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A low-background $\gamma\gamma$-coincidence spectrometer for radioisotope studies

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ABSTRACT

The performance of a new, low-background NaI(Tl) spectrometer, based on $\gamma\gamma$-coincidence counting, is discussed. We present experimental coincidence efficiencies, timing resolutions, background count rates, and minimum detectable activities. The spectrometer has been simulated using Geant4, and the results are used for estimating coincidence efficiencies for volume sources. To test the device, we measured the cosmogenic ^{26}Al activity in a small (17.7 g) meteorite fragment. We find a value of 52.9 ± 7.8 dpm/kg, in agreement with the activity measured previously in a much larger fragment of the same meteorite using a HPGe detector.

1. Introduction

Gamma-ray spectroscopy allows for the measurement of radioisotope concentrations without destroying the samples. The coincident detection of γ-rays is of particular interest because it improves significantly the signal-to-background ratio. Since more than one radiation detector is involved in these measurements, the method is also referred to as multi-dimensional γ-ray spectrometry. The smallest multi-dimensional spectrometer consists of two detectors. Such systems have been discussed before [1–8]. However, the complete performance of a $\gamma\gamma$ coincidence spectrometer in terms of coincidence efficiencies, timing resolutions, background count rates, and detection sensitivity has rarely been reported.

We will discuss an instrument that was recently commissioned at The University of North Carolina at Chapel Hill. It was built for assaying atmospheric, environmental, and extraterrestrial samples. We will describe the performance of the new spectrometer and, in particular, will focus on the detection of ^{22}Na, ^{26}Al, and ^{60}Co. The instrument was tested by measuring the concentration of ^{26}Al in a small meteorite fragment of the Farmville meteorite. The $\gamma\gamma$-coincidence spectrometer is described in Section 2. Measurements and results are discussed in Section 3. Conclusions are presented in Section 4.

2. Equipment

The spectrometer is shown in Figs. 1 and 2. It consisted of two NaI(Tl) detectors, purchased from Saint-Gobain Crystals/Bicron (Newbury, OH, USA), which faced each other at a distance of 38.1 mm along their symmetry axis. Each detector contained a crystal with a diameter of 152.4 mm and length of 101.6 mm, inside an aluminum housing with a wall thickness of 0.81 mm. The crystals were coupled to a photomultiplier tube (PMT) of 127.0-mm diameter via a low-background optical quartz window. The only spectrometer part selected for low-background radiation was the optical window.

The detectors were surrounded by several layers of different metals. The innermost layer consisted of 0.64-cm thick copper, surrounded by 10.2-cm thick lead. The outermost layer was made of 1.0-cm thick aluminum and provides support for the shielding above the detectors. The top shield consisted of a WWII (low-background) steel plate of 2.0-cm thickness, which supported a 10.2-cm-thick layer of lead bricks and another 2.0-cm-thick steel plate. A 10.2-cm-diameter hole at the center of the top shield provided convenient access to the sample located between the two detectors.

A lead plate of 2.54-cm thickness was located between the detector front faces to reduce background coincidence events caused by the

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Fig. 1. (Color online) The $\gamma\gamma$-coincidence spectrometer consisted of two NaI(Tl) detectors inside a passive shield. The top shield, made of steel and lead, was removed to show the detector geometry.

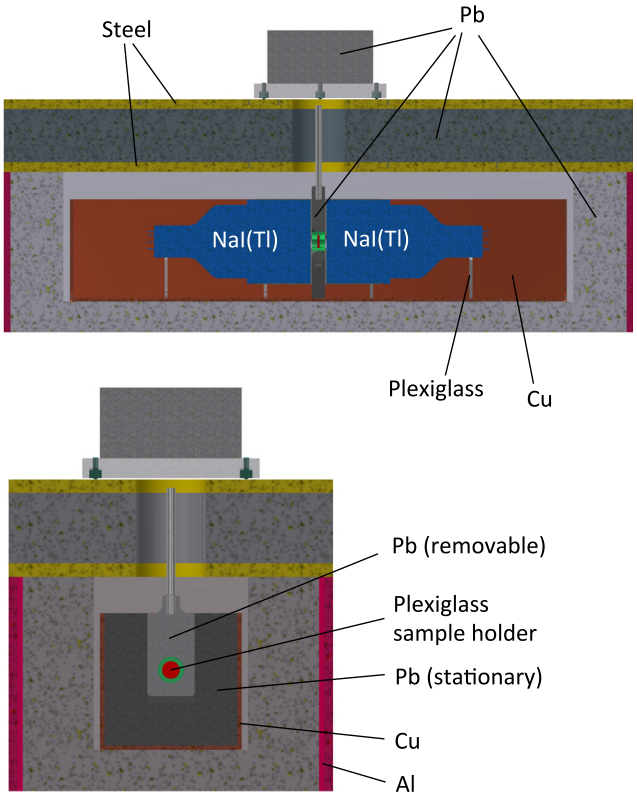

Fig. 2. (Color online) Cross-sectional views of the $\gamma\gamma$-coincidence spectrometer, showing the geometry and the different layers of materials. Part of the lead shield, located between the two detectors (see lower panel), was removable and contained the sample holder made of plexiglass.

Compton scattering of γ-rays between the detectors. Background radiation was reduced by a factor of two to four by this shield, depending on the coincidence gate used (Section 3.2). This lead plate had a central hole of 3.8-cm diameter, with tapered edges to reduce the absorption of

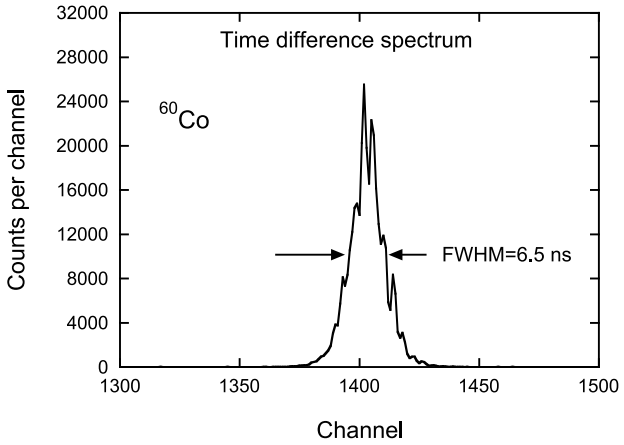

Fig. 3. Timing spectrum of the NaI(Tl) $\gamma\gamma$-coincidence spectrometer, measured using a ^{60}Co calibration source. A 13-ns wide software gate around this peak defined a coincidence event between the two detectors. Additional coincidence gates were applied to certain energy regions (see text).

γ-rays originating from the sample. The sample holder was made of 1.5-mm-thick plexiglass and could be conveniently inserted into the central hole of the lead plate (see lower panel of Fig. 2).

The detectors were biased with a voltage of +850 V. The output signal from each detector was split into two branches without pre-amplification. The first signal was processed by a spectroscopy amplifier with 0.5-μs shaping time and was subsequently fed into a 4096-channel VME amplitude-to-digital converter (ADC). The second signal was processed by a fast timing filter amplifier (TFA) with 50-ns integration and differentiation time constants, and was then fed into a constant-fraction discriminator (CFD) with a 64-ns shaping delay. The logic output signal provided the gate for the ADC and the start and stop signals for the time-to-amplitude converters (TAC). The output of the TAC was also fed into the ADC. The data were stored in list mode for subsequent offline analysis, where each event consists of the energy and timing information for both detectors. All timing and energy coincidence gating was performed using the data acquisition system JAM [9].

3. Performance

3.1. Calibration sources

A ^{60}Co calibration source was used to determine the energy and timing resolutions. The energy resolutions amounted to 5.1% at 1333 keV for both detectors. The timing spectrum obtained with detector 1 starting and detector 2 stopping the TAC is shown in Fig. 3. The time resolution, defined as the full width at half maximum (FWHM) of the peak, amounted to 6.5 ns. A software gate of 13 ns covered the timing peak and defined a coincidence event, and was applied to all coincidence spectra presented here. Additional software gates were applied to certain energy regions, as discussed below.

Fig. 4 shows two-dimensional histograms of the energy deposited in detector 2 versus the energy deposited in detector 1. The top and bottom panels were obtained using a ^{22}Na and ^{60}Co calibration source, respectively, located in the center of the spectrometer.

The radioisotope ^{22}Na has a half-life of $T_{1/2} = 2.6029 \pm 0.0008$ yr and decays predominantly by positron emission to the first excited state of ^{22}Ne.[1] For 100 decaying ^{22}Na nuclei, 99.94 ± 0.13 photons of 1274.5 keV energy and 180.7 ± 0.2 photons of 511.0-keV energy are emitted. The two-dimensional histogram in the top panel of Fig. 4 displays regions

[1] The half-lives and branching ratios quoted in the present work are adopted from the Laboratoire National Henri Becquerel; see http://www.nucleide.org/DDEP_WG/DDEPdata.htm.