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A basic research on radiological characterization in high-radiation environment

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1. Introduction

In the in-situ measurement method, analysis reliability must be secured by selecting appropriate equipment and optimal measurement conditions for the measurement environment. In particular, in the case of high-radiation environment, there is a large difference in analysis reliability according to the selection of measuring equipment and measurement conditions. Therefore, in this research, a basic research was conducted to evaluate the effect of each measurement condition using HPGe(High Purity Germanium) detector and CZT(Cadmium Zinc Telluride) detector in order to make appropriate in-situ measurements in a high-radiation environment during operation and decommissioning of nuclear facilities. In addition, the reliability of the experimental results was confirmed by comparing the results of the Monte Carlo simulation.

2. Methods

2.1 Experiment using Point source

In order to implement a high-radiation environment in the laboratory, an experimental device was constructed using a point source(Fig. 1). The point sources used in the experiment are ^{137}Cs, ^{60}Co, and ^{152}Eu, and the information of the point sources is shown in Table 1. The detectors used in the point source experiment are HPGe detector and CZT detector. The dose rate for each distance at a distance from 0 cm to 100 cm was measured with a portable dosimeter. Then, at the same distance except for several distances, the center of the point source and the center of the detector were positioned so that they coincide, and measurements where repeated three times for 600 seconds each. The detectors that measure the gamma rays of the point source are HPGe detector and the CZT detector. The detection efficiency was calculated by analyzing the net count rate of full energy peaks for each nuclide of the spectrum measured in each experiment. The correlation between the calculated detection efficiency and the measurement distance and dose rate was analyzed. The radioactivity of the spectrum measured in each experiment was calculated using a Geometry composer(Fig. 2). The error was confirmed by comparing the radioactivity calculated using the Geometry composer with the radioactivity of the actual point source.

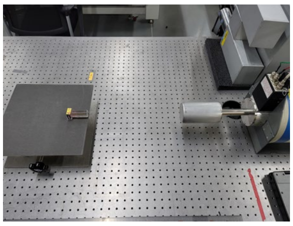

Fig. 1. Point source experimental equipment using HPGe detector and CZT detector

Table 1. Point source information used in the experiment

Nuclide	Radioactivity (Bq)	Energy (keV)	Intensity (%)
^{137}Cs	3.31E+06	661.66	85.00
^{60}Co	2.79E+06	1332.51	98.98
^{152}Eu	3.00E+06	1407.95	20.85

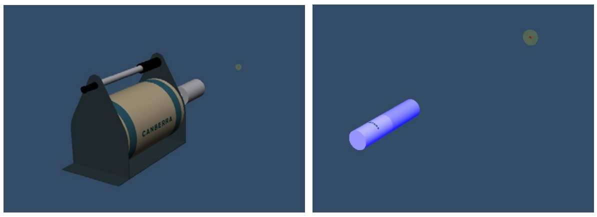

Fig. 2. HPGe detector and CZT detector Geometry composer

2.2 Monte Carlo Simulation

The Monte Carlo Simulation(MCNPX) was used to confirm the analysis reliability of the point source experiment results. The MCNPX input entered the same shape, detector specification, source information, and measurement conditions as the experimental environment. The results were output as spectra using F8 Tally. The net count rate of the full energy peaks of the output spectrum was analyzed, and it was assumed that the net count rate and detection efficiency were the same. The reliability of the analysis was confirmed by comparing the simulated results and the experimental results.

3. Results

The comparison results by normalizing the detection efficiency of experiments and simulations at a distance of 10 cm of the HPGe detector to 1 are shown in Fig 3. The comparison results by normalizing the detection efficiency of experiments and simulations at a distance of 3 cm of the CZT detector to 1 are shown in Fig 4. The dose rates measured at each distance are shown in

Fig 5. The results calculated from the geometry composer of HPGe detector and CZT detector are shown in Table 1-2.

As a result of analyzing the point source experiment of the HPGe detector, it was impossible to measure at a measuring distance of 3 cm and 5 cm. The reason is that the dead time is over 100 %. As a result of analyzing the point source experiment of the CZT detector, it was impossible to measure at a measuring distance of 100 cm. The reason is the low detection efficiency of the CZT detector. In both HPGe detector and CZT detector, detection efficiency decreased in the form of exponential functions as the measurement distances increased. As the measurement distance increased, the dose rate also decreased in the form of an exponential function.

As a result of comparing the experimental and simulated results of the HPGe detector, the average relative errors were 2.58 % for ^{137}Cs, 6.02 % for ^{60}Co, and 12.15 % for ^{152}Eu. The average relative errors of the CZT detector were 14.61 % for ^{137}Cs, 23.67 % for ^{60}Co, and 11.15 % for ^{152}Eu. The reason is that the CZT detector is small, so that even a slight difference in size between the simulated detector and the CZT detector greatly affects the efficiency.

The average error of radioactivity calculated by the geometry composer of the HPGe detector was 10.74 % for ^{137}Cs, 7.61 % for ^{60}Co, and 6.82 % for ^{152}Eu. The in-situ measurement method, under optimal conditions (well defined source) is capable of providing accurate results within 5–20%, while field conditions is capable of providing field accuracy of factors 1.3–2.0 or higher[1]. Therefore, the analysis results of HPGe detectors are considered reasonable.

The average error of radioactivity calculated by the geometry composer of the CZT detector was 21.24 % for ^{137}Cs, 13.17 % for ^{60}Co, and 8.83 % for ^{152}Eu. The reason why the average error of the CZT detector is large is that the closer the detector is, the more gamma rays are transmitted.

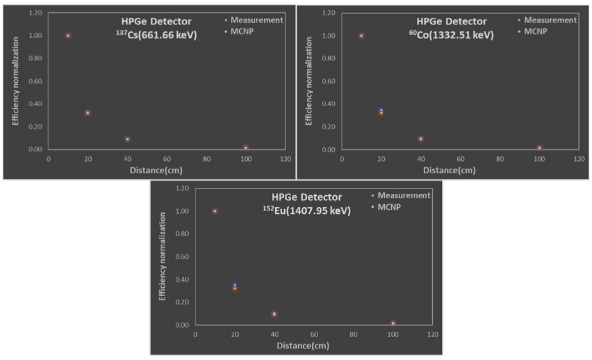

Fig. 3. Detection efficiency according to the distance between HPGe detector and point source

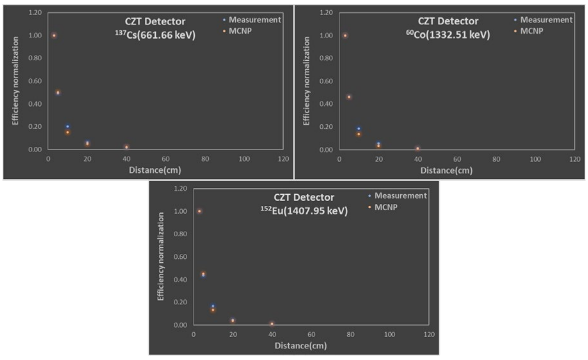

Fig. 4. Detection efficiency according to the distance between CZT detector and point source

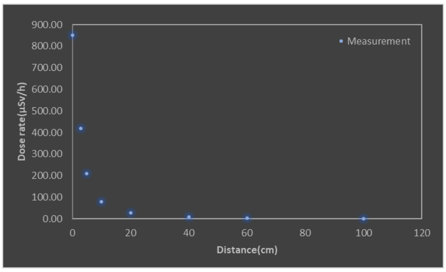

Fig. 5. Comparison of measured dose rates for point source

Table 2. Results of comparison with radioactivity calculated using HPGe detector Geometry composer

Nuclide	Point source radioactivity (Bq)	Distance (cm)	Geometry composer radioactivity (Bq)	Error (%)
^{137}Cs	3.31E+6	10	3.56E+6	7.59
		20	3.74E+6	12.82
		40	3.67E+6	10.68
		100	3.70E+6	11.86
^{60}Co	2.79E+6	10	2.69E+6	3.58
		20	2.99E+6	7.22
		40	3.01E+6	7.87
		100	3.12E+6	11.76
^{152}Eu	3.01E+6	10	2.71E+6	9.94
		20	3.05E+6	1.28
		40	3.21E+6	6.60
		100	3.29E+6	9.47

Table 3. Results of comparison with radioactivity calculated using CZT detector Geometry composer

Nuclide	Point source radioactivity (Bq)	Distance (cm)	Geometry composer radioactivity (Bq)	Error (%)
^{137}Cs	3.31E+6	3	1.89E+6	42.84
		5	2.11E+6	36.20
		10	2.83E+6	14.48
		20	3.21E+6	2.96
		40	3.63E+6	9.72
^{60}Co	2.79E+6	3	2.11E+6	24.20
		5	2.17E+6	22.34
		10	2.82E+6	1.14
		20	2.96E+6	6.09
		40	3.13E+6	12.06
^{152}Eu	3.01E+6	3	2.53E+6	15.80
		5	2.64E+6	12.22
		10	3.05E+6	1.46
		20	3.16E+6	5.18
		40	3.29E+6	9.47

4. Conclusions

A basic research was conducted to evaluate the effect of each measurement condition using HPGe detector and CZT detector in order to make appropriate in-situ measurements in a high-radiation environment during operation and decommissioning of nuclear facilities. As a result of confirming the analysis reliability of the point source experiment by MCNPX simulation, the average relative error of the entire nuclide was 6.92% for HPGe detector and 16.48 % for CZT detector. When the radioactivity was calculated using the geometry composer, it was confirmed that the HPGe detector could analyze the radioactivity within 13% of the average relative error and the CZT detector within the average relative error of 21.24 %. If the results of this research are used for on-site measurement of high-radiation environment during operation and decommissioning of nuclear facilities, it is expected that they can be used as basic data for deriving appropriate measurement conditions. In order to secure analysis reliability in the future, additional research that combines signal processing and artificial intelligence technology should be performed.

REFERENCES

[1] Idaho National Engineering and Environmental Laboratory INEEL, ISOCS for Free Release, INEEL. Innovative Technology Summary Report, 2001.