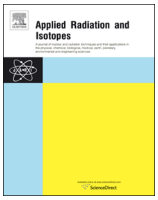
Applied Radiation and Isotopes 107 (2016) 160–164

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Validation of energy-weighted algorithm for radiation portal monitor using plastic scintillator

Hyun Cheol Lee [a], Wook-Geun Shin [a], Hyo Jun Park [a], Do Hyun Yoo [a], Chang-Il Choi [b], Chang-Su Park [b], Hong-Suk Kim [b], Chul Hee Min [a,*]

[a] *Department of Radiation Convergence Engineering, Yonsei University, Korea*
[b] *Radiological Emergency & Security Preparedness Department, Korea Institute of Nuclear Safety, Korea*

HIGHLIGHTS

- Energy spectra of ^{133}Ba, ^{137}Cs, ^{22}Na, and ^{60}Co were measured by a plastic scintillator.
- All energy spectra were converted to energy weighted spectra having clear peaks.
- Compared with theoretical value, the peaks have a maximum error of 6%.
- For validation, measurement with distance and shielding was also evaluated.

ARTICLE INFO

Article history:
Received 2 April 2015
Received in revised form
5 October 2015
Accepted 15 October 2015
Available online 19 October 2015

Keywords:
Monte Carlo simulation
Plastic scintillator
Energy weighted count
Radiation portal monitor

ABSTRACT

To prevent illicit tracking of radionuclides, radiation portal monitor (RPM) systems employing plastic scintillators have been used in ports and airports. However, their poor energy resolution makes the discrimination of radioactive material inaccurate. In this study, an energy weight algorithm was validated to determine ^{133}Ba, ^{22}Na, ^{137}Cs, and ^{60}Co by using a plastic scintillator. The Compton edges of energy spectra were converted to peaks based on the algorithm. The peaks have a maximum error of 6% towards the theoretical Compton edge.

1. Introduction

Nuclear terrorism is a concern of worldwide interest, and so world communities such as the Nuclear Security Summit and the Global Initiative to Combat Nuclear Terrorism have been organized to improve the international security of all nuclear material and other radioactive sources (Abedin-Zadeh et al., 2014; Guthe, 2014; Kwak et al., 2010). Illicit radioactive material could be imported at border crossings or ports/airports where vehicles and cargos pass through. Radiation portal monitor (RPM) systems have been used for border monitoring at checkpoints (McLay et al., 2011).

An RPM system employs a large radiation detector to allow the screening of large cargos. Polyvinyl toluene (PVT) is preferred as a scintillator material because of its excellent formability and relatively low manufacturing cost; inorganic scintillator materials such as NaI(Tl) and CsI(Tl) are more expensive and are limited in size (Burr et al., 2007). However, PVT is mainly composed of hydrogen and carbon, and thus is of low electron density; accordingly, PVT's photoelectric effect has fairly low quantum yield. Because the photoelectric effect is crucial in allowing energy prediction of incident gammas, PVT's poor quantum yield leads to poor energy resolution relative to that of highly electron-dense inorganic scintillators. As a result, although RPMs are highly sensitive, they are not highly selective; their poor energy resolution can allow innocent alarms to be caused by naturally occurring radioactive materials (NORM), and such alarms could seriously interrupt logistics when vehicles are held for extensive investigation to investigate the alarm further. Frequent false alarms and innocent alarms may render a monitoring system practically useless.

To distinguish artificial radioactive materials from NORM, an energy window (EW) method can be added to the gross count (GC) method (Ely et al., 2006), which is the fundamental function of RPM alarming whereby counts are measured during vehicles passing, and an alarm is raised if the counts exceed a certain threshold over the background counts. The EW method utilizes information in the measured energy spectra regarding the

---

[*] Corresponding author. Fax: +82 33 760 2891.
E-mail address: chmin@yonsei.ac.kr (C.H. Min).

http://dx.doi.org/10.1016/j.apradiso.2015.10.019

different Compton edge energies that correspond to different incident gamma energies. The energy spectrum is divided into several regions and the relative ratio between the regions caused by the broad Compton edge may allow rough estimation of the energy region of the incident gamma. However, it is still quite difficult to discriminate isotopes with similar energy, such as ^{60}Co (1.17/1.33 MeV) and ^{40}K (1.461 MeV) by using the EW method. Even though the EW and the GC are currently the main method in a commercial RPM system, there are other trials to distinguish the isotopes based on mathematical model algorithms using principal components' analysis or artificial neural networks (Runkle et al., 2006; Kangas et al., 2008); GAmma Detector Response and Analysis Software (GADRAS) using template-matching (Mitchell and Mattingly, 2008); algorithm with time-series and spectral filtering (Robinson et al., 2009). However, they are not matured yet to become commercialized.

To accurately determine the gamma energy with PVT, we proposed an isotope-based discrimination algorithm by employing energy-weighted counts (EWC) in the previous study (Shin et al., 2015). The aim of this study is to evaluate the principle by means of Monte Carlo simulations and experiments that radionuclides of similar Compton edge energy can be distinguished by converting the broad Compton edges to narrow and sharp peaks with EWC. The practical effect of the source-to-RPM distance and the shielding is also experimentally evaluated.

2. Materials and methods

2.1. Monte Carlo simulation

To simulate the RPM system, the Geant4 toolkit was employed to assess the energy spectra for four radionuclides: ^{133}Ba, ^{22}Na, ^{137}Cs, and ^{60}Co. Geant4 using the Monte Carlo method enables us to simulate the transport of optical photons. All radionuclides were assumed to be point sources located 2 m from a PVT scintillator (Model EJ-200 by Eljen Technology, USA) of $100 \times 50 \times 5$ cm^3 (height × width × depth); the density of the PVT was set at 1.032 g/cm^3 and the wavelength of maximum emission of optical photons was set at 425 nm. The PVT was wrapped with reflective polytetrafluoroethylene tape of 1.2 mm thick; the PVT's scintillation efficiency was set at 10,000 photons/MeV (E. technology, 2006). To compare the four isotopes, the isotropic emission of 10^8 photons from the source location was simulated for the representative energy of each isotope, and the optical photons generated by the photon-induced interactions in the PVT scintillator were collected at a photomultiplier tube (PMT) of 50 mm diameter and 100 mm height (Fig. 1).

For energy calibration of the PVT scintillator, 1 MeV monoenergetic gammas were delivered to the scintillator and the biasing technique forcing only the photoelectric effect was employed in the Monte Carlo simulation. The peak of the optical photon distribution was assumed as 1 MeV and the calibration factor of 5.26 keV/channel was assessed to convert channel to energy. The energy spectra of each of the four radionuclides were converted to energy-weighted spectra by using the following equation:

$$C_{EW,i} = C_i \times E_i \tag{1}$$

where $C_{EW,i}$ is the energy-weighted count of the ith bin of the optical photon distribution, and the original optical photon count and the energy in the ith bin are C_i and E_i, respectively.

EWC has been used to increase the signal-to-noise ratio in radiography research (Patatoukas et al., 2006). The detection efficiency of higher-energy photons is lower than that of lower-energy photons. Accordingly, the use of EWC can enable a conspicuous increase in the Compton edge in the relatively high-energy region, while decreasing the background and photon scattering in the relatively low-energy region.

2.2. Experiments

To validate the EWC algorithm, experiments were performed with the four radionuclides ^{133}Ba, ^{60}Co, ^{22}Na, and ^{137}Cs and an RPM system (Nucare Medical System Inc., South Korea). The PVT scintillator (Model EJ-200 by Eljen Technology, USA) in this system was of size 63.5 × 38.1 × 5.1 cm^3 (height × width × depth) and had the efficiency of 10,000 photons/MeV; the maximum wavelength of its optical photons was 425 nm. Its rise time and decay time were 0.9 and 2.1 ns, respectively, and its density was 1.032 g/cm^3. Optical photons generated by gamma interactions in the PVT were collected in a PMT (Model 9266B by ET Enterprises, USA) of 5.1 cm diameter, and the analog signals were amplified and converted to digital signals (Fig. 2).

For the energy calibration, the Compton edge presented in the simulated energy spectrum was systemically broadened with Gaussian broadening function and matched with the measured one (Ashrafi and Gol, 2014; Lee et al., 2014). To calculate the simulated energy spectrum, modeling of the same PVT scintillator was performed by using the Geant4 code. The calibration had the maximum error of 6.56% in the ^{137}Cs isotope relative to the theoretical energy of its Compton edge. After calibration, each of the counts in the energy spectra was recalculated by using Eq. (1) to yield energy-weighted spectra.

The activities of the test sources used in this study varied from

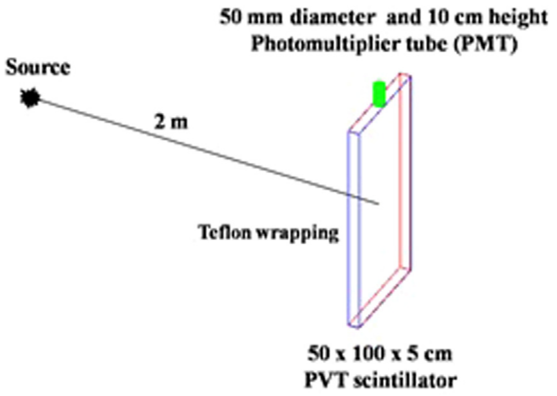


Fig. 1. Geant4 illustration of source, plastic scintillator, and PMT.

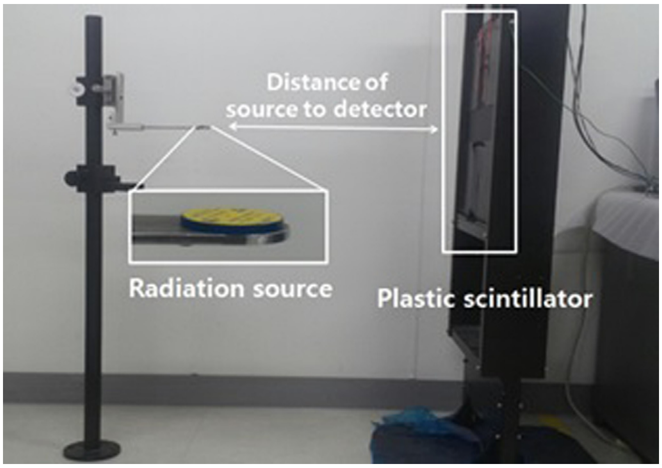


Fig. 2. Experimental setup including radiation source and RPM.