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Investigation into the properties of CdTe detectors for in-situ measurements

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ABSTRACT

As part of a program investigating means to improve gamma-ray spectra obtained with CdTe detectors, we report results obtained with two $10 \times 10 \times 5\,\mathrm{mm}^3$ CdTe detectors, one planar the other of quasi-hemispheric geometry. Applying a combination of cooling and pulse rise-time discrimination with the quasi-hemispheric detector, we obtain a resolution of 4 percent at 662 keV and a peak-to-valley ratio of 92 at a loss of approximately 25 percent of the counts in the full-energy region.

1. Introduction

In case of a release of radionuclides into the environment, it is necessary to have reliable methods to estimate the potential effects on population and ecosystem. Identification of the emitting radionuclides and determination of the total photon flux above the contaminated area are straightforward, for example using HPGe detectors. However, in order to determine the effects on the ecosystem total activity and its distribution are of importance [1–3]. Determining these from the photon flux above ground is not trivial, due to photon absorption caused by surface roughness and/or burial of the activity. Utilizing in addition to the flux of unscattered (characteristic) gamma rays also the intensity of scattered radiation, reliable estimates of surface activity and (effective) burial depth averaged over areas ranging from a few hundred to a few thousand square meters may be obtained from HPGe spectra measured in situ [4].

Migration of radionuclides into the soil is normally a slow process (a few centimeters a year) [5], but may be accelerated if the deposition occurs in rain as did in Sweden the major part of the deposition of the fallout following the Chernobyl accident. A similar complication occurs if the activity is deposited during or before snow fall [6]. Process of deposition, ground properties and topography can lead to large fluctuations even over small distances [3,6,7]. Traditionally, local variations in activity and depth distribution are determined by laboratory analysis of extracted soil samples, a labor intensive and slow process. In addition, it is not entirely reliable. Even though the laboratory analysis may be driven to any desired accuracy, the procedures used to take samples are inherently uncertain because of the limited volume of the sample compared to typical variations in soil composition (stones, roots, etc.) and the massive deformation of the sample when it is extracted. As an alternative to the traditional soil sampling, we are investigating the possibility of determining the local variations in the depth distribution of the deposited activity by measurements in situ with small detectors inserted into the ground. For this purpose we have been investigating the properties of CdTe detectors, and in particular methods to improve the spectral resolution obtainable with these detectors.

As a detector for gamma rays CdTe is rugged and requires no cooling. However, its application is hampered by poor charge collection in particular due to trapping of holes. The pulse shape, therefore, is strongly dependent on where in the crystal the energy is deposited. We have previously reported results obtained with a small $5 \times 5 \times 2\,\mathrm{mm}^3$ detector feeding the preamplifier output to two shaping amplifiers in parallel with different shaping times [8]. Fig. 1 shows a scatter plot of events obtained with a ^{137}Cs source. In the plot the digitized pulse height from the shaping amplifier with a shaping time of $0.5\,\mu$s determines the vertical position of the event, whereas the horizontal position corresponds to the pulse height from the second amplifier with a shaping time of $3\,\mu$s. Events with the fastest rise time, corresponding to a small contribution from holes, fall along the diagonal. Events with a larger contribution from holes fall below the diagonal. From the figure it is apparent that for this detector, disregarding the finite resolution, the pulse-height deficit was a single-valued function of the ratio of the two pulse heights. The measured spectrum could then be corrected for pulse-height

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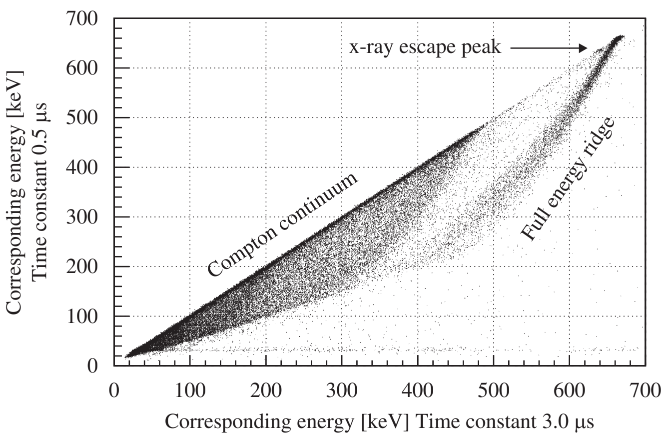

Fig. 1. Scatter plot of pulse-height spectrum for ^{137}Cs from a small planar CdTe detector using two amplifiers with 0.5 and 3.0 μs shaping times (from Ref. [8]).

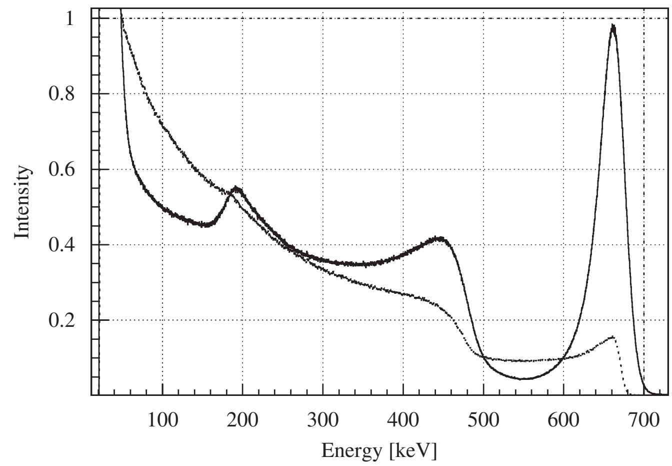

Fig. 2. Pulse-height distribution for ^{137}Cs for the planar (dots) and the quasi-hemispheric (line) CdTe detector both of 500 mm^3 volume. Applied high voltages are 500 and 1000 V.

deficit obtaining a resolution of 2 percent at 662 keV including all events.

In light of these results work has continued with detectors of larger size and correspondingly larger efficiency necessary in order to shorten the time required for the field measurements. Our aim, in particular, has been to minimize the detrimental effects of incomplete charge collection. Using a coincidence technique, we have created samples of events all characterized by the same energy deposition in the CdTe detector. For these samples the pulse-height distribution shows directly the effects of pulse-height deficit.

In the present paper, we report results obtained with two $10 \times 10 \times 5\,\mathrm{mm}^3$ detectors one planar, the other of quasi-hemispheric geometry. A brief description of the detectors is given in the next section, followed in Section 3 by a description of the experimental apparatus. The results obtained in measurements at room temperature and at $-7.5\,^{\circ}\mathrm{C}$ are presented in Section 4. Our main conclusions are summarized in Section 5.

2. Description of the detectors

The pulses from a CdTe detector are sum of two components, one originating from the drift of electrons and the other from holes. The proportion of the pulse generated from each one of these components depends on the distance from the point of interaction in the crystal to the respective electrode. The drift velocity of holes is approximately a tenth of that of electrons, but the trapping time is of the same order of magnitude [9]. Hence, the hole contribution to the pulse height is more severely affected by trapping effects, resulting in a final pulse height depending on where in the crystal the interaction takes place.

Typical pulse-height distributions from the two detectors are shown in Fig. 2. The pulse-height distribution from the planar detector is similar to that reported for the small planar detector before correction [8]. It is quite different from the hemispheric detector.

The major differences in the distributions can be understood by studying the crystal geometries and the electric field configurations for the two detectors. The detector referred to as hemispheric is actually a quasi-hemispheric detector [10]. Both the quasi-hemispheric and the planar detector have rectangular dimensions, $10 \times 10 \times 5\,\mathrm{mm}^3$. On the hemispheric detector all surfaces except one are held at negative potential. The remaining surface has a circular positive electrode with a diameter of 1.5 mm at its center (cf. Fig. 3).

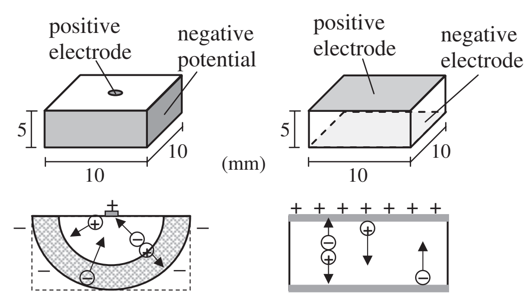

Fig. 3. Illustration of the quasi-hemispheric and planar crystal geometries (upper) and principles of charge collection for a truly hemispheric and a planar detector (lower).

The planar detector has (ideally) a uniform electric field and both charge carriers contribute to the pulse height. The pulse-height distribution is distorted mainly due to incomplete collection of holes. The hemispheric detector on the other hand has an electric field that is (ideally) radial and therefore much stronger near the positive electrode. This field configuration accelerates the collection of electrons and slows down the velocity of holes. As a result, the device works (in principle) in a single charge-collection mode. In addition, most interactions occur in the hatched region of the crystal in Fig. 3, close to the cathode, because this region contains the major part of the crystal volume. Hence the contribution due to electrons is further accentuated.

3. Experimental setup

In order to create samples of events all corresponding to the same absorbed energy in the CdTe detector, mono-energetic photons were Compton scattered in the CdTe detector and then detected in an HPGe detector.

The CdTe detector was irradiated by a collimated photon flux from a ^{137}Cs source. Small-angle scattering in the lead collimator was investigated experimentally and also by simulations. The effects were found to be small. A second detector (HPGe) was positioned at a given angle and carefully shielded from the radioactive source. Requiring a coincidence between the two detectors, events that correspond to a photon being scattered in