Performance Changes of an Anger Camera in Magnetic Fields up to 10 G

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Magnetic fields much larger than the earth's magnetic field can exist many feet away from NMR units. Gamma camera manufacturers already shield photomultiplier tubes from the earth's magnetic field (≈0.5 G). The effects of larger magnetic fields on an Anger camera, were made in fields up to 10 G. Sensitivity and positional stability were studied as a function of gantry angle in a magnetic field. Scans of uniform and hot rod sections of an ECT phantom were also performed. No visible artifacts were found in reconstructions of the phantom measured in a 5-G magnetic field, although some small sensitivity and linearity effects did exist. In 10-G fields, planar and reconstructed images were grossly distorted. Magnetic shielding placed across the collimator reduced the influence of the magnetic field but at a cost in sensitivity that varies with photon energy.

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Nuclear magnetic resonance (NMR) units exist in various research centers, and indications are that these units will be a part of many diagnostic imaging departments in the future. Maps of magnetic field intensity as a function of distance from NMR units have been published (*1*), showing that fields many times the earth's magnetic field can exist well beyond the boundaries of the NMR unit. Magnetic fields affect photomultiplier tubes (PMTs) (*2,3*) and, hence, gamma camera behavior (*4–7*). To evaluate the potential effects on gamma cameras, measurements were made with an Anger camera* in magnetic fields up to 10 G. These measurements are not meant to be an exhaustive study of magnetic effects but should be indications of the performance changes that can be found in these fields.

MATERIALS AND METHODS

Helmholtz Coils and Magnetic Field Strengths

A magnetic field was generated with Helmholtz coils, which had a diameter of 6 ft. These coils were spaced 4 ft apart, farther apart than the ideal separation distance (3 ft) because of the width of the camera housing and the coil supports. Because of this nonstandard separation, the magnetic field strength decreased slightly as one neared the midpoint of the region between the coils. The uniformity of the magnetic field was not important because of the large distortions caused by the orbiter yoke and other sizable ferromagnetic parts.

The magnetic field strengths given in this article were determined from a calibration of the power supply output current and magnetic field measurements made with a Bell Model 640 Gaussmeter. The camera head was extended to maximum radius in the collimator load (180°) position to minimize perturbations of the magnetic field along the coil axis of symmetry. Measurements of magnetic field strength as a function of current were made at the midpoint of the coils' symmetry axis. A given magnetic field was then generated by applying the appropriate current determined from the above calibration.

Choice of Camera and Acquisition Conditions

Magnetic effects were evaluated with a camera having PMTs shielded for the earth's magnetic field. The magnetic shield in this camera extends from the end of the PMT dynode chain, past the photocathode and into the sculptured lightpipe. This provides a large degree of shielding to the photocathode-first dynode area, which is the region most sensitive to magnetic influences.

Three-inch diameter PMTs were used because the effectiveness of the magnetic shielding decreases with increasing PMT diameter. Measurements with these tubes would give more of an upper limit or worst case picture of magnetic influences. Note that cameras using 2-in. diameter PMTs would be less influenced by mag-

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netic fields because the smaller tube diameter would have a more effective magnetic shield.

The magnitude of the magnetic effects will also be affected by choices of acquisition parameters. Probably the most important of these are the size of the energy analyzer window and the choice of either a tune-hold or constant tuning condition for the camera. During measurements, DigiTrac cameras digitally adjust PMT gains relative to a standard tuning matrix to keep the camera properly tuned. This process will be referred to as a "tuning" acquisition mode or, more simply, as "tuning." This process can be suspended, keeping the camera in the latest calibration. This latter condition will be referred to as a "tune-hold" state. Some camera measurements were done with the camera in a tune-hold state, which indicates the worst case or maximum effects of the field. This state also indicates the behavior of the camera in a low-intensity scan where not enough counts are collected to initiate a retuning of the PMTs, as is usually the case in single photon emission computed tomography (SPECT).

The analyzer window was a commonly used setting of 20%. A smaller energy window will amplify sensitivity variations caused by magnetic fields, because the analyzer window would intercept the sharply falling sides of the photopeak as opposed to the tail-region intercepted by the 20% window.

RESULTS

Flood Measurements

A cobalt-57 (^{57}Co) flood source was very firmly attached to a low-energy, all purpose (LEAP) collimator on the orbiter. Measurements in a 10-G field were taken with the camera in a tune-hold state. Selected images are shown in Fig. 1A and show a very strong orientation dependence. The global sensitivity of each image relative to the 0° view was calculated and is presented in Fig. 1B. Note that losses as great as 60 to 70% occur near 90° and 270°. This orientation dependence was attributed to the large ferromagnetic yoke of the orbiter. At 0° and at 180°, the yoke acted as a shunt for the magnetic field lines flowing along the coil axis and kept these lines away from the camera head. At 90° and 270°, the yoke plane was perpendicular to the Helmholtz-coil axis and hence could not redirect the field lines away from the camera head. Inside the camera, the magnetic field would most affect the electrons travelling from the PMT photocathode to first dynode (see Ref. 2 for further information).

The above measurements were repeated for 5, 3 and 0 G, and relative sensitivities for each scan are presented in Figs. 2–4, respectively. The 5-G flood data clearly show sensitivity changes with the maxima occurring near 90° and 270°. The sizable differences in the sensi-

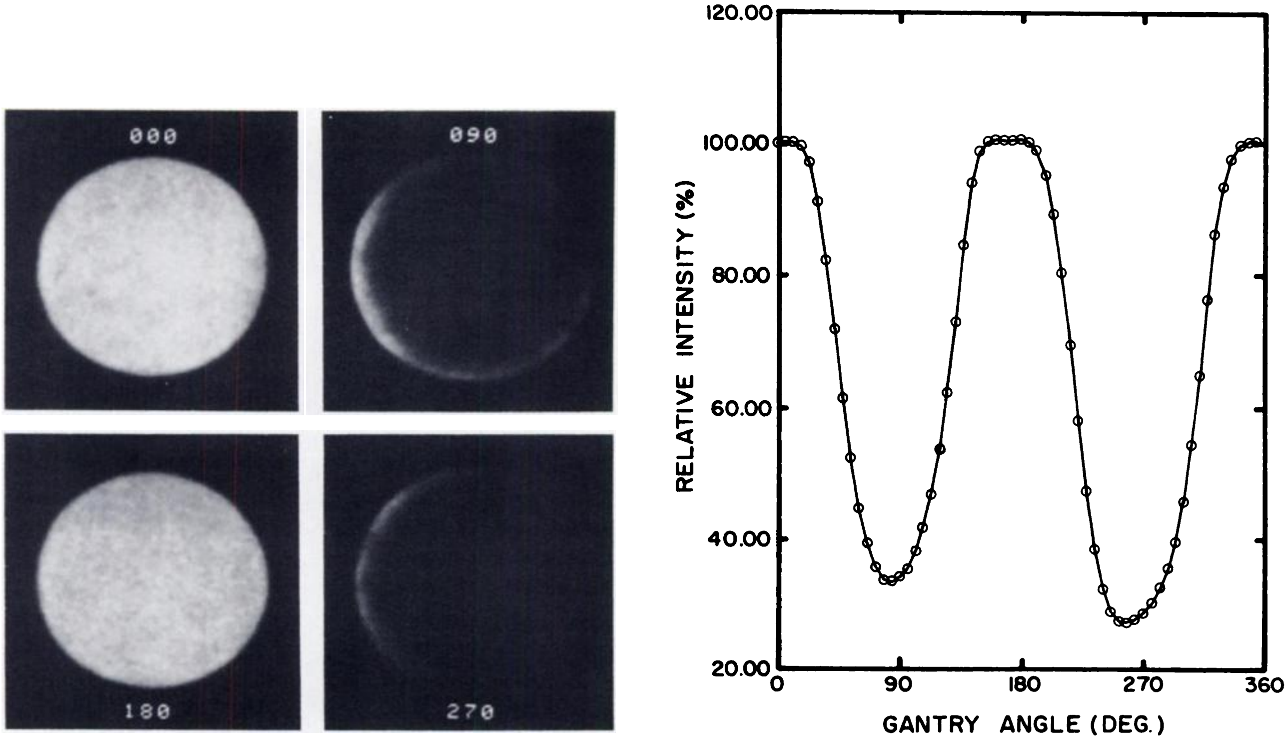

FIGURE 1
Left: Four views of 60-view ECT scan in 10-G field. Flood source was used to illuminate the field of view. Camera was in "tune-hold" state. Right: Sensitivity as function of angle for 60 views in 10-G field

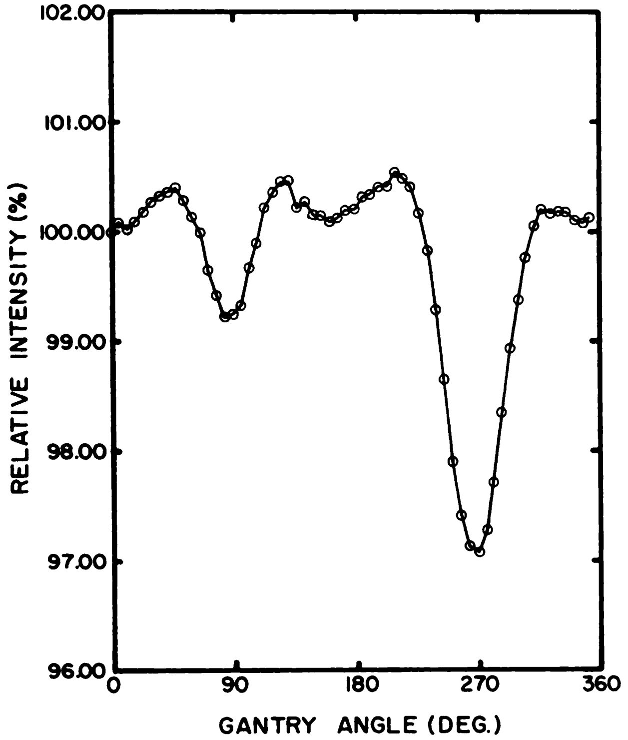

FIGURE 2
Sensitivity as function of angle for 60 views in 5-G field. Camera was in "tune-hold" state

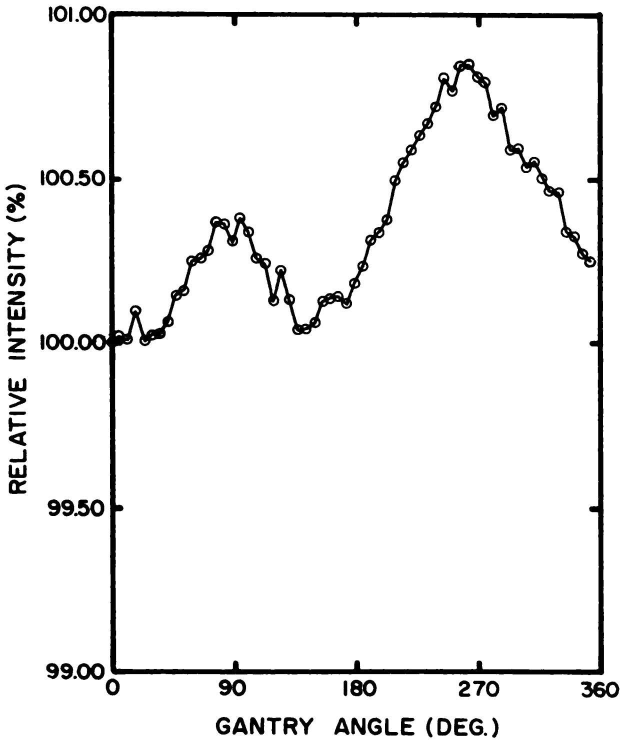

FIGURE 3
Sensitivity as function of angle for 60 views in 3-G field. Camera was in "tune-hold" state

tivity minima at 90° and 270° may be due to the asymmetry of the field and the highly nonlinear response of the camera in the field.

The 3-G data (Fig. 3) show a similar though smaller response, with the largest changes also occurring near 90° and 270°. In this case, the intensity changes are increases rather than decreases in sensitivity. Presumably, these increases are due to the movement of asymmetric photopeak tails in the window while the peak itself is still in the analyzer. The sensitivity decreases seen earlier are due to the movement of significant parts of the photopeak out of the window.

The 0-G data (Fig. 4) show only a very slight (≈0.1%) orientation dependence. This result confirms that the previously observed orientation effects were due only to the magnetic field.

The 3-G measurements were repeated with the camera now allowed to tune to see how this condition would affect the sensitivity changes previously observed at 3 G. The results are shown in Fig. 5. The magnitude of the changes was reduced by a factor of 2 in this case; however, the amount of improvement in general may well depend on the magnetic field strength and details of the source distribution.

Point Source Measurements

Four ^{57}Co sources were placed in a tube and firmly positioned 2⅞" above the surface of a LEAP collimator. The actual point source positions were arbitrarily chosen along an image diagonal. Areas near the center as well as near the edge of the image were examined. A 20% energy analyzer window was used, and the DigiTrac was utilized in a tune-hold state. Scans were taken at 0, 3, 5, and 10 G at a 0-cm scan radius. Sinusoidal fits to the data indicate that the coordinate shifts are ~0.06, 0.24, and 0.48 mm for 0, 3, and 5 G, respectively. Data and fits to one of the four point sources are shown in Fig. 6 as a function of magnetic field strength. The sensitivity loss at 10 G was so large that a centroid analysis could not be performed.

SPECT Phantom Measurements

To determine what effects the above sensitivity and linearity variations have on image quality, several ECT scans of a SPECT phantom† were made. The phantom was assembled with the hot rod insert and a large uniformity section in which one could look for reconstruction artifacts due to magnetic influences. An ultra high resolution (UHR) collimator was used, and the scan radius was ~14 cm. Initially, scans were taken in magnetic fields of 3 and 5 G. These images showed no artifacts, hence additional data were taken at 7 G and at 0 G (as a reference). Slices of the phantom uniform section for the above magnetic fields do not show artifacts that increase with increasing magnetic field. If uniformity artifacts do exist, then they are dominated by the noise of the images.

Figure 7 presents 4.8-cm-thick slices of the hot rod

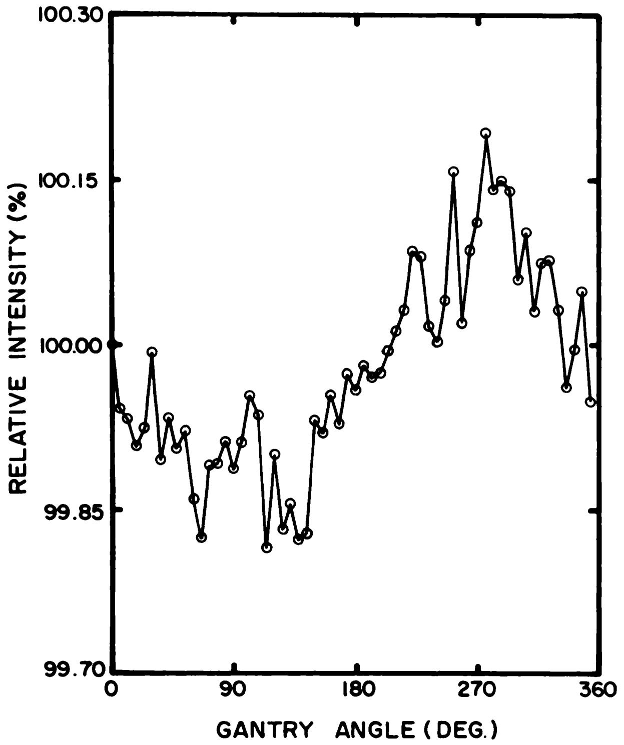

FIGURE 4
Sensitivity as function of angle for 60 views in only earth's magnetic field. Camera was in "tune-hold" state

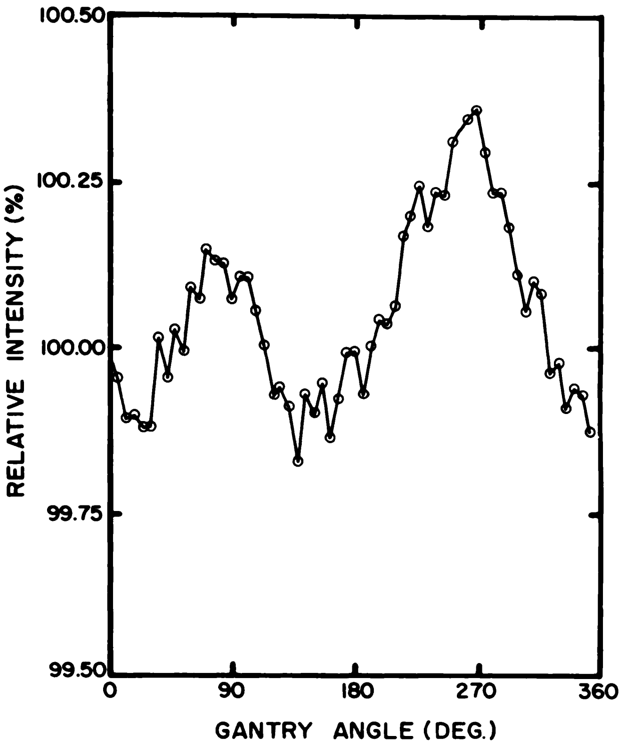

FIGURE 5
Sensitivity as function of angle for 60 views in 3-G field. Camera was tuning during this scan

section for the above cases. The 3- and 5-G images are very similar. Both resolve rods in the fifth (6.4 mm) section and have similar reproduction of rod shape. There may still be effects in individual slices; however, these effects were not visible in the higher statistical noise of an individual (3.2 mm thick) slice. It appears that the effects of the 5-G field on the reconstructed images are negligible in this case.

The 7-G data do show some effects. There is a loss of contrast in the rods of the phantom center, as well as a distortion of the rod-shape relative to the 0, 3, and 5 G cases. In part, these effects are due to lower statistics in this scan. The projection data for the 7 G case do show significant sensitivity losses near 90° and 270°, however, which is definitely a magnetic field effect. The previous point-source data indicate that event positioning is also affected at this field strength. These changes will certainly adversely affect the quality of reconstructions but will not destroy the image entirely.

Data were also taken in a 10-G field. The distortions are much larger (Fig. 1) than those present at 7 G and certainly prohibit measurements of meaningful ECT data.

Measurements with Magnetic Shielding on the Collimator

A sheet of high permeability (μ) magnetic material ~0.33 mm thick was placed over the collimator and additional sensitivity measurements were taken. The attenuation of this material for ^{57}Co photons was measured using a sheet source and was found to be only a few percent. The elemental composition of magnetic shielding varies, but is mostly Ni and Fe. These elements have much smaller attenuation for photons than Pb or other high-Z elements; however, the attenuation for lower-energy photons (e.g., thallium-201 photons) will be higher (~15–20%).

Additional ECT scans of a flood source were run with the DigiTrac in a tuning state. Scans were taken at 7 and 10 G. The magnetic shielding was removed and another scan was taken at 7 G. The unshielded scan had a sensitivity dependence similar in shape to Fig. 1B but with minima of 82% near 90° and 76% near 270°. Using magnetic shielding, a factor of 10 reduction in sensitivity loss was achieved for the 7-G case. The sensitivity for the 7-G scan with the high μ material now looks very similar to the 5-G case without shielding (Fig. 2). This indicates that the reconstructions for these two cases should be similarly free of artifacts.

The sensitivity loss in the 10 G case (Fig. 1B) was reduced with the use of shielding, but only by a factor of 2 instead of 10. Presumably, one could further reduce magnetic effects but at the expense of greater photon attenuation in thicker sheets. The magnitude of this sensitivity loss depends on the photon energy of the isotope of interest. In some cases, however, a high permeability magnetic shield could be a viable remedy.

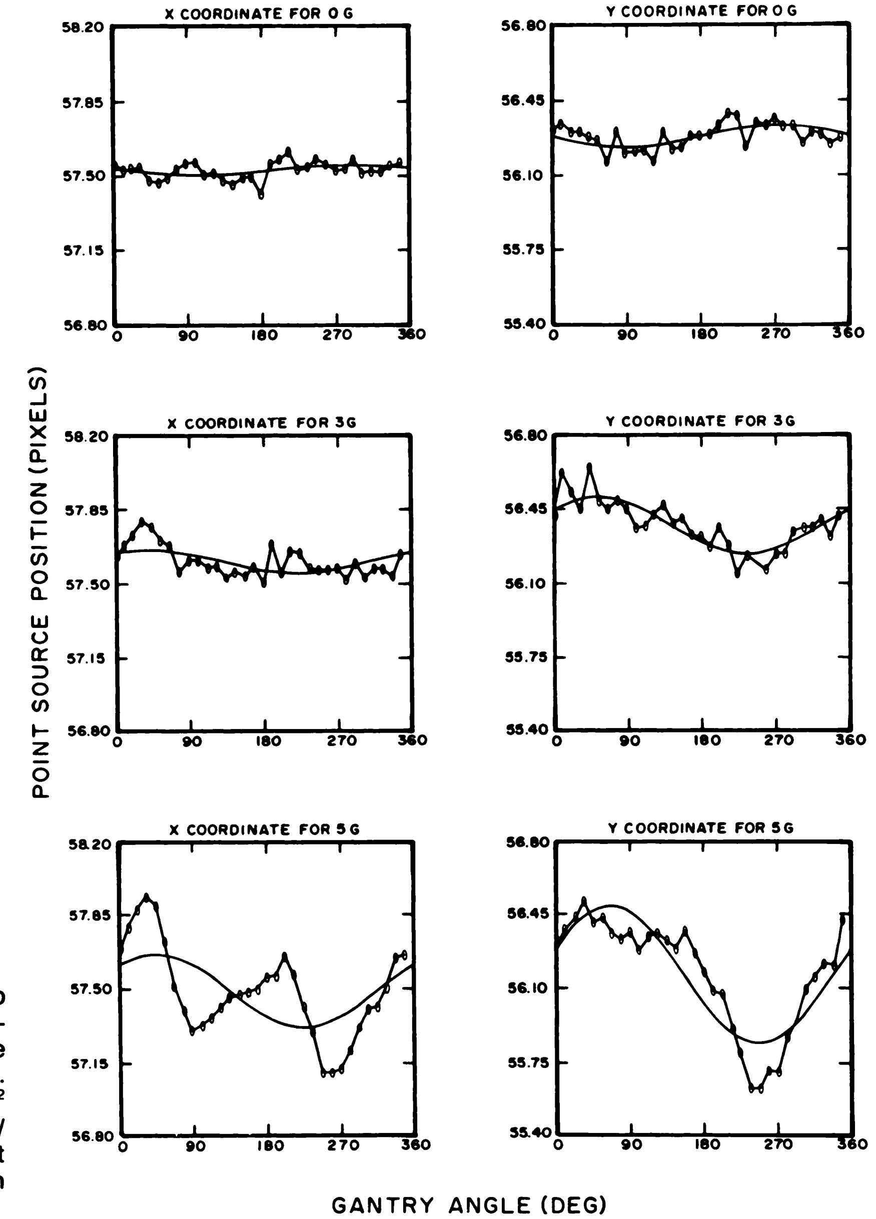

FIGURE 6
Positional stability of one of four ^{57}Co point sources as function of magnetic field strength. Sources were firmly attached to LEAP collimator. Projection data were taken in 256^2 images with digitization of 1.6 mm/pixel. These data were obtained at 32 angles over 360° and were fit with cosine function

CONCLUSIONS

Unshielded ECT and planar imaging should be avoided in a 10 G field. Images can dramatically deteriorate with changing gantry angle. Relative sensitivity losses of ~80% were found during one ECT scan. The severe, angularly-dependent data-loss can be considered as missing data over large angular regions in ECT and, hence, reconstructions cannot reproduce original source distributions in this situation.

Our ECT scans of the SPECT phantom at 5 G appear fine, to the statistical accuracy of our measurements. Sensitivity effects of ~3% exist in the flood measurements at 5 G, however, and quantitative accuracy may be affected in both planar and ECT imaging.

Positional shifts in point source locations exist and increase with increasing magnetic field strength. Measurements made with the camera in a tune-hold state indicate shifts of approximately 0.2 to 0.5 mm in the x and y components of point source positions with a field of 5 G. These shifts did not produce visual artifacts in our measurements; hence, it appears that one can operate in fields up to 5 G. This limit should increase for a camera less susceptible to magnetic influences (e.g., a camera with shielded 2-in. PMTs).

An external magnetic shield reduces the effects of a magnetic field. The amount of improvement depends on the magnitude of the magnetic field; however, the shield also reduces sensitivity by photon absorption. The amount of this reduction depends on the energy of the photon of interest and on the shield thickness.

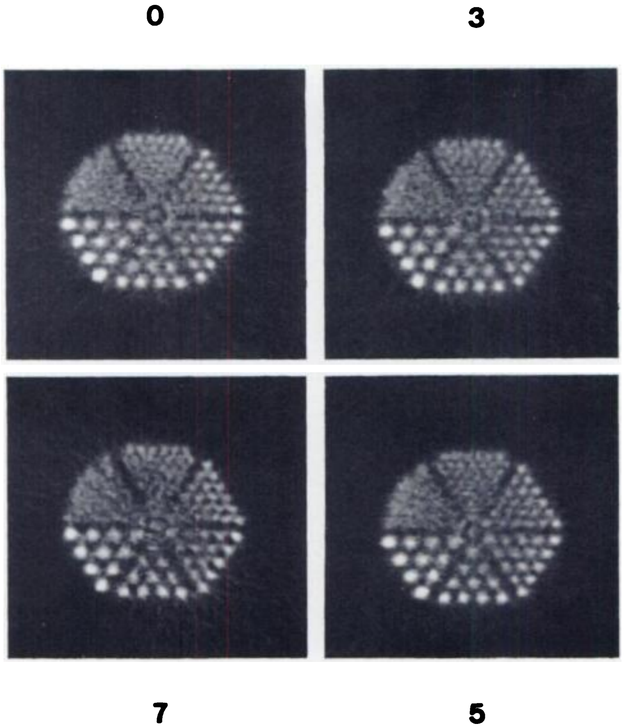

FIGURE 7
4.8-cm slices of hot rod insert of ECT phantom for 0-(1.15*M* cts), 3- (1.16*M* cts), 5- (1.18*M* cts), and 7- (0.83*M* cts) G fields

FOOTNOTE

*Searle-Siemens Medical Systems, Inc., Iselin, NJ. (Siemens, Digi Trac 3700s Orbiter).

†Data Spectrum Corporation, Chapel Hill, NC (SPECT Phantom).

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