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About the effectiveness of the ABPD methods in air-borne alpha-activity monitoring

S.V. Shevchenko[a,*], L.S. Saltykov[b], L.I. Slusarenko[b]

[a]SSC "Technocentre" Ministry of Emergency of Ukraine, Kiev, Ukraine
[b]Institute of Nuclear Researches of NAS of Ukraine, Kiev, Ukraine

Abstract

A modified version of the alpha–beta-pseudo-coincidence-difference (ABPD-M) method is proposed with a view to suppressing natural background radiation when measuring the transuranium radionuclide (TRU) content in aerosol samples. It is shown that complementing the traditional "pseudo-coincidence" method with a treatment of (comparatively) fast beta–alpha coincidences provides a means to significantly improve the suppression of background fluctuations and the accuracy of measurement results in comparison with the traditional method.

Keywords: Aerosol; Transuranium alpha-activity monitoring; Radon monitoring; Background compensation

1. Introduction

The alpha–beta-pseudo-coincidence-difference (ABPD) method was developed to compensate for the influence of natural background radioactivity (BG) fluctuations in radioactivity measurement results and has been used for airborne alpha-activity monitoring from the sixties onwards (Gebauer, 1965; Vaane and De Ras, 1966). Recently the ABPD method has been widely used in a variety of industrial continuous air monitors (CAMs) (Klett et al., 2002), as well as in more complicated laboratory and industrial facilities (Mattsson et al., 1996). The ABPD method uses known a priori information on radionuclide decay in order to distinguish between background events arising from natural radionuclides (^{212,214}Bi; ^{212,214}Po, see Table 1) and those arising from anthropogenic/industrial radionuclides.

In the sequenced beta–alpha decay Bi → Po → Pb, both thoron and radon progenies decay rather quickly—more than 95% of the $^{214}\mathrm{Bi}\rightarrow{}^{210}\mathrm{Pb}$ and essentially 100% of the $^{212}\mathrm{Bi}\rightarrow{}^{208}\mathrm{Pb}$ decay within the first 700–800 μs, whereas TRU alpha-decay is normally not accompanied by beta emission. By selecting sequenced beta–alpha events in the interval 0 to 700–800 μs, background events can be detected with high probability. The background spectrum obtained with this coincidence set-up is then used to process the spectrum of non-coincident alpha events (still containing some background), allowing the determination of TRU events.

However, the ABPD method does not enable the separation of individual BG contributing components (i.e. $^{214}\mathrm{Bi}\rightarrow{}^{210}\mathrm{Pb}$ and $^{212}\mathrm{Bi}\rightarrow{}^{208}\mathrm{Pb}$). Accordingly, variations in ^{220}Rn and ^{222}Rn progeny activity ratios can lead to uncertainties in the final measurement, mainly because of the contribution of 6.05 and 6.09 MeV ^{212}Bi alpha particles that are not in coincidence with any beta decay and that will be counted as 'true' events. In most cases, the ^{212}Bi alpha activity is comparatively small

*Corresponding author. Tel.: +380 44 5251 1492; fax: +380 44 5254320.
E-mail address: shevsv@i.kiev.ua (S.V. Shevchenko).

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Table 1
Radiation parameters of the ^{220,222}Rn progenies

Nuclei	Beta		Alpha		$T_{1/2}$
	Probability (%)	Particle energy (MeV)	Probability (%)	Particle energy (MeV)	
^{212}Bi	64.4	2.254	24.9	6.05	60.55 min
			10.7	6.09	
^{212}Po	—	—	~100	8.78	3.0×10^{-7} s
^{214}Bi	~100	3.272	—	—	19.9 min
^{214}Po	—	—	~100	7.69	1.64×10^{-4} s

(~10–30 times less than the activity of the sum ^{212}Po + ^{214}Po), and so, in zero approximation, its contribution can be considered as negligible. On the other hand, to comply with regulatory requirements, the air monitoring technique should be able to measure TRU concentrations in the order of ~0.03 Bq m^{-3}, which, in practice, is considerably smaller than the ^{212}Bi activity. Thus, a modification to the ABPD method that will allow ^{212}Bi alphas to be identified is needed in order to achieve the required sensitivity.

To modify the ABPD method, we use selection in two sequential intervals, i.e., the first 2–3 μs after beta detection, and the interval from ~3 to 700–800 μs after beta detection (Domnikov et al., 2001, Saltykov et al., 2003). A similar, though not identical, technique has been used for the measurement of U and Th series content in natural materials (Galloway, 1990). In the approach proposed here, three separate alpha spectra are recorded, two corresponding to beta–alpha coincidence events in two separate time intervals, and another corresponding to alpha events detected without coincidence (with a beta event). The method enables effective separation of the background components since, in coincidence mode in the first time interval the ^{212}Bi → ^{208}Pb (^{212}Po half-life 0.3 μs) decay events are detected, whereas in the second time interval the ^{214}Bi → ^{210}Pb (^{214}Po half-life 164 μs) decay events are detected. Specifically, the method enables both direct and separate estimation of the ^{214}Po (7.69 MeV) and ^{212}Po (8.78 MeV) peak tail contributions to background in the region of interest (the ROI), as well as estimation of the ^{212}Bi alpha contribution, thereby providing a more effective means of compensating for natural background radioactivity.

2. Experimental set-up

Both the ABPD and ABPD-M set-ups are shown schematically in Fig. 1. When measuring aerosol TRU content, an aspirated filter is placed between two detectors oriented face-to-face. The front surface of the filter faces the alpha (or alpha + beta) detector, whereas the back surface faces the second (beta) detector. Because the filter is usually rather thick, the TRU and radon + thoron progenies' alpha particles are not registered by the beta detector. In contrast, the much greater range of beta particles enables their detection with comparatively high efficiency.

The pulse from the alpha detector, after amplification and shaping, is delivered simultaneously to two modules, namely the analog-to-digital converter (ADC) and the analog discriminator 1 (AD1). Practically simultaneously on the ADC and the AD1 outputs occur the digital code and standard alpha pulse (indicated as "TTL" in Fig. 1), respectively. The beta detector pulse, after amplification and shaping, is delivered to a second analog discriminator (AD2), which produces a standard pulse. If the first detector is used for beta detection as well as alpha detection, AD1 also produces a standard beta pulse. The ADC code and standard alpha and beta pulses are delivered to the control unit (CU) input.

When the ABPD method is applied, every beta pulse triggers the CU timer in the [0–~700] μs interval. If the alpha standard pulse arrives at the CU input within this time interval, the ADC code is directed to the first spectrum accumulation unit (SAU-1). If the alpha standard pulse arrives outside this interval, the corresponding ADC code is directed to SAU-2. Since TRU activity is in most cases rather low, practically all TRU events are registered in SAU-2. In addition, a beta detection efficiency of less than 100% results in some fraction of the background alpha events being registered in this SAU. At the end of the measurement cycle, one has the net background spectrum in SAU-1 and the (BG + TRU) spectrum in SAU-2.

When the modified version of the method (i.e., ABPD-M) is used, every beta pulse triggers the CU timer in the [0–~3] μs and [~3–~700] μs time intervals, so that an alpha event is directed to SAU1 if the alpha standard pulse arrives at the CU input within the second time interval, to SAU2 if there is no coincidence, and to SAU3 if it arrives within the first (fast) time interval.

It can be easily shown that in zero approximation the ratio of the number of pulses in the ROI in SAU-1 and SAU-2, k, does not depend on the background