**Title**
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# A METHOD OF TOMOGRAPHIC IMAGING USING A MULTIPLE PINHOLE CODED APERTURE

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## ABSTRACT

A method of obtaining tomographic images from a single exposure to the gamma rays emitted by an object is described. The method uses an aperture of multiple pinholes to produce a coded shadowgram on a large area detector. The resultant pattern must be decoded with a diffuse white light source and the original aperture to produce the image.

THE SIMPLEST METHOD FOR IMAGING A GAMMA-EMITTING OBJECT is to interpose a single pinhole between the object and the recording detector. The gammas which originate from the object and which pass through the pinhole produce on the detector a recognizable image of the object with a lateral spatial resolution dependent upon the pinhole size. Decreasing the size of the pinhole increases the spatial resolution of the system, but reduces the detection rate of the gammas which are recorded. Thus exposure times are prolonged. Adding more pinholes increases the data-taking rate, but now the pinhole images produced on the detector overlap one another and are spread over a larger area of the detector. The object is no longer recognizable and a means of decoding the resulting shadowgram is required.

The multiple pinhole array described here has the property that the vector distance between any two pinholes occurs only once, i.e., the pinholes are spaced non-redundantly. Several examples are described in the literature (1,2,3). This non-redundancy means that the autocorrelation of the pinhole array function is peaked at the center, and is uniformly flat elsewhere. Thus if parallel light is directed toward two similar non-redundant pinhole arrays placed along the same axis, the light will pass through all the pinholes in both arrays if the arrays are completely aligned, but only through a pair of them, on the average, if the arrays are not aligned.

Wouters, et al (4), have shown with optical simulations that if the original pinhole array is used to decode the shadowgram the peaked shape of the autocorrelation produces an image of the object on a uniform background of light. We demonstrate that for gamma ray imaging, a faithful reconstruction of the object can be made in this way with a minimum of defects and artifacts produced. Further, because the pinhole aperture subtends a finite angle at the object, tomographic effects are obtained.

## MATERIALS AND METHODS

Figure 1A is a diagram of the imaging system. An actual coded shadowgram from a thyroid phantom is shown. It was photographically recorded from the face of the CRT on 4-in x 5-in film. The primary radiation detector that we used was a gas-filled multiwire proportional chamber with delay line readout (5,6). We choose this detector because it is capable of detecting efficiently single gamma interactions with good spatial resolution (~1 mm), and produces coordinate information which is easily displayed on a cathode ray tube or digitized for computer processing. The detector, in addition, is conveniently made with large detection areas of the order of 30-50 cm on a side. The resolution is necessary if the smallest details of the object are to be clearly imaged. The large area is necessary in order to record all of the overlapping images of the coded shadowgram. Thus the pinhole diameters can be made correspondingly smaller to match the detector response and the object resolution desired, while the detector area is still large enough to record the entire field of view of the coded aperture.

The lateral spatial resolution is similar to that for a single pinhole, and is given by

$$\delta = d(1 + \frac{S_1}{S_2}) ,$$

where d is the diameter of the pinhole and $S_1$ and $S_2$ are as shown in Figure 1A. The depth resolution is given by

$$\Delta = 2 \frac{d}{D} S_1 (1 + \frac{S_1}{S_2}) ,$$

where D is the largest lateral distance between any two pinholes of the array. This calculation for the depth resolution assumes that 50% of the light from the out-of-focus planes overlaps the light from the in-focus plane.

The coded aperture consists of twenty seven 2-mm diameter pinholes drilled into a flat sheet of lead 2-mm thick, and was designed to work with gammas up to 140 keV energy. In this application, the radiation was the 28 keV x-rays emitted by a $^{125}I$-filled thyroid phantom. The resolution of the system is limited by the 2-mm diameter size of the individual pinholes and, thus, for a typical imaging geometry in which $S_1 = S_2$, the overall lateral resolution is 4 mm.

The reconstruction system is shown in Figure 1B. An intense, uniform, and diffuse light source is made by focussing the light from a slide projector onto a ground glass screen. The rays of light emitted from the screen are further transmitted through the transparency of the shadowgram, and through a mask which is a duplicate of the original non-redundant pinhole array. When the shadowgram and the mask are properly aligned the decoded image comes into sharp focus at an image plane where it can be directly observed on a second ground glass screen and subsequently photographically recorded.

RESULTS AND DISCUSSION

An image of a Picker thyroid phantom taken with the 27 non-redundant pinhole coded aperture is shown in Figure 1A. The shadowgram consisting of 540,000 dots was recorded on Kodak Ektapan film. The reconstructed image as shown in Figure 1B was printed on high contrast paper to reduce the background of light and enhance the contrast. The right and left lobes differed in activity, and this difference can be seen in the reconstruction. The smallest of the cold nodules is 5 mm in diameter and is clearly imaged.

The tomographic capability of this coded aperture is shown in Figure 2. Figure 2A shows the shadowgram of a radioactive phantom consisting of three geometrical patterns labelled with $^{125}I$ (a cross, a triangle, and a circle) which were separated by a distance of 2.5 cm in depth. A total of one million gammas was recorded on the shadowgram. Figures 2B, C, and D are the reconstructions of each of the patterns obtained by adjusting the mask-to-image plane distance in the reconstructions so as to bring each pattern into sharp focus. Each of the in-focus images is superimposed on a background arising from the planes at other depths in the phantom.

As seen from these reconstructions, good resolution and tomographic effects are easily obtainable with the non-redundant pinhole array. Only a strong light source, a diffusing screen, some optical alignment equipment, and photographic materials are needed to reconstruct the shadowgram. In fact with some modifications to the set-up, direct image decoding is also possible without going through the intermediate step of photographing the shadowgram separately. For example the spot of light from the CRT display, which defines the coordinates of the detected radiation, could be made to pass through the reconstruction pinhole mask and be directly observed in the image plane. By a system of lenses, the various planes within the object could be separately focussed and recorded. Since no movement of the detector is necessary and all the information of the object's shape and size is recorded in a single picture, dynamic studies are possible.

## SUMMARY

Good resolution images of an x-ray emitting extended object have been obtained using a non-redundant pinhole array and an incoherent white light source. The added burden of decoding the shadowgram is offset by the ability to obtain tomographic information with no sacrifice in lateral spatial resolution. The non-redundant nature of the pinholes results in a sharp image on a uniform background which tends to minimize defects or artifacts in the image.

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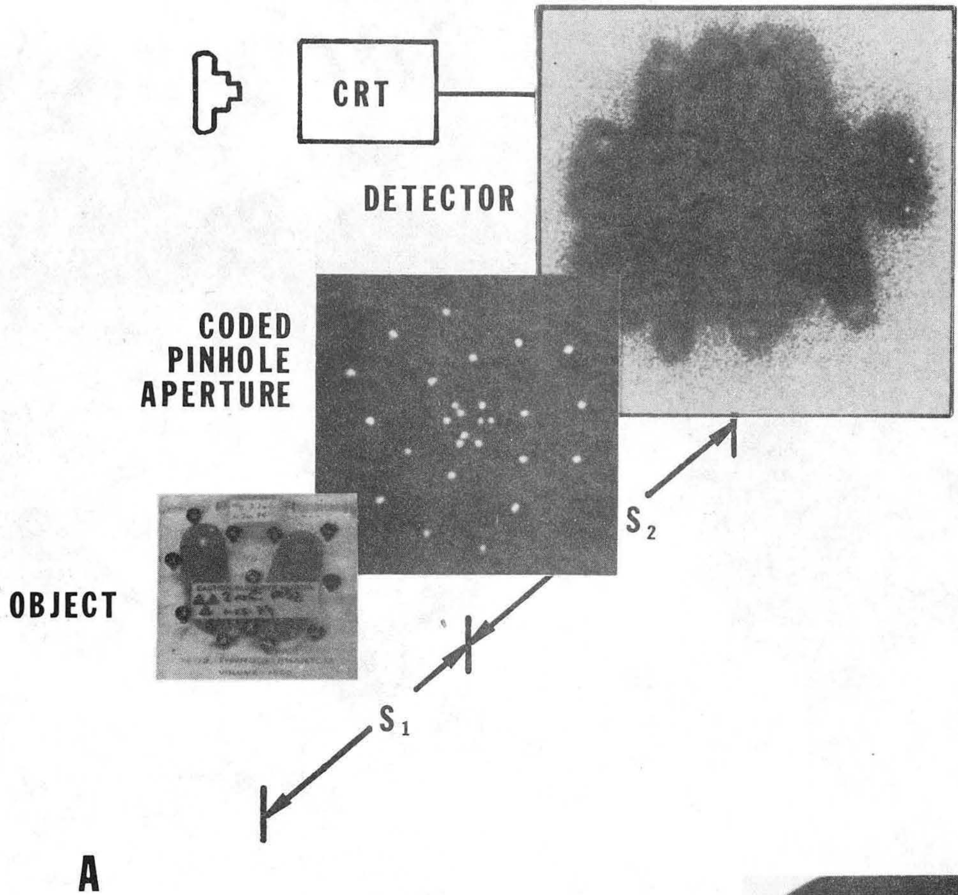
FIGURES

FIG. 1. (A) Composite diagram of the imaging system showing the spatial placement of the various components. The 27 non-redundant pinhole array and an actual shadowgram of a Picker thyroid phantom is shown. (B) Composite diagram of the reconstruction system showing the decoded image of the shadowgram.

FIG. 2 (A) Coded shadowgram of a cross, a triangle, and a circle. Each pattern was spaced 2.5 cm in depth from one another. (B,C,D) Reconstructed images of each of the patterns.



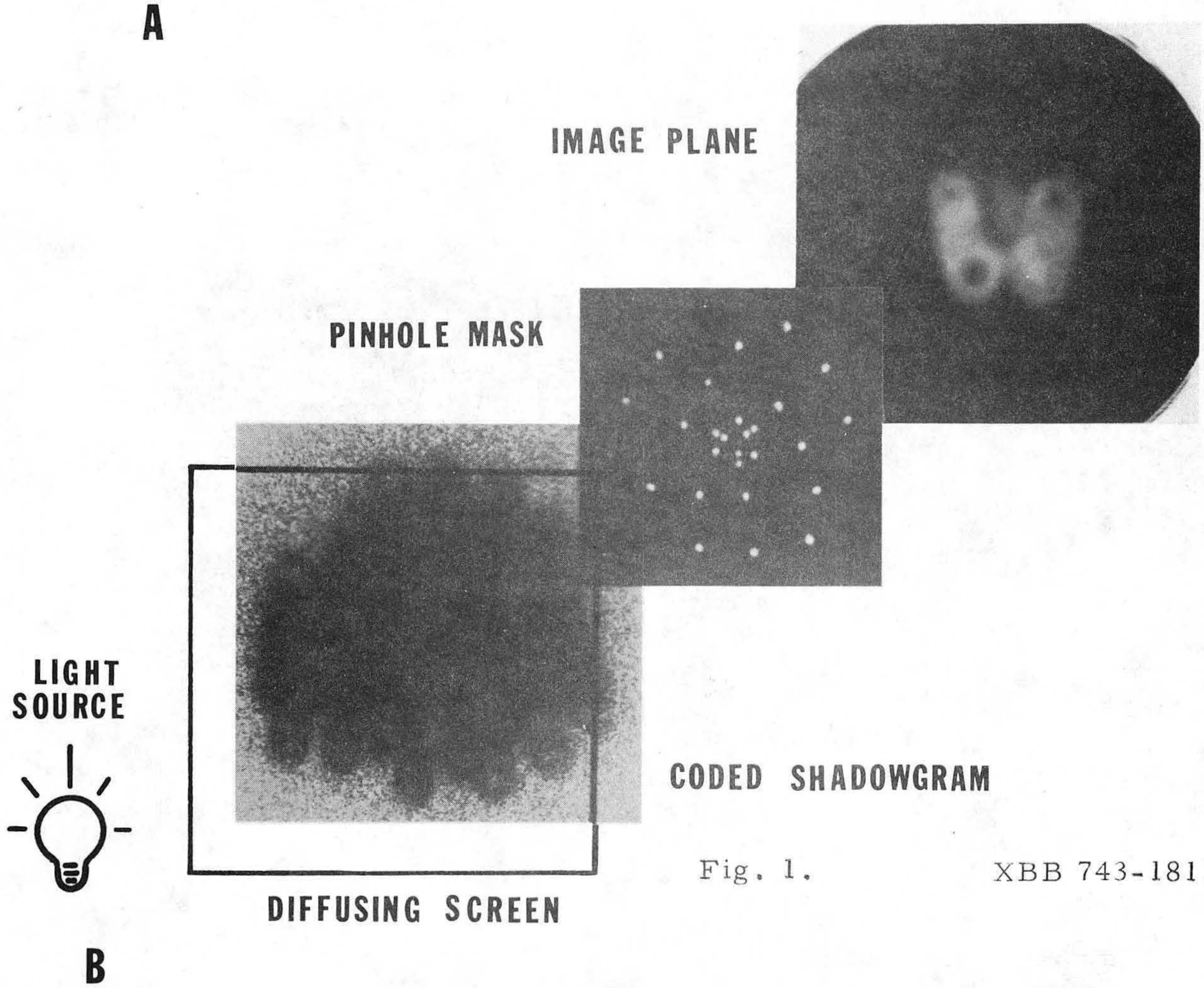




Fig. 1. XBB 743-1811

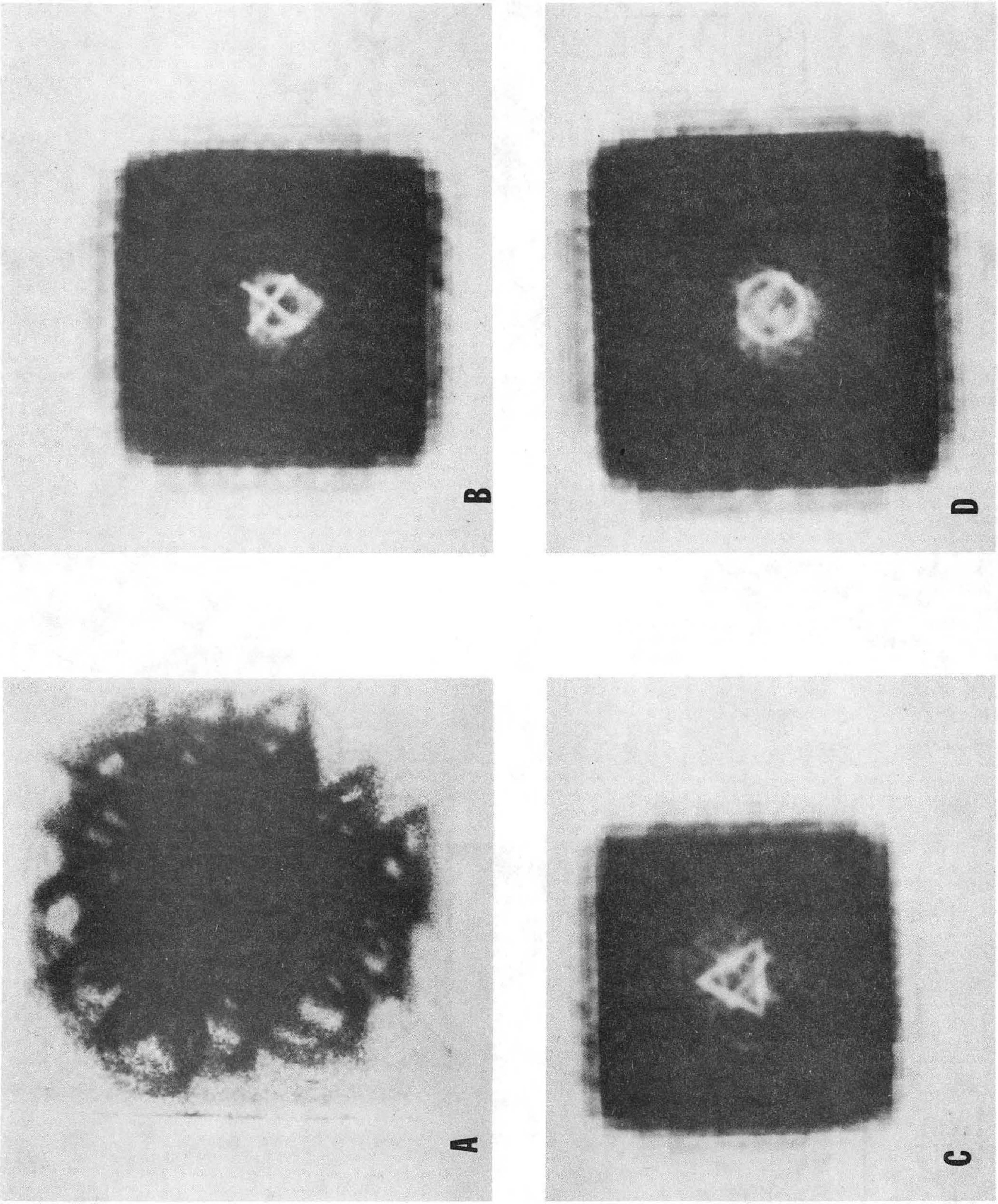



Fig. 2.

XBB 743-1812

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