LA-13393-MS

Comparisons Between Digital Gamma-Ray Spectrometer (DSPec) and Standard Nuclear Instrumentation Methods (NIM) Systems

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

Edited by Jeff Skiby, Group CIC-1
Prepared by Celina M. Ortiz, Group NIS-5

This work was supported by the US Department of Energy, Office of Nonproliferation and National Security, Office of Security Affairs, Office of Safeguards and Security.

LA-13393-MS

UC-706 and UC-700
Issued: March 1998

Comparisons Between Digital Gamma-Ray Spectrometer (DSPec) and Standard Nuclear Instrumentation Methods (NIM) Systems

D. T. Vo
P. A. Russo
T. E. Sampson

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

Comparisons Between Digital Gamma-Ray Spectrometer (DSPec) and Standard Nuclear Instrumentation Methods (NIM) Systems

by

D. T. Vo, P. A. Russo, and T. E. Sampson

Abstract

Up until about a year ago, gamma-ray spectroscopy has always been done using the analog amplifier, which processes the pulses from the preamplifier to remove the noise, reject the pile-up signals, and shape the signals into some desirable form before sending them to the analog-to-digital converter (ADC) to be digitized. In late 1996, EG&G Ortec introduced a digital gamma-ray spectrometer (DSPec) which uses digital technology to analyze the preamplifiers' pulses from all types of germanium and silicon detectors. Considering its performance, digital-based spectroscopy may become the way of future gamma-ray spectroscopy.

I. INTRODUCTION

Safeguards isotopic measurements require the best spectrometer systems with excellent resolution, stability, and throughput. With the arrival of good digital stabilizers on the market today, the stability is not a problem anymore. However, the resolution and throughput, which depend mainly on the amplifier and the analog-to-digital converter (ADC), can still be improved. These modules have been in continuous development and improvement for many years, and the results are generally excellent.

In 1996, EG&G Ortec produced a new package, a digital gamma-ray spectrometer (DSPec), which uses a completely different means to process the signals. Instead of processing the pulses from the preamplifier in a similar way to that of a conventional analog spectroscopy amplifier, DSPec processes the pulses digitally. It is a compact AC-powered system. Despite the compactness, however, it is not a portable system because of the large power required (110 W) and the inability to run on batteries.

II. PARAMETERS

A. Parameter Descriptions

Beside the essential functions such as amplifier gain (coarse and fine) adjustment, stabilization, baseline restoration (slow, fast, auto), and pole zero compensation, DSPec also provides an advanced shaping that uses a model based on the input parameters. The modeled pulse shape is a quasi-trapezoid whose sides and top may be adjusted to represent a near-rectangular, -triangular, or -Gaussian shape. The four parameters that control the shape are rise time, cusp, flattop, and tilt. These four parameters can be adjusted for each measurement to achieve the best results.

The rise time value is for both the rise and fall times. The DSPec rise time value is roughly equivalent to twice the integration time set on a conventional analog spectroscopy amplifier. A rise time value of $2x$ µs would correspond to x µs shaping time in a conventional amplifier. The DSPec rise time can be adjusted in multichannel analyzer emulator software from EG&G Ortec (MAESTRO™) in the range from 0.8 to 25.6 µs in steps of 0.8 µs using the horizontal scroll bar or the spin box.

The cusp value also applies to both the rise and fall times. It controls the curvature of the sides of the quasi-trapezoid. The cusp value can be adjusted from 0.5 to 1.0 in steps of 0.1 using the spin box where a value 0.5 corresponds to the largest positive curvature, and 1.0 corresponds to zero curvature (straight line).

The flattop adjusts the width of the top of the quasi-trapezoid. Its width can be adjusted in the range from 0.8 to 2.4 µs in steps of 0.4 µs using the spin box. A larger width of the flattop makes the pulse shape wider which may (or may not) improve the resolution and decrease the throughput rate. For an incoming rate of about 30 kHz, the throughput rate is reduced by as much as 20% when the flattop's width is changed from 0.8 µs to 2.4 µs.

The tilt varies the flattop slope. For best resolution, one should not try to set the tilt values manually but let the DSPec optimizer set it automatically.

Besides the step increases using MAESTRO™, all the rise time, cusp, flattop, and tilt values can also be adjusted using the MCBDIAG program that is provided with MAESTRO™ for Windows™ by the manufacturer.

B. Parameter Search

In order to optimize DSPec's usage with a germanium detector, one needs to find the best set of operating parameters for the detector. One of the detectors used was a two-year-old Canberra HPGe coaxial detector (~25% relative efficiency). A MAESTRO™ job file was constructed to automatically set the parameters and collect data. For this search, the stabilizer was turned off. The rise time values were varied from 4 to 12 μs in steps of 4 μs (corresponding to 2-, 4-, and 6-μs shaping times in the analog systems). The cusp values were changed from 0.5 to 1.0 in steps of 0.1 and the flattop's width values were changed from 0.8 to 2.4 μs in steps of 0.4 μs. The tilt values were automatically set by the optimizer. The sources used were 8.4-μCi ^{57}Co and 9.8-μCi ^{60}Co. The distances from the sources to the detector were varied to achieve the desirable count rates, which were 1, 3, 10, and 30 kHz. DSPec has no built-in counter, so the second output from the detector was connected to an amplifier which in turn was connected to a counter in a nuclear instrumental methods (NIM) system to monitor the count rate. For each data set, the full width at half maximum (FWHM) and the throughput of the 122-keV or 1332-keV peak were calculated. The FWHM results at each count rate and rise time were least-square fitted to the simplified two-dimensional quadratic equation

$$\text{FWHM} = a_1 + a_2*(\text{cusp}) + a_3*(\text{flattop}) + a_4*(\text{cusp})^2 + a_5*(\text{flattop})^2 \,.$$

Table I shows the optimal FWHMs (and the corresponding cusps and flattops) obtained from the search. Note that the cusp values of DSPec can only be adjusted by steps of 0.1 and the flattop by steps of 0.4 μs. The second row (of the double rows) shows the rounded values (to the nearest values allowed by DSPec) and the resulting FWHMs. From Table I, one can see that in general, for optimal resolution at small rise time, the cusp and flattop values need to be greater, and vice versa.

Table I. Optimal FWHM for various incoming count rates and rise times using DSPec with the Canberra germanium coaxial detector. The values inside the parentheses are what should be set with DSPec for optimal resolution.

		122-keV peak of ^{57}Co			1332-keV peak of ^{60}Co		
Count rate (kHz)	Rise time (μs)	Fitted cusp	Fitted flattop (μs)	FWHM (keV)	Fitted cusp	Fitted flattop (μs)	FWHM (keV)
1	4	0.920	1.921	0.849	0.815	2.653	1.787
		(0.9)	(2.0)	0.849	(0.8)	(2.4)	1.788
3	4	0.960	2.291	0.850	0.915	2.022	1.822
		(1.0)	(2.4)	0.850	(0.9)	(2.0)	1.822
10	4	1.000	2.126	0.849	0.939	1.609	1.797
		(1.0)	(2.0)	0.850	(0.9)	(1.6)	1.798
30	4	0.787	2.201	0.870	0.875	2.091	1.834
		(0.8)	(2.4)	0.871	(0.9)	(2.0)	1.839
1	8	0.808	1.854	0.753	0.790	1.639	1.765
		(0.8)	(2.0)	0.753	(0.8)	(1.6)	1.765
3	8	0.834	1.675	0.752	0.675	1.739	1.759
		(0.8)	(1.6)	0.752	(0.7)	(1.6)	1.760
10	8	0.757	1.625	0.751	0.996	1.698	1.744
		(0.8)	(1.6)	0.751	(1.0)	(1.6)	1.744
30	8	0.687	1.830	0.777	0.800	1.342	1.800
		(0.7)	(2.0)	0.777	(0.8)	(1.2)	1.801
1	12	0.677	1.391	0.717	0.689	1.757	1.747
		(0.7)	(1.2)	0.718	(0.7)	(1.6)	1.748
3	12	0.614	1.331	0.717	0.623	1.566	1.739
		(0.6)	(1.2)	0.717	(0.6)	(1.6)	1.739
10	12	0.608	1.280	0.723	0.892	1.787	1.725
		(0.6)	(1.2)	0.723	(0.9)	(1.6)	1.728
30	12	0.640	1.471	0.779	0.826	1.851	1.802
		(0.6)	(1.6)	0.781	(0.8)	(2.0)	1.803

It is interesting to note that while changing the cusp value does not affect the throughput rate, changing the flattop value changes the throughput rate significantly. The effects of the flattop width on the throughput rate of the ^{57}Co and ^{60}Co are shown in Fig. 1. The data are the averages of the results of all the possible cusp values (0.5, 0.6, 0.7, 0.8, 0.9, and 1.0). One can see that changing the flattop value from 0.8 µs to 1.6 µs does not have much effect on the throughput rate; it is less than 0.5% at 3 kHz and about 5% at 30 kHz for both ^{57}Co and ^{60}Co. However, when the flattop values are changed from 1.6 µs to 2.4 µs, the throughput rates are reduced significantly; it is about 10% at 3 kHz and 14% at 30 kHz for ^{57}Co, and about 4% at 3 kHz and 8% at 30 kHz for ^{60}Co. Also note that, for low count rate, the throughput at a large rise time is not much lower than that at a small rise time. (At 3-kHz count rate and 1.6-µs flattop, the throughput at 12-µs rise time is only about 7% less than that at 4-µs rise time.) Therefore, when optimizing DSPec, one should not only try to optimize the flattop but the rise time also. A slightly larger rise time and smaller flattop may give better resolution and throughput than smaller rise time and larger flattop.

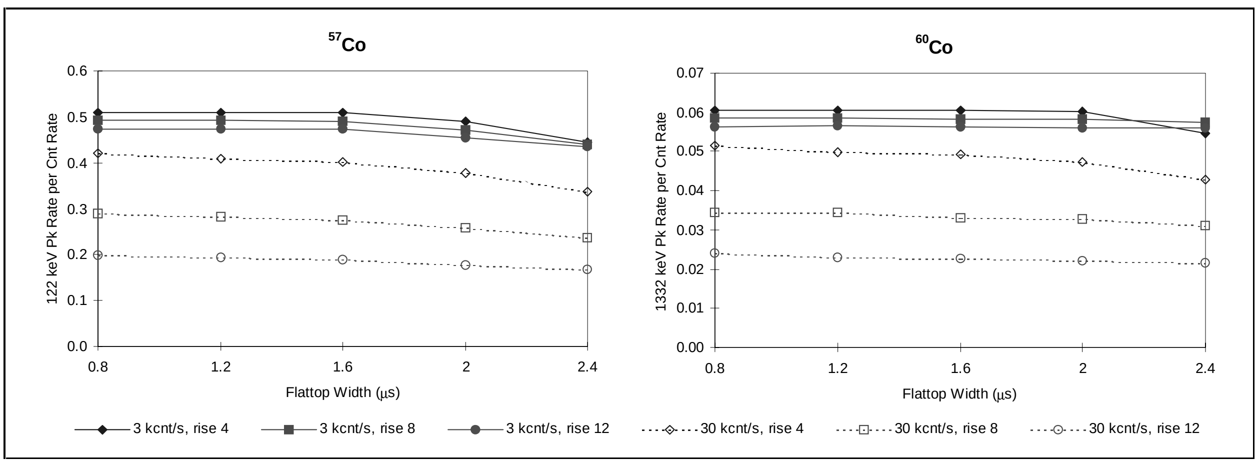

Fig. 1. Effects of the flattop width on the throughput rate of ^{57}Co and ^{60}Co.

III. COMPARISONS OF DSPEC AND NIM

A. Detectors

Two detectors were used in the measurements: one was a two-year-old HPGe coaxial detector manufactured by Canberra with a relative efficiency of about 25% (the same detector used in the parameter search in section II) and the other was a brand new HPGe coaxial detector manufactured by EG&G Ortec with a relative efficiency of about 23%. The detectors were shielded with lead bricks and cadmium sheets (except the fronts) to reduce the background gamma rays. The sources used were 8.4 μCi of ^{57}Co and 9.8 μCi of ^{60}Co, which give clean gamma rays and cover both ends of the energy range (122 keV from ^{57}Co for low energy and 1332 keV from ^{60}Co for high energy).

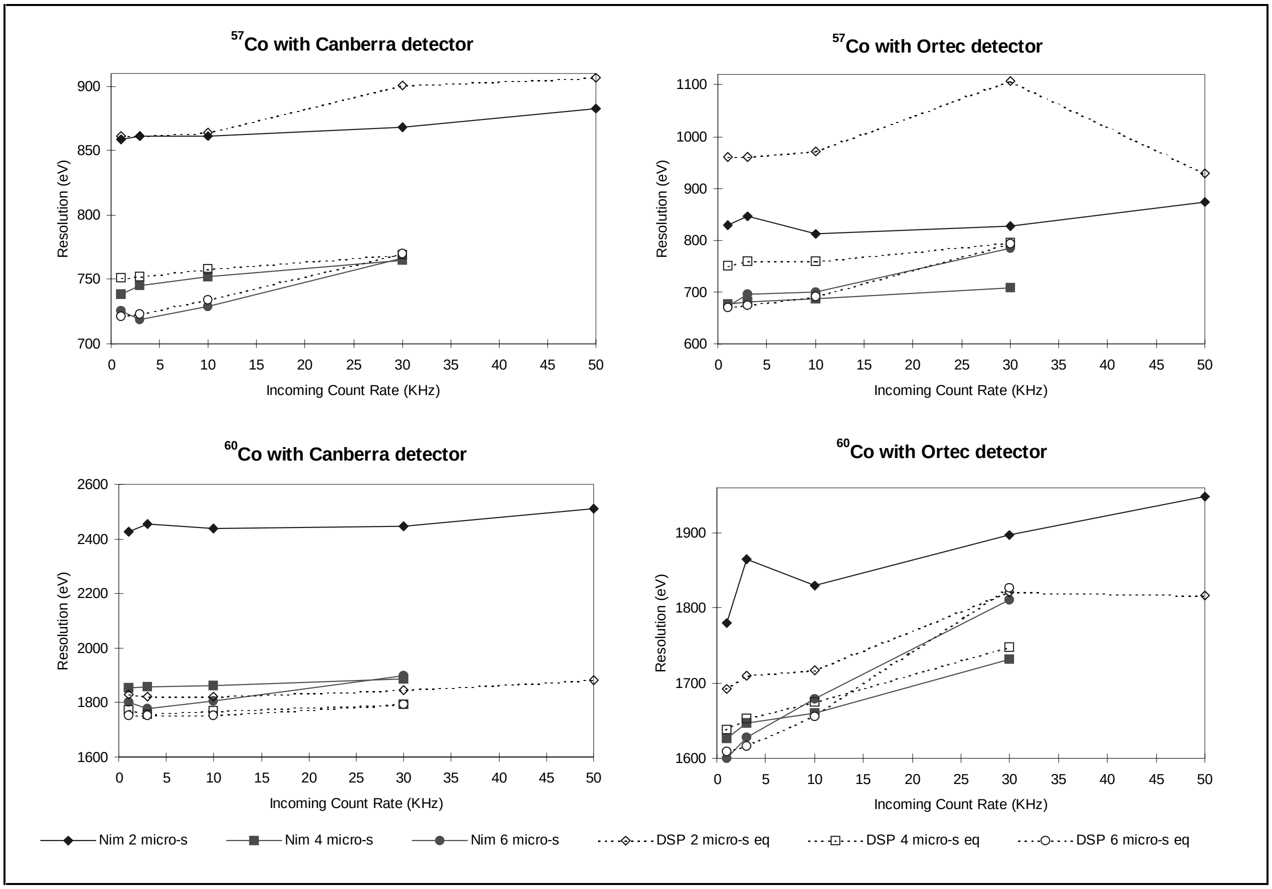

Fig. 2. Comparative resolutions of the NIM and DSPec systems. The rise times of the DSPec are reported as their shaping time equivalents. The actual rise times of DSPec are twice the shaping time equivalents.

B. NIM Set Up

The NIM system was a standard system that consisted of an Ortec 4002D power supply, Canberra 3106D HV power supply, Canberra 8077 Fast ADC, Canberra 8232 Digital Stabilizer, and Canberra 2071AS Dual Counter Timer. An Ortec 672 Spectroscopy Amplifier with triangle shaping was used for data collection at the 2- and 6-μs shaping times and a Canberra 2025 AFT

Research Amplifier with triangle shaping was used for data collection at the 4-μs shaping time. The Canberra 4610 System 100 multi-channnel analyzer (MCA) board was used for the interfacing. An IBM docking station was used to hold the MCA board, and the host computer was an IBM ThinkPad 760L. The software used for collecting data was the System 100 software from Canberra.

C. DSPec Set Up

DSPec is an AC-powered stand-alone unit, and it can be connected to the computer by means of an ethernet BNC connector, dual-port memory 37-pin D-type connector, or low-speed serial link. In this experiment, DSPec was connected to the IBM ThinkPad 560 by ethernet through the 3Com Etherlink III PCMCIA card. The software used to acquire data was MAESTRO™ for Windows™ from EG&G Ortec.

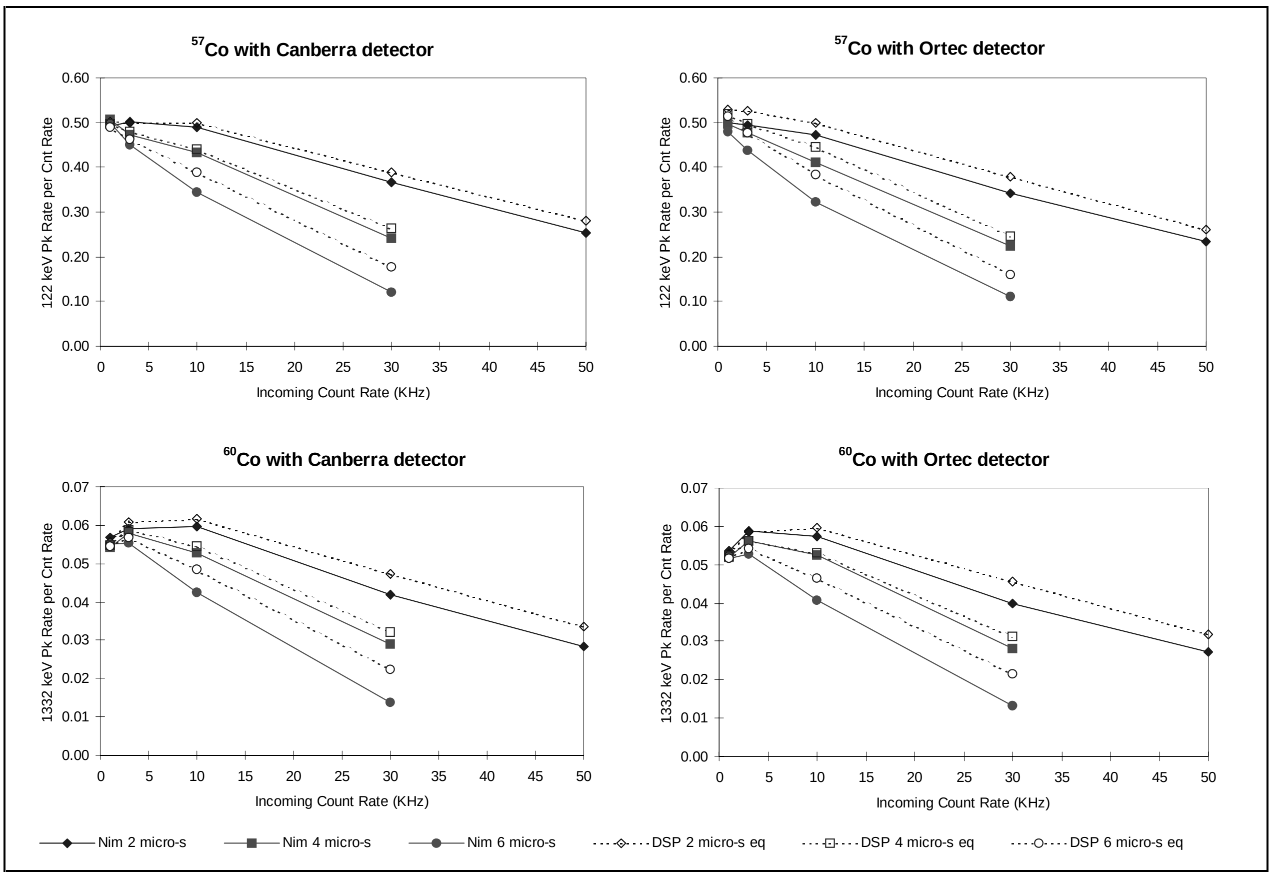

Fig. 3. Comparative throughputs of the NIM and DSPec systems. The rise times of the DSPec are reported as their shaping time equivalents. The actual rise times of DSPec are twice the shaping time equivalents.

D. Data Analysis and Comparisons

For all of the measurements, each source (^{57}Co or ^{60}Co) was measured separately. The sources were moved close to or far away from the detectors in order to achieve the desired count rates. Data with count rates of 1, 3, 10, and 30 kHz were obtained with 2-, 4-, and 6-μs shaping times (NIM) and 4-, 8-, and 12-μs rise times (DSPec). In addition, data were also obtained at a count rate of 50 kHz with a shaping time of 2 μs (NIM) and a rise time of 4 μs (DSPec). As for the DSPec's cusp and flattop parameters, it was determined that it is not very realistic if one tries to adjust the parameters to achieve the best results for every single measurement. Therefore, based on the Table I and Fig. 1 above, a cusp value of 0.8 and a flattop value of 1.6 μs were selected as the general purpose parameters to use throughout the measurements. The ADC conversion gain and range were set at 8K on both systems. The amplifier gains were adjusted so that for the ^{57}Co data the 122-keV peak was at channel 3000 and for the ^{60}Co data the 1173-keV peak was at channel 7000. The zero stabilizers were not used and the gain stabilizers were set on the 122-keV (^{57}Co) and 1173-keV (^{60}Co) peaks. The spectra taken with the NIM system were in the Canberra MCA format. These were all converted to the Ortec CHN format to use with the analytical functions in the MAESTRO™ software. The reason for the conversion of the NIM spectra is that the same analytical functions from a single software can be performed on both data sets (so if there are any biases from the analysis algorithms, they should be the same for both data sets). The energy calibrations were done using either the 122.06-keV and 136.47-keV peaks of ^{57}Co or the 1173.23-keV and 1332.49-keV peaks of ^{60}Co. For the throughput rate, the live times on the two systems are not exactly the same, so the recorded live times in the spectra were not used to calculate the throughput rate. The total counts in the 122-keV and 1332-keV peaks were used instead. For all the results shown in Figs. 2, 3, and 4, the analysis was done on the 122-keV peak of the ^{57}Co and the 1332-keV peak of the ^{60}Co.

It is interesting that, during the acquisition with DSPec, the stabilizer gain was suddenly shifted to some extreme values several times, which in effect shifted the peaks by as much as tens of keV. In DSPec, the status of the stabilizers is shown on the front panel. When the stabilizer is active, the display shows the value of the stabilizer amplifier setting which ranges from -999 to 999 A. Normally it will move quickly to the base value and then move up and down around this value. When the stabilizer suddenly shifts, the stabilizer amplifier setting is shown to shift to either -999 or 999 A and the peaks are shifted by tens of keV, negative or positive. It was later found that the sudden shifts occur only when the peak chosen for gain stabilization is set so close to the desired value (less than 0.5 channels) that when the gain stabilizer is turned on, very little correction is needed to bring the peak to the desired position. In this case, the stabilizer amplifier setting value from the display is shown to move up and down around zero. It is speculated that the stabilization algorithm of DSPec may have included a division by the stabilizer amplifier setting. When the stabilizer amplifier setting is exactly or nearly zero, the sequential stabilizer's correction may have involved dividing a value by zero (or a very small number) and this would shift the stabilization to the extreme value. The stabilizer seems to be working fine when the gain peak is set somewhat far away from the desired value (greater than 1 channel). In this case, the stabilizer amplifier base value may be less than -100 or greater than 100, and it is very unlikely for the stabilizer amplifier setting to ever come near zero for the sudden shift to happen. It is not exactly known if this sudden shift is a common feature of our DSPec only or of all the DSPecs.

Fig. 2 compares the energy resolution of both systems with both detectors and sources. It is seen that, at low energy (122-keV gamma rays of ^{57}Co), the NIM system has better resolution than DSPec, especially with the newer Ortec detector. However, at high energy (1332-keV gamma rays of ^{60}Co), the DSPec performs better than the NIM, especially for small shaping time (2 μs) and with the older Canberra detector. Looking at the data from the Canberra detector, the resolution with the DSPec is not as good as the optimal resolutions shown in Table I because the cusp and flattop parameters of the DSPec were set for general purpose data acquisition and not for optimal data acquisition. It is also because of the stabilizer, which has the tendency to broaden the peaks slightly. (The stabilizer was not turned on when taking data for the parameter search as described in Section II.)

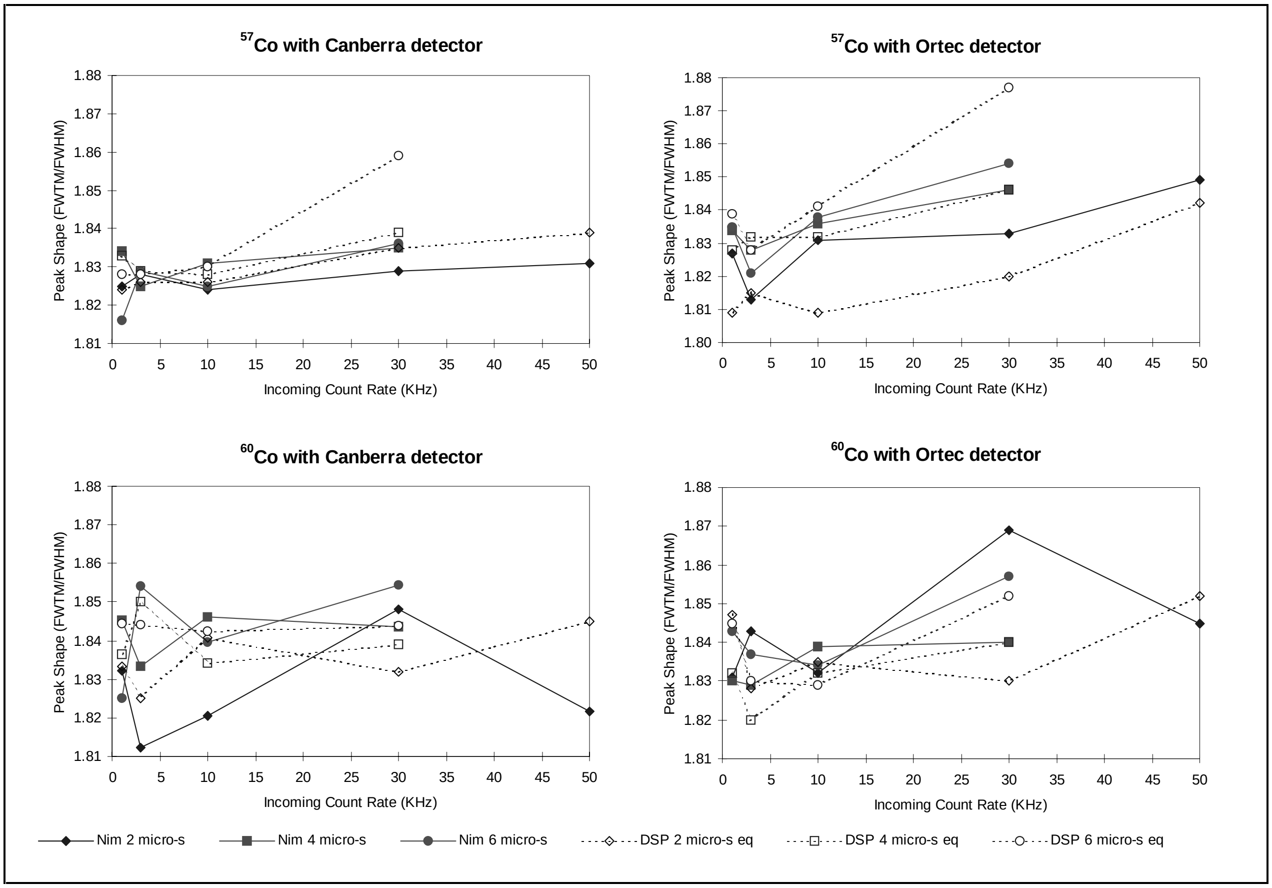

Fig. 4. Comparative peak shapes of the NIM and DSPec systems. The rise times of the DSPec are reported as their shaping time equivalents. The actual rise times of DSPec are twice the shaping time equivalents.

Fig. 3 shows the throughput comparisons. It is clearly seen that the results with DSPec are better than the NIM results at all count rates and shaping times. At a high count rate, especially at 30 kHz and 6-μs shaping time, the throughput with DSPec is almost twice the NIM throughput. Note that the throughputs of ^{60}Co with both detectors at 1 kHz are lower than those at 3 kHz. The reasons are partly from the background gamma rays from the surroundings (~ 30 Hz, which affects the low count rate more than high count rate) and mainly from the back-scattered gamma rays. For the 1 kHz count rates, the ^{60}Co source was placed at the far end of the shielding cavity against the lead wall. This would increase the chances of the back-scattered gamma rays entering the detectors, which would reduce the 1332-keV peak rate (with respect to the total incoming count rate). Therefore, the throughputs of the 1332-keV peak at 1 kHz appear to be slightly less than those at 3 kHz.

Fig. 4 shows the ratios of the FWHM to the full width at tenth maximum (FWTM). For a perfect Gaussian, the ratio would be 1.823. As one can see from Fig. 4, all the peak shapes from both NIM and DSPec are good.

IV. CONCLUSIONS

A new digital gamma-ray spectroscopy system was evaluated. Aside from the sudden shifts, the DSPec's stabilizer seemed to work satisfactorily. The energy resolution with DSPec has been shown to be about the same as that with the NIM system when used with the brand new Ortec germanium detector. (In fact, the DSPec is better at high energy but worse at low energy.) For the older Canberra germanium detector, the resolution with DSPec is better, especially at high energy and small shaping time. (It is about the same as the resolution with the NIM system at low energy.) The throughput obtained with DSPec is clearly superior to that obtained with the NIM system for compatible resolution. With benefits in both resolution and throughput, and with the ability to fine tune the cusp and flattop parameters to achieve the optimal results, the conclusion is that the DSPec performs better than the standard NIM system and should be seriously considered for safeguards isotopic measurements.

This report has been reproduced directly from the
best available copy.

It is available to DOE and DOE contractors from
the Office of Scientific and Technical Information,
P.O. Box 62,
Oak Ridge, TN 37831.
Prices are available from
(615) 576-8401.

It is available to the public from the
National Technical Information Service,
US Department of Commerce,
5285 Port Royal Rd.,
Springfield, VA 22616.

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545