A New Approach to NEMA Scintillation Camera Count Rate Curve Determination

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The method of determining count rate curves suggested by the National Electrical Manufacturers Association (NEMA) is based upon a single reference count rate. Inaccuracies in the reference value are propagated to the rest of the curve values. NEMA also requires the measurement of individual attenuation factors for every absorber. Errors can easily occur during the measurement and during the subsequent calculations which utilize these factors. An alternative approach is suggested: count rate curves are based upon at least five low count rate values and the determination of individual attenuation factors is eliminated. Count rate curves are generated from graphs of the 1n of the observed count rate against the number of equally thick copper absorber plates, by back-extrapolation of a line which is fitted to the linear low count rate data. The method was successfully implemented in practice. Agreement was found between the results of the NEMA method and the alternative method suggested.

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The specification of scintillation camera count rate curves, i.e., graphs of observed count rate against "true" count rate, has the advantage that no assumptions are made about the model according to which the camera functions. Such assumptions are made in the specification of, for example, paralyzable deadtime.

The National Electrical Manufacturers Association (NEMA) requires the measurement of count rate curves, utilizing pre-calibrated copper attenuation plates, as a class standard (*1*). It is necessary to measure the attentuation factors of the copper absorber plates in order to calculate the "true" incident count rates for the count rate curves. The NEMA specifications are vague about this measurement; they only specify "a number of equal thickness copper absorber plates, individually calibrated for attenuation of Tc-99m gammas (approximately 2.5 millimeters thick)" (*2*). The NEMA specifications furthermore state: "The number of absorber plates to produce a background corrected count rate no greater than 2,500 cps shall be determined. From this count rate, knowing the calibration of each absorber and the decay rate of the source, any input count rate can be obtained by removal of a calculated number of absorber plates" (*2*).

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THEORY

Literal interpretation of the NEMA specification of "... absorber plates, individually calibrated for attenuation ...", would imply the measurement of the ratio of the counts registered with and without each copper absorber plate attenuating a low count rate source. The ratio, A, of the counts after attenuation (R) to the counts before attenuation (N) could be regarded as an individual attenuation factor for every copper plate, i.e., for one copper plate (n = 1)

$$N(n{=}0) = A^{-1}\,R(n{=}1). \qquad (1)$$

In general, for any number of copper plates, n,

$$N(0) = A_1^{-1} A_2^{-1} A_3^{-1} A_4^{-1} \ldots\ldots A_n^{-1} R(n)$$
$$N(0) = R(n) \prod_{i=1}^{n} A_i^{-1} \qquad (2)$$

where N(0) = true count rate calculated for n=0 absorber plates, i.e., without absorber plates

R(n) = observed count rate for n number of attenuation plates

A_i = individual attenuation factors

n = number of attenuation plates

The true count rate N(0) of the source without copper attenuation plates can only be calculated from the observed count rate, R, when R is lower than 2,500 cps, i.e., when there are k copper plates. This count rate R becomes a reference count rate, R_{ref}. Thus

$$N(0) = R(k) \prod_{i=1}^{k} A_i^{-1} = R_{ref} \prod_{i=1}^{k} A_i^{-1} \qquad (3)$$

To calculate "true" count rates for the numbers of copper plates between 0 and k, this maximum count rate, N(0), is multiplied by the corresponding A_i for every additional copper attenuation plate added, i.e.,

$$N(1) = R_{ref} \prod_{i=1}^{k} A_i^{-1} * A_1 \quad (4)$$

Generally

$$N(n) = R_{ref} \prod_{i=n+1}^{k} A_i^{-1}, \quad (5)$$

where (N(n) = the calculated "true" count rate N when the source is attenuated by n copper attenuation plates and R_{ref} = the low observed count rate R taken as reference, when the source is attenuated by k copper attenuation plates.

The following problems were encountered with this method as implied by the NEMA specifications. All the calculated true count rates N are based on the value of the reference count rate R_{ref} [Eq. (5)]. Inaccuracies in the value determined for R_{ref} will be propagated to all of the calculated N values. Furthermore, in the computation of N(n) from Eq. (5) one must keep track of the identities of the absorber plates used to achieve a specific count rate R, and the corresponding attenuation factors must be utilized for the calculation of N.

Finally, no filtering of the source used for the individual calibration of the absorber plates is mentioned (*2,3*). Adams reported in 1984 (*4*) that the energy spectrum for technetium-99m (^{99m}Tc) changed markedly when it was attenuated by up to five 1.28-mm-thick copper plates. The spectrum did not change further when more than five copper plates were used. Therefore, at least 5 mm of copper should be used to filter the source before individual copper plates are calibrated.

An alternative approach to measuring individual attenuation factors in order to determine the count rate curves would be to plot the ln of the observed counts, R, against the number of copper plates, n. Because the attenuation of the copper plates obeys an exponential law (*5*), a straight line results. For a thickness of d cm copper or n corresponding attenuation plates, each with thicknesses of x cm copper:

$$R = N \exp(-ud) = N \exp(-uxn) \quad (6)$$

$$\ln R = \ln(N) - uxn \quad (7)$$

The linear attenuation coefficient, u, could be determined from the slope of the graph, and N(0), the number of counts when no copper plates are used, would be the exponent of the Y-intercept. The relation between u and A_i can be found by combining Eq. (2) and Eq. (6):

$$\prod_{i=1}^{n} A_i = \exp(-ud) \quad (8)$$

MATERIALS AND METHODS

The proposed procedure was used to generate count rate curves for a scintillation camera (Searle LFOV scintillation camera, Searle-Siemens Medical Systems, Inc., Iselin, NJ). The experimental method and geometry suggested by NEMA (*2*) were utilized to obtain observed count rates, R, for n number of absorber plates attenuating a ^{99m}Tc source. The technetium source was contained in a glass bottle, which fitted into a lead holder with at least 6 mm lead shielding at the back and sides. The source was positioned at a distance of ~1.3 m in front of the center of the detector. An open scintillation camera was used, with the NEMA edge ring to mask edge effects. The count rate was observed with a 20% energy window, and was corrected for background counts.

Individual attenuation factors were also determined. A ^{99m}Tc source, which was filtered by at least 5 mm copper, was utilized. Count rates were lower than 15k cps.

Graphs were drawn of the ln of the observed counts, R, against n, the number of absorber plates. A mean attenuation factor, A, was determined from the straight line portions of these graphs, according to Eq. (7). When absorbers were utilized for the first time, measurements were performed at low count rates to ensure that the thickness variation among individual absorbers was small enough so that the ln of the observed count rates followed a straight line. Anomalous absorbers were eliminated at this stage. Attenuation factors were determined for 1 and 3 mm copper attenuation plates. These factors were compared with mean factors determined by utilizing Eq. (1). For reference purposes, the linear attenuation coefficient u was also calculated. The thicknesses of the absorber plates, which were necessary for this calculation, were measured with a micrometer for the 1 mm and 3 mm plates. Mean thicknesses were utilized for the calculation of the linear attenuation coefficients, u.

Finally, the results were plotted as count rate curves. N was determined by linear back-extrapolation directly from the previous graphs for the determination of the attenuation. For each (n, ln R) pair, a corresponding (n, ln N) value was determined from the fitted straight line where the observed values, R, started curving.

TABLE 1
Mean Attenuation Factors (A) and Corresponding Linear Attenuation Coefficients (u)

Absorber plate thickness	Attenuation factor, A (calculated)	Attenuation factor, A (graphically)	Linear att. coeff., u* (graphically)
1 mm	0.783	0.787	1.99/cm
	0.791	0.791	1.95/cm
	0.783	0.787	1.99/cm
	0.787	0.788	1.98/cm
Mean	0.786	0.788	1.98/cm
Std. Dev.	0.004	0.002	0.02/cm
3 mm	0.525	0.536	1.92/cm
	0.541	0.535	1.93/cm
Mean	0.533	0.536	1.93/cm

* The calculation assumes values of 1.20 ± 0.02 mm and 3.25 ± 0.02 mm for the thicknesses of the 1 mm and 3 mm copper absorber plates, respectively. These values correspond to coefficients of variation of 1.7% and 0.6%, respectively.

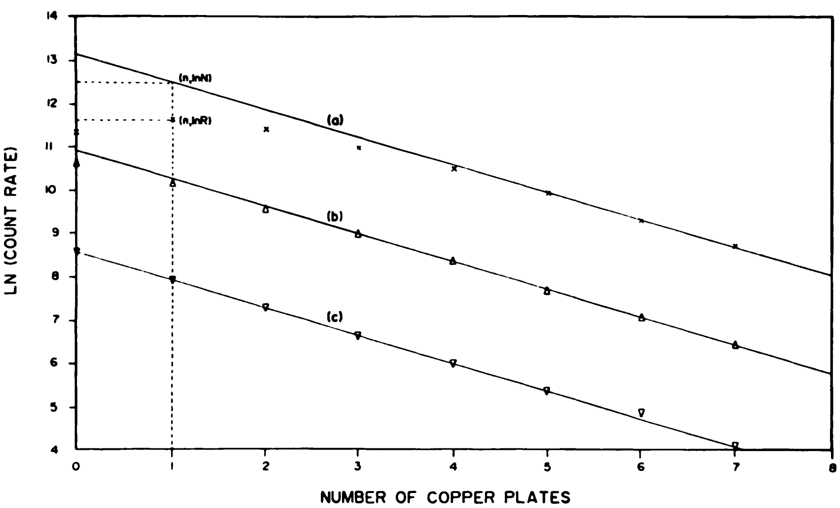

FIGURE 1
Graphs of the 1n of the observed count rate (R) against the number of copper plates (n). Copper absorber plates of nominally 3 mm thickness were utilized with ^{99m}Tc sources. Lines were fitted for the linear regions of the data. Curve(a) illustrates the deviation of the observed count rate points (n, 1nR) from the true incident count rate (n, 1nN) as a result of the scintillation camera deadtime. The deviation is smaller for curve (b), which was measured at lower count rates. Curve (c) illustrates that outliers due to experimental errors can easily be detected, as for the measurement at n = 6.

A line was fitted to the low count rate data in a region where at least five points fall on the line. The slope of this line was used to fit lines for measurements at higher count rate ranges. A sufficient number of copper absorber plates must be utilized to reach a count rate range where at least three points fall on a straight line. Otherwise, the data points at the lower count rates should be corrected from the previous low count rate data in order to fit the line.

RESULTS

Values determined on different occasions for the mean values of the individual attenuation factors by utilizing Eq. (1) are presented in Table 1 for 1 mm and 3 mm copper absorber plates. The corresponding attenuation factors and the linear attenuation coefficients, u, determined graphically from the slopes of the graphs of ln R against n, are also tabulated. Means and standard deviations were calculated for the individually determined attenuation factors as well as the factors determined graphically. The factors determined in these two ways corresponded well. The coefficient of variation of the factors measured with the proposed method was 0.3% for the 1 mm absorbers.

Examples of graphs of the ln of the observed counts, R, against the number of absorber plates, n, are given in Figure 1 for three independent determinations with 3 mm copper absorber plates. Values of R and N determined from curve (a) and (b) of Figure 1 are plotted in Figure 2 as count rate curves.

DISCUSSION

The proposed method assumes that the absorber plates are equally thick. This assumption was met in this case, because the coefficients of variation of the thickness of the plates as measured with the micrometer, were 1.7% and 0.6% for the 1 mm and 3 mm absorber plates respectively (Table 1). Gross differences in plate thicknesses would however be detected quite easily on the graphs of ln R against n during the initial low count rate measurements.

The alternative approach has the following advan-

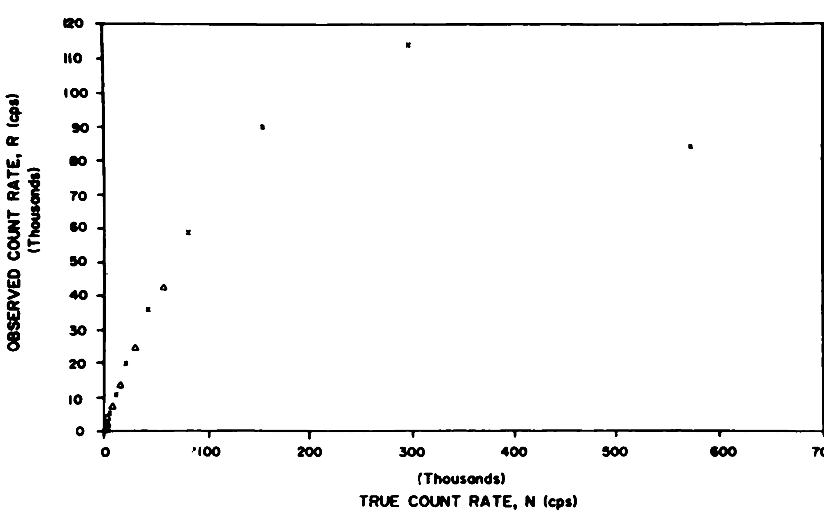

FIGURE 2
Count rate curves calculated from Figure 1.

tages. Firstly, it is easy to determine the region where count rate losses start occurring on the graphs of ln R against n. This is the region where the ln R values start deviating from the fitted straight line [Figure 1, curve (a)]. Outliers due to experimental errors are also detected easily [i.e., Figure 1, curve (c)] and can be excluded. Furthermore, attenuation factors (A) can be determined directly from the measurements for each count rate curve, if necessary. Differences in experimental geometry between that used for the determination of A and for the count rate curve measured, are therefore eliminated. However, for the approach suggested the intermediate determination of individual attenuation factors is unnecessary, because N could be determined directly from the linear graphs.

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