# Performance of the Zero-Dead-Time Mode of the DSPEC Plus

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**Abstract**

Gamma ray spectroscopy systems have dead time losses during data collection 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't 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 gives the correct peak area for changing count rates in different conditions.

## 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 is based on the accumulated live time. Thus the activity of the nuclides contained within the bubble will be underestimated by any LTC method. The error is progressively worse for higher activity bubbles.

The loss-free counting (LFC) method of correcting for dead time losses, as introduced by Harms[1,2] and improved by Westphal[3,4] 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 instead of the normal 1 count. However, the LFC approach of adding counts to the spectrum dynamically results in corrected spectra where the data no longer obey Poisson statistics. That is, the uncertainty in a channel with N counts is not $N^{1/2}$. Because of this, the calculation of the resulting activity uncertainties is not easy, if it can be done at all. Pomme[5] 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 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 are presented to compare the ZDT net peak count rate as calculated in the DSPEC Plus with the same values determined using measurements for a wide range of dead times and changing count rates.

## The ZDT Uncertainty

In earlier work[5,6,7], the ZDT uncertainty testing was described. The results are shown in Figure 1. The calculated uncertainty is based on the measurement of the distribution of the peak areas from a large number of spectra. As shown, the ZDT uncertainty is within 4% of the measured values for all deadtimes shown (0 to 60%).

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1 J. Harms, *Nucl. Instr. and Meth.*, **53**, (1967), p 192.

2 C. F. Masters and L. V. East, *IEEE Trans. Nucl. Sci.*, **17**, (1970), p 383.

3 G. P. Westphal, *Nucl. Instr. and Meth.*, **146**, (1977), pp 605 – 606.

4 G. P. Westphal, *Nucl. Instr. and Meth.*, **163**, (1979), pp 189 – 196.

5 To be published.

6 Keyser, Ronald M., Gedcke, Dale A., Upp, Daniel L., Twomey, Timothy R., and Bingham, Russell D., Presented at the *23rd* Annual ESARDA meeting, Bruge, May 2001

7 D. L. Upp, R. M. Keyser, D. A. Gedcke, T. R. Twomey, R. D. Bingham, *Journal of Radioanalytical and Nuclear Chemistry*, Vol. 248, No. 2(2001), pp 377-383.

## The net peak area in a burst

The ZDT peak was tested to the peak area where the incident intensity of the reference gamma ray varied significantly during the counting time. 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 2.

The temporal behavior of the gamma ray flux on the detector represented in Figure 3. To simulate this situation, spectra were taken with the shielded 100% GEM detector, DSPEC Plus and sources of thorium and $^{60}$Co. The thorium and a 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.

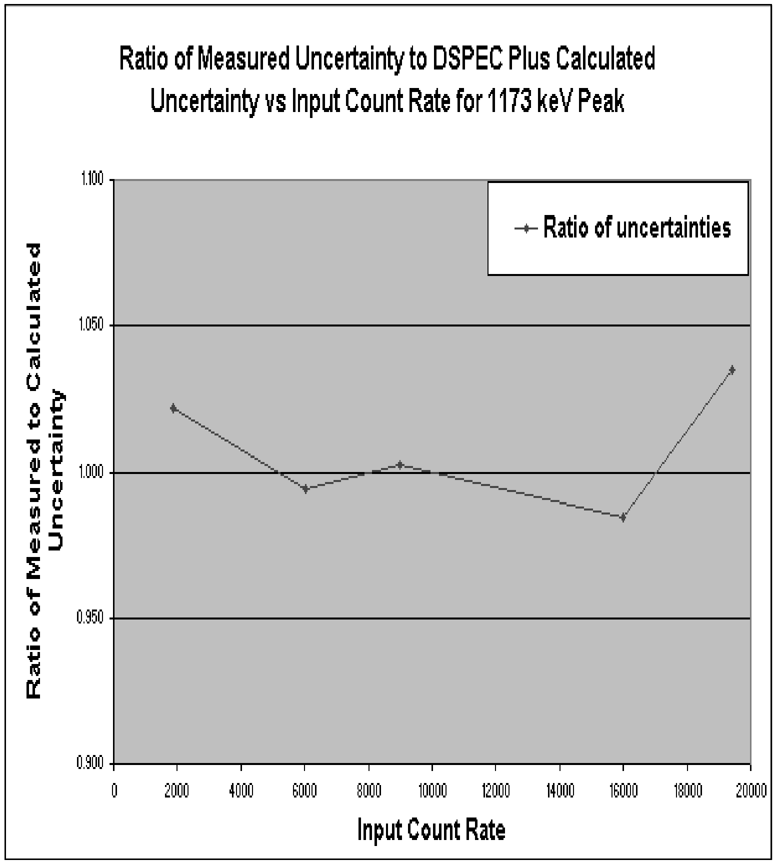


**Figure 1**

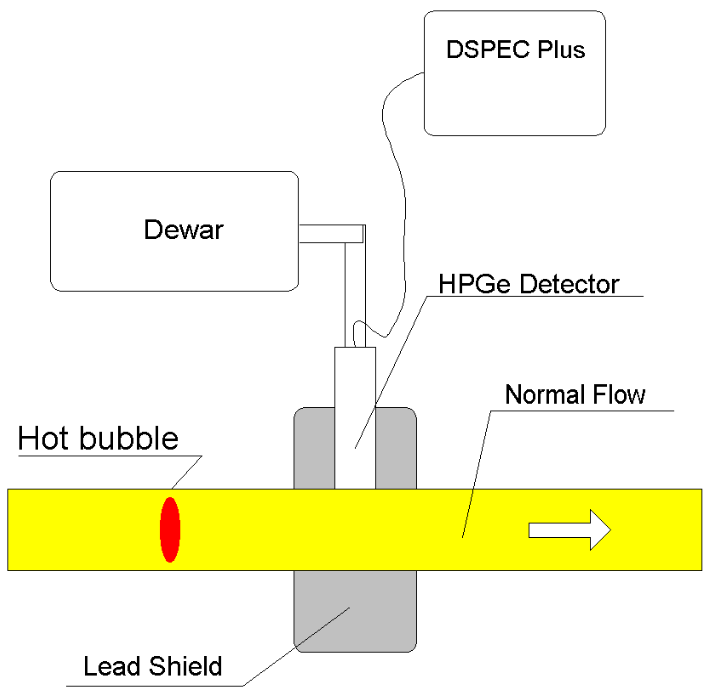


**Figure 2**

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 were 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 60,000 counts per second, at 12uS risetime.

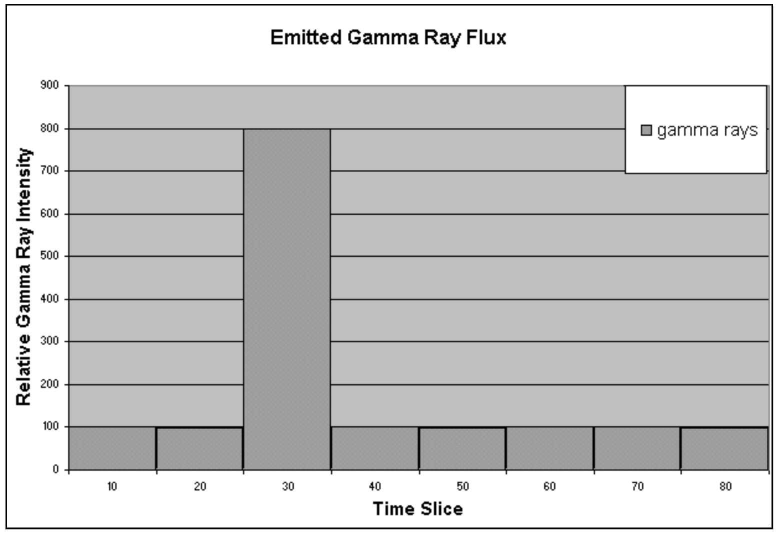


**Figure 3**

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 (summed components LTC corrected) passing the detector for each of the two gamma rays. Figure 4 shows the results for the case where the higher activity represents 50% of the data collection time. There are three curves plotted for the 1173 line: composite LTC corrected, composite ZDT corrected, 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 are considered to represent the results that would be obtained with a loss-less (or perfect) counter.

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 a factor of 5.

Figure 5 shows the same situation for the higher activity being 33% of the total.

Figures 6, 7, 8, and 9 show the curves for 25%, 20%, 17% and 5%.

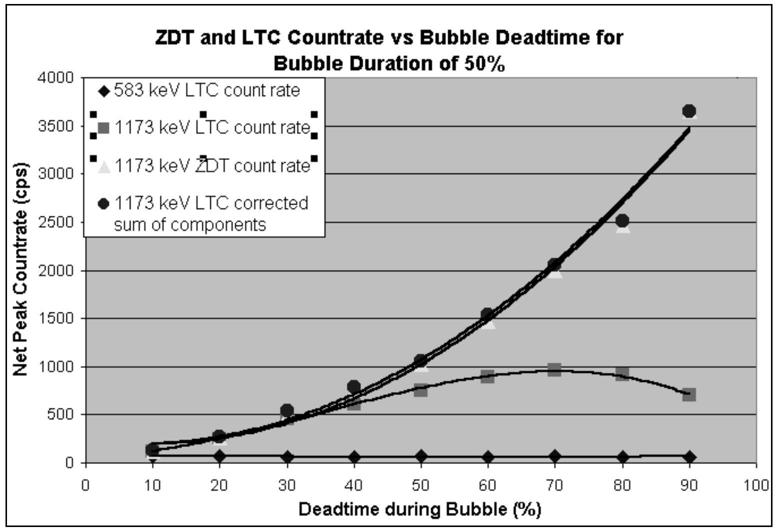


**Figure 4**

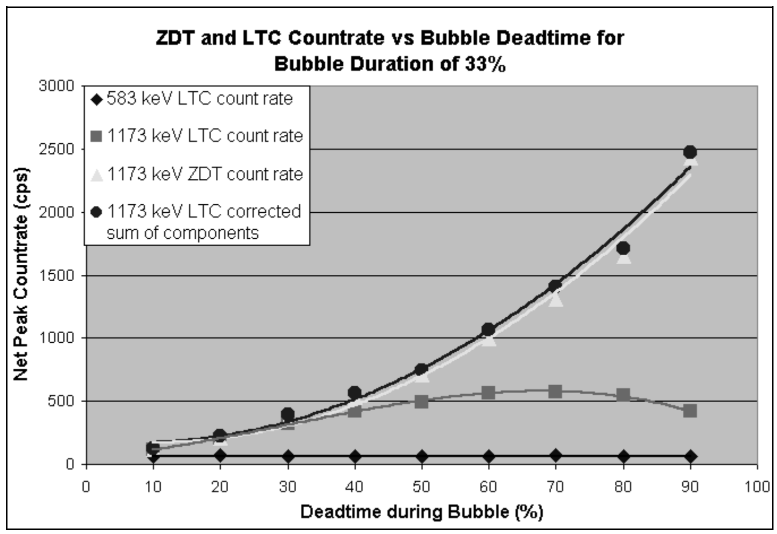


**Figure 5**

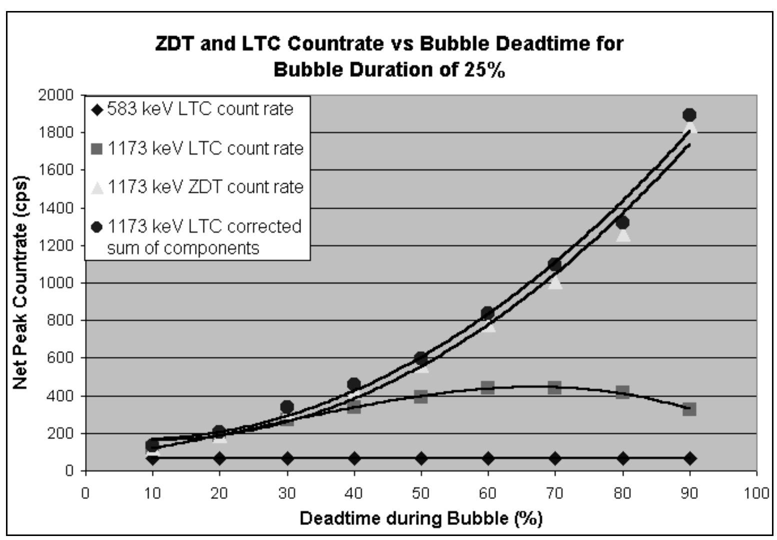


**Figure 6**

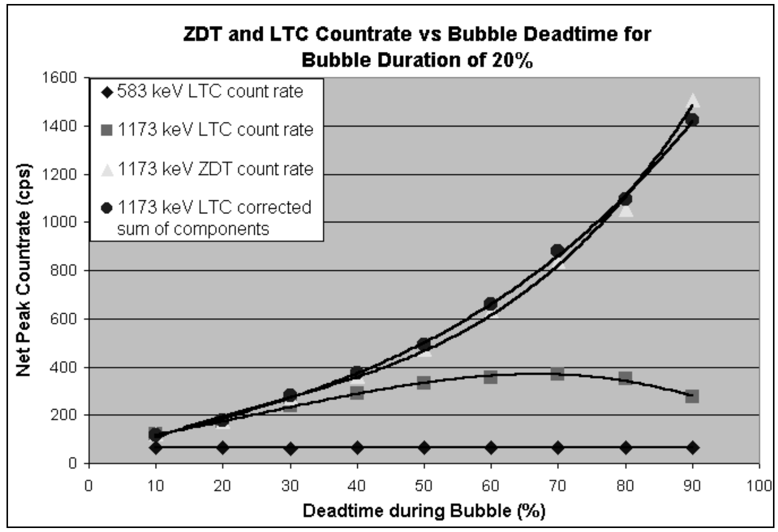


**Figure 7**

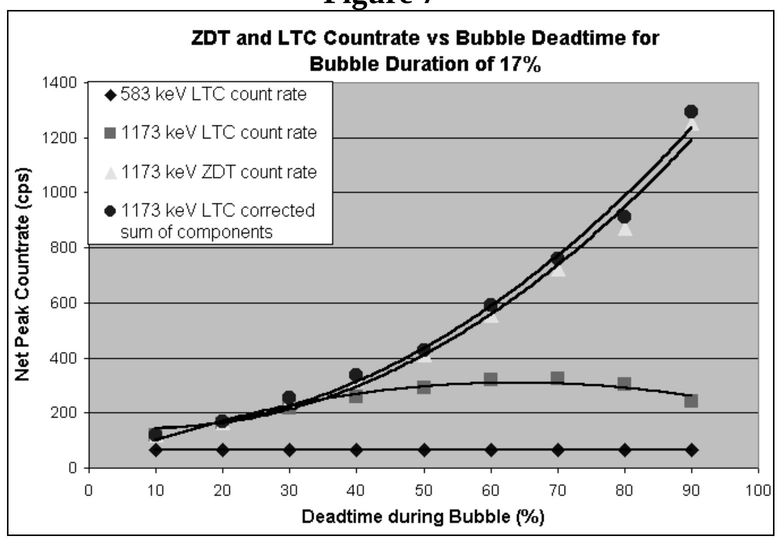


**Figure 8**

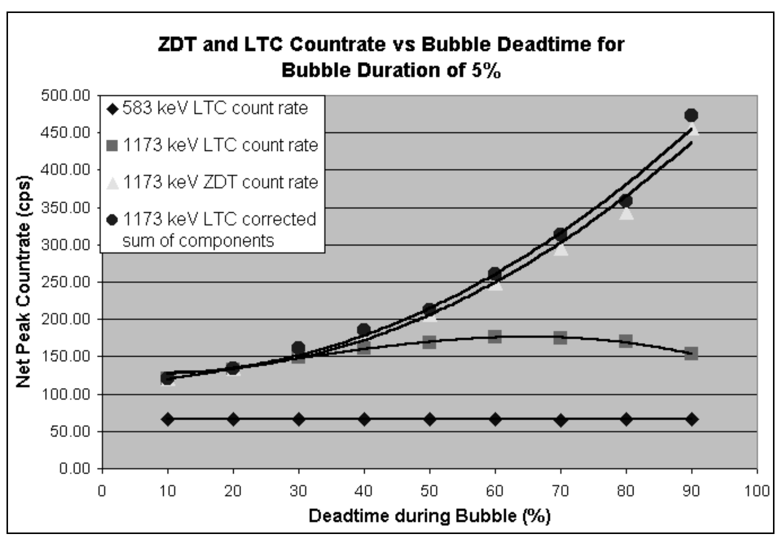


**Figure 9**

Figure 10 shows the case where the higher activity is present only 0.2% of the total collection time (about 1 second in 10 minutes).

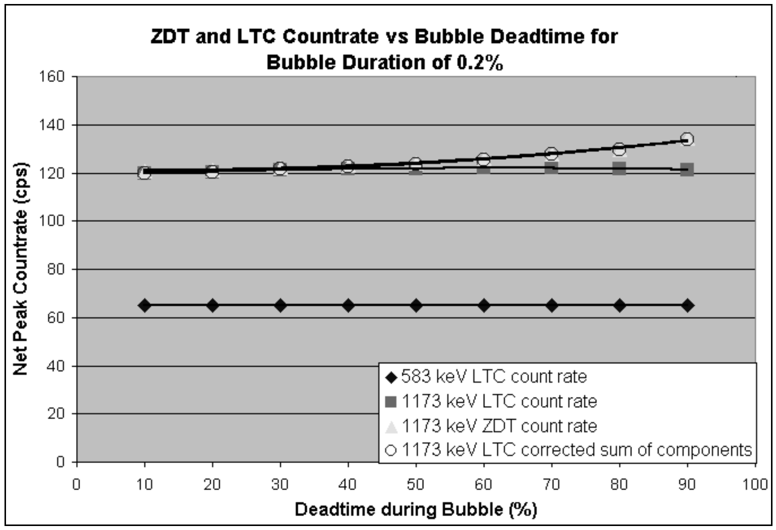


**Figure 10**

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 net peak count rate curve. Since there are two points where the net count rate is the same, but at widely different input count rates, there is a danger of  gross under estimates or over estimates of the true activity.

Figure 11 shows the same data presented as net peak area error as a function of the bubble duration in units of percent of total acquisition time.  Note that the error is zero for both the no bubble and the all bubble cases, as expected when the countrate is constant during the acquisiton time.  The maximum error occurs between 20% and 35% duration for all deadtimes.

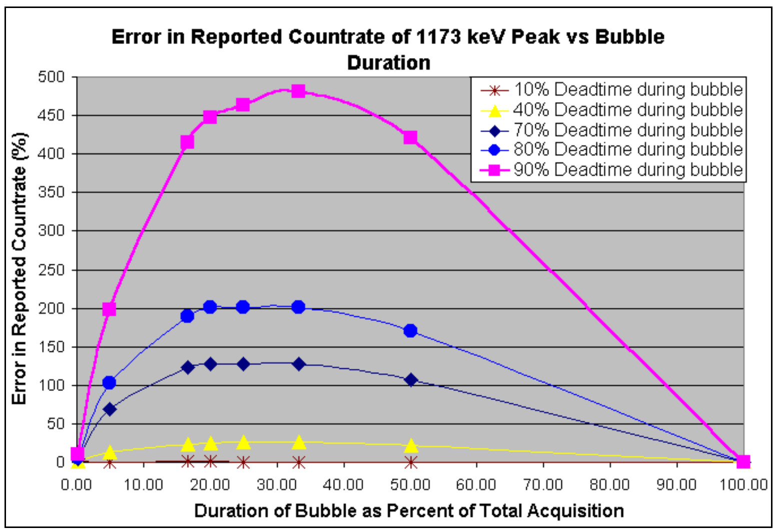


**Figure 11**

Figure 12 shows an expanded portion of Figure 11 at the low duration end. Note that even at 0.2% high activity duration, the high deadtime bubble LTC activity is 10% in error.

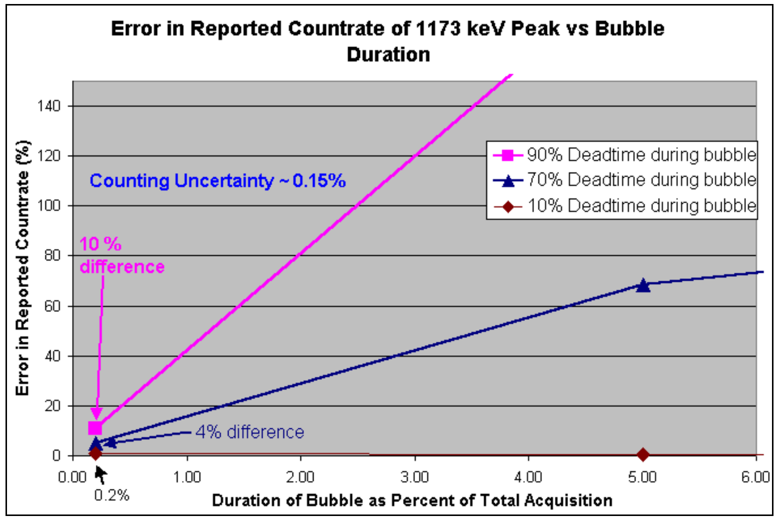


Figure 12

## The net peak during rapid decay

A separate study was done at XXX[8] to determine the ZDT-calculated activity in reactor water where the activity in the sample is rapidly decreasing due to the decay of the short-lived nuclides. For this test, the reactor water was collected and then counted as quickly as possible — normally 15 to 20 minutes later. The spectrum was collected for 30 to 60 minutes in the ZDT mode. A second spectrum was then collected in the LTC mode. A representative spectrum is shown in Figure 13.

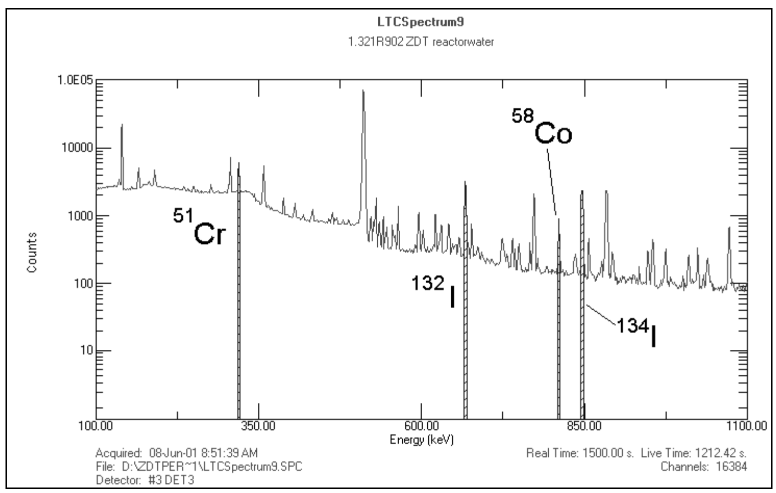


Figure 13

Four of the many nuclides in the sample were chosen for analysis. These four have halflives from 50 minutes to 71 days. The activities were calculated for each of these in both the ZDT and LTC spectra. The activities were decay corrected to the sample collection time for comparison. To compare the values from both analyses, the ratios of the decay-corrected activities were taken. This analysis was done for spectra with average deadtime in the ZDT spectrum of 3.8% to 45%. The ratio of the activities is shown in Figure 14. The uncertainties shown are the estimated total uncertainties for the individual measurements. The ratios show that the ZDT spectrum taken as quickly as possible after sample collection produce results consistent with the results from the decayed sample. In addition, any very short-lived nuclides can be detected in the ZDT spectrum much easier than in the decayed spectrum.

[8] Swedish reactor

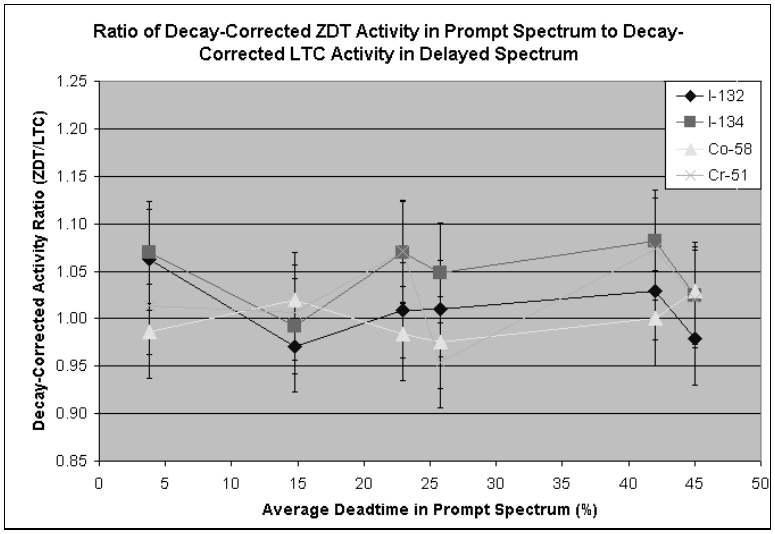


**Figure 14**

# Conclusion

The data presented have shown that the DSPEC Plus ZDT with uncertainty spectrum is shown to more accurately represent the gamma-ray intensity in cases where the intensity is varying without degrading the intensity calculations for peaks with constant intensity. The data also show that even short bursts of high activity in an otherwise constant situation can produce substantial errors in the results. This technique 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, there being no loss of accuracy in any situation when compared to the classical LTC methods.