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Spectral Analysis Method of Plastic Scintillator-based Radiation Detector against Nuclear/Radiological Terrorism

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1. Introduction

In these days, the threats relating to nuclear or radioactive materials have become a matter of internationally increased grave concern. A plastic scintillation detector in radiation portal monitoring (RPM) application has been used to detect radioactive sources in steel scrap entering reprocessing facilities, and to detect illicit transport of radioactive material across border ports-of-entry. The detection systems for RPM application usually are large and can not easily be moved to a different location. For some situations, an inconspicuous and mobile system for the radioactive or nuclear material during road transport is needed. The mobile radiation detection system has employed a NaI-based radiation detector to detect and identify the material hidden in vehicle [1]-[2]. There are some operational constraints - short measuring time, weak activity due to heavy shield of illegal source, long distance - of inspection system in such nuclear security applications [3]. Due to these constraints, large area sensor is required to maximize its sensitivity. Large NaI material, however, is extremely expensive. In designing a radiation detector for prevention of illicit trafficking of nuclear or radioactive materials, the trade-off should be carefully optimized between performance and cost in order to achieve cost-effective inspection system. For the cost-effective mobile radiation detection system, this paper describes new spectral analysis method to use the crude spectroscopic information available from a plastic detector to discriminate other man-made radiation source from NORM.

To determine optimal edges of energy regions, spectral distributions of various radioactive sources are simulated by Monte Carlo transport code, MCNPX and segregated into several regions [4]. From sub-regions of a spectral distribution, a count density of each region is calculated and the target material is identified by using the determined location of Compton edge. Experiment using a plastic detector of 5.7cm x 30cm x 30cm and several sources has been conducted to verify the method discussed in this paper.

2. Theoretical Calculation

To compare performance of three detectors (two NaIs and one plastic detectors), absolute detection efficiency (the number of pulses recorded divided by the number of radiation quanta emitted by source) was calculated by using Monte Carlo simulation code, MCNPX. For two NaIs, one has 7.62cm (3 inch) diameter x 7.62 cm (3 inch) length and the other 10.16cm(4 inch) x 10.16cm(4 inch) x 40.64cm (16 inch). BC-412 is one of plastic scintillation materials. Two 30cm x 30cm x 5.7cm BC-412 plastic scintillators are used as a detector sensor. At distance of 1m from a detector, gamma-ray is isotropically emitted. Fig.1 shows absolute detection efficiency of three different detectors as function of incident photon energy. As shown in Figure 1, BC-412 plastic scintillator has higher absolute detection efficiency than other two commercial NaI sensors. It indicates that the plastic detector could be more superior for detecting illicit materials in fast moving vehicle in order to inspect whether any radioactive material is present in a vehicle.

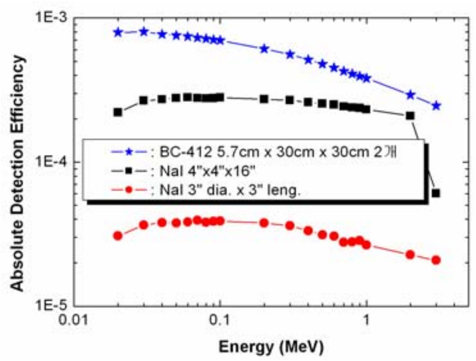

Fig. 1. Absolute detection efficiency of three different detectors

To estimate spectrum of plastic scintillator and to divide it into several regions, theoretical calculation was carried out by Monte Carlo simulation code, MCNPX. In simulation, radioactive sources were placed at the center of a plastic scintillator with size of 5.7cm x 30cm x 30cm. The distance of the sources from the detector is 100cm and the type of plastic material is BC-412. The spectra for several sources were obtained from a pulse height tally (tally type 8). For simulation, several sources (Co-57, U-235, Ir-192, Ba-133, Cs-137, Co-60, K-40) are selected because their gamma-rays span energy region of interest, and they emulate sources of concern. The Gaussian Energy Broadening parameters (a, b, c) used in this simulation had values (0.0, 0.114, 0.0) for PVT. For more reasonable calculation, the parameter should be determined from experimental results because the peak-broadening effect of spectra depends on the properties of a detection system (dimension and material of a detector, characteristics of data acquisition system etc.)

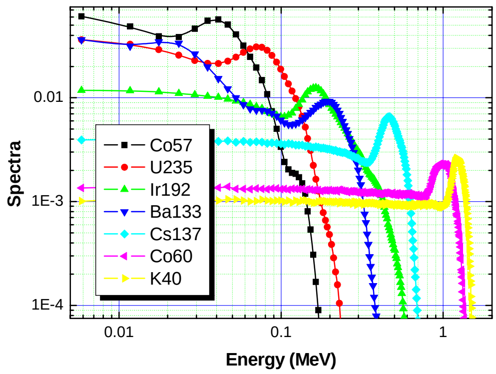

Fig. 2. Spectral distribution calculated by MCNPX

Figure 2 is spectral distributions of several isotopes calculated by MCNPX. Figure 2 shows that the Compton edge of each isotope can be distinguished from other Compton edges and the number of counts around the Compton edge in a given spectrum is large. To identify more clearly radioactive sources in Figure 2, the spectrum obtained with plastic scintillator is divided into seven regions as follows ; less than 0.02 MeV, 0.02 ~ 0.130 MeV (G1), 0.130 ~ 0.3 MeV (G2), 0.3 ~ 0.6 MeV(G3), 0.6 ~ 1.2(G4) MeV, more than 1.2 MeV (G5). The counts in region less than 0.02 MeV aren't considered in discussion because they might be mainly due to electronic noise and the Compton scattering reaction deposited only low energy.

3. Experiment

To verify spectral analysis method discussed in previous section, spectra of various sources was measured with plastic scintillation detector of 5.7cm x 30cm x 30cm. The light generated in a plastic scintillator by gamma-ray is converted into electronic signal by photomultiplier tube (PMT). The distance of the sources from the detector is 100cm. Activity of sources is in the range of 7 μCi to 10 μCi. The amount of national uranium is 0.5 kg.

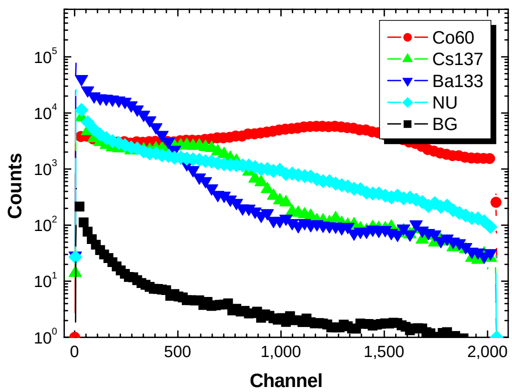

Fig. 3. Spectral distribution obtained with BC-412 plastic scintillator.

As shown in Figure 3, Cs-137 and Co-60 have clear peaks. Ba-133 decreases sharply beyond Region 3. The count due to background reduces constantly over the whole energy range. The targeted material (Cs-137, Co-60, Ba-133, NU) can be discriminated from background by using this difference.

4. Results and Discussion

To distinguish the targeted materials from background or NORM(nationally occurring radioactive material), spectral distribution obtained with plastic scintillator was divided into several regions based on the Monte Carlo simulation. The identification of the dangerous targeted radioactive sources was possible by analyzing the count number in each sub-region.

The mobile radiation detection system adopting the spectral analysis discussed in this paper will reduce the number of nuisance alarms due to acceptable or innocent source such as NORM or medical radioisotopes. This system can also improve the detection capability of illicit trafficking of nuclear or radioactive materials without impeding normal traffic flow and contribute to protecting the public health, safety and the environment against nuclear/radiological terrorism.

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