New Concept of Rapid Radiation Monitoring: Transformable In-situ Gamma Monitoring Device (TRIGAM)

Min Sun Lee[a*], Mee Jang[a], Jong-Myoung Lim[a]
[a]*Environmental Radioactivity Assessment Team, Korea Atomic Energy Research Institute*
**Corresponding author: mlee1024@kaeri.re.kr*

1. Introduction

To prevent unexpected nuclear accidents including release of radioactive materials, it is important to conduct radiation monitoring around facilities [1]. The fixed radiation monitoring system provides stable and continuous monitoring data but limited in the specific area, so it is hard to track the origin of the accident. Hence, we come up with the importance of portable gamma monitoring system, which allows immediate scanning of the target area. However, it is still demanding and time-consuming to track the origin of accident because portable gamma monitoring device that consists of a single gamma detector can cover only a small area.

In this study, we propose a new concept of in-situ transformable radiation detection system that provides faster and more accurate monitoring results. This study covers conceptual design of the proposed design and a proof-of-concept simulation study.

2. Materials and Methods

2.1 Concept of Transformable In-situ Gamma Monitoring Device (TRIGAM)

We propose a new concept of TRansformable In-situ GAmma Monitoring device (TRIGAM). TRIGAM consisted of eight radiation detectors with stretchable and rotational arm. The red box in Fig.1 shows a basic unit of TRIGAM. A stretchable arm is attached on one side of a detector block and it can be adjusted from 5 to 20 cm. At the two-ends of the stretchable arm, a rotation gear is attached with rotation range from -90° to +90°. This basic unit is repeated for eight times to build-up a full TRIGAM system.Compared to a single detector-based system, TRIGAM transforms its shape, resulting in site-specific radiation monitoring. Also, TRIGAM can boost its sensitivity up to ×8, resulting in faster and more accurate monitoring.

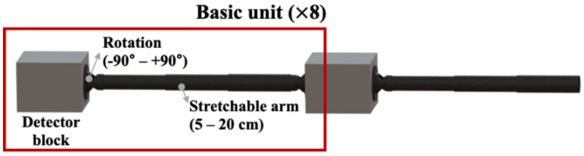

Fig. 1. Basic unit of TRIGAM consisted of stretchable and rotational arm.

2.2 Measurement modes of TRIGAM

Depending on the monitoring target, TRIGAM can be transformed into different shapes using stretchable and rotational arm. We categorized it into three modes: wide-range, high-sensitivity, and high-resolution.

2.2.1 Wide-range mode

Fig. 2 shows examples of the wide-range mode. When TRIGAM is stretched out in one direction, it can be extended into maximum 1.4 m, and this can be used for in-situ application for measuring underground soil profiles. For a wider area monitoring, TRIGAM can be transformed to cover area with the maximum size of 60×20 cm^2 by bending arms in 90° as Fig. 2(b). This wide-range mode allow faster monitoring in one shot, compared to that of a single detector.

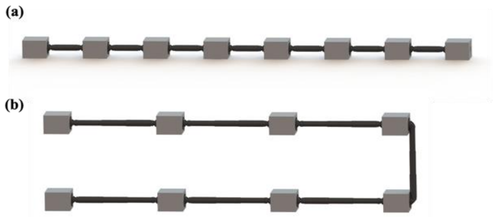

Fig. 2. TRIGAM in the wide-range mode.

2.2.2 High-sensitivity mode

The sensitivity of detector increases when the monitoring object and detector gets closer. However, it is hard to approach objects with atypical structures (e.g. long or circular structure, pile of earth) with a typical detector. Fig. 3(a) shows an example of high-sensitivity mode using a long TRIGAM to reach out a radioactive source in a pipe structure which is very difficult to access. TRIGAM can be also transformed to fit on the atypical shape as Fig. 3(b) to get closer and maximize sensitivity.

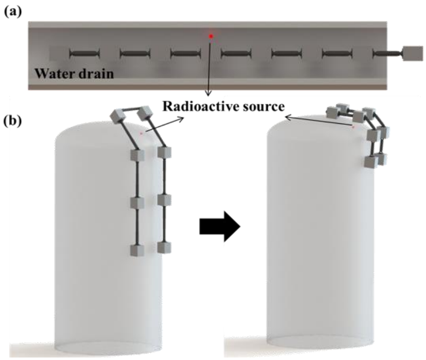

Fig. 3. TRIGAM in the high-sensitivity mode.

2.2.3 High-resolution mode (Imaging mode)

When TRIGAM is transformed into a cubical formation, it can be used for a high-resolution purpose. For the objects with hot spot placed within the TRIGAM as Fig. 4, we can better localize the hot spot. In this mode, the maximum object volume that can be measured is 20×20×20 cm^3 in the current design.

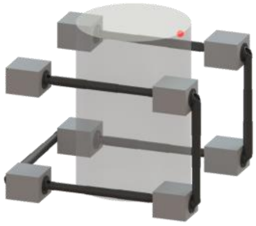

Fig. 4. TRIGAM in the high-resolution mode.

2.3 Simulation study

To validate proposed concept, a simulation study was conducted using GATE Monte Carlo simulation toolkit. The detector of TRIGAM consisted of 48×48×20 mm^3 GAGG crystal coupled with 8×8 SiPM array with 6 mm pixel size. The detector block was covered with 50×50×30 mm^3 plastic casing. Each stretchable arm was simulated to have a hollow pipe structure (ID=3cm, OD=3.5cm) composed with carbon fiber.

As a first scenario, a 2-m-long concrete pipe (ID=30cm, OD=40cm) was simulated with ^{137}Cs point source (37 kBq) located in the middle. The TRIGAM in wide-range mode with the length of 1.4 m was placed in the pipe and measured for 10 sec to figure out the contaminated area. For the second scenario, a cylindrical plastic structure (D=20cm, H=30cm) with a 1-cm-wide hot spot (^{137}Cs, 370 kBq) at two different positions were simulated. The TRIGAM in cubical formation as Fig. 4 and each detector block was placed 20 cm apart.

2.4 Proposed event positioning algorithm

In typical, weighted mean detector responses (8×8, tot. 64 ch in this study) is used to find gamma interaction position within a detector. Here, we suggest to use maximum likelihood (ML)-based positioning algorithm to further improve the gamma positioning. We assume that each 8×8 detector response follows individual Gaussian distribution: i^{th} channel of a detector has characteristic μ_i and σ_i value at different interaction position $\vec{d}$=(x, y). Look-up table of μ and σ at each i^{th} channel is generated by irradiating detector at 24×24 interaction position using a collimated source. Finally, te interaction position ($\vec{d}$) can then be estimated from an ML estimate, $\hat{\vec{d}}$, which maximizes the below likelihood function for a single event [2].

$$\hat{\vec{d}} = \underset{\forall\vec{d}}{\arg} \underset{\vec{d}=\vec{d}}{\min} \sum [\frac{(s_i - \mu_i(\vec{d}))}{2\sigma_i^2(\vec{d})} + \ln \sigma_i(\vec{d})]$$

Gamma heat maps can be simply generated by using count rate of 24×24 gamma positions. For the high-resolution mode, 3-D gamma position can be further calculated by weighting with geometrical position of each detector. Moreover, since TRIGAM provides gamma spectroscopy, heat map can be generated for the whole energy range or for the specific radionuclide.

3. Results and Discussion

3.1 Simulation scenario 1: Gamma mapping

As a common application of TRIGAM, we can simply generate a heat map based on the count rate of each detector block. Fig. 5 shows the 1-D gamma heat map and its depth profile as a result of simulation, indicating that there is a radioactive material at the center.

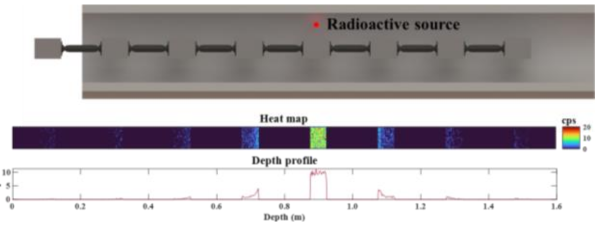

Fig. 5. 1-D gamma mapping results using wide-range TRIGAM.

3.2 Simulation scenario 2: Gamma imaging

We generate a 3-D heat map based on the geometrical position and count rate of each detector block, using a high-resolution mode of TRIGAM. When a hot spot was located near the middle of the TRIGAM structure (Fig 6(b)), source position was estimated almost same to the true source position. However, when a hot spot located near to the detector, there was about 5 – 10 mm offset from the true source position.

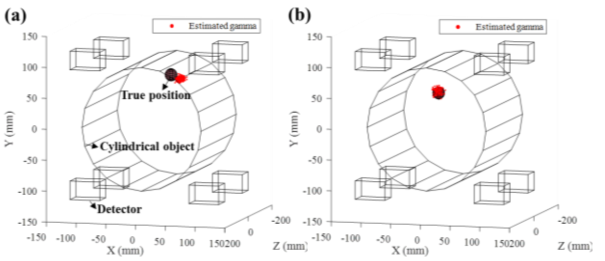

Fig. 6. 3-D gamma mapping results from high-resolution mode TRIGAM. A cylindrical object marked with true source position (1 cm sphere) and estimated gamma position (red dots).

4. Conclusion

In this study, we suggest a new concept of in-situ gamma monitoring device. The proposed TRIGAM design provides transformable structure, which will act as a powerful monitoring tool in urgent situations which requires immediate scanning. Not only three different measurement mode suggested in this paper, TRIGAM can be used in various situations depending on its purpose. Moreover, once TRIGAM mounts collimator on the top face, it can be also utilized as a multi gamma camera with transformable geometry.

REFERENCES

[1] Brown *et al* 2016 Safecast: successful citizen-scinence for radiation measurement and communication after Fukushima *J Radiol. Prot.* **36** S82.
[2] Lee *et al* 2015 Depth-of-interaction measurement in a single-layer crystal array with a single-ended readout using digital silicon photomultiplier *Phys. Med. Biol.* **50** 6495-514.