Reduction of nuclear and Compton backgrounds via pulse shape recognition

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Introduction. The reduction of nuclear background in x-ray measurements can reduce the limit of detection, or improve the accuracy of basic physics measurements. Using a signal processor with the capability of both pulse shape and rise time discrimination, we have observed almost an order of magnitude reduction in components of the spectral background, compared with previous systems. We will present the spectra of ^{65}Zn, ^{133}Ba, and ^{241}Am, measured with the same detector and the same geometry but with different signal processors.

High energy gamma rays can interact with the detector crystal via Compton scattering. As a consequence, some of the electrons participating in the scattering will be registered by the detector while a large number of the Compton scattered photons will leave the detector. The result of the Compton scattering is a Compton plateau in the x-ray spectrum. It spans downward in energy from the cut off energy, and is commonly observed as a flat plateau. Part of this plateau can be reduced via pulse shape inspection and rise time discrimination. It is observed that the shape of the Compton plateau can vary significantly using different signal processors. It is therefore important to know the capabilities of the signal processor before the experimental spectra can be compared with model calculations and simulations.

Experiments: The experiments were carried out with several radioactive sources. All spectra were collected with an Oxford Instruments Si(Li) detector (25mm²x3mm) with its XP3 signal processor and the CSX-3 digital signal processor developed at Cambridge Scientific in Canada. The Oxford Instruments detector and analog signal processor (XP3) were selected as a reference.

Experiment1.

Fig.1 presents two spectra measured simultaneously using two signal processors. There are marked differences in the background. It was important to understand what characteristic of the preamplifier signal allow such a reduction in the background component. The CSX-3 signal processor has three discriminators, based on the noise, pulse shape and signal rise time. The CSX-3 processes all events and generates several spectra based on whether the events met the requirement of the discriminator tests thus producing a good event spectrum and several rejected events spectra. This allows immediate determination of which requirement was not satisfied by the preamplifier signal.

Figure 2. Shows that the improvement is achieved by noise and shape discrimination, while in this case the rise time discrimination which was set to 300 ns had a limited effect. To our surprise the longer rise time events were at the low energy end of the spectrum.

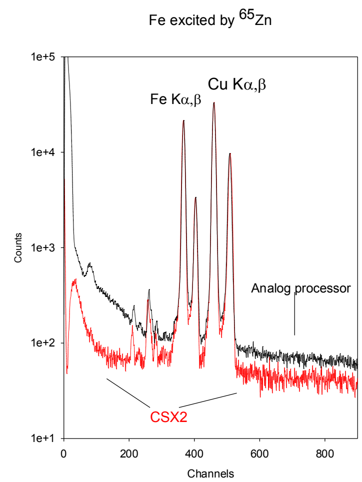


Figure 1. An Fe sample is irradiated with Cu K radiation from a ^{65}Zn source in transmission geometry. The background is substantially reduced using the CSX2 or CSX3 by noise discrimination and risetime discrimination. The manufacturers analog processor (—), and the Cambridge Scientific CSX2 digital processor (—).

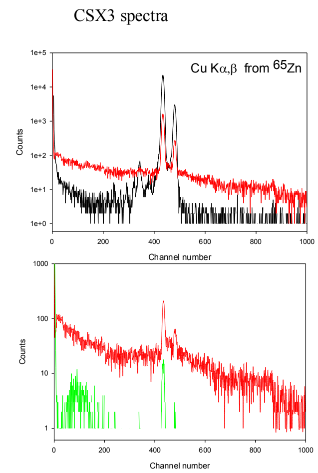


Figure2. The copper K spectrum from a ^{65}Zn source measured with CSX3 processor, shows the effect of noise, shape and risetime discrimination on the recorded spectrum. Upper panel: the red spectrum is the events rejected by the discriminators and the black spectrum is those events which pass all the criteria.
Lower panel: the rejected events are separated to two spectra, the red spectrum containing those rejected by the noise and/or shape discrimination, while the green is the events which is rejeced by rise time discrimination alone.

Experiment 2. Frequently there are large nuclear backgrounds originating from sources other than the studied radioactive source. We simulated such a situation by placing a ^{133}Ba source on the side of the detector nose. We placed weak ^{55}Fe and ^{109}Cd sources in front of the detector. The shape of the Compton structure is highly dependent on the signal processor and its settings. Therefore one should be cautious when comparing real spectra to model calculations.

Experiment 3. In an ^{241}Am spectra we have demonstrated that the Compton background can be preferentially suppressed, relative to the peak intensities. This would be useful in analytical work where high backgrounds worsen the limit of detection. This is demonstrated in figure 4 and 5.

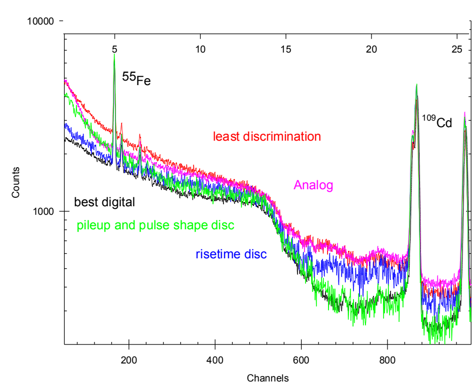


Figure 3. Manganese and silver K x-rays spectra superimposed on ^{133}Ba nuclear and Compton background.The shape of the Compton profile depends on the signal processing approach.

Fig 4. ^{241}Am spectra measured with our CSX-3 signal processor and a Si(Li) detector. An Al absorber was used to absorb the M x-rays. The rejected events spectrum is shown in red, and the good events spectrum in black. The lower energy side of the spectra are shown with a linear scale below in Fig. 5.

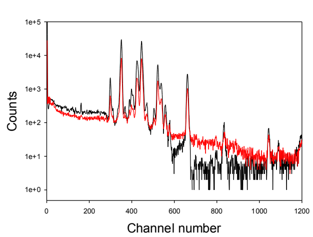
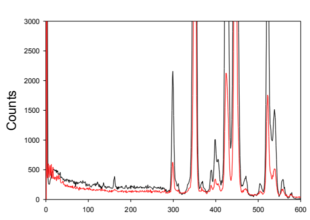


Fig. 5. Part of fig. 4 with a linear scale for better visualization.



Conclusion: The main point we can draw from the above experiments is that the magnitude of the observed Compton and nuclear background is highly dependent on the processor.

- Studies which try to model this background by comparing model spectra to real spectra must be caution as to the processor conditions with which the real spectra is collected.
- In analytical work where it is important to reduce background to improve the limit of detection for elemental peaks it is useful to set the processor to reduce the background.
- The rejected event spectra of several radionuclides have well defined low energy peaks which merit further investigations.

The CSX-3 digital signal processor with its great versatility and its ability to separate the events into good events and events that do not pass various inspection criteria is ideal for both high quality analytical and fundamental research measurements.

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