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Assessment of dead layer in HPGe detector for in-situ gamma spectroscopy

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1. Introduction

The High Purity Germanium (HPGe) detector is used for nuclide analysis in various fields with high resolution. Recently, HPGe detectors for in-situ measurements have been used to analyze radioactivity directly at the site. However, in-situ measurement is difficult to calibrate the Full Energy Peak(FEP) efficiency due to various types of sample shapes and measurement conditions. To overcome these problems, FEP efficiency can be assessed using MCNP simulation [1]. But there is a dead layer on the surface of germanium crystal that cannot measure radiation. Also, the thickness of the dead layer is difficult to measure, limitations exist in MCNP simulation.

The Lithium(Li) was deposited on the high purity germanium crystal surface for voltage supply. Therefore, areas, where gamma-rays cannot measure due to lithium impurities exist on the surface of a germanium crystal. This area is called a dead layer. It is increasing due to lithium (Li) propagation when high purity germanium crystal is not cooled and remains at room temperature in a long time or detector is old [2]. Thus, the dead layer increase means the effective detection area is reduced. And Dead layer functions as a kind of shield because of the high gamma-ray reaction rate in the Germanium crystal [3]. So, the dead layer thickness is an important factor of FEP efficiency calibration.

In this study, the thickness of the dead layer on the front and the side of the HPGe detector was evaluated through MCNP simulation and actual measurement experiment. And after applying the evaluated dead layer thickness, FEP efficiency was assessed under various measurement conditions using MCNP simulation. And the accuracy of the dead layer thickness assessment results was evaluated through comparison with the actual measurement results under the same conditions.

2. Methods and Materials

2.1 Assessment of full energy peak efficiency

Measurement experiments were conducted to assess the FEP efficiency by location of the Point source. The HPGe detector in the Dead layer evaluation experiment used the GC4019 model (Canberra) manufactured in 2004. In addition, ^{137}Cs, ^{60}Co, and ^{152}Eu point sources were used to assess the FEP efficiency for various gamma-ray energies range. The FEP efficiency was measured after the point source was located 20cm away from the front and side of the HPGe detector. (fig.1)

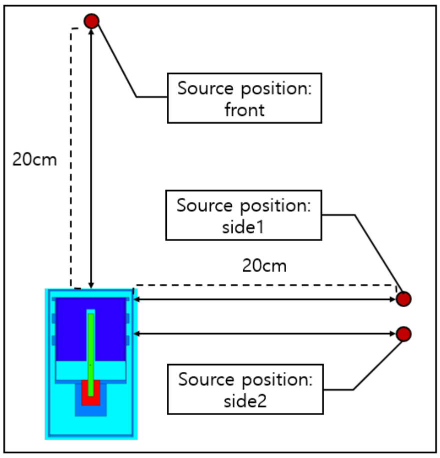


Figure 1 Point source position

The FEP efficiency of point sources at the location is used as the basis for the dead layer thickness assessment.

2.2 MCNP modeling

The detailed geometry of the HPGe detector (model: GC4019) was modelled as MCNP code for the evaluation of the dead layer thickness. (fig.2)

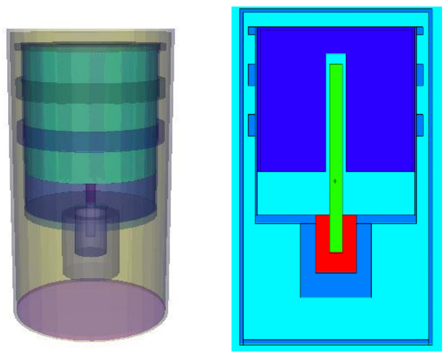


Figure 2 HPGe detector geometry in MCNP

The geometry of the HPGe detector was modeled internal and external structures with reference to drawings provided by the manufacturer. The FEP efficiency was calculated by altering the thickness of the crystal outer surface dead layer in the corresponding geometry. The initial value of the dead layer thickness is set to 0.42mm in the drawings provided by the manufacturer (Canberra). The dead layer thickness was increased by up to 2mm. And Tally8 (Energy distribution of pulses created in a detector by radiation) was used to calculate the FEP efficiency [4]. This allows the FEP efficiency of energy to be assessed.

3. Results

3.1 Correlation of Full Energy Peak efficiency and Dead layer

The correlations of the dead layer and calculated FEP efficiency by energy were derived by MCNP simulation. The data were used to drive an approximation formula between the FEP efficiency and the dead layer thickness (fig.3).

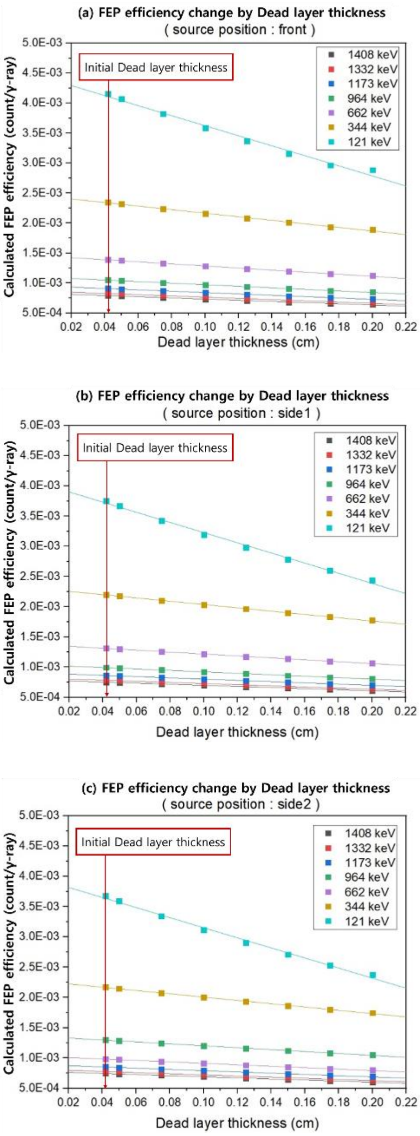


Figure 3 Approximation formula between the calculated FEP efficiency and the dead layer thickness (121~1408keV) (a) front (b) side1 (c) side2

As a result, the calculated FEP efficiency decreases linearly as the dead layer increases. Thus, the dead layer thickness can be assessed using the approximation formula and FEP efficiency of a point source that in the same position.

3.2 Dead layer assessment

The dead layer thickness of HPGe detector was evaluated using the result of point source FEP efficiency and approximation formula. To this end, the count rate of point sources was measured and calculate the FEP efficiency using the below equation. (Table.1).

$$FEP\ efficiency = \frac{Count\ rate\ (cps)}{A * Y}$$

A : point source activity(Bq), Y : Branch ratio(%)

Table 1 Measured FEP efficiency of point source by gamma energy and position

Gamma-ray Energy	**Measured FEP efficiency (count/γ-ray)**		
	Front	Side1	Side2
121 keV	3.54E-03 (±0.77%)	3.51E-03 (±0.34%)	3.44E-03 (±0.37%)
344 keV	2.12E-03 (±0.45%)	2.04E-03 (±1.05%)	2.01E-03 (±0.33%)
662 keV	1.23E-03 (±0.2%)	1.15E-03 (±0.4%)	1.14E-03 (±0.02%)
964 keV	9.86E-04 (±0.80%)	9.44E-04 (±1.73%)	9.32E-04 (±0.79%)
1173 keV	8.07E-04 (±0.3%)	7.73E-04 (±0.5%)	7.59E-04 (±0.3%)
1332 keV	7.15E-04 (±0.8%)	6.86E-04 (±1.1%)	6.74E-04 (±0.2%)
1408 keV	6.88E-04 (±1.61%)	6.54E-04 (±1.56%)	6.52E-04 (±2.15%)

* Uncertainty with a coverage factor of 3 for a confidence level of 99%

Based on the measured FEP efficiency and approximation formula, the dead layer of the HPGe detector was calculated (Table.2).

Table 2 Result of dead layer thickness assessment using point source FEP efficiency

Gamma-ray Energy	Dead layer thickness (mm)		
	Front	Side1	Side2
121 keV	1.104 ±0.009	0.671 ±0.002	0.657 ±0.002
344 keV	1.144 ±0.005	0.996 ±0.010	0.989 ±0.003
662 keV	1.315 ±0.003	1.445 ±0.006	1.371 (±0.001
964 keV	0.891 ±0.007	0.812 ±0.014	0.837 ±0.007
1173 keV	1.307 ±0.004	1.275 ±0.006)	1.307 ±0.004
1332 keV	1.490 ±0.012	1.448 ±0.016	1.500 ±0.003
1408 keV	1.456 ±0.023	1.491 ±0.023	1.435 ±0.031
Average	1.244 ±0.212	1.163 ±0.335	1.157 ±0.328

* Uncertainty with a coverage factor of 3 for a confidence level of 99%

As a result, dead layer thickness by gamma-ray energy and position has a difference. This result caused by the structure of the HPGe detector. Around the HPGe crystal, there is a complex structure for protecting and maintain the detector's cooling, and the interaction cross-section of gamma-ray with materials depended on gamma-ray energy. So, the penetration rate of gamma-ray is dependent on gamma-ray energy. For this reason, the FEP efficiency varies depending on the location of the source and the gamma-ray energy, and the thickness of the dead layer was also evaluated differently by energy and source position.

Therefore, the dead layer thickness of the HPGe detector was set to the average value of each position. The average thickness of the dead layer on the surface of the germanium crystal was assessed at 1.244 cm in the front and 1.163 cm and 1.157 cm in the side 1 and 2 respectively. And the thickness of the side dead layer used side 1 or 2 average values. Using the results, the MCNP code was written by adjusting the dead layer of the germanium crystal. (fig.4)

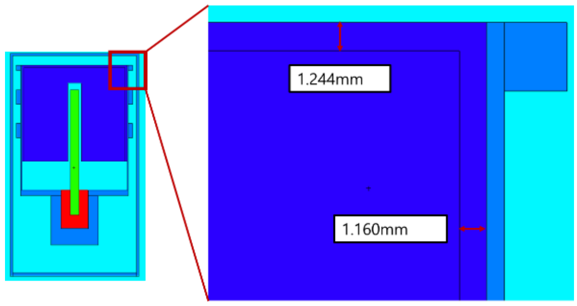
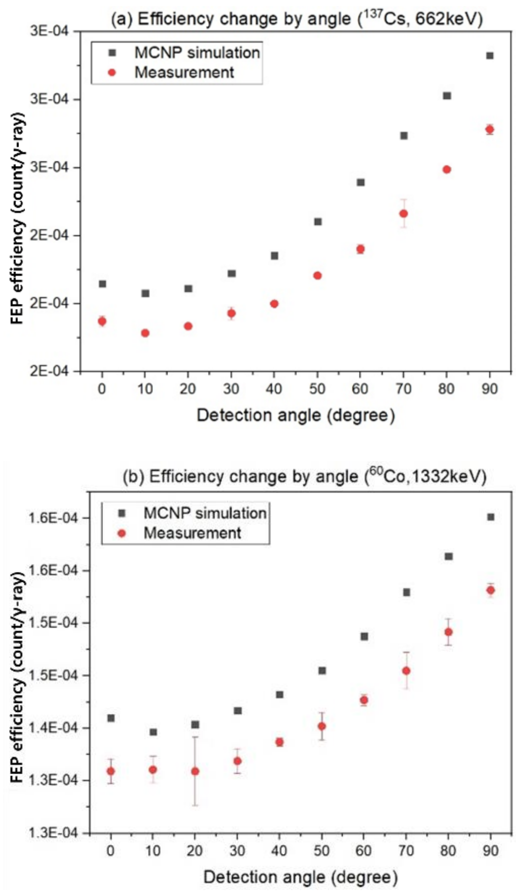


Figure 4 Adjusted geometry of HPGe detector

3.3 Verification of dead layer thickness

To evaluate the accuracy of the measured dead layer thickness, MCNP computer simulation, and measured FEP efficiency was compared. Because there are sources in various locations in the in-situ measurements, the test performed measurements by placing the point source at 20 cm away from the surface of the instrument and increasing the angle of measurement at 10° intervals from 0° to 90°. (fig.5)



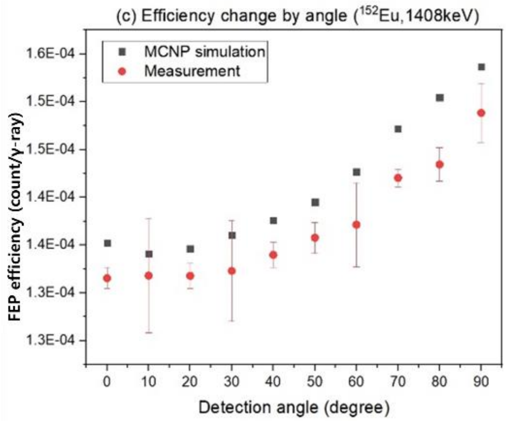


Figure 5 Comparison of calculated FEP efficiency (MCNP) and measured FEP efficiency by angle (a) ^{137}Cs (b) ^{60}Co (c) ^{152}Eu

As a result, calculated FEP efficiency and measured FEP efficiency of point source was matched to within 5% of maximum error. This was evaluated relatively accurately, considering that the radioactive uncertainty of the used point source was 3% at 99% accuracy.

4. Conclusions

This study was conducted to increase the accuracy of the FEP efficiency assessment using MCNP simulation. To this end, the average dead layer thickness of the HPGe detector front and the side was evaluated. As a result, the GC4019 model manufactured in 2004 showed that the dead layer thickness increased from the initial 0.42mm to 1.244mm in the front and 1.160mm in the side.

The HPGe detector was modeled by adjusting the dead layer thickness for verification of the evaluation results. Then, MCNP simulation and actual measurement results were compared. The comparison was made with the FEP efficiency of the ^{137}Cs, ^{60}Co, and ^{152}Eu point sources measured from various detection angles. As a result, the FEP efficiency was consistent within the maximum error of 5%. Considering that the uncertainty of the actual point source radioactivity was 3% when the confidence level is 99%, the measured FEP efficiency could be assessed relatively accurately using MCNP simulation.

Through this study, it is confirmed that measured FEP efficiency can be accurately assessed for various source locations and shapes when MCNP simulations are used based on accurate dead layer thickness. Therefore, it is possible to assess the FEP efficiency of various source types through MCNP simulation during in-situ measurements. Later, the method will be used to assess dead layer thickness by germanium crystal area and to verify the various types of sources and nuclides. It will also be applied to various detectors to analyze the trend of creating dead layers according to their operational history. This is expected to increase the accuracy of source radioactivity quantitative with complex forms that make it difficult to assess FEP efficiency in in-situ measurements.

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