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Influence of Dead Layer Thickness on the PhotopeakDetection Efficiency of an HPGe Detector

M. Abdelati
Nuclear Safeguards and Physical Protection department, Egyptian nuclear and Radiological Regulatory Authority (ENRRA) - Cairo, Egypt

Abstract

Germanium crystal in anHPGe detector containsan inactive layer known as a dead-layer. The influence of this layer on the efficiency of the detection is investigated with the aid of the general Monte Carlo N-Particle Code (MCNP5 version).Monte Carlo calculations using the MCNP5 code are carried out to estimate the Full Energy Peak Efficiency (FEPE)ateight different values of the dead-layer thickness, in the range from 0 mm to 0.7 mm and a 1 mm step-size.Obtained MCNP5 results indicated that the maximum change of the FEPE is observed at low energies, where a change in the thickness of the dead-layer by 0.1 mm causes a relative difference of about 2.35 % at the ɤ-energy line 122.1 KeV, while it causes a relative difference of about 0.9 % at 1332.5 KeV. Experimental measurements are carried out using a set of standard point-like sources, including ^{57}Co, ^{137}Cs, ^{22}Na, and ^{60}Co, to determine the FEPEfor five ɤ-energiesin the range from 122 to 1333 KeVat 5 cm source-to-detector distance.

The obtained peak efficiencies at different dead-layer thicknesses utilizing the MCNP5code are then compared with thisone which calculated experimentally to determine the optimum dead-layer thickness. The comparison results showed that the optimum value of the dead-layer on the front face of the germanium crystal is about 0.4 mm.The value of the activity of each standard point-like source is calculatedat this value of the dead-layer thickness, and compared with the certified value. The maximum relative difference between the calculated activities, at 0.4 mm dead-layer, and certified activities is about 0.35 %.

Keywords:
Germanium crystal; dead-layer; HPGe detector; Detection efficiency; full energy peak efficiency; MCNP5code; gamma-ray

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I. Introduction

Using an HPGe ɤ-ray spectrometry for radiation measurement requires determination of the efficiency of the detection over the ɤ-energy region of interest to obtain accurate measurement [1].There are different factors which affectthe efficiency of the detection, such as the distance between the radiation source and the detector, geometry characteristic of the crystal of the detector and its housing, the energy of ɤ-ray, and thickness and composition of the absorbing material in the path between the radiation source and the detector [2].

Germanium crystal in HPGe detector containsan inactive part;this part produces on the topand side of the crystal due to the gradually diffusion of atoms of the contact layer on its surface to the crystal, known as the dead layer.Increasing the thicknessof this layer has an influence on the efficiencyof the detection;itwill decrease the active volume of the germanium crystal and,as consequence, reduces the detector efficiency [3].

Simulation methods such as the general Monte Carlo N-Particle Code (MCNP5 version)and semi-analytical methods, which simulate radiation transport, provide a tool to address virtually any aspect of the Non-Destructive Assay (NDA)that departs from the ideal case [4].The generation of an accurate model for the detector using the MCNP5 codewould require precise information about the characteristic of the germanium crystal (active volume dimensions andthe thickness of the dead-layer).Usually, the manufacturer information about these partsis not accurate and not enough [5].

Relation betweenthe number of ɤ-photons(pulses)recorded by the detector to the number of ɤ-photons emitted from the radiation source is called the absolute full energy peak efficiency. In general, the absolute full energy peak efficiency for gamma-rays spectrometryat energy Ecould be defined as [6]:

$$\boldsymbol{\varepsilon}_{abs} = \frac{No\ of\ photons\ recorded\ \ by\ the\ detector}{No\ of\ photons\ emitted\ \ by\ source} \quad \text{------- (1)}$$

Which depends on the detector characteristics and the material in the path between the radiation source and the detector, and the intrinsic full energy peak efficiency, it can be specified as follows:

$$\boldsymbol{\varepsilon}_{abs} = \frac{\mathrm{N}}{\mathrm{A}\ \mathrm{I}_{\gamma}\ t} \text{ --------------- } (2)$$

Where: N Net area under the photo-peak of energy E,
Aactivity of gamma source,
$I_\gamma$gamma emission probability,
tlive time of the counting, in second.

Aim of the work isinvestigating the influence of the dead-layer thickness on the Broad-Energy HPGe (BEGe) detector efficiency using MCNP5 code as well as calculating the optimum dead-layer through comparing experimental measurements and MCNP5 simulation results.

II. Method and experiment

2.1 Detector specification

Figure 1 shows a 3-D representation of the Canberra BEGe system (Model BE2830) used in this study. The detector is coupled with a pre-amplifier (Model PSC823C), a built-in MCA (inspector, Model IN2K), Genie-2000 software to collect the spectrum, and the recommended bias voltage is -3300 V.

Figure 1:*Falcon 5000 detector (BEGe detector)* [7]

2.2 Experimental setup

The FEPE is determined using a set of standard ɤ-ray point-like sources, including ^{57}Co, ^{137}Cs, ^{22}Na, and^{60}Co, with the corresponding ɤ-energy line in the range 122 to 1333KeV.Activity, production date, the corresponding ɤ-energies, and their branching ratios are presented in Table 1.As showing in Figure 2, each ɤ-source is located axially at source-to-detector (S-D) distances of 5, 10, and 15 cm apart from the front facet of the detector end-cap, where the measurement dead-time is about 2%, and the acquisition time is about 500 sec. The obtained count rate for each ɤ-energy line is corrected for the background and then used to calculate the FEPE according to the equation (2).

Table 1:*Specification of the certified point sources*[8]

Source	Activity (μci)	Production date	E (*KeV*)	Iγ%[9]
Co-57	5.188	15/7/2007	122.1	85.6
			136.5	10.68
Cs-137	5.002		661.7	85.1
Na-22	4.322		1274.53	99.944
Co-60	4.430		1173.23	99.86
			1332.5	99.98

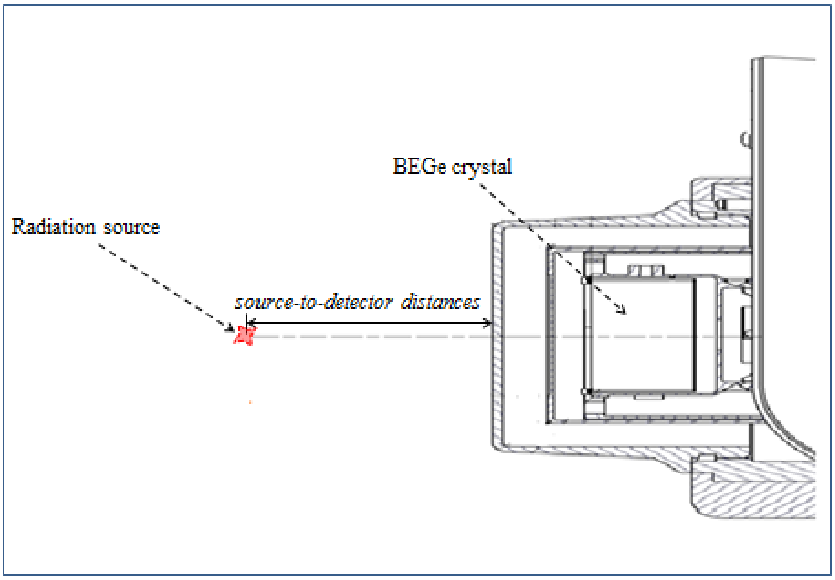


Figure 2:*illustration diagram of experimental setup*

2.3 Monte Carlo simulation

The BEGe detector is modeled using the MCNP5, where the F8 tally is included. The pulse height tally (F8 tally) is used to calculate the FEPE of the detector [10]. The parameters used to simulate the BEGe detector based on the manufacturer-provided data are described in Figure3.where 60.80 mm diameter and 30.90 mm crystal lengthare concerned, the crystal is held by an aluminum cup in a 1.5-mm-thick aluminum end cap and placed 13.2 mm from the front window. The front window is made of 1.2 mm-thick aluminum [11].

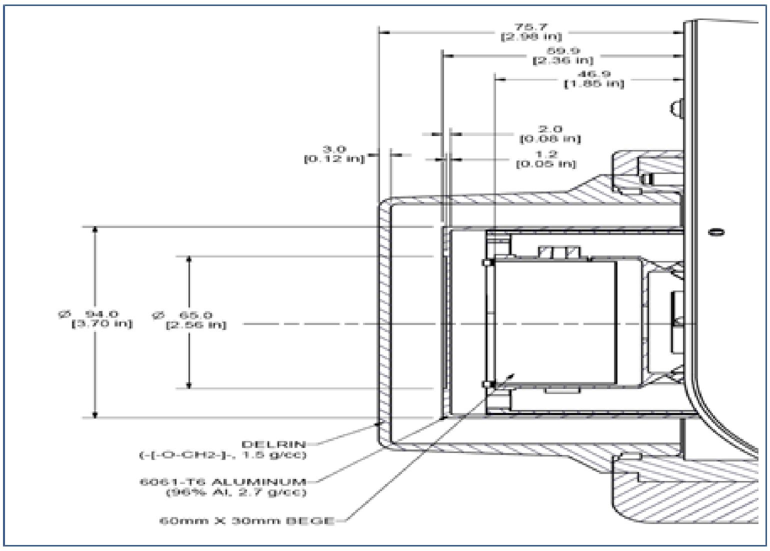


Figure 3:*Schematic view of the BEGe detector*

The manufacturer does not provide the exact value of the dead-layer thickness, so in order to optimize and study the dead-layer thickness effect on the detector efficiency, the FEPE is estimated by using the MCNP5 simulation at different values (eight value)ofthe dead-layerthicknesses in the range 0 to 0.7 mm with a 1 mm step and at S-D distance of 5 cm. Once the optimized value of the dead-layer thickness is obtained, the refined MCNP5 model is validated by calculating the FEPE at different S-D distances including 5, 10, and 15 cm.

All the calculations are performed in the ɤ-energy range 122-1333KeV, (where a total of five ɤ-energy lines are considered), and on the2.5 GHz processor, and the number of histories isto equal 10^7events, to keep the relative standard deviation due to MCNP5 calculations less than 2%.

III. Results and discussion

Results of MCNP5 forestimation the FEPE,at each particular energy lineof five considered ɤ-energy lines at each thickness ofthe dead-layerand at S-D distance of 5 cm, indicates that the maximum change of the FEPE is observed at low energies, where a change in the thickness of the dead-layer by 0.1 mm causes a relative difference of about 2.35 % at the ɤ-energy line 122.1 KeV, while it causes a relative difference of about 0.9 % at the ɤ-energy line 1332.5 KeV.Figure 4shows therelative difference due to change in the thickness of dead-layer by 0.1 mm at considered ɤ-energy lines.

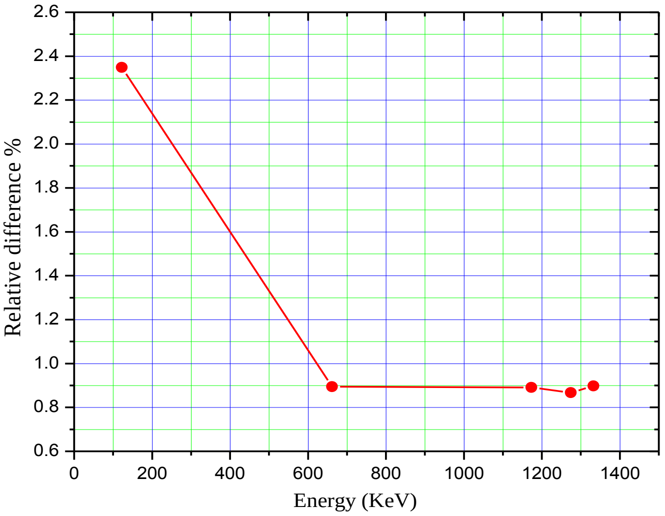
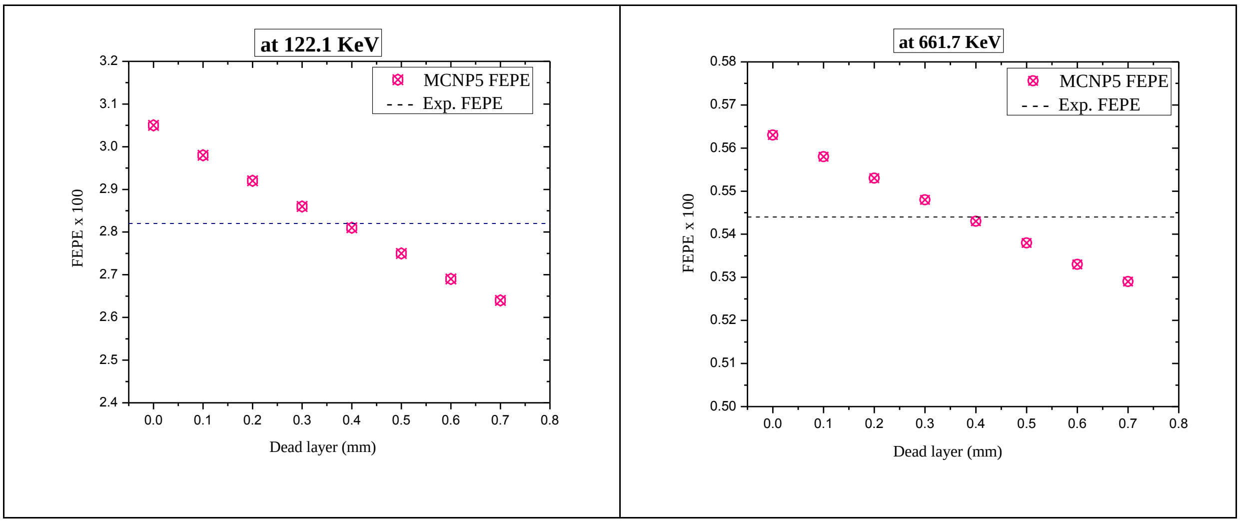


Figure 4:*the relative difference causes due to change in the thickness of the dead-layer by 0.1 mm at considered ɤ-energy lines*

It is clear that an increase in the relative difference value atlowenergy of ɤ-ray and this is due to the absorption of low energy ɤ-ray inside the dead-layer which leads to decrease the probability of its interaction with the active volume of the crystal.

FEPE obtained from MCNP5simulation at each value of dead-layer thickness, in the range0 mm to 0.7 mm,iscompared with the experimentallyvalue.Figure 5showsthe deviation of FEPEsimulation values, obtained from MCNP5 simulation at each dead-layer thickness, from an experimentally valueat each particular ɤ-energy line.



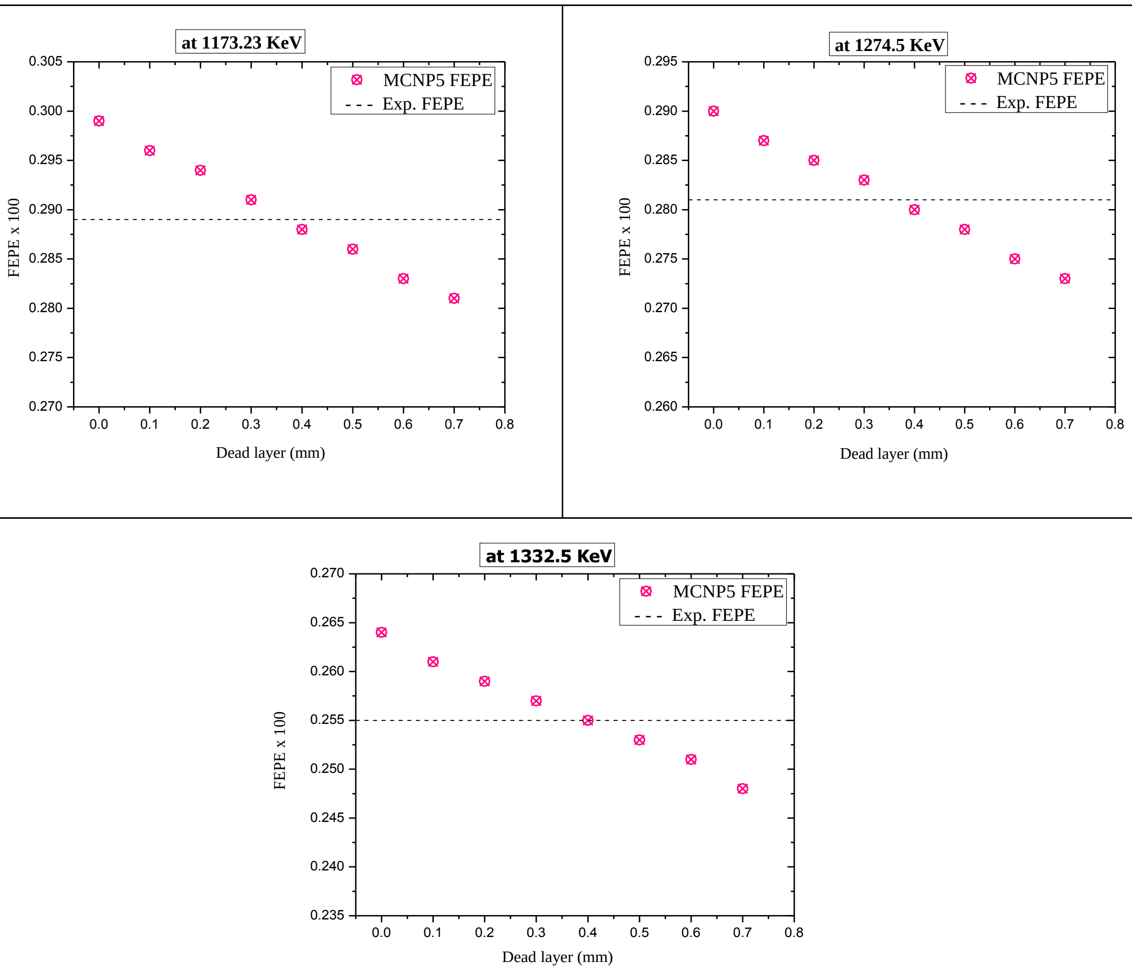


Figure 5:*FEPE obtained from MCNP5 simulation at each dead-layer thickness in comparison with experimentally value at each particular energy line*

Resultspresent that,the FEPE value and the dead-layer thickness are inversely proportionaldue to the absorption of a portion of ɤ-rays in the dead-layer before interaction with the active volume of the germanium crystal. This means that the efficiency of the detection decreases with increasing the thickness of the dead-layer. Also, comparison between simulation and experimental showed that the thickness of the dead-layer on the front face of the germanium crystal is about 0.4 mm.

Figure 6 shows the difference between the FEPE values obtained from a simulationwith MCNP5 code, for each dead-layer thickness, and an experimentally value at the same ɤ-energy line.

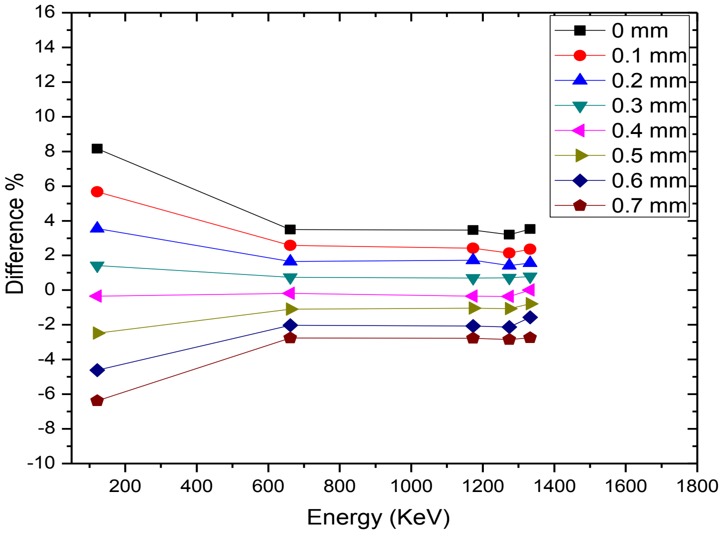


Figure 6:*Difference between the FEPE values obtained from MCNP5 simulation, at different dead-layer thickness, and experimental.*

At 122.1KeVɤ-energy line the difference,between the FEPE values obtained from simulationand experimentally value,is range from 8.2 % (at 0 mm thickness) to -6.4% (at 0.7mmthickness) while at 1332.5 KeVthe difference is range from 3.5 % (at 0 mmthickness) to -2.7% (at 0.7mmthickness).Absorption of a portion of ɤ-rays during its path through the detector window and the dead-layer in front face of the germanium crystal can explain largevalue of the difference at low ɤ-energy.At high ɤ-energythe probability of ɤ-rays interaction is proportional tothe size of the active volume of the germanium crystal.Active volume of the germanium crystal is decreasing with the increase of the thickness of the dead-layer, and, as a result, the FEPE value will decrease.For 0.4 mm of dead-layer thickness, the difference isapproximately zero; where it is equal -0.35 % (the maximum value)at 122.1 KeV and equal 0.00 % at 1332.5 KeV. Thus,0.4 mm thickness can be considered an optimum value of dead-layeron the front face of the germanium crystal.

FEPE values which were obtained for each thickness of the dead-layer, based on MCNP5 simulation, were drawn with the five considered ɤ-energy values to produce the efficiency curve. Also, efficiency curve for experimental value was drawn.

Figure 7showsthe detection efficiency curve for eachdead-layer thickness in comparison with the efficiency curve obtained experimentally.

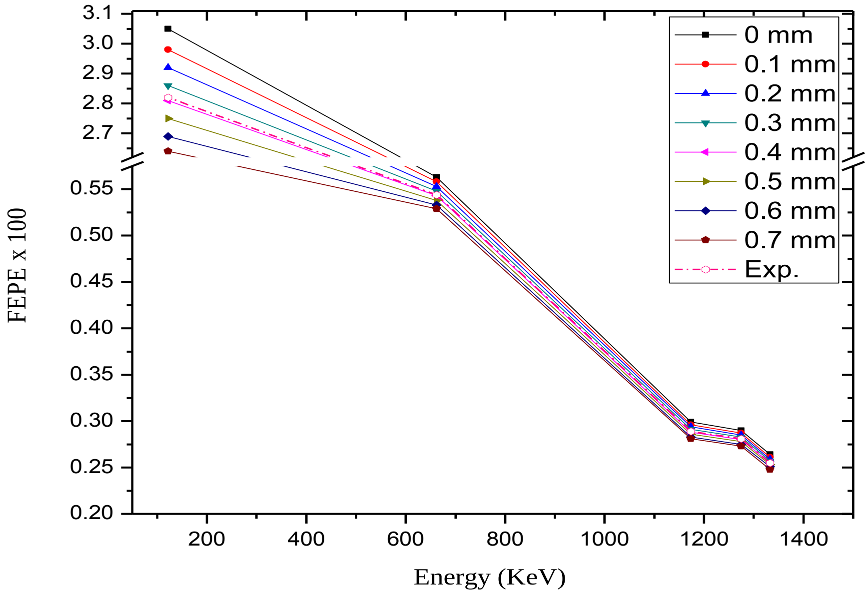


Figure 7:*Efficiency Curve at each dead-layer thickness in comparison with experimental.*

Decrease in the FEPE value with increasing the ɤ-ray energy is due to the inverse proportional between the energyof ɤ-ray and its probability interactioninsidethe active volume of the germanium crystal.

Influence of the thickness of the dead-layer on theFEPE value is clear at low ɤ-energy (at 122.1 KeV), where the difference between the value of FEPE at 0 mm thickness and its value at 0.7 mm is 0.41,while at 1332.5 KeVthe differencebetween the two is 0.016.

To clarify the influence of the thickness of the dead-layer on the efficiency of the detection and the accuracy of radiation measurement results; the activity of each standard point-like sourcewas calculated (using equation 2) based on FEPE valueproduced from MCNP5 simulationat each thickness of the dead-layer. Obtained activity value compared with the certified activity value. Figure 8shows the difference between activities calculated based on MCNP5simulation and the certified activity.

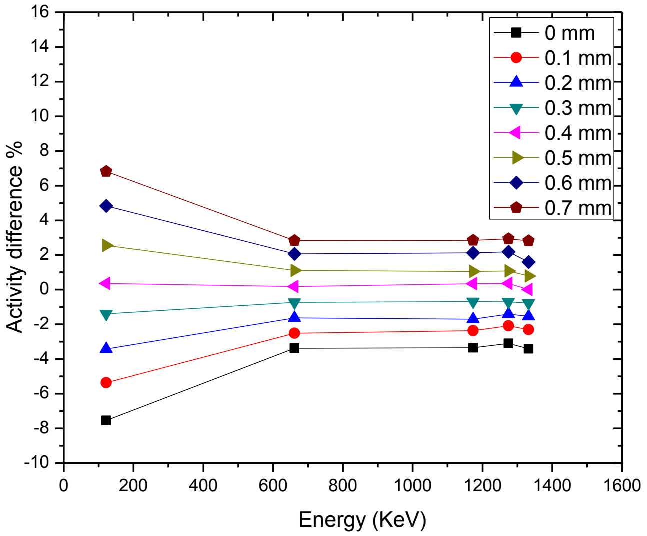


Figure 8: Difference of activities calculated based on MCNP5 simulation from a certified activity

Due to the depend of the calculation of activityon the value of the FEPE;the difference between activity calculatedbased on MCNP5 simulation and a certified activityat low energies is greater than the difference between the two athigh energies.

At 122.1KeV ɤ-energy line, the difference between activity calculated and the certified activity is range from -7.54 % (at 0 mm dead-layer thickness) to 6.82 % (at 0.7mmdead-layer thickness) while at 1332.5 KeVthe difference is range from -3.41 % (at 0 mmdead-layer thickness) to 2.82 % (at 0.7mmdead-layer thickness).

Also, the dependence of the FEPE on the distance between the radiation source and the detector is investigated. Figure 9shows the variation of the FEPE value with the change of thesource position to the detector.

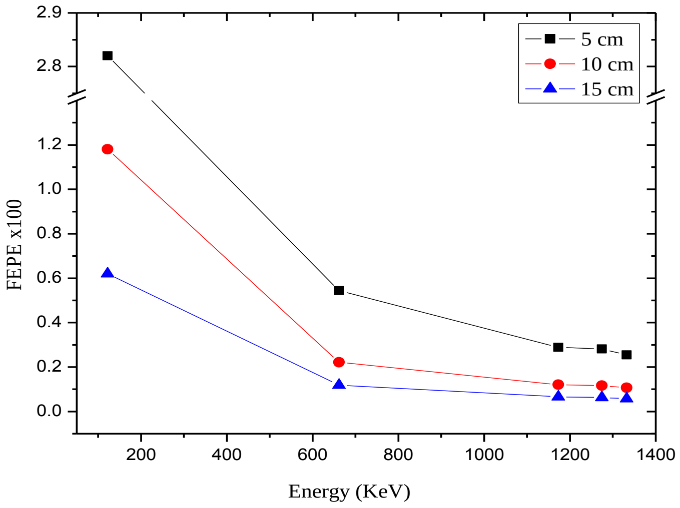


Figure 3:*FEPE variation with the distance between source anddetector*

The FEPE, for each consideredɤ-energy line, is determinedexperimentally (based on equation 2) at S-D distancesof 5, 10, and 15 cm. The results show that the FEPE depends on the geometry of experimental. For all energy lines, the FEPE decreased by increasing the distancebetween the source and the detector.

IV. Conclusions

During performing the radiation measurements, it is important to take into consideration the factors that affect the obtained results. Absorption or attenuation of ɤ-rays in the material, which present in the path from the radiation source to the active volume of the germanium crystal in HPGe detector, is one of the important factors that must be considered.Influence of the thickness of the dead-layer (inactive layerof the germanium crystal) on the efficiency of the detection is investigated in this work. MCNP5 code is utilized to investigate the effect of the variation ofthe thickness of the dead-layer in the FEPE value. MCNP5 simulation is carried out to estimate the FEPE for five ɤ-rays energies in the range 122 to 1333 KeV, at eight values of the thickness of the dead-layer. Dead-layer thicknessis ranged from 0 mm to 0.7 mm and a 1 mm step-size is considered. Obtain results indicated that a change in the thickness of the dead-layer by 0.1 mm causes a relative difference of about 2.35 % at the ɤ-energy line 122.1 KeV, while it causes a relative difference of about 0.9 % at 1332.5 KeV.A set of standard point-like sources, including ^{57}Co, ^{137}Cs, ^{22}Na, and ^{60}Co,and ^{60}Co, are used to determine the FEPE experimentally, for the considered five ɤ-rays energies in the range from 122 to 1333 KeV.Comparisonbetween the simulation and experimental results indicated a good agreement at 0.4 mm thickness of the dead-layeron the front face of the germanium crystal.

In general, the influence of the thickness of the dead-layer is clear at the low energies of ɤ-rays; where a portion of ɤ-rays is absorbed inside it and the residual part interacts with the active volume of germanium. For 122.1 KeV ɤ-energy line, the differencebetween the FEPEobtained from simulationand experimentally value is equal 8.2 % for 0 mm of the dead-layer thickness, and equal -6.4 % for 0.7 mm.For1332.5 KeV,the difference is range from 3.5 % for 0 mm to -2.7% for 0.7mm.

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