True and Random Coincidence Effects with Semiconductor Detectors

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The most common design for semiconductor detectors used in the spectroscopy of gamma-rays is a coaxial one ("pop-top"). Therefore the source must be positioned outside the detector. The overall detection efficiency is reduced by the solid angle, because not every gamma-ray emitted by the source hits the detector. Even in the case when the gamma-ray enters into the detector, the probability of detecting the total energy of the gamma-ray is substantially less than 100%, and it depends on the gamma-ray energy. For example for a gamma-ray having an energy of 1333 keV, the probability of detecting the total energy (total energy peak) is 23%. (This is a figure for our detector.)

In environmental samples very small activities may occur. If a large amount of the emitted gamma rays are lost because of the small solid angle, either very long measuring times are needed to accumulate spectra with acceptable statistics, or it is not possible at all, because the natural background becomes higher than the activity to detect. One way to solve the problem is to change the detection geometry such a way, that the detection solid angle for the sample will be increased, without increasing the overall detection efficiency for the natural background. This can be done using "well-type" detectors, where there is a "hole" (well) inside the detector. The source can be positioned in the well, and so nearly 4π geometry can be achieved for the gamma-rays emitted by the source. Of course, the gamma-rays coming from the environment (natural background) do not profit from this enhanced solid angle, therefore their overall detection efficiency will not be increased.

This technique, however, causes additional problems. One of these is the occurence of coincidence peaks in the spectrum. Many radioactive isotopes decay to their ground-state by emission of more than one gamma-ray. A highly excited state does not decay directly to the ground state, but it decays first to a lower excited state, then to an other lower excited state, and so on, until finally the ground state is reached. Generally the lifetime of these excited states are very short (in the order of 10^{-20} s), so the gamma-rays coming from these transitions will be emitted practically in the same time. This process is called *gamma-cascade*. The members of a cascade generally have some weak angular correlations determined by the spins and parities of the excited states involved. For the practical spectroscopy, however, they can be considered as emitted more or less in random directions. If the source is positioned far outside the detector, the probability that more than one gamma-ray of a cascade hits the detector is very small, therefore only the individual gamma-rays will be detected.

Contrary, if the source is positioned inside the detector, the probability of detecting more than one gamma-ray of a cascade (emitted in different directions) is clearly increased. This is called true coincidence. For this event a signal corresponding to the *sum* of the energies will be detected, and the signals at the individual energies will be *missing*. The peak detection efficiency will not depend on the gamma-ray energy alone. It will be different for two gamma-rays which have the same energy, but one is a member of a cascade and the other one is not.

It may happen, that two gamma-rays coming from the decay of two *different* nuclei hit the detector in the same time. They do not belong to the same cascade, their coincidence is accidental. They are called *random coincidences.* Their importance can be decreased by

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It may happen, that two gamma-rays coming from the decay of two *different* nuclei hit the detector in the same time. They do not belong to the same cascade, their coincidence is accidental. They are called *random coincidences*. Their importance can be decreased by decreasing the overall counting rate. In environmental samples, where the counting rate is not very high, their effect is not substantial.

The true coincidence effect has been studied in a model system using a well-type HPGe (high purity germanium) detector (energy resolution 1.95 keV FWHM at 1333 keV), and a ^{60}Co source. The ^{60}Co has been chosen, because it emits two gamma-rays in a cascade with energies 1173 keV and 1333 keV respectively.

The source was positioned first outside, at 15 cm distance from the detector surface and later inside the well. The measuring periods have been chosen such a way that the resulting spectra have approximately the same counts/channel. The measurements show, that in the latter case the yield of the coincidence peak is much larger. This corresponds to the expectations outlined above.

Theoretical investigations have also been made using Monte-Carlo calculations. We used the Geant 3.15 Monte-Carlo code (Cern). The geometry of the well-detector has been built in the program. Several millions of gamma-ray cascades (corresponding to the ^{60}Co gamma-energies) have been generated. It is known that there is a small (approximately 12%) anisotropy in the angular correlation function of the emitted gamma-rays. This was neglected in the calculations, we assumed fully random directions for each gamma-ray in the cascade. The simulated spectra will be shown in the poster and they will be compared to the measured ones.

The Monte-Carlo results describe well the experimentally observed effect. Because all parameteres involved can be controlled, the overall efficiencies can also be determined easily. These calculations represent an efficient tool in the analysis of the spectra taken with well-type detectors to determine the correct efficiencies.

Monte-Carlo calculations might be tedious if many gamma-lines are present, therefore a simple method is needed to determine the importance of the coincidence effect. In the poster we show a simple method for that.

An ^{152}Eu source has been measured in 3 different distances outside the detector: 5 mm, 50 mm and 100 mm . The ^{152}Eu source has many gamma-lines, and some of them are emitted in cascade. Therefore the spectrum is quite complex. The peak areas of the gamma-lines have been determined from the experimental spectrum and are denoted by N(x,E). Here E refers to the gamma-energy, and x to the source-detector distance.

It is clear that the importance of the coincidence peaks should decrease with increasing the source-detector distance. Therefore we normalised the peak-areas using the N(100,E) values:

$$Q(x,E) = N(x,E) / N(100,E)$$

The results show that for x=50 mm the normalised Q values do not scatter very much, indicating that the coincidence effect is not very important even at 50 mm.

On the contrary, for x=5 mm the scatter of the points is much larger, showing that some yields are (statistically) missing from the individual total-energy peaks due to coincidence effects. This enables the experimentator to determine whether a coincidence correction is necessary for a given peak or not. With other words the peaks, where no coincidence corrections are necessary (they can be easily analysed) can be selected.