Development of High-throughput Multi-detector System for Rapid Clearance Verification of Decommissioned Soil Waste

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1. Introduction

The decommissioning of a single nuclear power plant (NPP) unit generates approximately 17,000 tons of contaminated soil, a significant portion of which is eligible for self-disposal[1]. To ensure efficient site remediation within a limited timeframe, it is essential to rapidly classify large volumes of soil based on their radioactivity levels. According to the Nuclear Safety and Security Commission (NSSC) notice[2], the measurement system must achieve a minimum detectable activity (MDA) below 0.01 Bq/g, which is one-tenth of the regulatory clearance level. In this study, we developed and evaluated a high-throughput multi-detector system designed for the rapid and accurate quantification of ^{137}Cs and ^{60}Co to facilitate the clearance verification of decommissioned soil waste[3].

2. Methods & Materials

2.1 System Configuration

The developed system is a dual-stage integrated platform designed to rapidly classify large volumes of soil waste based on their radioactivity levels. As shown in Fig.1, the integrated system features a T-shaped conveyor layout that synergizes a high-speed screening unit (3×3 NaI(Tl) array) and a high-precision quantification unit (dual HPGe detectors) to optimize the clearance process. The high-speed unit, designed for rapid throughput, utilizes a 3x3 array of NaI(Tl) detectors, each featuring a crystal size of 146x146x25.4 mm^3. To ensure uniform light collection and high energy resolution, a square frustum light guide with a height of 110 mm was integrated. This configuration was optimized through Monte Carlo simulations to maximize detection efficiency for fast nuclide identification. The high-precision device, intended for final verification of soil below the clearance level, employs two High-Purity Germanium (HPGe) detectors. To minimize the background interference, each detector is encased in a 50 mm thick lead shield. The geometry and shielding were designed to achieve a Minimum Detectable Activity (MDA) of less than 0.01 Bq/g for ^{137}Cs and ^{60}Co, which corresponds to less than one-tenth of the regulatory clearance level.

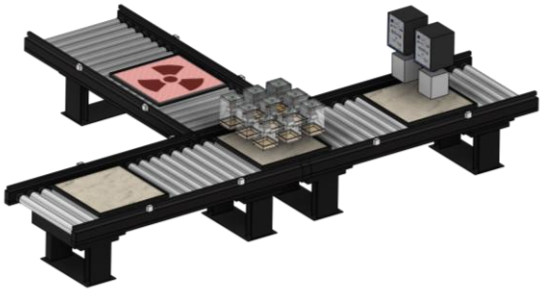

Fig. 1. 3D modeling of the developed soil classification system featuring the high-speed NaI(Tl) array and high-precision HPGe detectors.

2.2 Experimental Evaluation

The MDA was evaluated under the condition that the sample container was fully filled with soil, with the background count rate and absolute efficiency determined experimentally. Fig. 2a shows the background energy spectrum, where the background counts in the ROIs for ^{137}Cs and ^{60}Co were measured at 12,762 and 8,918, respectively. To determine the absolute efficiency, measurements were conducted using a soil Certified Reference Material (CRM) containing both ^{137}Cs and ^{60}Co. Fig. 2b presents the net count energy spectrum of the CRM, yielding absolute efficiencies of 0.0150 for ^{137}Cs and 0.0053 for ^{60}Co. Based on these parameters, the high-speed unit achieved an MDA of 0.01 Bq/g for both nuclides. This result meets the detection target of one-tenth of the regulatory clearance level.

The system's quantification performance was further validated using a 46-kg soil waste sample (75×75×9 cm^3) with a certified 137Cs concentration of 0.563 Bq/g. For a 60-second measurement, the system estimated the ^{137}Cs concentration to be 0.641 Bq/g. This 13.85% relative difference from the certified value demonstrates that the high-speed unit provides a reasonable level of accuracy for rapid radioactivity classification within a short measurement timeframe.

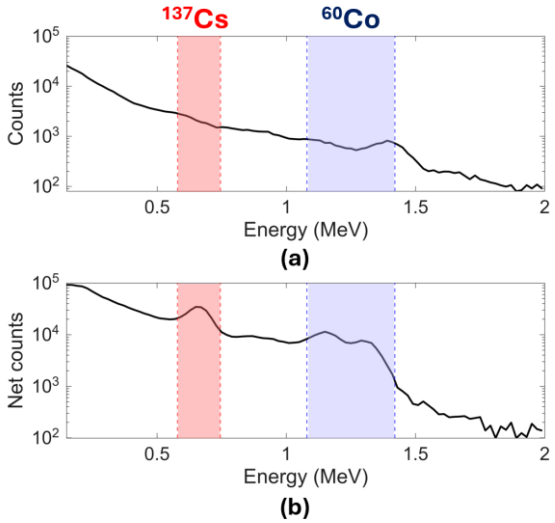

Fig. 2. Energy spectrum of the background radiation (a) and the soil CRM (b), measured by a high-speed screening unit

3. Conclusions

In this study, we developed a high-throughput multi-detector system designed for the rapid clearance verification of decommissioned soil waste. By integrating a high-speed NaI(Tl) screening unit with a high-precision HPGe quantification unit, the system achieved a processing capacity of 3.5 tons/hour and a minimum detectable activity (MDA) of 0.01 Bq/g. This performance satisfies the regulatory requirement of one-tenth of the clearance level for both ^{137}Cs and ^{60}Co. Experimental validation using contaminated soil samples demonstrated that the system can accurately quantify radioactivity within a 60-second measurement window, showing a reasonable error rate of 13.85%. This dual-stage technology provides a robust and efficient solution for managing large-scale contaminated soil, significantly accelerating site remediation while reducing the economic burden of radioactive waste disposal.

REFERENCES

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