TA3 Dosimetry and Instrumentation

RESULTS OF MONTE CARLO CALIBRATIONS OF A LOW ENERGY GERMANIUM DETECTOR

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1. Introduction

Normally, measurements of the peak efficiency of a gamma-ray detector are performed with calibrated samples which are prepared to match the measured ones in all important characteristics, like its volume, chemical composition and density [1, 2, 3]. These samples, so called standards, have to contain well known activities of the questionable radionuclides in the samples under investigation. The activities of the radionuclides in the measured samples are obtained from the known activities of the standards and the ratios of the count rates in the corresponding full energy peaks in the spectrum of the standard and the sample. The preparation of the standard is hard going and time consuming, especially if the laboratory has to measure different kinds of samples. Another way to determine the peak efficiency is to calculate it with special Monte Carlo programs [4].

2. Method

For our measurements we used a Low Energy Germanium Detector (LEGe, Canberra). This detector is located in a special shielded room at the Low Level Counting laboratory [5] which is part of the Federal Office of Metrology and Surveying. Due to the cylindrical symmetry of the detector and the samples we were able to use the specially designed simulation program “Pencyl”, which was taken from the “PENELOPE 2003” source code. PENELOPE is a FORTRAN 77 code system which performs Monte Carlo simulation of coupled electron-photon transport in arbitrary materials. The scattering model allows the simulation of electron/positron and photon transport in the energy range from 100 eV to 1 GeV [6].

The design of the LEGe offers major advantages over conventional planar or coaxial detectors, especially at low and moderate energies [7]. This detector has an active area of 2800 mm^2 and a thickness of 20 mm. The window is a carbon-epoxy material with a thickness of 0,5 mm. The detector has a lead shield with a 1 mm tin and 1,6 mm copper graded liner to prevent interference by lead x-rays. The interior is coated with clear polyurethane to prevent oxidation and facilitate cleaning.

First of all we had to set the parameters of the certain materials in the simulation in a way to get the same results like in the measurements. This was done by comparison of measurements and simulations of a Cs-137 point source. The measurements were analyzed with the gamma spectrometry software “Genie 2000”. The same settings were used to simulate point, surface and volume sources with different radionuclides. For the calculations of the peak efficiency we used the energies of 46,5 keV and 661,7 keV corresponding to the gamma lines of the environmentally important nuclides Pb-210 and Cs-137 respectively.

Simulation times were 170000 and 250000 seconds. With these simulation times we get standard deviations for Pb-210 of one-tenth of a percent. The number of different materials, which can be used in the simulations, is set to ten. In consideration of the fact that we needed more than ten materials for our simulations we increased the respective parameter in the source code. The sample tin is made of polystyrene and is our most used bin for soil samples. Following elements were used for the chemical composition of the sample: silicon (42 % proportional mass), oxygen (48 %) and carbon (10 %). We simulated densities from 0,2 to 2,6 g/cm^3 and filling heights from 2 to 24 mm.

3.Results

Generally we have a good correlation between simulations and measurements for Cs-137 due to the fact that simulation parameters were set by comparison with a Cs-137 source and because Cs-137 has only one gamma line and therefore no summation effects [8, 9] in consequence of the decay occur (table 1). The accuracy of standards is around ±2 %. Moreover there are uncertainties from analysing the measurement results in a range of 1 - 1,5 %. Due to these facts deviations between measurements and simulations around 5 % seem quite acceptable. The background in the laboratory is so low that we don’t take it into account for the counting. For the Pb-210 standards the measurement values are too low especially for high activities because of random summation effects (table 2).

Table 1: Deviations of different Cs-137 standards

				Probability		
Number	Eγ [keV]	Activity [Bq]	FWHM [eV]	Measurement [1/(eV*particle)]	Simulation [1/(eV*particle)]	Deviation Simulation-Measurement [%]
25	662	32000	1660	1,04E-06	1,04E-06	0
26	662	438	1650	8,92E-06	9,21E-06	+3
27	662	414	1640	7,50E-06	7,54E-06	+1
28	662	32000	1810	1,75E-05	1,69E-05	-3
29	662	458900	1790	9,82E-07	1,03E-06	+5
30	662	4730	1630	1,43E-05	1,37E-05	-4
31	662	381470	1670	1,04E-06	1,02E-06	-2
32	662	44400	1630	1,07E-06	1,03E-06	-4

Table 2: Deviations of different Pb-210 standards

				Probability		
Number	Eγ [keV]	Activity [Bq]	FWHM [eV]	Measurement [1/(eV*particle)]	Simulation [1/(eV*particle)]	Deviation Simulation-Measurement [%]
40	47	78900	510	4,52E-04	5,08E-04	+13
41	47	40400	490	4,82E-04	5,08E-04	+5
42	47	202000	490	3,47E-05	4,40E-05	+27
43	47	1517	490	2,25E-04	2,33E-04	+4
44	47	1080	490	2,67E-04	2,65E-04	-1
45	47	721	490	3,07E-04	3,05E-04	-1
46	47	547	490	2,40E-04	2,58E-04	+7
47	47	386	490	2,33E-04	2,30E-04	-1
48	47	232	490	2,73E-04	2,93E-04	+7
49	47	77	490	3,70E-04	3,89E-04	+5
50	47	155	490	3,30E-04	3,55E-04	+8
56	47	677	490	2,35E-04	2,56E-04	+9
57	47	1000	490	1,92E-04	2,16E-04	+13
58	47	1427	490	1,52E-04	1,69E-04	+11
59	47	336	490	2,87E-04	3,32E-04	+16

After these measurements compared with the simulations we tried to find the coefficients of a special equation which describes the peak efficiency against the sample density and the filling height of the sample. This formula was set up for this detector with many calibration measurements of different radionuclides in a previous work. [3].

The equation is:

$$\varepsilon_p(D,H) = a \cdot e^{-(b \cdot H)}$$

H…filling height [mm]

$$a = c_1 \cdot e^{-(c_2 \cdot D + c_3 \cdot D^2)}$$

D…density [g/cm^3]

$$b = d_1 \cdot e^{-(d_2 \cdot D)}$$

From the simulations we obtained 156 values for the efficiency (13 densities each with 12 filling heights) and they were fitted by the exponential function above. Then the parameters of the function were determined with a least square fit in the software “SigmaPlot” (table 3).

Table 3: Parameter values for the efficiency function

Parameter	Pb-210	Cs-137
c_1	0,2161566	0,0183757
c_2	0,1125888	0,0136404
c_3	-0,029767	-0,003057
d_1	0,0225253	0,0212065
d_2	-0,356574	-0,150274

Results for the least square fits are shown in figures 1 and 2.

The biggest deviations between the least square fit and the simulations appear at extremal values of densities and filling heights. Typical soil samples in our laboratory have densities between 1 and 2 g/cm^3 and in this range the deviations lie within ±5 %. More problems can occur when there is not much material of a sample and so we get small filling heights.

With these parameters for our efficiency function we are able to calculate the peak efficiencies for Cs-137 and Pb-210 at arbitrary densities and filling heights.

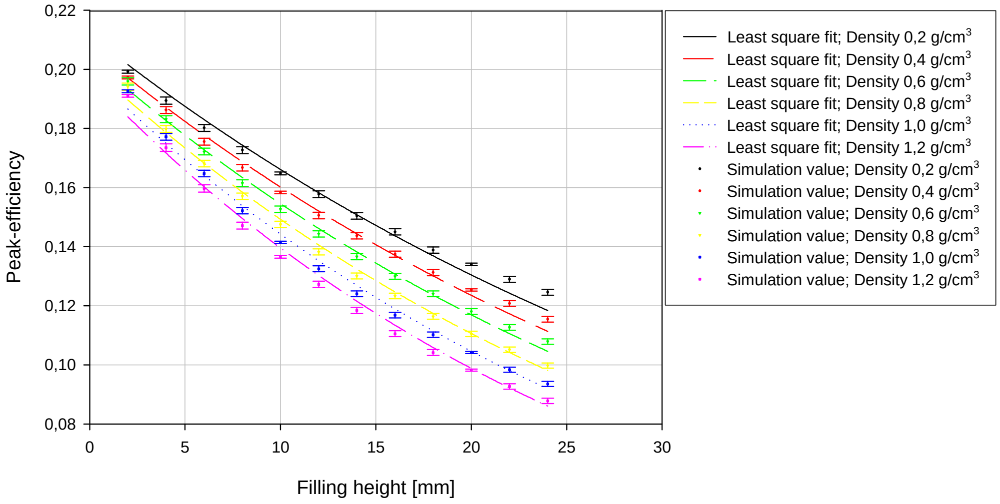

Figure 1: Peak-efficiency-curves of Pb-210 for densities from 0,2-1,2 g/cm^3 (error bars mark the standard deviation of the simulation values)

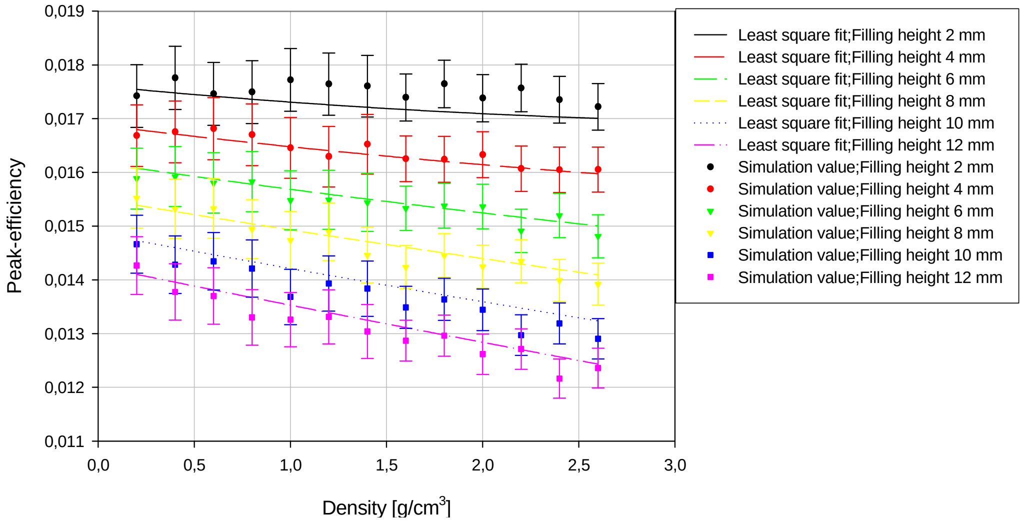

Figure 2: Peak-efficiency-curves of Cs-137 for filling heights from 2-12 mm (error bars mark the standard deviation of the simulation values)

4.Conclusion and Prospects

In principle the program “Pencyl” from the source code “PENELOPE 2003” can be used for peak efficiency calibration of a cylinder symmetric detector however exact data for the geometries and the materials is needed. The interpretation of the simulation results is not clear but we found a way to convert the data into values which can be compared to our measurement results [10]. It is possible to find other simulation parameters which perform the same or better results. Further improvements can be expected by longer simulation times and more simulations in the questionable ranges of densities and filling heights.

5.Acknowledgements

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6.References

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