Development of a Compact Spherical CsI(Tl)-SiPM Detector with Isotropic Response for Environmental Radiation Monitoring

Jeonghoon Lee[1], Yoon Soo Chung[1], Juwan Kang[1], Jiwon Ra[1], Yong Hyun Chung[1]

[1]*Dept. of Radiation Convergence Engineering: Yonsei University, Republic of Korea*
Corresponding Author Email: ychung@yonsei.ac.kr

Radiological accidents and the expanding use of radioactive materials are increasing the risk of radioactive contamination and the resulting threats to human health and the environment. Accordingly, there is a growing need for environmental radiation monitoring technologies that can enable early detection and reliable assessment of radiological emergencies. However, conventional environmental radiation monitoring systems typically based on cylindrical NaI(Tl) scintillators have the following limitations: (1) the cylindrical geometry increases the direction-dependent (angular) response, causing fluctuations in dose rate estimates and requiring additional angular correction, and (2) the use of photomultiplier tube (PMT) makes the system bulky. To address these limitations, we propose a novel spherical radiation monitoring system that combines a spherical scintillator for isotropic sensitivity with a silicon photomultiplier (SiPM) readout for compactness and simplified integration. This configuration enables radiation detection from all directions and facilitates flexible and scalable deployment of monitoring networks.

In the simulation stage, CsI(Tl) was adopted as the scintillator material because (1) its high density increases the gamma-ray interaction probability, which is advantageous for achieving sufficient sensitivity even in a compact volume, and (2) its high light yield is beneficial in terms of photon statistics. System performance was evaluated through simulation. Optical-photon transport and radiation-transport simulations were performed using the Geant4 Application for Tomographic Emission (GATE) toolkit. The proposed detector consists of a 60-mm-diameter CsI(Tl) scintillator coupled to a 3×3 array of 6×6 mm^2 SiPM.

The simulation study follows a three step scintillator optimization procedure. (1) reflector material and surface treatment conditions were optimized to maximize light collection efficiency while minimizing optical non-uniformity. (2) under the optimized optical configuration obtained in (1), a diameter providing the most appropriate balance between sensitivity and energy resolution was determined. (3) using the optimized reflector, surface treatment, and diameter conditions, directional response uniformity was quantitatively evaluated for multiple gamma ray incidence directions. The proposed system is broadly applicable to diverse environments, including underwater monitoring, soil contamination assessment using vehicle-mounted platforms, and aerial radiation surveys using drones. By integrating isotropic detection with a compact design based on SiPM readout, the system can enhance environmental radiation monitoring capability and contribute to improved preparedness for both radiological emergency response and routine radiation safety operations.

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