Performance Evaluation of Mobile Gamma Monitoring System for Direct Measurement and Scanning of Decommissioning Site

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1. Introduction

Decommissioning of nuclear power plants (NPPs) have become important in Korea, so as to ensure public safety until site release. While it was determined that dose rate below 0.1 mSv/y is criteria for releasing decommissioning site, radiological survey is needed to estimate radionuclide concentration on surface materials (e.g., soil, concrete, metal…) throughout the entire process. The process includes historical site assessment, scoping survey, characterization, remedial action support, and final site release. In this case, a mobile system can make survey procedures more effectively and efficiently, by enabling both direct measurement and scanning of wide area of NPP decommissioning sites. Therefore, in this study, we develop a mobile gamma monitoring system, which is suitable to such mission, with large effective area and low cost. Also, we quantitatively assess the system performance by assuming several on-site measurement scenario.

2. System design

2.1. Compton suppression spectrometer

The gamma spectrometer deployed in mobile gamma system consists of primary detector and guard detector, that is, two NaI(Tl) and three polyvinyltoluene (PVT) scintillators, respectively. Geometry of the scintillators and shield, housing is shown in Fig. 1 [1].

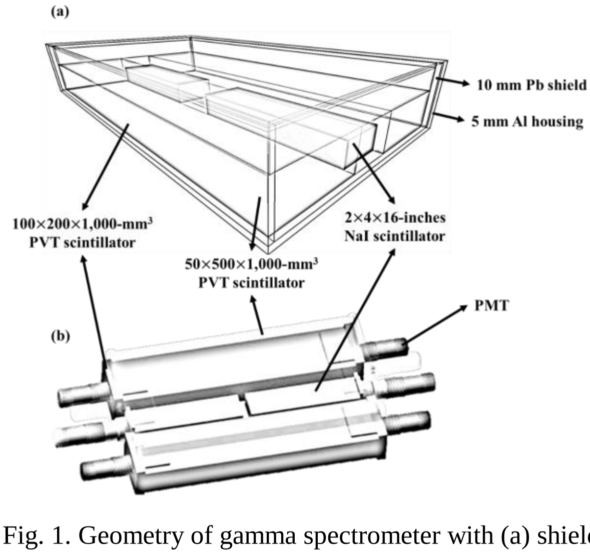

Fig. 1. Geometry of gamma spectrometer with (a) shield and housing, and (b) PMTs [1].

By configuring anti-coincidence circuit between the primary and guard detectors, the spectrometer can significantly deny acquisition of counts, which is made from Compton scattering.

2.2. Mobile trailer

The Compton suppression spectrometer in Section 2.1, in combination with gross alpha and beta detector made from ZnS(Ag) and PVT, is conveyed on a mobile trailer. The trailer can control the height of each detector from surface materials by using programmable logic controller, and can be transported by a car. Detailed geometry of the trailer is shown in Fig. 2.

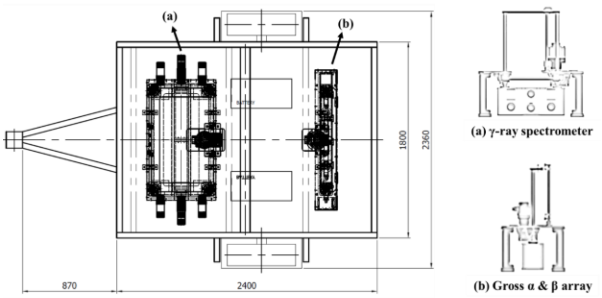

Fig. 2. Mobile trailer with (a) gamma spectrometer and (b) gross alpha and beta array (unit: mm) [1].

3. Experimental methods

Among surface materials considered in nuclear decommissioning, we choose agricultural soil as target material for experiment, which occupies absolute majority of quantity except building materials generated from NPPs. Thus, some important features such as scanning coverage will be evaluated more reasonably for soil than other surface materials.

3.1. Direct measurement scenario

Three contamination scenarios were set to evaluate direct measurement performance, including surface-only contamination, heterogeneous contamination, and depth profile contamination, varying concentration and depth. We used solid check sources as a surrogate, with radioactivity of 9.25 kBq and 37 kBq for ^{137}Cs and ^{60}Co, respectively. By positioning the sources onto acrylic frame, different set of radiological contamination samples were fabricate, as shown in Fig. 3 [1].

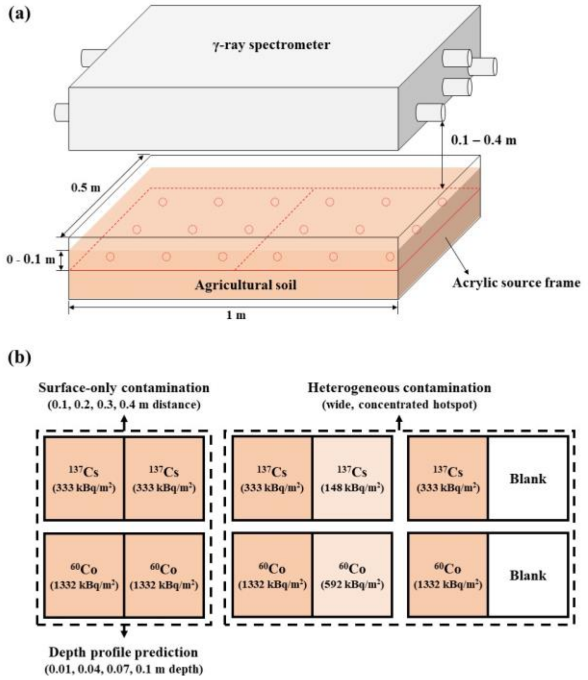

Fig. 3. (a) Dimensions and (b) concentration of fabricated surrogate samples.

3.2. Scanning scenario

At first, we calculated scan minimum detectable concentration (MDC), by using equation defined in Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [2,3].

$$\text{Scan MDC } [\text{Bq/m}^2] = \frac{MDCR_{95\%,60\%}}{\sqrt{p}\,\varepsilon_p A}, \quad (1)$$

where:
- $MDCR_{95\%,60\%}$ is the minimum detectable count rate with 95% true positive and 60% false positive (s^{-1}),
- p is the surveyor efficiency.
- A is the area of detector (m^2).

Here, we set surveyor efficiency as 0.5, and photopeak efficiency from calibration results during test of direct measurement scenario. We then verified whether the theoretical result fit well with results from field test. In case of filed test, especially, we defined different hotspot size but the same survey unit size (Fig. 4).

Fig. 4. Field test of the mobile system with a car.

4. Results and discussion

In case of surface-only contamination, the calibration results of photopeak efficiency made error less than 4% for 0.1 m distance, when comparing with MCNP6 simulation results [4] as in Fig. 5 [1].

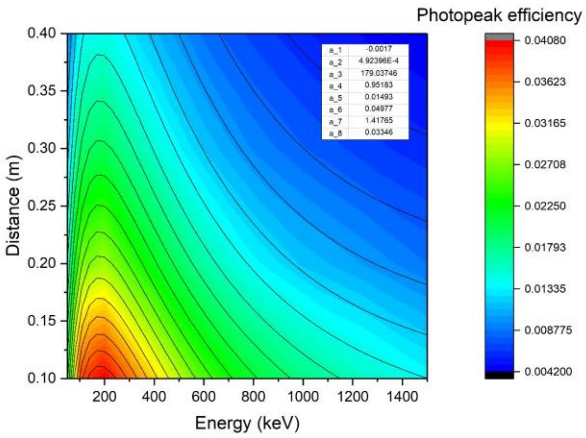

Fig. 4. Field test of the mobile system with a car [1].

For heterogeneous contamination, each side of two NaI(Tl) showed its representativeness by detecting perpendicularly contacted soil with 0.1 m distance, within 15% error against actual concentration. Moreover, if we use peak-to-Compton ratio method, the system could predict vertical contamination profile of up to 0.1 m depth with sensitivity about 1.7, despite of low resolution of NaI(Tl).

(7)

The theoretical scan MDC result implied that the system would be operated well up to 5 m/s based on 0.1 mSv/y criteria and derived Kori-1 concentration guideline levels (DCGLs). However, it should be noticed that such tendency will not be found unless the hotspot is fairly distributed homogeneously. For example, when we defined same radioactivity concentration with Kori-1 DCGLs with solid check sources, the system could not detect their existence, because in most case the source was located outside lead shielding surrounding gamma spectrometer.

5. Conclusion

In this study, we developed a mobile gamma monitoring system suitable to surveying wide area decommissioning sites. Especially, the system was tested for direct measurement and scanning scenario. Both scenario showed that the system can find spatial and vertical contamination or hotspot unless its moving velocity exceeds 5 m/s or the hotspot area is extremely heterogeneous. In the future, we will analyze various field test data to find optimal procedure quantitatively, for detecting hotspot in any conditions timely while moving.

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