Title

MAPPING THE DISTRIBUTION OF GAMMA-RAY-EMITTING ISOTOPES WITH THE SCINTILLATION CAMERA

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DISCLAIMER

MAPPING THE DISTRIBUTION OF GAMMA-RAY-EMITTING ISOTOPES WITH THE SCINTILLATION CAMERA

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The scintillation camera is a new, more sensitive type of gamma-ray camera which permits taking an autoradiograph of a gamma-ray-emitting subject located a small distance from the camera. It consists of the camera head shown in Fig. 1, a deflection computer circuit, a cathode-ray oscilloscope, a pulse-height selector, and a Polaroid camera to photograph the image of the subject that is produced on the oscilloscope screen. The camera head is a hollow cylindrical lead shield with a small aperture at the lower end. Within the shield is a large flat thallium-activated sodium iodide crystal, and spaced some distance above the crystal is a bank of seven photomultiplier tubes.

PRINCIPLE OF OPERATION

The scintillation camera operates as follows. Some of the gamma rays emitted from the subject travel through the aperture in the lead shield and continue traveling in straight lines until they impinge on the sodium iodide crystal. Some of the gamma rays then produce scintillations or flashes of light in the crystal. The light that is produced in any given scintillation is emitted isotropically and divided between all the phototubes, with those closest to a given scintillation receiving the most light. Each of the phototubes produces a pulse, the amplitude of which depends on the amount of light received. The duration of the pulses is short compared with the average time interval between successive scintillations.

The pulses are applied to the deflection computer circuit, which adds and subtracts their amplitudes in such a way that three output signals are obtained. Two of the signals are positioning signals which are applied to the X and Y input terminals of the oscilloscope. The X-positioning signal is obtained by adding together the pulses from the phototubes located on one side of a dividing line through the crystal, adding the pulses from the phototubes located on the other side of the dividing line, and then subtracting one signal from the other. The circuit is arranged so that phototubes located at a greater distance from the dividing line contribute proportionately more to the amplitude of the positioning signal than the other phototubes. The center phototube, and any phototubes lying on the dividing line, do not contribute to the positioning signal. The Y-positioning signal is obtained in the same way except that the dividing line through the crystal is at 90° to the dividing line for the X signal. Both go through the geometric center of the crystal. The amplitude and polarity of each of the positioning signals depend on

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the displacement of the scintillation from its respective dividing line and also upon the brightness of the scintillation. However, only scintillations falling within a certain narrow range of brightness are displayed on the oscilloscope screen.

The third, or Z signal, is obtained by adding the pulses from all seven of the phototubes, with equal value being given to each. Then a scintillation of a given magnitude produces a Z signal of approximately the same magnitude regardless of where it originates in the crystal. This signal is applied to the input of the pulse-height selector and then to the intensity-input terminal of the oscilloscope. Only scintillations of a certain magnetude pass the pulse-height selector.

When a scintillation occurs, the oscilloscope beam, which is normally in an extinguished state, is deflected by the X and Y signals to a point corresponding to the location of the original scintillation in the crystal. Then the beam is turned on momentarily, provided the Z signal passes the pulse-height selector. The result is that scintillations in the crystal that fall within a certain brightness range are reproduced as flashes on the oscilloscope screen in approximately the correct location and at greatly increased brightness.

The flashes on the oscilloscope screen are photographed, usually by a Polaroid-Land camera which develops the picture within the camera in one minute. The exposure time may last from a few seconds to an hour or more. During this time an image is built up from the flashes that occur. If only a few flashes are recorded, they appear as separate dots which are more numerous in the areas of maximum activity. If many are photographed in one exposure and the brightness of the flashes is suitably adjusted, the dots merge together and show a gamma-ray image of the subject in shades of gray and white against a black background.

In normal operation the pulse-height selector is adjusted to accept the photopeak pulses from a given gamma-ray-emitting isotope. Photopeak pulses are those in which the full energy of the gamma ray is transferred to the crystal in a single reaction. Any scattered gamma rays are eliminated, since (assuming the subject is emitting gamma rays of only one energy) they will have been degraded in energy before reaching the crystal. This results in good sensitivity and pictures with high contrast. Although seven phototubes are employed, the number of picture elements that can be resolved is not limited to this number because scintillations that occur at intermediate points between the phototubes are reproduced approximately in that position. The actual limitations on resolution and a more detailed description of the operation of the camera are given in an earlier paper.[1]

Among the advantages of the scintillation camera are the following. It is concurrently sensitive to all parts of its field of view. There is no line structure to the image, since scanning is not employed. An area of any size may be examined by moving the camera closer or further away. The camera can be oriented readily in any direction so that horizontal, vertical, and oblique views can be taken. Remote viewing and recording are feasible. It can be adjusted to be sensitive only to photopeak scintillations of the isotope being studied, thus rejecting radiation scattered by adjacent objects or tissue. Also, the background due to cosmic rays and stray radioactivity is substantially reduced by use of the pulse-height selector.

SENSITIVITY

The absolute sensitivity of the camera can be given in terms of the number of gamma rays recorded in the picture divided by the number entering the aperture. Therefore it is a quantity dependent upon the thickness, density, and atomic number of the crystal, assuming that all the photoelectric recoils in the crystal are displayed. However, the over-all sensitivity can be given as the number of gamma rays recorded divided by the number emitted by the subject. Then the sensitivity varies also as the square of the diameter of the aperture and as the inverse square of the distance from the aperture to the subject. Therefore, greater over-all sensitivity, as well as better definition, result when the subject is as close to the aperture as is consistent with the area to be seen.

When a 1/4-inch-thick sodium iodide crystal is used, the absolute sensitivity is such that about 10% of the 0.365-Mev gamma rays of I^{131} that enter the aperture produce a photoelectric recoil and therefore a flash in the oscilloscope screen. About 15% produce Compton recoils, which are not normally reproduced on the oscilloscope screen because the full energy of the gamma ray is not transferred to the crystal in a Compton reaction, and 75% pass through the crystal without producing any scintillation at all.

At the present time a 3200-dot picture of the thyroid can be obtained with as little as 5 microcuries of I^{131} in the gland, when a 1/4-inch-diameter aperture and an exposure time of 20 minutes are used. Better pictures containing more dots or shorter exposure times are possible if the subject contains a greater amount of activity.

RESOLUTION

The resolution obtained with four different aperture sizes is shown in Fig. 2. The test subject contains twelve small I^{131} sources arranged in rows. The pictures were taken with apertures 5/16, 1/4, 3/16, and 1/8 inch in diameter. The increase in definition with the smaller apertures is quite apparent. The exposure time for the above pictures was varied so that each contains about the same number of dots, namely 25,000. The pictures also show that there is no great variation in sensitivity over the area of the picture and that the geometric distortion is negligible.

THYROID PICTURES

The scintillation camera has been used clinically for more than a year to take pictures of the human thyroid. In that time it has been shown that very satisfactory pictures can be taken with 5 or more microcuries of I^{131} in the gland. In Fig. 3 are shown a few examples of clinical pictures of the thyroid.* The first two pictures contain 6400 dots each and were taken with a 1/4-inch-diameter aperture. The other two pictures contain 3200 dots each and were taken with the same aperture. The last shows remnants after a thyroid operation and a "hot" cervical node at the upper border of the picture.

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*The author is indebted to Dr. John C. Weaver and Dr. Donald J. Rosenthal for referring the subjects of these pictures.

Normally, all thyroid pictures are taken with a standard distance of 4 inches between the camera and the subject. Then the size of the gland can be estimated from its appearance in the picture. However, it is possible to map a larger area by increasing the distance, or show greater detail in a small area by moving the camera closer. It is also possible to take lateral or oblique views to determine, for instance, if a hot nodule is anterior or posterior to the gland. An example of this is shown in Fig. 4. The regular anterior-posterior (A-P) view shows the thyroid with a hot nodule at the isthmus. The lateral view from the left shows the thyroid as seen from the edge with the nodule slightly anterior to the plane of the thyroid. Each of these pictures contains 3200 dots.

Some means of reproducing landmarks in the picture will probably be added soon. Although the instrument is useful at this time, primarily for showing the thyroid gland, it awaits only the development of new tracer compounds before other soft tissues not visible by x-ray can also be shown.

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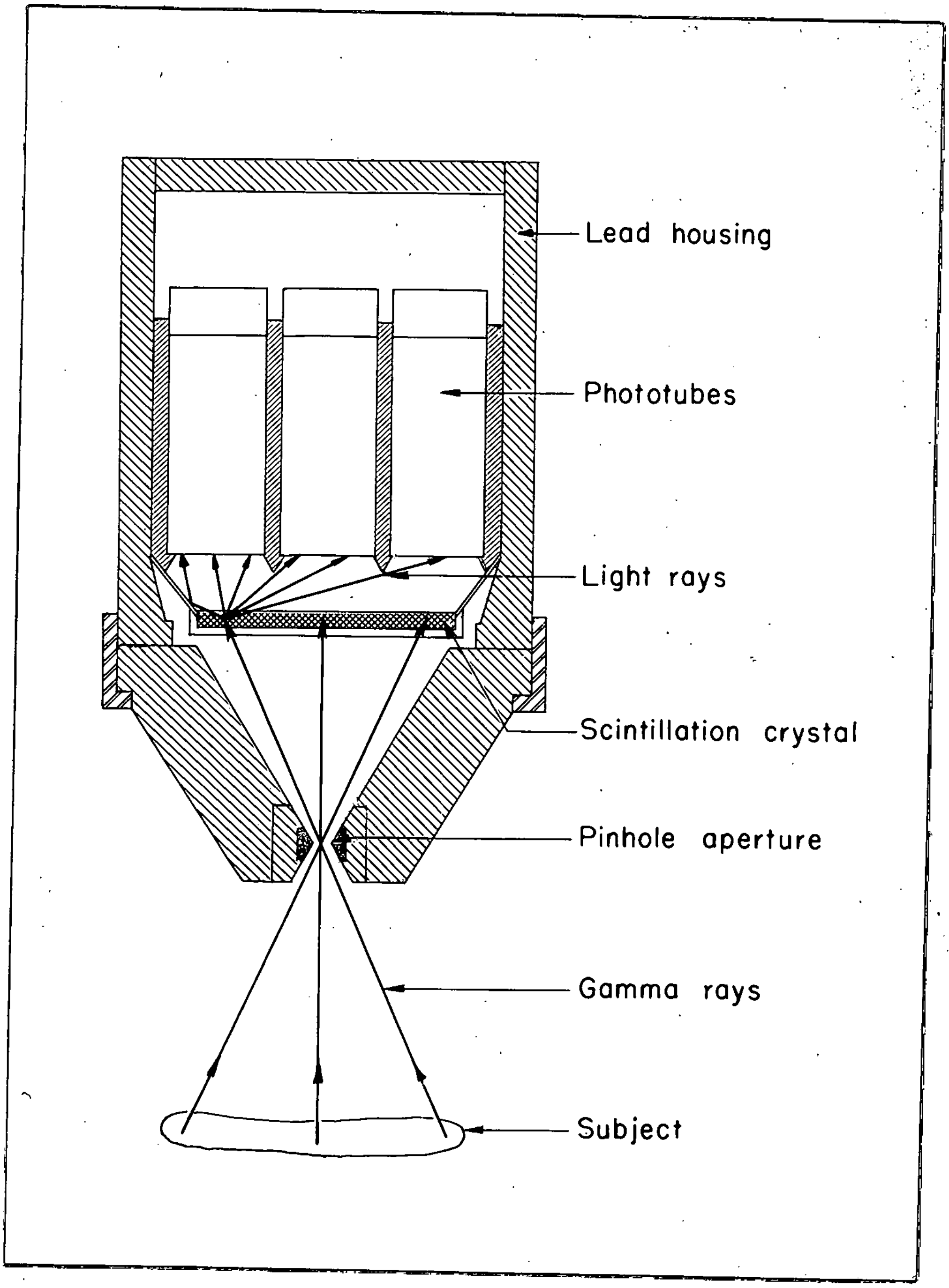

Fig. 1. Sectional drawing of scintillation camera.

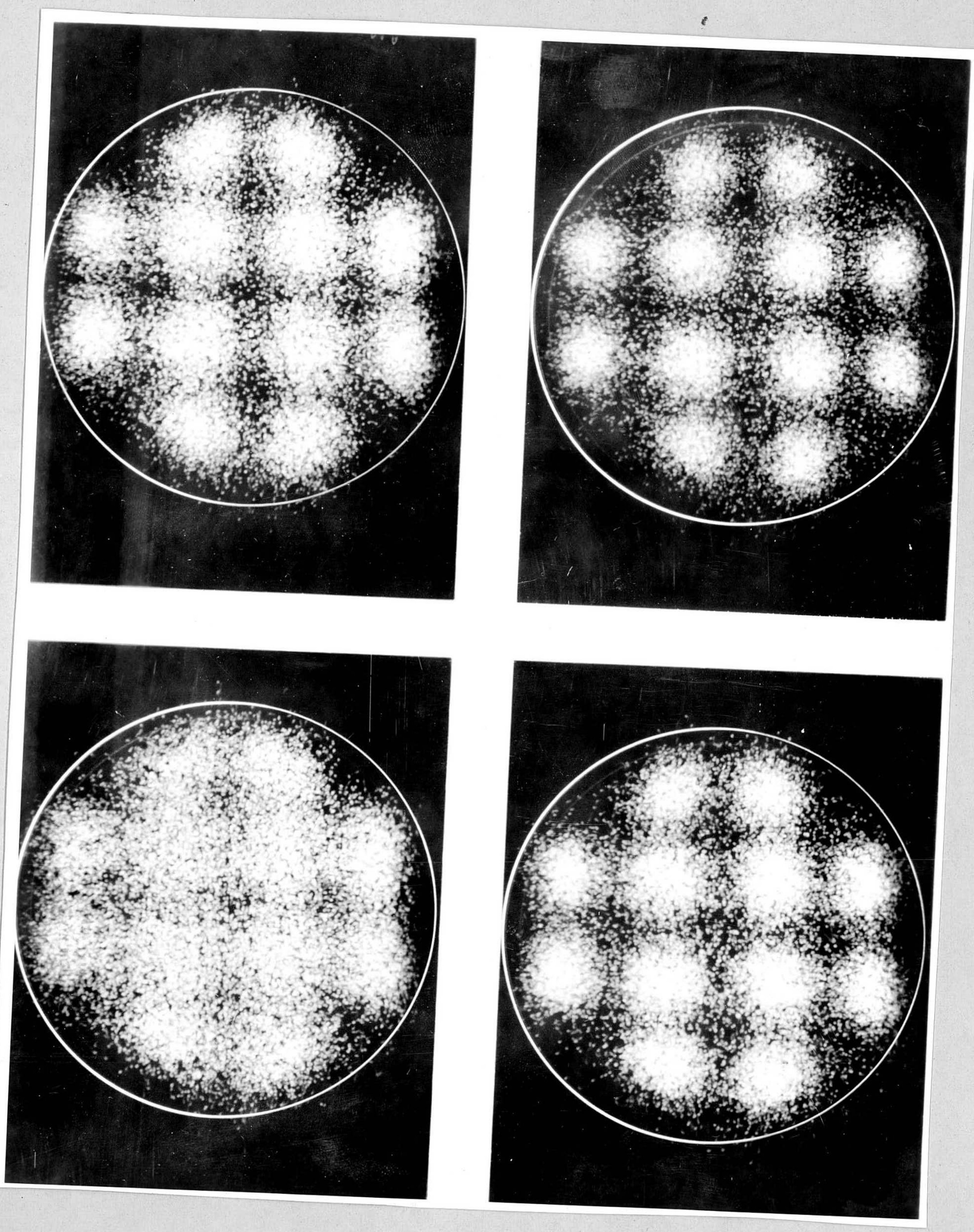

Fig. 2. Resolution obtained with 5/16-, 1/4-, 3/16-, and 1/8-inch apertures.

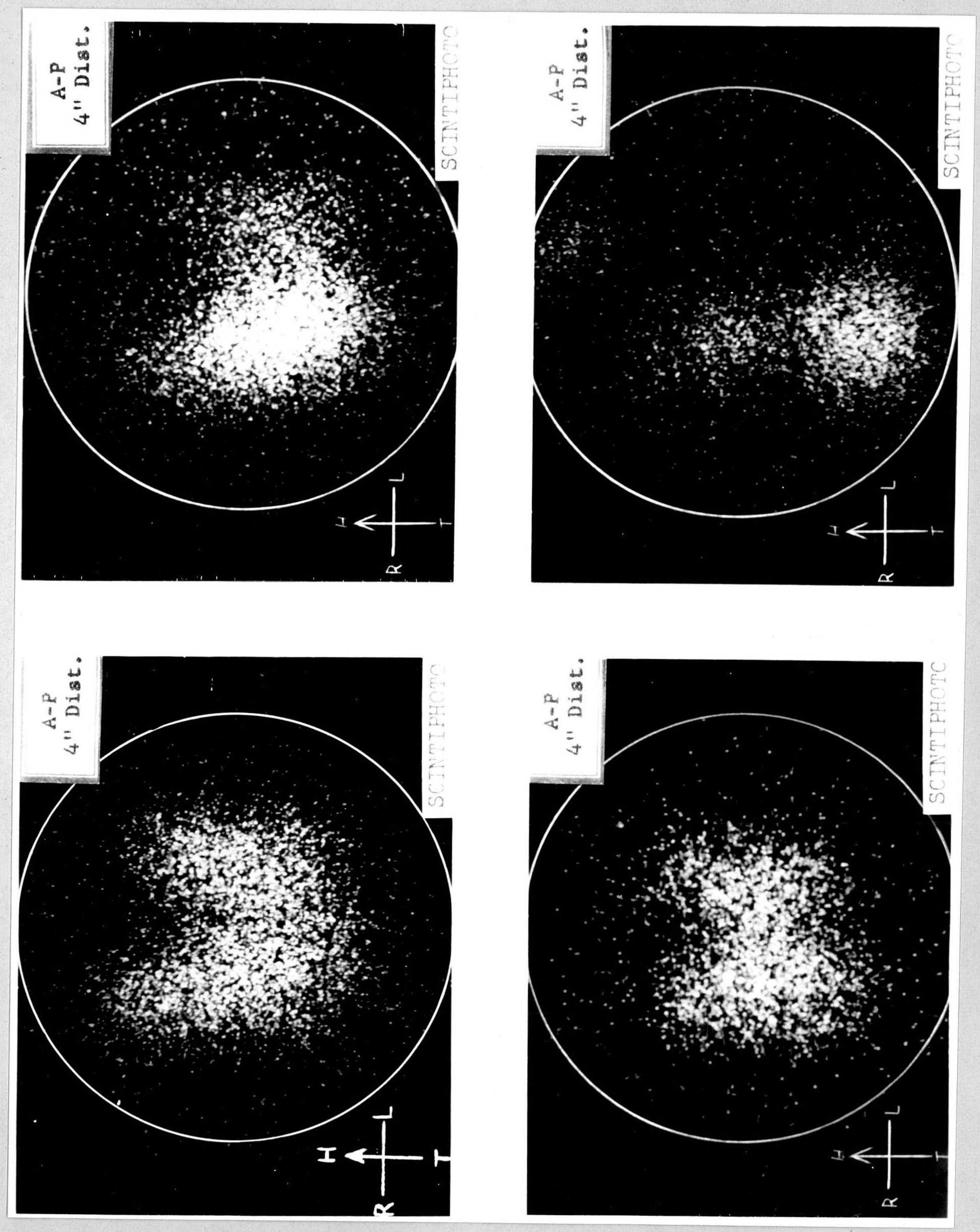

Fig. 3. Scintillation-camera pictures of the human thyroid.

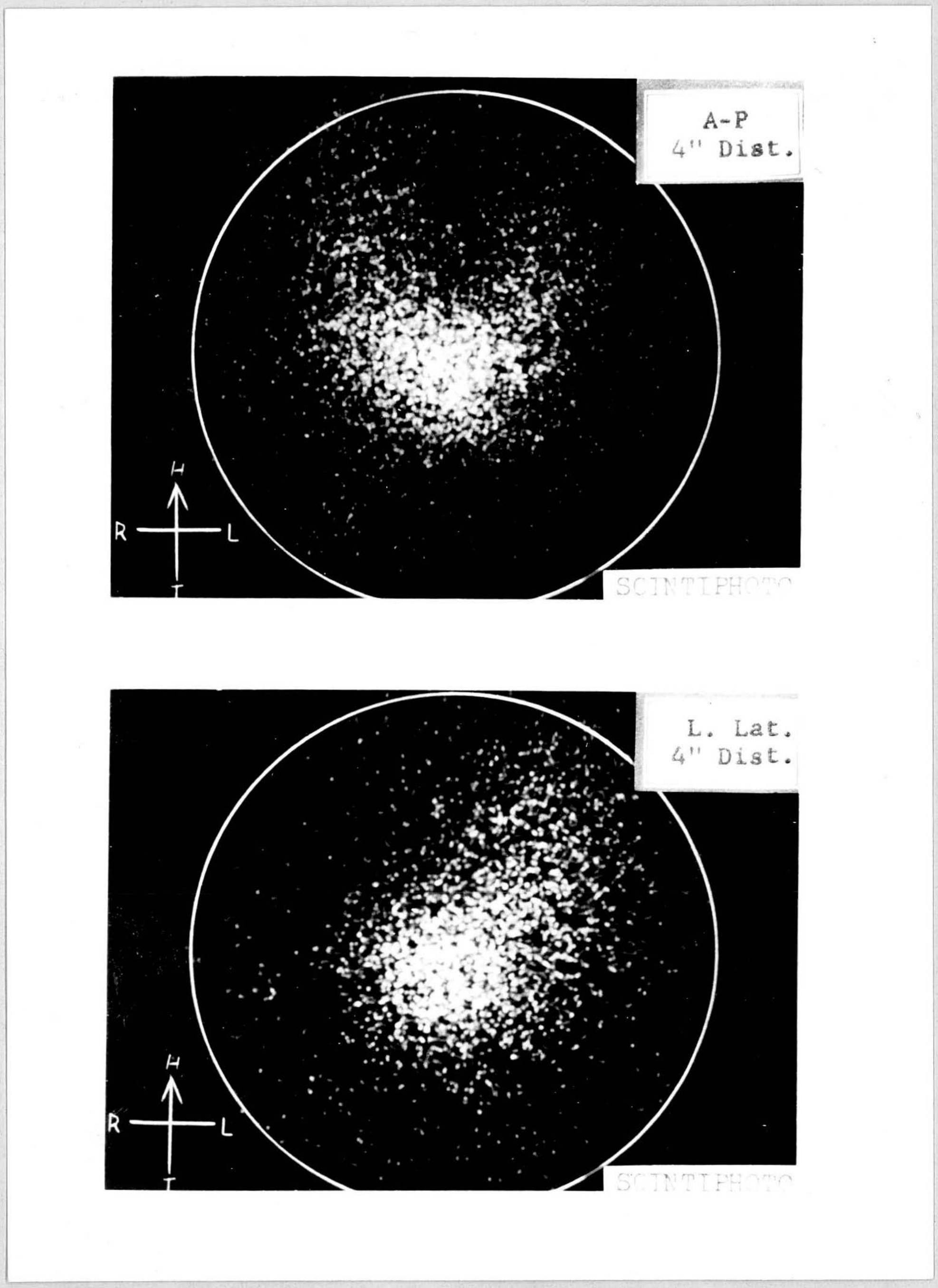

Fig. 4. A-P and left lateral views of thyroid.