Nuclear Instruments and Methods in Physics Research A 784 (2015) 470–473

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

High resolution alpha particle spectrometry through collimation

Seunghoon Park*, Sung-Woo Kwak, Han-Byeol Kang

Technology Development Division, Korea Institute of Nuclear Non-proliferation and Control, 1534 Yuseong-daero, Yuseong-gu, Daejeon, 305-348, ;Republic of Korea

ARTICLE INFO

Available online 21 November 2014

Keywords:
Alpha particle
Spectrometry
Collimator
Radiation

ABSTRACT

Alpha particle spectrometry with collimation is a useful method for identifying nuclear materials among various nuclides. A mesh type collimator reduces the low energy tail and broadened energy distribution by cutting off particles with a low incidence angle. The relation between the resolution and the counting efficiency can be investigated by changing a ratio of the mesh hole diameter and the collimator thickness. Through collimation, a target particle can be distinguished by a PIPS® detector under a mixture of various nuclides.

1. Introduction

Alpha particle spectrometry has been used in the measurement of nuclear materials in various fields, such as safeguard verification, nuclear security, nuclear decay, data and environmental surveys. In order to verify the nuclear activity of states, it is important to identify nuclear materials in a radioactive source–which can be presented in very small portions in the environment or atmosphere [1].

Alpha particles from a radioactive source are incident to a detector with a solid angle distribution. Most particles are emitted with an angle lower than the normal incidence (90 degree). These particles with a low angle have longer traveling paths than the incident particles along the normal direction of the detector. As a result, the particles with a low angle have a greater probability of interaction with absorbing layers and air between the source and the detector. The energy resolution is degraded because particles lose energy by interaction with air. A collimation is needed to improve the energy resolution for identifying radionuclides.

A collimator between a radiation source and a detector plays a crucial role in identifying specific radionuclides among various species in a radioactive source collected from the atmosphere or environment. Collimation has been studied in order to obtain a higher resolution of alpha energy peaks from ionization chambers and to exclude particles that lost a lot of energy under the atmosphere pressure. Mechanical collimation (which is focused on in this study) is a direct method to cut off particles entering at a low angle [2–4]. Electronic collimation using a voltage pulse for a specific angle of alpha particles in ionization chamber has been studied for several decades [3,5,6]. Electronic collimation cannot be applied to a semiconductor detector because the detector signal in a PIPS ® is independent of incidence angle. A high vacuum system of alpha spectrometer with a semiconductor detector is one solution that can be used to reduce the interaction with air. Unfortunately, in order to implement high vacuum (<1 mTorr) system, a turbo molecular pump which is connected to rotary pump to lower pressure is required. The system is not cost-effective and complicated. In a moderate vacuum (~ 10 Torr), the collimation of alpha particles can be effective in improving the energy resolution in the spectra. This has been proven for alpha spectrometry performed in atmospheric pressure and ionizing detector [3,7]. However, there has not been any confirmation yet as to its effect in a moderate vacuum system and the relationship between the counting efficiency and the resolution for collimator geometry.

This work shows that a mesh type collimation was designed and implemented based on the Monte Carlo simulation. The collimation effects were studied by simulation and verified by experiment, measuring a mixture of various nuclides. The simulations and experimental results were compared and discussed. The goal of this work has been to show that a mesh type collimator can improve resolution by cutting off particles that travelled over a long pathway.

2. Simulation of collimation

2.1. Simulation description

The detector system with the collimator consists of a silicon detector, a radiation source, and an aluminum collimator–as shown in Fig. 1. The detector utilizes PIPS® which is manufactured

---

* Corresponding author.
E-mail address: shpark@kinac.re.kr (S. Park).

http://dx.doi.org/10.1016/j.nima.2014.11.045
0168-9002/

by Canberra. Pure silicon was adopted for simplification of the simulation because the doping concentrations are low and do not affect the deposition energy calculated. The vacuum pressure is 10 Torr, which is generally used for alpha particle energy spectrum measurement. The collimator is placed between the detector and the source. The detector has a diameter of 25 mm. The collimator has a diameter of 50 mm, number of holes of 42, 109, and 253 for 6 mm, 4 mm, and 2.5 mm diameter, respectively, and a thickness of 5 mm. The alpha particles emit in the flat-surface source, diameter of 25 mm. The gap between the collimator and detector (or source) is one millimeter. Close-packed hexagonal type meshes are chosen to maximize the counting efficiency. Meshes with different diameters were tested: 1, 2.5, 4, and 6 mm. The effect of collimation in alpha particle spectrometry is simulated using the Monte Carlo method, Geant4 [8]. The simulated alpha particles corresponded to the main peaks of eight radionuclides (selected as rich nuclides from environmental samples and nuclear facilities [9,10]) with characteristic energies as shown in Table 1. An isotropic angle distribution and the energy loss in air are simulated. Energy loss in the dead layer of the PIPS®, with thickness of < 50 nm, was neglected (14 keV for 100 nm dead layer for 5 MeV) [11].

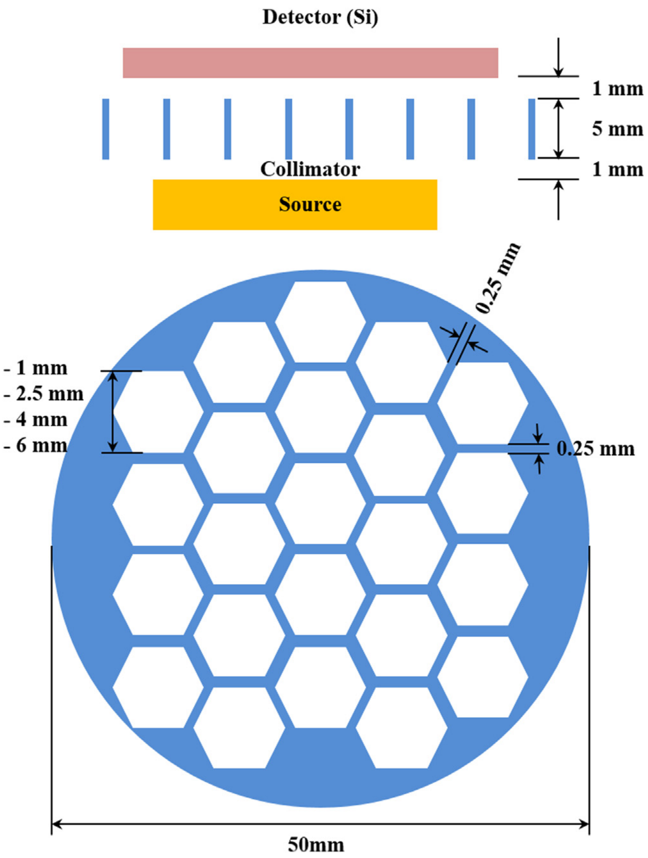

Fig. 1. (a) Dimension of alpha particle spectrometer with a hexagonal mesh type collimator.

Table 1
Alpha particle energy of nuclear species.

Nuclear species	Energy (MeV)
^{232}U	5.26 (32%), 5.32 (68%)
^{234}U	4.72 (28%), 4.77 (71%)
^{235}U	4.37(17%), 4.40 (55%)
^{238}U	4.15 (21%), 4.20 (79%)
^{226}Ra	4.60 (6%), 4.78(94%)
^{222}Rn	5.76(24%), 5.81(76%)
^{232}Th	3.95(22%), 4.01(78%)
^{210}Po	5.30 (100%)
^{241}Am	5.44 (15%), 5.49 (85%)

2.2. Simulation results

Fig. 2 shows simulated energy distribution of alpha particles with and without a collimator for eight nuclear materials. The low energy tail is observed for all peaks without collimation, but the low energy tail is significantly smaller using the collimator. The effect of the collimation can be observed by the enlarged energy peaks in Fig. 2, which are much better separated when the collimator is used. We can infer that the low energy tail is caused by particles with a low angle. The alpha emission in the decay of ^{210}Po and ^{232}U are quite similar, which makes it difficult to distinguish them without collimation (see Fig. 2).

For an energy difference < 10 keV between the ^{234}U and ^{226}Ra peaks, the energy resolution of the detector is too low and also collimation does not help to separate both lines.

The use of collimation implies loss in counting efficiency and a compromise has to be made between them. The relationship between counting efficiency and the averaged FWHM is shown in Fig. 3. The efficiency clearly diminishes with decreasing collimator mesh size, whereas the resolution (expressed in peak full-width-half-maximum) does not improve drastically below a mesh hole diameter of about 2.5 mm.

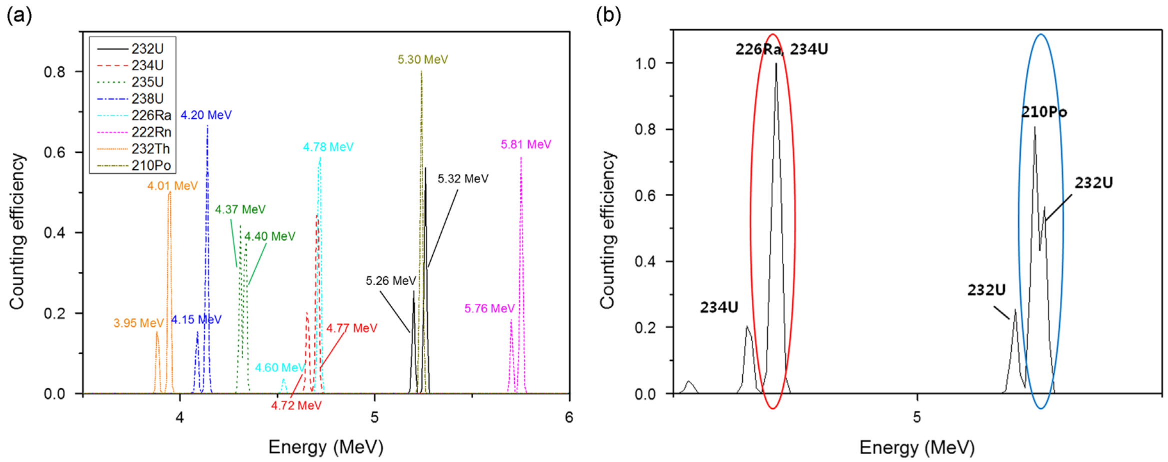

Fig. 2. (a) simulated alpha particle energy distribution of each radionuclide with collimator (mesh hole diameter is 2.5 mm) (b) Summation of specific energy.