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High-resolution alpha spectrometry at ambient air pressure—Towards new applications

R. Pöllänen *, K. Peräjärvi, T. Siiskonen, J. Turunen

STUK—Radiation and Nuclear Safety Authority, P.O. Box 14, FI-00881 Helsinki, Finland

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ABSTRACT

An approach for alpha spectrometry is introduced that allows measuring alpha spectra at ambient air pressure with energy resolution comparable to measurements in vacuum. The developed prototype equipment uses a semiconductor alpha detector and a honeycomb collimator. Contamination of 1 Bq/cm^2 at any smooth and flat surface can be detected in approximately 10 s data acquisition time, but longer time is needed for radionuclide identification. A hand-held instrument for *in-situ* measurements can be manufactured opening a wide range of novel applications in alpha spectrometry.

1. Introduction

Alpha particle spectrometry with semiconductor detectors is usually applied for radiochemically processed sources in vacuum. However, in some applications such as continuous air monitoring [1,2], the measurement is done at ambient air pressure although the energy resolution may be far from optimal. In general, alpha particle energy losses in the source, in the dead-layer of the detector and in air or other media between the source and the detector may have a notable influence on the measured alpha spectrum. Varying alpha particle path length with varying energy loss causes displacement of the peaks in the alpha spectrum as well as peak spreading and peak tailing that, subsequently, may lead to difficulties in the spectrum analysis.

Alpha spectra with good energy resolution may be obtained provided thin (in terms of alpha particle range) sources are used in the measurements performed in vacuum. In addition to radiochemically processed samples, other types of sources, such as air filters [3,4], swipes [5] and evaporated liquid residues [6] and other types of smooth surfaces are possible. This makes high-resolution alpha spectrometry feasible even in the field [7].

Energy resolution, measured as the Full Width at Half Maximum, *FWHM*, of modern semiconductor alpha detectors may be even less than 10 keV depending on the active area of the detector. Thickness of the dead layer of the detectors operating in vacuum is approximately 50 nm. However, detectors operating at ambient air pressure have a thicker entrance window (Fig. 1), which has a substantial influence on the peak shape in particular at short source–detector distances, *SDDs* (Fig. 2).

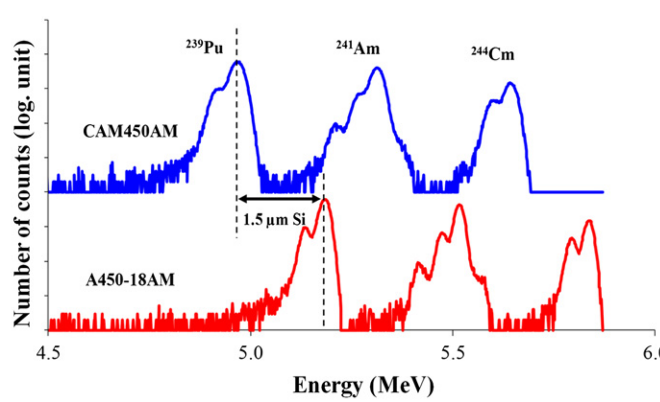

Fig. 1. Alpha-particle energy spectra from a radiochemically processed source measured in vacuum at *SDD*=48.5 mm using semiconductor alpha detectors of area 450 mm^2. Lower spectrum was obtained with an alpha detector A450-18AM (Canberra PIPS, nominal *FWHM* 18 keV) whereas the upper spectrum was measured by a CAM450AM (nominal *FWHM* 34 keV) with an entrance window of thickness 1.5 µm equivalent silicon. Both spectra were measured using the same energy calibration, which refers to the lower spectrum. The source contained ^{239}Pu, ^{241}Am and ^{244}Cm with the active area diameter of 7 mm.

The spectra presented in Figs. 1 and 2 can be analyzed provided that appropriate peak shape models are available in the spectrum unfolding. The analysis may be challenging if there is air or other media between the source and the detector. From the applications point of view it would be highly desirable to measure alpha spectra with good energy resolution at ambient air pressure, i.e. to get rid of

* Corresponding author. Tel.: +358 9 75988425; fax: +358 9 75988433.
E-mail address: roy.pollanen@stuk.fi (R. Pöllänen).

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disturbing effects of air without using vacuum pumps and vacuum chambers. This would certainly facilitate *in-situ* measurements and operations especially in the field. Totally new areas of applications may arise if high-resolution alpha spectrometry could be performed using handheld equipment similar to those used in gamma-ray spectrometry [8].

Different types of equipment have been used to detect and identify alpha-particle emitting radionuclides in the field. For example, alpha spectrometers similar to those used in a laboratory have been mounted in moving laboratories [9,10]. A portable equipment that can be operated in reduced air pressure has been elaborated, too [11]. Portable equipment have also been developed to measure retrospective indoor radon concentrations *in situ* [12]. The construction was recently described in Ref. [13].

A handheld alpha/beta spectrometer was devised for monitoring surface contamination [14]. The instrument used collimation to obtain better energy resolution. It was applied for a set of sources but the details and the operation principle were not fully documented. A commercial contamination monitor with a collimator, known as Alpha Analyzer—AP-2 [15], was developed, too. In the present paper we report an approach for alpha spectrometry that allows measuring alpha spectra with good energy resolution at ambient air pressure.

2. Principles of measuring alpha spectra with good energy resolution at ambient air pressure

In alpha spectrometry it is customary to utilize all possible alphas entering the detector. However, especially when there is air between the detector and the source, alpha particles entering the sensitive layer of the detector on the slant do not contain as much useful information as those entering perpendicularly. In other words, alpha particles α_1 and α_2 in the left part of Fig. 3 lose substantial and different amounts of energy in air, causing wide tails in the alpha spectrum. Their presence deteriorates rather than helping the spectrum analysis. Although alpha particles α_3 and α_4 also lose energy in air the variation of the energy loss is much smaller. Thus, in the alpha spectrum they remain at the position of the alpha peaks. The absolute value of their energy loss (i.e. location of the peaks in the spectrum) causes only shifting of the peak position and this shift is almost equal for all alphas entering nearly perpendicularly to the detector. This is true provided that the source–detector distance remains the same during the measurement.

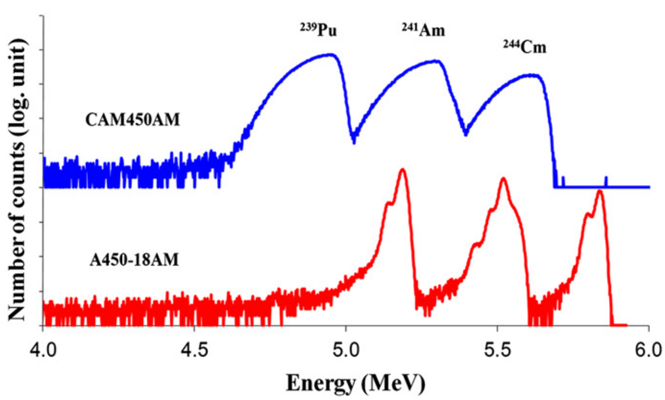

Fig. 2. Alpha-particle energy spectra from a radiochemically processed source measured in vacuum at $SDD=9$ mm. The source and the detectors were the same as in the measurements presented in Fig. 1.

Collimation is an old technique to facilitate measuring ionizing radiation [16], but how to collimate alpha particles entering the detector from different directions without losing too much detection efficiency? A honeycomb collimator may be an ideal solution. Using the honeycomb collimator between the detector and the source prohibits alpha particles α_1 and α_2 from entering the detector whereas alphas α_3 and α_4 remain unaffected (Fig. 3 in the right). The collimator provides apparent benefits as evidenced in Fig. 4 resulting in dramatic improvement of the energy resolution.

The principle of the collimation from the point of view of one cell of the honeycomb is presented in the following assuming a cylindrical cell shape. The alpha-particle emitting material is assumed to be located in the bottom of the cell, and either close to the walls of the cell (Fig. 5 left) or close to the symmetry axis of the cell (Fig. 5 right). It is clear that the walls of the collimator cells should be thick enough to fully stop the alphas (tens of micrometers in the case of aluminum), but thin enough to minimize masking those alphas that are just below the walls.

When the alpha-particle emitting material is close to the cell walls some of the alphas (such as α_3 in Fig. 5) that otherwise would enter the detector almost perpendicularly might collide the walls and, thus, do not enter the detector. On one hand, the cell size should be as large as possible to avoid this negative effect, i.e. the bottom area of one cell should be maximized with respect to its perimeter. On the other hand, too large cell size would lead to poor energy resolution.

In the following, the energy loss of the alpha particles transporting through air is considered using a simplified geometrical approach (see notations and dimensions in Fig. 6). The maximum path length of an alpha particle, l_2, can be calculated as follows:

$$\cos\beta = \frac{b}{c} \tag{1}$$

$$l_2 = \frac{l_1}{\cos\beta} = l_1\sqrt{a^2/b^2+1}. \tag{2}$$

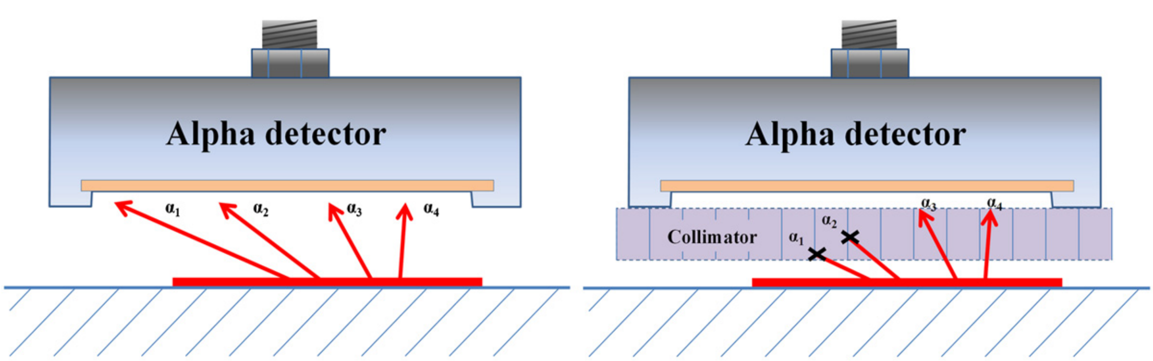

Fig. 3. Schematic representation of the detection of alpha particles for the measurements performed at ambient air pressure. The alpha-particle emitting radioactive material is assumed to be on a surface below the detector and all alphas emitted toward the sensitive layer of the detector are detected unless their energy is not fully absorbed in air (figure in the left). A honeycomb collimator will stop those alphas (α_1 and α_2 in the right figure) whose entering angle to the detector is too small.