The Effect of Window Fraction on the Deadtime of Anger Cameras: Concise Communication

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The deadtime characteristics of an Anger camera are analyzed using a model consisting of a paralyzable front end and nonparalyzable display circuits. This model differs from previous deadtime analyses in that it considers the change in the fraction of counts passed by the pulse height analyzer as a function of the true count rate. Deadtime curves are analyzed for a Pho/Gamma IV Anger camera using 10%, 20%, and 35% windows.

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An Anger camera may be considered to be a two-component system (*1*): (A) a paralyzable component (crystal, amplifiers, and pulse height analyzer) followed by (B) a nonparalyzable component (display circuits) (Fig. 1). The relationship between the true and observed counting rates for the individual components is quite simple and is given by Evans (*2*):

$$\text{Paralyzable} \quad R = Ne^{-N\tau}, \qquad (1)$$

$$\text{Nonparalyzable} \quad R = \frac{N}{1 + NT}, \qquad (2)$$

where R = recorded rate; N = true rate; τ = paralyzable deadtime; and T = nonparalyzable deadtime.

The output of the paralyzable component is the input to the nonparalyzable component. In addition one must consider that the gamma spectrum as seen by the pulse-height analyzer (PHA) is influenced by the true counting rate, particularly at high counting rates (*3*). Two pulses that the PHA would normally reject as too small may overlap and be accepted, and the probability that this may occur is increased as the true counting rate increases. There is also an increased probability that a pulse normally accepted by the PHA may overlap with another pulse and be rejected as too large. Thus the fraction of events passing the PHA window, F, is a function of the true count rate. In an Anger camera, all events must be processed by the PHA. The electronics up to and including the PHA may be considered as the paralyzable component. The input to this component is the total true event rate, N, and the output, R′, is given by

$$R' = FNe^{-N\tau}. \qquad (3)$$

This relationship includes the event-rate loss due to the deadtime of the paralyzable component, and it also includes the rejection of pulses that do not fall within the PHA window. Both of these are a function of the true counting rate. The importance of the fraction of events that pass the PHA window has been pointed out previously (*4,5*) but this fraction has not been considered to change as a function of the true count rate.

The PHA output, R′, is now the input event rate to the nonparalyzable component. The true deadtime of this component is T, but its effective deadtime is (T − τ), since there are no input events into the nonparalyzable component for an interval of at least τ following each pulse (*1*). At high event rates the input pulses to the nonparalyzable component will be separated by time intervals greater than τ, i.e., the effective deadtime of the nonparalyzable component will be less than (T − τ). However, the above approximation does seem to work reasonably well for an Anger camera (*1*). The output of the nonparalyzable component, R, is therefore

$$R \approx \frac{R'}{1 + R'(T - \tau)}. \qquad (4)$$

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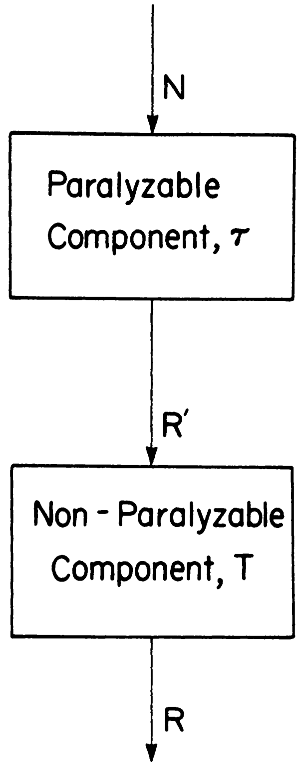

FIG. 1. Paralyzable–nonparalyzable counting system. Output of paralyzable component is input to nonparalyzable component.

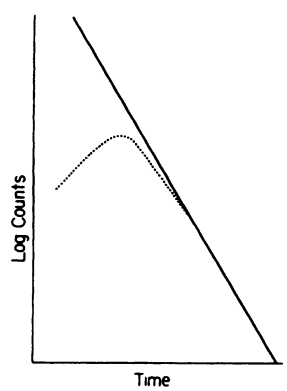

FIG. 2. Decaying-source method. Dotted line is R, recorded event rate. Solid line is Nw, the true event rate in window corresponding to the decay of Tc-99m.

This is also an approximate relationship because Eq. 2 applies only to random input events, whereas in this two-component system the input R′ is a series of events separated by at least the time interval τ, and thus is not truly random.

Combining Eqs. 3 and 4 we obtain

$$R \approx \frac{FNe^{-N\tau}}{1 + FNe^{-N\tau}(T - \tau)}. \qquad (5)$$

METHOD AND RESULTS

Determination of Nw, the true rate passing the PHA. The experimental relationship between Nw, the true rate passing the PHA, and R, the recorded rate, was measured on a Pho/Gamma IV Anger camera using a decaying-source method. A "point" source, approximately 1.7 mCi of Tc-99m, was placed 30 cm from the uncollimated crystal, and count rates were recorded with 10%, 20%, and 35% windows over a 52-hr period.

The recorded rates for the three windows were plotted against time on semilog paper. At low count rates, where there is negligible deadtime loss or pulse pile-up, straight lines were obtained corresponding to the decay of Tc-99m (Fig. 2). Points on the linear section of these graphs were used in a "least-squares" computer program to obtain the best fit to the known half-life of 6.03 hr (*6*). The computer program was then used to calculate Nw for the other points on the three curves. Thus the experimental relationship between R and Nw was established.

Determination of F, the fraction of events passed by the PHA. The total true event rate, N, which is what we really need, is given by:

$$N = \frac{Nw}{F_0}, \qquad (6)$$

where F_0 is the fraction of events passed by the PHA assuming negligible pulse pile-up, i.e., at low count rates.

The fraction of events passed by the PHA, F, as a function of the true rate, was measured in the following manner. The "z out" (input to the camera's PHA) of the Pho/Gamma IV was connected to a single-channel analyzer (SCA) with a pulse-pair resolution of 0.75 μsec. If one assumes that the crystal and electronics preceding the PHA have a paralyzable deadtime of at least 1 μsec, the deadtime loss of the SCA may be neglected.

Using the same geometry (same amount of scatter) as in the prior deadtime experiments, a source of Tc-99m was placed under the crystal. At low counting rates 10%, 20%, and 35% windows were matched on the Pho/Gamma IV and the SCA. The SCA windows were "fine tuned" to obtain the same count rates as the corresponding windows on the Pho/Gamma IV. Using these window settings, increasing activities of Tc-99m were placed under the crystal and the counting rates were recorded on the Pho/Gamma IV scaler and the SCA. The integral count rates on the SCA were also recorded at each level of Tc-99m activity. The fraction of events in the window, F, was calculated by dividing the count

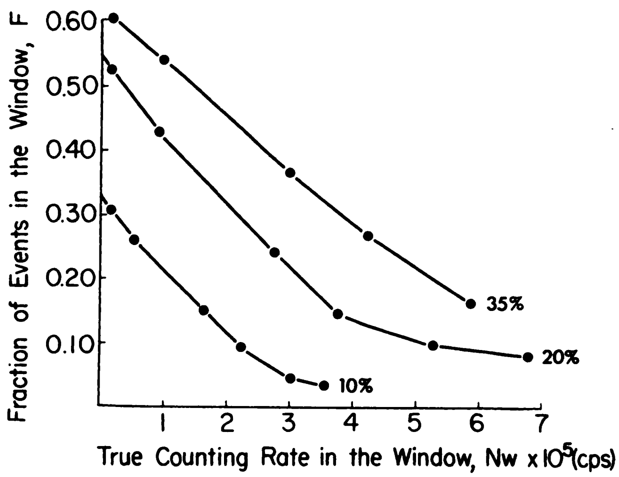

FIG. 3. Fraction of events in window plotted as function of true event rate in that window. Curves for Tc-99m in 10%, 20%, and 35% windows.

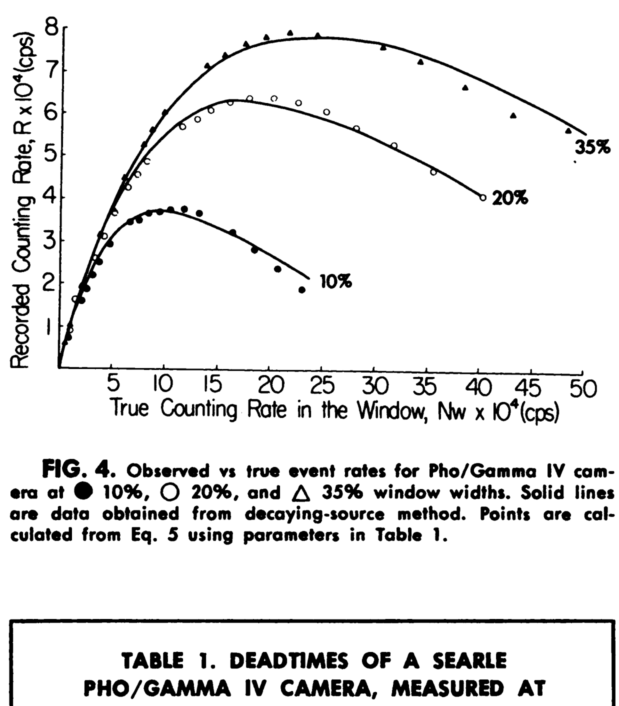

FIG. 4. Observed vs true event rates for Pho/Gamma IV camera at ● 10%, ○ 20%, and △ 35% window widths. Solid lines are data obtained from decaying-source method. Points are calculated from Eq. 5 using parameters in Table 1.

TABLE 1. DEADTIMES OF A SEARLE PHO/GAMMA IV CAMERA, MEASURED AT SEVERAL WINDOW SETTINGS

Window	τ (μsec)	T (μsec)	F_0
10%	1.7	2.6	0.32
20%	1.3	2.9	0.54
35%	1.5	3.1	0.62

rate in the corresponding window on the SCA by the integral count rate.

Since both the experimental relationship between R and Nw, and the relationship between F and R are known, F can be expressed as a function of Nw. This relationship is shown in Fig. 3. By extrapolating F to zero count rate, the values of F_0 are obtained for the three windows. It can be seen that the fraction of events in the window changes rapidly with count rate (*7*).

Deadtime calculations. The experimentally derived values of N and F were used in Eq. 5 to fit a curve to the observed count rates (R), thus obtaining values of T and τ for the three windows. Figure 4 and Table 1 summarize the results. Note that in Fig. 4 the solid lines represent the observed count rates, whereas the points are the values of R calculated from this model. These curves show good agreement between the observed values of R and the values of R calculated from this model. This implies that the Pho/Gamma IV Anger camera can be treated as a paralyzable–nonparalyzable system provided one considers the fraction of events in the PHA window as a function of the true event rate.

DISCUSSION

This model differs from previous models (*1,4*) in that the total true event rate (N)—and not just the event rate in a particular window—is used to calculate the deadtime of the paralyzable component. By considering the fraction of events in the window (F) as a function of the true count rate, an attempt has been made to separate out the event-rate loss due to deadtime from that due to pulses piling up and leaving the window. The net result of these considerations is that the values of the deadtimes for the paralyzable and nonparalyzable components remain essentially the same regardless of the window chosen. This is the expected result, since the electronics in the individual components should take the same amount of time to process every event regardless of the window width. When the window fraction is neglected there is an apparent change in measured deadtime (*1*).

The formulation in Eq. 5 separates the true deadtime losses from the effects of pulse pile-up, and therefore gives a clearer picture of the operation of an Anger camera. This model is not easy to use for correction of deadtime losses in the clinical situation because the fraction of events in the window is not usually known and varies with the gamma energy and the target distribution. It is important to realize that these factors do influence deadtime losses, and that they vary greatly from one clinical situation to another.

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