

Loss Free Counting with Uncertainty Analysis Using ORTEC's Innovative Zero Dead Time Technique

Objective

Show that the ORTEC loss free counting method with estimation of the uncertainty associated with the collected data is accurate for rapidly changing count rate applications.

Intended Audience

Users of High Purity Germanium (HPGe) detectors, hardware, and analysis software in applications where count rates change fast enough during the acquisition period that Live Time correction techniques may be statistically inaccurate. Such applications include: neutron activation analysis, real time monitoring of effluents, and other sample counting procedures where the half life of one or more nuclides is significantly less than the counting time.

Definitions

Live Time The period of data collection during which the electronics, such as a Multichannel Analyzer (MCA), are available to collect and process pulses from the detector, in this case an HPGe detector, typically measured in seconds.

Real Time The actual time expired during data acquisition, typically measured in seconds.

Dead Time The percentage of real time that the detector is not available for counting pulses. Dead time is calculated by the following formula:

$$DT = 1 - \frac{LT}{RT}$$

Live Time Clock (LTC) A method for determining the live time during a given real time counting period in an MCA.

Loss Free Counting A method for correcting the number of counts in an MCA for the dead time exhibited during the real time counting period.

Problem

All MCA's exhibit counting losses due to the dead time required to process pulses from any given source of radioactivity. Many algorithms, both electronic and computational, are available to determine the amount of time during which those losses occur. When count rates of the samples being measured are constant over the counting period (i.e. the dead time is constant \pm a few percent), then the standard method for calculating this time is by use of Live Time Clocks. At ORTEC, the Gedcke-Hale¹ Live Time Clock has been employed for many years in the MCAs to provide the live time of the electronics during any given counting period. Because of its innovative design, the Gedcke-Hale LTC has the best accuracy for measuring the Live Time of an MCA during acquisition of constant count rate samples. The dead time for any measurement is then calculated per the equation above and displayed with the spectral data along with the actual real time and live time.

Accurate knowledge of the live time of the count allows the analysis calculations to yield statistically valid results in terms of count rates. In simplest form, the count rate for any given peak is given by the following equation:

$$P = \frac{\text{Area}}{\text{Live Time}}$$

with the uncertainty in the Peak Count Rate given by (in simplest form):

$$\sigma_P = \sqrt{\frac{\text{Area}}{\text{Live Time}}}$$

because the events recorded in the peak areas follow normal Poisson statistical relationships.

It has been shown that when the counting rates vary greatly during the counting period, the Live Time Clock methods for estimating the live time become inaccurate. Loss Free Counting methods have been developed to correct this problem.

Unlike Live Time Clocks, loss free counting does not try to predict and record the actual time that the electronics are available for counting. Instead, these methods record the actual number of counts that would have been present had there been no dead time in the electronics. In these methods, there is only a real time displayed with the spectral data. The fundamental drawback to loss free counting up until now, is the loss of Poisson statistics and thus the

ability to determine the uncertainty with the number of counts in the spectrum.

Solution

In April of 2000, ORTEC introduced an upgrade to its DSPEC PLUS hardware with ZDT correction technique along with analysis algorithms in its GammaVision-32 software which simultaneously solve the problem of performing loss free counting while calculating the uncertainty in the corrected spectrum.² This innovative technique has been shown to be accurate for constant counting rates up to 90% dead time.³ The remainder of this Application Note describes how ORTEC's loss free counting method with error correction was tested under conditions of rapidly changing count rates during the acquisition time.

Setting Up ZDT Modes

Before performing the ZDT test, a few moments will be spent on how to set up the DSPEC PLUS in its various ZDT modes. The DSPEC PLUS has two memory buffers in which to store spectral data simultaneously: Buffer 0 and Buffer 1. There are three (3) modes in which the DSPEC PLUS operates: LTC Only, LTC with ZDT Spectrum, and ZDT with Variance Spectrum. Depending on which mode is selected, the DSPEC PLUS will collect the required spectrum. The modes and which memory buffer contains which data is summarized in Table 1 below.

Mode	Contents of Buffer 0	Contents of Buffer 1
—*	LTC Spectrum (will display normal spectrum with Live Time, Real Time and Percent Dead Time)	Empty
0	LTC Spectrum (will display normal spectrum with Live Time, Real Time and Percent Dead Time)	ZDT Spectrum (will display spectral counts corrected for the dead time losses with Real Time display only)
1	Variance Spectrum (will display the data associated with the variance in the ZDT-corrected spectrum with Real Time display only)	ZDT Spectrum (will display spectral counts corrected for the dead time losses with Real Time display only)

*ZDT Mode Disabled.

Loss Free Counting with Uncertainty Analysis

Results of ORTEC Experiments**Experiment No. 1:** Loss Free Counting with Varying Count Rates during the Acquisition

Tables 1 and 2 below summarize the results of the experiments done using the strong ^{137}Cs and ^{57}Co sources on the rotating disk. The results in Table 1 clearly show that for varying count rates the loss free counting mode in the DSPEC PLUS accurately corrects for the lost pulses in the spectrometer using the ZDT correction method. The counting uncertainty (1-sigma) for each test, as well as the

input count rate are also shown. The difference in the net peak count rates with the variable sources present compared to those without the sources are less than 1.0%.

Similar results are shown in Table 2 using the strong ^{57}Co source to generate the dead time in the spectrometer. In this case, all net area count rates had a difference from the known value of less than 1.8% despite input count rates varying a factor of 6 during acquisition.

Table 1. Varying Count Rate During the Measurement Using Strong ^{137}Cs Source on Rotating Disk.

	ICR*	Net Rate	1173 keV 1σ	Δ	Net Rate	1275 keV 1σ	Δ	Net Rate	1332 keV 1σ	Δ
Known	1900	33.8	0.5%	–	38.3	0.5%	–	30.0	0.6%	–
Test 1	7200	33.8	0.2%	–0.2%	38.1	0.1%	0.6%	29.8	0.7%	0.6%
Test 2	8000	34.0	0.2%	–0.6%	38.3	0.4%	0.0%	30.2	3.2%	–0.8%

Table 2. Varying Count Rate During the Measurement Using Strong ^{57}Co Source on Rotating Disk.

	ICR*	Net Rate	1173 keV 1σ	Δ	Net Rate	1275 keV 1σ	Δ	Net Rate	1332 keV 1σ	Δ
Known	1900	33.8	0.4%	–	38.3	0.5%	–	30.1	0.5%	–
Test 1	7000	33.6	0.4%	0.6%	37.8	0.1%	1.2%	29.9	0.2%	0.5%
Test 2	8100	33.2	0.5%	1.8%	38.3	0.5%	–0.2%	30.2	0.5%	–0.3%
Test 3	11000	33.8	0.5%	–0.1%	38.2	0.4%	0.1%	30.0	0.5%	0.1%

*ICR: Average Input Count Rate during the acquisition.

Experiment No. 2: Estimation of Uncertainty in Loss Free Counting System

Tables 3 and 4 show the results of the Gross and Net Peak Area uncertainties as predicted by both the standard deviation of the counts in the peaks and the variance spectrum in the DSPEC PLUS. As can be clearly seen, all values have a variance less

than 4.5% and most have a variance less than 2%. This shows that the DSPEC PLUS with ZDT and Error Estimation Algorithms properly calculates the uncertainty associated with additional counts in the ZDT spectrum.

Table 3. Comparison of Predicted Uncertainties in the Gross Peak Area of ZDT-Corrected Spectra under Varying Count Rate Conditions

Input Count Rate (cps)*	511 keV (Na-22)			1173 keV (Co-60)			1332 keV (Co-60)		
	Std Dev of Gross Counts (1 σ)	Avg Error from Uncertainty Spectra	Δ of Variance	Std Dev of Gross Counts (1 σ)	Avg Error from Uncertainty Spectra	Δ of Variance	Std Dev of Gross Counts (1 σ)	Avg Error from Uncertainty Spectra	Δ of Variance
3500	35.3	35.1	-0.5%	15.3	15.4	0.6%	15.7	15.4	-1.3%
4900	29.9	29.5	-1.3%	29.8	30.5	2.6%	12.3	12.5	1.3%
6900	38.0	37.9	-0.2%	16.7	16.6	-0.1%	16.4	16.6	1.3%
7250	31.1	31.0	-0.3%	32.1	32.1	-0.1%	13.2	13.1	-0.8%
8550	32.2	32.0	-0.7%	33.2	32.7	-1.5%	13.5	13.5	-0.1%
11700	43.8	44.5	1.5%	18.8	19.6	4.2%	18.8	19.6	4.2%

Table 4. Comparison of Predicted Uncertainties in the Net Peak Area of ZDT-Corrected Spectra under Varying Count Rate Conditions

Input Count Rate (cps)*	511 keV (Na-22)			1173 keV (Co-60)			1332 keV (Co-60)		
	Std Dev of Net Counts (1 σ)	Avg Error from Uncertainty Spectra	Δ of Variance	Std Dev of Net Counts (1 σ)	Avg Error from Uncertainty Spectra	Δ of Variance	Std Dev of Net Counts (1 σ)	Avg Error from Uncertainty Spectra	Δ of Variance
3500	37.0	36.7	-0.9%	17.0	16.9	-0.4%	14.5	14.6	0.2%
4900	32.9	32.6	-1.0%	32.2	32.8	2.1%	27.8	27.9	0.5%
6900	39.8	39.6	-0.6%	18.4	18.2	-1.0%	15.4	15.6	0.7%
7250	34.7	34.3	-1.2%	34.4	34.5	0.2%	30.1	29.5	-2.0%
8550	36.8	36.3	-1.4%	35.3	34.8	-1.3%	30.9	30.2	-2.2%
11700	45.5	46.7	2.7%	21.0	21.5	2.4%	18.3	18.3	0.0%

*Average input count rate during the acquisition.

A Brief Note on the Contents of the Buffers

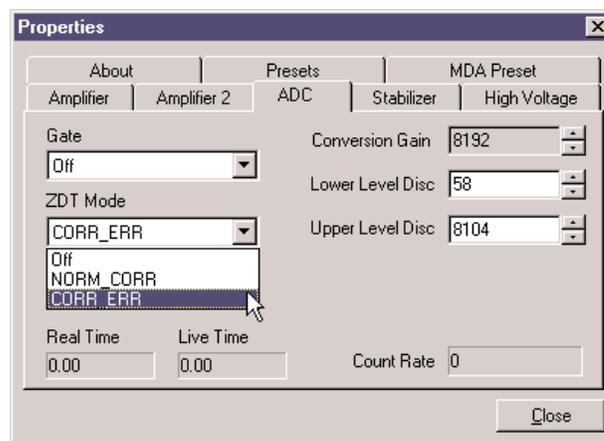
If both memory buffers are used, they will always have the same number of channels (512 to 16,384). When using Mode 1, the variance spectrum contains the data associated with the uncertainty of every corresponding channel in the ZDT spectrum. Therefore, the uncertainty associated with the number of counts in Channel 5328 in the ZDT spectrum is equal to the square root of the number of counts in Channel 5328 in the variance spectrum. It is important to note that the data stored in the DSPEC PLUS is the variance of the spectral data rather than the actual uncertainty. It follows that to calculate the uncertainty for a given peak, which is either an integer or fractional number of channels in the ZDT spectrum, the uncertainty is the square root of the counts in the same channels or fraction thereof. This is what GammaVision-32 does during its analysis of these spectra.

When saving the data in either Mode 0 or Mode 1, the ORTEC SPC format will contain the data from both memory buffers as well as the mode selected by the hardware so that the files can be recalled and analyzed at a later time. The format of the data in the SPC files is given in the File Structures Manual which accompanies the manual for GammaVision-32.

Selecting the Mode for the DSPEC PLUS

The DSPEC PLUS can be placed into any of the three ZDT modes in a number of ways. The simplest method is to use the control panels in the application software such as GammaVision-32 (AcquireIMCB Properties from the menu).

Alternatively, a JOB file can be created that will set the DSPEC PLUS into the proper mode before any measurement is made. The following JOB file contents set the DSPEC PLUS into each of the three modes and collects a spectrum for 1000 seconds Real



Time in each mode (see GammaVision-32 Manual for complete set of JOB commands).

The final method for setting the ZDT modes is through the MCB Diagnostics program that installs with ORTEC application software.

1. Select "Start|Run..." from the Windows taskbar
2. Type "C:\User\Program Files\Common Files\ORTEC Shared\UMCBI\MFCdiag.EXE" and click OK

```

SET_PRESET_TRUE 1000
CLEAR
SEND_MESSAGE "DISABLE_ZDT"      REM Sets LTC Only mode
START
WAIT
SAVE "C:\User\NoZDT.SPC"
CLEAR
SEND_MESSAGE "ENABLE_ZDT"      REM Enables ZDT Modes
SEND_MESSAGE "SET_MODE_ZDT 0"  REM Sets LTC and ZDT mode
START
WAIT
SAVE "C:\User\Mode0.SPC"      REM Saves both spectra in single file
CLEAR
SEND_MESSAGE "SET_MODE_ZDT 1"  REM Sets ZDT with Error mode
START
WAIT
SAVE "C:\User\Mode1.SPC"      REM Saves both spectra in single file

```

3. From the Drop Down list at the top of the screen, select the DSPEC PLUS

4. In the "Command" bar, type in the command "ENABLE_ZDT" to enable the ZDT Modes (or "DISABLE_ZDT" to use LTC only)

5. If in ZDT modes, in the "Command" bar, type in the command "SET_MODE_ZDT *n*" where *n* is either 0 or 1 depending on the mode desired

Demonstrating the ZDT with Uncertainty Analysis

The following section describes the experimental setup used to determine the accuracy of ORTEC's new ZDT method and the uncertainty analysis and the subsequent test results.

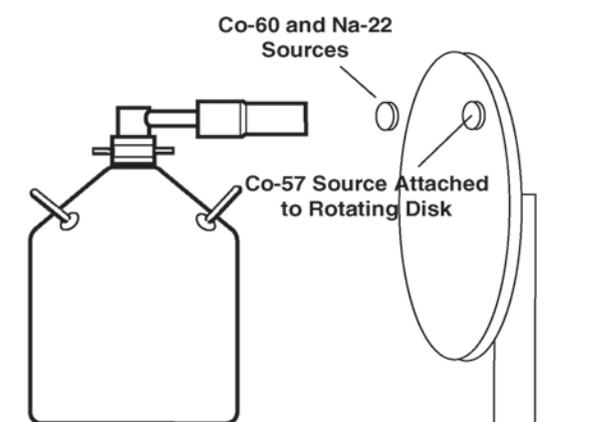
Demonstration of ORTEC's Loss Free Counting System using the ZDT Method

Two sources, ^{60}Co and ^{22}Na , are positioned at a fixed location from the detector. 1800 acquisitions are made of the two sources in the absence of any other sources to determine their "true" counting rates. A high count rate ^{57}Co source is then attached to a rotating disk. The rotating disk gives rise to variable dead times between 11% and 85% during acquisition. The input count rate is increased by adding additional sources to the rotating disk. Each "test" corresponds to a different input count rate. The net areas for the 1173, 1275, and 1332 keV peaks are then calculated and divided by the recorded real time to give the count rates (in cps) in the peak areas. The net area count rates with the rotating sources are then compared to those without the sources present and the difference should be 0%. The experiment is then repeated using a high count rate ^{137}Cs source.

Demonstration of the Uncertainty Estimation as Determined through the Collection of the Variance Spectra with the ZDT-corrected Counts Spectra

Two sources, ^{60}Co and ^{22}Na , are positioned at a fixed location from the detector. A high count rate ^{57}Co source is then attached to a rotating disk. The rotating disk gives rise to variable dead times between 11% and 55–85% during acquisition. 1800 spectra are then collected and stored to disk with the DSPEC PLUS in Mode 1. The input count rate is increased by adding additional ^{60}Co and ^{22}Na sources and the 1800 dual-spectra collected again. The average input count rate is calculated for each of the series of spectra. The set up for this experiment is shown graphically below.

The gross and net peak areas of ^{60}Co and ^{22}Na are then determined and a standard deviation of the 1800 ZDT-corrected spectra calculated for each of the count rates. The same peak areas (gross and net) are calculated and averaged for the 1800 variance spectra collected at the same time as the ZDT-corrected spectra. This average value is then compared to the standard deviation of the ZDT spectra. The input count rate is calculated at each of the disk rotation speeds. The ratio of the variance spectra and ZDT-predicted uncertainties is then plotted against the input count rate and ideally should be equal to 1.00.



Variable count rate setup using strong source attached to rotating disc.

Conclusions

The changing count rate experiments demonstrate that the use of ORTEC's new ZDT method for loss free counting using the DSPEC PLUS (a) accurately corrects the spectrum for lost counts due to dead time in the spectrometer, and (b) predicts the uncertainty associated with the counts in the spectrum added by the loss free counting method. By incorporation of the innovative ZDT technique along with the analysis capabilities of ORTEC's GammaVision-32 software, the spectroscopy counting laboratory and real-time monitoring applications have one complete solution for collecting, correcting, and analyzing any sample with no dead time losses and obtaining quantitative results with an accurate uncertainty estimation.

Acknowledgements

ORTEC would like to thank Dr. Stefaan Pomme for providing data for the experiments performed in this application note.

¹ Jenkins, Ron; Gould, R. W.; Gedcke, Dale; Quantitative X-ray Spectrometry; Marcel Dekker, New York, 1981.

² Patent applied for.

³ Upp, Daniel L. et al; An Innovative Method for Dead Time Correction in Nuclear Spectroscopy; MARC V Conference Proceedings; April 2000.

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Specifications subject to change
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