In addition, the peak shape usually has significant low-energy tailing. These three factors dictate that a new standard be written.

There are several wide-bandgap detectors in use. The most popular is CZT, so it will be the basis for the examples here. The standard defines the tests and test methods for determining the following: detector leakage current, detector capacitance, peak resolution, peak-to-valley ratio, and efficiency. Here we will discuss only the last three, as these differ most from previous standards.

II. PEAK SHAPE OR ENERGY RESOLUTION

The typical peak shape for CdTe and CZT is shown in Figs. 1 and 2 [1]. The peak shape function for spectrum peaks with significant tailing was introduced in an early LANL spectrum analysis program [2], and further refined for use by subsequent programs [3], [4]. This function was used to generate the example figures in the following text.

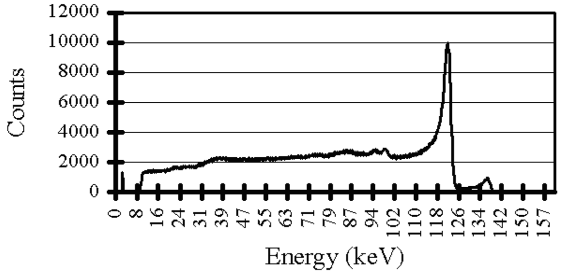

Figure 1 2x2x2 mm CdTe Detector Spectrum of ^{57}Co

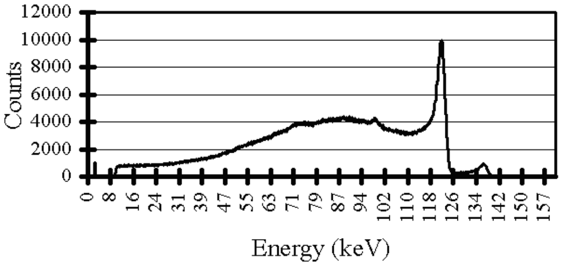

Figure 2 2x2x2 mm CZT Detector Spectrum of ^{57}Co

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The energy resolution is described by the full-width at half maximum (FWHM), full-width at tenth maximum (FW.1M) and if possible the full-width at 25th maximum (FW.04M). These are all calculated using the net peak or the peak above the background. Only the first two can be used here. In addition, the low-energy tailing may be so severe in some detectors it is impossible to determine the actual net peak for the calculations.

For the energy measurement, the source must be a point source (less than 2 mm diameter) located at 10 cm from the front face of the detector housing and along the principal axis of the detector. The principal axis is along the direction between the detector and the sample in the intended application. Material around the source should be minimized to reduce backscatter and other interfering peaks.

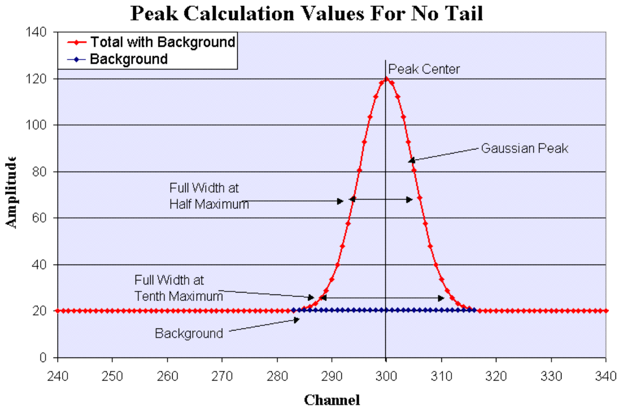

Figure 3 Peak without tailing

In the example shown in Fig. 3, it is possible to determine the background under the peak and obtain the net peak. The background is defined to be the spectrum counts not associated with the full-energy peak. The FWHM and the FW.1M can both be determined. The FWHM is determined by calculating the net peak height, locating the channels with net amplitude bounding the half height on both sides of the peak, linearly interpolating the fractional channel value between the two bounding channels on the low and high energy sides, and then subtracting the two values to obtain the full width.

The background can be determined by extending a straight line from below the low-energy side of the peak to above the high-energy side of the peak. The FW.1M value is obtained in a similar manner.

In the case where the peak has tailing, as shown in Fig. 4, the low-energy side of the peak is dominated by the peak tail. The figure shows the single Gaussian and a two component tail. The tail has a quickly decaying tail and a slowly decaying tail.

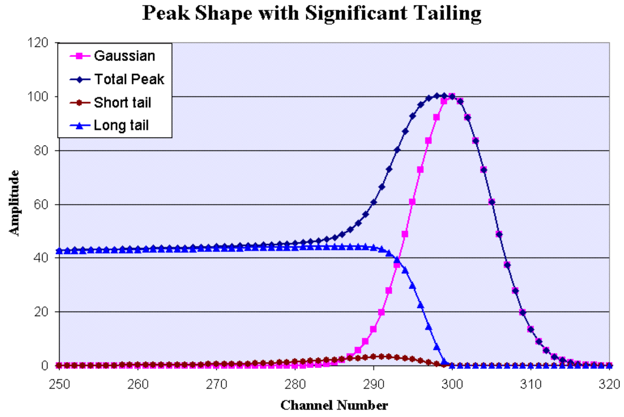

Figure 4 Peak with long and short tailing

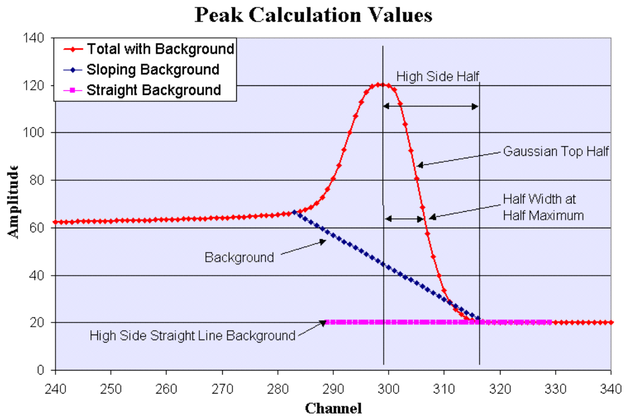

Figure 5 Peak calculations with large tailing

Fig. 5 shows just the total peak with the background as calculated above. However, in this case the low-energy background position is difficult to determine. Clearly, the position of the low energy channel of the background has a large effect on the value of the calculated background at the peak center. In addition, the peak centroid (center of mass) will be shifted away from the peak maximum as the background low energy point is shifted to lower channels.

To eliminate the variability in the background and all subsequent calculations based on the background, the background is calculated by fitting the high side background with a straight line and extending this straight line to the peak center. Thus the values calculated are based on only the high-energy side of the peak.

The use of only the high side relies on the assumption that the peak shape is Gaussian above the center. Based on the peak model and observations of actual spectra, this assumption is justified.

The background is subtracted from the peak area to obtain the net peak above the center. The half maximum is calculated as described above. The center peak value is subtracted from the fractional channel of the half height to obtain the Half Width at Half Maximum (HWHM). The FWHM is twice the HWHM. The FW.1M is calculated in the same way.

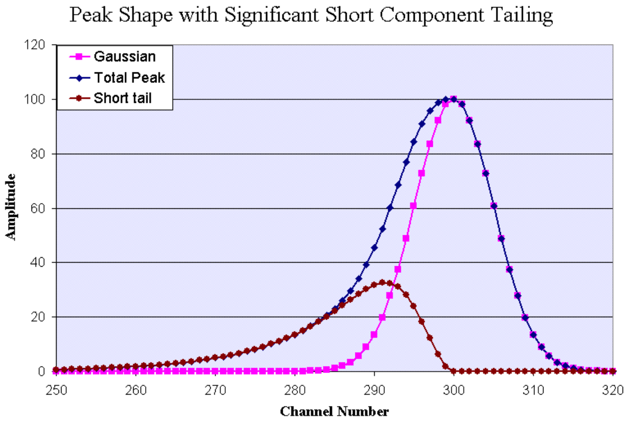

Figure 6 Peak with small tailing

In many cases, the peak tailing is not as severe as shown in Fig. 4 and is better represented by the peak in Fig. 6. In this case, the slowly decaying tail is too small to affect the peak. However, as shown in Fig. 7, the low energy channel of the sloping background can still have a large affect on the net peak. In this case, the FWHM could be calculated directly or calculated based only on the top half. The FH.1M will most likely not be reliably calculated on the full peak.

When the FWHM, FW.1M and FW.04M are reported, they can be calculated in either (or both) ways, but the method used must be stated with the result.

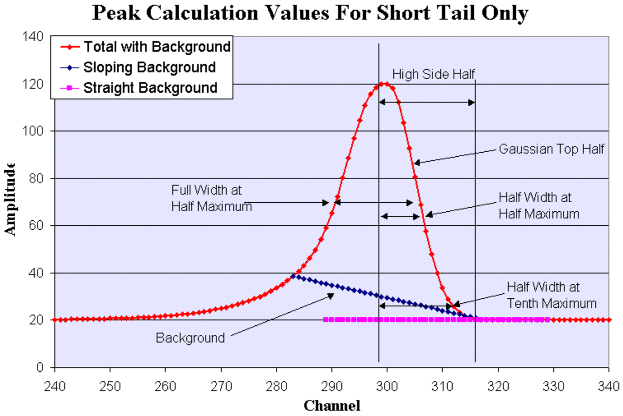

Figure 7 Peak calculations for peak with small tailing

The crystal size for these detectors is currently small. Thus, the efficiency for gamma rays above several hundred keV is small. There are applications where only low energy gamma rays are used and where the gamma ray flux is large enough to overcome the low efficiency. To cover all these cases, the resolution should be measured for those energies relevant to the intended application. The gamma rays used must be one or more of the following: 122 keV of ^{57}Co, 661 of ^{137}Cs and 1332 of ^{60}Co.

III. PEAK-TO-VALLEY RATIO

The quantification of tail is also important in assessing the quality of the detector. To quantify the tail, the peak-to-valley ratio is calculated at several points below the peak. The peak-to-valley ratio is the ratio of the peak counts at the center channel, to the channel contents at a point in the spectrum below the peak. An analogous measurement is the peak-to-Compton measurement for HPGe detectors. The energy resolution spectrum is used for this measurement.

The positions of the channels is determined by the resolution at the main peak energy. The background under the entire low energy region is calculated using the straight line projection of the background on the high energy side of the peak. The peak amplitude is the value of the net channel contents at the peak center. The valley is calculated as the average of the 5 channels centered at the following channels: 1) a distance of 0.5 FWHM from the peak center channel; 2) a distance of 2 FWHM from the peak center channel; and 3) a distance of 5 FWHM from the peak center channel.

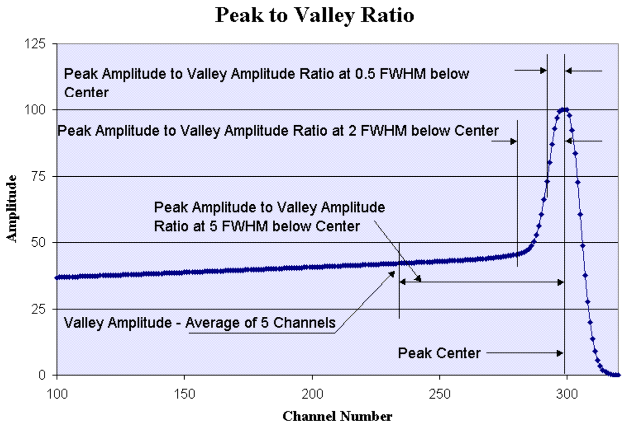

Figure 8 Peak- to-valley calculation

These are shown in Fig. 8. If these channel locations coincide with other peaks, such as escape peaks or X-rays, then the next closest region shall be selected. Every effort must be taken to eliminate extraneous peaks for this measurement.

IV. EFFICIENCY

The efficiency of the detector is a measure of its ability to detect the gamma rays. It is generally defined as the ratio of the counts in the spectrum full energy peak and the source emissions.

For the efficiency measurement, several different geometry sources can be used. Each source has several nuclides which together emit gamma rays over a wide energy range. The sources are a point source and a flat disk source. A recommended list of nuclides is ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co. In all cases, material around the source should be minimized to reduce backscatter and other interfering peaks.

The point source must be less than 2 mm in diameter and located at 10 cm from the front face of the detector housing and along the principal axis of the detector.

The disk source must have the activity uniformly deposited on a material such as filter paper and be 5 cm in diameter. The efficiency is measured at two source positions. For the close efficiency, the source is positioned at the front of the detector housing and along the principal axis of the detector. For the distant measurement, the source is located at 10 cm from the front face of the detector housing and along the principal axis of the detector.

For all detector-source geometries, the efficiency is calculated as follows:

$$\eta_E = 100 \frac{A_E}{N_E} \qquad \textbf{(1)}$$

Where η_E is the counting efficiency in percent
A_E is the total net peak count rate (cps)
N_E is the total number of full-energy photons emitted by the source in one second.

The total net peak count rate is the total, background subtracted peak area divided by the live time of the MCA. If the peak tailing is not severe, that is, FWHM/ FW.1M < 2.0, then the total peak area is summed from the low energy side to the high energy side of the peak. If the peak tailing is severe, that is, FWHM/FW.1M > 2.0 or the resolution (either FWHM or FW.1M or both) is calculated by the HWHM method, then the total peak area is twice the sum of the area from the peak center to the high energy background point. The calculation used shall be given in the specification.

V. EQUIPMENT

The standard includes a complete description of the test equipment needed to perform these tests as well as other tests of the detector. Also, a description of the operation of the detectors is given to help the understanding of the nature of and need for these tests.

VI. CONCLUSION

This new standard gives useful and workable definitions for the parameters needed to describe the performance of wide-bandgap detectors, such as CZT. The use of this standard will help researchers and manufacturers to better specify and use these detectors.

At this time, this is a draft standard. Please send any comments on the proposed standard to RonKeyser@IEEE.org.

VII. REFERENCES

[1] Lavietes, A. D. and McQuaid, J. H., “Characterization Inconsistencies in CdTe and CZT Gamma-Ray Detectors,” presented at the 1994 IEEE NSS/MIC meeting.

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