Nuclear Instruments and Methods in Physics Research A 785 (2015) 129–134

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Development of a three-layer phoswich alpha–beta–gamma imaging detector

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ARTICLE INFO

Article history:
Received 5 January 2015
Received in revised form
11 February 2015
Accepted 26 February 2015
Available online 9 March 2015

Keywords:
Alpha particle
Beta particle
Gamma photons
Imaging detector
Phoswich
Simultaneously

ABSTRACT

For radiation monitoring at the sites of such nuclear power plant accidents as Fukushima Daiichi, radiation detectors are needed not only for gamma photons but also for alpha and beta particles because some nuclear fission products emit beta particles and gamma photons and some nuclear fuels contain plutonium that emits alpha particles. In some applications, imaging detectors are required to detect the distribution of plutonium particles that emit alpha particles and radiocesium in foods that emits beta particles and gamma photons. To solve these requirements, we developed an imaging detector that can measure the distribution of alpha and beta particles as well as gamma photons. The imaging detector consists of three-layer scintillators optically coupled to each other and to a position sensitive photomultiplier tube (PSPMT). The first layer, which is made of a thin plastic scintillator (decay time: ~5 ns), detects alpha particles. The second layer, which is made of a thin Gd_2SiO_5 (GSO) scintillator with 1.5 mol% Ce (decay time: 35 ns), detects beta particles. The third layer made of a thin GSO scintillator with 0.4 mol% Ce (decay time: 70 ns) detects gamma photons. Using pulse shape discrimination, the images of these layers can be separated. The position information is calculated by the Anger principle from 8×8 anode signals from the PSPMT. The images for the alpha and beta particles and the gamma photons are individually formed by the pulse shape discriminations for each layer. We detected alpha particle images in the first layer and beta particle images in the second layer. Gamma photon images were detected in the second and third layers. The spatial resolution for the alpha and beta particles was ~1.25 mm FWHM and less than 2 mm FWHM for the gamma photons. We conclude that our developed alpha–beta–gamma imaging detector is promising for imaging applications not only for the environmental monitoring of radionuclides but also for medical and molecular imaging.

1. Introduction

The reactors at the Fukushima Daiichi nuclear power plant were severely damaged by a tsunami caused by an earthquake. Huge amounts of radionuclides were released into the environment from the damaged reactors in Japan [1,2]. For radiation monitoring at the sites of nuclear power plant accidents such as Fukushima Daiichi, radiation detectors are needed not only for gamma photons but also for alpha and beta particles because some nuclear fission products emit beta particles and gamma photons and some nuclear fuels contain plutonium that emits alpha particles. Recently we successfully developed a radiation detector that can simultaneously monitor alpha and beta particles as well as gamma photons for radiation monitoring [3]. Our developed alpha–beta–gamma detector, which consists of three-layer scintillators optically coupled to each other and to a photomultiplier tube, provides good separation of these different types of radiations. Similar multilayered detectors for different types of radiations were also developed by other groups [4–12]. However, most of these layered detectors did not have the imaging capability. In some applications, an imaging detector is needed to identify the plutonium particle distribution that emits alpha particles [13], the Sr-90 distribution that emits beta particles, and the radiocesium in food that emits beta particles and gamma photons. For this purpose, we expanded the layered concept to an imaging detector that can measure the distribution of alpha and beta particles as well as gamma photons to realize an alpha–beta–gamma imaging detector.

2. Materials and methods

2.1. Principle of operation of alpha–beta–gamma imaging detector

Fig. 1(A) shows a schematic drawing of the developed alpha–beta–gamma imaging detector, which consists of three-layer

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http://dx.doi.org/10.1016/j.nima.2015.02.062
0168-9002/

scintillators optically coupled to each other and to a position sensitive photomultiplier tube (PSPMT).

The first layer, which is made of a thin plastic scintillator (decay time: ~5 ns), detects alpha particles. We selected a thin plastic scintillator for the alpha particle detector because it is transparent and its energy spectrum can be obtained [14,15]. The second layer, which is made of a thin Gd_2SiO_5 (GSO) scintillator with 1.5 mol% Ce (decay time: 35 ns) [16], detects beta particles. The third layer made of a thin GSO scintillator with 0.4 mol% Ce (decay time: 70 ns) [17] detects gamma photons. Using pulse shape discrimination [18–21], the counts of these layers can be separated. The position information is calculated by the Anger principle from 8 × 8 anode signals from the PSPMT. The images for the alpha and beta particles and the gamma photons can be separated by the pulse shape discrimination of each layer.

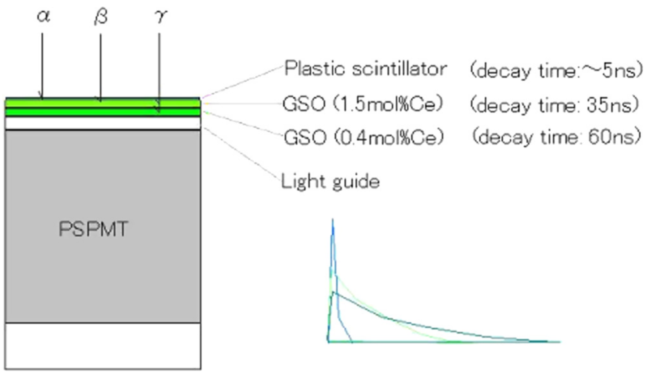

Fig. 1. Schematic drawing of developed alpha–beta–gamma imaging detector.

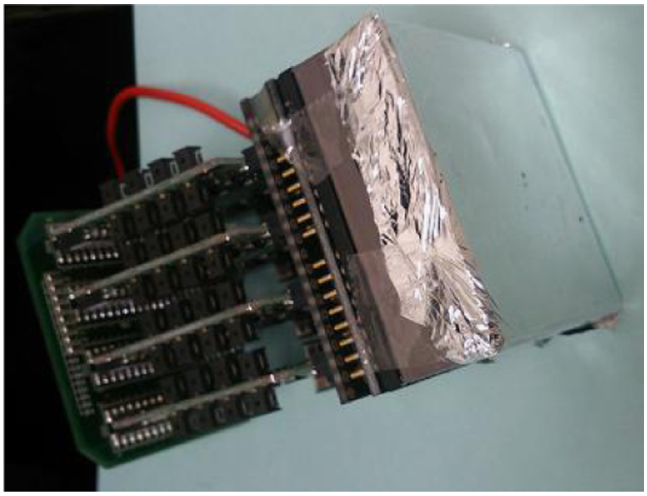

Fig. 2. Developed alpha–beta–gamma imaging detector.

2.2. Developed alpha–beta–gamma imaging detector

We show a photo of the developed alpha–beta–gamma imaging detector in Fig. 2. The plastic scintillator's size for the first layer was $50 \times 50 \times 0.05$ mm^3. Its thickness was determined to be 0.05 mm because the range of alpha particles such as Am-241 (energy: ~5.5 MeV) in plastic is around 0.05 mm, and all of their energy is absorbed in the first layer and second and third layers do not detect alpha particles.

The size of the GSOs with 1.5 mol% Ce for the second layer and 0.4 mol% for the third layer was $50 \times 50 \times 0.5$ mm^3. Since the energy loss of 2 MeV electrons of 0.05 mm plastic scintillator is ~10 keV [22], the detection of the first layer is almost zero because the energy loss was much lower than energy threshold level of the detector (~300 keV). The beta particle absorption for Y-90 (maximum energy: ~2 MeV) in 0.5-mm thick GSO was ~80% from the rough calculation [22]. The third layer detects rest of the beta particles, so ~20% of the beta particles from Y-90 are detected in the third layer.

The detection efficiency of the 0.05 mm plastic scintillator for Cs-137 gamma photons (662 keV) is calculated to be ~0.05% and the detection

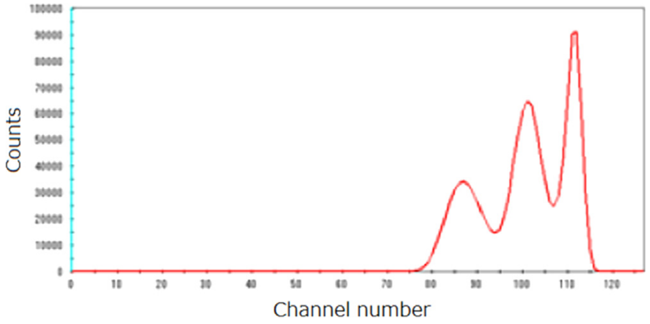

Fig. 4. Pulse shape spectra for irradiating alpha and beta particles and gamma photons.

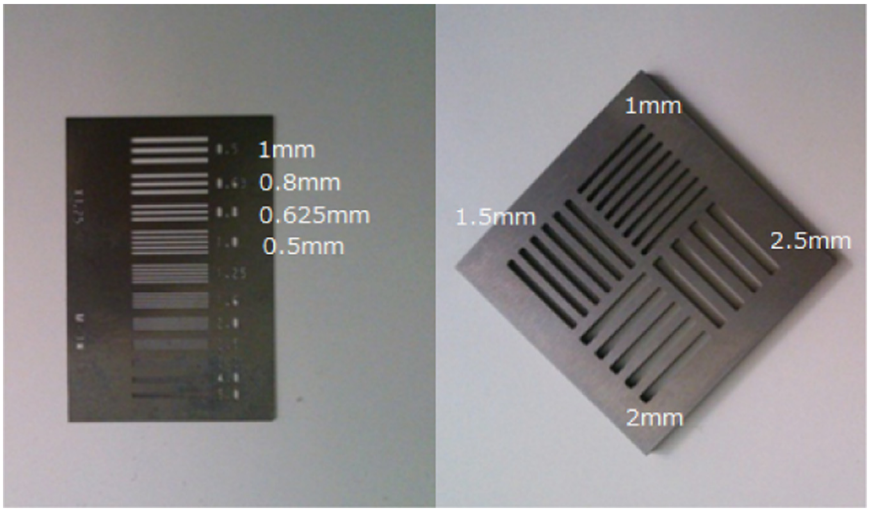

Fig. 3. Slit chart used for spatial resolution evaluation: alpha and beta particles (left) and tungsten slit phantom used for gamma photons (right). Sizes shown in mm in figures are the widths of the slits.