Gamma-ray spectrometry: Development, testing and validation of computer models by using the simulation package EGSnrc

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Introduction

The most common laboratory technique used for analysing samples containing gamma-ray emitting radionuclides in any radiometric laboratory is called gamma-ray spectrometry. The key instruments are the High Purity Germanium (HPGe) detectors because of their good resolution enabling the possibility to distinguish different radionuclides in the sample. Before applying gamma-ray spectrometry to various projects it is important to calibrate the Full Energy Peak (FEP) efficiency of the HPGe detector used. This allows the operator to evaluate the activity of unknown samples. The efficiency transfer method is the most accurate method to determine FEP efficiency. Besides experimental reference source measurements, computer simulations are required to employ the efficiency transfer method [1]-[3].

This thesis aims to optimise and validate the computer models of one coaxial HPGe detector located in the above ground (RADMET) lab, the Ge-T10 detector and one HPGe well-detector in the underground research facility HADES, the Ge14 detector. The validated model of the Ge14 detector is then used to determine the distribution of radiocaesium in the organs of large wild mammals (wolves and bears) in collaboration with the Ruder Boskovic institute in Zagreb, Croatia (ROWAN application project).

Method

To optimise and validate computer models of both detectors, calibration sources are measured to acquire experimental data of the efficiency at different energies. The same radionuclides and FEPs are then simulated using the computer model and the simulation code EGSnrc, whereafter both experimental and simulated efficiencies are compared in Glysis. To minimise the difference between the FEP efficiency obtained using the computer model and experimental data, the model is adjusted by varying four parameters: crystal position, thickness of the top deadlayer, thickness of the side deadlayer and thickness of the endcap. The optimised model is then validated at three different source-detector distances: on endcap, 4 cm and at 10 cm. After that, the computer model is validated for four volume sources [3].

Result Ge-T10

The coaxial Ge-T10 detector is visualised in figure 1. Figure 2 represents the optimised computer model of the Ge-T10 that has been obtained. The original model of the detector was based on the manufacturer's data. For the optimization of the model, the following changes were made: the crystal has been moved down by 0.15 cm, side deadlayer has been increased with 0.05 cm and the thickness of the endcap was decreased by 0.01 cm.
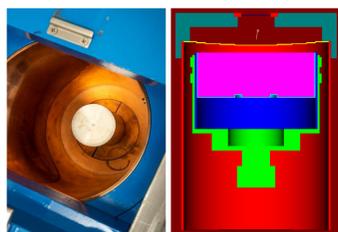

Figure 1: View inside the coaxial Ge-T10 detector
Figure 2 : Computer model of the Ge-T10 detector

Figure 3 shows that the relative difference between experimental data and the optimised computer model is better than 5% with a standard deviation of 1.493724% for 10 cm source-detector distance and 8% with a standard deviation of 3.785185% for sources on the endcap.

By comparing figure 3 and figure 4, it can be seen that the spread on relative difference between experimental data and simulated FEPs efficiencies is higher at lower source-detector distances. Besides a general increase in spread, it is shown that Eu-152 differs more from the mean average compared to other radionuclides.
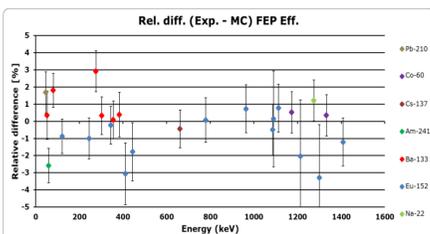

Figure 3: Relative efficiency difference between experimental and computer model for 10 cm source-detector distance
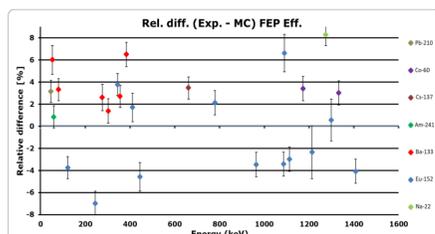

Figure 4: Relative efficiency difference between experimental and computer model for 0 cm source-detector distance (on endcap)

Result Ge14

The HPGe well-detector Ge14, in the underground research facility HADES, is visualised in figure 5. Figure 6 represents the optimised computer model of the Ge14 that has been obtained. Compared to the original model, a few changes were made: the crystal has been moved down by 0.05 cm, the side deadlayer thickness has been increased by 0.12 cm and the thickness of the well-deadlayer has been increased by 0.01 cm
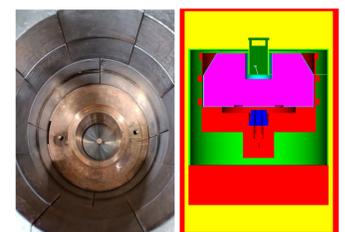

Figure 5: View inside the Ge14 HGPe well-detector
Figure 6: Computer model of the Ge14 detector

Figure 7 shows that the relative difference between experimental data and the optimised computer model has been limited to an average of 2% with a standard deviation of 1.045895% for the CMI5 volume source. The calibration point outlier at 2734 keV is the sum peak for Y-88.

Concerning the distribution of Cs-137 in the organs of wild mammals (two wolves and one bear), it was found that very low activity levels of Cs-137 were present in all organs that were measured (spleen, heart, kidney, lungs, muscle, liver). Additionally Pb-210 were detected and quantified in the kidney-samples but was surprisingly not detected in the liver (and other) samples.
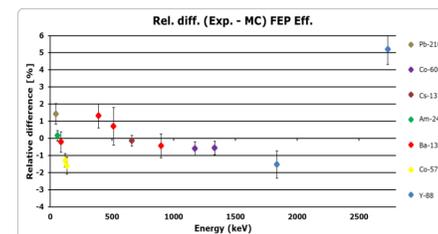

Figure 7: Relative efficiency difference between experimental data and computer model for Ge14 with the CMI5 volume source

Conclusion

Both the Ge-T10 and Ge14 computer models are now suitable for applying in various accredited measurement projects. By comparing figure 3 and 4 it can be concluded that the optimal starting point for an efficiency calibration is at a higher source-detector distance in order to minimise the impact of phenomena such as bad alignment, incorrect coincidence correction, dead-time, etc. These factors are more prominent at lower source-detector distances. The remarkable deviation of Eu-152, at lower source-detector distance (on endcap), in relative efficiency difference to the mean average compared with other radionuclides is due to the fact that coincidence summing is more prominent for this radionuclide. Thus, it is suspected that the decay scheme of Eu-152 or the summing code used in the model may have imperfections. As explained is the impact of this factor more dominant at lower source distant and therefore more visible in figure 4 than in figure 3.

Finally, the validation of the model through the use of volume sources for the Ge-T10 confirmed the validity of the optimised computer model. The validation for the Ge14 with the CMI4 volume sources resulted in a small change to the optimised model in order to reach more conformity for both models (crystal moved down by 0,05 cm).

The measurements of freeze-dried individual organs from two wolves and one bear show that it is possible to obtain the necessary information regarding pathways of anthropogenic Cs-137 in large wild mammals. This is contrary to the expectations of the biologists. It can be concluded that the low levels of Cs-137 present in different organs, originate from the Chernobyl accident in 1986.

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