Preparation of Gamma Spectrum Dataset by Monte Carlo Simulation for AI-based Radiological Characterization

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1. Introduction

The operation of nuclear power plant unavoidably entails radioactive waste. According to recent Korean national power supply plan, expected amount of low-intermediate level radioactive waste is about 700,000 to 800,000 drums [1]. For disposal of the wastes, radiological characterization must be conducted to determine the concentration of radionuclides in the waste drum. As increase in the amount of radioactive waste, errors in characterization also occur frequently, e.g., data loss, misuse of scaling factors, and inappropriate measurement processes. Anomaly detection techniques based on machine learning is useful to alleviate these errors.

The machine-learning-based technique, however, requires a huge number of datasets in pairs of concentration of radionuclides in the waste and its gamma-ray energy spectrum. The massive datasets can be efficiently produced by following process: selecting representative nuclides included in radioactive waste, obtaining spectra for each nuclide through simulation, and summing the spectra according to the nuclide concentration of the waste. In the present study, a simulation spectrum correction method was developed to well imitate the experimentally obtained spectrum. The methodology was verified by comparing the spectrum obtained by experiment, by naïve simulation, and by simulation with correction method.

2. Materials and Methods

A high purity germanium (HPGe) detector (GR6022; CANBERRA) was used to obtain gamma-ray energy spectrum. A ^{60}Co point-like source (5.74 µCi) placed at the distance of 7.5 cm was measured for 1800 s in live time. Geant4 Monte Carlo simulation toolkit [2] (version 11.0) was used to obtain a simulated energy spectrum under the same condition as the experiments. The detector and its simulated model are shown in figure 1.

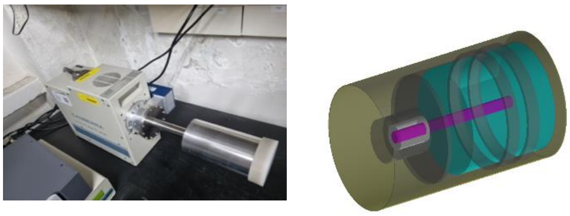

Fig. 1. High purity germanium detector (left) and its simulated model by Geant4 (right)

For the simulation, each primary particle was assumed to correspond to a single decay of radionuclide; so that all simulation results were supposed to contain time information following the activity of the radionuclide in the experiment. The ordinal number to each primary particle event absorbed by the detector during the simulation is expressed as event number in this study. We converted the event number into appropriate time information expected to collapse depending on the radioactivity of the radioactive material, and determined whether the time information overlaps with the detector dead time and charge collection time. The dead time of the detector generally depends on the physical characteristics of the detector. The configuration method of the signal processing system, and the equipment used in this experiment was evaluated. Due to the characteristics of an analog-to-digital converter (ADC), the dead time for each signal may vary depending on the signal size, but this study didn't consider this variation. The Monte Carlo simulation spectrum data was corrected by deleting or overlapping of recorded primary particle energy data was conducted. The energy broadening was also considered to match energy resolution of the detection system.

3. Results

As the actual experimental environment, when multiple reactions occur within a short time interval, the reactions within the charge collection time (under 0.7 µs) are summed by the pulse pile-up effect and the reactions during the dead time (0.7–30.7 µs) after the charge collection time are ignored and deleted. Figure 2 shows the comparison of energy spectra between experimental result (black) and simulation result with correction (red). The corrected spectrum well matched with experimental one, not only for lower energy region of gamma-ray energy of ^{137}Cs(662 keV), ^{60}Co (1173, 1332 keV) but also for higher energy region which is mainly contributed by coincidence sum due to the dead time. There was a tendency to increase in uncertainty of the spectrum for higher energy region, which can be improved by increasing the number of primary particles in the simulation.

4. Conclusion

In the present study, the correction of simulated energy spectrum well imitated the experimental one, in terms of count loss, coincidence sum, and energy broadening. With additional tests using multiple radionuclides, the correction method will be applicable to efficiently generate a huge number of datasets in pairs of concentration of radionuclides in the waste and its gamma-ray energy spectrum.

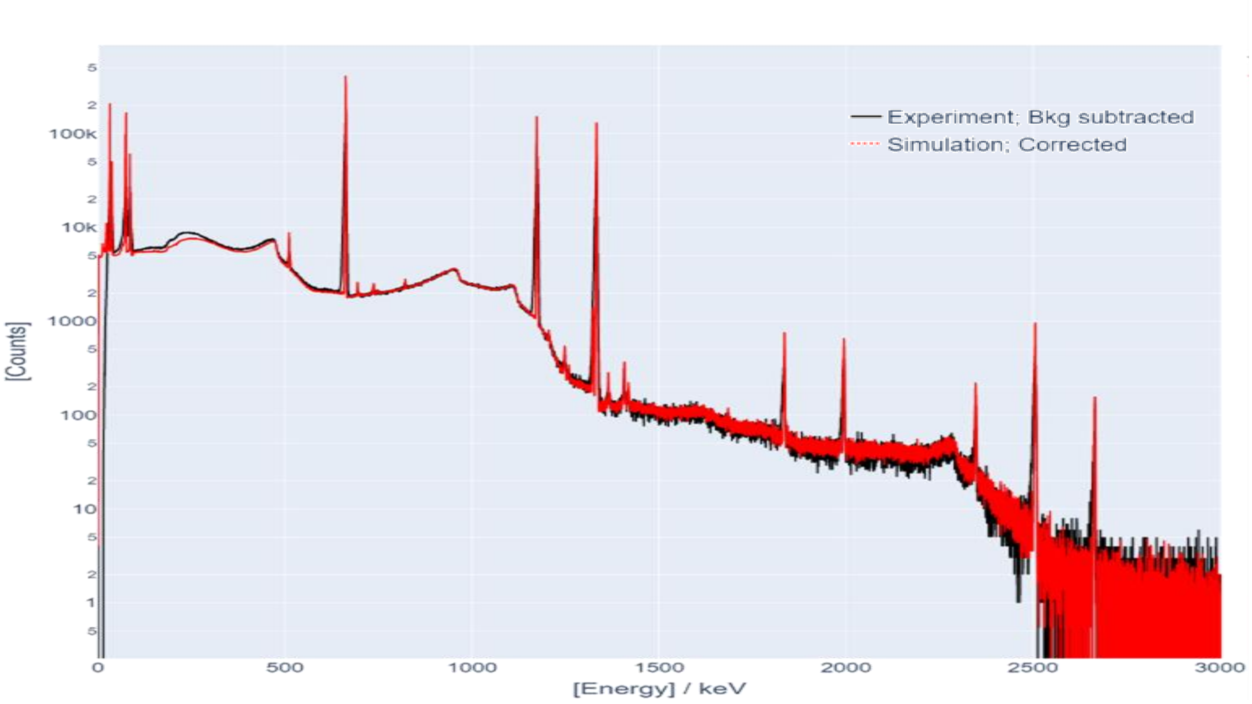

Fig. 2. Comparison of gamma-ray energy spectrum of ^{60}Co and ^{137}Cs source, experiment (black), simulation with correction (red)

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