Simultaneous Emission and Fluorescent Scanning of the Thyroid

J. A. Patton and A. B. Brill

Vanderbilt University Medical Center, Nashville, Tennessee

A comparison study of lithium-drifted silicon [Si(Li)] and high purity germanium (HpGe) was performed to explore the feasibility of replacing the current Si(Li) detector with the higher-efficiency HpGe detector. The improved efficiency of HpGe permits the use of collimators with higher resolution, which results in improved image quality over that achieved by the current Si(Li) system in use at Vanderbilt with an overall reduction in sensitivity of 29%. Since a 10 mm thick HpGe detector is about 75% efficient at 140 keV, the added advantage exists of simultaneously (a) imaging the stable-iodine distribution within the thyroid by x-ray fluorescence, and (b) the distribution of administered radiotracers such as [^{99m}Tc] pertechnetate. This comparison study shows that HpGe can compete with Si(Li) in overall detector efficiency, with the added benefits of better collimation to improve spatial resolution plus the simultaneous imaging of Tc-99m, all at the same equipment cost.

J Nucl Med 19: 464–469, 1978

The first clinical system for in vivo mapping of the stable-iodine distribution within the thyroid gland was developed at the Argonne Cancer Research Hospital in 1968 (*1*). Since that time, work has centered on improvements in sensitivity and resolution of the technique. Currently there are two commercially available systems*† with different source-detector geometries. Both system use Am-241 as the irradiation source and a 25-mm-diameter lithium-drifted silicon [Si(Li)] crystal as the detector. Several systems are now in clinical use and evaluations of these systems have been reported (*2–4*).

It has been suggested that germanium detectors may provide an alternative to Si(Li) for x-ray fluorescence scanning of the thyroid (*2*). We have studied this possibility by using a high-purity germanium detector (HpGe) in an attempt to improve the sensitivity and resolution of our fluorescent system. If feasible, this replacement could also permit the detector system to be used for routine emission scanning of the thyroid with [^{99m}Tc] pertechnetate, due to the significantly greater efficiency of germanium at higher energies. This is of special interest to us because of ongoing work in our laboratory in the differentiation of benign and malignant solitary nodules that are "cold" on radioisotope scans on the basis of the iodine content of the nodule (*5*). Thus, the combination of germanium detector and fluorescent source could possibly become a complete thyroid-imaging system to evaluate both the uptake and storage functions of the gland.

MATERIALS AND METHODS

Our original fluorescent system (Fig. 1A) consisted of 16 individual disk sources, each containing 1 Ci of Am-241, arranged in a circle. It served as a model for one of the commercial systems*, and is still in routine use in our Nuclear Medicine Clinic. Each source is individually collimated to a point 1.75 in. from the face of the collimator. Situated concentric with the sources, but shielded from them, is a high-resolution lithium-drifted silicon [Si(Li)] detector* (25 mm diameter, 5 mm thick). The detector is collimated by a single hole tapered to the focal point of the field of irradiation. Thus most of the

---

Received Aug. 11, 1977; revision accepted Dec. 19, 1977.

For reprints contact: James A. Patton, Vanderbilt University Medical Ctr., Div. of Nuclear Medicine, Nashville, TN 37232.

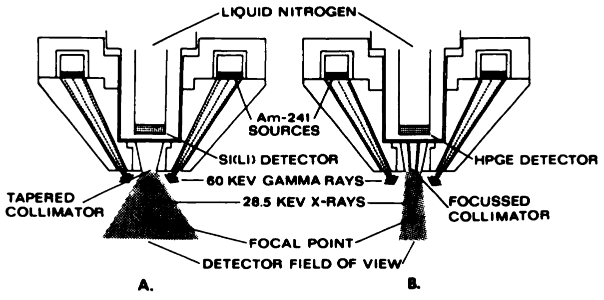

FIG. 1. Comparison of configurations for (A) original Si(Li) detector with tapered, single-hole collimator, and (B) new HpGe detector with focussed collimator for x-ray fluorescence scanning of thyroid. Shaded areas correspond to collimator fields of view.

spatial resolution of the system results from the collimation of the sources. The intersection of the detector's field of view and the focusing of irradiation provides a relatively uniform response over a depth of 0.75 in., centered at the focal point. The system is mounted on the upper drive mechanism of a commercial rectilinear scanner‡. Signal processing is handled by a linear amplifier and single-channel analyzer, and the resulting digital signals are recorded on one of the scanner's two photoplotters. Scan speed, line spacing, photoplotter intensity, and digitization frequency are standardized so that calibrations and meaningful comparisons between studies can be made from the film recordings themselves. The rectilinear scanner and the detector's electronics are also interfaced to a PDP-9 computer for on-line acquisition of digital data. Approximately 1,100 clinical studies have been performed with this system.

In order to evaluate the capabilities of germanium, the Si(Li) detector was temporarily replaced by a HpGe detector 25 mm in diameter by 10 mm thick*. The linear amplifier was replaced by a state-of-the-art amplifier with greater count-rate capability. In order to reduce the number of undesired counts from singly- and multiply scattered Compton photons that enter the detector, the tapered collimator was replaced by a seven-hole focussed collimator so designed that its focal point coincides with the focal point of the source collimators (Fig. 1B). A second single-channel analyzer was added to the system in order to place a window bracketing the 140-keV peak of Tc-99m. This was interfaced to the second photoplotter and also to the PDP-9 computer.

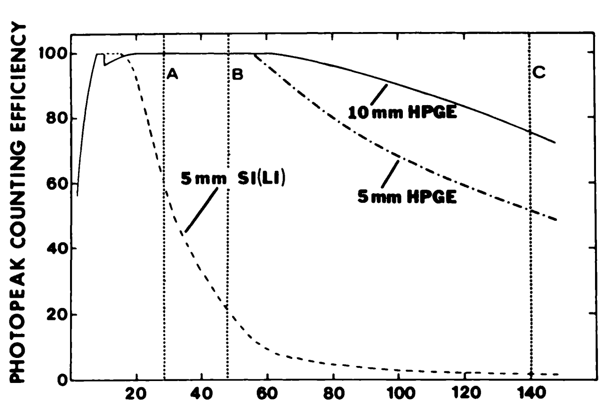

FIG. 2. Photopeak counting efficiency contrasted with energy for a 5-mm-thick Si(Li) detector, a 5-mm-thick HpGe detector, and a 10-mm-thick HpGe detector; comparing efficiencies at energies of iodine x-ray (A), the scattered photons from Am-241 (B), and the gamma ray from Tc-99m (C).

RESULTS

The two detectors were first compared using the original tapered-collimator configuration shown in Fig. 1A. For the comparison, a plane source of stable iodine was embedded in a paraffin phantom and placed at the focal point of the scanning system. The iodine content of the phantom was adjusted such that the count rate obtained was roughly equivalent to that from a normal thyroid gland. With the HpGe detector, an integral count rate of 65,000 c/sec was obtained compared with 12,500 c/sec with the Si(Li) detector. This difference is due to the greater efficiency of germanium at energies above 16 keV, as shown in Fig. 2. At this count rate with the HpGe detector, a severe degradation in spatial and energy resolution resulted, and it was necessary to reduce this count rate. This was accomplished by constructing a seven-hole focussed collimator to replace the tapered collimator (Fig. 1B). This collimator has a geometric resolution of 0.50 in. and a focal length of 1.75 in. and it reduces the penumbra of the detector field of view. This significantly reduced the area from which primary and Compton-scattered photons could reach the detector (compare the shaded areas in Fig. 1). With this collimation, the integral count rate was reduced to 20,000 c/sec, which is within the count-rate capability of the detector and associated electronics. Energy spectra collected from the two detector configurations are shown in Fig. 3 using the plane source. The superior energy resolution of the HpGe system can easily be observed in the iodine x-ray region. This is due partly to differences in detectors and partly to differences in electronics. The HpGe detector had an energy resolution of 744 eV full width at half maximum of the photopeak (FWHM) compared with the Si(Li) detector's resolution of 883 eV measured at 27.5 keV and 1,000 counts per second. When the count rate was increased to 10,000 counts per second, however, the values were 799 eV and 1544 eV, respectively. This degradation in resolution with the Si(Li) detector was due to the use of an outdated

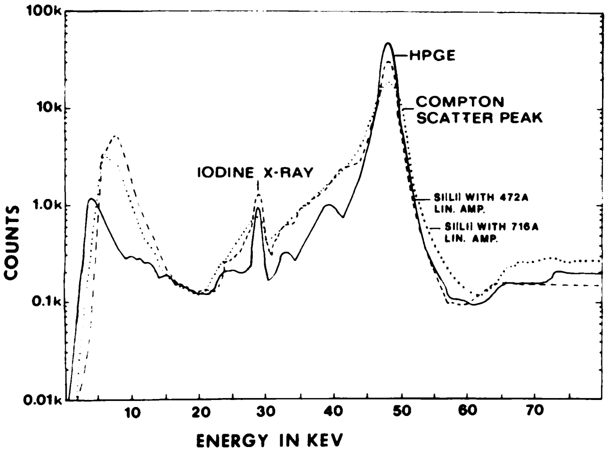

FIG. 3. Energy spectra collected from original Si(Li) detector with tapered collimator (dashed line), and HpGe detector with focussed collimator (solid line), each for 300 sec, from plexiglass phantom containing iodine embedded in a paraffin scatter medium, in concentrations comparable with that in normal thyroid. Replacement of original linear amplifier (716A) with new state-of-the-art module (472A) improved resolution of Si(Li) detector system (dotted line).

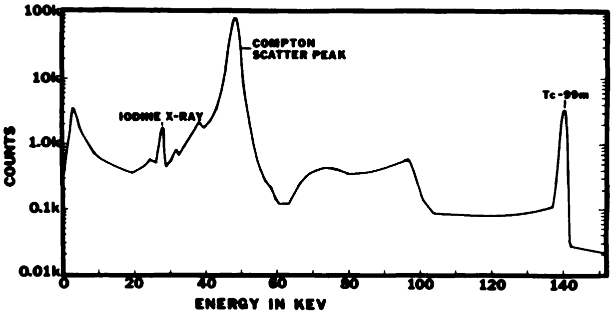

FIG. 4. Energy spectrum collected with HpGe detector from iodine-containing phantom to which 100 μCi of Tc-99m had been added to simulate simultaneous imaging situation in thyroid clinic.

linear amplifier. Replacing this component with a state-of-the-art module—which has greater count-rate capability, lower noise, and more versatility in shaping-constant selection significantly improved the capability of the silicon detector system as shown by the spectra in Fig. 3 (FWHM energy resolution of 994 eV at 27.5 keV at 10,000 counts per second).

The imaging comparisons described in the remainder of this report were performed with the original system, since this was the configuration in routine clinical use at Vanderbilt. A 1.5-keV window was set to bracket the 28.5-keV iodine Kα x-ray peak with the Si(Li) detector and a 1.0-keV window was used with the HpGe detector. These windows were approximately equal to the FWHM values stated above. Table 1 shows window count rates from the phantom along with background counts in the window with only paraffin present to provide a scatter geometry similar to that of the neck. From these measurements, it is observed that a reduction in sensitivity of 29% was obtained by using the configuration of the HpGe detector and focussed collimator instead of the Si(Li) detector and tapered collimator arrangement. Peak-to-background ratios were only slightly reduced (3.5 to 3.3). Thus it was concluded that the germanium detector was a viable alternative to lithium-drifted silicon for fluorescent scanning applications. (Use of the state-of-the-art amplifier with the Si(Li) detector increases the window count rates, with an improvement in the iodine-to-background ratio to 4.0, as shown in Table 1, thereby yielding an advantage in image contrast in favor of the Si(Li) detector.)

An added benefit from the use of germanium is its photopeak detection efficiency in the 75- to 150-keV range, due to its proton number and density both being greater than that of silicon. Figure 2 shows the efficiency at 140 keV to be about 75% compared to less than 2% for Si(Li). (For purposes of comparison, an efficiency curve for a 5-mm-thick HpGe detector is also shown.) It also becomes feasible, therefore, to use the germanium system for imaging radioactive distributions of low-energy emitters in

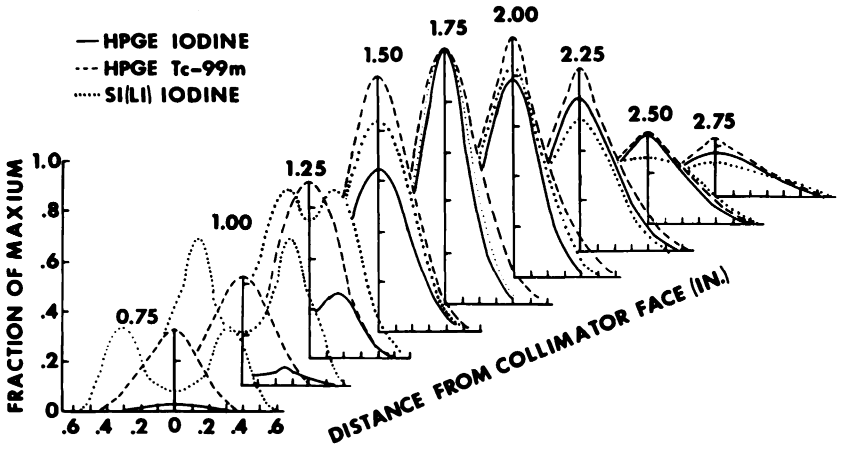

FIG. 5. Line spread functions measured with HpGe detector and focussed collimator from a line source of stable iodine and a line source of Tc-99m. Line spread functions measured with original Si(Li) detector and tapered collimator are shown for comparison.

TABLE 1. CONFIGURATIONS INVOLVING COMPARISON OF DIFFERENT DETECTOR LINEAR AMPLIFIER AND COLLIMATOR

			Window			
Detector	Lin Amp	Collimator	CPS Integral	CPS Iodine	CPS Bkgd	Iodine Bkgd
Si(Li)	716A	Tapered	12,500	140	40	3.5
HpGe	472A	Tapered	65,000	*	*	*
HpGe	472A	Focussed	20,000	100	30	3.3
Si(Li)	472A	Tapered	20,000	200	50	4.0

---

* Measurements not valid due to degradation in resolution at this count rate.

small organs such as the thyroid. Figure 4 shows a simultaneous fluorescence and radioactive emission spectrum collected from the plane phantom of iodine plus 100 μCi of Tc-99m (equivalent to a 1% uptake from a 10 mCi dose) embedded in paraffin. From this energy spectrum it appears that the sensitivity of the system is sufficient to provide radioactive images of statistical quality comparable with those of the fluorescent images. In fact, the radioactive image is statistically superior, due to the fact that the iodine x-rays are sitting on a high Compton background that reduces image contrast. A second single-channel analyzer was set to bracket the 140-keV peak of Tc-99m with a 1.5-keV window for emission scanning. Line spread functions (LSF's) were collected from the germanium system using a line source of stable iodine and a line source of Tc-99m, and are compared with the original silicon detector system in Fig. 5. FWHM of the LSF's at the focal point (1.75 in.) were 0.32, 0.47, and 0.37 inches, respectively. These values are comparable with the value of 0.40 in. for the 5-in. rectilinear scanner‡ with the 24L collimator (*6*). The superior spatial resolution of the fluorescence technique over the radiotracer technique is due to the double collimation—i.e., collimation of both the source and the detector. These line spread measurements show that it is possible to collect simultaneously images of the stable-iodine distribution by x-ray fluorescence, and of the uptake distribution from pertechnetate with reasonable spatial resolution and record them on separate photoplotters and in the computer.

Images of a thyroid phantom containing 20 mg of stable iodine and 100 μCi of Tc-99m are shown in Fig. 6. The superior spatial resolution of the fluorescence technique is again demonstrated in these images. Although the spatial resolution of the Tc-99m image is not as good as that obtained with the rectilinear scanner, for example, it appears to be sufficient for regional comparisons of uptake contrasted to iodine content.

Fluorescent images of three volunteers are shown in Fig. 7. The images at the bottom were made with the Si(Li) detector and single-hole collimator and the images at the top with the HpGe detector and focussed collimator. The same scan speed, line spacing, and photoplotter intensities were used in all cases. The slight decrease in sensitivity of the germanium configuration is observed, along with the improvement in spatial resolution due to the addition of the focussed collimator.

Figure 8 shows fluorescent and radiotracer images obtained simultaneously from five patients using the HpGe detector system. One can observe from these studies that the resolution of the fluorescent scan is indeed superior. It can also be seen, however, that the resolution of the radiotracer scan is sufficient to make comparisons between images. This comparison is especially useful in studies where the iodine

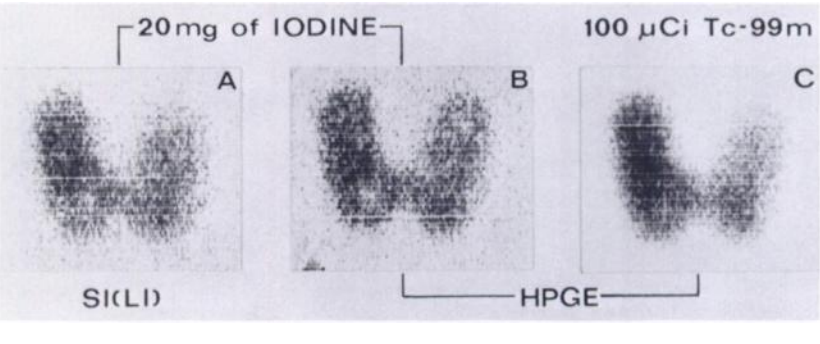

FIG. 6. Photoplot images obtained from thyroid phantom containing 20 mg of iodine and 100 μCi of Tc-99m. Scan A was performed with Si(Li) detector to image iodine distribution. Scans B and C were performed simultaneously with HpGe detector to image both iodine and Tc-99m distribution. Same speed and intensity settings were used in each scan. Scan time was 15 min.

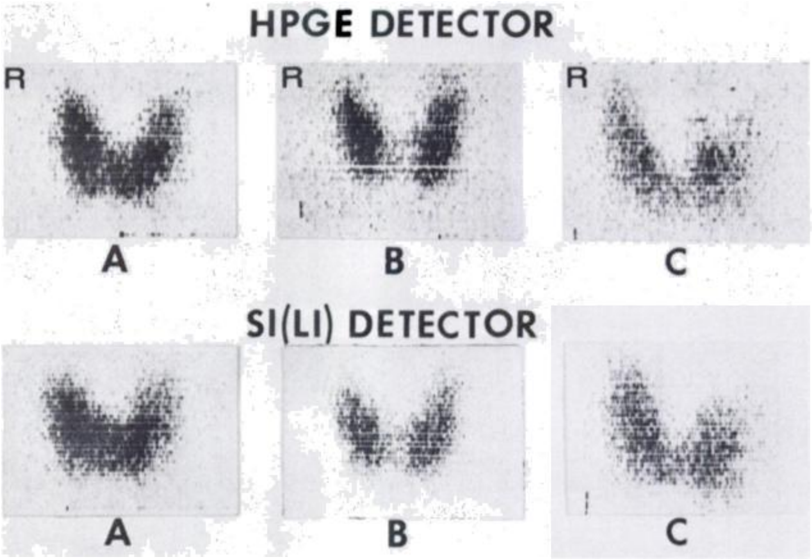

FIG. 7. X-ray fluorescence scans of thyroidal iodine distribution in three volunteers obtained with HpGe and Si(Li) detectors. The same speed and intensity settings were used in each scan. Scan time was 15 min.

and pertechnetate distributions differ—as in Fig. 8D and E.

DISCUSSION

From these comparison studies it appears that germanium detectors can be used in place of the currently used Si(Li) detectors for x-ray fluorescence scanning of the thyroid. The detector's count rate is significantly increased due to the greater efficiency of germanium, but this can be handled effectively through the addition of a focussed collimator to limit the field of view of the detector. This feature actually improves the overall spatial resolution of the system. Also, the greater efficiency is a positive factor because it permits the system to be used as an imaging device for low-energy tracers such as Tc-99m. This makes possible a complete imaging evaluation of the uptake and storage properties of the thyroid simultaneously with the same system. Errors due to patient repositioning and different display readouts are eliminated (e.g., x-ray film with 1:1 image ratios contrasted with Polaroid film of reduced size). The fluorescent image and the Tc-99m emission image can then be overlaid to compare the functional status of the thyroid on a regional basis. Another distinct advantage of high-purity germanium is the elimination of the lithium-drift process—the detector can be allowed to warm up to room temperature without certain detector damage. This cannot be done with lithium-drifted germanium and some investigators have experienced problems in recycling lithium-drifted silicon. Moreover, germanium detectors currently are available with diameters greater than 25 mm. This permits increase in the

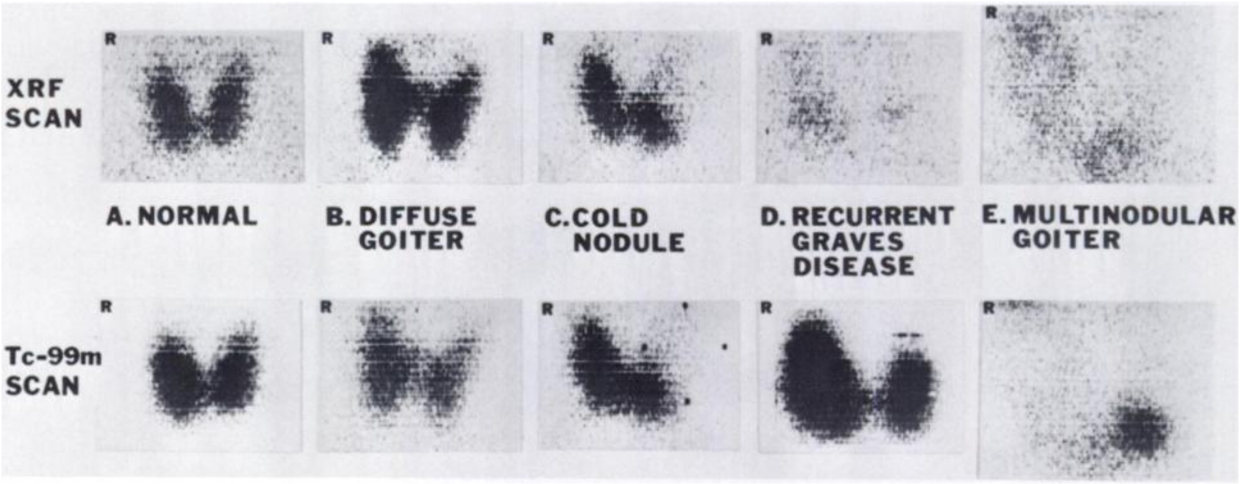

FIG. 8. Images from five patients with various thyroid conditions. The stable iodine and [^{99m}Tc] pertechnetate distributions are recorded simultaneously on separate photoplotters with the HpGe detector system.

sensitivity of the system and further improvement in spatial resolution through the use of higher-resolution collimators.

The use of HpGe instead of Si(Li) removes some of the criticism of x-ray fluorescence systems because the original single-purpose device can now become a multipurpose instrument. The addition of a source opposite to the detector would permit the system to be used for transmission studies in determining bone mineral content for example (*3*).

On a cost-comparison basis, a 25-mm-diameter HpGe detector is priced approximately the same as a Si(Li) detector of the same diameter. Thus there is no additional cost to obtain the additional advantages of germanium.

CONCLUSION

From these comparison studies it appears that germanium is a viable alternative to lithium-drifted silicon for x-ray fluorescence imaging of the thyroid. Although the net count rate in the iodine window and the peak-to-background ratio are reduced with the germanium detector, the reduction does not appear to be sufficient to appreciably alter image quality. The use of germanium also permits the imaging of distribution of low energy emitters such as Tc-99m simultaneously with the stable-iodine distribution. Although the spatial resolution of the system in imaging radiotracer distributions is slightly worse than state-of-the-art systems, it is sufficient to make regional comparisons of uptake contrasted with iodine content. Further work in the area of collimator design could improve the resolution of the system. We believe that the use of germanium will significantly enhance the capabilities of this already useful diagnostic instrument. Another consideration emphasized by this study is the importance of supporting the semiconductor detectors with circuitry that can adequately handle the high count rates associated with x-ray fluorescence applications without degrading energy resolution. We have shown that germanium can replace Si(Li) for x-ray fluorescence applications, and as a bonus we found that the quality of the fluorescent images obtained with our original Si(Li) detector system could be improved through proper matching of detector and its signal-processing circuits.

FOOTNOTES

* Ortec, Inc., Oak Ridge, Tenn.
† Kevex, Inc., Burlingame, Cal.
‡ Ohio-Nuclear, Solon, Ohio.

ACKNOWLEDGMENTS

We are indebted to Ortec, Inc. for the loan of the germanium detector used in this work and to the Isotope Development Group at Oak Ridge National Laboratory for loan of the Am-241 sources. Also we express appreciation to the technicians and clinicians of the Nuclear Medicine Division at Vanderbilt University Medical Center for their assistance in this evaluation. This work was supported by N.I.H. Grant AM 17484-03.

REFERENCES

1. Hoffer PB, Jones WB, Crawford RB, et al: Fluorescent thyroid scanning: A new method of imaging the thyroid. *Radiology* 90: 342–344, 1968

2. Hoffer PB, Beckerman C, Bowie J, et al: Fluorescent thyroid scanning: What's new. In *Semiconductor Detectors in Medicine.* Oak Ridge, Tennessee, USAEC Conference 730321, 1973, pp 238–248

3. Patton JA, Brill AB, Blanco J, et al: Experiences with semiconductors in imaging and function studies at Vanderbilt. In *Semiconductor Detectors in Medicine.* Oak Ridge, Tennessee, USAEC Conference 730371, 1973, pp 254–294

4. Gillin MT, Thrall JH, Corcoran RJ, et al: Evaluation of a thyroid fluorescent scanning system of concentric source-detector design. *J Nucl Med* 18: 163–167, 1977

5. Patton JA, Hollifield JW, Brill AB, et al: Differentiation between malignant and benign solitary thyroid nodules by fluorescent scanning. *JNucl Med* 17: 17–21, 1976

6. Hine GJ, Erickson JJ: Advances in Scintigraphic Instruments. In *Instrumentation in Nuclear Medicine,* Vol. 2. New York, Academic Press, 1974, p 8