Design of a two-dimensional pseudo coincidence Compton suppressor system for Neutron Activation Analysis

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Abstract

Compton scattering events are the main source of error on the peak counting during the Neutron Activation Analysis (NAA). The application of compton suppressor system in instrumental NAA reduces the detection limit of the technique and leads to a data with higher degree of precision. In this paper, a two-dimensional pseudo coincidence Compton suppressor system is presented for the NAA technique. The system is established based on a CAEN digitizer which directly records the pre-amplifier output signals of the two HPGe detectors. The recorded events in list mode file are analyzed offline by a Matlab code and the correlated photopeak events are realized. The performance of the system for Compton suppression is tested by measuring the gamma lines of ^{133}Ba and ^{137}Cs standard sources. The results show that the presented technique provides the peak to Compton ratio up to 10^4 and can be an alternative for conventional Compton suppressor systems.

Keywords: Compton suppressor, Neutron Activation Analysis, list mode, digitizer

Introduction

Neutron Activation Analysis is a well-established non-destructive technique for the determination of elements and their concentration in the bulk of the samples [1]. The technique is based on the activation by neutron using neutron emitter radioisotope sources or research reactor facilities. After activation via (n,ɣ) reaction, the gamma-ray spectroscopy of the resulting compound nucleus performs using a high-resolution detector to determine the yield of gamma lines in the spectrum. Each gamma line is a specific signature of the elements and its yield determines the concentration of an element in the content. The quality of gamma-ray spectroscopy has a significant effect on the accuracy of the results. The conventional gamma-spectroscopy system in this method includes an HPGe detector, power supply, spectroscopy amplifier, and a computer equipped with suitable software for recording and data analysis. Since the investigated samples (soil, plant, milk, and alloys) contain a large number of elements, their related gamma spectrum includes many (10 to 100) peaks [2]. The most important source of error during the analysis is the background spectrum caused by Compton scattering and its overlap with the other gamma lines. The Compton background leads to the disappearance of many peaks or even if observed, due to the predominance of the Compton, the value of the area under the peak is inaccurate. So the result of the analysis of that particulate element will be reported with great inaccuracy. To overcome the mentioned problem, in a typical gamma-ray spectroscopy system used for NAA, a Compton suppression system is used to increase the peak to Compton ratio [3]. This system includes a central HPGe detector surrounded by either NaI(Tl) or BGO detectors. The Compton scattering events will be detected by both detectors and the photo peaks will be detected by the HPGe detector. The acquisition system measures the gamma-rays in anti-coincidence mode. The mentioned Compton suppressor systems are expensive (about 150k$) and are not easy to access. In this paper, a 2D pseudo coincidence Compton suppressor system is designed using two conventional HPGe detectors.

Experimental

The presented spectrometer at Nuclear Science and Technology Institute (NSTRI) is established based on a 14-bit CAEN waveform digitizer that samples directly from the preamplifier output of the two face-to-face HPGe detectors (ORTEC-GEM 20200, Canberra3001c). In this configuration, all the nuclear electronic modules are omitted and the system is loaded with a pulse height analyzer (PHA) firmware which transforms the sampled signals to pulse height amplitude and its timestamp [4]. The detected gamma-rays of ^{133}Ba (276.4, 302.9, 356, 383.8keV) and ^{137}Cs (662keV) in the two detectors are recorded in a list file (a file contains energy and time of each event). The experiment lasted 4 hours to record enough photopeak events on the list. The size of the list file is 2GB for each channel of the digitizer. The algorithm for the identification of pseudo coincidence events and conversion of list-mode data to the 2D spectrum is shown in Figure 1. Using this algorithm, the offline analysis of the list mode data is done to extract the pseudo coincidence correlated counts. In offline analysis, the optimum value of 5µs is selected for pseudo coincidence time window to obtain the maximum peak to Compton ratio and to efficiently detect the chance coincidence gamma-rays of 133Ba and 137Cs. Assume that E_1 and E_2 are the recorded energy by detectors 1 and 2, respectively. A 5500×5500 matrix array of E_1 and E_2 events is built-up.

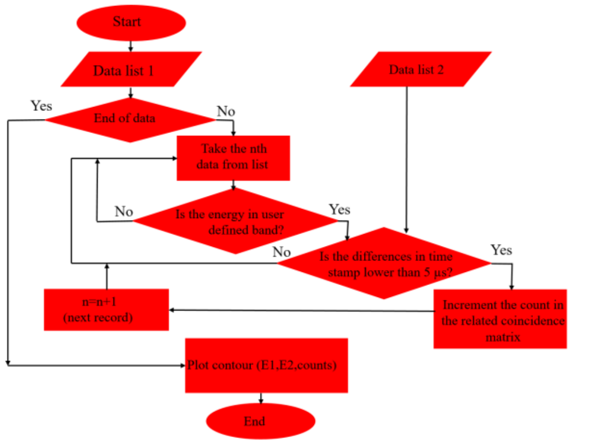

Figure 1. The algorithm for conversion of list-mode data to the 2D spectrum.

Results and discussion

Figure 1 shows the 2D pseudo coincidence spectrum of the gamma-rays. Due to limitations in the RAM of our computer, we plot the data in 270-370 keV region. The circles shown on the matrix diameter represent the background-free photopeak events. This region carries the most valuable information about the NAA experiment. The ridges parallel to the axis are Compton scattered (low energy side) or pile-up events. To obtain the photopeak events a diagonal cut of the matrix with a bandwidth of 10keV is selected. Figure 2 shows the projection of the 2D spectrum to conventional 1D spectrum for gamma lines of 356 and 662 keV. As shown in Figure 2, by separation of unwanted events such as Compton scattering, background, and pile-up the peak to Compton ratio increased up to 10^4 in the 2D pseudo coincidence mode.

Moreover, the energy resolution of the 2D spectrometer (R_T) can be predicted by the resolution of each HPGe detector using the equation.1 [5].

$$R_T = \frac{1}{2}\sqrt{R_1 + R_2} \qquad (1)$$

Where R_1 and R_2 are the resolution of the detectors 1 and 2, respectively. So, for two identical detectors, the spectrometer energy resolution improves by a factor of $1/\sqrt{2}$.

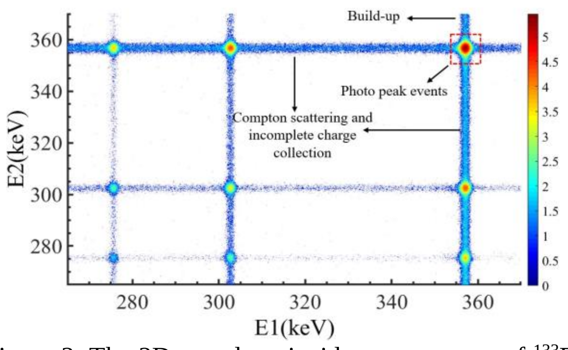

Figure 2. The 2D pseudo coincidence spectrum of ^{133}Ba radioisotope. The gamma-region of 256, 302, and 356 keV of ^{133}Ba.

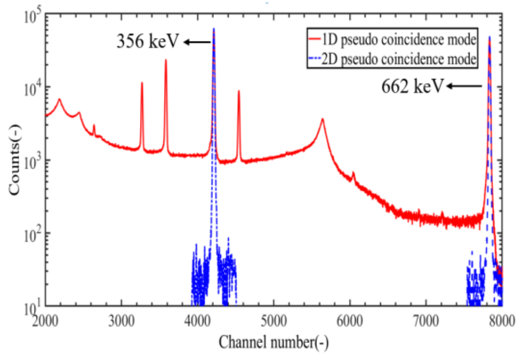

Figure 3. The projection of the 2D spectrum with a bandwidth of 10 keV is also shown.

Conclusions

In the past decade, many efforts have been devoted to using Compton suppression systems for NAA. These systems are often very expensive and include complex nuclear electronics. In this paper, we switched from analog to digital gamma-ray spectroscopy to design a Compton suppressor system using conventional HPGe detectors. The results of our experiment confirm that the 2D gamma-ray spectroscopy using a list mode file can increase the peak to Compton ratio up to 10^4 and improve the spectrometer energy resolution. Although significant improvement have been achieved using the 2D Compton suppresser system, this technique needs long time data acquisition (4hours) to obtain enough data of photopeak events Further to this work, we are going to initiate a series of NAA experiments using the presented technique to investigate the possible improvement of the detection limit in the NAA technique.

References

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