A New Method for Counting Loss Correction with Uncertainty in Gamma Spectroscopy Applications

Gedcke, D. A., Keyser, R. M., Twomey, T. R.
ORTEC, PerkinElmer Instruments, Inc
801 South Illinois Avenue
Oak Ridge, TN 37831

Abstract

The loss of valid counts from the spectrum due to the system being busy is referred to as counting loss. The traditional method of correcting for the counting losses in spectroscopy applications is the so-called extended live-time correction. The live time is extended to count for a longer clock or real time to compensate for the loss of counts during the counting interval. This method fails to correctly account for the lost counts when count rates and dead times change widely during the time of acquisition of the spectrum. Examples of such cases are when monitoring a rotating waste container with a "hot spot," counting flowing samples in a pipeline or stack, or when counting samples with high levels of short half-life components. So-called "loss free" counting methods have been developed in analog-type instruments to correct the spectrum data "pulse by pulse." This avoids the limitations caused by the changing count rates. None of these methods have gained wide acceptance because 1) the difficulty of setup and 2) there is no way to determine the channel-by-channel uncertainty of the spectrum. To overcome both of these shortcomings, a new system was developed based on instruments using digital signal processing (DSP) for the processing of the signals from the germanium detector. This system collects the corrected spectrum and an uncertainty spectrum. The uncertainty spectrum is calculated pulse by pulse, thereby allowing accurate uncertainties of the corrected spectrum to be derived from the uncertainty spectrum. Performance data for both the operation of the correction as a function of count rate and the calculation of the uncertainty will be presented.

Introduction

In many circumstances it is desirable to operate a spectroscopy system at a high count rate in order to minimize the measurement duration. In some cases systems must operate over a broad range of count rates, such as may be encountered in applications such as waste assay, holdup, and stack monitoring. Wide count-rate range counting is the most difficult, because it imposes severe demands on system stability: peak position and resolution. The system must remain stable, if multiple calibrations are to be avoided. The latest generation of DSP-based spectrometers are exhibiting extremely good stability with both temperature and count rate.

At high count rates, all spectrometry systems suffer loss of data due to the finite time it takes to process each pulse. Even the new DSP-based systems are still afflicted by dead time, even though they are capable of operating at high data rates with great stability.

During a dead-time interval, the system is incapable of accepting and processing further pulses until it has finished with the one being processed. As count-rates increase, the probability of a pulse arriving for processing while the system is still busy increases, as does the probability that two pulses arrive so close together that they must be rejected as being inseparable by the system. This effect is the familiar pulse pileup, which further increases system dead time.

In almost all gamma-ray applications, the spectral analysis requires the accurate determination of the net peak count rate, which is then converted to activity via a calibration factor. (A notable exception is the determination of isotopic ratios, where the acquisition time is not needed.) Over the years, techniques have been developed 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 must be made that dead-time losses from the pulser peak are the same as those in the spectrum.

Live-time clock (LTC) extension techniques are the most commonly used. Two clocks run in the instrument. The real time clock measures the elapsed “clock on the wall” time of the measurement, while the live time clock is “slowed down” to account for the periods in which the system is dead. The net peak count rate is simply the peak area divided by the live time. There are several different implementations of the LTC. The most sophisticated LTC in common use is the Gedcke-Hale clock, which has been shown to be accurate to a few per cent up to high system dead times. However, LTC methods can only 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 problem may be simply illustrated as follows: Imagine the system is running at 50% dead time and we want a 100 live second acquisition. The acquisition could be extended to 200 Real time seconds which would give us 100 seconds of live time, but what if the count rate during the first 100 seconds is different from the 100 second extension period? Suppose as an extreme example, someone took away the source after the first 100 seconds, but that the 100 seconds of live time was still used to compute the net peak count rate? The measurement would be in error by 100%.

A real world example is when a burst or “bubble” of activity passes the detector, causing large dead-time losses for a short period. The calculated net count rate is computed from the total accumulated live time. Thus the activity of the nuclides contained within such a bubble will be underestimated by any LTC method; the error being progressively worse for higher activity bubbles. A possible way to avoid the problem is to “slice up” the acquisition into time slices short enough that the count rate is constant and to analyze each one separately. The activity passing the detector is the sum of the calculated activities for the slice. This is accurate, but may have its own problems for example if the count rate is changing on a timescale close to the time taken to read out the MCA and restart the acquisition.

The so-called "loss-free" counting (LFC) method of correcting for dead time losses, as introduced by Harms[1,2] and improved by Westphal[3,4] gives much improved results compared to LTC techniques in such cases. 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. The net peak count rate is then calculated as the corrected net area divide by the real time. 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. Clearly it is impossible, post-facto, to determine from the corrected spectrum alone the statistical uncertainties on the channel contents. 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 LFC method, which has been called "zero dead time" (ZDT). As with previous LTC methods, the ZDT correction is calculated pulse-by-pulse. The new development is that a separate variance spectrum is also maintained, 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 added to the total variance calculated and stored is largest when the ZDT correction is made for the processing of an individual pulse stored during a period of highest dead-time.

The ZDT method finally removes the major limitation of previous loss-free counting methods. It has been necessary to wait until the arrival of DSP systems capable of pulse by pulse computations to make this possible. ORTEC has enhanced its software products to capitalize on this new technique: The latest GammaVision-32® analysis software can use the two spectra to calculate the counting uncertainty and apply it in the activity calculation. Performance data for both the operation of the correction as a function of count rate and the calculation of the uncertainty are be presented in this paper.

---

[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] Pomme, Stephan; To be published.

The ZDT Uncertainty

In earlier work[5,6] the ZDT reported uncertainty was tested. The results are shown in Fig. 1. The calculated uncertainty is based on the distribution of the peak areas from a large number (2000 at each point) of spectra. As shown, the ZDT measured uncertainty is within 4% of the calculated values for all deadtimes shown (0 to 60%).

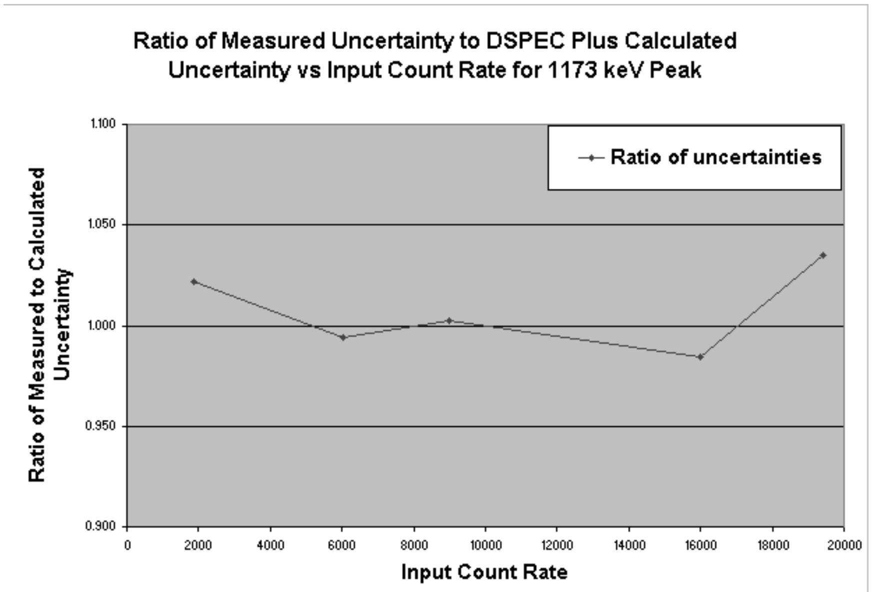


Figure 1

The net peak area in a spike

The accuracy of the ZDT-corrected peak areas were tested under conditions which simulated the case that the incident intensity of the reference gamma ray varied widely during the counting time.

The test was designed to simulate the counting situation in a system monitoring the activity content of a liquid flowing in a pipe (see Figure 2). It could equally well apply to measurement situations encountered in site characterization or waste assay. There is a baseline level of activity in the stream and a spike, or "bubble" of higher activity occurring

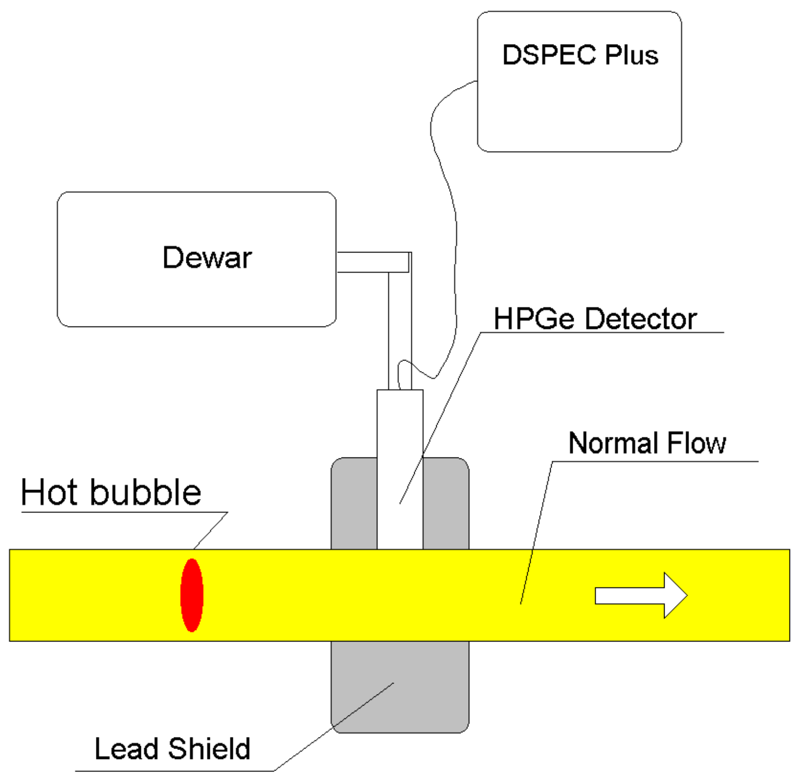


Figure 2

---

[6] Keyser, R. M., Gedcke, Dale A., Upp, Daniel L., Twomey, Timothy R. and Bingham, Russell D.; A Digital Method for Dead Time Compensation in Nuclear Spectroscopy, Proceedings of the 22nd ESARDA meeting, Brugge, May 2001.

intermittently. The variation over time of the gamma ray flux at the detector is represented in Figure 3. The total acquisition is divided up in this example into 80 time slices, with the bubble present at the detector between slices 20 to 30. Constant count-rate time slices, or "component spectra" were acquired which could then be combined to simulate the measurement as desired. Spectra were taken with a shielded ORTEC 100% relative efficiency P-type GEM HPGe 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 low (10%) total dead-time when the pulse shaping in the DPSEC Plus was set to 12 microsecond rise-time. 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 60,000 cps, far higher than in earlier experiments. These "component" spectra were collected in the mode where both the ZDT and LTC spectra are stored in the DSPEC plus memory.

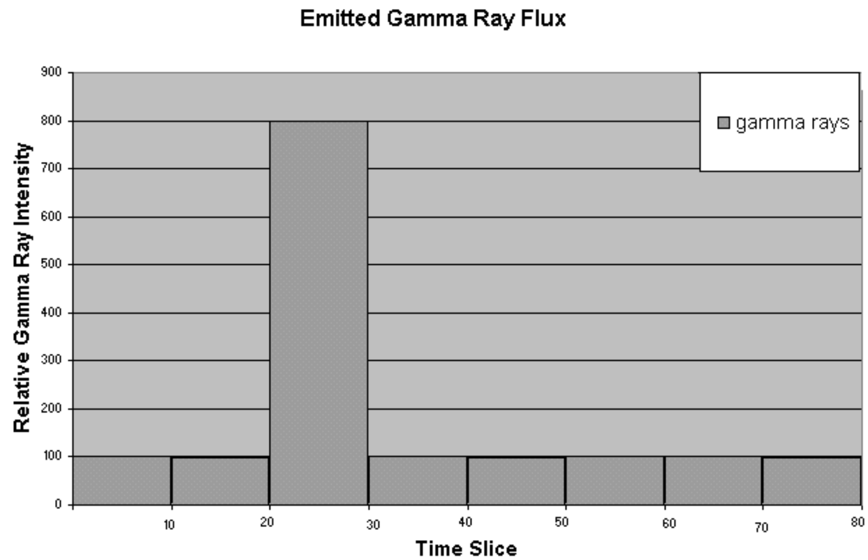


Figure 3

To simulate situations where the bubble might contain different activities, giving rise to different levels of dead times, 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 total spectrum corresponding to a single, longer acquisition covering the time before, during and after the bubble in the liquid passed the detector. (This is the case in which the LTC methods always fail.) Simulations could be made of bubbles of different activities and durations 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 of 3000 to 60,000 counts per second, at 12 μS rise time.

In addition to the ^{60}Co peak, with changing count rate, there are also several peaks from thorium which should be of constant rate 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.

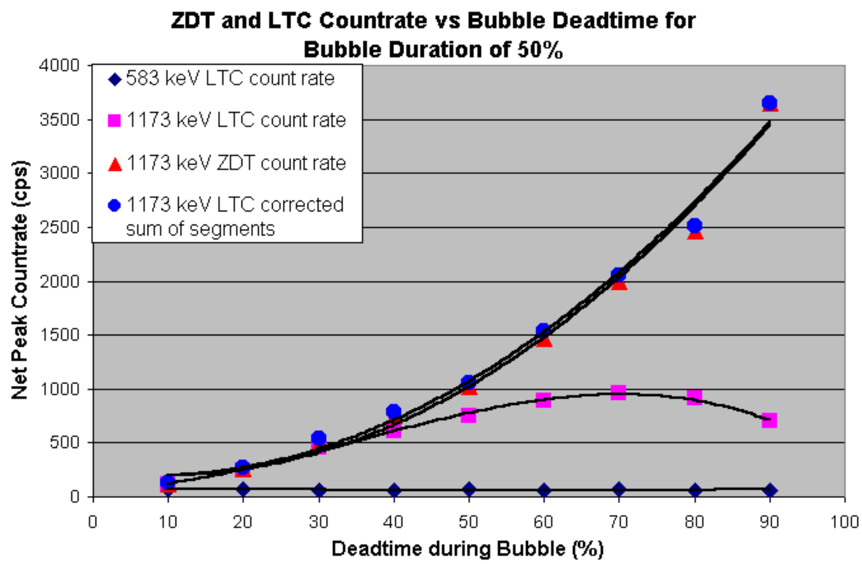
The peak areas of the 583 keV (fixed, thorium) and 1173 keV (varying ^{60}Co) peaks were calculated for the composite, that is the summed spectra in both the LTC and ZDT modes. In addition, the two peak gamma ray intensities were calculated from the individual "component" LTC spectra and these intensities were summed and normalized to constant time to obtain the total intensity ("LTC corrected sum of segments") passing the detector for each of the two gamma rays. Figure 4 shows the results for the case where the bubble occupies 50% of the total acquisition time. There are three curves plotted for the 1173 line: "1173 keV LTC count rate" is the composite spectrum LTC corrected; "1173 keV ZDT Count rate" is the composite spectrum ZDT corrected; and "1173 keV LTC corrected sum of segments" is the normalized summation of the component count rates, described above, which can be assumed to be the "correct answer" that would be obtained with a loss-less (or perfect) counter.

The three 583 keV curves (LTC, ZDT, corrected sum of segments) are essentially equal and only the LTC result is plotted. These are plotted versus the dead time seen in the bubble, for FIXED bubble duration.

The curves show that the ZDT corrected composite spectra results, which can be made in the real world, almost exactly replicate the synthesized "correct" result for the varying ^{60}Co peak. For this same peak, however the LTC results on the composite spectra are increasingly in error as the activity contained within the bubble increases. When the dead-time due to the bubble is 90%, the LTC method underestimates the total activity seen by the detector by a factor of 5.

Figure 5 shows the same situation for the bubble duration being 33% of the acquisition.

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



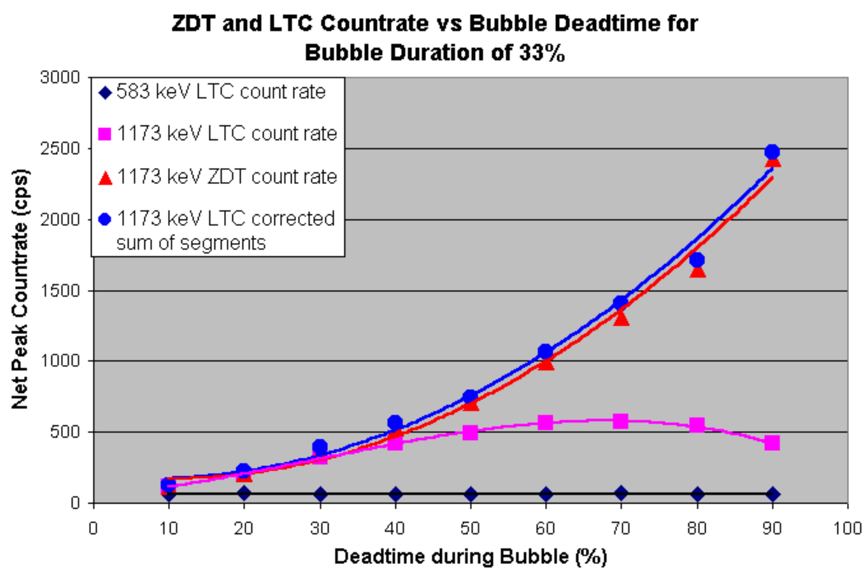


Figure 5

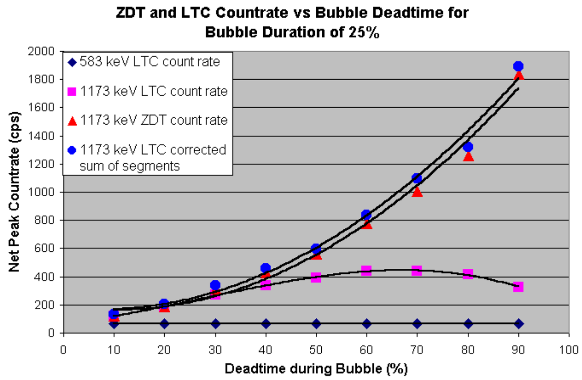


Figure 6

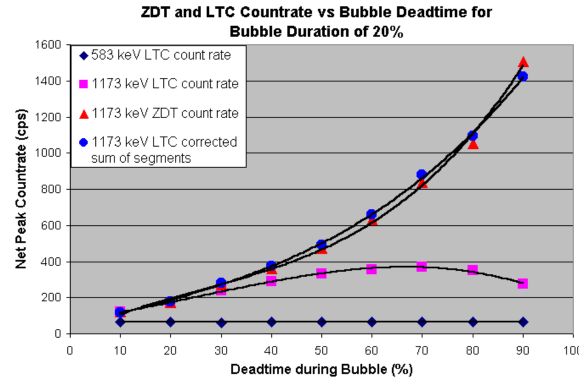


Figure 7

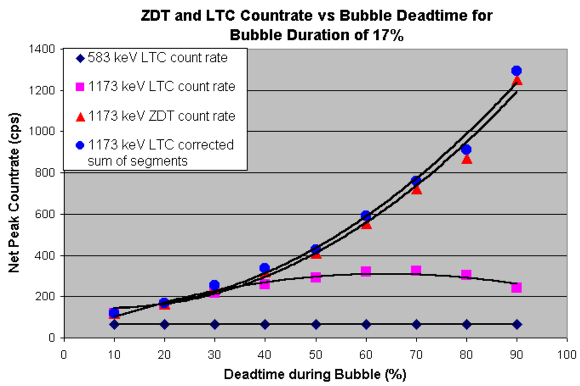


Figure 8

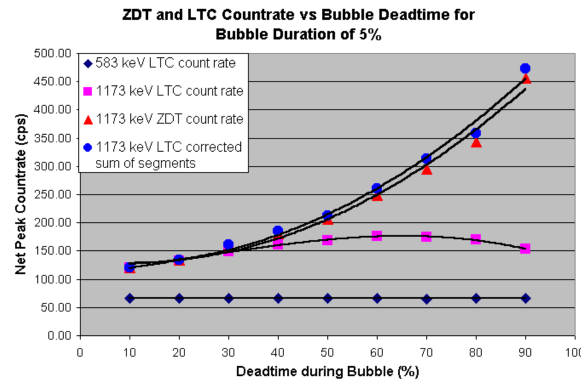


Figure 9

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).

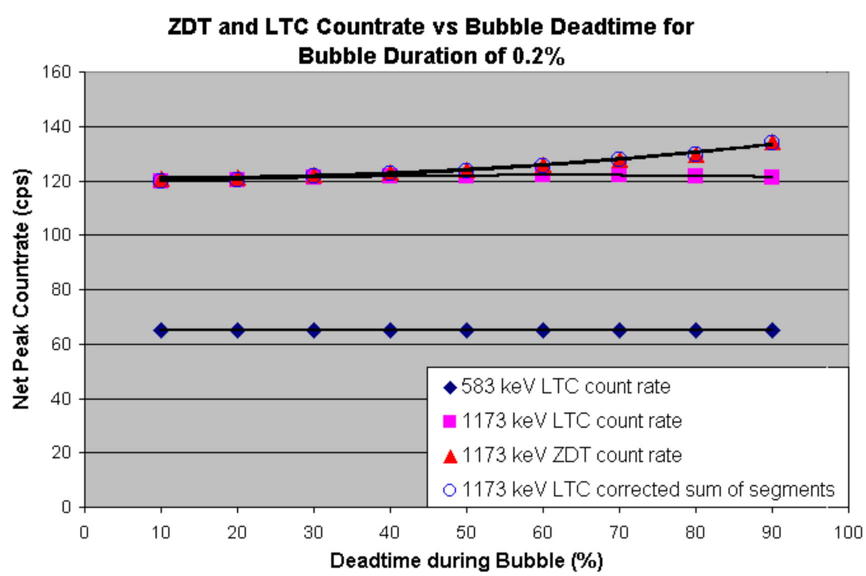


Figure 10

Results of the "Net Area in a Spike" Test

The actual and reported 583 keV activity is constant in all cases, showing that both ZDT and LTC methods are working as designed. As expected, the LTC method fails badly when the count rate is varying in the peak of interest. Of special importance is the "double-valued" nature of the LTC curve. This can easily produce incorrect activities if the peak area due to the high bubble activity is considered to be the peak area due to a low activity bubble. Even if a correction factor for the LTC method could be devised, we would have to know if the nuclides were in the bubble or in the background to know how to apply the correction.

Figure 11 shows the same 1173 keV LTC data presented as error in reported count-rate as a function of the bubble duration expressed as a percentage of total acquisition time. The error is zero for both the "no bubble" and the "all bubble" cases, as expected, since the count-rate is constant. The maximum error occurs between 20% and 35% duration for all dead-times. For the 90% dead-time case, the LTC system is catastrophically in error to the extent of 450%. The high dead-time curve rises very rapidly, showing that even for short bursts of high activity, results can be badly in error with an LTC system.

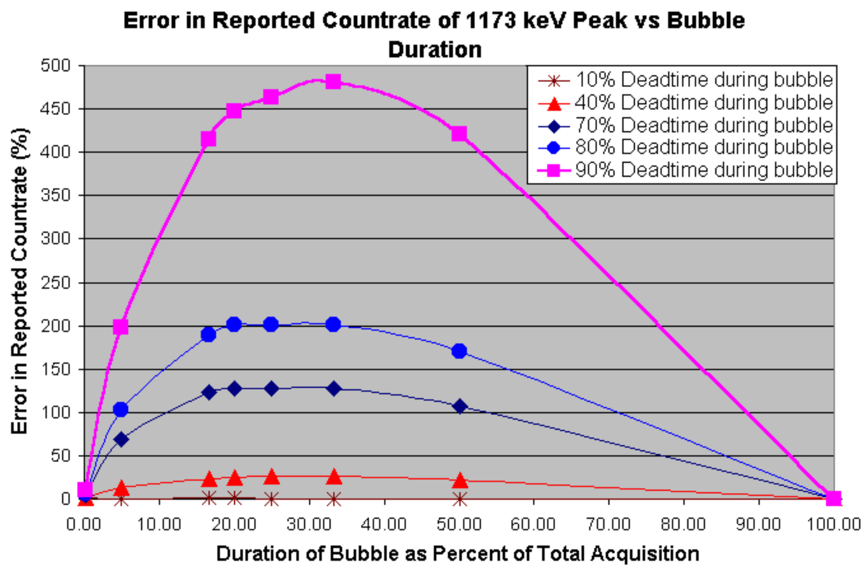


Figure 11

Conclusions

The implementation of the ZDT loss-free counting mode of the ORTEC DSPEC-plus has been thoroughly tested in simulations which accurately represent analysis situations. Both the correction itself and the reported uncertainties in the variance spectra have been shown to be accurate . The simulations have graphically demonstrated the serious problems inherent when a variety of systems might be implemented using the LTC form of deadtime correction. This work leaves open to question whether LTC systems should ever be deployed when varying count rates are to be encountered, especially if the measurements have any impact on health and safety of installations or personnel.