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UTILIZATION OF CONCURRENTLY GATHERED PULSER DATA FOR COMPLETE SPECTRAL VALIDATION OF GAMMA-RAY SPECTRA FROM GERMANIUM DETECTORS*

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SUMMARY

Some of the capabilities and limitations of using concurrently gathered pulser data for energy calibration, dead time correction, and pile-up loss correction of gamma ray spectra from germanium detectors have been investigated. This report deals with the pulser, charge injection into the charge sensitive preamplifier, hardware separation of gamma and pulser events, and analysis techniques to improve the accuracy of gamma peak area corrections from pulser data. Data is presented indicating achievable short and long term energy calibration stability of better than .01% and accuracy of rate dependent peak area loss corrections of ±1% up to 50,000 pulses per second (pps) and ±2.5% up to 100,000 pps, energy independent.

INTRODUCTION

The application of high resolution gamma ray spectroscopy to non-laboratory or field instrument system uses has generated a stringent requirement for at least semi-automatic data validation. Field systems include systems such as remote effluent monitors, gamma transmission densitometers, mobile spectroscopy systems, and in some instances isotopic radiation monitoring facilities. One approach to this requirement is to use concurrently gathered pulser data as an aid in data validation. In theory, with ideal components and ideal analysis algorithms, this pulser data will allow accurate energy calibration under most conditions, and accurate peak area correction for losses due to count rate effects as long as count rate changes during a particular counting interval are small or well known.

The pulser is not used as a part of an automatic gain or zero adjusting network. Pulser amplitude spectra are gathered concurrently with gamma ray spectra, stored in a separate section of analyser memory, and recorded as a permanent header to the corresponding gamma ray spectrum. Pulser centroid information is used to energy calibrate the gamma ray spectrum, and pulser peak area information is used for live time and pile-up loss correction to the gamma ray peak areas.

The pulser data is also used to determine zero energy spectral line width, to monitor system noise levels, and to detect unacceptable zero or gain shifts during a measurement interval.

PULSER

The pulser is a free running crystal frequency controlled unit with two precision current sources and current switching circuitry.[1] It is similar in concept to the pulser designed by Chase, Rogers, and Radeka at BNL.[2] Measured current source stability is better than ±2 ppm/°C. Calculated contributions to instability from switching circuitry is less than ±2 ppm/°C. The pulser enclosure is temperature controlled to vary less than 1°C for an outside temperature variation of 30°C. The pulser output is a square topped pulse of two discrete amplitudes with a factor of 10 difference in pulse height.

The pulser output is fed into the preamplifier input through a charge injection capacitor internal to the detector cryostat (see Fig. 1). The square topped pulse is a necessary shape for high gamma rate applications in order that the pulser will introduce no baseline distortions at the filter amplifier output due to two-pole response at the charge sensitive preamplifier output. The trailing edge of the square pulser pulse generates a negative pulse at the amplifier output that renders the system "dead" for its duration. The pulser pulse width is set to be as narrow as possible without interfering with the amplitude of the preceding positive pulse from the pulser leading edge, so that the dead time introduced by the negative pulse will be, for the most part, coincident with the ADC rundown time for the positive pulse and will not appreciably extend system dead time. A 100 pulse per second repetition rate (50 each of the high and low amplitude) is used in most applications to minimize the fractional amount of time used to analyze pulser pulses, though a higher rate is preferable for extended high gamma rate operation.

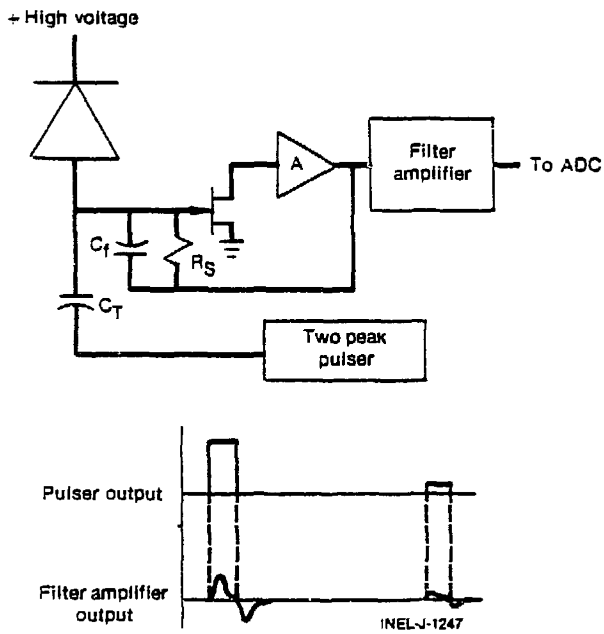

Figure 1. Pulser Charge Injection

The pulser spectral centroid location is used to energy calibrate the concurrently gathered gamma spectrum. There are four main contributors to systemmatic inaccuracies in this calibration:

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1. detector charge production instability
2. pulser amplitude instability
3. centroid algorithm instability contributions
4. charge injection capacitance instability

Charge injection capacitor instability is the major contributor to calibration inaccuracies. Early commercial cyrostats configurations utilized low noise, poor temperature stability capacitors which were not included inside the infra-red shield surrounding the detector. Cyrostat end cap temperature changes induced sufficient capacitance change in the charge injection capacitor to render the calibration unsatisfactory in field conditions. It was necessary to install end-cap temperature controllers on these units. Newer commercial units exhibit acceptable charge injection capacitance stability for many applications (see Fig. 2). Richard Pehl (LBL) utilizes high stability charge injection capacitors in some units, and for fully depleted high purity germanium detectors, uses the detector capacitance itself as the charge injection capacitor. This latter method is very suitable for fully depleted detectors, but is not suitable for most Ge_{Li} detectors. There are other instabilities in charge injection that are independent of the charge injection capacitor itself.

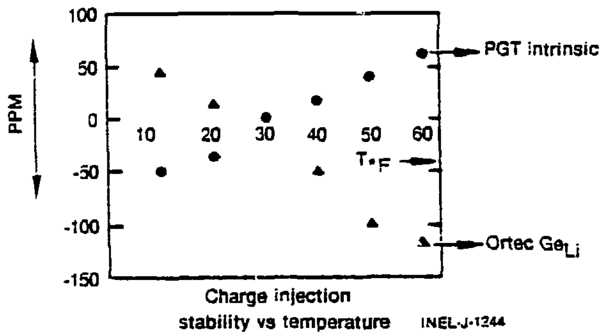

Figure 2. Stability of charge injection vs. external temperature change in two different commercial cryostats.

Some centroid algorithms have trouble determining centroid location consistently under high rate conditions where spectral peak shapes are distorted by high side tailing. Fit limits need to be kept fairly narrow to avoid relative discrepencies in centroid location of narrow pulser peaks as compared to centroid location determination of broader gamma ray peaks.

With these two contributions (charge injection capacitor instability and centroid algorithm instability) reduced to acceptable limits, pulser amplitude instability and detector charge production instability are also acceptable (±.01% calibration accuracy both long term and over a 50°F ambient temperature change.)

HARDWARE SEPARATION OF PULSER AND GAMMA EVENTS

Since the pulser peak areas are used for pile-up and live-time corrections of gamma ray peak areas, the pulser is free running at a crystal controlled 100 pulse per second repetition rate. In order to prevent spectral interference with the concurrently gathered gamma ray spectrum, the pulser data is stored in a seperate section of analyser memory.

Each time the pulser injects a pulse into the preamplifier input, it also generates a pulser tag signal. This signal is delayed in time to within 200 nanoseconds of peak detect time in the ADC for a nonpiled-up pulser pulse. If the ADC is not busy at this time, a routing signal is set to route the next ADC output data to the pulser section of analyser memory. This routing signal is reset if the signal is internally or externally rejected or at the time the selected event is stored. If the ADC is already busy processing a previous pulse when the pulser tag signal comes along, the pulser routing signal is not set. Thus, pulser events and pulser events distorted by succeeding coincident gamma pile-up are stored in the pulser section of memory, whereas gamma events whose peak value is detected before the delayed pulser tag signal occurs are stored in the gamma spectrum. This hardware separation removes all discrete energy pulser pulses from the gamma spectrum and all discrete energy gamma events from the pulser spectrum.

ANALYSIS TECHNIQUES

Analysing high count rate gamma-ray spectra is made difficult by peak shape distortions and background distortions caused by coincident pulse pile-up. The difficulty is increased when the peak fitting algorithm tries to force a symeterical peak fit to these nonsymetric peaks. Even most fitting algorithms that have been developed for fitting non-symetric peaks[3] have been tailored to fit low-side tailing and are not directly applicable to peaks with high-side tailing due to pulse pile-up.

The attempt that has been made in this application is to fit the pulser peaks in the same manner that the gamma ray peaks are fit. The first obvious problem with this is that pulser peaks are narrower than gamma ray peaks. This problem is discussed by Debertin and Schotzig.[4] Thus, for a given pile-up pulse addition, more events will be thrown out of the narrow peak than out of the broader peak depending both upon the peak fitting algorithm used and the fit limits prescribed within the algorithm. For this reason, the first requirement of making a reasonably accurate correction of pile-up losses from gamma ray peaks by measuring pulser peak area losses is that the pulser peak be made to look as wide as the gamma-ray peak to be corrected. This is accomplished by first measuring the width of the gamma ray peak, W_γ, the pulser peak, W_p, and then constructing a unit area Gaussian peak whose width, W_G, is such that $(W_\gamma)^2=(W_p)^2+(W_G)^2$. This unit area Gaussian is then point-by-point convoluted across the pulser peak, generating a new pulser peak whose width is equal to W_γ and whose area has not been changed. The area of the gamma-ray peak and convoluted pulser peak are then determined using the same fit limits. The convoluted pulser peak area is applied to correct the area of the gamma-ray peak (in peak area counts per second) in the following manner:

$$\frac{Ag}{\text{second}} = \frac{Agm}{Apm} \times f \qquad (1)$$

Where: Ag = Gamma Area Corrected; Agm = Gamma Area Measured; Apm = Pulser Area Measured; f = Pulser Frequency.

This convolution and peak fitting uniformity is a first order answer to a whole host of fitting problems. Events which, due to rate dependent distortion, are ejected from the peak fit of the gamma-ray area are, to the first order at least, also ejected from the convoluted pulser peak fit, and vice-versa. Figure

3 illustrates the results of a narrow pulser peak convoluted to the width of the 1115 Kev ^{65}Zn peak in a spectrum taken at 135,000 pps input rate.

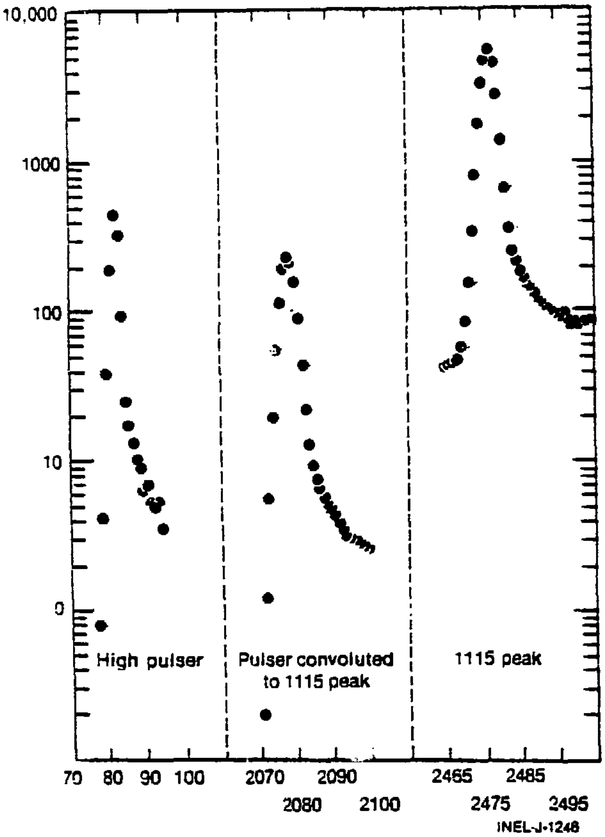

Figure 3. Effect of convoluting a narrow pulser peak with a unit area Gaussian to yield a pulser peak whose shape approximates the shape of a wider gamma-ray peak.

Another problem in operating a system at high rates is that there may be energy dependent pile-up rejection either in external pileup rejection circuitry or in the ADC itself. Figure 4 illustrates the high side tailing difference between the high pulser and low pulser (locations channel 2705 and channel 270 of a 4096 spectrum) in a system which includes no intentional pulse pile-up rejection. Equipment used was a PGT coaxial detector and preamplifier, an Ortec 572 amplifier at 2 µsec shaping with the BLR in "threshold" mode and optimally adjusted, and an NS-621 ADC. The high side tail is seen to be more pronounced on the high pulser peak than the low pulser peak at either high or low rates. This effect was reduced to an essentially indistinguishable difference with a carefully designed external pile-up rejection circuit in which care was taken to guarantee relatively equal dead time per pulse in the pile-up rejector, independent of amplitude. The effect was also checked by making fixed live time runs at a fixed count rate of 96,000 pps and changing the pulser amplitude for each succeeding run, then comparing the peak areas with fixed fit limits. The effect was found to be approximately a 4% loss in net area in a relatively linear fashion between channel 200 and channel 1200 and essentially no change from there to channel 3500.

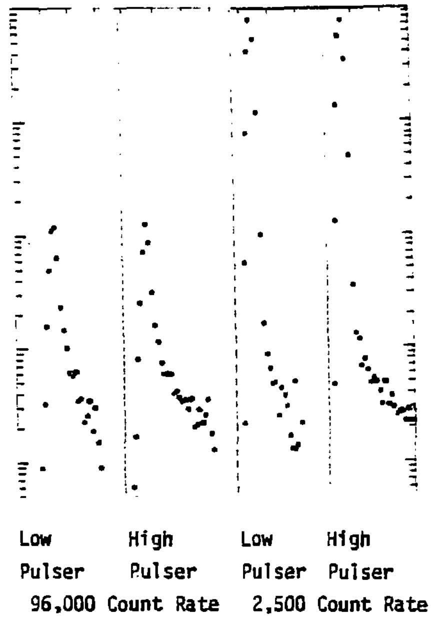

Figure 4. Energy dependence of pile-up tail at low and high rates in a system with no intentional pile-up rejection.

Energy dependence of the pile-up correction is very dependent upon the fitting algorithm used and the fit limits assigned, particularly the background endpoint limits, due to the significant high side tail induced at high rates. The only fitting algorithms readily available at our laboratory are GAUSS V[5] and summation of counts. In both these fitting algorithms, fit limits and background limits are assigned on the basis of measured FWHM of peaks. For consistency in fitting high rate data, this limit needs to be reduced, i.e. fit limits set to be very little wider than the FWHM points. This allows consistent centroid location determination and a symmetric fit to the portion of the peak which is symmetric. Figure 5 illustrates the energy dependence and algorithm dependence of the pile-up correction at 96,000 pps.

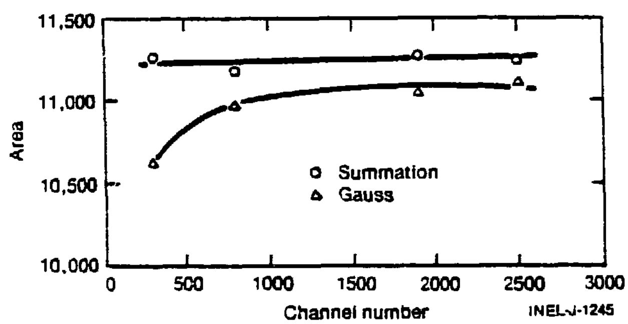

Figure 5. Energy dependence of peak area loss at 96,000 pps using two different fitting algorithms.

Another effect that was observed is that gamma peak width is affected in optimized systems in a very convenient manner, in that the zero energy width term increases with rate, but the energy dependent width term remains essentially constant. Therefore the pulser width, which is a measure of the zero energy width term, may be measured for each spectrum and proper correction of the width term used in data analysis of this spectrum can be generated from pulser information.

For an automatic fitting routine, the above mentioned effects have dictated the manner in which the pulser corrections are implemented. First, the pulser peaks are fit to determine the zero energy width term and to check for gain shift information which might cause the upper pulser peak to be broader than the lower pulser peak. These corrections are applied to the resident width equation. The lower pulser peak is fit as a zero energy peak, the upper pulser peak is convoluted to the width dictated by the width equation and then fit with fit limits determined from the width equation. Areas of the two pulser peaks are determined and an energy dependent correction equation is developed as follows:

$$Ap = \frac{Aup - Alp}{1200} \times C + Alp, \quad 0 \leq C \leq 1200$$

$$\text{and } Ap = Aup \quad 1200 \leq C \leq 4095 \qquad (2)$$

Where: Ap = pulser area used for correction; Aup= upper pulser area; Alp=lower pulser area; C=channel location of gamma centroid to be corrected.

This equation is a linear approximation of the energy dependence measured. Then the gamma peak areas are corrected in the following manner:

$$\frac{Ag}{\text{second}} = \frac{Agm}{Ap} \times f \qquad (3)$$

Where: Ag=Gamma area corrected; Agm=Gamma area measured; Ap=pulser area from equation 2; f=pulser frequency.

EXPERIMENTAL RESULTS

The analysis technique has been tested in several different front end electronics configurations. Data has been taken in systems utilizing no intentional pile-up rejection circuitry as well as specifically designed high rate systems with results that we feel make the technique valuable in most automatic analysis systems.

Rate performance was checked with a set of 8 IAEA mixed radionuclide sources[6] providing well known source strengths over a counting rate ratio of about 45 to 1. Peaks utilized in analysis were the 122 Kev line from ^{57}Co, the 356 Kev line from ^{133}Ba, the 834 Kev line from ^{54}Mn, and the 1115 Kev line from ^{65}Zn. Source-detector distance was chosen to provide input counting rates as high as 135,000 pps. Rate performance was also checked via the fixed source-movable source method using ^{152}Eu as the fixed source and ^{137}Cs as the movable source.

Low to moderate rate performance was checked using an Ortec coaxial Ge_{Li} detector and preamplifier, an Ortec 572 amplifier with 2 μsec shaping and BLR in "threshold" mode, and a Northern Scientific NS-1243 200 MHz ADC. Source strength measured ratios were compared to source strength known ratios to determine accuracy. Rates listed are detected input events per second. Table 1 lists the results.

High rate performance was checked in the same manner using a PGT coaxial detector and preamplifier, an Ortec 572 filter amplifier with 2 μsec shaping and BLR in "threshold" mode, and a Northern Scientific NS 621 50 MHz ADC. Peaks were fit both with Gauss V and summation. Table 2 lists the results.

TABLE I

Pulser Pile-up Correction
From Pulser Information

Deviation of Relative Peak Area
From Known Relative Value

Ortec 572 Amplifier,
2 μsec Shaping, Gauss Fit

Rate	122 keV	356 keV	834 keV	1115 keV
650	0	0	0	0
2400	+0.02%	+ .02%	-0.17%	+0.15%
7000	+0.15%	+ .09%	-0.42%	-0.12%

TABLE II

Pulse Pile-up Correction
From Pulser Information

Deviation of Relative Peak Area
From Known Relative Value

Ortec 572 Amplifier,
2 μsec Shaping, Gauss Fit

Rate	122 keV	356 keV	834 keV	1115 keV
2,500	0	0	0	0
13,000	+0.06%	-0.2%	+0.1%	+2.5%
45,000	-0.1%	-3.0%	-0.1%	+0.7%
96,000	+0.4%	-2.4%	+1.3%	+3.2%

Summation

Rate	122 keV	356 keV	834 keV	1115 keV
2,000	0	0	0	0
13,000	+0.5%	+0.4%	+0.1%	+0.3%
45,000	+0.4%	-1.3%	+0.1%	-0.7%
96,000	+0.9%	-2.1%	+2.3%	+2.4%

High rate performance was also checked in a system using a Nuclear Diodes coaxial detector with a Model 111 preamplifier, EG&G fabricated filter amplifier with 2 μsec shaping, EG&G fabricated pulse pile-up rejector, and a Northern Scientific NS 623 100 MHz ADC. Table 3 and Table 4 list the results.

CONCLUSIONS

Careful implementation of concurrently gathered pulser data allows for nearly complete spectral validation of gamma-ray spectra and can be an aid in verifying proper operation of a complete spectroscopy system.

Some limitations of the method are the following:

1. Energy calibration - Energy calibration accuracy is primarily limited by the stabililty of the charge injection capacitance. This capacitance unfortunately includes the stray capacitance around the capacitor itself, so that mechanical stresses internal to the detector cryostat due to external

Table III

Pulse Pile-up Correction
From Pulser Information

Deviation of Relative Peak Area
From Known Relative Value

(Known Strength Sources)
EG&G System

Rate	122 keV	356 keV	834 keV	1115 keV
3,000	0	0	0	0
8,500	+0.7%	+0.7%	+0.8%	+0.7%
16,000	-0.1%	+0.05%	+0.06%	+0.2%
30,000	-0.8%	+0.3%	-0.4%	-1.1%
45,000	+0.1%	+0.9%	+0.3%	-0.9%
60,000	+1.0%	+1.3%	+0.9%	-0.2%
84,000	-0.5%	+0.7%	-0.5%	-2.0%
135,000	-1.3%	+0.5%	-1.0%	-2.9%

Accuracy of Energy Calibration
Using Pulser Information

Rate	122.06 keV	356.01 keV	834.83 keV	1115.52 keV
3,000	122.351	356.01	834.84	1115.52
8,500	122.01	356.02	834.88	1115.56
16,500	122.01	356.03	834.89	1115.57
30,000	122.02	356.04	834.89	1115.58
45,000	122.01	356.03	834.90	1115.59
60,000	122.01	356.03	834.90	1115.59
84,000	122.00	356.02	834.89	1115.59
135,000	121.98	356.01	834.93	1115.67

TABLE IV

Pulse Pile-up Correction
From Pulser Information

Deviation of Relative Peak Area
From Known Low Rate Value

(Fixed Source-Movable Source)
EG&G System

Rate	121 keV	1408 keV
5,000 cps	0	0
5,000 + 45,000 cps	-0.3%	+0.2%
5,000 + 100,000 cps	+1.1%	+1.3%

temperature variations degrade this stability. For instance, spilled liquid nitrogen may cause the detector assembly to be mechanically moved in relationship to the cryostat enclosure, causing a stepwise change in effective charge injection capacitance-hence a stepwise change of energy calibration. In the same manner, mechanical shock to the detector assembly may cause a stepwise change of calibration. In high purity germanium detector systems that are allowed to temperature cycle, recalibration is necessary after every cycle. Energy calibration accuracy may also be limited by centroid location algorithms which are sensitive to the distorted peak shapes encountered in high rate data.

2. Peak Area Corrections - Peak area correction accuracy is limited by the same factors that limit the accuracy of peak area determination. Algorithms which uniformly handle the problems of rate induced assymetric peaks and summation induced background shape changes should improve the accuracy of the peak area determination of the gamma ray peaks and the accuracy of the pile-up corrections applied from pulser peak area determinations.

It should be noted at this point that the fitting algorithms used for these data make no attempt to address the problem of assymetric peaks other than adjusting fit limits so that a minimum effect is observed.

The important thing is that the pulser peaks are fitted in the same manner as the gamma-ray peaks, and their width is adjusted by unit area Gaussian convolution so that their shape accurately reproduces the shape of equal energy gamma ray peaks.

3. Pile-up Rejection - In each different system used, inherent or purposely built-in pile-up rejection exists. The energy dependence of this pile-up rejection must be known and possibly modified in order that accurate pile-up corrections may be made.

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6. Sets of five sources (intensity ratio 15 to 1) were prepared by the IAEA laboratory, Sübersdorf Austria, for the ICRM Intercomparison G-2 of dead-time and pile-up corrections. By special request three more sources were provided to extend the intensity ratio.