GAMMA-RAY CAMERA USING A COAXIAL GERMANIUM DETECTOR

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The use of lithium-drifted germanium detectors for imaging organs in vivo offers numerous advantages over NaI(Tl) detectors. Ge(Li) detectors have an energy resolution which is about 25 times better than NaI(Tl) at 140 keV (^{99m}Tc), thus paving the way for improving the performance of existing imaging techniques as well as making new techniques feasible. The clinical benefits of Ge(Li) detectors to isotopic organ imaging have been shown by Hoffer, et al (*1*) and Brill, et al (*2*). The main contributions of these detectors lie in the following areas:

1. Rejection of gamma rays that are even slightly degraded by scattering in intervening tissue. The resulting improvement in image contrast is particularly significant when using a monoenergetic isotope such as ^{99m}Tc for imaging "cold" lesions in deep-lying organs which do not move during respiration.
2. Improving the peak-to-background ratio of low-energy peaks in the presence of higher energy lines. This feature assumes an important role when the low-energy peak is contaminated by the underlying background produced by scatter from higher energy gamma rays emitted by another radionuclide or by the same one as in ^{67}Ga (92, 182, 296 keV).
3. Resolving closely spaced energy peaks due to different isotopes. This provides for imaging with multiple isotopes such as ^{75}Se (136 keV) and ^{99m}Tc (140 keV) or rejecting fluorescent x-rays (73, 75, 85, 87 keV) emanating from the lead collimator when using low-energy isotopes such as ^{67}Ga (92 keV).

The great potential of high-resolution semiconductor detectors in nuclear medicine stimulated the application of these devices to new gamma-ray cameras. Parker, et al (*3*) and McCready, et al (*4*) developed a camera using a grooved planar Ge(Li) detector. We are currently developing a new gamma-ray camera using a coaxial Ge(Li) detector. Due to present efficiency limitations the new Ge(Li) camera is not envisioned as a substitute for existing imaging devices but rather as a complementary tool to be used where the virtues of a Ge(Li) detector can benefit diagnostic procedures.

DESCRIPTION OF CAMERA

The basic concept of the new camera is shown schematically in Fig. 1. Slots parallel to the detector axis are machined in the outer n-layer contact of the crystal thereby producing effectively independent

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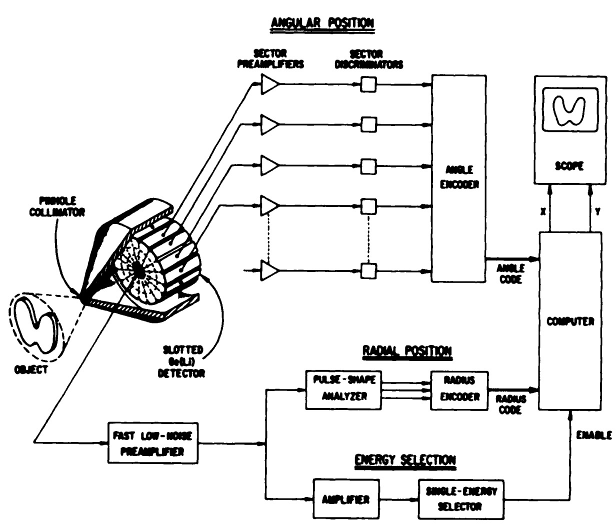

FIG. 1. Slotted coaxial Ge(Li) gamma-ray camera. Gamma rays emanating from viewed object are focussed on Ge(Li) detector by pinhole collimator. Radial location of gamma-ray interaction is determined by pulse-shape analyzer and angular position by one of sector preamplifier-discriminator sets. Pulse-height analysis is performed in single or multiple energy selector. Position signals corresponding to selected gamma-ray energies are stored in small computer which transforms polar coordinates into Cartesian coordinates and displays image on x-y oscilloscope.

pie-shaped sectors*. A simple preamplifier is connected to each sector. The sector preamplifier-discriminator that is activated due to a gamma-ray interaction in the detector specifies the angular position of the interaction. The radial location of the interaction is determined by pulse-shape analysis of the signal from a common broadband low-noise preamplifier connected to the p core. Thus with an appropriate collimator the spatial distribution of radiation intensities is determined in polar coordinates. Pulse-height analysis is performed in a single or multiple energy selector. Position signals corresponding to the selected gamma-ray energies are stored in a small computer which transforms the polar coordinates into Cartesian coordinates and displays the image on an x-y oscilloscope.

The angular and radial responses of a coaxial detector have been studied with a 1-mm collimated beam of gamma rays from ^{57}Co. The current pulses corresponding to 122 keV were photographed as a function of the beam position along the radius as shown in Fig. 2A. The waveforms are distinctly different at each of the positions shown (2.5 mm apart). Thus A and B rise with a shoulder on the leading edge of the pulse, while E and F fall with a shoulder on the trailing edge. Pulse D rises faster than C, but both decay in equal times—a time governed by the response of the pulse-shaping circuits. The theoretical waveforms have been calculated and plotted. They appear to be in good agreement with those observed experimentally (Fig. 2A).

Circular scans of a coaxial detector with four slots† have been made with the 1-mm collimated beam parallel to the detector axis. Several such scans were made at different radii with beam positions 1 mm apart. The relative intensity of the 122-keV line as a function of angle obtained from each sector preamplifier-discriminator for one such scan is shown in Fig. 2B. When the beam is aimed at a given sector, the preamplifier-discriminator of that sector produces an output, thus indicating the sector in which the interaction took place. When the beam is on the boundary zone between two sectors, two preamplifiers are activated. Inter-sector coincidence logic will be provided to recognize such events and display them accordingly.

The principle of operation outlined above limits the gamma-ray energies for which the camera is useful. Gamma rays interacting in the detector by the photoelectric process create charge which is

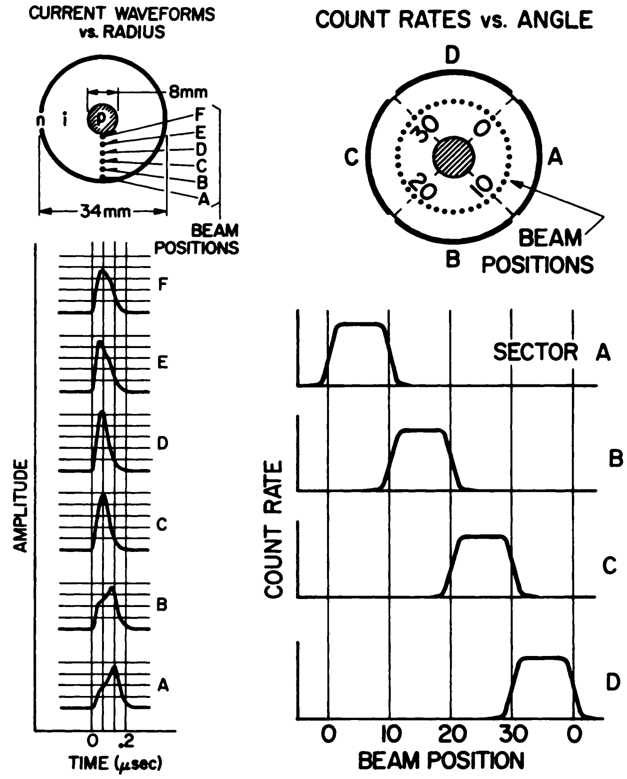

FIG. 2. Position response of coaxial Ge(Li) detector to 1-mm gamma-ray beam from ^{57}Co (A, B). A shows current pulses corresponding to 122 keV obtained at different beam positions (2.5 mm apart) along radius. Note that pulse shapes are distinctly different at each position. B shows relative intensities of 122-keV line obtained from each sector preamplifier-discriminator when beam was moved around face of detector with four slots. Note that preamplifier-discriminator corresponding to position of beam is one that is activated, thus indicating sector in which gamma rays interacted.

highly localized. Pulses corresponding to such gamma rays usually activate only one sector preamplifier and produce a pulse-shape characteristic to the radius at the point of interaction. When the gamma ray is Compton scattered before being absorbed by the photoelectric process, two sector preamplifiers may sometimes be activated and the p-core pulse may sometimes have a composite shape corresponding to two different radii. This in turn will degrade the spatial resolution unless the range of the scattered photon is short and the scattering angle is in the forward direction. In germanium the photoelectric cross section is about 75% of the total at 100 keV, 50% at 150 keV, and 30% at 200 keV. Gamma rays of 200 keV scatter largely at 45 deg off the forward direction and have an average range approaching 1 cm. Thus above 200 keV the usefulness of this camera is likely to be rather limited.

Electronic noise from the center preamplifier distorts the signals going into the pulse-shape analyzer. Thus with the beam directed at any given radial location the individual pulses deviate somewhat from the characteristic shape. At decreasing gamma-ray

* Divided Ge(Li) detectors were first used for Compton spectrometers by Gruhn, et al (*5*) and Kraner, et al (*6*).

† The slotted detector was made by H. W. Kraner of Brookhaven National Laboratory.

energies the fraction of events with poorly determined coordinates increases. Our observations indicate that the spatial resolution will not be appreciably degraded at energies above 75 keV.

Since each detector sector is pie-shaped, the area of each picture element and therefore the counts within a sector increase as the radius increases. On the other hand, we (*7*), as well as others (*8,9*), have observed that the full-energy peak efficiency decreases as the radius increases. Although we are hopeful that this nonuniformity of detector response can be reduced, we doubt that it can be eliminated entirely. Thus we envision that each picture element will have an associated equalizing factor in the computer which will compensate for the element size and detector nonuniformities.

The shape of the sector also affects the spatial resolution. The sector width near the periphery of the detector is the limiting dimension. As the sector gets narrower the spatial resolution improves until the sector is so narrow that an increasing number of single events register in more than one sector. Coincidence logic will recognize the latter events and will display them accordingly.

DISCUSSION

In the prototype camera we intend to use a detector with an outer diameter of about 5 cm, a core diameter of 1 cm, and a thickness of 1–2 cm. Such a detector will have a sensitive area of about 19 cm^2 and core area of 0.8 cm^2 (4%). In a later model we hope to increase the outer diameter to 7.5 cm which corresponds to a sensitive area of 42 cm^2. Assuming a spatial resolution of 3 mm with a Ge(Li) detector and 11 mm with NaI(Tl), a camera with a 7.5-cm diam Ge(Li) will have approximately as many picture elements as a 28-cm diam NaI(Tl) used in an Anger camera. Since each picture element in a Ge(Li) usually subtends a smaller solid angle than that in NaI(Tl) and germanium is generally a less efficient gamma-ray absorber than NaI(Tl), for equal statistics the counting time with a Ge(Li) camera will be longer than with an Anger camera. However, the extra counting time is not as long as may at first be suspected. In order to reduce the effect of scatter with NaI(Tl) systems, a substantial fraction of the peak events may have to be rejected (*1,10*), whereas with a Ge(Li) detector virtually the entire peak is usable. Furthermore when polyenergetic radionuclides (e.g., ^{67}Ga) are used, the efficiency of a Ge(Li) camera is enhanced by its ability to use more than one peak. In addition, the sensitive area of a Ge(Li) camera can be further increased by combining several crystals into a scanning one-dimensional array or a stationary two-dimensional configuration.

The p core in the center of a coaxial Ge(Li) detector is a dead region. Although the area of that region is small, it constitutes a blind spot. If this is likely to result in a loss of diagnostically important information, the second picture to be taken can be made to overlap the dead region.

CONCLUSION

The coaxial geometry provides Ge(Li) detectors with a number of features which make these devices particularly attractive for use in gamma-ray cameras:

1. Large-area coaxial detectors inherently have low capacity (e.g., a 20-cm^2 × 1-cm detector has a capacity of only 5 pF). Since only one high-performance preamplifier is required, it can easily be operated at cryogenic temperatures. The combination of a low-capacity device and a low-noise preamplifier will yield high-energy resolution which can be of great importance when imaging with more than one gamma-ray energy.
2. A camera system using a coaxial detector minimizes the number of duplicate components without compromising on performance. It requires only one high-performance preamplifier, n low-cost sector preamplifiers (n = number of sectors), and no more than one single-channel analyzer per gamma-ray peak used.
3. At present, large area coaxial detectors (1–2 cm thick) are more economical and more readily available than comparable size planar detectors.

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