

A Collimator System for Scanning at Low Energies¹

P. Richards² and Harold L. Atkins³

Upton, New York

INTRODUCTION

The increasing use of low-energy gamma emitters in radioisotope scanning, particularly those gamma emitters emitting photons below 200 keV, has created an interest in collimators designed for such energies. At least until quite recently, available commercial collimators were designed for higher energies and did not allow optimum use of the lower-energy emitting nuclides. Special collimators have been reported by Harper, *et al* (1), Beck (2), and by Harris, *et al* (3), but, to date, these designs have not been generally available.

To carry out some scanning studies at the Brookhaven Medical Research Center involving the use of ^{99m}Tc, it was felt that a thin-septum collimator was needed that would more fully take advantage of the properties of the radioisotope. As a number of different applications were to be involved, a collimator system was needed that was sufficiently versatile to encompass a number of different scanning requirements.

COLLIMATOR DESIGN

A basic collimator design was developed which is suitable for use with ^{99m}Tc and other low-energy photon emitters and which has sufficient resolution for thyroid scanning and other applications where high resolution is desired. A relatively high counting rate is achieved by having the crystal intercept the maximum solid angle that was considered acceptable from the standpoint of resolution loss above and below the focal point. To maintain a reasonable focal length-3.5"-a large angle is achieved by having the collimator relatively thin. The basic 1" thick unit is designed for use with a commercial scanner having a 3" crystal and will give approximately the same counting rate as a 4" thick collimator with the same focal length and resolution when used with a 5" crystal.

¹This work was supported by the Atomic Energy Commission.

²Nuclear Engineering Department, Brookhaven National Laboratory, Upton, N. Y.

³Medical Research Center, Brookhaven National Laboratory, Upton, N. Y.

High resolution is achieved by having small diameter holes. A tapered round hole is used which is 0.054" in diameter at the small end resulting in a radius of view at the focus of approximately 0.24 inches. Hexagonal holes were not used because of the increased complexity in fabrication and higher cost. Failure to use such holes results in a transmission loss of about 10%. A septum thickness of 0.015" was chosen as the minimum thickness having sufficient mechanical strength. This choice resulted in a collimator with 1045 holes in a hexagonal pattern when rounded off for a 3" crystal.

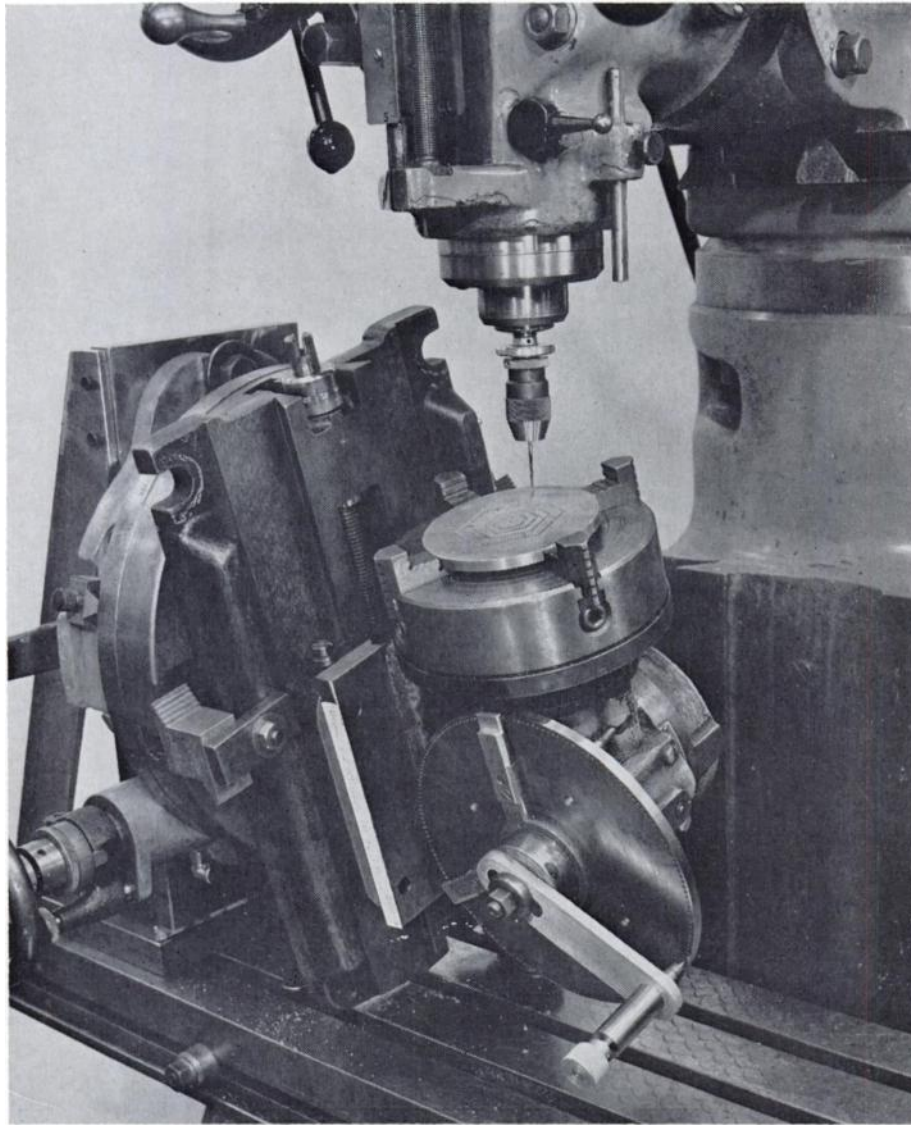


Fig. 1. Milling machine set up for base plate fabrication

For certain applications where maximum sensitivity or high counting rate may be more important than resolution, (such as in brain or bone marrow scanning), the basic collimator may be made thinner thereby increasing the field of view and, therefore, the count rate. Thus, by a simple modification of the basic collimator, one may have a set of collimators with different degrees of sensitivity and resolution. As the sensitivity increases, the resolution decreases (field of view enlarges).

One other situation has been considered in the design of the collimator; namely, the problem of scanning a thick organ such as the liver and trying to detect voids that may be located well above or below the focal point. For collimator-detector systems that intercept a rather large solid angle, the problem of loss of resolution above and below the focus can result in a rapid loss of detail. For applications where this may be a problem, provisions have been made for mounting lead masking rings or an iris on the face of the basic collimator, so that the angle intercepted by the detector can be varied at will and, thus, the depth response of the system changed. Of course, any reduction in angle is accomplished at the expense of counting rate. The same system may also be used for mounting lead discs which mask the center holes and in this way decrease the depth of focus of the collimator. This procedure may be useful in reducing background radiation lying above or below a point of interest.

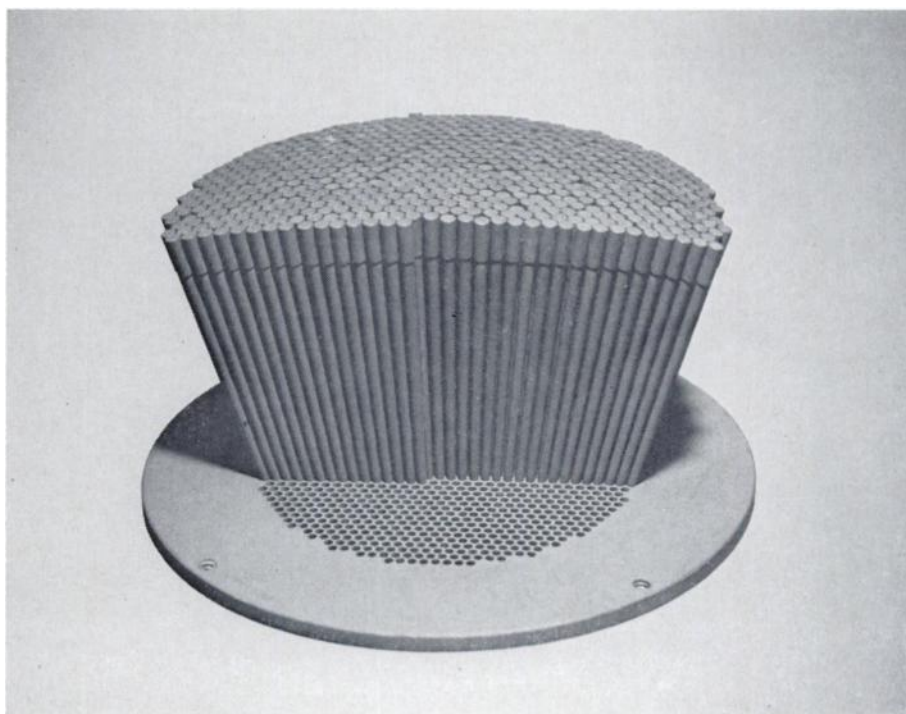


Fig. 2. Special pins partially loaded in base plate.

COLLIMATOR FABRICATION

A simple rapid vacuum technique was developed for casting the lead collimators. The units are formed by casting lead around 1045 special tapered pins that are mounted in a base plate or "pin cushion". The fabrication of the base plate is the most critical part of the operation and requires the precise drilling and tapering of 1045 holes in the proper hexagonal array. Drilling is done on a standard milling machine with the plate mounted in a dividing head (Figure 1) which in turn is mounted on a vertical rotary table. The distance from the face of the base plate to the center of rotation is set for the focal length or 3.5". Two angles for each hole in one 60° sector of the array were calculated by computer; (1) the angle to aim the hole at the focal point which is set on the rotary table and (2) the angle of each hole off the center line of the sector which is set on the dividing head. Six holes are then drilled for each setting 60° apart. The holes are tapered, using a standard tapered reamer.

The specially tapered steel pins are made commercially to specifications on precision screw machines. The bottom $\frac{5}{16}$ " of the pins are tapered to seat in the holes of the base plate with $\frac{1}{16}$ " protruding through the $\frac{1}{4}$ " base plate. The body of each pin has the proper taper for the designed focal length. A head on each pin maintains proper separation of the pins at the top. Both pins and base plate are coated with graphite to assist in separation from the plate and from the final casting. Figure 2 shows the base plate partially loaded with pins.

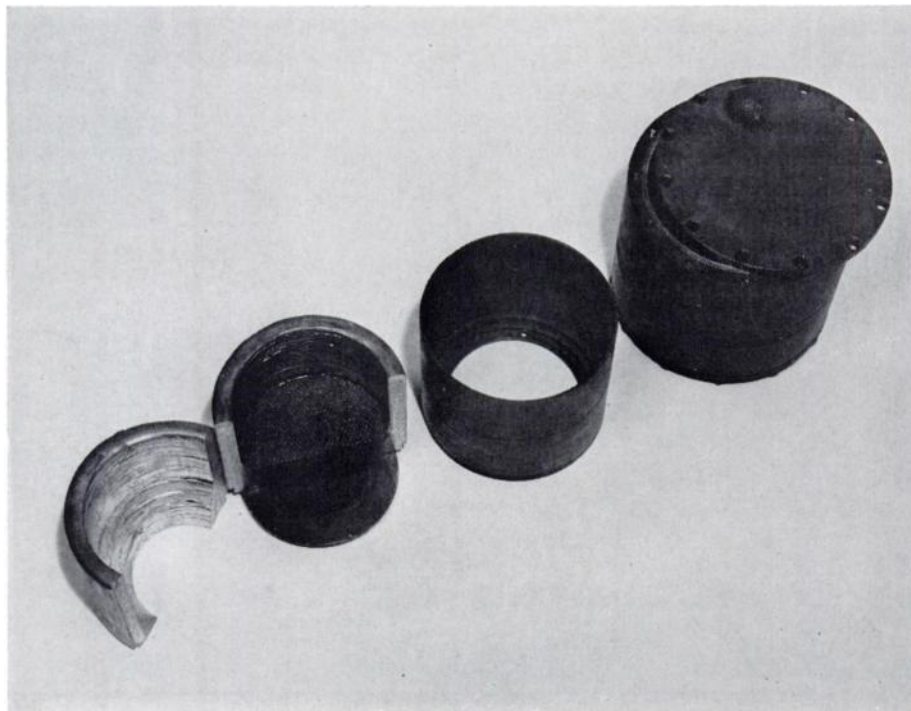


Fig. 3. Setup for Casting Operation. From Left: Half of lead supply other half positioned around pin-base assembly, melting cup and vacuum pot.

The fully loaded base plate is then surrounded by a special casting of lead containing 4% antimony. The purpose of the antimony is to harden the lead. The base plate, pins, and lead are placed in a cup which, in turn, is placed in a pot (Figure 3). After bolting on the top, the pot is placed in a furnace and connected to a vacuum pump after which the assembly is evacuated. The temperature is then raised well above the melting point of lead. Vacuum casting is essential to assure the flow of lead through all of the small clearances between pins. Sufficient lead is used so that when molten, the lead fills up the cup to about $\frac{1}{4}$ " above the tops of the pins.

The assembly is cooled and the base plate and casting is removed from the cup. The lead is then melted away from the tops of the pins with a hand torch so that the pins can be driven from the base plate and casting from the bottom. Both the plate and the pins are reusable many times. The lower end of the collimator is in a finished condition as cast. The large end is carefully machined until the unit is 1" thick for the basic collimator or 1.3" for the fine focus collimator. Thinner units are made by further machining of either face or both. Small machining burrs are removed from the holes with a tapered reamer.

The finished casting is mounted in a threaded brass sleeve which, in turn, screws into a threaded ring on the scanner detector head. Three pins are located in the brass sleeve for mounting an adapter which holds the masking rings or discs on the face of the collimator. The collimator is completed with the installation of a small light bulb in the center hole for use in positioning over the patient. Figure 4 is a set of three completed collimators, 1.3" thick (the maximum thickness using the 2" long pins), 1" and 0.67". Figure 5 shows the adapter mounted on the face of a collimator for holding the rings and discs. In addition a collimator with thinner septa (~ 0.010 ") was prepared by opening the holes in one of the units with a special tapered reamer.

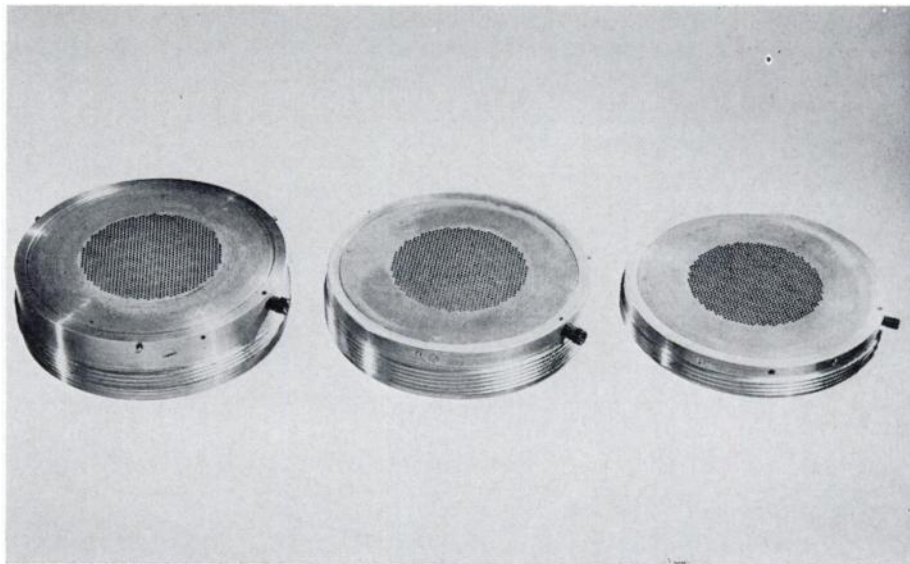


Fig. 4. A set of three completed collimators.

EXPERIMENTAL

A number of tests have been carried out to determine the characteristics and performance of the basic collimator and of several variations. Isoresponse plots for a 1 mm source of ^{99m}Tc in air for three different collimator thicknesses are shown in Figure 6. The loss in resolution is readily seen as the collimator is made thinner. The diameter of the 50% isoresponse level at focus increases from 0.16" for the 1.3" collimator to 0.35" for the 0.67" thick unit while the 1" thick collimator has a diameter of 0.23". It will also be noted that the length of the 50% isoresponse level increases with a decrease in thickness of the collimator. The increase in the counting rate for an extended source with decreasing thickness is $\sim 70\%$ for the 1" collimator over the thicker unit while the thinnest unit has more than twice the rate of the 1" collimator. The commercially available 31-hole collimator has a sensitivity of $\frac{1}{6}$ that of the 1" collimator while the diameter at focus of the 50% isoresponse level is 0.32".

Isoresponse plots were also made for the 1" collimator using a 1" iris or masking ring, which blocked all but the central holes, and with a 1" disc which blocked the central holes. Figure 7 compares the plots under these conditions with the standard collimator. The pronounced elongation of the response curve for the 1" iris is evident as a result of the large reduction in the angle intercepted by the detector. The use of the disc shows the expected narrowing of the depth

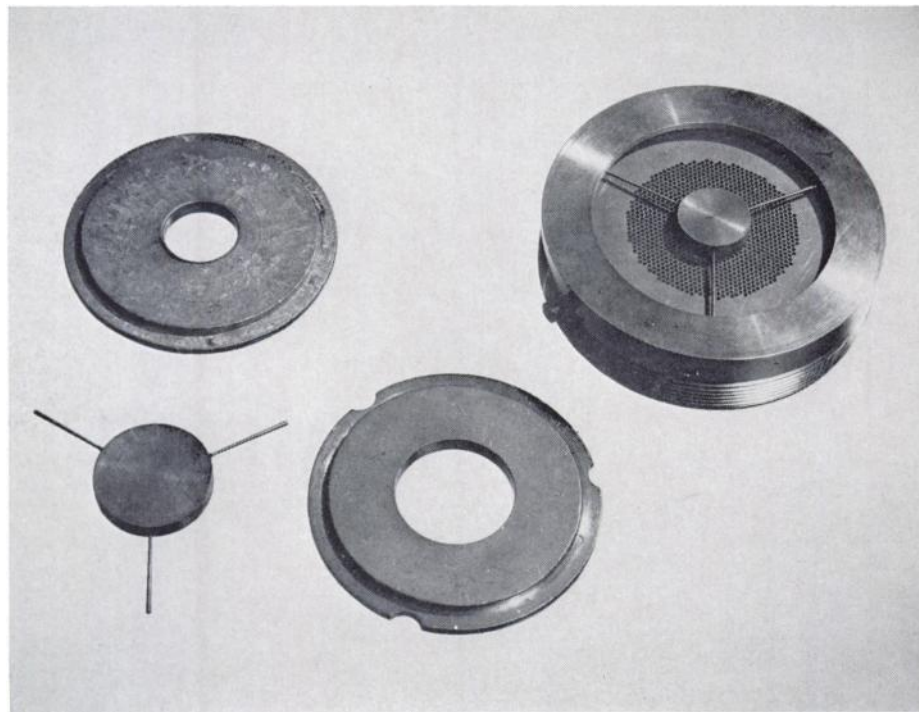


Fig. 5. Adapter for mounting rings and discs on collimator face.

response. Both modifications result in a substantial loss of sensitivity. Table I summarizes some of the data resulting from these studies.

A phantom was fabricated to study the performance of the basic collimator and the various adaptations under simulated scanning conditions. The phantom as shown in Figure 8 is a hollow cylinder of lucite 6" in diameter and 5" deep, with provisions for mounting three equally spaced 1" lucite cylinder either solid or hollow, one near the surface, one at the middle and one near the bottom. The phantom was filled with gelatin containing ^{99m}Tc and using the solid lucite pieces. Scans were made with four collimator variations to see the effect of angle and resolution on the ability to detect voids. All scans were made with the same settings, except for scanner speed and with the middle void at the focus. Figure 9 shows the four scans—upper left the basic 1" collimator, upper right with a 1" iris, lower left the 0.67" collimator and lower right the 1" collimator with a 1.5" disc. It can readily be seen that the collimator with the 1" iris and the small solid angle detects the voids the best, particularly the void closest to the collimator face and with the deepest void visible. The scan with the standard collimator

IO45 HOLE COLLIMATOR ISO-RESPONSE CURVES (IN AIR, 1mm Tc^{99m} SOURCE)

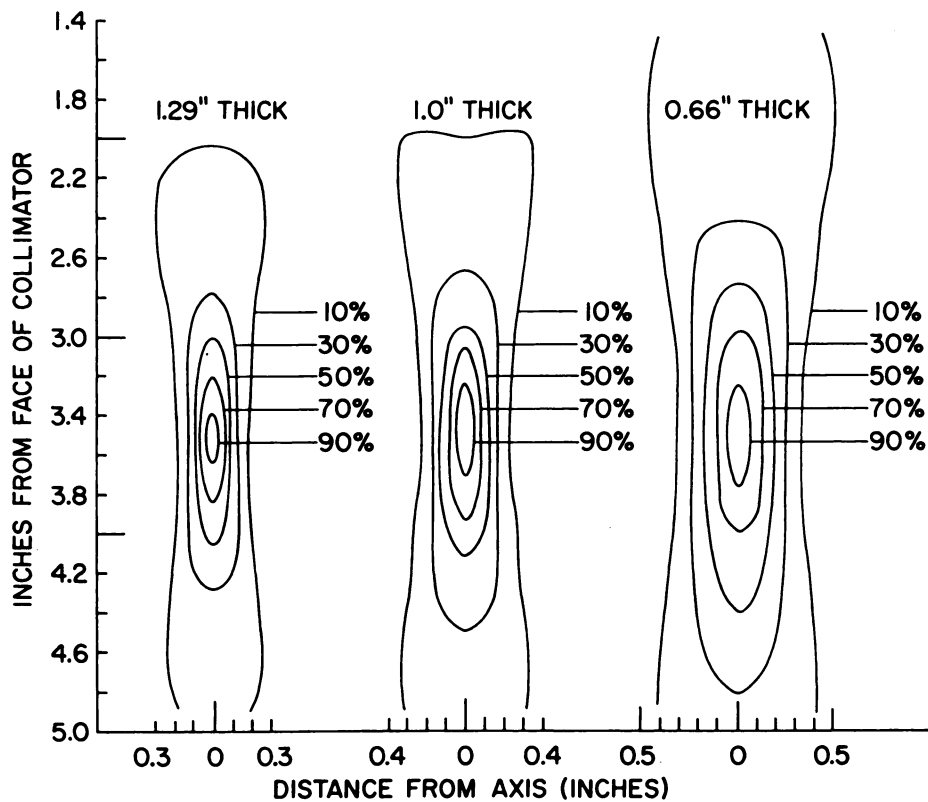


Fig. 6.

ISO-RESPONSE CURVES
 IO45 HOLE COLLIMATOR (1.0" THICK)
 (IN AIR, 1mm Tc^{99m} SOURCE)

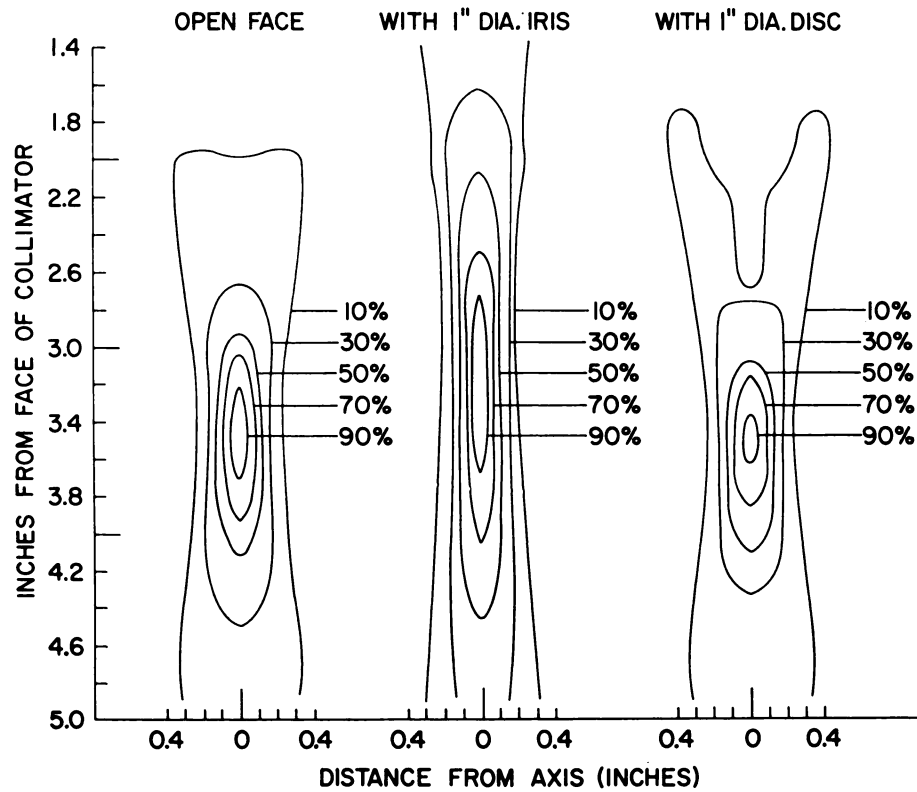


Fig. 7.

TABLE I

Collimator	50% Response		Relative Count Rate
	Diameter	Length	
1.3" thick	0.16"	1.0"	0.6
1.0" thick	0.23"	1.2"	1.0
0.67" thick	0.35"	1.7"	2.2
1.0" with 1.0" iris	0.21"	2.4"	0.2
1.0" with 1.5" disc	0.24"	0.95"	0.4
1.0" thick ¹	0.25"	1.25"	1.3

¹Special collimator with holes reamed to give 0.010" septa thickness.

was scanned at five times the speed of the one using the iris and shows the upper and middle voids with fairly good resolution while the lower void is barely visible, if at all. The thinner collimator doubles the scanning speed, but with some loss of resolution for the upper void with the lower void barely visible and out of focus. The fourth scan with a disc covering the central holes seems to offer no advantage to warrant the loss of counting rate involved for this application. It would appear, on the basis of these scans, that the best combination for scanning a thick organ such as the liver might be the thinner collimator in conjunction with an intermediate diameter iris.

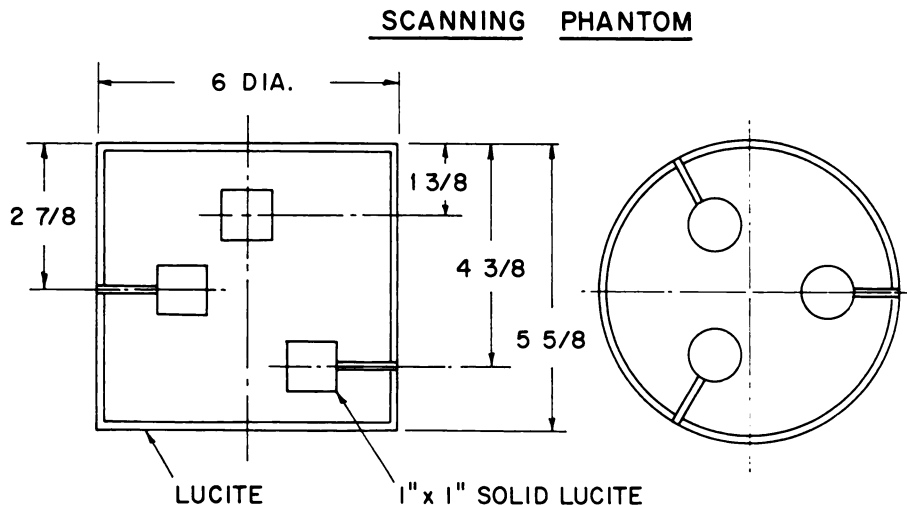
A comparative scan (not shown) of the phantom was made using ^{131}I and the commercial 19-hole collimator. The scans proved to be inferior to those made using $^{99\text{m}}\text{Tc}$ and the special collimator.

Scans were also made under the reverse situation where the phantom was filled with water and activity was placed in the 1" cylinders to simulate brain scanning. Figure 10 shows scans with the plain 1" collimator (above) and with the addition of a 1" iris (below). All three sources can be clearly seen in both scans with the only major difference in the magnification of sources in the case of the open face collimator. This disadvantage is probably more than counter-balanced by the greatly increased scanning speed.

SUMMARY

A special thin septa collimator has been designed for use with $^{99\text{m}}\text{Tc}$ and other low-energy gamma-emitting isotopes in scanning. The basic 1"-thick collimator, designed for use with a 3" detector, has 1045 holes, a 0.015" septa thickness, a 3.5" focal length and a 50% response diameter of ~ 0.23 ".

Variations of the basic collimator are made by making the unit thinner or thicker. Thinner collimators give an increased field of view resulting in higher counting rates, while increased thickness gives higher resolution with decreased



sensitivity. Provisions have also been included for mounting masking rings or discs on the face of the collimator for use in altering the angle intercepted by the detector and thereby changing the depth response of the system.

A simple rapid technique has been developed for vacuum casting the collimator by melting lead around pins mounted in a base plate. Base plate and pins may be reused many times for additional castings.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. James S. Robertson of the Brookhaven Medical Center for computer calculations and to Mr. Clifton Kiesling for technical assistance in collimator fabrication.

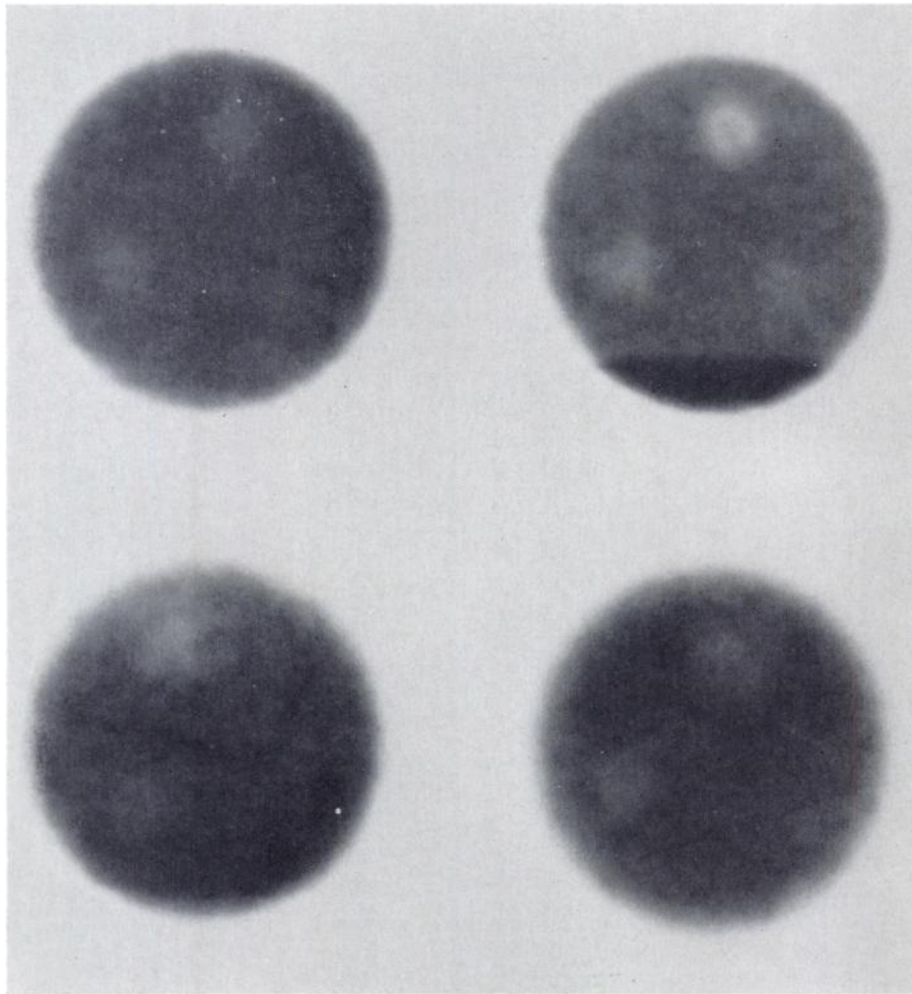


Fig. 9. Simulated liver phantom scans using four collimator variations.

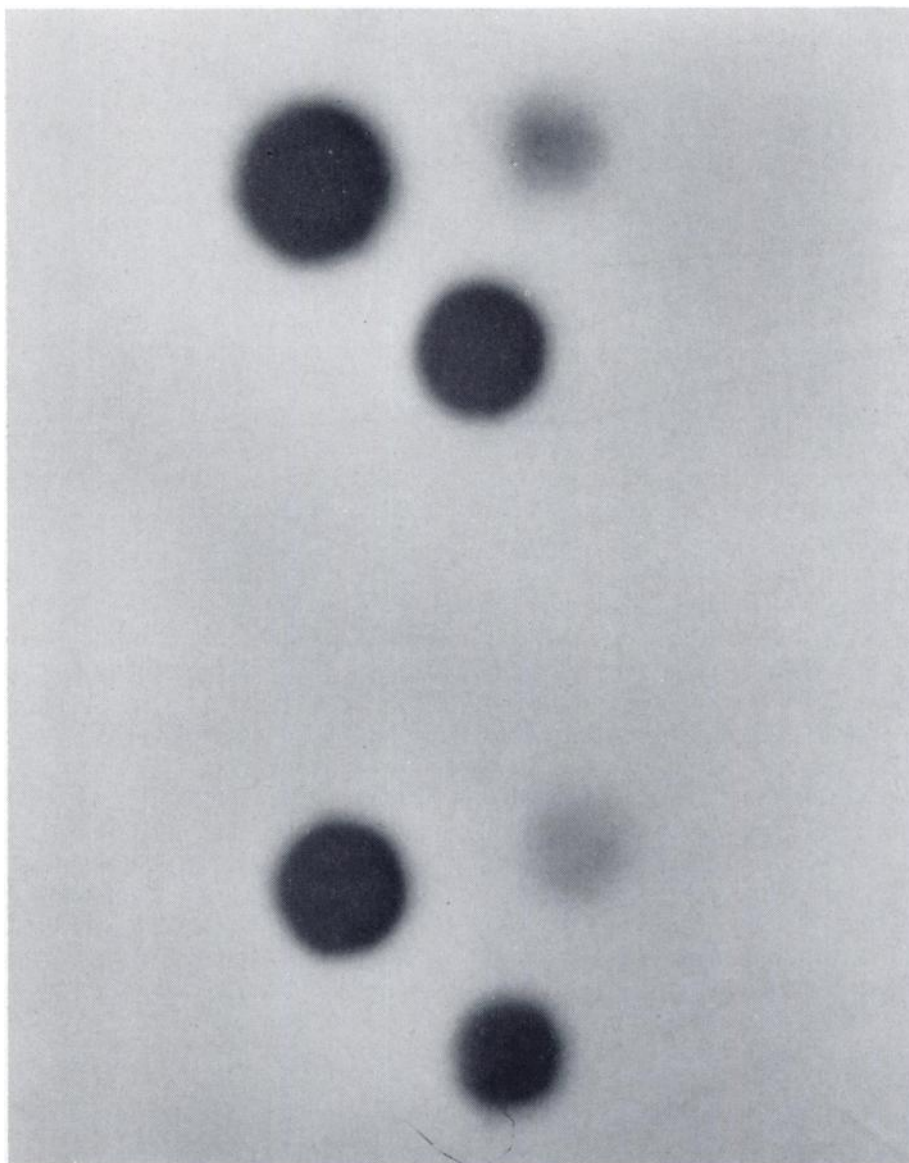


Fig. 10. Simulated brain phantom scans.

REFERENCES

1. HARPER, P. V., BECK, R., CHARLESTON, D. AND LATHROP, K. A. Optimization of a Scan-Method Using ^{99m}Tc . *Nucleonics* **22** (1):50-54 (1964).
2. BECK, R. N. Collimators for Radioisotopes Scanning Systems. Proceedings of the IAEA Symposium on Medical Radioisotope Scanning, Athens, Greece, April 20-24, 1964. In press.
3. HARRIS, C. C., JORDAN, J. C., SATTERFIELD, M. M., GOODRICH, JACK K., M. D., STONE, H. L., PH.D., HILL, REBECCA. A Collimator for Scanning with Low-Energy Photons. *Journal of Nuclear Medicine* **5**:653-656, (1964).