Deadtime Measurements in Scintillation Cameras under Scatter Conditions Simulating Quantitative Nuclear Cardiography

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Deadtime performance of scintillation cameras is sensitive to such factors as scatter fraction and analyzer window width. Data from manufacturers and previous investigators do not predict counting-rate losses under clinical conditions. Scintillation cameras used with Tc-99m for quantitative nuclear cardiology should be evaluated for deadtime performance by the two-source method using a scatter phantom designed to simulate the spectrum from Tc-99m in the heart. Under these conditions, scintillation cameras were found to follow the paralyzable model; accurate estimates could be obtained for data losses and maximum useful counting rates in a clinical setting.

A survey of 39 contemporary scintillation cameras yielded a range of paralyzing deadtime values of 4.3 to 10 μsec, with a 20% window centered on the Tc-99m photopeak. For an average deadtime of 6 μsec, counting rates should be maintained below 36,000 cps to avoid undue data losses in excess of 25%.

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The use of scintillation cameras in quantitative nuclear cardiography requires an estimate of data losses at high counting rates. Camera manufacturers usually specify temporal resolution in terms of the greatest possible counting rate in the absence of scatter, or else by pulse-pair resolution, although neither of these values is of much clinical significance. Quality-assurance programs for scintillation cameras usually do not include an evaluation of temporal resolution. Deadtime losses degrade counting statistics, but otherwise they do not affect the diagnostic quality of most imaging procedures. But in first-pass imaging for quantitative nuclear cardiography, count-

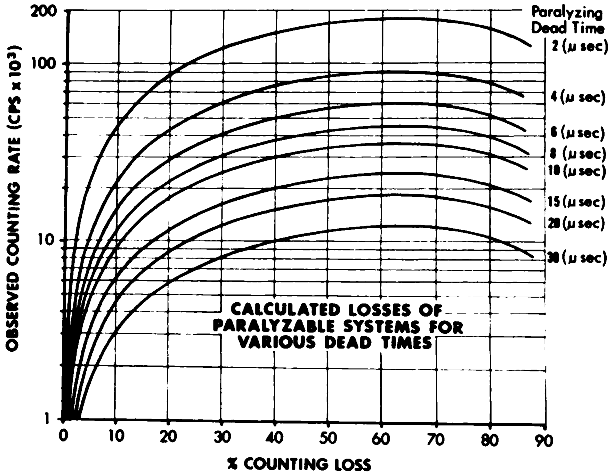

FIG. 1. Deadtime losses as functions of observed counting rate for various paralyzing deadtimes. Data for the curves are derived from a FORTRAN program.

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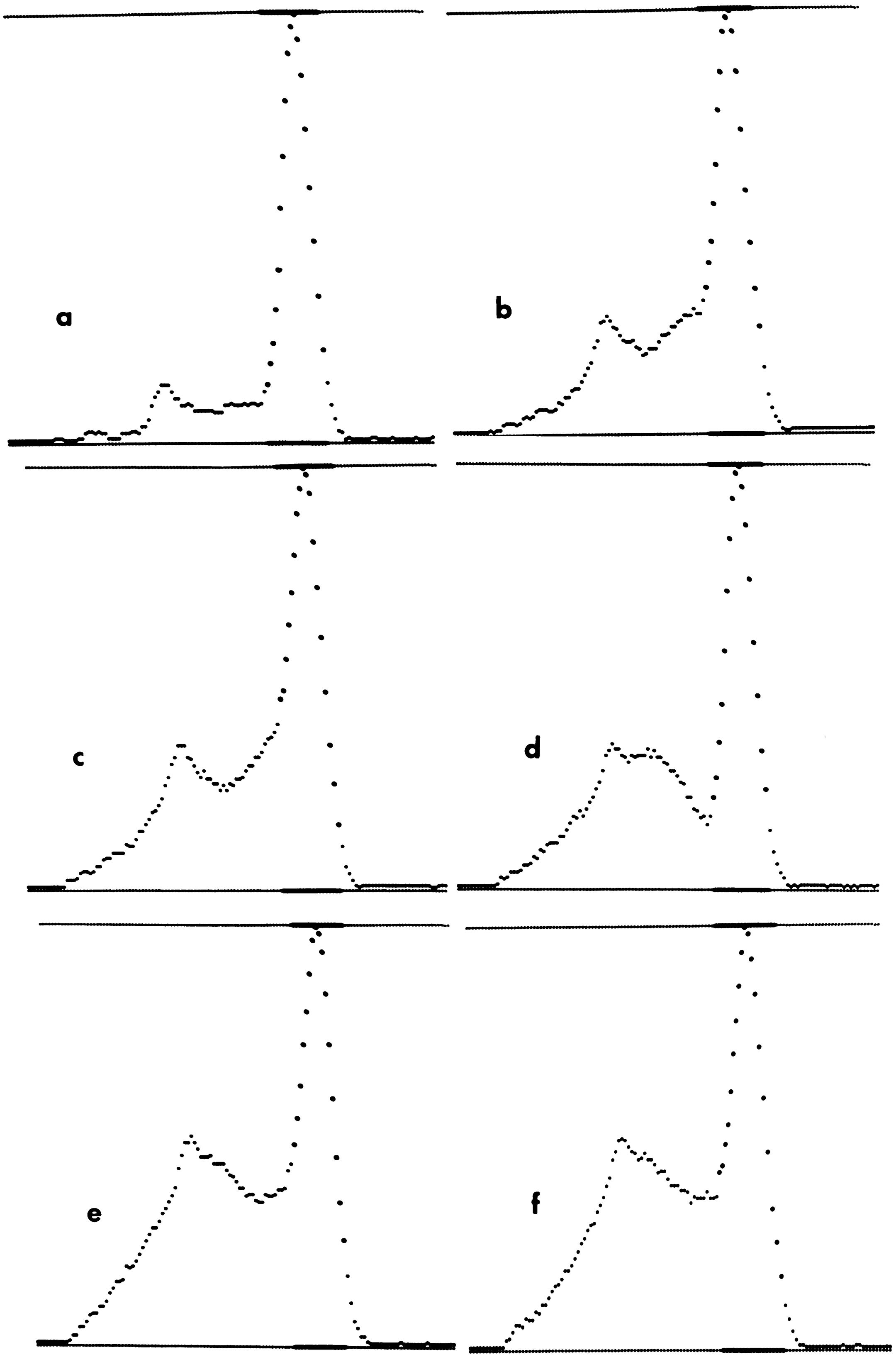

FIG. 2. Effect of scattering material on Tc-99m spectra observed with multichannel analyzer of an Ohio-Nuclear 120 scintillation camera: (a) minimal scatter; (b) 2.2 cm Masonite in front of source; (c) 4.6 cm Masonite in front of source; (d) 10.2 cm Masonite; behind source; (e) plexiglass scatter phantom providing 5 cm for forward scatter and 10 cm for backscatter; (f) spectrum from Tc-99m-labeled microspheres in myocardium, LAO 30° view.

ing losses present a significant problem because counting rates are pushed to the maximum compatible with data-disk performance or acceptable deadtime losses. Several widely used computer-controlled data-acquisition and -processing systems limit the maximum acquisition rate in list mode to about 30,000 cps. At this counting rate a camera with a nominal paralyzing deadtime of 6 μsec will incur a 20% data loss (Fig. 1). The availability of disk drives of higher performance places the counting-rate limitation definitely on the camera. What maximum counting-rate loss is acceptable is a somewhat arbitrary decision. We believe the limit should be placed at about 25% because at greater losses the patient is subjected to a rapidly increasing radiation exposure without a corresponding improvement in diagnostic information.

The calculated data of Fig. 1 are applicable for estimations of deadtime loss* only after the investigation of the following questions:

1. Is a scintillation camera a paralyzable system, a nonparalyzable one (*1*), or does it function somewhere between these two performance limiting modes?
2. Has the deadtime been determined under conditions corresponding to those in quantitative nuclear cardiography?
3. What range of deadtime performance may be expected of contemporary scintillation cameras?

In this article we attempt to answer these questions.

Designing a scatter phantom. As has been pointed out previously by several authors (*2–4*), the observed deadtime of a scintillation camera is greatly dependent on the fraction of those events that passes the pulse-height analyzer. None of these authors, however, has attempted to match the pulse-height spectrum present during his measurements with that observed under clinical conditions.

The spectra from a Tc-99m source were observed with the multichannel analyzer of a scintillation camera† (Fig. 2). The source in a plastic test tube was first evaluated with minimal scatter (Fig. 2a). Then through varying thicknesses of Masonite between source and collimator, the effects of forward-scattering material were observed (Fig. 2b, c). Masonite placed behind the source showed the effects of backscatter (Fig. 2d). Various combinations of the thicknesses of forward and backscatter material were tried until the resulting spectrum matched that from Tc-99m labeled microspheres contained in the human heart, as observed from the LAO view in routine perfusion studies (Fig. 2f). The LAO projection was chosen as the standard because of the relative frequency with which it is used in procedures that require quantitative counting-rate data. Approximately 5 cm forward and 10 cm backscatter provided good agreement (Fig. 2e). A plexiglass scatter phantom designed accordingly is diagrammed in Fig. 3. The phantom appears to be valid also for other projections; we have observed almost identical spectra from anterior and RAO views.

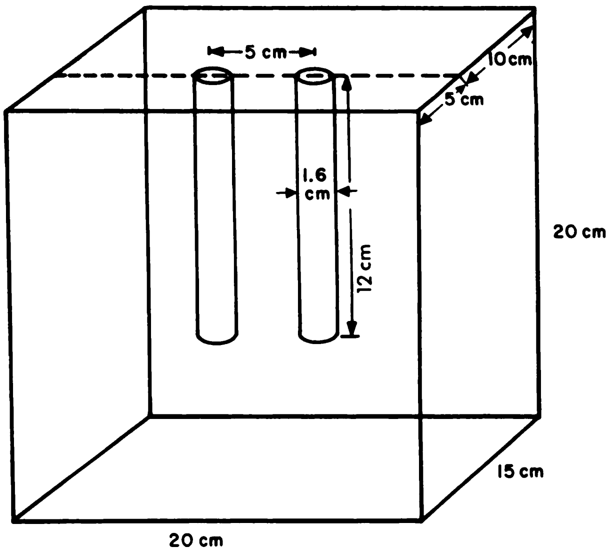

FIG. 3. Plastic scatter phantom designed to match Tc-99m spectrum from the heart (cf. Fig. 2e & f).

Paralyzable or nonparalyzable camera systems? The observed counting rates of four scintillation cameras from different manufacturers were determined for increasing activities of Tc-99m in the scatter phantom. A 20% analyzer window, centered on the Tc-99m photopeak, was used for these measurements. The data from a Picker 4–15 with large field of view, and from an Ohio-Nuclear 120 mobile camera, followed quite precisely those of hypothetical paralyzable systems over a wide range of counting rates (Fig. 4a, b). The data from a General Electric Maxicamera and a Searle LEM mobile camera appeared to follow the paralyzable model throughout the clinically useful range of counting rates, as defined later, although with input giving greater counting rates they are shown to lie in the semiparalyzable area (Fig. 4c, d). We therefore feel justified in treating the responses of all scintillation cameras we tested in a clinical setting as those of paralyzable systems.

Measurement of paralyzing deadtime. Two Tc-99m sources, labeled 1 and 2, are prepared, each of sufficient activity to produce 20,000 cps (±10%) when placed in the scatter phantom. The activities do not require accurate calibration, and vary from 3 to 7 mCi depending on the collimator sensitivity. With the scintillation camera directed horizontally, the scatter phantom is positioned with the surface nearest the test tubes at the face of the collimator, with the test tubes vertical at the center of the field of view. The deadtime determination is carried out as follows with a counting time of 100 sec for each step:

1. Determine the background counting rate in cps.
2. Place source 1 in the scatter phantom and record C_1.
3. Add source 2 and measure the combined sources. (C_{12}).
4. Remove source 1 and measure source 2 only. (C_2).
5. Repeat the above set of measurements in reverse order as a control procedure.

The same elapsed time between the various source measurements should be maintained in order to cancel the effect of radioactive decay as explained below. A set of measurements is shown in Table 1 as an example. As discussed previously (5–7), Huttig has derived an equation to calculate the paralyzing deadtime (τ) from measurements by the two-source method, based on Poisson statistics. We have modified it slightly as follows:

$$\tau\,(\mu\text{sec}) = \left[\frac{2\,R_{12}}{(R_1 + R_2)^2} \ln \frac{(R_1 + R_2)}{R_{12}}\right] \times 10^6$$

where R_1, R_2, and R_{12} are the measured net counting rates in cps from sources 1, 2, and 1 and 2, together. The computation of the deadtime as given by the equation is easily performed on a pocket calculator with natural log functions.

For a stable scintillation camera the forward- and

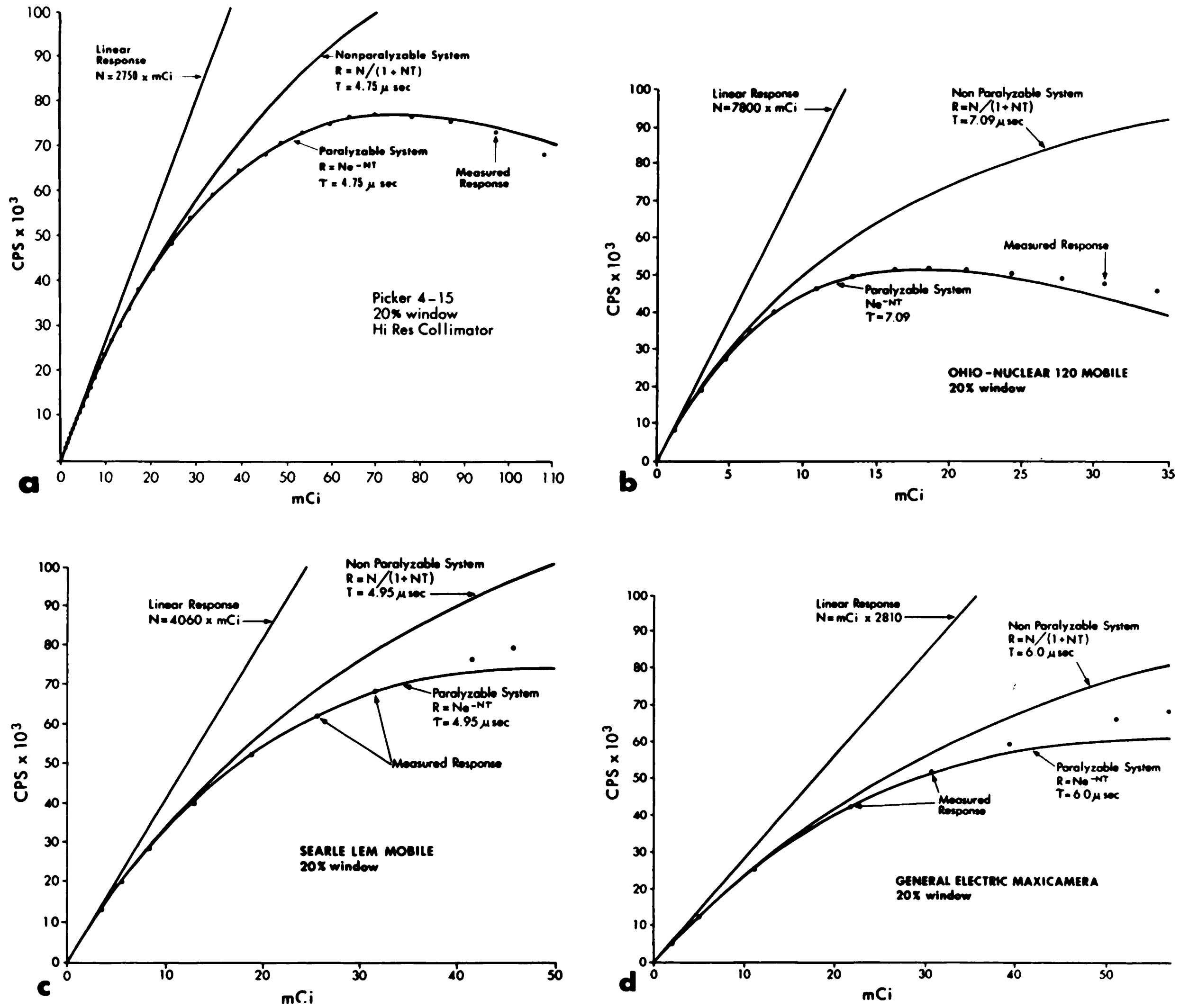

FIG. 4. Output counting rates of four scintillation cameras with increasing Tc-99m activities in scatter phantom of Fig. 3. Picker 4-15 (a) and Ohio-Nuclear (b) cameras give performance nearly identical to hypothetical paralyzable systems. Searle LEM (c) and General Electric Maxicamera (d) give performance essentially identical to hypothetical paralyzable systems throughout clinically useful range of counting rates, but are shown to be semiparalyzable at higher counting rates.

TABLE 1. TYPICAL SET OF DATA RECORDED FROM A SEARLE PHO/GAMMA V*

Source no.	Counts (100 sec)	Gross cps	Net cps	Paralyzing deadtime (μsec)
1	2029928 (C_1)	20299	20292 (R_1)	
1,2	3643837 (C_{12})	36438	36431 (R_{12})	4.75
2	2027023 (C_2)	20270	20263 (R_2)	
2	2020465 (C_2)	20205	20198 (R_2)	
2,1	3610398 (C_{12})	36104	36097 (R_{12})	4.79
1	1998337 (C_1)	19983	19976 (R_1)	
				Av. 4.77

* Background counting rate: 7 cps.

reverse-order measurements should yield identical deadtime values within statistical limits of accuracy. In a typical determination, during which about 2 million counts are acquired from each of sources 1 and 2, and about 3.6 million counts from the two combined, statistical analysis‡ shows the standard deviation of τ to be about 0.7%||.

Radioactive decay will not introduce an error if the protocol is followed carefully so that the elapsed time between the measurements of R_1 and R_{12} is the same as between R_{12} and R_2. Allowing 20 sec for recording the data and for changing the source, the measurement of R_1 will start 2 min before that of R_{12}, and the measurement of R_2 will start 2 min after that of R_{12}. The effects of the two decays cancel because the value of $(R_1 + R_2)$ will be identical to that obtained if it were possible to perform all three measurements simultaneously. If the two elapsed times differ by 1 min, radioactive decay would introduce an error of about 0.5% in the value of τ.

For Anger cameras the measured deadtime is independent of source volume from 0.5 to 10 ml, although a volume of at least 5 ml may be required to evaluate the performance of a combined camera and computer system in order to prevent data overflow.

The paralyzing deadtime is quite sensitive to the thickness of scattering material about the source (Fig. 5), and therefore it is important to standardize the design of the scatter phantom.

The measurement of τ is affected by the width of the pulse-height analyzer window (Fig. 6). For this protocol we use the 20% window width setting on the scintillation camera's control panel. In a quality-assurance protocol such as this one, electronic equipment to calibrate the analyzer window is usually not available.

The centering of the photopeak in the analyzer window also affects the measurement of τ. The deadtime is shortened when more of the Compton scatter pulses are included (Fig. 7). With a Tc-99m source in air, the centering is accomplished using the multichannel analyzer or the photopeak and window displays on the camera, if available; otherwise one must resort to careful adjustment to achieve the maximum counting rate.

The spatial resolution of the collimator has no significant effect on the measurement. With sources that produce about 20,000 cps each with the respective collimators, the same value τ, within statistical limits of accuracy, is observed with a collimator of high resolution as with one of high sensitivity.

Measured values of τ may change slightly with counting rate. We have observed slopes ranging from −0.02 to +0.009 μsec/1000 cps (Fig. 8). This reasonably flat response lends further justification for the use of the paralyzable model as a matter of practical convenience. The fact that the slope may not be zero, however, requires the counting-rate specification in the protocol. If R_1 and R_2 are about 20,000

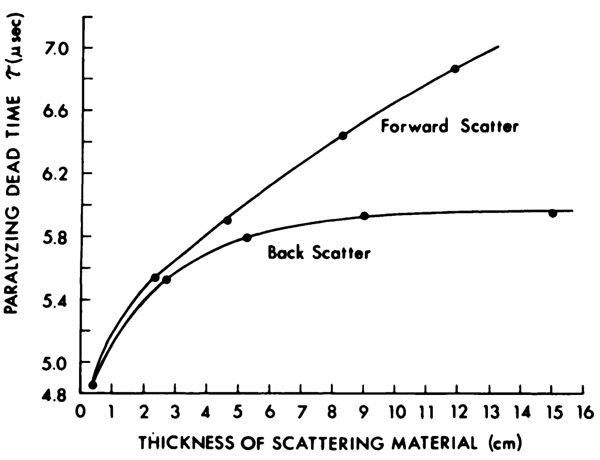

FIG. 5. Effect of thickness of scattering Masonite on measured value of paralyzing deadtime (data from Ohio-Nuclear 120).

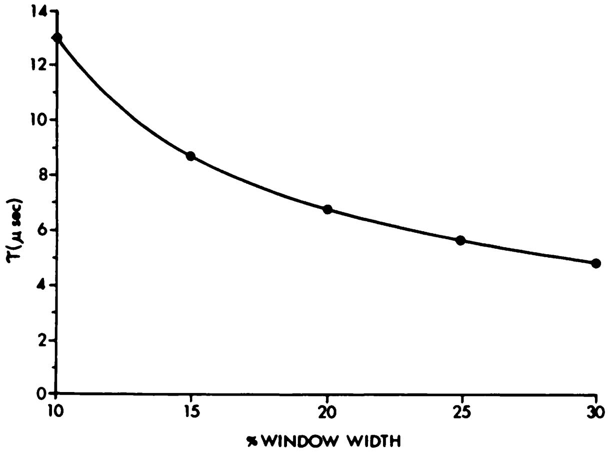

FIG. 6. Effect of pulse-height window width on measured value of paralyzing deadtime (data from Ohio-Nuclear 120).

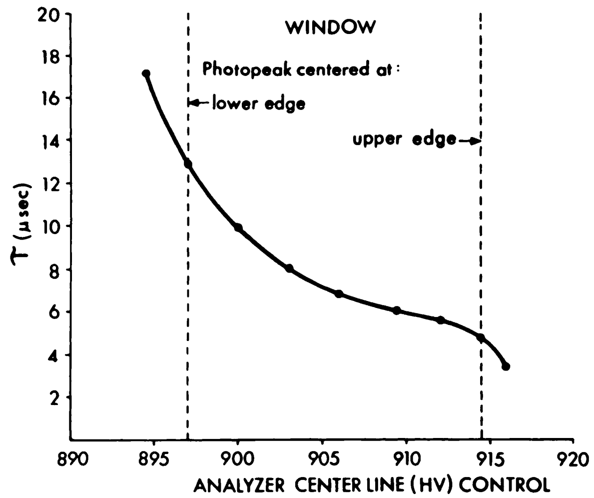

FIG. 7. Effect of photopeak centering in a 20% pulse-height analyzer window on measured value of paralyzing deadtime (data from Ohio-Nuclear 120).

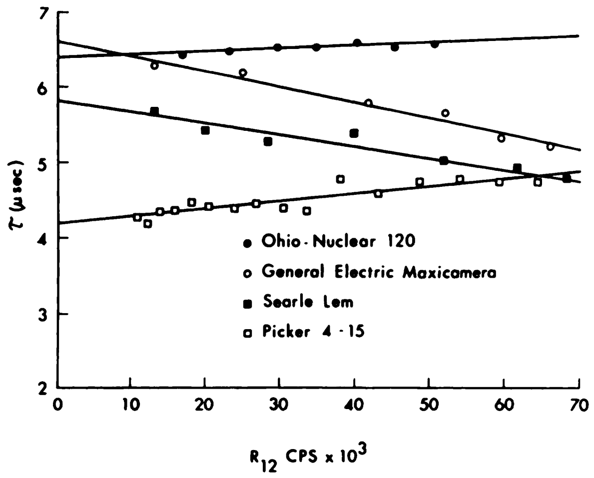

FIG. 8. Effect of varying source activities on measured value of paralyzing deadtime. Slopes of lines (fitted to data by least-squares linear regression) range from —0.02 to +0.009 μsec/1000 cps. Data variations outside statistical limits noted in two of the cameras usually result from short-term camera instability, to which the procedure is sensitive.

cps, R_{12} is usually 34,000–36,000 cps. In the 20,000–36,000-cps range, τ varies not more than 5%. Counting rates from 20,000 to 40,000 cps are usually those of critical concern for most deadtime corrections. At lower counting rates the correction factors are small, and a slight undercorrection or overcorrection is usually not significant. Higher counting rates may incur excessive deadtime losses (Fig. 1).

Survey of deadtime performance of scintillation cameras. Using the foregoing protocol for deadtime measurements, we have determined the paralyzing deadtimes of 39 scintillation cameras of recent design, as well as those of nine older ones (*8*). The results of the survey are summarized in Table 2 and Fig. 9. The survey demonstrated significant variation among instruments of apparently identical models, with no consistent pattern for any of the camera models.

The Searle cameras provide a high/normal rate switch that furnishes a trade-off between spatial resolution and deadtime. In the high-rate position, the paralyzing deadtime is reduced by an average of 1.1 μsec.

It became evident that many instruments were operating below their design optimum. As is to be expected, the deadtime performance of the newer cameras is far superior to that of the older ones. Indeed, with one exception, all the "newer" cameras (listed in Table 2) exhibited deadtimes well below 10 μsec, whereas with one exception the deadtimes of the

TABLE 2. SURVEY OF MEASURED DEADTIME PERFORMANCE

No. of cameras	Manufacturer	Models	Deadtime (μsec) min.	max.	avg.
1	General Electric	Maxicamera			6.2
15	Ohio-Nuclear	100, 110, 120 400, 410	5.7	10.1*	7.7
13	Picker	4-11, 4-12 4-15, Dyna-Mo	4.3	7.6	5.3
10	Searle	Pho/gamma V LFOV, LEM	4.5† 5.2‡	5.4 7.2	4.9 6.0
	Older-generation cameras				
9	Nuclear-Chicago Nuclear-Data Picker	Various types	6.5	29.0	15.6

* With tape-recording system.
† High-rate switch on.
‡ Normal rate.

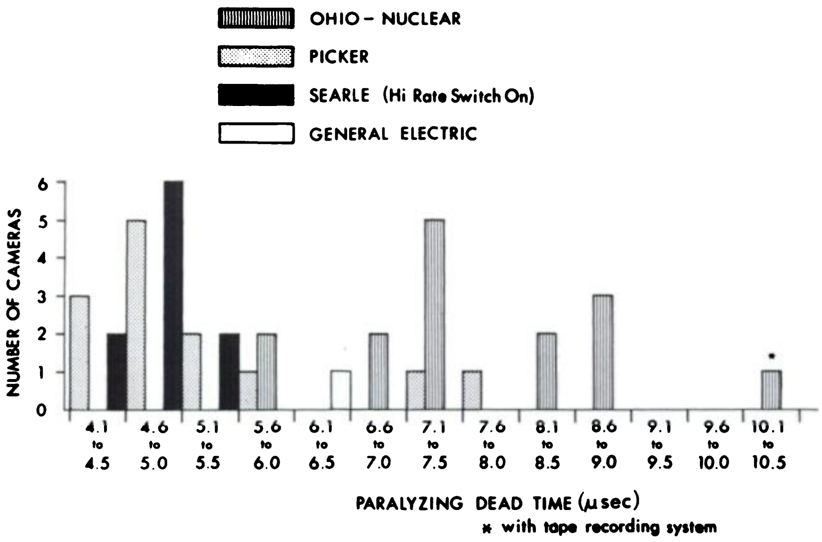

FIG. 9. Results of survey of 48 scintillation cameras for deadtime performance as evaluated by procedure described.

"older" ones were considerably greater than 10 μsec.

Adopting the premise that the maximum clinically useful observed counting rate is one that incurs not more than a 25% data loss, this maximum useful rate performance can be estimated from Fig. 1. The best-performing camera in this series, with a 4.3-μsec paralyzing deadtime, should be limited to an observed counting rate of 50,000 cps; the average-performance camera (6 μsec) to 36,000 cps; and the slowest type of camera (10 μsec) to 20,000 cps.

CONCLUSION

A simple, reliable, inexpensive 15-min procedure has been developed for evaluation of the temporal resolution of scintillation cameras used in quantitative nuclear cardiography. The only equipment needed is a scatter phantom, a calculator with natural log functions, and Tc-99m sources not requiring accurate calibration. We have shown that scintillation cameras in the presence of scatter approximate paralyzable systems and that the values for paralyzing deadtimes obtained with the present procedure can be used to evaluate data losses in a clinical setting. A survey of 39 scintillation cameras of recent manufacture yielded values of paralyzing deadtime ranging from 4.3 to 10.1 μsec, with an average of about 6 μsec. The corresponding maximum clinically useful counting rates are in the range of 50,000 to 20,000 cps if the data losses are to stay within 25%. The advertised achievable counting rates for Anger cameras, of 100,000 cps or more, are beyond the range of clinical application.

FOOTNOTES

* A FORTRAN program to generate deadtime loss data for any specified paralyzing deadtime is available from the authors.

† Ohio-Nuclear 120.

‡ Brenneman, P., personal communication.

|| A FORTRAN program to calculate τ and its s.d. is available from the authors.

ACKNOWLEDGMENT

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