Title
VISUALIZING TECS DISTRIBUTION OF GAMMA-RAY AND POSITRON EMITTERS

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ABSTRACT

The principle of operation of the scintillation camera, a sensitive type of pinhole camera for gamma rays, is described. Scintillations occurring in a large flat sodium iodide crystal are detected by a bank of 7 or 19 phototubes, and then are reproduced as flashes on a cathode-ray tube. The flashes are photographed over a period of time and yield a picture of the distribution of activity in a subject. This instrument has been used for some time to visualize the uptake of I^{131} in the thyroid gland.

The positron camera, a specialized version of the above instrument, utilizes a gamma-ray counter placed on the opposite side of the subject and coincidence circuitry. The pinhole aperture is no longer required. An instrument of improved sensitivity and definition is then obtained.

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One well-known method of showing the distribution of gamma-ray-emitting isotopes is by scanning. Another method is to amplify the light produced in a mosaic of scintillator crystals in an image-intensifier tube. A third method is by means of the gamma-ray scintillation camera. This instrument, and the positron camera, are the subjects of this paper.

In the gamma-ray camera, a pinhole aperture is situated in a lead camera body so that it projects a gamma-ray image of the subject onto a large, thin sodium-iodide crystal. The crystal is viewed by seven photomultiplier tubes arranged with six of the tubes in a circle and the seventh in the center. The tubes are spaced about an inch above the crystal. When a scintillation occurs, the light divides among the phototubes in ratios depending on the location of the scintillation in the crystal. Each phototube yields a pulse proportional to the amount of light it receives. The pulses from the phototubes are converted into X- and Y-axis deflection signals, which indicate the position of the scintillation in the crystal. These signals deflect the beam of a cathode-ray tube to the point corresponding to the location of the scintillation, and then the cathode-ray beam is turned on momentarily. The scintillation is reproduced as a flash on the cathode-ray-tube screen. A pulse-height selector is provided to reject scintillations not falling within the photopeak of the pulse-height spectrum of the isotope used. The flashes on the oscilloscope are recorded by time exposure of a photographic film, usually Polaroid Land film, and an image of the distribution of activity in the subject is obtained.

The scintillation camera has a number of advantages over other methods. There is no line structure to the image, since scanning is not employed. It is concurrently sensitive to all parts of its field of view, and thus can show the distribution of isotopes with rapidly changing distribution or short half-lives. It can be readily adapted to taking time-lapse motion pictures of dynamic processes.

Remote viewing and recording are quite feasible. When the pulse-height selector is adjusted to the photopeak of the most energetic gamma-ray present, gamma rays that have been scattered through a large enough angle are rejected, whether the scattering occurs in the subject or in the camera body, since the gamma rays will have been degraded in energy before they reach the crystal. The pulse-height selection also reduces background due to cosmic rays and stray radiation.

A sectional view of the camera is shown in Fig. 1. The camera housing is lead, and the pinhole aperture is tungsten or platinum for high stopping power at the edges of the aperture. The thallium-activated sodium iodide crystal is above the aperture. It is a single solid crystal backed with magnesium oxide to reflect maximum light. The bank of seven photomultiplier tubes is about an inch above the crystal. The tubes are a minimum distance apart and the areas between the photocathodes are covered by white reflecting surfaces. The outermost reflecting surface, near the edge of the crystal, is polished aluminum. The space between the crystal housing and the phototubes is filled with fluid for better optical coupling.

A block diagram of the electronic circuit is shown in Fig. 2. A pulse signal indicating the position of the scintillation along the X axis of the crystal is obtained by adding signals from the right-hand phototubes, numbers 3, 4, and 5, and subtracting from this the signals from the left-hand phototubes, 1, 2, and 6. Similarly, the Y signal is obtained by adding the signals from upper phototubes 2 and 3, and subtracting those from the bottom tubes, 5 and 6.

These signals are amplified and applied to the X- and Y- deflection input terminals of the oscilloscope. A third signal, the Z signal, is obtained by adding equally the signals from all the phototubes. Then scintillations of equal brightness produce pulses of equal height regardless of where they occur in the crystal. The Z signal is amplified and fed to the input of the pulse-height selector, which is usually set to the photopeak of the isotope being used. The output of the pulse-height selector goes to a shaper-and-delay circuit, which shortens the pulses and delays them so that they coincide with the peaks of the X and Y positioning signals. The shortened pulses are then applied to the intensity input of the cathode-ray oscilloscope, where they turn on the beam momentarily and reproduce the desired scintillations.

Sensitivity and Resolution

The inherent resolution and linearity of the crystal and phototube combination were determined experimentally in the following way. Fifteen gamma-ray beams, each about 1/8 in. in diameter, were directed at the crystal from holes in a block of lead, as shown in Fig. 3. The sources in the central part of the pattern were 1/2 in. apart and the others 1 inch. A picture of the resulting pattern is shown in Fig. 4. Each source appears to be about 1/4 in. in diameter, referred to the crystal.

The resolution of the complete camera, including the pinhole aperture, is shown in Fig. 5. The source of gamma rays in this case was a pattern of 1/4-in.-diam sources of I^{131}. The spacing between sources was 2 in., and the pattern was 10 in. away from the camera. The four pictures were taken with 1/4, 3/16, 1/8, and 1/16-in. apertures.

The effect of exposure time and subject activity on the quality of the pictures is shown in Fig. 6. The two pictures on the left were taken of a thyroid phantom containing 6.7 μC of I^{131}. A 1/4-in. aperture was used, and exposure times were 7 min for the upper picture and 24 min for the lower picture. The two pictures on the right are of the same phantom, except that it contained 30 μC. The aperture size was 1/8 in., and the exposure times were 9 min and 35 min.

The main cause of definition loss, aside from that due to the finite size of the pinhole aperture, is from statistical fluctuations in the X and Y positioning signals, which are in turn caused by statistical fluctuations in the photomultiplier tubes. On the average only 40 to 50 photoelectrons are released from each phototube by photopeak scintillations from the 0.36-Mev gamma rays of I^{131}. The number of photoelectrons is, of course, subject to statistical fluctuations, and an uncertainty in placement of the flashes on the oscilloscope screen results. This uncertainty corresponds to a diameter of about 1/4 in. in the crystal.

A second cause of definition loss is due to Compton recoils that sometimes produce a secondary gamma-ray recoil in the crystal. When a Compton recoil occurs, a weak scintillation and a secondary gamma ray are first produced. The secondary gamma ray travels a distance in the crystal and may produce a second scintillation. The total amount of light produced is then the same as that which would be produced if all the energy of the gamma ray were spent in a single recoil. Therefore, the resulting signal passes the pulse-height selector, and a flash appears on the cathode-ray tube. The flash is located part way between the points that represent the two scintillations.

The average distance a secondary gamma ray from I^{131} travels in the crystal is about 6 mm, and the resulting flashes are misplaced an average distance equivalent to 3 or 4 mm in the crystal. Most secondary gamma rays escape the crystal without producing secondary recoils, however, and the scintillations produced by the initial recoil are rejected by the pulse-height selector.

The scintillation camera has been used for the past 3 years to take pictures of the thyroid glands of more than a hundred patients. An example is shown in Fig. 7. Pictures such as these are taken with 5 to 10 μC of I^{131} in the gland, and exposure times of 5 to 20 min. Usually a 3/16- or 1/4-in. diam aperture is used, and the distance between the aperture and the thyroid is about 4 in. Three thousand to six thousand dots are recorded.

Positron Camera

It became apparent a short time after the scintillation camera was built that the imaging crystal and phototube assembly used in the scintillation camera would have unique advantages when used with positron emitters, and that sharp images of positron-emitting subjects could be obtained without the use of a pinhole aperture or other collimator.

Figure 8 shows a camera for positron-emitting isotopes that is now in operation. It consists in part of the crystal and phototube assembly, computing circuit, and cathode-ray oscilloscope, such as the one described for the scintillation camera. Additional components are a scintillation counter, a second pulse-height selector, and a coincidence circuit.

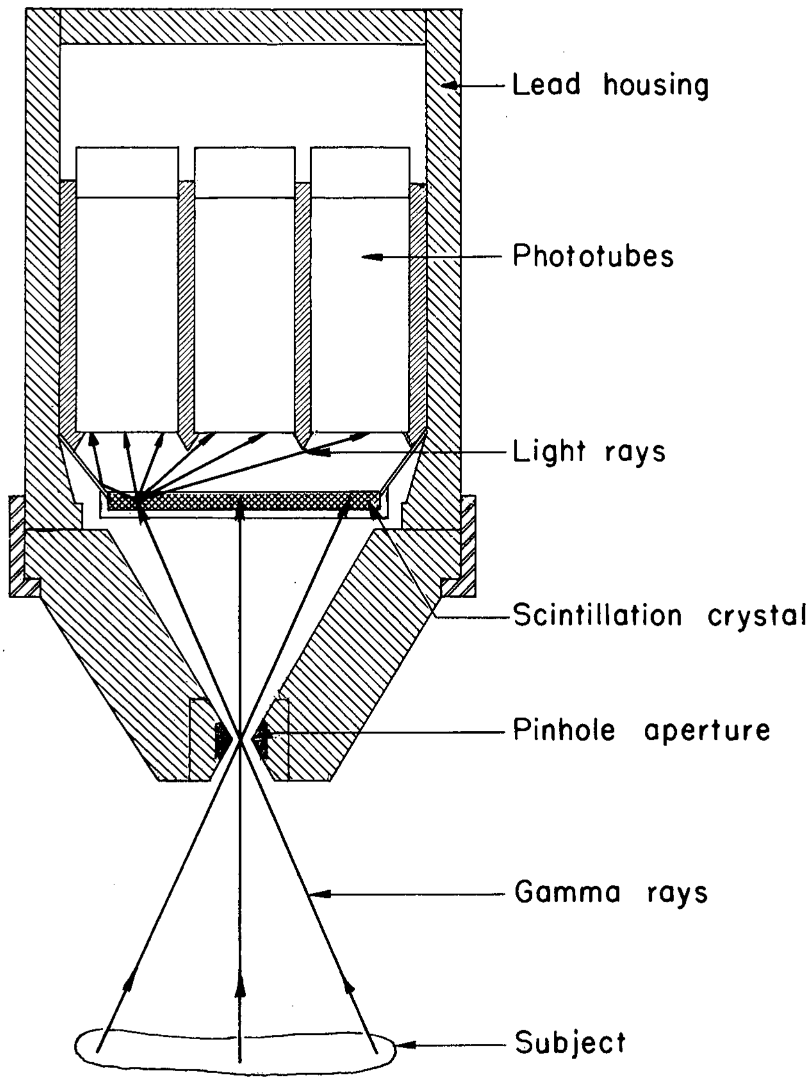
The image crystal is placed on one side of the subject, and the scintillation counter is placed on the opposite side at some distance. When a positron is annihilated in the subject, two gamma rays of 0.51-Mev energy are produced that travel away in opposite directions. When one gamma ray produces a count in the scintillation counter, the other gamma ray impinges on the image crystal at a given point. If a scintillation is produced in each crystal, the pulses actuate the coincidence circuit, and a flash corresponding to the location of the scintillation in the image crystal is displayed on the cathode-ray tube. All other scintillations occurring in the image crystal are rejected.

Thus the coincidence circuit selects, from many scintillations occurring in the crystal, those that form an image of the distribution of activity in the subject. The scintillation counter is a point of focus of the gamma-ray pairs that form the image. Gamma rays that have been scattered appreciably by Compton scattering are rejected by the pulse-height selectors.

Figure 9 shows a picture obtained with this instrument. The subject consisted of 12 small sources of gallium-68, a short-lived positron emitter. The pattern contained 4 μC of activity. Exposure time was 1 min and the subject was about 1 in. away from the image crystal.

Most of the background is due to gamma rays which have undergone multiple scattering in the image crystal. Background due to cosmic rays, and ordinary room background, is less than 1 count per minute.

The image crystal in this camera is 8 in. in diameter and 1/4 in. thick. Nineteen phototubes are arranged in a hexagonal pattern over the face of the crystal. The coincidence detector consists of a sodium-iodide crystal 2 in. in diameter by 2 in. thick and a single phototube. Obviously, the best definition is obtained for thin subjects that can be placed quite close to the image crystal. However, the camera can also be used to advantage with relatively thick subjects, such as the brain and liver, and tests are under way at present to determine its usefulness in this regard.



MU-13578

Fig. 1

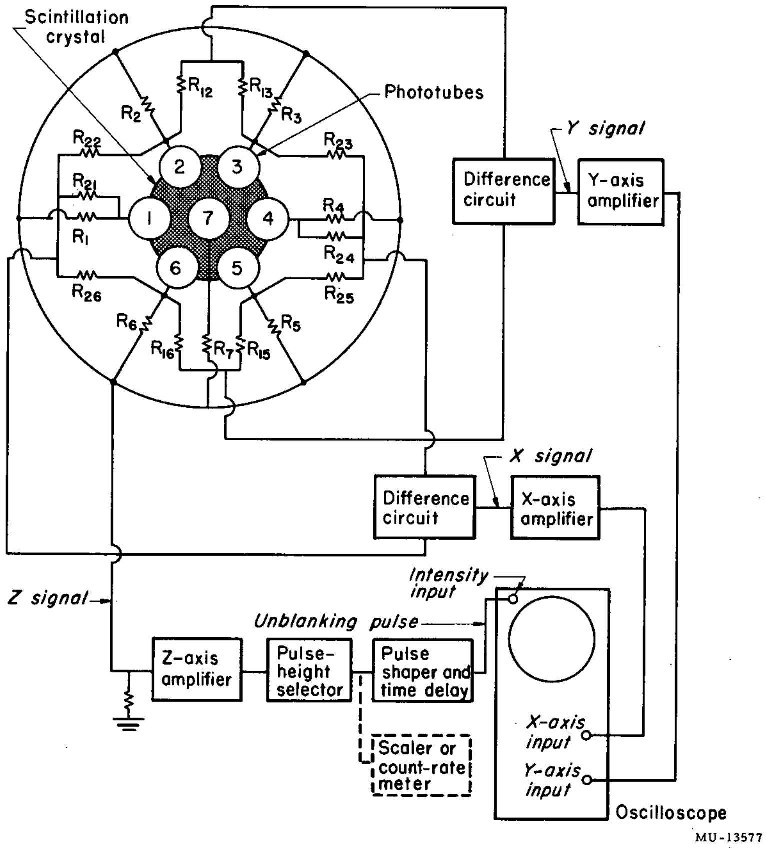

Scintillation crystal
Phototubes
1
2
3
4
5
6
7
R1
R2
R3
R4
R5
R6
R7
R12
R13
R15
R16
R21
R22
R23
R24
R25
R26
Difference circuit
Y signal
Y-axis amplifier
Difference circuit
X signal
X-axis amplifier
Z signal
Z-axis amplifier
Pulse-height selector
Unblanking pulse
Pulse shaper and time delay
Scaler or count-rate meter
Intensity input
X-axis input
Y-axis input
Oscilloscope
MU-13577

Fig. 2

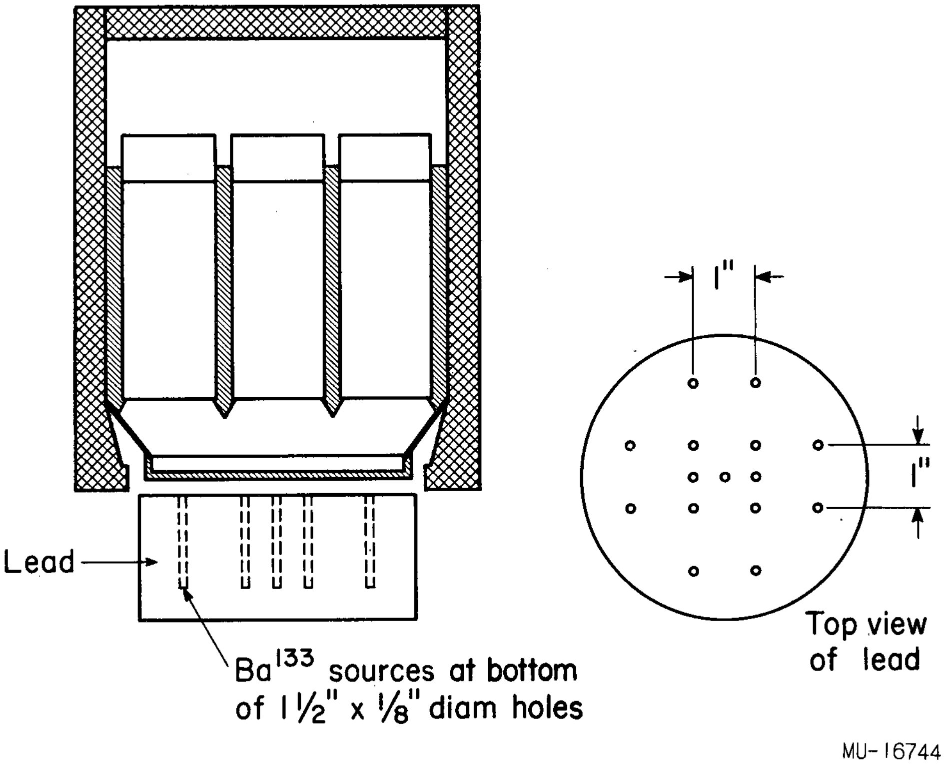
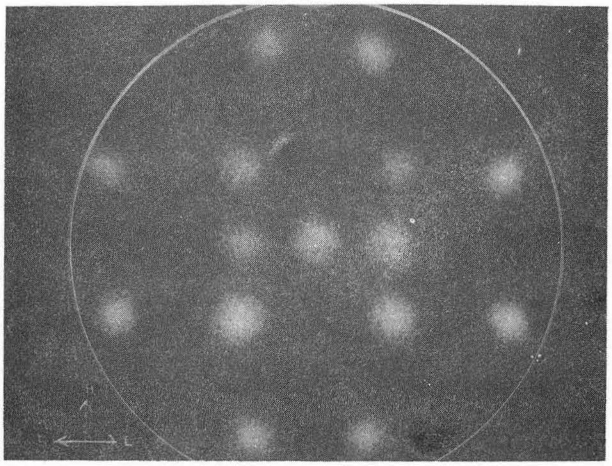
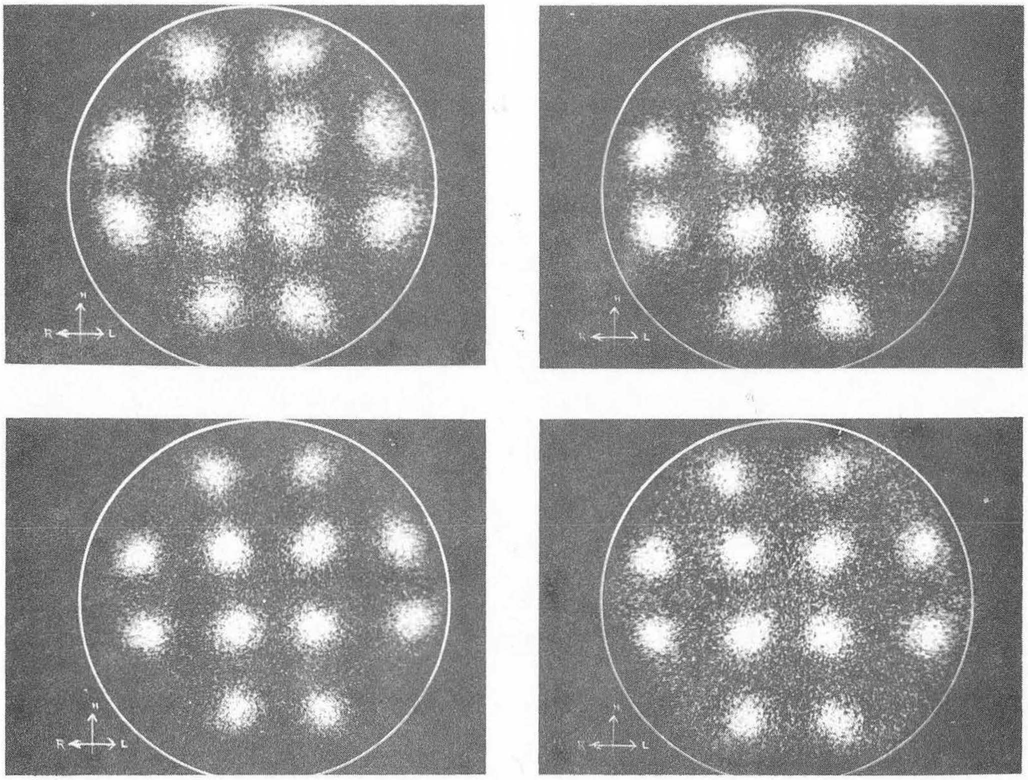

Lead
Ba^{133} sources at bottom of 1½" x ⅛" diam holes
1"
1"
Top view of lead
MU-16744

Fig. 3



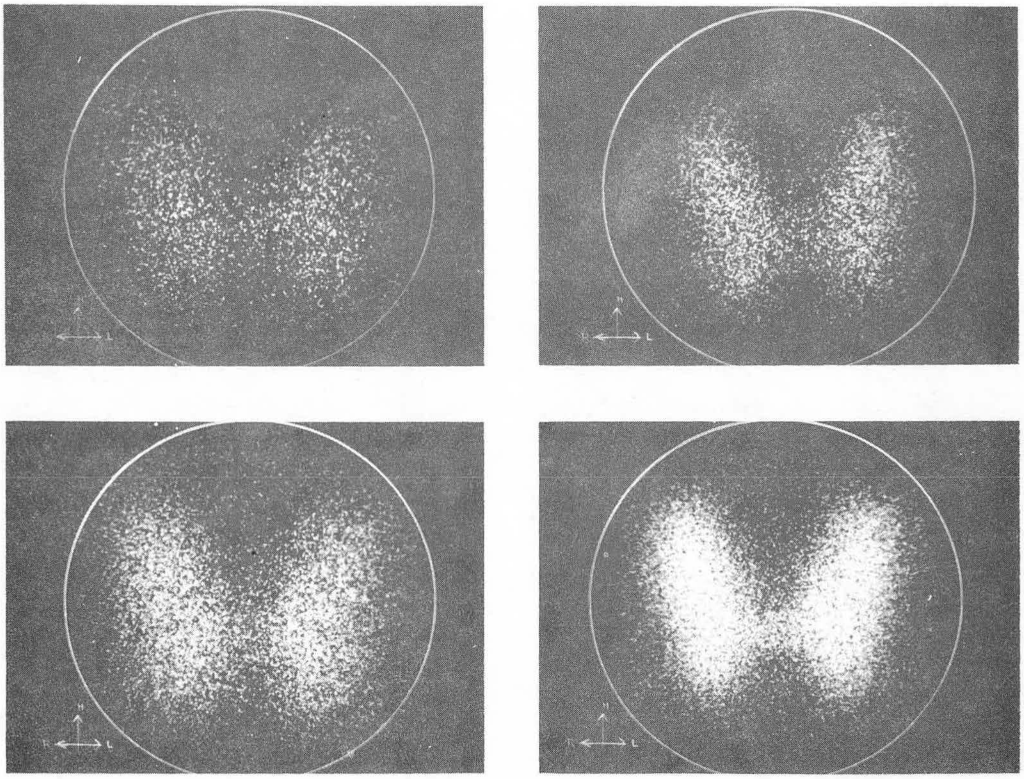
ZN-2205

Fig. 4



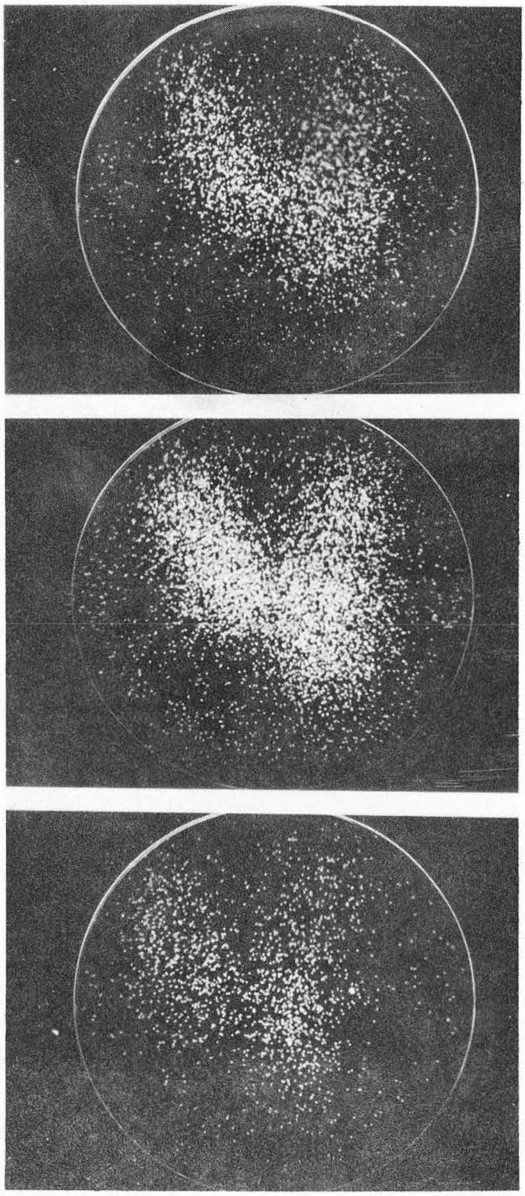
ZN-2208

Fig. 5



ZN-2207

Fig. 6



ZN-2685

Fig. 7

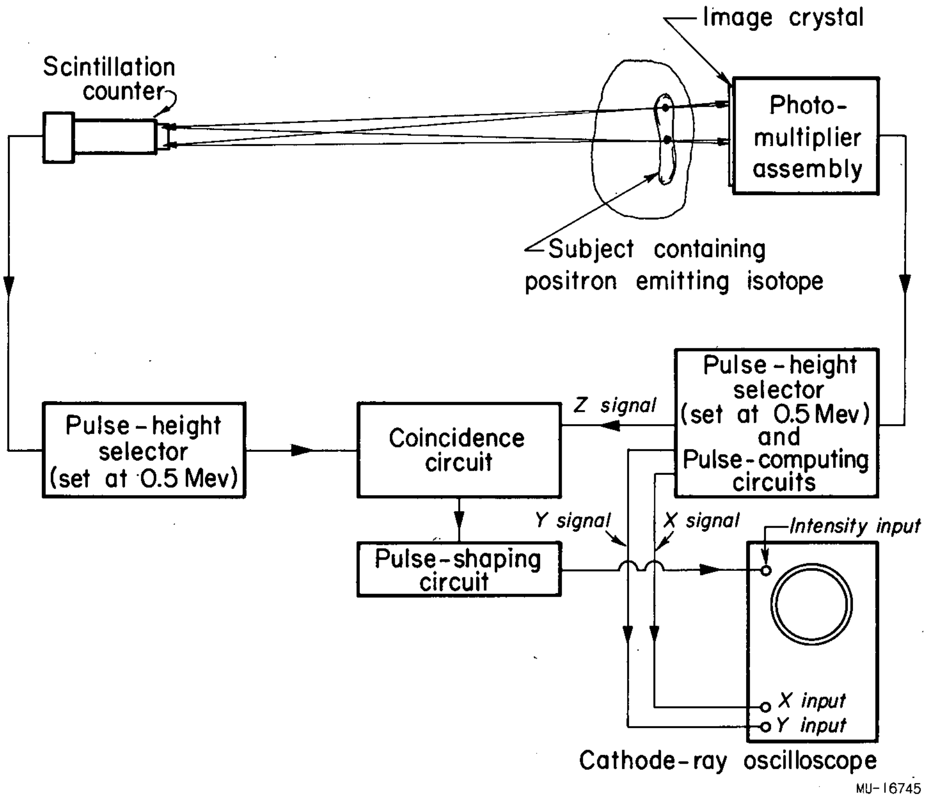
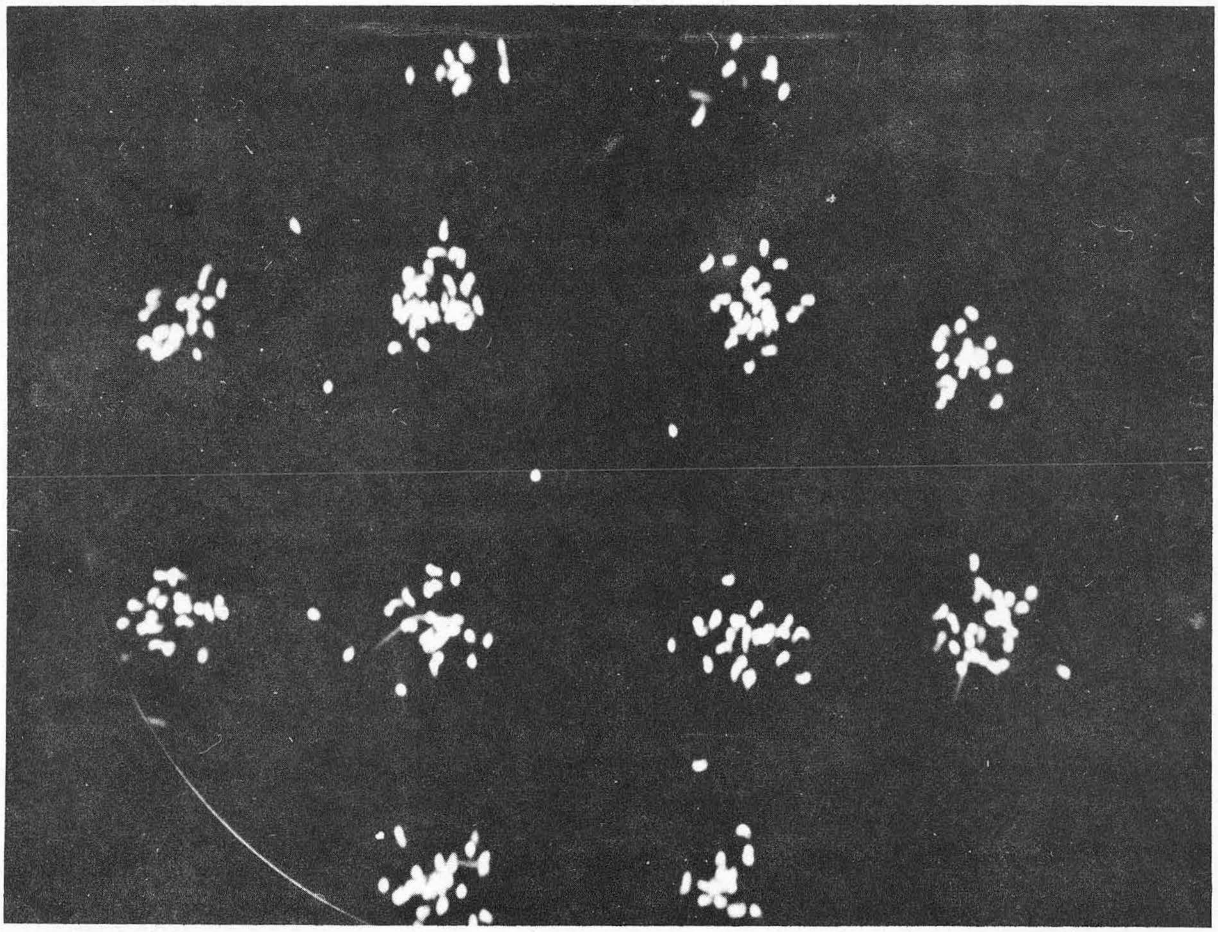


Image crystal
Scintillation counter
Photo-multiplier assembly
Subject containing positron emitting isotope
Pulse-height selector (set at 0.5 Mev) and Pulse-computing circuits
Z signal
Pulse-height selector (set at 0.5 Mev)
Coincidence circuit
Y signal
X signal
Intensity input
Pulse-shaping circuit
X input
Y input
Cathode-ray oscilloscope
MU-16745

Fig. 8



ZN-2684

Fig. 9