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Comparison of gamma-ray coincidence and low-background gamma-ray singles spectrometry

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ABSTRACT

Aerosol samples have been studied under different background conditions using gamma-ray coincidence and low-background gamma-ray singles spectrometric techniques with High-Purity Germanium detectors. Conventional low-background gamma-ray singles counting is a competitive technique when compared to the gamma–gamma coincidence approach in elevated background conditions. However, measurement of gamma–gamma coincidences can clearly make the identification of different nuclides more reliable and efficient than using singles spectrometry alone. The optimum solution would be a low-background counting station capable of both singles and gamma–gamma coincidence spectrometry.

1. Introduction

The multiple gamma-ray coincidence method is a commonly used tool in fundamental nuclear physics research (Beausang and Simpson, 1996). The technique has also been applied to the studies of nuclear waste, neutron activation and prompt gamma-ray analysis (Oshima et al., 2008). In the work of Smith et al., the performance of a gamma–gamma coincidence system was investigated by studying an irradiated sample of ^{235}U (Smith et al., 2003). The main outcome of this work was to show that unshielded gamma–gamma coincidence spectrometry decreases the minimum detectable activities (MDA) of several nuclides when compared to unshielded gamma-ray singles spectrometry. This is obviously a very important and interesting conclusion from the point of view of in-situ measurements.

In the present study gamma-ray coincidence spectrometry is used in an environment with elevated background radiation and primarily compared to gamma-ray singles spectrometry performed in a low-background environment, using High-Purity Germanium (HPGe) detectors. The gamma-ray coincidence studies were realized at the Accelerator Laboratory of the University of Jyväskylä, Finland and the low-background gamma-ray singles spectrometry at the Radiation and Nuclear Safety Authority (STUK), Helsinki, Finland. The aim of the present measurements is to complement other ongoing attempts to improve the analysis of aerosol particulate filters using gamma-ray spectrometry (Keillor et al., 2009). Aerosol samples of ambient air were selected for these studies due to their central importance for several radiation safety and security applications (Medici, 2001 and Pöllänen et al., 2009), for example verifying compliance of the Comprehensive Test-Ban-Treaty (CTBT). In addition, such aerosol samples are used to evaluate the ratio of atmospheric ^{22}Na and ^{7}Be, which is used as a chronometer to probe the vertical movements of air (Jasiulionis and Wershofen, 2005). Since the concentration of ^{22}Na is low (about 10,000 times smaller if compared to ^{7}Be) and its 1274.6 keV gamma lies in the Compton background of ^{40}K its detection is often challenging. Normally a detection of ^{22}Na requires a very large air sample – several days of sampling – and a long (> 24 h) measurement with HPGe detector in a low background laboratory. In the following, focus is given to a coincidence study of ^{22}Na as this may serve to improve the quality of atmospheric studies. A further aim was to investigate the feasibility and the sensitivity of gamma–gamma coincident spectrometry in high background conditions, similar to those

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found in in-situ measurements at radiation accident sites. In this respect, ^{22}Na is also a challenging case due to the Compton background from ^{40}K and the required coincidence with 511 keV photons, which come from a number of sources. The same aerosol samples were studied at both laboratories and the MDA analysis was carried out for the same nuclides as studied by Smith et al. (2003).

2. Experimental techniques and results

Two aerosol samples required for the study were collected using the high-volume air samplers of SENYA, Finland (Medici, 2001). The first aerosol sample of 86,435 m^3 was collected in Kotka, Finland between 23.6.2009 4:26 UTC and 29.6.2009 7:46 UTC and the second sample of 16,544 m^3 in Helsinki between 18.8.2009 8:02 UTC and 19.8.2009 8:01 UTC. The sample from Kotka was first studied at STUK using a lead-shielded Broad Energy HPGe detector from Canberra (crystal diameter 80 mm and thickness 30 mm). The detectors used at STUK were mounted in a vertical orientation and the samples were directly placed on top of the end-cap. The detectors were calibrated with the MCNPX code (Pelowitz, 2005) and with traceable solutions containing single gamma-ray emitters. Singles data from the Kotka air sample were acquired for 65.3 h starting at 3.7.2009 11:18 UTC and analysed with the UniSAMPO-Shaman software (User's Guide, 2003). The sample was found to contain 0.0707 Bq (10.46% uncertainty) of ^{22}Na ($T_{1/2}=2.603$ a), which is amongst the highest activities detected during the summer of 2009 in Finland. Fig. 1 presents a partial singles gamma-ray spectrum. As shown, even with a measurement time of 65.3 h the background remains low allowing clear observation of 1274.6 keV gamma-ray peak of ^{22}Na.

Due to the relatively high ^{22}Na activity this sample was also examined at the University of Jyväskylä by placing it between two unshielded Clover HPGe detectors (Duchêne et al., 1999). The composite Clover detectors house four individual germanium crystals in a common cryostat. Each individual germanium crystal has a diameter of approximately 50 mm and length of 70 mm. The close measurement geometry of the detectors is illustrated in Fig. 2, which was produced using GEANT4 visualisation

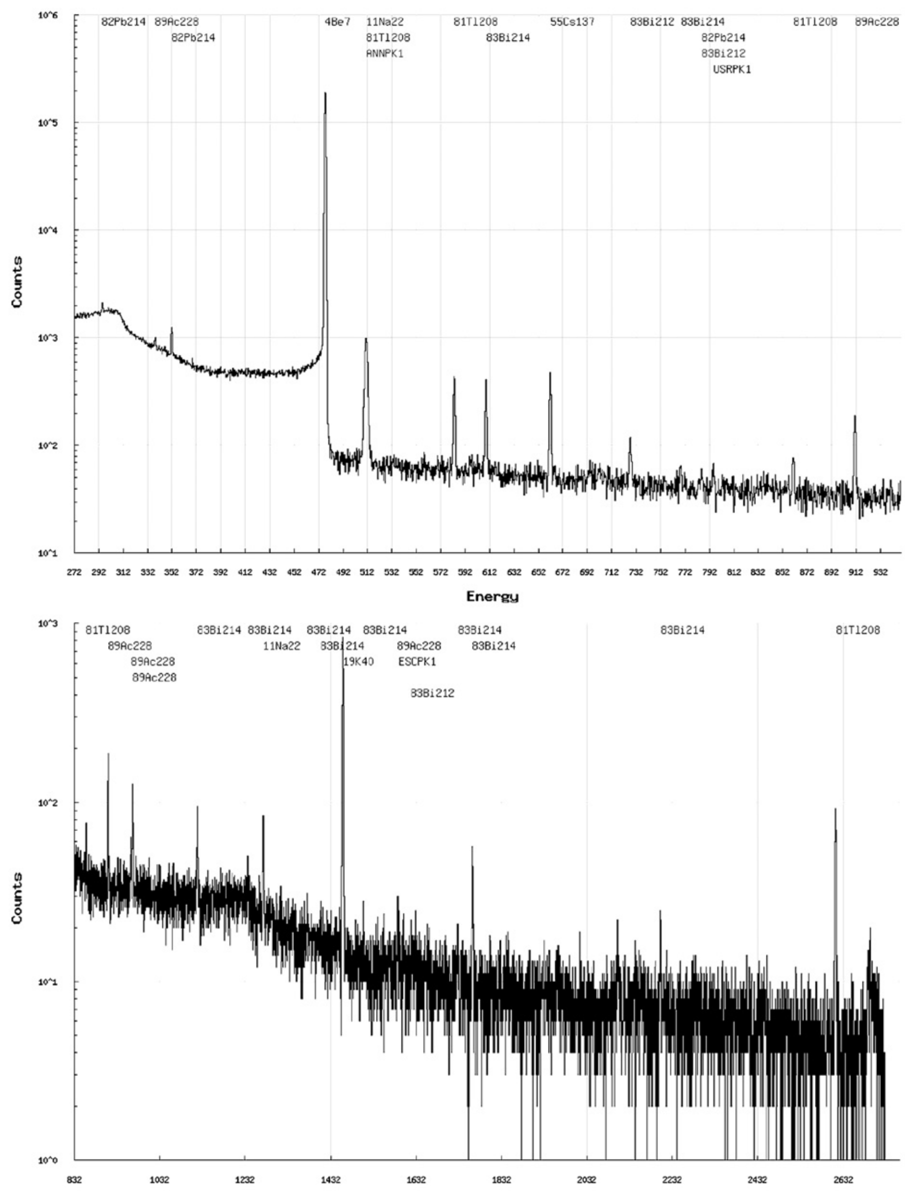

Fig. 1. Part of the singles gamma spectrum related to the Kotka aerosol sample measured at the relatively low background environment at STUK.