Assessment of Self-Absorption Correction Factors for Cs-137 662 keV Gamma-ray Measurements in Magnetite and Ordinary Concrete Samples

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1. Introduction

In the measurement of Cs-137 radioactivity in concrete samples using an HPGe detector, it is commonly derived by comparing the count value of Cs-137's 662 keV gamma rays measured in a standard sample. For accurate analysis through this comparison method, it is advantageous for the standard and measured samples to be in identical conditions, namely, the same geometric shape, composition, and density. However, since standard sources used for gamma spectroscopy efficiency calibration are mainly made in water or paraffin form with a density of 1 g/cm³, there is a significant difference when compared to concrete samples. [1, 2]

In this study, we focused on concrete samples and used the Monte Carlo N-Particle code (MCNP) to simulate the detection process of 662 keV gamma rays emitted from Cs-137 isotopes contained in the samples by an HPGe detector, and calculated a self-absorption correction factor. Additionally, the sensitivity of the HPGe detector's Cs-137 662 keV gamma ray detection quantity to changes in sample density was assessed.

2. Methods and Results

2.1 Composition and density of the measured samples

The composition and density of the concrete samples were based on the compositions listed in PNNL[3] materials. Considering the grinding of the samples to be contained in a Marinelli beaker, the analysis for ordinary concrete was performed within a density range of 2.3 ~ 1.5 g/cm³, and for heavy concrete within a range of 3.45 ~ 2.0 g/cm³ using MCNP.

2.2 Geometric modeling

The detector model applied in the simulation was the GEM30P4 model from ORTEC, with specifications as shown in Table 1. For more accurate simulation, geometric modeling of the detector was conducted by reflecting detailed detector characteristics such as the detector end radius and dead layer.

Table 1: Detector specifications

	Dimensions
Detector Diameter	58.8 mm
Detector Length	52.7 mm
Detector End Radius	8 mm
Hole Diameter	9 mm
Hole Bottom Radius	9/2 mm
Hole Depth	39.6 mm
End Cap Wall	1.3 mm
Dead Layer	500 microns

Standard samples were measured by diluting Cs-137 isotopes in 1 liter of water in a Marinelli beaker, and concrete samples were also ground to a 1 liter volume and measured in a Marinelli beaker. Geometric modeling as shown in Figure 1 was applied to the MCNP input, reflecting the measurement conditions of the HPGe detector installed at the Institute for Nuclear Science and Technology of Jeju National University.

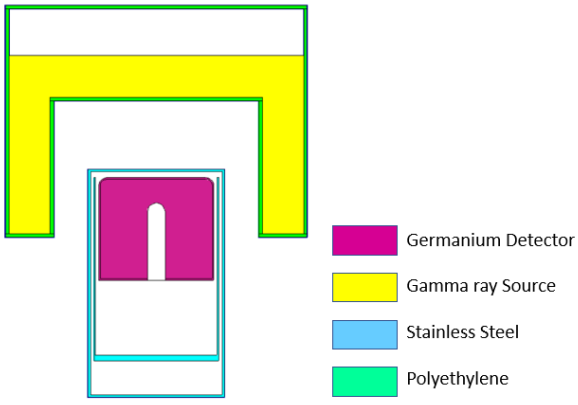

Fig. 1. MCNP Geometry Model

2.3 MCNP analysis results

For simulating the gamma ray spectrum measured by the detector, the F8 tally was used to display the photon count spectrum, with a history cutoff (NPS) value set at 1e7. The relative error of the count value at Cs-137 662 keV energy being below 0.38% suggests that the NPS value is appropriate. By comparing the efficiency of a 1 g/cm³ density Cs-137 standard sample to the efficiency

with changes in density of concrete, a self-absorption correction factor can be calculated. The self-absorption correction factor is the ratio of the sample's efficiency to the efficiency of a standard source with a density of 1 g/cm³, and the evaluation results are presented in Table 2. The increase in sample density reduces the gamma rays escaping from the sample due to self-absorption. Thus, an increase in density decreases the value of the density correction factor.

MCNP evaluation results indicate that for ordinary concrete with densities ranging from 1.5 to 2.3 g/cm³, the self-absorption correction factor ranged from 0.895 to 0.963, showing a 0.85% decrease in the density correction factor value for every 0.1 g/cm³ increase in density. Additionally, for heavy concrete with densities ranging from 2.0 to 3.45 g/cm³, the density correction factor ranged from 0.814 to 0.923, indicating a 1.36% decrease in the density correction factor value for every 0.1 g/cm³ increase in density.

Table 2: Detector specifications

Density, g/cc	MCNP Efficiency (662 keV)	relative error	correction factor
Cs-137 Standard Source			
1.0	8.57E-03	0.0034	
Ordinary Concrete			
1.5	8.25E-03	0.0035	0.963
1.7	8.10E-03	0.0035	0.945
1.9	7.95E-03	0.0035	0.928
2.1	7.80E-03	0.0036	0.911
2.3	7.67E-03	0.0036	0.895
Magnetite Concrete			
2.0	7.91E-03	0.0035	0.923
2.5	7.57E-03	0.0036	0.884
3.0	7.25E-03	0.0037	0.846
3.45	6.98E-03	0.0038	0.814

3. Conclusions

When measuring the 662 keV gamma rays of Cs-137 isotopes in concrete samples, if there is a significant difference in density between the standard and measured samples, self-absorption correction should be considered to reduce measurement errors. In this study, using the Monte Carlo code MCNP, we simulated the measurement environment for standard samples with a density of 1 g/cm³ and concrete samples of various densities, evaluated the efficiency, and calculated the self-absorption correction factor. According to the results of this study, failure to apply self-absorption correction could result in underestimation of radioactivity values by approximately 4-10% for ordinary concrete and 8-19% for heavy concrete within the analyzed density range.

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