A Digital Method for Dead Time Compensation in Nuclear Spectroscopy

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Abstract

Gamma ray spectroscopy systems have dead time losses during acquisition due to pulse processing in the electronics. Several methods have been developed in the past to recover from dead time losses. These include live-time clocks and loss-free counting. The live-time clock (LTC) extension technique (where the counting time is extended to compensate for the lost counts) gives accurate results for samples where the total count rate (dead time) is constant during the measurement. The Harms-Westphal loss-free counting (LFC) method gives better results when the counting rate varies significantly during the acquisition period. However, this LFC method does not give the uncertainty of the spectral counts. Thus, the analysis of the spectral data with uncertainty calculations can not be done. The ORTEC® DSPEC*PLUS*™ implements a digital "zero dead-time" (ZDT) method for loss free counting that also gives the uncertainty for each channel in the ZDT spectrum. Data will be presented to show that the new method duplicates the well-proven Gedcke-Hale live time clock when the count rate is constant and gives both the correct peak area and uncertainty for changing count rate.

Summary

All nuclear spectroscopy systems, even the new digital types, have a dead time associated with the processing of each pulse. During this dead time, the system is unable to collect and process further pulses. System dead time results from the fact that during the time period that the system is processing one pulse, it can not process any subsequent pulses. Several techniques have been developed in an effort to compensate for the dead time losses in a spectroscopy system. The most common are: pulser injection, live-time extension and loss-free counting. Pulser injections requires the injection of pulses from a highly stable, calibrated pulser into the counting chain. The assumption is made that dead-time losses from the pulser peak are the same as those in the spectrum. Live-time clock extension techniques can give accurate results when measuring samples where the activity remains roughly constant during the measuring process (i.e., the dead-time does not change significantly during a single measurement period). The fundamental problem with these methods is that , if a "bubble" of activity passes the detector, causing large dead-time losses for a short period, the calculated activity can be based on the accumulated live time. Thus the activity of the nuclides contained withing the bubble will be underestimated by an LTC method. The error will be progressively worse for higher activity bubbles.

The loss-free counting (LFC) method of correcting for dead time losses, as introduced by Harms and improved by Westphal gives dramatically better results than LTC techniques in cases where the counting rate changes significantly during the measurement. It makes a loss-free spectrum by estimating the number of counts lost during a dead time interval, and adding this number to the channel of the just-processed pulse. However, the LFC approach of adding counts to the spectrum dynamically results in corrected spectra where the data no longer obey Poisson statistics. Because of this, the calculation of the resulting activity uncertainties is not easy, if it can be done at all. Pomme[1] has shown that it is not even possible to correctly determine the uncertainty post-facto by storing a corrected and an uncorrected spectrum. The ORTEC® DSPEC*PLUS*™ implements an improved zero dead time (ZDT) method for loss free counting. The ZDT correction is dynamically calculated in the digital signal processor (DSP) to produce both the corrected data spectrum and the channel-by-channel variance spectrum. Both the data spectrum and the variance spectrum are updated pulse-by-pulse; the size of the variance contribution to the total variance calculated and stored is therefore largest when the correction is made for the processing of an individual pulse stored during a period of highest dead-time. This new method removes the major limitation of previous loss-free counting methods. The GammaVision-32® analysis algorithm has the ability to use the two spectra to calculate the counting uncertainty and apply it in the activity calculation. Data will be presented to compare the uncertainty from the DSPEC Plus with the uncertainties using the well-proven[2] Gedcke-Hale live-time extension method. Data are also presented to compare the ZDT net peak count rate and uncertainty as calculated in the DSPEC Plus with the same values determined using measurements covering a wide range of dead times and changing count rates.

[1] To be published.

[2] Ron Jenkins, R.W. Gould, and Dale Gedcke, Quantitative X-Ray Spectrometry, (New York and Basel; Marcel Dekker, Inc.,) 1981, pp. 208-287, First Edition. See also 1998 ORTEC catalogue, page 2-282.

Testing the reported ZDT Uncertainty

In the DSPEC Plus, the ZDT spectrum is stored in one portion of memory and the corresponding channel-by-channel variance is stored in another portion of memory. The variance is based on the scaling factors used to generate the ZDT spectrum. The uncertainty in any channel is therefore given by:

$$\sigma_i = \sqrt{v_i}$$

Where σ_i is the uncertainty of the i^{th} channel of the ZDT spectrum
v_i is the contents of the i^{th} channel of the ERR spectrum

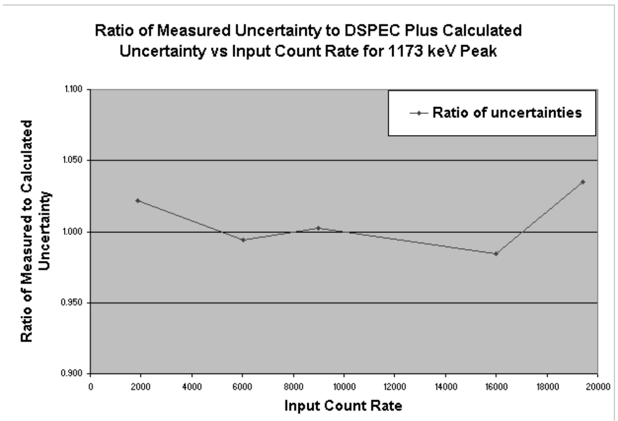

Figure 1

Previous work by Pomme compared the uncertainty in the gross peak area calculated from a large number of measurements at different, but constant count rates and by using the uncertainty spectrum. In Pomme's work, 2000 spectra were collected. The gross counts in the 1173 keV peak of ^{60}Co were calculated by simple summation of the channel counts. The standard deviation was calculated for the set of peak areas for different input count rates (ICR). The ICR was determined by the DSPEC Plus built in rate meter. Figure 1 shows the ratio of the ZDT calculated uncertainty to the corresponding standard deviation over a range of count rates.

This experiment showed that, over a wide range of fixed count rates, the ZDT method correctly reports the associated peak area uncertainty.

To extend these measurements to varying count rates, an additional 250 identical spectra were collected. The spectra were collected with a 100% GEM detector and DSPEC Plus. The detector was placed in a lead shield to minimize the influence of any change in the external gamma ray flux. The sources were thorium oxide and ^{60}Co placed on the detector endcap to give an input count rate of about 26000 counts per second. This count rate yields a deadtime of 65% when the rise time is set to 12 microseconds. This deadtime corresponds to the maximum throughput rate. All of the spectra were collected for a real time of 1400 seconds with a corresponding live-time of about 400 seconds. In this case the net peak area uncertainty, rather than the gross peak area uncertainty was calculated. This was done because in "real" measurements, the continuum background must always be subtracted. The net peak areas at 209, 463, 583, 1173, 1332, and 2614 keV were calculated for each of the 250 spectra to give the expected distribution and uncertainty for each peak.

The peak area was calculated using the normal GammaVision ROI method. In this method, the background is the straight line between the average of the three channels on each end of the ROI. The net peak area is the sum of the channels in the ROI, not including the three points on each end, minus the calculated background in these channels based on the straight line. The uncertainty in the net peak area is calculated from the set of 250 peak areas from 250 replicate measurements. Table 1 shows the average peak area and standard deviation (column 3) based on the replicate measurements for the 6 peaks.

Table 1

Peak energy (keV)	Average net peak area	standard deviation (%)	uncertainty (%)
209	137376	1.43	1.52
463	237805	0.95	0.69
583	1246269	0.46	0.24
1173	180506	0.98	0.74
1332	167644	0.82	0.74
2614	645146	0.48	0.29

A separate set of 40 spectra were collected of ZDT and uncertainty spectra of the same sources and similar arrangement as the previous spectra. For these spectra, the uncertainty in the net peak area of the ZDT peak areas was calculated by:

$$\sigma_E = \sqrt{A_G + \frac{(v_l + v_h)W}{6}}$$

Where
σ is the peak uncertainty
A_G is the sum of the peak ROI channels (less the ends) in the uncertainty spectrum
v_l is the 3 channel low-energy variance from uncertainty spectrum
v_h is the 3 channel high-energy variance from uncertainty spectrum
W is the ROI width (less the ends)

Table 1, column 4, shows the average net peak area and the uncertainty as calculated using the ERR spectrum as above.

Figure 2 compares the two uncertainty calculations.

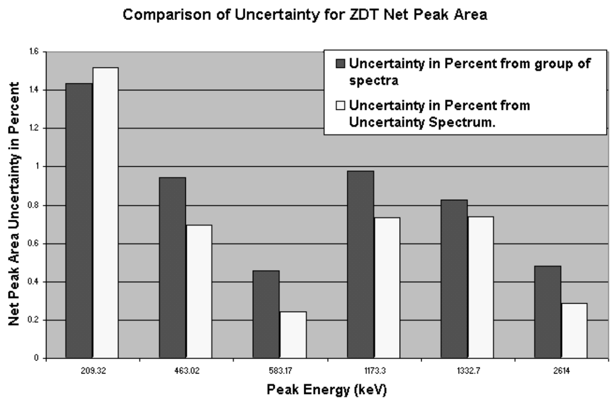

Figure 2

What this experiment shows is that at any constant count rate, the derived uncertainties determined from the multi-peak ZDT and ERR spectra are correct to within 5 %.

Testing the reported net peak area

The ZDT peak area was tested using a method similar to the methods previously reported by Pomme. He used Figure 3 to show the net peak area of the 1173 peak from a fixed ^{60}Co source remained constant as a function of input count rate, when the overall input count rate was increased by increasing the count rate from a ^{57}Co source.

The peak area test was extended here to include the calculation of the peak area where the incident intensity of the reference gamma ray varies significantly during the counting time.

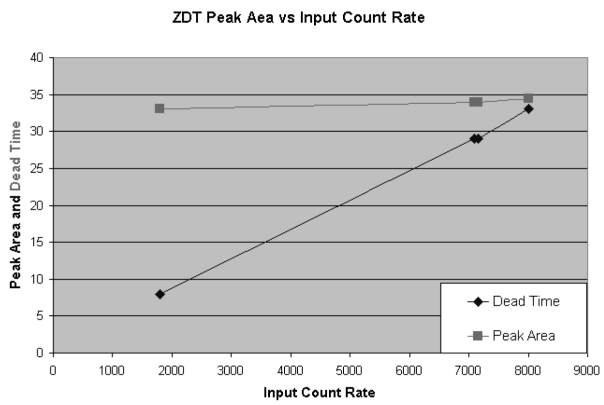

Figure 3

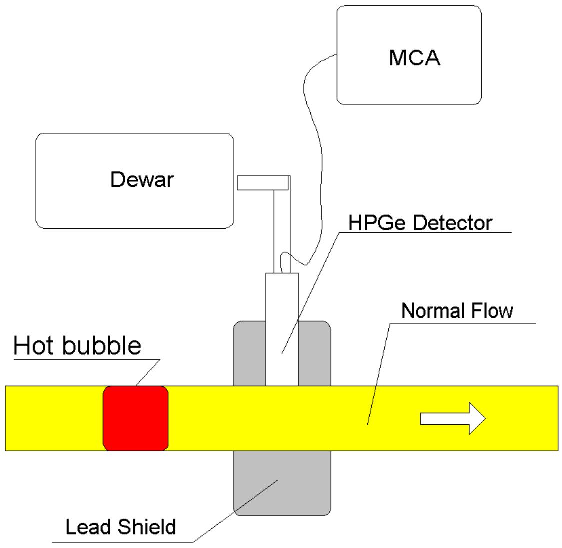

Figure 4

The test was designed to simulate the counting situation in a system monitoring the radio-content of a liquid flowing in a pipe. There is a normal low level of activity in the stream and a "bubble" of higher activity occuring from time to time. This is shown in Figure 4.

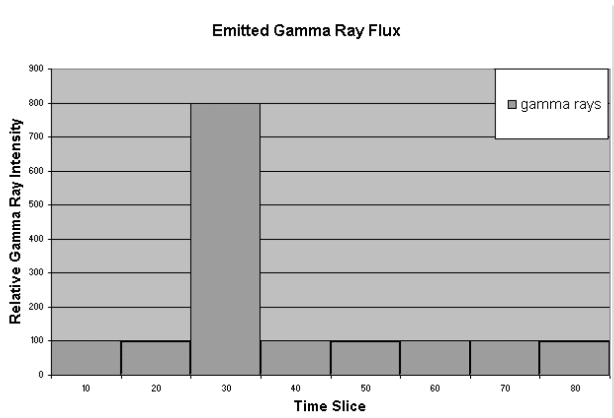

Figure 5

The temporal behavior of the gamma ray flux on the detector is represented in Figure 5. To simulate this situation, spectra were taken with the shielded 100% GEM detector, DSPEC Plus and thorium with ^{60}Co sources. The thorium and small ^{60}Co source were fixed in front of the endcap at a position to create a 10% total deadtime with 12 microsecond risetime. The

Total gamma ray flux was varied in steps with a second ^{60}Co source placed in front of the endcap at different distances to give the total dead-time of 20, 30, 40, 50, 60, 70, 80, and 90%. This extends the input count rate to 60000 cps, far higher than in earlier experiments. These "component" spectra were collected in the mode where both the ZDT and LTC spectra are stored and saved.

To simulate situations where the bubble might contain different activities, a set of "baseline" component spectra were collected as well as the set of component spectra with total count rates increased by the movable ^{60}Co source. Because the count rate in each of these component spectra is constant, both the ZDT method and the LTC method would provide the correct area and uncertainty. These spectra could be added to make composite spectra which would simulate the overall spectrum resulting in a single, longer acquisition covering the time before, during and after the bubble in the liquid passed the detector. Simulations could be made of bubbles of different activities passing the detector. Composite spectra were constructed in which the dead-time during the passing of the bubble varied from 10 to 90%, as the count rate varied from "baseline" 3000 to 60000 counts per second, at 12 μS risetime.

In addition to the ^{60}Co peak, with changing amplitude, there are several peaks from thorium which should be constant throughout the measurement since the thorium source is static. One of the thorium peaks is included in the analysis. The spectra were analyzed using the simple analysis methods of GammaVision as described above.

The peak areas of the 583 (fixed, thorium) and 1173 keV (varying ^{60}Co) peaks were calculated for the composite spectra in both the LTC and ZDT modes. In addition, the two peak gamma ray intensities were calculated from the individual "component" LTC spectra and these intensities were summed to obtain the total intensity passing the detector for each of the two gamma rays. Figure 6 shows the results. There are three curves plotted for the 1173 line; composite LTC corrected, composite ZDT corrected, and summed components LTC corrected. The three 583 curves are essentially equal. These are plotted versus the dead time seen in the bubble. The last "summed component" results may be considered as the "correct answer." of course, In a real experiment it is not possible to make this measurement of the expected "correct answer". The curves show that the ZDT corrected composite result, which can be made in the real world almost exactly replicates the synthesized correct result for the varying ^{60}Co peak. For this same peak, the LTC result on the composite spectra is increasingly in error as the activity contained within the bubble increases. When the dead-time due to the bubble is 90%, the LTC method will underestimate the average activity by 80%. The 583 keV (constant rate) activity is constant in all cases, showing that both ZDT and LTC methods are working correctly, even though the LTC method fails badly when the count rate is varying. Of special importance is the "double valued" nature of the LTC curve. This can easily produce incorrect activities if the high bubble activity is interpreted to be the low bubble activity.

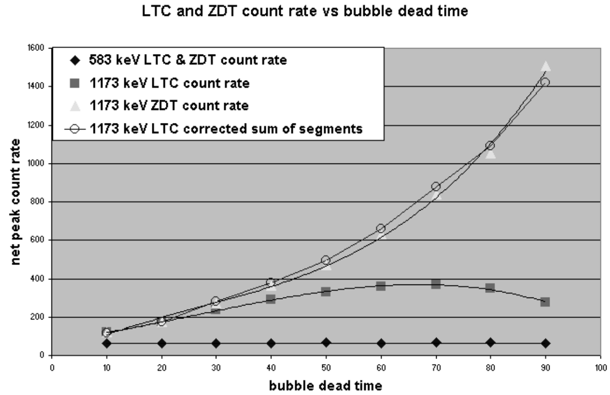

Figure 6

Conclusion

The data presented have shown that the DSPEC Plus ZDT with uncertainty spectrum correctly predicts the uncertainty of the ZDT peak area. In addition, the ZDT peak area is shown to more accurately represent the gamma ray intensity in cases where the intensity can be widely varying without degrading the intensity calculations for peaks with constant intensity. This can be a distinct benefit in a wide range of applications: Assays of non-homogeneous waste, Air monitoring, process monitoring, activation analysis, or stack monitoring.