METHODS OF CORRECTING ANGER CAMERA DEADTIME LOSSES

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Three different methods of correcting for Anger camera deadtime loss were investigated. These included analytic methods (mathematical modeling), the marker-source method, and a new method based on counting "pileup" events appearing in a pulse-height analyzer window positioned above the photopeak of interest. The studies were done with ^{99m}Tc on a Searle Radiographics camera with a measured deadtime of about 6 μsec. Analytic methods were found to be unreliable because of unpredictable changes in deadtime with changes in radiation scattering conditions. Both the marker-source method and the pileup-counting method were found to be accurate to within a few percent for true counting rates of up to about 200 K cps, with the pileup-counting method giving better results. This finding applied to sources at depths ranging up to 10 cm of presdwood. The relative merits of the two methods are discussed.

This paper deals with methods of correcting for deadtime losses in Anger cameras. As shown in an earlier paper (*1*), the Anger camera is not always describable in terms of simple textbook models, since it often consists of a combination of paralyzable and nonparalyzable components. Various data-buffering schemes may be used between these components to further complicate the mathematical description of a system (*2*). To complicate the problem further, measured deadtimes are affected by such parameters as window width and choice of radionuclide (*1*), and by the amount of scattering material between the source and detector (*3–5*).

In this paper we describe an evaluation of the comparative accuracy of three different methods of Anger camera deadtime correction. These include:

1. Analytic methods which are based on the measurement of camera deadtime and the derivation of mathematical expressions relating observed (R_o) and true (R_t) counting rates. The mathematical expressions were used to obtain deadtime correction factors for counting rates recorded under various experimental conditions.

2. The "marker source" method, originally described by Freedman et al (*6*), in which a shielded small-volume source is placed on the periphery of the detector and a region of interest is selected to monitor counts from this source during the study. Changes (reductions) in these counts are presumed to characterize deadtime losses for the entire detector and are used to derive deadtime correction factors.

3. A new method based on counting of "pileup" events collected by an analyzer window positioned for an energy higher than the photopeak of interest. The basis for this technique is indicated in Fig. 1, which shows a series of ^{99m}Tc pulse-height displays from a Searle Radiographics camera with increasing source activity and counting rate. At higher activities and counting rates, it often happens that two separate events are recorded as a single event of apparent amplitude equal to the sum of the amplitudes of the two individual events. As pointed out by Wolff (*3*), if either of these events had been acceptable for a selected analyzer window, it may now be rejected and lost. This process is therefore responsible, at least in part, for the observed camera deadtime losses. Measurement of pileup events should thus provide an indicator of deadtime losses.

Another previously described method for deadtime correction involves measurement of changes in pulse rate for pulses injected into the camera circuitry from a pulse generator (*7,8*). For lack of appropriate equipment we did not evaluate this technique.

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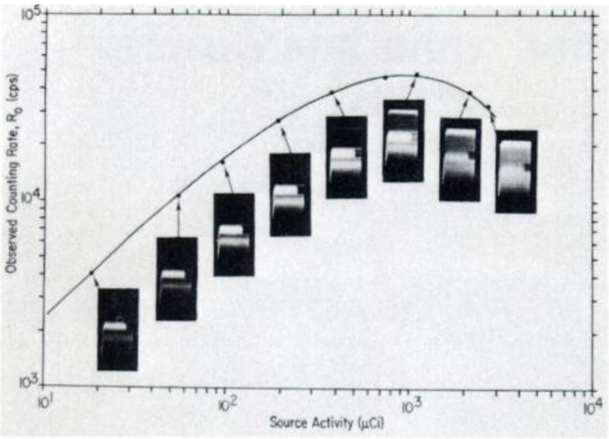

FIG. 1. Appearance of ^{99m}Tc pulse-height display on Searle Radiographics Pho/Gamma III (HP) camera as a function of source activity and observed counting rate. Window is 20%, centered on 140-keV photopeak.

EXPERIMENTAL METHODS

All studies were carried out on a Searle Radiographics Pho/Gamma III camera, upgraded to HP status, with a low-energy high-sensitivity collimator attached to the detector. The camera "unblank" switch was in the "short time constant" position for all studies.

The test sources were ^{99m}Tc solutions in 30-ml glass vials. Experiments were carried out with the test sources placed either directly on the collimator or behind 5-cm or 10-cm thicknesses of presdwood. Eight to ten sources of various strengths were used in each experiment. The maximum source activities and true counting rates were as follows: directly on collimator, 20 mCi, 200 K cps; on 5 cm presdwood, 40 mCi, 240 K cps; on 10 cm presdwood, 55 mCi, 175 K cps.

Observed counting rates R_o were determined from the front panel scaler on the camera console, and true counting rates R_t were determined by a method employing dose-calibrator assay of source activities (*1*). Briefly, this method involves measurement of the activity (mCi) and counting rate (cps) for a relatively weak source that generates only small deadtime losses. These values are used to derive a calibration factor for true counting rate versus source activity (cps/mCi), which in turn is used to determine the true counting rate for more intense sources after they are measured in the dose calibrator. With careful application, this method can provide true counting rates to within 1–2%.

For evaluation of the analytic method, a mathematical expression relating observed and true counting rates was developed from data obtained for sources measured behind a 5-cm thickness of presdwood. The accuracy of this relationship for obtaining correction factors for sources directly on the collimator and behind a 10-cm thickness of presdwood was then evaluated.

For the marker-source studies, a small-volume marker source of ^{99m}Tc (10-ml vial) was positioned directly against the collimator, off-centered by approximately 8 cm to one side of the detector. Test sources of different activities were positioned at approximately the same off-centered distance toward the opposite side. Both the marker source and the test source were shielded by inverted lead pigs. Split-crystal counting was used to monitor counts from the two sources. For experiments with scattering material between the test source and detector, the presdwood slabs were positioned no closer than 3 cm from the center of the crystal to avoid scattering from the test source to the marker-source side of the crystal. Preliminary counting experiments with test sources on the presdwood and the marker source absent indicated that this technique was successful. We also obtained images of a test source with marker sources of various strengths to investigate possible image distortions caused by the presence of the marker source and to determine possible limitations on marker-source strengths.

For the pileup-counting technique the second window used was a 35% window centered at 220 keV (180–260 keV). Preliminary experiments indicated that of the energy windows conveniently obtainable on the Searle Radiographics camera, this choice offered maximum sensitivity of recorded pileup counts to deadtime losses, together with minimum sensitivity to changes in scattering conditions. The relationship between the ratio of observed counting rate in the pileup window to observed counting rate in the photopeak window, $K = R_o^{220}/R_o^{140}$, and the deadtime correction factor for the photopeak counting rate, $C = R_t^{140}/R_o^{140}$, was investigated for different scattering conditions. The value of R_t^{140} was determined by the dose-calibrator technique discussed earlier. Effects of small misadjustments of the "isotope peak" (high voltage) control were also investigated. Intentional misadjustments made toward both the high and the low sides were sufficient to cause the observed photopeak counting rates to fall by about 5% (40 divisions on the isotope peak control). This was judged to be somewhat beyond the limits of probable "normal" misadjustments in camera operation.

RESULTS

Analytic method. Experiments with ^{99m}Tc sources indicated that the camera behaved as a two-component system, in agreement with previous investigations (*1*). The deadtimes of both the paralyzable component τ_p and the nonparalyzable component τ_n were observed to increase with the amount of scattering material between the source and the collimator (Table 1). The results obtained with 5 cm of presdwood were used to graph the deadtime correction factor C as a function of R_t. This curve was applied to data obtained with sources directly on the collimator or behind 10 cm of presdwood. The corrected counts obtained in this manner were then compared to the true counts. The results are summarized in Fig. 2, showing the relative error in corrected counts as a function of the true counting rate of the test source.

Marker source. The first evaluation was to determine the appropriate activity and counting rate R_0^m for the marker source. On the one hand, this counting rate should be sufficiently high that the statistical error in the correction factor measurement will be small. On the other hand, it should not be so high as to introduce significant deadtime losses or produce image distortions. Figure 3 shows the results of an experiment with a test source providing a counting rate of approximately 10 K cps, with marker sources of various strengths and counting rates. The test-source activity was such that it produced deadtime losses of about 6% on this camera (see Table 1). Increase of marker-source activity increased the losses to about 12% for a marker-source counting rate $R_0^m \approx 10$ K cps. The losses rapidly became larger as the marker-source strength was increased beyond this value.

TABLE 1. DEADTIMES (μsec) OF SEARLE RADIOGRAPHICS PHO/GAMMA III (HP) CAMERA MEASURED UNDER DIFFERENT SCATTERING CONDITIONS

Scatterer	τ_p	τ_n
None	4.8	6.2
5 cm presdwood	5.6	6.5
10 cm presdwood	6.1	7.1

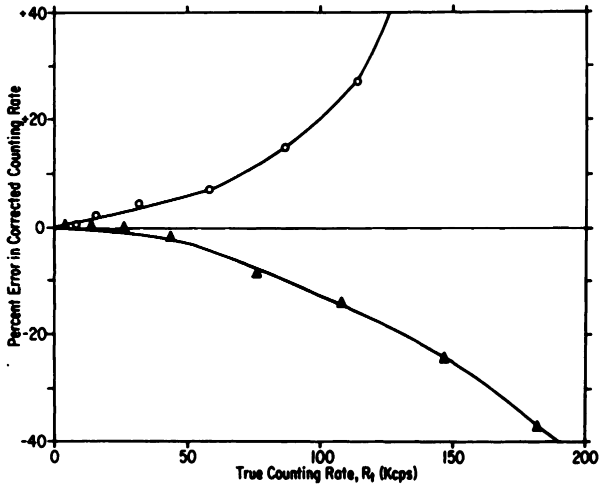

FIG. 2. Error in counting rates corrected by analytic method, based on data obtained for sources behind 5-cm-thick presdwood scatter material. Error for different scatter conditions is shown against true counting rate. ○) Sources directly on collimator, ▲) sources behind 10 cm presdwood.

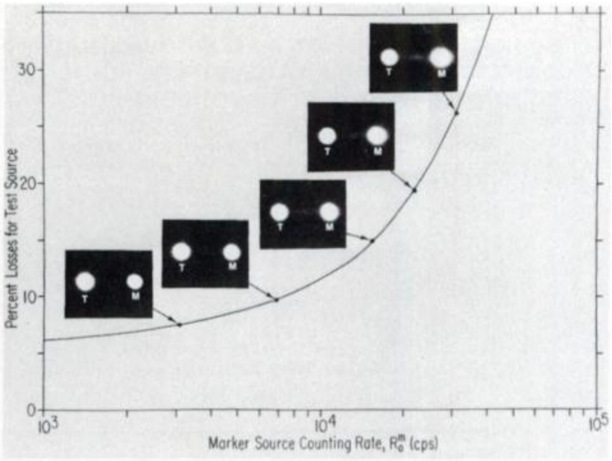

FIG. 3. Percent losses for 10 K cps test source, and appearance of marker source (M) and test source (T) images, shown against observed counting rate for marker source.

The intensity of the band of apparent activity between the two sources also became more pronounced with increased marker-source activity (Fig. 3). This band is caused by coincident detection of events from the marker source and the test source, which the camera circuitry locates somewhere between the two sources. This type of Anger camera image distortion at high counting rates has been noted before (*9,10*). The results of these experiments suggested that a reasonable maximum for the marker-source counting rate on this particular camera was around 10 K cps. For the remaining marker-source studies, the counting rate R_0^m was actually kept at around 5 K cps.

The results of marker-source correction experiments are summarized in Table 2. These results are based on 3-sec counting measurements for both the marker source and the test sources. Marker-source corrections consistently underestimated the true counting rates for the test sources, by an average of 0.7% for test sources directly against the collimator, 2.1% for test sources behind 5 cm of presdwood, and 3.8% for sources behind 10 cm of presdwood. Variations in individual measurements for the 8–10 sources of different strengths used in each experiment were somewhat larger, but consistent with the statistical limits imposed by marker-source and test-source counting rates and the accuracy with which true counting rates could be estimated by the dose-calibrator assay technique.

The reference or "zero activity" counting rate for the marker source was the marker-source counting

TABLE 2. RATIOS OF MARKER-SOURCE CORRECTED COUNTING RATES TO TRUE RATES, FOR DIFFERENT SCATTER CONDITIONS

Scatterer	Ratio (corrected/true)*
None	0.993 (0.959–1.020)
5 cm presdwood	0.979 (0.952–0.995)
10 cm presdwood	0.962 (0.916–1.009)

* Values in parentheses are the ranges of ratios recorded in an experimental series involving 8–10 sources of different strengths.

rate with no test source present and corrected for its own induced deadtime losses (about 3% at 5 K cps). Also, the marker-source reference counting rate was corrected for ^{99m}Tc decay, which also amounted to about 3% for a 15-min experiment. If these corrections are not employed, there is the possibility of further significant error.

Pileup counting. Figure 4 shows the relationship between the ratio $K = R_o^{220}/R_o^{140}$ and photopeak deadtime correction factor $C = R_t^{140}/R_o^{140}$ for sources directly against the collimator and behind 5-cm- and 10-cm-thick presdwood. A nearly linear relationship was obtained, with very little difference among different scattering conditions. The relationship was accurately described by

$$C = 6.11\,K + 1. \qquad (1)$$

The results of pileup-counting corrections based on Equation 1 for the three scattering conditions and for intentional misadjustments of the "isotope peak" control are summarized in Table 3. On the average, the results obtained with a properly adjusted isotope peak were accurate within 1% for all scatter conditions. Misadjustment of the "isotope peak" control only increased the error to 2–3%. The variations in individual measurements were again somewhat larger, but smaller than the individual variations noted in the marker-source studies.

DISCUSSION

The linear relationship between $K = R_o^{220}/R_o^{140}$ and $C = R_t^{140}/R_o^{140}$ noted in Fig. 4 and Equation 1 can be explained if it is assumed that the number of counts appearing in the pileup window is linearly related to the number of counts lost from the photopeak window, i.e.,

$$R_o^{220} = a(R_t^{140} - R_o^{140}). \qquad (2)$$

Thus, we have

$$R_o^{220}/R_o^{140} = a[(R_t^{140}/R_o^{140}) - 1] \qquad (3)$$

$$K = a(C - 1) \qquad (4)$$

$$C = (1/a)K + 1, \qquad (5)$$

which is of the same form as Equation 1. Other systems in which significant deadtime losses are introduced by components following the pulse-height analyzer (e.g., an ADC or a computer) might not provide a linear relationship since the additional losses might not be linearly related to pileup counts as in Equation 2.

The fact that individual random variations in the deadtime correction factor were somewhat smaller for the pileup-counting method than for the marker-source method can be explained on the basis of counting statistics. For example, the following 1-sec counts (N) were noted in one pileup-counting experiment (approximate values):

$$N_o^{140} = 33{,}000 \text{ counts}$$

$$N_o^{220} = 2{,}000 \text{ counts}.$$

Thus, $K = 0.06$. Assuming that the random error in the calculated correction factor C is caused entirely by random variations in N_o^{220} and N_o^{140}, one obtains from Equation 1:

$$(\Delta C)^2 = (\partial C/\partial N_o^{220})^2\,(\Delta N_o^{220})^2 + (\partial C/\partial N_o^{140})^2\,(\Delta N_o^{140})^2, \qquad (6)$$

from which we have

$$(\Delta C/C) = 6.11\,K \times \sqrt{(1/N_o^{220}) + (1/N_o^{140})}/(6.11\,K + 1) \qquad (7)$$

$$(\Delta C/C) \approx 0.006. \qquad (8)$$

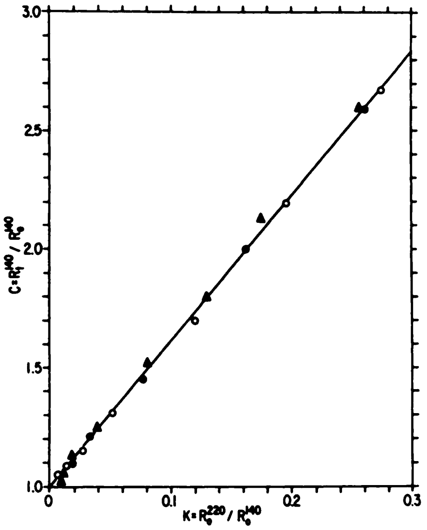

FIG. 4. Correction factor for ^{99m}Tc photopeak counts, $C = R_t^{140}/R_o^{140}$, shown against ratio of observed counting rates in pileup and photopeak windows, $K = R_o^{220}/R_o^{140}$. ○) Sources directly on collimator, ●) sources behind 5 cm presdwood, ▲) sources behind 10 cm presdwood. Straight line is $C = 6.11\,K + 1$.

Note that the error is quite small, even though only 2,000 counts were recorded in the pileup window. To obtain the same random error by the marker-source method would require marker-source counts of at least $(1/0.006)^2 \approx 26{,}000$ in the same 1-sec counting interval, well above what could be tolerated for the marker source on this camera. Similar relatively small random errors were calculated for other source strengths and counting rates by the pileup-counting method.

The results presented here indicate that analytic methods are not reliable for correcting deadtime losses, except perhaps at relatively low counting rates where corrections are small in any case. Variations in scatter conditions (e.g., source depth) cause unacceptably large errors at higher counting rates: $>10\%$ at true counting rates of 70–80 K cps on the camera used in this study.

On the other hand, both the marker-source and the pileup-counting technique provided accurate corrections for true counting rates of up to about 200 K cps and over a reasonable range of scattering conditions, with the pileup-counting method being somewhat more accurate and precise. Neither requires the addition of electronic hardware such as a random- or fixed-rate pulse generator. They offer the following relative advantages and disadvantages:

1. The pileup-counting technique is more accurate (less sensitive to variations in measurement conditions) and precise (less sensitive to random counting errors).
2. The pileup-counting technique introduces no additional counting losses or image distortions.
3. Pileup counting does not require monitoring counts in a separate region of interest, or even region-of-interest capabilities. Thus, for example, it could be implemented in "split crystal" flow studies. On the other hand, it does require the use of a second analyzer window.
4. Pileup counting requires preliminary experiments (and probably also periodic reevaluation) to determine the relationship between C and K for each radionuclide and counting window used and also on different cameras, whereas the marker-source method can be applied in a more simple and direct manner.
5. The marker-source method with ^{99m}Tc requires additional corrections (i.e., continuous correction for marker-source decay) and also correction for deadtime losses introduced by the marker-source counting rate itself.
6. Some new cameras are equipped with improved pileup-rejection circuits to gate off pulse processing circuitry when two events occur within the circuit resolving time. The pileup-counting technique might not be applicable to these cameras unless some method for monitoring the number of events thus rejected was available.

TABLE 3. RATIOS OF CORRECTED TO TRUE COUNTING RATES FOR THE PILEUP-COUNTING TECHNIQUE, FOR DIFFERENT SCATTER CONDITIONS AND INTENTIONAL MISADJUSTMENTS OF THE CAMERA "ISOTOPE PEAK" CONTROL

	"Isotope peak" adjustment		
Scatterer	Correct	40 divisions high	40 divisions low
None	1.006 (0.994–1.018)*	1.025 (1.013–1.036)	1.013 (0.984–1.031)
5 cm presdwood	1.000 (0.981–1.018)	1.018 (0.965–1.052)	1.011 (0.985–1.031)
10 cm presdwood	0.997 (0.971–1.034)	0.992 (0.964–1.011)	1.010 (0.986–1.026)

* Values in parentheses are the ranges of ratios recorded in an experimental series involving 8–10 sources of different strengths.

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