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IMPROVED RESOLUTION OF THE ANGER SCINTILLATION CAMERA THROUGH THE USE OF THRESHOLD PREAMPLIFIERS

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One of the major limitations of the Anger scintillation camera as it exists today is its limited resolution capability. At the higher gamma-ray energies—for example, the 511-keV gamma radiation emitted after positron decay—the resolution of the camera system is largely determined by the collimator. However, at the lower energies—for example, at 140 keV which corresponds to the gamma-ray energy emitted by the widely used ^{99m}Tc—the system resolution could be improved significantly if the camera had a higher intrinsic resolution. We have therefore investigated the intrinsic resolution limitation in order to improve the device.

THEORETICAL CONSIDERATIONS

The first thorough theoretical analysis of the performance of the Anger camera was performed by Baker and Scrimger (*1*), who investigated and optimized transfer efficiency, linearity, and resolution and came to the conclusion that the camera was already close to optimum for a 19 photomultiplier tube array. Recently, Tanaka, Hiramoto, and Nohara (*2,3*) have investigated the resolution performance in an effort to optimize the position-arithmetic network which combines the 19 signals from the multipliers into x and y coordinate signals. Our efforts have been along similar lines, searching for improved resolution by optimizing the signals from the 19 photomultipliers.

At low energies the resolution of the Anger camera is a strong function of the statistical variations of the signals. For example, let us assume that a gamma ray strikes the crystal and produces a scintillation. All the light can be considered to emanate from a point, at least for low gamma-ray energies. The light spreads in all directions and strikes either a reflecting surface or—after passing through the glass covering the crystal as well as a Lucite lightpipe—strikes the photocathode of one of the 19 photomultipliers. Because of the reflecting surfaces, a large percentage of the total light emitted finally reaches the photocathodes. For a gamma ray with an energy of 140 keV, approximately 5,600 photons reach the cathodes and are converted into approximately 1,100 photoelectrons. The photomultiplier directly over the point of interaction in the crystal receives 33% of this light and yields roughly 360 photoelectrons; photomultipliers around this central one each receive 6% of the light or the equivalent of 66 photoelectrons; the rest is divided among the other 12 photomultipliers (Fig. 1). The number of photoelectrons emitted from each photocathode is subject to statistical fluctuations, as is the amount of light striking the photocathode. These two effects introduce a significant uncertainty into the signals from each photomultiplier. It is this uncertainty in the individual signals which limits the resolution of the Anger camera.

The resolution of the Anger camera as derived by Baker and Scrimger and expanded by Tanaka, et al in the notation of the latter is given by

$$R = \frac{\sigma}{S} = \frac{(\Sigma k_i^2 G_i^2 n_i)^{1/2}}{\Sigma k_i G_i dn_i/dx} \qquad (1)$$

where

- σ is the standard deviation associated with the position signals,
- S is the position sensitivity,
- k_i is the position arithmetic contribution factor for the ith photomultiplier with the source at x,
- n_i is the signal from the photocathode of the ith photomultiplier,
- G_i is the gain from the photocathode to the position arithmetic network of the ith photomultiplier,
- x is the position coordinate in the object space.

While Baker and Scrimger have investigated primarily the effect of variations in the light pipe thick-

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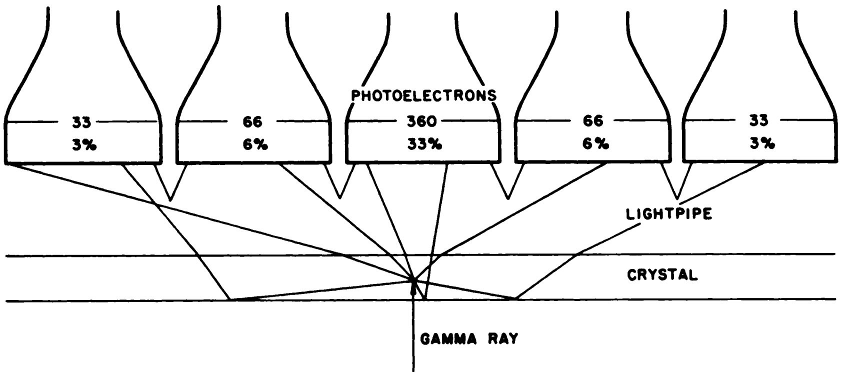

FIG. 1. Light distribution in Anger camera and number of photoelectrons emitted by each photocathode for 140-keV gamma ray.

ness which influences n_i as a function of x, Tanaka, et al have summed the photomultiplier signals using pulse delay and shaping techniques so that the value of R is minimized; we have improved the resolution by modifying G_i.

The resistor matrix used in the camera position arithmetic network is basically a centroid generator. This results in k_i-values which increase linearly with the distance from the point of interaction. Thus photomultipliers which are far from the point of a scintillation in the crystal and which therefore receive a small signal nevertheless have a large influence on the position signal: they influence the resolution through the term $k_i^2G_i^2n_i$ in Eq. 1. The denominator of Eq. 1 is only slightly affected by the contribution from those photomultipliers since in the summation the quantity dn_i/dx is very small for distant photomultipliers. As an example consider a scintillation at the center of the crystal as shown in Fig. 1 in which case the contribution factors k_i become proportional to the distance of the photomultiplier from the center, and the ratio of the k_i for a photomultiplier in the first ring to that for a photomultiplier in the outer ring is therefore approximately 1:2. Using the above approximations, a photomultiplier in the first ring then has n_i proportional to 6 whereas an outer photomultiplier has an n_i proportional to 3. For constant G_i the factors $k_i^2G_i^2n_i$ are then proportional to 6 for a photomultiplier in the first ring but 12 for an outer photomultiplier, despite the fact that it receives only ½ the amount of light. These considerations led us to the realization that photomultipliers which are far from the point of scintillation add more uncertainty to the location of that point rather than aiding in its determination.

EXPERIMENTS

In order to verify the validity of the above conclusion the resolution of an Anger camera was measured digitally at several points: first, with all photomultipliers connected, and then with those photomultipliers disconnected which are far from the location of the scintillations and which therefore produce only small signals. It was found that the resolution (FWHM) improved approximately 15% when these multipliers were disconnected.

The effect of disconnecting photomultipliers far from the point of scintillation in the crystal can be performed as well by preamplifiers with modified input-output characteristics. The preamplifier which would exactly duplicate the action of disconnecting photomultipliers with small signals would be a linear preamplifier with a lower-level cut-off, the gain characteristics of which are shown in Curve A of Fig. 2. It was thought that the sudden step at which signals are either cut off or passed might well introduce nonuniformities in the positional response of the device which would degrade positional linearity. Therefore preamplifiers with the gain characteristics shown in Curve B of Fig. 2 were used.

As a further improvement the charge collection time was increased from 0.4 to 0.8 μsec for all preamplifiers. Since the decay-time constant of NaI(Tl),

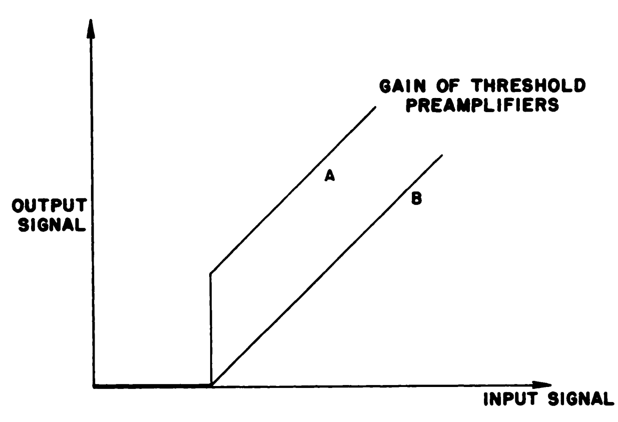

FIG. 2. Gain characteristics of preamplifiers which would correspond to switching off preamplifiers receiving low signals (Curve A) and preamplifiers as constructed (Curve B).

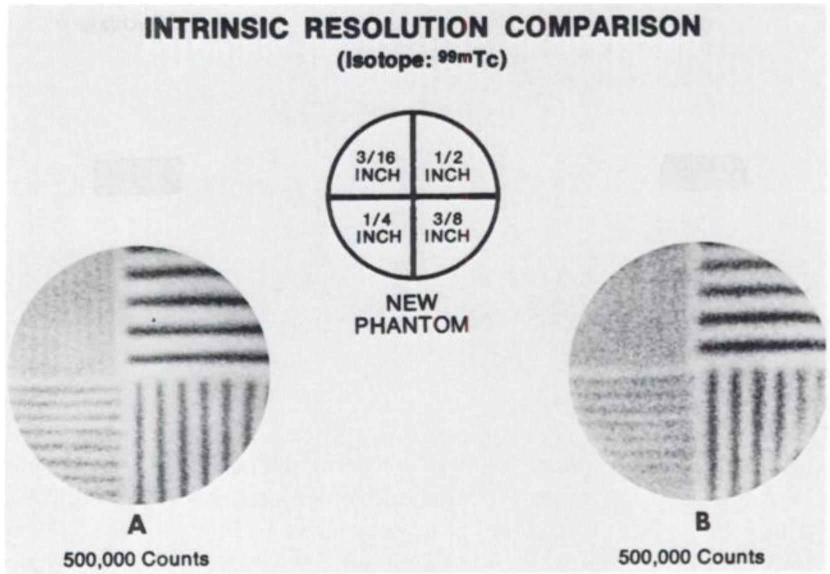

FIG. 3. Resolution of Anger camera (A) with threshold preamplifiers and increased charge collection time, and (B) unmodified, as measured with lead bar pattern.

the scintillator used in the camera, is 0.25 μsec, the longer time constant permits a 96% light collection as compared with 80% for the 0.4-μsec collection time. The resultant improvement in resolution is approximately 10% at ^{99m}Tc energies.

The results obtained with these preamplifiers are shown in Fig. 3. The scintiphotos show images of a lead absorption pattern placed over a ^{99m}Tc sheet source with the pattern placed directly against the scintillation crystal, both with the old and the new preamplifiers. The pattern consists of 0.125-in.-thick lead bars in which the lead bars are ½, ⅜, ¼, and $\frac{3}{16}$ in. wide, separated by an equal distance. It can be seen that the $\frac{3}{16}$-in. bars with the new preamplifiers are as well resolved as the ¼-in. bars with the old preamplifiers, thus illustrating an improvement of about 25% in resolution. This was also confirmed by digital measurements of a line source response function.

SUMMARY

Theoretical considerations of the position arithmetic network of the Anger scintillation camera show that multipliers which are far from a scintillation in the crystal and which therefore receive small signals do not contribute to the accuracy of the position determination but rather reduce that accuracy. Through the use of threshold preamplifiers (which also incorporate a 0.8-μsec charge collection time) small signals are eliminated and the intrinsic resolution is improved by approximately 25% of which 10% is due to the increased charge collection time.

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