^{123}I THYROID MEASUREMENTS WITH A Ge(Li) DETECTOR

V. J. Sodd, H. N. Wellman and B. M. Branson

National Center for Radiological Health, Cincinnati, Ohio

For the past several years, most *in vivo* thyroid measurements have been made with ^{131}I and a NaI(Tl) detector. The NaI(Tl) detector is used primarily because of its relatively good resolution characteristics and its availability in the thick layers needed for efficient absorption of the 364-keV gamma rays of ^{131}I.

More recently, however, advances have been made in detector technology and radiopharmaceutical production which suggest a more efficient technique. First of all, lithium-drifted germanium—Ge(Li)—detectors, which are tenfold better in resolution than NaI(Tl), are now commercially available in large-enough sizes to measure efficiently low-energy gamma radiation ($E \lessapprox 200$ keV). These detectors range in size from about 4 cm^3 for a large planar-drifted device to as high as 54 cm^3 for a "state-of-the-art" coaxial device (*1*).

Second, ^{123}I is now commercially available.* Because of its shorter half-life and minimal emission of charged-particle radiation, this radionuclide is regarded as a more ideal radioisotope of iodine than ^{131}I for low-dose *in vivo* measurements (*2–4*). Furthermore, because ^{123}I emits primarily a 159-keV gamma ray, it requires a much thinner detector for efficient measurement than does ^{131}I.

The combined consideration of these two recent developments suggest the use of a high-resolution Ge(Li) detector for efficient low-dose ^{123}I thyroid measurements. We explored this possibility using a planar-drifted Ge(Li) detector with a sensitive volume of 4.2 cm^3 for measuring human thyroid uptake of ^{123}I *in vivo*.

The efficiency of this detector for measuring ^{123}I was determined using a modified ORINS neck phantom (*5*) which was used successfully by Wellman *et al* (*6*) for NaI(Tl) calibration. In addition, the ^{123}I counting efficiency for a given thyroidal measurement when the thyroid depth is unknown was determined using the photopeak-area to scatter-area (P/S) ratio. This technique is based on the fact that the ratio of the photopeak area to the scatter area varies nearly proportionally with the depth of the simulated thyroid in the neck phantom. This proportionality is then used to infer an ^{123}I counting efficiency in an actual thyroid measurement by comparing the ratio of the photopeak area to scatter area to the calibration curve obtained with the neck phantom.

EXPERIMENTAL CONSIDERATIONS

The ORTEC† 7-mm-thick Ge(Li) detector with an active area of 6 cm^2 was mounted in a 2.75 in. o.d. × 2.50 in. high aluminum vacuum-jacket conduction-rod assembly which was positioned vertically in a 25-liter Dewar flask. This detector was coupled to a low-noise, charge-sensitive amplification system and a multichannel analyzer. The system resolution (FWHM) was 3.4 keV or 0.5% for 661.5-keV gamma ray of ^{137}Cs. The subject to be counted was seated comfortably in a chair with the Dewar flask between his legs. In this position, the subject could lean forward with the uncollimated detector centered just below the thyroid cartilage over the isthmus of the thyroid.

The efficiency for *in vivo* counting of ^{123}I in human thyroids was determined using a modified ORINS thyroid neck phantom (*5*) which has been described in detail elsewhere (*6*). This Lucite phantom held a pair of 1-in. o.d., 15-ml, thyroid-simulating ^{123}I standards with their centers at 1.8, 2.3, 2.8, 3.3 or 3.8 cm from the detector face. Counting rates for ^{123}I standards at these distances from the detector were used to determine the efficiency for counting ^{123}I in thyroid glands located at various

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* The Isotopes Development Center of Oak Ridge National Laboratory announced in March 13, 1967, *Newsletter* that it will produce and distribute ^{123}I.

Received Jan. 3, 1968; revision accepted Sept. 19, 1960.

For reprints contact: V. J. Sodd, National Center for Radiological Health, Nuclear Medicine Unit, Radioisotope Laboratory, Cincinnati General Hospital, Cincinnati, Ohio.

† Oak Ridge Technical Enterprises Corp. Mention of commercial products does not constitute endorsement by the Public Health Service.

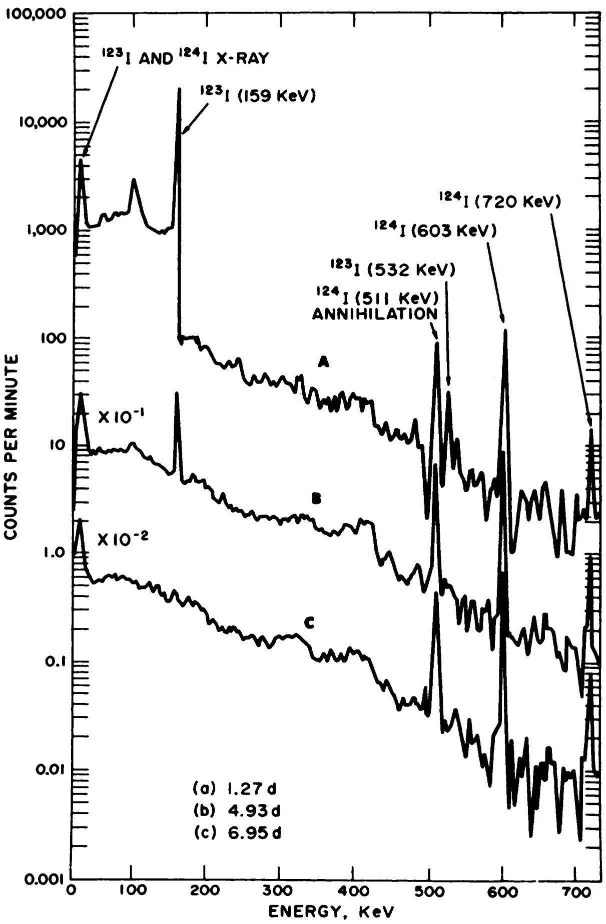

FIG. 1. ^{123}I *in vivo spectra.*

depths in the neck. The standards were counted with the detector centered over the thyroid area of the phantom.

The effective depth of the thyroid gland in the individual being counted and the *in vivo* ^{123}I counting efficiency was inferred from the P/S ratio of the neck measurement compared to ratios obtained using the phantom with sources at various depths.

RESULTS

In vivo thyroid measurements. The spectra in Fig. 1 were obtained at various times after 95 μCi of ^{123}I were administered orally. The administered activity was dissolved with 1.6-μg iodide carrier in 26 ml of 0.1 *N* NaCl solution.

Figure 1A was accumulated during a 1-min count 1.27 days after ingestion. By this time, the 13.3-hr ^{123}I had undergone 2.3 half-lives. The prominent peak at 159 keV represents the principal ^{123}I gamma ray. This peak contains 39,000 total counts with a 2σ counting error of ± 1%. The resolution (FWHM) of the 159-keV peak is 3.2 keV or 2.0%. The broad peak at 26–32 keV represents primarily the 27.2–31.7-keV x-rays of ^{123}I with slight contributions from other radioiodine x-rays which have the same energies. The skewed peak at 100 keV is probably due to backscatter of the 159-keV photons. The 532-keV peak is also caused by an ^{123}I gamma ray which is only 2% abundant compared to the 159-keV gamma ray.

Also present in Fig. 1A are the 511-keV annihilation peak and the 603 and 702-keV gamma-ray peaks of ^{124}I. At the time this spectrum was counted, the ^{124}I content was 6.7% of the ^{123}I concentration.

The spectrum in Fig. 1B was obtained 4.93 days or 8.9 half-lives after ^{123}I ingestion. The 159-keV gamma-ray peak of ^{123}I is still prominent and contains 460 ± 20 net cpm. The 2σ counting error of ± 20 cpm results from a 5-min count and a background in the peak region of 200 cpm. The gamma-ray peak of ^{123}I at 532 keV is no longer evident because of interferences from the ^{124}I peaks. The x-ray peak at 26–30 keV is now caused chiefly by the x-rays of ^{124}I.

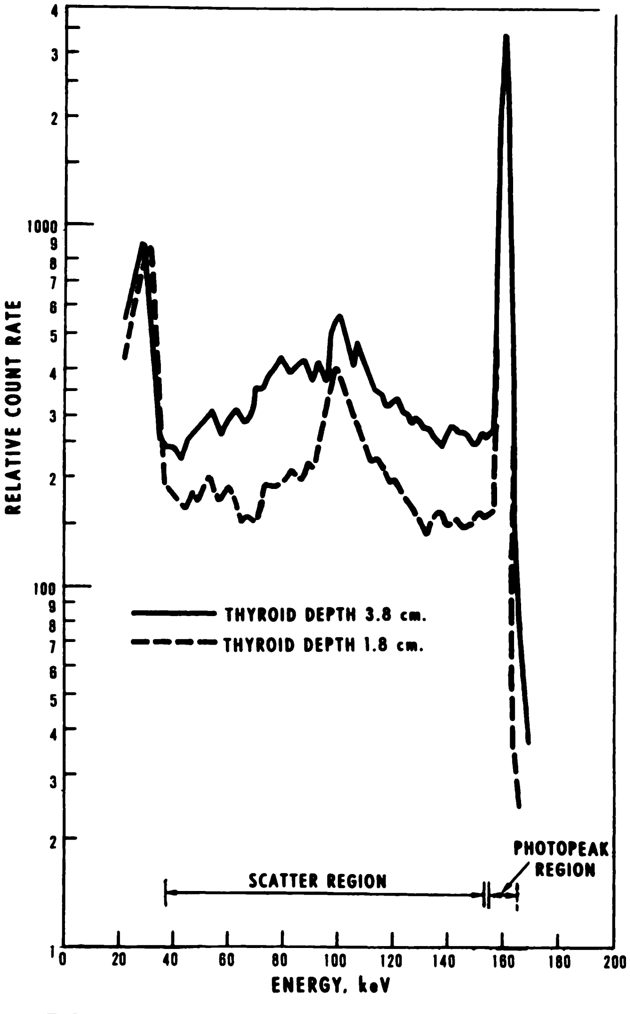

FIG. 2. Variation of ^{123}I spectra with source depths in Lucite phantom.

In Fig. 1C, obtained 6.95 days or 12.5 half-lives of ^{123}I after ingestion, the 159-keV gamma-ray peak of ^{123}I is no longer evident, leaving only the photon peaks of 4.2-day ^{124}I.

Neck phantom. Some typical Ge(Li) spectra, obtained using the neck phantom with the standard thyroid-simulating ^{123}I sources centered 3.8 and 1.8-cm from the detector, are shown in Fig. 2.

The 159-keV photon peaks found in these spectra have been adjusted to equal height to emphasize the differences in the lower-energy scatter region at various source depths. The areas under the photopeak and scatter regions, indicated at the bottom of Fig. 2, were integrated and their ratio was calculated. The scatter region included Compton scatter as well as the broad backscatter peak at ~ 100 keV; it did not include any of the area under the 0–38-keV x-ray region. A plot of the P/S ratio as a function of the distance of sources from the detector is shown in Fig. 3A. It can be seen that the P/S ratio varies smoothly with the depth of the sources from 1.8 to 3.8 cm. The efficiency of the detector for counting ^{123}I in these sources at various depths in the neck phantom is shown in Fig. 3B. The errors shown in Fig. 3A and B are 1σ counting errors.

Uptake determination. Assuming that the scattering of gamma rays in the phantom approximates that in the human neck, a thyroid depth can be determined from the P/S ratio of an actual neck measurement using the standard P/S ratio-vs.-depth curve in Fig. 3A. After the thyroid depth for an actual neck measurement is determined, the ^{123}I counting efficiency for a given thyroid depth is then obtained from the curve of efficiency as a function of source distance for the neck phantom which is shown in Fig. 3B. The fractional thyroid uptake is then determined as a ratio of the ^{123}I activity in the thyroid (corrected for counting efficiency) to the standard ^{123}I activity administered to the patient. Using this technique and the standard curves shown in Fig. 3A and 3B, the 30-hr thyroid uptake of ^{123}I measured in two subjects was 2.0 and 22.6%. The thyroid uptake of ^{123}I in the same two subjects were respectively, 1.7 and 18.7% when measured with a dual ¼ in.-thick x 3 in.-o.d. NaI(Tl) detector. This dual detector was in contact with the subject neck with the 3 in.-o.d. surfaces 90 deg from each other. The measurements on the NaI(Tl) detector were made about 15 min before those on the Ge(Li) detector.

DISCUSSION

The thyroid uptakes measured in the two subjects with the Ge(Li) detector agree within 0.3 and 3.9% uptake units of those measured with the dual NaI(Tl) detector. The authors feel that this is very good agreement in view of the fact that a normal thyroid can vary in percent uptake between 15 and 45%.

A distinct advantage of the Ge(Li) detector is its resolution of 3.2 keV which is a factor of 10 times better than that of the dual NaI(Tl) crystals. The highly resolved spectra are easily "spectrum stripped" to give accurate P/S ratios even when more than one photopeak is present. This advantage makes the Ge(Li) diode a practical detector for making two or more *in vivo* measurements simultaneously. Furthermore, the high resolution results in narrow photopeaks which are associated with only a narrow energy band of background counts. The low background results in a low minimum-detectable activity (MDA).

The minimum-detectable activity, which is defined (*7*) as the activity that increases the analyzer count in the peak channels by three times the standard deviation of the background, was calculated for the Ge(Li) detector under both "normal" and "contaminated" background conditions. The normal

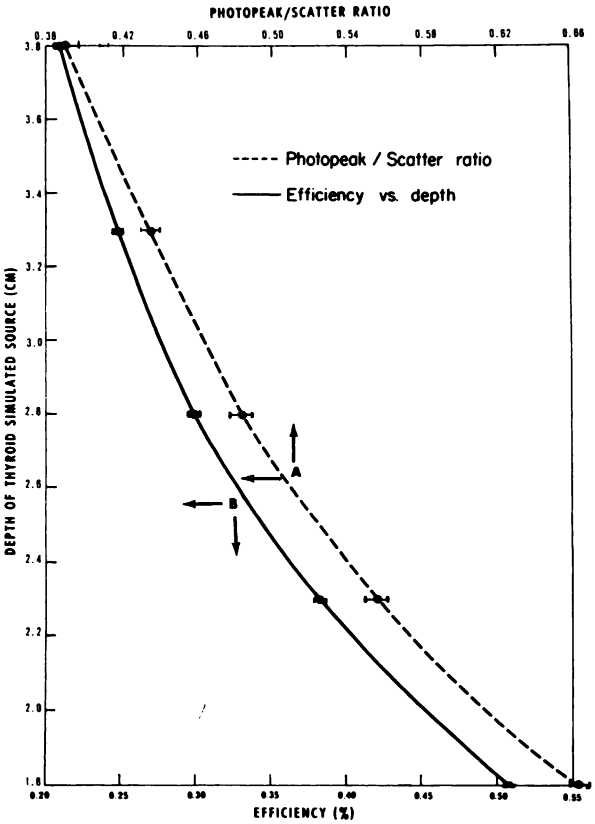

FIG. 3. Photopeak/scatter ratio and efficiency as function of depth of thyroid-simulated source.

background is obtained when one measures a subject before ^{123}I administration. After administration, the contaminated background is caused by the ^{124}I scatter interference in the ^{123}I photopeak region.

Because of the 7.6-fold longer half-life of 4.2-day ^{124}I than 13.3-hr ^{123}I, the ^{124}I contaminated background—and hence the MDA—of ^{123}I remains essentially the same during the useful lifetime of the ^{123}I. A normal background of 12 cpm, accumulated during a 5-min measurement with 0.5% counting efficiency gives an MDA of 430 pCi. A contaminated background of 150 cpm accumulated during a 5-min measurement at the same counting efficiency gives a MDA of 1,430 pCi. The MDA based on the normal background would be reduced by counting in a shielded room; the MDA based on the contaminated background would approach that based on the normal background as the ^{124}I contamination is reduced.

The ^{123}I P/S ratio decreases smoothly with the depth of thyroid-simulating sources in the Lucite neck phantom. This relationship, coupled with the smooth decrease in counting efficiency with source distance, gives a uniform decrease in efficiency with decreasing P/S ratio. The relationship between P/S ratio and efficiency provides a means of quantitating ^{123}I thyroid uptake measurements.

The efficiency of the Ge(Li) detector for counting an ^{123}I thyroid-simulating source 1.8 cm from the detector was 0.52%—a factor 20 times less than that of the dual NaI(Tl) crystals. This great difference in counting efficiency is mainly due to the 15-fold difference in the detector areas. Because of the great differences between the 90-deg dual-crystal geometry and the centered single Ge(Li) detector geometry in relation to the anatomy of the pair of lobes of the thyroid, it is difficult to compare quantitatively the respective detector solid angles and hence to equate their efficiencies accurately. The results do indicate, however, that the area and not the depletion depth of the semiconductor detector limits its efficient use for *in vivo* thyroid measurements of ^{123}I. This limitation is not a serious one because Ge(Li) detectors are now commercially available with active areas 2–3 times larger than the one used in this work. Furthermore, a multiple-detector system could be used to increase the counting efficiency.

It should be emphasized that the "state-of-the-art" coaxial Ge(Li) detectors are now being produced with sensitive volumes as high as 54 cm^3. While these detectors are beset with such problems as dead layers and nonuniform electric fields (*1*), steady improvement in the fabrication indicates they show promise for eventual routine use.

SUMMARY

The high resolution of the Ge(Li) detector and its reasonably good counting efficiency for low-energy gamma rays suggest its use in nuclear medicine. In our work we used a Ge(Li) detector with a sensitive volume of 4.2 cm^3 to measure human thyroid uptake of ^{123}I. A Lucite neck phantom was used to calibrate this detector system for varying thyroid depths using the P/S ratio technique. The percent uptake measured in two subjects using the calibrated Ge(Li) detector agreed with measurements made with a dual NaI(Tl) detector. The future of the semiconductor detector for low-energy *in vivo* measurements becomes more promising as larger detectors become available.

REFERENCES

1. Glos, M. B.: Advances in nuclear-particle detection. *Nucleonics* **24**:No. 5, 44, 1966.

2. Myers, W. G.: In *Radioactive Pharmaceuticals.* Andrews, G. A., ed., USAEC Conf. 651111, April 1966, p. 217.

3. Myers, W. G.: Radioiodine-123 for scanning. *J. Nucl. Med.* **7**:390, 1966.

4. Rhodes, B. A., Buddemeyer, E. U., Stern, H. S. and Wagner, H. N., Jr.: The use of iodine-123 in studies of iodine metabolism. *J. Nucl. Med.* **7**:385, 1966.

5. Brucer, M.: Thyroid radioiodine uptake measurements. A standard system for universal intercalibration. *ORINS* **19**:6, 1959.

6. Wellman, H. N., Kereiakes, J. G., Yeager, T. B., Karches, G. J. and Saenger, E. L.: A sensitive technique for measuring thyroidal uptake of iodine-131. *J. Nucl. Med.* **8**:86, 1967.

7. Handbook 86—Recommendations of the International Commission of Radiological Units and Measurements, U.S. Dept. of Commerce, National Bureau of Standards, Nov. 29, 1963, p. 26.