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Evaluating a Digital Gamma-ray Spectrometer (DSPec50) System and Comparison with the Standard Nuclear Instrumentation Method (NIM) System

Le Bao Viet and Geehyun Kim
Department of Nuclear Engineering, Sejong Univ.
209, Neungdong-ro, Gwangjin-gu, Seoul, South Korea
Corresponding author: gkim01@sejong.ac.kr

1. Introduction

Nuclear radiation measurements for the nuclear safeguard requires the best spectrometer systems possible with an excellent resolution and stability. In the contemporary field of radiation detection, digital signal processing technique has been exploited extensively in many applications, replacing the conventional analog signal processing systems. Radiological Sciences Laboratory (RSL) in Sejong University has recently acquired a new digital gamma-ray spectrometer system, DSPec50 from ORTEC. In this paper, we will evaluate the pulse processing performance of DSPec50 by investigating energy resolutions of the gamma-ray spectra depending on the pulse shaping parameters and by comparing it with the performance of the standard nuclear instrumentation method (NIM) systems based on analog pulse shaping technique. We have obtained a few results showing better performance by using digital spectroscopy system.

2. Materials and Methods

The HPGe detector used in this experiment was a p-type Ge detector with 55.1 mm diameter and 45.6 mm length, and the relative efficiency of the detector was 20%. Standard disk sources of Co-60 and Ba-133 produced by Spectrum Techniques LLC were measured using both digital and analog systems. The data were collected with the flat top time of the signal pulse as 0.8 μs and the rise times covering the minimum value to the maximum value allowed for DSPec50. Note that the digital spectroscopy systems use the rise times as a pulse shaping parameter, instead of the shaping time in the analog systems. The rise time of the digital signal processing (DSP) system is approximately equivalent to two time of the shaping time set on NIM. The shaping times for the NIM system of 1, 2, 3, and 6 μs correspond to the rise times for DSPec50 of 2.4, 4.0, 6.4, and 12 μs, respectively. The data collection was automated using Gamma Vision (MAESTRO 7 software) with the real time collections of 1000 seconds in both cases.

3. Results and Discussion

3.1 Energy and Resolution calibration

The energy calibration consists in the experimental determination of a function, usually a first degree polynomial, energy depend on the channel in the spectrum is given a function of:

$$E_\gamma = a + b * ch \quad (1)$$

Where E_γ is the gamma-ray energy, ch is the spectral channel number for the center of the peak corresponding to E_γ , and a, b are constants to be determined for calibration.

To energy calibration, standard sources were used: Ba-133 (80.997 keV, 276.4 keV, 302.85 keV, 356.02 keV, 383.85 keV) and Co-60 (1173.24 keV, 1332.5 keV).

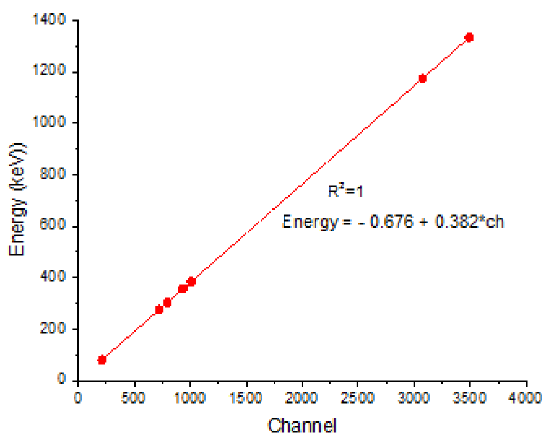

Fig. 1. Energy calibration curve.

The implication of this equations is that for any given channels on the MCA by plugging that channel number into equation, the energy that the MCA channel represents can be calculated. This mean that the MCA is linear each channel has the same width of energy.

R^2 is the best fit line. It has a value of 1 meaning that the best fit line is a perfect match for the data. This is an excellent results.

The resolution calibration, also called FWHM (Full-width at half maximum) calibration, establishes a function to describe the peak width versus the spectral energy. It is important characterizing the system performance in separating different photon emission in a narrow energy range.

FWHM is given a function of:

$$FWHM = aE^{1/2} + bE + c \quad (2)$$

Figure 2 below is showed relationship between energy and FWHM corresponding.

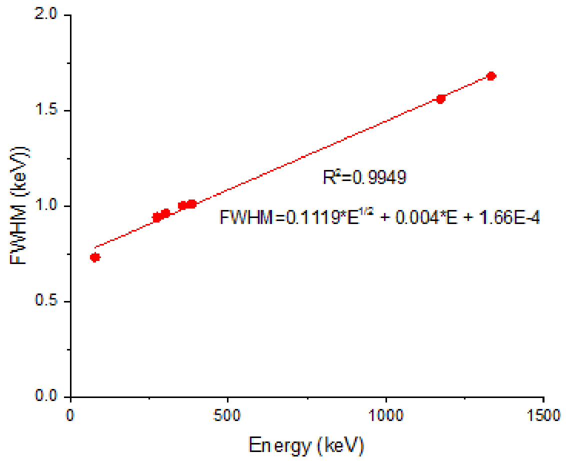

Fig. 2. FWHM (keV) of HPGe detector.

It is clearly see that FWHM (keV) depend on energy of gamma-ray.

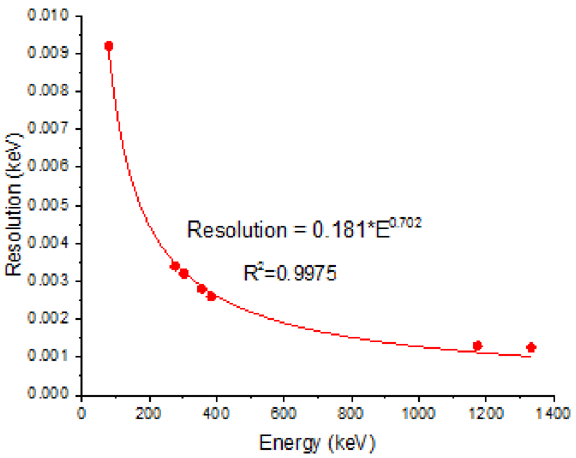

Fig. 3. Resolution calibration curve.

Figure 3 is the plot of resolution vs. energy of gamma-ray. The slope of this plot represent what the resolution does as energy increases. Resolution gets smaller as energy goes up. This means that at higher energies the detector is able to better discriminate between different energies. The dominate cause of peak broadening is having a low resolution.

3.2 Evaluation DSPEC 50

The FWHM and FW1/5M of the 1173.24 keV peak is shown in the figure 4. The 1173.24 keV gamma rays will have multiple interactions in the crystal to deposit all of energy, giving rise to longer charge collection time. The FWHM show some increase at short times, especially the shortest rise times. The FW1/5M show more of an increase at the shorter time. The rise time has minimal impact on the FWHM and FW1/5M about 12 – 13 us, and show a small and steady increase starting at a rise time of 15 us.

In very short rise time (<3 us) have contribute from noise caused by the detector leakage current and the preamplifier. In choose function at small (<3 us) or large (>15 us) rise time, noise contribution is larger than optimum rise time (6 – 14 us).

Furthermore, at very small rise time (< 3 us), the FWHM has an addition factor is potential for a ballistic deficit effect. Ballistic deficit effect is that charge collected by detector is less than the actual.

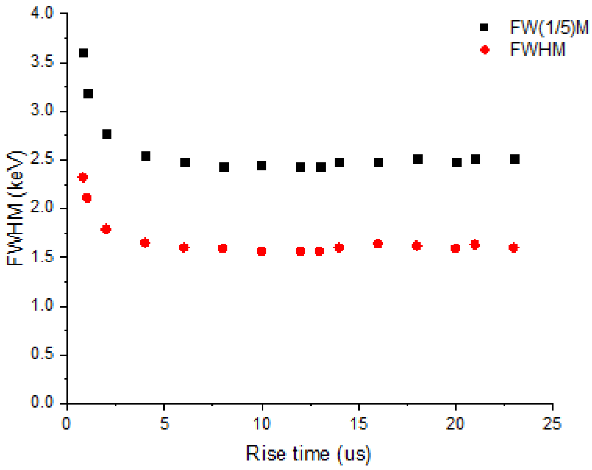

Fig. 4. Resolution at 1173.24 keV vs. many rise time (FWHM and FW1/5M).

Figure 5 shows that dead time depends on rise time and figure 6 shows the counts of peak 1173.24 keV depends on rise time. Small dead time means processing time the pulse is shorter, but very small dead time it happens ballistic deficit effect (previous discuss) affect to resolution of peak and count of peak is low caused by incomplete charge collection (previous discuss). At the very large rise time (specify at more than 15 us), dead time goes up so count of peak tends to goes down. It is caused by detection systems can lose a significant amount of data as events that occur during the dead time are ignored.

The reasonable value of rise time is range from 5 to 15, these are combination of statistical (number of count) and spectral quality (resolution, stability…).

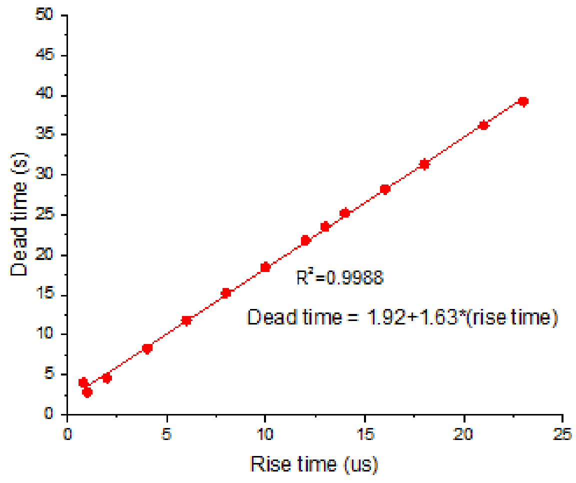

Fig.5. Dead time of Co-60 source.

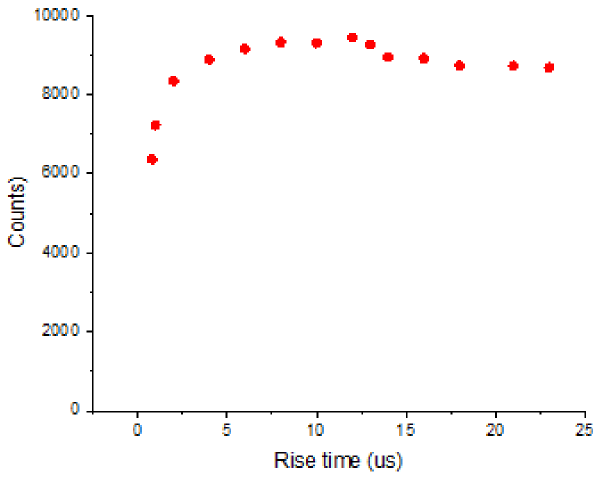

Fig. 6. Counts of 1173.24 keV peak vs. many rise times.

3.3 Comparison between DSPec 50 and NIM

Data were obtained with 1, 2, 3, 6 us shaping time (NIM) and 2.4, 4, 6.4, 12 (DSPec50).

Figure 7 and 8 compare the energy resolution of both systems with the same source (Co-60 and Ba-133). It is seen that, at energy (1173.24 keV gamma-ray of Co-60 and 80.997 keV of Ba-133), the DSPec50 system has better resolution than NIM. Especially for small shaping time (2 or 3 us) at the high energy (1173.24 keV).

The excellent performance resolution of the DSPec50 systems comparing with the analog systems (NIM), especially at high energy with small shaping time. It is caused by the large ballistic deficit effect. The digital signal-processing circuits of the DSPec50 systems can minimize the ballistic deficit much more effectively then the analog systems, which results in much better resolution.

The resolution of the NIM system at low energy is worse than DSPec50 system might be caused by noise. This probably means that the NIM system is noisier than the DSPEC.

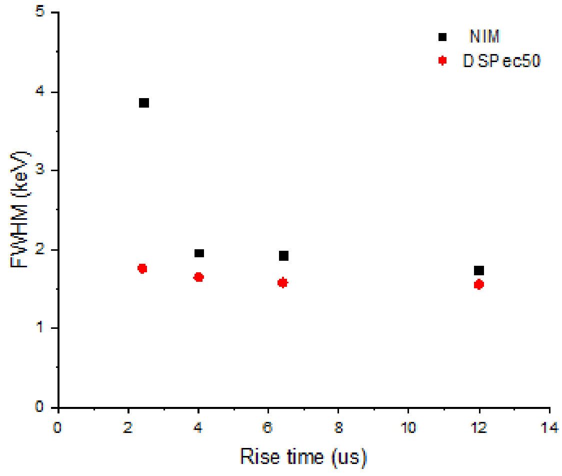

Fig. 7. Comparison FWHM between NIM and DSPec50 at 1173.24 keV.

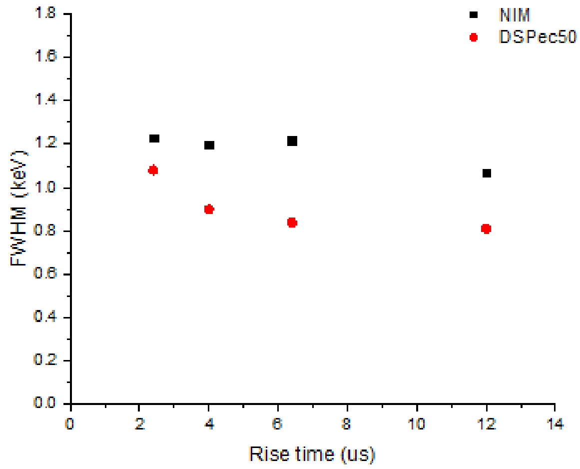

Fig. 8. Comparison FWHM between NIM and DSPec50 at 80.997 keV.

Figure 9 shows the dead time comparisons between NIM and DSPec50 system. We can see that the results of both systems are nearly the same.

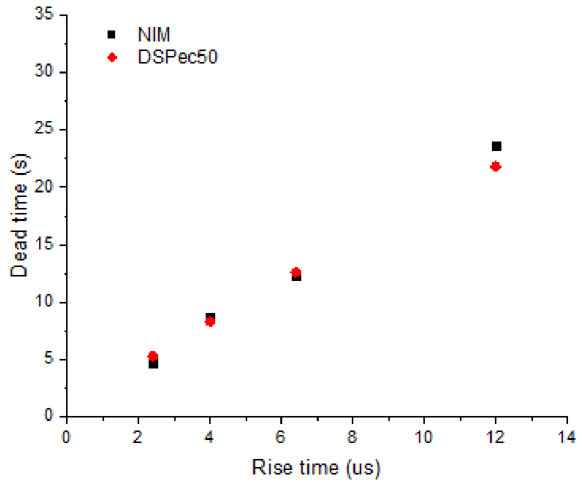

Fig. 9. Comparison dead time between NIM and DSPec50 of Co-60.

Figure 10 and 11 shows the counts of peak comparisons. It is clearly that the results with DSPec50 are better than the NIM system at all counts and shaping times. At the low rise time, the counts of peak of DSPec50 is almost 2 or 3 times the NIM counts of peak at high energy peak (1173.24 keV), this is explained because of the aforementioned ballistic deficit effect at high energy, counts of peak of the NIM system is not good.

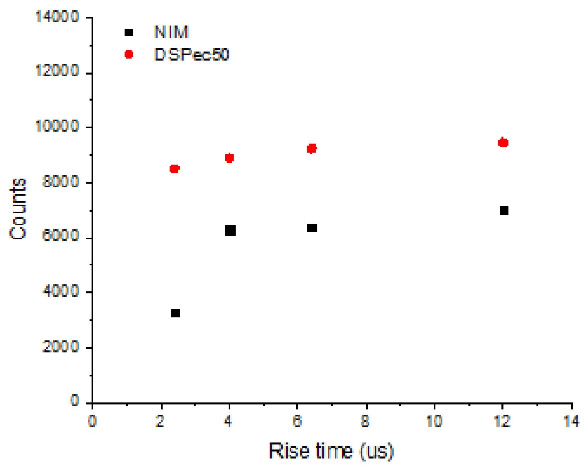

Fig. 10. Comparison counts of peak between NIM and DSPec50 at 1173.24 keV.

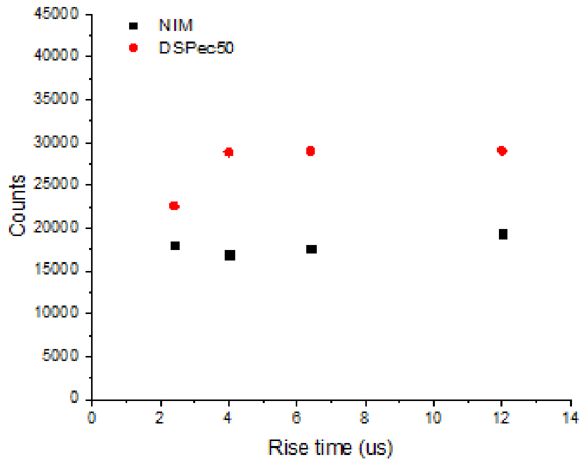

Fig. 11. Comparison counts of peak between NIM and DSPec50 at 80.997 keV.

4. Conclusions

A new digital gamma-ray spectroscopy system was evaluated. The energy resolution with DSPec50 has been shown better than NIM system. The counts of peak obtained with DSPec50 is clearly superior to that obtained with the NIM system. With benefits in both resolution and counts, and with the ability to fine tune and flattop parameters to achieve the optimal results, the conclusion is that the DSPec50 performs better than the standard NIM system. It is strongly recommended the DSPec50 for use in gamma-ray acquisition system using germanium detector.

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