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**TECHNICAL MATERIAL**

# Monte Carlo Simulation of a HP-Ge Pulse Height Spectrum over the Entire Energy Range

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The TU Dresden Monte Carlo code AMOS is used to simulate a low level HP-Ge detector stationed at the Felsenkeller laboratory from the VKTA Rossendorf e.V.. The detector is a p-type 92% HP-Ge detector manufactured by Canberra Industries, Inc. and its geometry is highly determined. Therefore it allows precise digital remodelling, and Monte Carlo calculations are applicable. The simulation program AMOS carries out coupled photon electron transport especially in the low energy region. ENSDF data and beta spectra calculations were implemented to follow quasi-timedependent nuclide decays. In all, this enables a differentiated calculation of pulse height spectra and comparison over the entire energy range.

***KEYWORDS: HP-Ge detector, pulse height spectrum, Monte Carlo simulation, coupled photon electron transport, beta spectra***

## I. Introduction

For low level gamma spectrometry it is essential that not only the shielding from the outside radiation is sufficient but also that the self activity of detector components is as low as possible. Still, as low activity materials are very expensive or not accessible, it is useful to know the extent of the background due to the device's internal activity. This would enable one to estimate the gain when the question arises whether to invest more effort into the usage of lower activity materials.

The required information is only accessible by simulation. Monte Carlo radiation transport programs are a common tool to analyse or calibrate gamma spectrometry systems.[1,2] For this, the full energy peak areas are usually evaluated or compared. But the analysis of the entire spectrum is much more efficient as the scattered contributions to the spectrum are very sensitive to small changes in geometry or source distribution.

This requires precise 3D Monte Carlo Simulations, taking into account not only the gamma emissions of the source but all emitted particles contributing to the detector response. Therefore, this work includes X-Ray and beta particle emissions to estimate the entire pulse height spectrum down to the low energy region of few 10 keV.

A first step is presented in this paper. The detector response for standard volume sources is estimated and compared. Furthermore, the effect of the dead layer thickness on the spectrum shape is examined.

## II. Experimental Setup

The low level laboratory Felsenkeller from the VKTA Dresden Rossendorf e.V. is placed in former brewery caves 47 m beneath solid rock. The rock reduces the cosmic ray intensity by a factor of 45, which leaves about 2% of the muon flux to cause the main background. A cabin shields the radiation from the activity of the stone material. It houses several Germanium detectors for low level measurements. The latest is the here discussed Canberra detector which is additionally embedded in a 25 cm copper housing which is nitrogen flushed.

### 1. Detector Description

The detector is a p-type 92% HP-Ge detector with an active volume of 362 $cm^3$, the external diameter is 78.2 mm and its length 75.2 mm. The crystal dead layer is given as less than 0.5 mm. The distance between end cap and detector crystal is 4 mm, the end cap is 1.6 mm aluminium.[3-5] Very good collaboration with the manufacturer gave the authors precise information about the entire geometry, which enabled a 3D modelling to enter into the Monte Carlo code.

### 2. Standard Sources

Two standard volume sources were in a tin geometry of 70 mm diameter and 21.5 mm height. They were placed in the centre on top of the detector. Probe VS59 is of KCl with an activity of 1,406 Bq $^{40}$K. Probe VS02 is a mixed nuclide reference source containing a plastics matrix with mainly $^{60}$Co, $^{137}$Cs and $^{241}$Am of different activities.

### 3. Computational Modelling

AMOS provides a tool to easily model and visualize 3D-geometries made of primitives. **Figure 1** shows a vertical cut through the detector geometry. Different colours denote the different materials of the detection system: blue is

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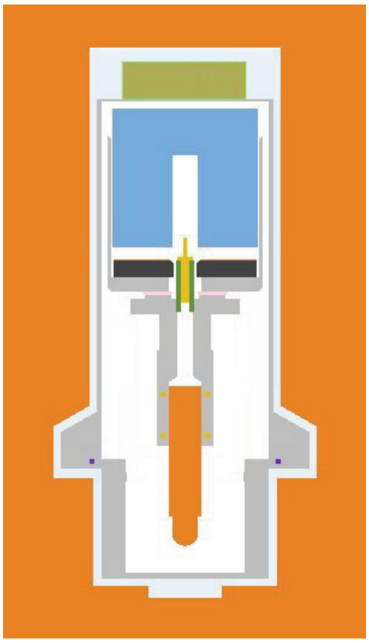

**Fig. 1** AMOS realisation of the geometric setup

germanium crystal, orange is the copper shielding, and light gray is the aluminium end cap on top of which the probe (green) is seated.

## III. Monte Carlo Simulation

The radiation transport program AMOS has been developed at the TU Dresden since 1989.[6] It is a Monte Carlo code especially designed for low energy photon and electron transport up to a few MeV. Electron transport is carried out by single scattering algorithms in the low energy region below about 900 keV. The coupling of photon and electron transport is provided by photoelectric absorption, incoherent scattering and pair production, atomic relaxations, and Bremsstrahlung emission.

Electrons are simulated down to 10 keV, photons down to 1 keV. By adding the thus, inside the detection volume deposited energy, the pulse height spectrum can be estimated. But to be able to reproduce sum effects and continuous shares, the emission cascades of the nuclides have to be followed in detail including X-Ray and beta emissions.

The ENSDF[7,8] data were broken down to give the probabilities of all decay paths and the corresponding emissions, gamma and beta, and atomic excitations induced by electron capture and internal conversion. The relaxation routine of AMOS handles the atomic excitations to provide the X-Ray and electron emissions. The beta spectra are separately calculated on the basis of the tables of Behrens and Jänecke.[9] In special cases as $^{137}$Cs, additional literature is consulted.[10]

Similar to Sima and Arnold,[11] the time dependency in one decay path is regarded by discriminating between simultaneous and non-simultaneous particle emissions. This simultaneity depends on the detector time resolution $T$. If an intermediate stationary state has a decay constant $\lambda$, the probability of these two events to be recognised as one is

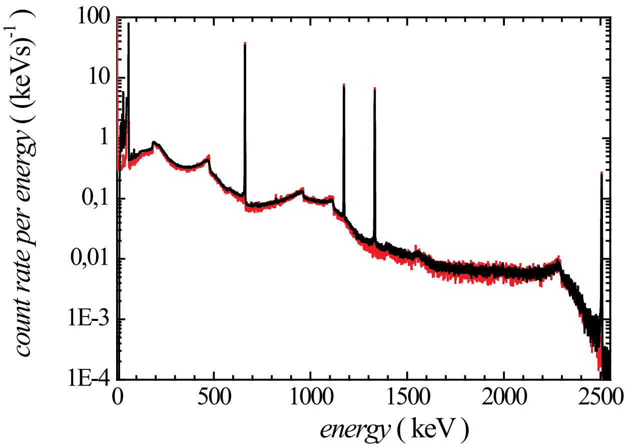


**Fig. 2** Measured (black) and calculated (red) spectra of the VS02 mix probe

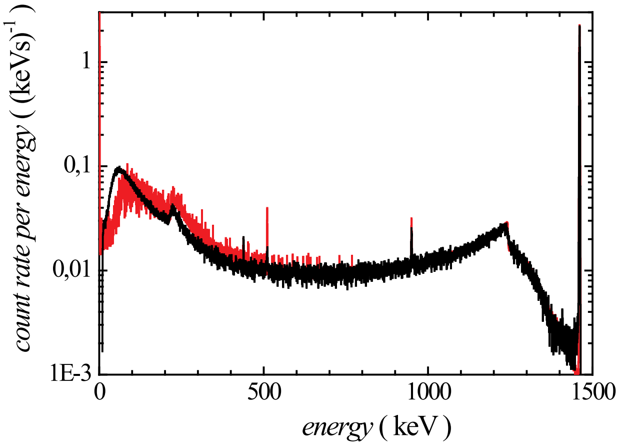


**Fig. 3** Measured (black) and calculated (red) spectra of the VS59 $^{40}$K probe

$$P = 1 - e^{-\lambda T}$$

Further sum events in gamma spectrometry occur at measuring sources of such activity, that the medium time between the decays is in the range of or less than $T$. But as in the low level laboratory the measured probes are of low activity, this simultaneity is irrelevant.

Charge transport in the semiconductor cannot be included. The energy resolution of the detector is taken into account via Gaussian broadening of the spectrum entries within the simulation. Therefore, the peaks are pure Gaussian distributed, but the experimental asymmetry cannot be reproduced.

## IV. Results

**Figures 2** and **3** show the comparison between measurement and simulation according to the described parameters. All peak areas of the full energy peaks show a good agreement with a slight overestimation by the calculation (see **Table 1**), and the overall shape is consistent in the high energy range.

In the low energy region, there are major differences for both sources. For the VS02 probe, there is an underestimation of the low energy emissions of $^{241}$Am and of the X-Ray

**Table 1** Full energy peak analysis, high energy peaks

| nuclide | energy (keV) | deviation of calculation from measurement (%) |
|---|---|---|
| $^{137}$Cs | 662 | + 6 |
| $^{60}$Co | 1173 | + 8 |
| | 1332 | + 8 |
| | 2506 (sum peak) | + 8 |
| $^{40}$K | 1461 | + 5 |

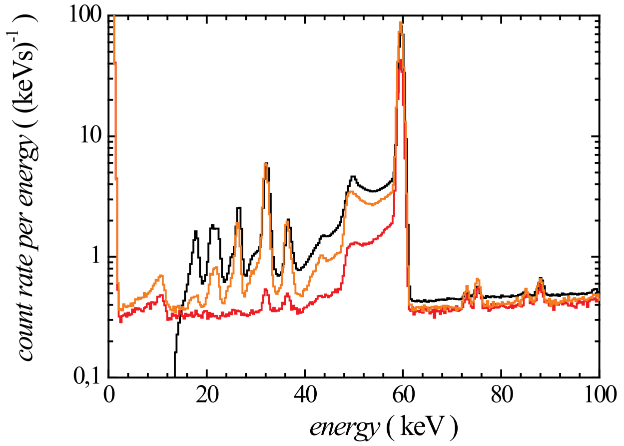


**Fig. 4** VS02 probe measured (black), calculated with 500 µm dead layer (red) and 50 µm dead layer (orange)

emissions of $^{137}$Ba. This large effect can only be caused by absorption processes in the detector dead layer. Therefore, the insensitive region was reduced to 50 µm thickness on the front and in the hole. The result is shown in **Fig. 4**, where the full energy peaks are grown to agreement. Two problems remain. On the one hand, the dead layer should not be further reduced, because this would lead to a further overestimation of the now fitting peaks. On the other hand, the very low energy peaks are clearly still underestimated, which speaks for a reduction of some absorbing layer. Overall, it seems that contributions of scattered photons are underestimated compared to full energy events.

A closer look at the VS59 low energy region in **Fig. 5** reveals different aberrations. Below 100 keV, the dead layer reduction to 50 µm also yields a satisfying improvement. Further, this change has no significant effect on the shape for higher energies.

Still, below 500 keV, the calculation overestimates the spectrum clearly. Down to the Compton backscattering peak at 220 keV, the scattering of the 1,460 keV gamma emission dominates the spectrum. Below, the counts originate from the ß emissions and the secondary bremsstrahlung. For both, there seems to be a slight overestimation between 150 keV and 400 keV.

## V. Conclusion

Overall, the simulation of pulse height spectra is possible and gives good results. The shape of the measured spectra

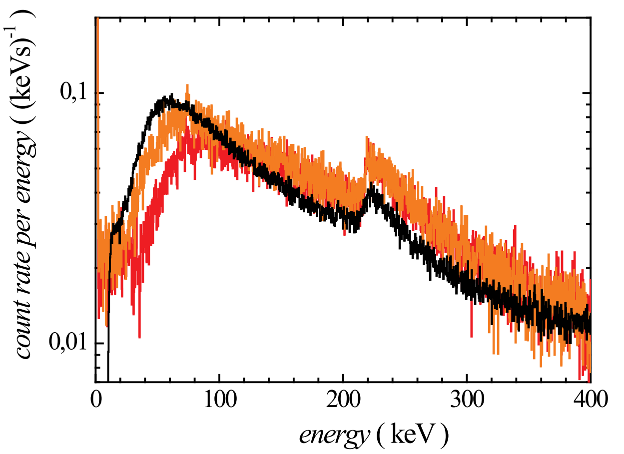


**Fig. 5** VS59 probe measured (black), calculated with 500 µm dead layer (red) and 50 µm dead layer (orange)

can be reproduced nicely, and analysis of the low energy region provides information about uncertainties in the geometry of the detection system. For example, the dead layer thickness could be estimated to be less than 100 µm.

Still, the reproduction of the measured data by the simulation is not entirely satisfying. Improvement could bring the displacement of the source from the centre position in further simulations, which could cause missing or additional scattering contributions. Such a displacement will also reduce the full energy efficiency.


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