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# Study on Monte-Carlo calculation of peak efficiencies of the superpure Hp Ge detector (Gmx) in environmental gamma spectrometry with using MCNP4C2

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**Abstract.** Monte-Carlo modeling allows calculating the detector efficiency in gamma spectrometry of environmental samples with taking into consideration both the photon self-absorption in sample itself and absorption in all other materials between the sample and the detector's active part. In this paper, the peak efficiencies of the Hp Ge detector (GMX) for gammas at various energies (emitted isotropically from the standard disk source and volumetric source - environmental sample, in which the different radionuclides are present) are calculated based on MCNP4C2-Monte-Carlo multi-purpose radiation transport code system developed in the Los-Alamos laboratory, U.S.A. The obtained calculating results are compared with the experimentally measured data and a good agreement between them is shown out.

## 1. Introduction

Radioactive gamma sources which are often encountered in practice are in different forms from tiny specks of contaminants to sources spread over a surface as in a swipe test, or a volume of source as in a sample contained in a vial and etc. In reactor environments these gamma sources are found not just in the reactor core, but also elsewhere, like in the spent fuel, working area of the operators and so on. In all these cases gamma counting is needed for control and monitoring, and for such a purpose one needs to know the detector efficiency correctly [1,2].

The detector efficiency is often measured experimentally with using a standard source. However, for the decrease of experimental costs in the analysis of samples (especially, environmental ones) one can specify the detector efficiency based on theoretical calculations.

Nowadays, the numerical calculation of efficiency of various types of gamma detectors has been a field of research. The Monte-Carlo modeling allows to calculate the counting efficiency of the detector after correcting for the loss of photons in the sample itself and all other materials between the sample and the detector's active part. Concerning the applications of environmental gamma spectrometry, in this paper, we consider the modeling of peak efficiencies of the hyperpure HP Ge detector (GMX) for gamma rays at various energies (emitted from the standard disk source and volumetric source-environmental sample containing the mixture of the different radionuclides) based on MCNP4C2-

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Monte-Carlo multi-purpose radiation transport code system developed in the Los-Alamos laboratory, U.S.A [3], and at the same time the comparison of the obtained calculating results and experimentally measured data is made.

## 2. Monte-Carlo modeling with MCNP4C2

When the particles hit the detector surface and enter it, they will interact with atoms of the detector materials and be registered into the channels corresponding to total energy deposited in detector by each particle. For modeling the efficiencies of the hyperpure HP Ge detector (GMX) based on MCNP4C2 we need to provide an input file containing the information involved to the cross-section library and the description of the physical geometry of the source, detector, and other materials as well as of the gamma energy, energy bins (called channels in an measured spectrum) in which the events are tallied for the energy lost in the detector volume, and the number of photons to be emitted.

MCNP4C2 tracks each photon as it travels through space and interacts with atoms in the various materials to be present there. The electrons and secondary photons created in these interactions are also tracked until all of their energy has been dissipated in the various materials or escaped out of the physical space included in the model.

For the interaction in the detector volume, MCNP4C2 produces a tally of the number of events in each energy bin. It means that it provides an energy-loss spectrum. As a measurement system does not directly measure the energy deposited in the detector, the calculated spectrum will differ to some extent from a measured spectrum even if the modeling is done without any approximations or errors . For a Ge semiconductor detector, which has a very linear response (i.e the amplitude of the signal from the detector is proportional to the energy deposited) and very good energy resolution (i.e any observed peaks are very narrow) these differences are often small.

The geometrical description of the source-detector system for MCNP4C2 includes the following parts:

- The sensitive volume of the detector
- The mounting materials around detector
- The entrance window or cover over the front of the detector
- The shielding to decrease the response of photons from the other locations from the desired source
- The air between the source and detector

The peak efficiency is simply the ratio of the peak counts to the number of photons emitted by the source and it will depend on the photon energy and the source-detector-geometry

## 3. Application MCNP4C2 for calculation of peak efficiencies of the hyperpure HP Ge detector (GMX)

The hyperpure HP Ge detector (GMX) used by us here in simulation and experimental measurement is the n-type one with the relative efficiency of 41.4 % and a Be window. It’s material structure and main parameters is given in [4]. The detector has the coaxial configuration as shown on fig. 1.

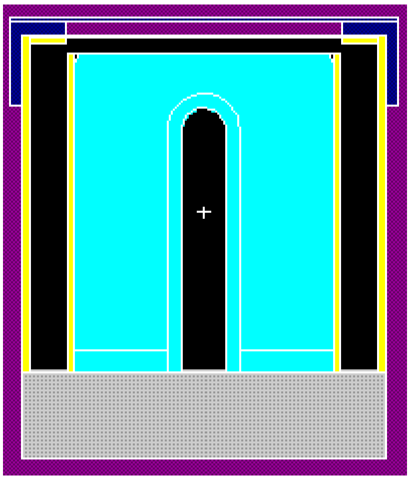

Fig.1. The confguration of the HP Ge (GMX) detector.

Relating to the physical dimensions of the above detector the thickness of the dead layer lying at the back of the detector crystal is still unknown. Therefore, it is necessary to firstly specify it. To determine the thickness of this dead layer, we modeled the peak eficiencies of the detector for gamma rays at 1.332 MeV, emitted isotropically from the point source Co-60 to be located in open geometry in the front of the detector on it's axis at the source-detector distance of 25 cm with using the various assumed values of the dead layer thickness and compared the obtained calculating results with the efficiency supplied by the manufacturer. Best agreement was obtained with the dead layer thickness of 5 mm as indicated below in table 1.The difference between the calculated efficiency and the efficiency supplied by manufacturer is then 1.1 . $10^{-3}$ .

Table 1. The calculated efficiencies with various thicknesses of the dead layer, $\varepsilon_{cal}$ , and the efficiency supplied, $\varepsilon_{sup}$, by the manufacturer.

| Dead layer thickness (cm) | Eficiency calculated by MCNP4C2, $\varepsilon_{cal}$ | Eficiency supplied by manufacturer , $\varepsilon_{\sup}$ | Ratio $\varepsilon_{sup} / \varepsilon_{cal}$ |
|---|---|---|---|
| 0.1 | $(5.1688 \pm 0.0574).10^{-4}$ | | 0.9704 |
| 0.2 | $(5.1287 \pm 0.0570).10^{-4}$ | | 0.9780 |
| 0.3 | $(5.0900 \pm 0.0570).10^{-4}$ | | 0.9855 |
| 0.323 | $(5.0798 \pm 0.0569).10^{-4}$ | $5.0160.10^{-4}$ | 0.9874 |
| 0.35 | $(5.0677 \pm 0.0568).10^{-4}$ | | 0.9898 |
| 0.4 | $(5.0531 \pm 0.0566).10^{-4}$ | | 0.9927 |
| 0.45 | $(5.0302 \pm 0.0563).10^{-4}$ | | 0.9972 |
| 0.5 | $(5.0105 \pm 0.0566).10^{-4}$ | | 1.0011 |

After specifying the thickness of the dead layer lying at the back of the detector crystal we calculated the peak efficiencies of the detector for gamma rays at 46.52 kev, 63.29 kev, 74.81 kev, 92.8 kev, 241.92 kev, 351.99 kev, 609.32 kev, 911.07 kev, 1120.28 kev, 1764.51 kev, emitted isotropically from the cylindrical volumetric source – soil sample with a density of 1.25 g/ $cm^3$ in which the Pb-210, Th-234, Pb-214, Bi-214 and Ac-228 radionuclides are present. As for the chemical composition of this soil it is, by weight, H 2.2%, O 57.5%, Al 8.5%, Si 26.2%, Fe 5.6%.

The above volumetric source is 2 cm thick, contained in the box made of PVC having the radius of 5.15 cm and 0.2 cm thick stand. It is placed in front of the detector, coaxial with the crystal at the source-detector distance of 0.2 cm.

The calculated efficiencies are shown in table 2 together with the experimentally measured efficiencies. It should be noted here that the difference between the calculated and experimental efficiencies are within 0.51% - 7.93%, except for gamma rays at 46.52 kev this difference is of 16.64 %. It means that the calculated and experimentally measured efficiencies are, in general, in a good agreement.

The large difference between calculated and experimental efficiencies for gamma rays of 46.52 kev may be caused both by the detector's size and structure and by the fact that the MCNP treatment of low energy photons where the distribution of secondary electrons in germanium crystal and the field distortions near the edges of the detector are not properly done.

The modeling of peak efficiencies of the detector has also been considered by us for gamma rays at 88.04 kev, 122.07 kev, 136.43 kev, 165.85 kev,320.07 kev, 514.01 kev, 661.62 kev, 834.81 kev, 898.02 kev, 1173.23 kev,1332.51 kev, 1836.01 kev, emitted isotropically from the standard disk source containing the the mixture of the Cd-109, Co-57, Ce-139, Cr-51, Sr-85, Cs-137, Mn-54, Y-88, Co-60 radionuclides.This disk source is laid on the 0.15 mm thick plexyglass plate having the radius of 3 cm. The plexyglass plate is located in front of the detector on it's axis at the source-detector distance of 2.95 cm.

The results of modeling calculations are shown in table 3 together with the experimentally measured data. From this table we note that the calculated and experimental efficiencies are in a good agreement within 0.46% - 5.57% of errors.

Table 2. The calculated and experimentally measured efficiencies for gamma rays at various energies, emitted isotropically from the cylindrical volumetric source containing the mixture of different radionuclides

| $E_\gamma$ (kev) | Eficiency calculated byMCNP4C2 | Efficiency mesured experimentally | Percentage difference |
|---|---|---|---|
| 46.52 | $(4.36 \pm 0.01).10^{-2}$ | $(5.23 \pm 0.27).10^{-2}$ | 16.64 |
| 63.29 | $(6.15 \pm 0.52).10^{-2}$ | $(6.68 \pm 0.34).10^{-2}$ | 7.93 |
| 74.81 | $(6.33 \pm 0.05).10^{-2}$ | $(6.52 \pm 0.33).10^{-2}$ | 2.9 |
| 92.8 | $(5.85 \pm 0.05).10^{-2}$ | $(5.88 \pm 0.29).10^{-2}$ | 0.51 |
| 241.92 | $(3.78 \pm 0.06).10^{-2}$ | $(3.73 \pm 0.19).10^{-2}$ | 1.34 |
| 351.99 | $(2.88 \pm 0.28).10^{-2}$ | $(2.86 \pm 0.14).10^{-2}$ | 0.7 |
| 609.32 | $(1.71 \pm 0.04).10^{-2}$ | $(1.67 \pm 0.08).10^{-2}$ | 2.4 |
| 911.07 | $(1.25 \pm 0.04).10^{-2}$ | $(1.22 \pm 0.06).10^{-2}$ | 2.46 |
| 1120.28 | $(1.11 \pm 0.03).10^{-2}$ | $(1.06 \pm 0.06).10^{-2}$ | 3.8 |
| 1764.51 | $(7.89 \pm 0.24)10^{-3}$ | $(7.96 \pm 0.39).10^{-3}$ | 0.88 |

Table 3. The calculated and experimentally measured efficiencies for gamma rays at various energies, emitted isotropically from the disk source containing the mixture of different radionuclides.

| $E_\gamma$ (kev) | Eficiency calculated by MCNP4C2 | Efficiency measured experimentally | Percentage difference |
|---|---|---|---|
| 88.04 | $(6.94 \pm 0.06).10^{-2}$ | $(6.85 \pm 0.35).10^{-2}$ | 1.3 |
| 122.07 | $(6.21 \pm 0.05).10^{-2}$ | $(6.05 \pm 0.30.10^{-2}$ | 2.65 |
| 136.43 | $(5.87 \pm 0.09).10^{-2}$ | $(6.07 \pm 0.33).10^{-2}$ | 3.29 |
| 165.85 | $(5.15 \pm 0.07).10^{-2}$ | $(4.89 \pm 0.24).10^{-2}$ | 5.32 |
| 320.07 | $(2.94 \pm 0.05).10^{-2}$ | $(2.91 \pm 0.15).10^{-2}$ | 1.03 |
| 514.01 | $(1.89 \pm 0.02).10^{-2}$ | $(1.95 \pm 0.10).10^{-2}$ | 3 |
| 661.62 | $(1.54 \pm 0.03).10^{-2}$ | $(1.56 \pm 0.08).10^{-2}$ | 1.28 |
| 834.81 | $(1.25 \pm 0.03).10^{-2}$ | $(1.26 \pm 0.06).10^{-2}$ | 0.79 |
| 898.02 | $(1.18 \pm 0.02).10^{-2}$ | $(1.13 \pm 0.06).10^{-2}$ | 4.43 |
| 1173.23 | $(9.59 \pm 0.08).10^{-3}$ | $(9.29 \pm 0.47).10^{-3}$ | 3.23 |
| 1332.51 | $(8.65 \pm 0.07).10^{-3}$ | $(8.69 \pm 0.44).10^{-3}$ | 0.46 |
| 1836.01 | $(6.63 \pm 0.06).10^{-3}$ | $(6.28 \pm 0.32).10^{-3}$ | 5.57 |

## 4. Conclusion

The problem of photon self-absorption in gamma spectrometry of environmental samples has no simple solution because of the attenuation of photons depending on many various parameters as energy, sample composition, sample density, and sample-detector geometry. For calculation of the detector efficiency the absorption corrections must be then done not only to the photon self-absorption in sample itself, but also to the photon absorption in all other materials between the sample and the detector's active part. Monte-Carlo modeling allows to take into consideration all these corrections during computation. In this paper, the modeling calculation of peak efficiencies of the hyperpure HP Ge detector (GMX) for gamma rays at various energies (emitted from standard disk source and volumetric source - environmental sample, in which the different radionuclides are present) has been made based on MCNP4C2-Monte-Carlo multi-purpose radiation transport code system developed in the Los-Alamos laboratory, USA.The comparision of the obtained calculating results and experimentally measured data has shown out a good agreement between them within the errors ranging from 0.51% - 7.93% for the volumeric source and from 0.46% to 5.57% for the disk source.

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