SOURCES OF GAMMA CAMERA IMAGE INEQUALITIES

L. M. Morrison, F. P. Bruno, and W. Mauderli

University of Florida College of Medicine and
Veterans Administration Hospital, Gainesville, Florida

Recently there has been a keen interest in the application of digital-computer techniques to scanning (*1–4*). Although it has not been demonstrated that there is a significant improvement in the diagnostic accuracy of computer-processed scans, computer applications can be extremely useful in studies where quantitative information is desired. These studies might include CSF movement, uptake measurement of isotopes relative to cerebral lesions, and the function of organs such as the lung, liver, and kidney (*5*). We have recently reported on the construction of a system used at our institution for quantitative organ scanning using a small digital computer (*6*). Early investigations of the response of the Anger camera computer system disclosed gross inequalities on quantitatively analyzed crystal floods. These inequalities were considered large enough to require computer correction. The purpose of this report is to record our evaluation of a computer program which was written to correct these inequalities and the various parameters by which it may be influenced.

MATERIALS AND METHODS

The system consists of a PDP-8/I computer with 8K memory, an interface for digitizing and processing data from the camera, a teletype printer-keyboard for input of computer commands, and a high-speed printer for output data. Digital-to-analog converters and an oscilloscope provide a visual display of the data image. The 10-in.-diam crystal of the scintillation camera is currently represented as a 50 × 50 matrix of 2,500 addresses located in the memory of the computer with each matrix entry corresponding to a detector area of 29 mm^2.

A software routine has been written to apply correction factors to all collected data. Correction factors are calculated from data collected when the Pho/Gamma crystal is uniformly irradiated with a suitable source of radioactivity. This procedure will be referred to throughout the text as crystal flooding. The program calculates correction factors in the following sequence.

After 3 million counts are collected and stored in the computer during a crystal flood, the number which is one less than the minimum count in any matrix location representing the crystal is entered into the computer by the teletype. A simple command causes the count content of each matrix location to be divided into this number, location by location. The correction quotient so formed for each location is thus always less than unity, thereby simplifying the software. The computed correction matrix is stored in the memory and is available for multiplication with any subsequent data matrix. The Pho/Gamma camera crystal floods were analyzed to study the various parameters which might affect the correction factor (K). Radiation sources used for flooding were a 3-mCi "point" source of ^{57}Co with a diameter of 0.5 cm and a sheet source with a total volume of 3.3 liter and a 14-in. diameter.

RESULTS

The data are presented by plotting the count profile across the center row of the data matrix with the counts normalized to the center point. The selection of the center row of the data matrix is arbitrary. Analysis of several floods revealed the mean count in horizontal, vertical, and off center rows did not vary by more than 0.1%. These plots will be referred to throughout the text as slices.

Figure 1A shows a horizontal slice through the center of an uncorrected scan which was made with a point source of ^{57}Co and no collimator. Figure 1B shows the same slice after corrections with the com-

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For reprints contact: Walter Mauderli, Div. of Radiation Physics, Dept. of Radiology, University of Florida College of Medicine, J. Hillis Miller Health Center, Gainesville, Fla.

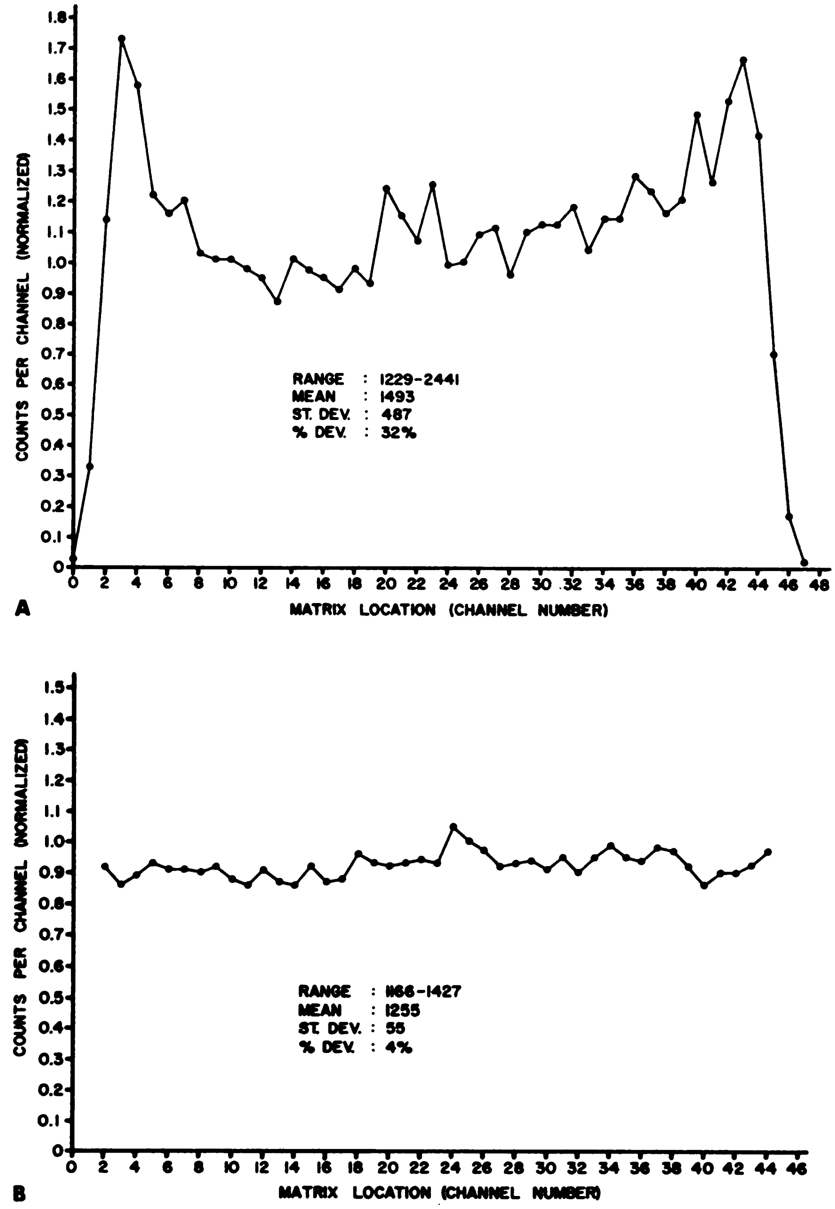


FIG. 1. Count profile across center of Anger camera crystal using ^{99m}Tc sheet radiation source. A is uncorrected data. B is corrected data.

puter program using previously stored correction factors. As seen by these plots, the standard deviation was reduced from 32 to 4%.

A comparison of the two methods of flooding was made by generating correction factors with a sheet source and then correcting with these factors, a sheet source, and point-source crystal flood. Figure 2 is a plot of the center slice from each of the two floods. In the center of the plots, the two do not differ significantly. However, if the extreme ends are included, the two differ by over 10%. This variation is due to the edge effect of the uncollimated crystal during point-source flooding.

When performing large organ scans, it is a frequent practice to use both the straight-bore and diverging collimator. For this reason it is necessary to know if the two collimators produce the same correction factors. A flood made with the diverging collimator was corrected with correction factors generated from a straight-bore flood. A center slice of each is given in Fig. 3 which shows the reduction of image size resulting from the use of the diverging collimator. (Approximately four channels on each end are lost.) The center portions of the slice, however, show similar results.

The effect of spectrometer window width on corrected data was found by correcting floods made with 10, 20, 25, and 35% window widths by correction factors resulting from a flood made with a 20% window. Figure 4 shows slices of the four floods with the 35% window having a slightly higher relative variation but not over 2% from the others.

Since the correction factors are calculated from crystal flood data, an acceptable criterion for flood

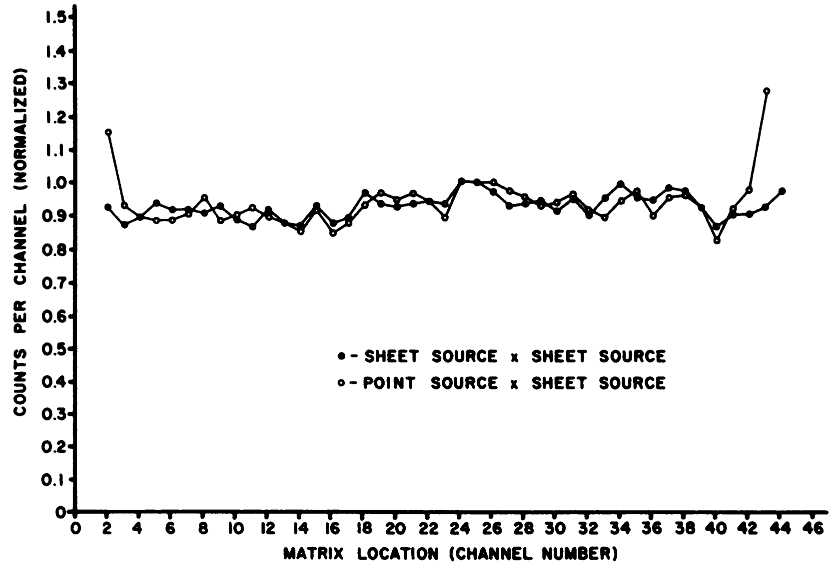


FIG. 2. Count profile across crystal face of sheet and point-source flood corrected by sheet-source data.

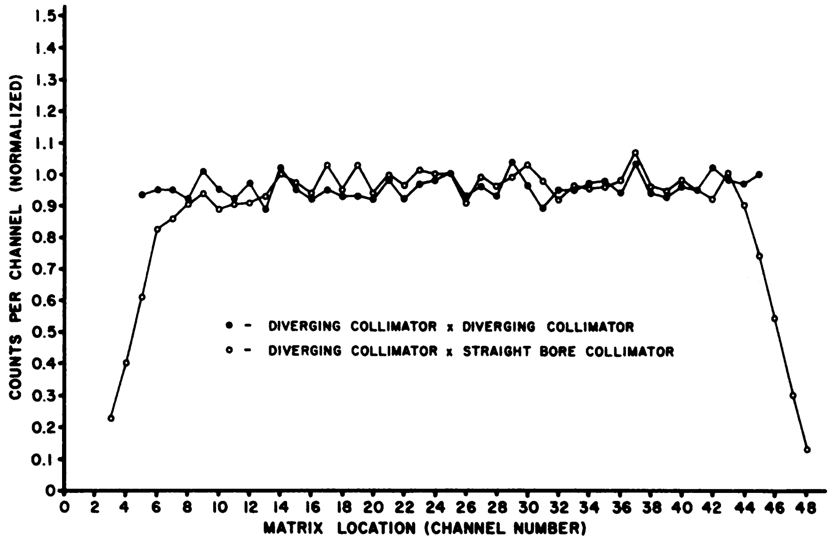


FIG. 3. Effect on count profile by correcting diverging collimator flood with straight-bore and diverging collimator data.

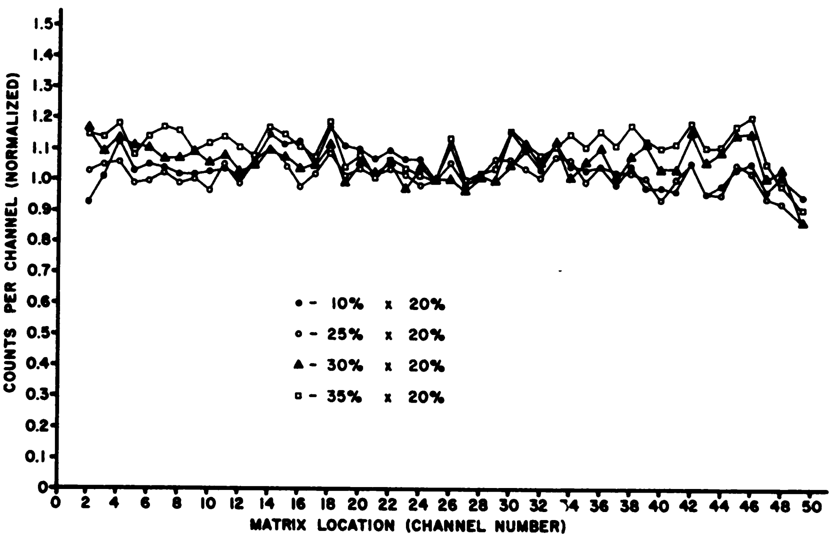


FIG. 4. Count profile across center of crystal floods made with various spectrometer window settings. Data corrected with 20% window data.

conditions should be established. For example, as seen in Fig. 5, there is little or no change observed between floods made with 400,000 and 1,100,000 cpm.

However, with counting rates of 2,000,000 cpm, a reduction in the count of up to 50% is noted in the centermost portion of the crystal.

The stability of the correction factors with respect to time is essential to determine the frequency of flooding necessary in case of clinical applications. Two floods were collected 2 hr apart and then repeated 48 hr later. A flood at 46 hr was used to generate correction factors, and all other floods were corrected with them.

The three corrected floods are given in Fig. 6. The similarity between the three floods is remarkable and was reproducible on subsequent studies. A large number of floods during a single day showed insignificant differences except when a major component, such as a photomultiplier tube, failed.

The fact that crystal response varies with energy is well known, but energy effects on correction factors had not been investigated. Several floods were stored using ^{131}I and ^{99m}Tc in the sheet source and

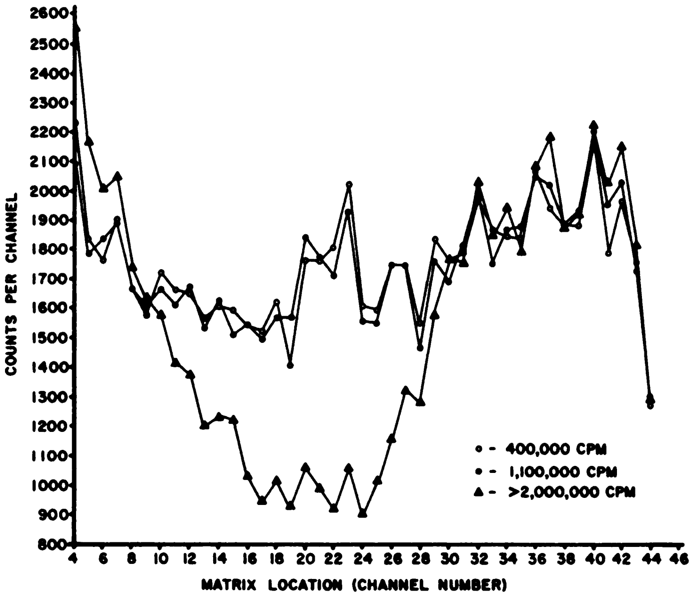


FIG. 5. Effect of different counting rates on count profile across crystal face.

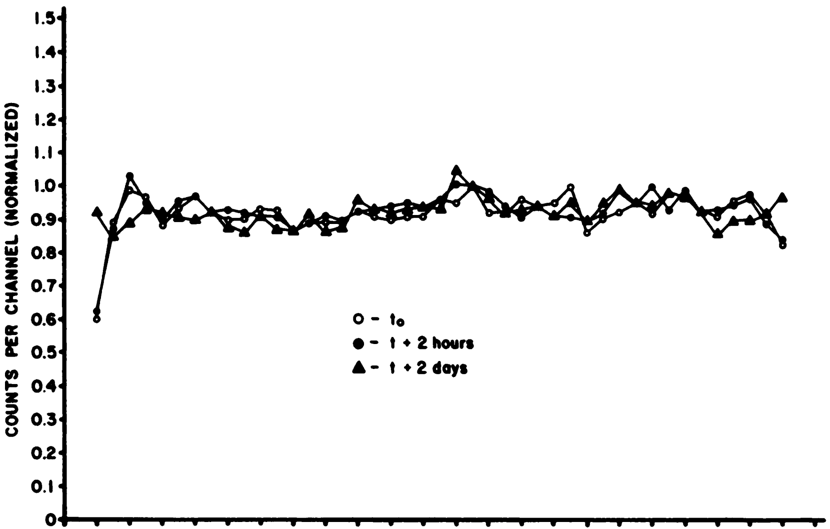


FIG. 6. Count profile across crystal face of three computer-corrected floods over 2-day period.

^{137}Cs as a point source. A ^{131}I flood was corrected with ^{131}I and ^{99m}Tc correction factors. A graph of a horizontal slice of each is shown in Fig. 7. The variations of each are readily apparent.

Response data from four point sources, placed on the crystal face, were used to calculate resolution, system drift, and the crystal area represented by one matrix location. The sources were constructed by casting a lead plug 6 mm in diameter around thin-walled stainless steel tubing 3½ in. long with an outside diameter of 1 mm. These sources were inserted through the holes of the high-energy straight-bore collimator. Each source contained 15–20 μl of high-specific-activity ^{99m}Tc. An array of four of the sources was placed directly on the crystal face, and the distance between the sources were measured accurately. A printout of the computer matrix response to a single source is shown in Fig. 8A. Matrix response data were analyzed on an IBM 360 Model 65 computer to obtain the location and magnitude of the center point of the count distribution assuming a Gaussian count distribution. The center point from the response data of each source was determined using the same method and from these data it was

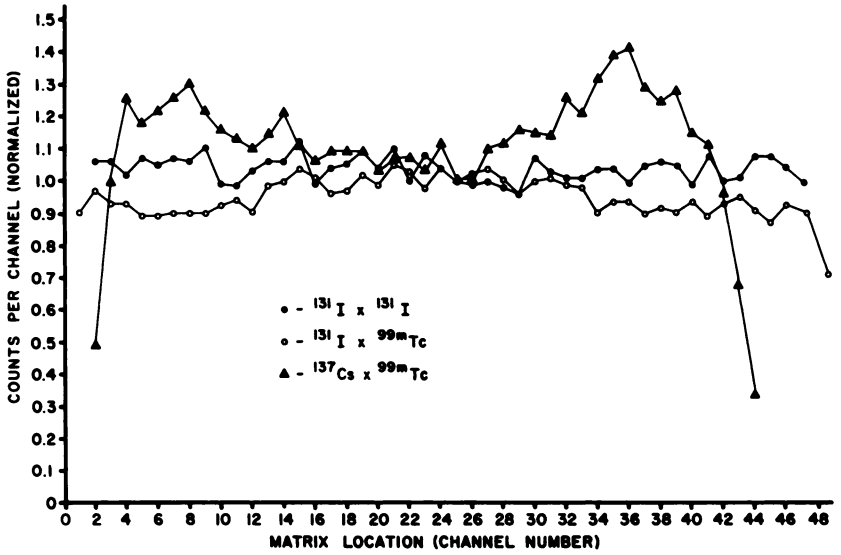
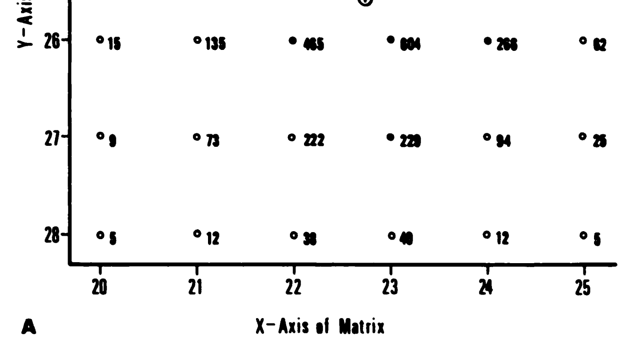
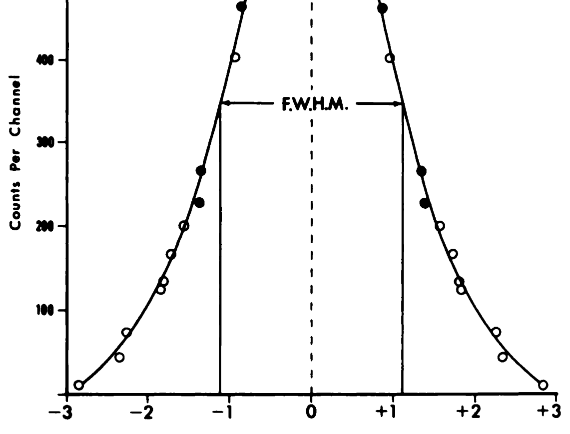


FIG. 7. Variation of count profile with respect to radiation energy.



A



B

FIG. 8. Computer-generated matrix showing crystal response to point source of radiation (A). Plot of distribution obtained from point-source data in A, using computed center point as maximum count, is shown in B.

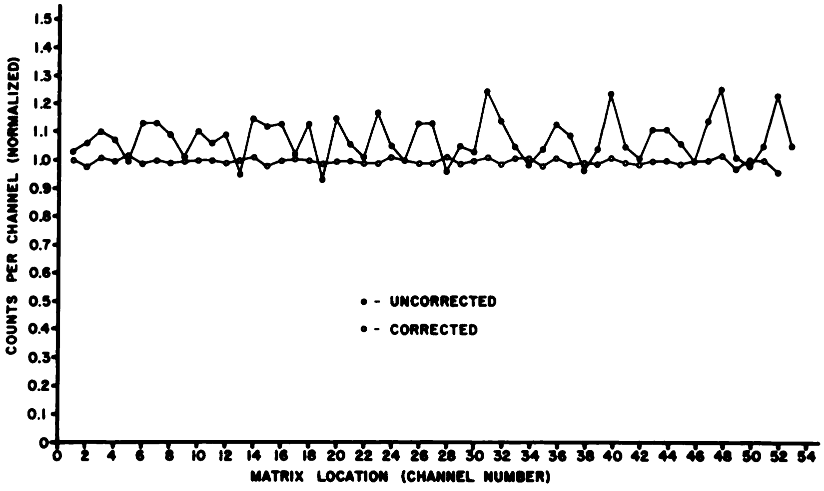


FIG. 9. Inequalities produced by interface in count profile before computer correction of simulated flood. Maximum deviation of uncorrected data was 7% reduced to 1% by computer correction.

determined that one matrix location represented an area of 5.4 × 5.4 mm on the crystal face.

Drift of the computed center points of the four-source array was evaluated over several 6-hr periods. The largest apparent drift observed was 1.8 mm or less than one matrix location.

System resolution was also calculated from the point-source response data using the computed center point. The points around this center point were plotted and the full width at half maximum graphically determined (Fig. 8B). Resolution was calculated to be 2.2 matrix locations or 11.9 mm.

The computer-camera interface was analyzed by making a series of artificial floods. An operational amplifier was used to generate a voltage ramp which was connected to the x- or y-input of the analog-to-digital converter. Z-pulses were obtained from a variable digital clock. A large number of such artificial scans were made at various pulse rates. Correction factors from one ramp were used to correct other scans and the data printed out. A slice from a typical uncorrected and corrected ramp scan is given in Fig. 9. The calculated deviations were 7% for the uncorrected and 1.1% for the corrected ramp scan. The time dependence on these figures was negligible. The fluctuations appearing in the uncorrected scan are caused by the analog-to-digital converter used in this particular interface.

DISCUSSION

The correction factors have proven to be quite effective in reducing system errors. The correction factors are sensitive to certain operating parameters, but these errors can be reduced in most cases. Flooding is best accomplished with a sheet source and collimator since this eliminates the edge effect. However, over most of the detector face, the point flood is equally useful. The correction factors obtained with the straight-bore collimator are accurate when used to correct scans taken with the diverging collimator. The opposite is not true unless only the center portion of the crystal is used. No significant variations were encountered at spectrometer window widths around 20%. It would be advisable to obtain different correction factors when using windows which are more than 10% different.

The counting-rate measurements showed that counting rates above 1,100,000 cpm produce irregularities in the system response. For this reason, counting rates are restricted to less than 1,000,000 cpm.

The study of system variations over a 2-day period indicated that the system is quite stable with respect to time. The results of many floods over a 1-day period do not reveal the need for flooding during periods of less than one day, but routine flooding is recommended on a daily basis. The effect of isotope energy on correction factors was significant and clearly suggests that correction factors must be obtained for each radionuclide used. The scale factors obtained were quite uniform showing point-to-point variations of less than 6%. The time variations were only 1.8 mm maximum which represents only about one-third of a matrix location. The crystal resolution was measured at four points on the crystal, and all had a full width at half maximum of 1.2 cm. The ramp scan studies indicate that most errors resulting from the analog-to-digital conversion are removed with the correction routine.

SUMMARY

Quantitative studies of the system response of an Anger camera represented as a 50 × 50 matrix were carried out with a digital computer. Uniform flooding resulted in variations in matrix elements of

+32%. A simple program was written to correct these inequalities. With the program the variation in the matrix-element response to a uniform flood was reduced to +4%. The dependence of these correction factors on time, isotope energy, spectrometer window width, collimators, and counting rate was investigated. The stability and resolution was also specified as a function of the total system.

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