

# Absorption-Edge Transmission Technique Using Ce-139 for Measurement of Stable Iodine Concentration

James A. Sorenson

*University of Utah Medical Center, Salt Lake City, Utah*

**We have investigated a technique for measuring stable iodine concentrations by absorption-edge transmission measurements using a Ce-139 radiation source. The lanthanum daughter emits characteristic x-rays whose energies just bracket the absorption edge of iodine at 33.2 keV. Relative transmission of these x-rays is sensitive to iodine concentration in the sample, but is relatively insensitive to other elements. By applying energy-selective beam filtration, it is possible to determine the relative transmission of these closely spaced x-ray energies with NaI(Tl) detectors. Optimizations of sample thickness, detector thickness, and Ce-139 source activity are discussed. Using sample volumes of about 10 ml, one can determine iodine concentration to an uncertainty (standard deviation) of  $\pm 5 \mu\text{g/ml}$  with a 5-mCi source in a measurement time of 400 sec. Potential clinical applications of the in vitro technique are discussed, along with comparative aspects of the Ce-139 technique and other absorption and fluorescence techniques for measuring stable iodine.**

**J Nucl Med 20:1286-1293, 1979**

X-ray emission and absorption techniques for the measurement of stable iodine concentrations are based on stimulated fluorescence emission of iodine K x-rays (27-33 keV) (1, 2), or on differential absorption by iodine atoms of photons having energies just above and just below the iodine K-shell absorption edge ( $K_{ab} = 33.2$  keV) (3-7). These techniques have been used for measurements of iodine concentrations in blood samples, urine specimens, etc. In comparison with chemical or spectrophotometric techniques, the x-ray emission or absorption techniques for in vitro measurements have the advantages of ease of sample preparation and handling, and the avoidance of sample destruction. X-ray techniques also are applicable to in vivo studies (e.g., imaging of stable thyroidal iodine) that are not possible with chemical or spectrophotometric methods.

X-ray absorption techniques are based on the marked

decrease in the attenuation coefficient of iodine across its K-shell absorption edge at 33.2 keV (Fig. 1). By comparing a sample's absorption of a beam of x-rays having energies just above the K-shell energy with that of a second beam having energies just below the absorption edge, one obtains a result that is sensitive to sample iodine content but not to other elements, because only for iodine is there a significant difference in attenuation coefficients. It is desirable to have the two beams bracket the iodine absorption edge as closely as possible, to obtain maximum sensitivity to iodine concentration and minimum sensitivity to other elements.

A basic problem with the absorption-edge technique is to create the required energy spectra. Filtered x-ray beams (3, 6), secondary fluorescence targets in x-ray beams (5, 7), diffraction gratings (4), and high-resolution semiconductor detectors (5) have been used to create or separate the desired beam energies. We have investigated the application of a radionuclide source, Ce-139, to the absorption-edge technique. Cerium-139 decays by electron capture with a 140-day half-life. The emissions of interest are the  $K_{\alpha}$  x-rays from the lantha-

---

Received Dec. 28, 1978; revision accepted June 7, 1979.

For reprints contact: James A. Sorenson, Div. of Medical Physics, Dept. of Radiology, Univ. of Utah College of Medicine, 1C 402 Medical Ctr., Salt Lake City, UT 84132.

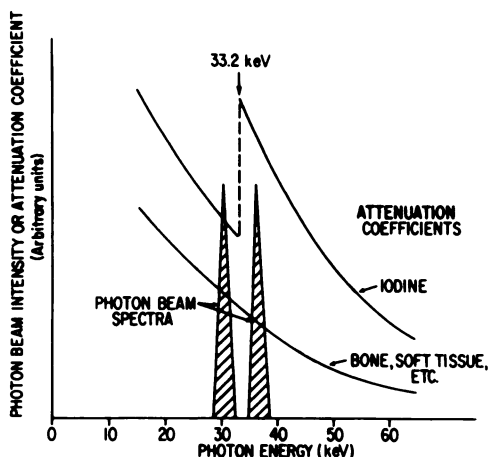


FIG. 1. Principles of absorption-edge transmission technique for measuring stable iodine concentrations. Vertical axis is beam intensity or attenuation coefficient (arbitrary scale).

num daughter, which bracket the iodine absorption edge (Table 1).

Because the  $K_{\alpha 1}$  and  $K_{\alpha 2}$  x-rays of lanthanum are too close together in energy (400 eV) to be separated even with semiconductor detectors, we used energy-selective beam filtration to obtain the necessary energy separation. This permitted us to use NaI(Tl) detectors in our measurements, as described below.

THEORETICAL BASIS

In the measurement system shown in Fig. 2, a sample of thickness  $t$ , containing a concentration  $c_i$ (g/ml) of iodine in water solution, is placed between a Ce-139 source and a radiation detector. The source is assumed to emit only the characteristic K x-rays of lanthanum, in the ratio  $K_{\alpha 1} : K_{\alpha 2} : K_{\beta} = 0.54 : 0.28 : 0.18$  (total = 1.0). The intensity,  $I_u$ , of an unfiltered beam from the Ce-139 source transmitted through the sample is given by

$$I_u = I_w (0.54e^{-\mu_i c_i t} + 0.28e^{-\mu_w c_i t} + 0.18e^{-\mu_b c_i t}) \quad (1)$$

TABLE 1. EMISSIONS OF Ce-139\* AND THEIR MASS ATTENUATION COEFFICIENTS † (cm<sup>2</sup>/g) IN IODINE ( $\mu_i$ ), WATER ( $\mu_w$ ), AND COMPACT BONE ( $\mu_b$ )

Emission	Energy (keV)	Frequency (per dis.)	$\mu_i$	$\mu_w$	$\mu_b$
$K_{\alpha 1}$	33.4	0.44	35.8	0.290	0.702
$K_{\alpha 2}$	33.0	0.23	6.03	0.295	0.728
$K_{\beta}$	38-39	0.15	22.3	0.252	0.500
$\gamma$	166	0.79	0.57	0.145	0.142

\* Data from ref. 8.

† Values determined by interpolation of data presented by Hubbell (9).

where  $I_w$  is the transmitted intensity for a water sample ( $c_i = 0$ ), and  $\mu_i$ ,  $\mu_w$ , and  $\mu_b$  are the mass attenuation coefficients (cm<sup>2</sup>/g) of iodine at the lanthanum  $K_{\alpha 1}$ ,  $K_{\alpha 2}$ ,  $K_{\beta}$  x-ray energies, respectively (Table 1).

If the beam passes through a filter containing approximately 0.15 g/cm<sup>2</sup> of iodine, the relative intensities of the x-rays transmitted by the beam filter, compared with their intensities in the unfiltered beam, are:

$$K_{\alpha 1}: 0.54e^{-36 \times 0.15} = 0.0024$$

$$K_{\alpha 2}: 0.28e^{-6 \times 0.15} = 0.1138$$

$$K_{\beta}: 0.18e^{-22.3 \times 0.15} = 0.0063$$

$$\text{TOTAL} \quad 0.1225$$

The iodine filter, therefore, reduces overall beam intensity by a factor of about eight, relative to the intensity of the unfiltered beam (0.1225 compared with 1.0), but transmits for practical purposes a pure  $K_{\alpha 2}$  x-ray beam. The relative intensity ratios in the filtered beam are  $K_{\alpha 1} : K_{\alpha 2} : K_{\beta} = 0.02 : 0.93 : 0.05$ .

If the small contributions from  $K_{\alpha 1}$  and  $K_{\beta}$  x-rays are ignored, the intensity,  $I_f$ , of the iodine-filtered beam transmitted by the sample is given by

$$I_f = I_{fw} e^{-\mu_w c_i t} \quad (2)$$

where  $I_{fw}$  ( $\approx I_w/8$ ) is the intensity transmitted by a water sample,  $c_i = 0$ . Taking the ratio,  $R = I_u/I_f$ , of transmitted intensities for the unfiltered and filtered beams, one obtains

$$R = R_0(0.54e^{-\Delta\mu' c_i t} + 0.28 + 0.18e^{-\Delta\mu'' c_i t}) \quad (3)$$

where  $R_0 = I_w/I_{fw}$ ;  $\Delta\mu' = \mu_i - \mu_w$ ; and  $\Delta\mu'' = \mu_b - \mu_w$ .

Thus, the ratio,  $R$ , can be used to estimate the iodine concentration in the sample. The sensitivity,  $S_i$ , of the technique for small concentrations of iodine ( $c_i \lesssim 0.01$  g/ml) may be defined as the percentage change in  $R$ , per g/ml of sample iodine concentration (g/ml), at  $c_i \sim 0$ :

$$S_i (\%/g_i/ml) = \frac{\partial R}{\partial c_i} \times \frac{100\%}{R_0} \quad (4)$$

$$= [0.54\Delta\mu' t - 0.18\Delta\mu'' t] 100\% \quad (5)$$

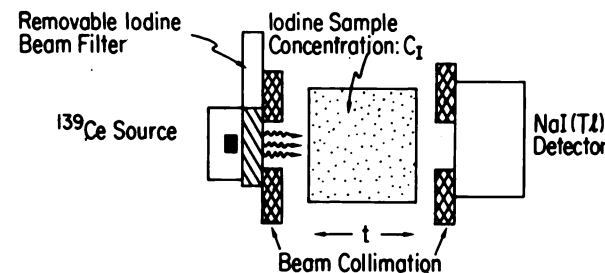


Fig. 2. Components of Ce-139 technique for measuring stable iodine concentrations.

Substituting attenuation coefficients from Table 1, one obtains

$$S_i \approx -1900 t (\%/g_i/ml) \approx -1.9 t (\%/mg_i/ml) \quad (6)$$

the minus sign indicating that R decreases with increasing sample iodine concentration.

The analysis presented above is oversimplified because the 166-keV emissions of Ce-139 have been ignored. A certain fraction of the photons counted in the transmission measurement will be 166-keV photons, e.g., by Compton downscatter into an x-ray photopeak window. In general, it is desirable to minimize  $\gamma$ -ray contamination, because it increases statistical counting noise, reduces the sensitivity to iodine concentration, and increases counting losses at high counting rates. The amount of  $\gamma$ -ray contamination depends on the detector's energy resolution, the iodine filter thickness, the detector thickness (differential detection efficiency for lanthanum x-rays compared with 166-keV photons), the counting window setting, and the sample thickness (overall transmission of x-rays compared with  $\gamma$ -rays). Because of the multiple factors involved, it is easier to determine experimentally the effects of gamma contamination than it is to calculate them.

In order to determine concentrations in the  $\mu g - mg$  range, the measuring system must be designed carefully for reproducible sample positioning, filter positioning, etc., to minimize measurement errors. It is also necessary to accumulate large numbers of counts so that random counting errors are small. For example, if  $I_u$  and  $I_f$  are the counts recorded with unfiltered and filtered beams, the percentage uncertainty,  $V_R$  (standard deviation), in their ratio,  $R = I_u/I_f$ , is given by

$$V_R = (\sigma_R/R) \times 100\% \quad (7)$$

$$= \sqrt{1/I_u + 1/I_f} \times 100\% \quad (8)$$

where  $\sigma_R$  is the uncertainty (standard deviation) in the ratio R. Typically,  $I_f \approx I_u/8$ . Thus

$$V_R \approx 3/\sqrt{I_u} \times 100\% \quad (9)$$

The ratio of the uncertainty,  $V_R(\%)$ , to sensitivity,  $S_i(\%/mg_i/ml)$ , gives the uncertainty,  $\sigma_i(mg_i/ml)$ , in estimated iodine concentration

$$\sigma_i = V_R/S \quad (10)$$

Substitution from Eqs. 6 and 9 yields

$$\sigma_i(mg_i/ml) \approx 160/(\sqrt{I_u} \times t) \quad (11)$$

Thus, for example, to achieve an uncertainty  $\sigma_i \approx 0.01 - 0.1 mg_i/ml$ , with 3-cm-thick samples, requires  $I_u$  in the range  $2.8 \times 10^5 - 2.8 \times 10^7$  counts. The detector system and electronics must be capable of relatively high counting rates, preferably  $10^5$  cps or higher, and further, the Ce-139 source strength must be sufficient to provide these counting rates, to make the Ce-139 technique

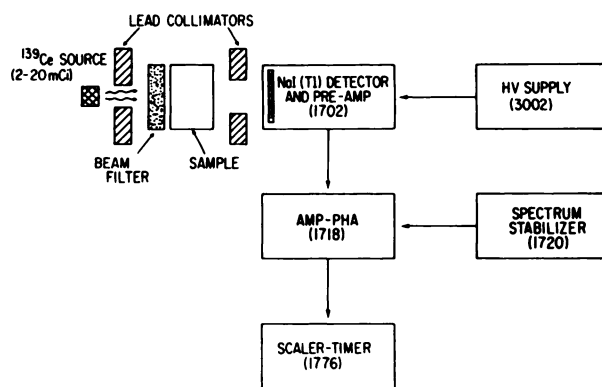


FIG. 3. Electronic components for Ce-139 transmission measurement system. Model numbers are for Canberra components,<sup>†</sup> which were chosen for high counting-rate capabilities at x-ray energies.

practical for measurements of concentrations below 1 mg/ml.

#### EXPERIMENTAL APPARATUS

Figure 3 is a diagram of our apparatus for experimental testing of the Ce-139 technique. The Ce-139 was encapsulated in a sealed source housing,\* with an aluminum exit window 0.005-in. thick. The housing was modified by replacing the usual tungsten insert with a lanthanum metal insert, eliminating the production of tungsten fluorescence x-rays by the 166-keV photons of Ce-139, and enhancing the production of lanthanum x-rays. The source's active area was 3 mm in diameter. Source activities of up to 20 mCi were used.

The radiation detector was a NaI(Tl) crystal 2.54 cm in diameter, mounted on a photomultiplier tube of the same diameter. Crystal thicknesses of 0.1, 0.3, and 1.0 mm were studied. Electronic components were chosen for high counting-rate performance at x-ray energies.

Sample containers were square, polystyrene spectrophotometry cuvettes. Each cuvette contained sample solution 1 cm thick, of approximately 3 ml total volume. The source-to-detector distance was adjustable for different numbers of cuvettes, i.e., variable sample thicknesses. Lead collimation on the source and detector limited beam dimensions to 10 mm wide  $\times$  20 mm high at the detector. Except for the beam exit aperture, the source was surrounded on all sides by 6-mm-thick lead, which reduced radiation levels around the experimental apparatus to background levels. The removable iodine beam filter was a 0.5-mm-thick cleaved crystal of pure NaI ( $\approx 155 mgI/cm^2$ ), hermetically sealed in an aluminum housing with aluminum entrance and exit windows 0.01 in. thick.

Iodine test samples were prepared by dilution of spectrophotometry standard solutions or iodinated contrast media. Iodine concentrations were verified on a fluorescence excitation analysis (FEA) system using

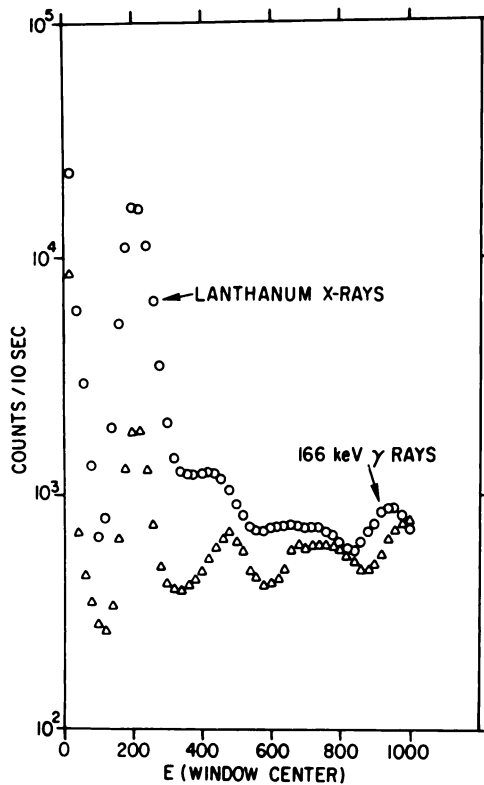


FIG. 4. Cerium-139 spectra recorded with system shown in Figs. 3 and 4, with ( $\Delta$ ) and without ( $O$ ) iodine beam filters. Spectrum stabilizer (Fig. 3) was centered on lanthanum x-ray photopeak, resulting in slight shift in position of 166-keV photopeak for the two beams.

a 600-mCi Am-241 excitation source.<sup>†</sup>

Figure 4 shows Ce-139 pulse-height spectra obtained with a 1-mm-thick NaI(Tl) detector, for unfiltered and iodine-filtered beams. Figure 5 shows comparative spectra for the 0.1-, 0.3-, and 1.0-mm-thick crystals, demonstrating selective detection of lanthanum x-rays compared with 166-keV gammas, and decreasing x-ray detection efficiency, for the thinner crystals.

Counting-rate performance characteristics of the system were investigated using the three detector thicknesses and a 25- to 55-keV x-ray photopeak window. For unfiltered beams, the system was found to have paralyzable deadtime values of 0.53, 0.75, and 0.80  $\mu$ sec, for the 0.1-, 0.3-, and 1-mm-thick detector crystals, respectively. Deadtimes were 2-3 times greater for the iodine-filtered beam than for the unfiltered beam, this difference being due to "window-fraction" effects (10). However, counting rates recorded with the filtered beam were only about  $1/8$  those of the unfiltered beam. Therefore, counting-rate limits were determined by measurements with the unfiltered beam.

#### EXPERIMENTAL RESULTS

The optimal pulse-height window setting, based on minimization of the uncertainty in estimated iodine

concentration,  $\sigma_i$  (Eq. 13), was found to be 25-55 keV. Widening the analyzer window increased the recorded counting rate, thus decreasing the statistical counting uncertainty,  $V_R$ , but it also reduced sensitivity to iodine concentration,  $S_i$ , by increasing the contribution of the 166-keV photons down-scatter to the recorded counting rate. All of the studies described in the remainder of this section were performed using this window setting.

Figure 6 shows the ratio,  $R/R_0$  to sample iodine concentration, for 1-cm-thick iodine solutions at concentrations up to 282 mg/ml, measured with the 0.3-mm-thick NaI(Tl) detector crystal. The iodine samples for this experiment were prepared by dilution of Conray-60 (full concentration = 282 mg/ml). The solid line was calculated from Eq. 3. Measurement of concentrations up to about 200 mg/ml appears to be feasible for 1-cm-thick samples.

For small iodine concentrations (less than a few mg/ml), the relationship between  $R$  and sample iodine concentration,  $c_i$ , was found to be linear. Sensitivity was found to increase linearly with sample thickness, as predicted by Eq. 6, with the following values for the three detector crystal thicknesses:

$$0.1\text{-mm detector: } S_i = 2.1t(\%/mg_i/ml) \quad (12)$$

$$0.3\text{-mm detector: } S_i = 1.8t(\%/mg_i/ml) \quad (13)$$

$$1.0\text{-mm detector: } S_i = 1.55t(\%/mg_i/ml) \quad (14)$$

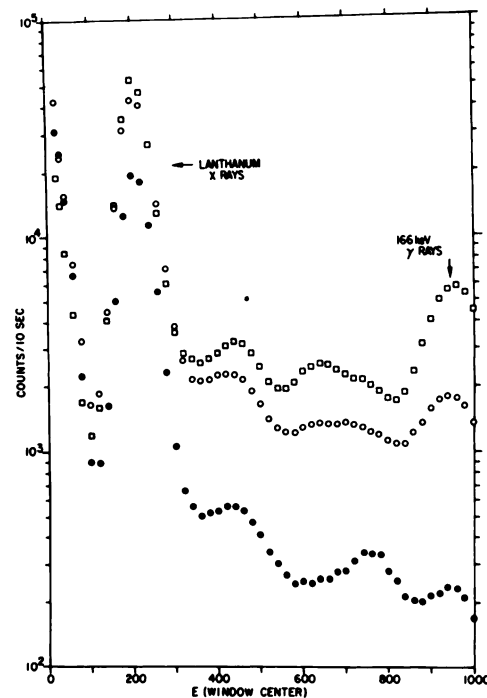
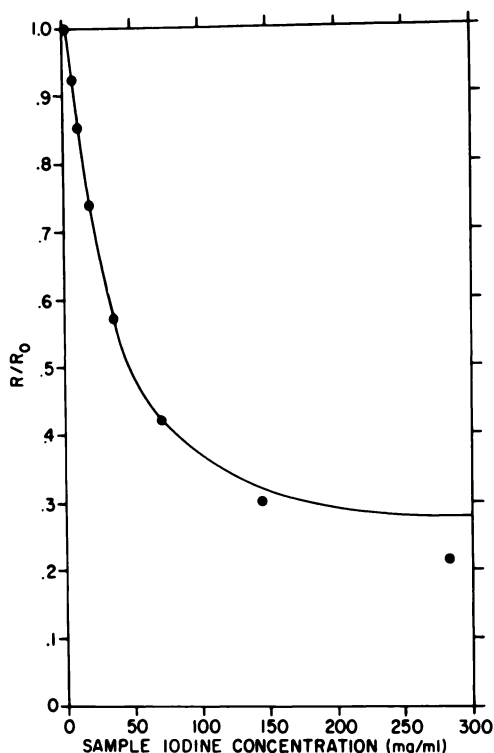


FIG. 5. Cerium-139 spectra recorded with three NaI(Tl) detector crystal thicknesses:  $\bullet$  = 0.1 mm,  $\circ$  = 0.3 mm,  $\square$  = 1.0 mm. Thinner crystals enhance differential detection efficiency between x-rays and unwanted 166-keV gammas, but also have less efficiency for detecting x-rays.



**Fig. 6.** Measured values of  $R/R_0$  as a function of sample iodine concentration.  $R$  = ratio of unfiltered- to filtered-beam cpm;  $R_0$  = similar ratio for water. Detector crystal is 0.3-mm thick. Solid line is theoretical, from Eq. 3.

Sensitivity increases with decreasing detector crystal thickness for two reasons. First, thinner detectors have smaller detection efficiencies for the unwanted 166-keV photons (Fig. 5). Second, with a very thin NaI(Tl) detector (e.g., 0.1 mm), the detection efficiencies for the  $K_{\alpha 1}$  and  $K_{\beta}$  x-rays of lanthanum, whose energies lie above the iodine absorption edge, exceed by a factor of two or three the detection efficiency for the  $K_{\alpha 2}$  x-rays, whose energies lie below the absorption edge. This increases the relative contribution of  $K_{\alpha 1}$  and  $K_{\beta}$  x-rays to the detected radiation beam, increasing the system's sensitivity to iodine (Eqs. 3-6). As a result, the observed sensitivity with 0.1-mm-thick detector (Eq. 12) exceeds even the theoretical value (Eq. 6), which was calculated assuming equal detection efficiencies for the lanthanum x-ray emissions. Nearly equal (~100%) detection efficiencies are achieved with detectors 0.3-mm or thicker.

System sensitivity to differences in sample thickness also was evaluated. For 3-cm-thick samples the change in  $R_0$  was approximately 5%/cm change in sample thickness. Comparative measurements on blood ( $\rho \approx 1.05 \text{ gm/cm}^3$ ) with water samples demonstrated similar effects for sample density variations. These effects may be attributed to beam-hardening (preferential absorption lower-energy x-rays as compared with higher-energy x-rays and 166-keV  $\gamma$ -rays).

When measurements are made on samples of substantially different thicknesses (e.g., 2 cm as against 3 cm), values for  $R_0$  should be determined by measurements on iodine-free samples for each thickness. Sensitivity to iodine concentration also must be adjusted for sample thickness (Eqs. 12-14). When sample thickness variations are negligible (e.g., spectrophotometry cuvettes), corrections are not needed. If samples of materials with density other than unity are measured, the value of  $R_0$  should be determined on an iodine-free sample of that material (e.g., blood) rather than on a water sample.

From Eqs. 12-14 one can see that the combination of thickest sample and thinnest detector crystal gives the maximum sensitivity to iodine concentration. Table 2 shows that this combination also provides the lowest counting rate and, thus, the largest statistical counting uncertainty. The data in Eqs. 12-14 and Table 2 were analyzed to determine the combination of detector crystal and sample thicknesses providing the minimum value of  $\sigma_i$ . A total counting time of 200 sec, divided equally between iodine-filtered and unfiltered beam measurements, and source activity of 1 mCi, was assumed. The results (Fig. 7) indicate that the 0.3-mm-thick crystal and sample thicknesses of 2-3 cm provide the smallest value  $\sigma_i$ . However, there was not much difference between the 0.3- and 1.0-mm-thick crystals.

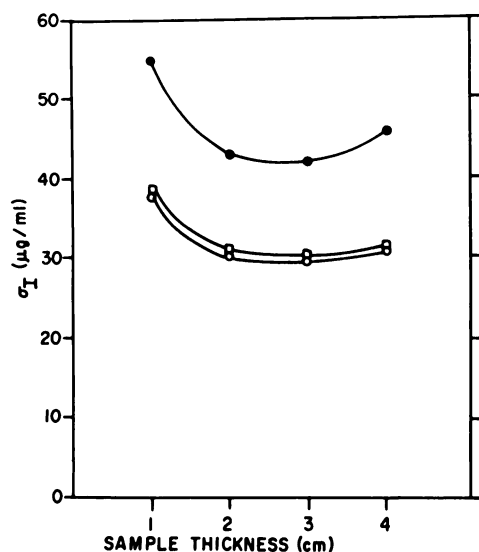
The above results apply to measurements made at counting rates for which deadtime losses are negligible ( $\leq 5\%$ ). When losses are larger, the situation is more complicated. Deadtime counting losses decrease sensitivity,  $S_i$ , because the changes in observed counting rates are smaller than the changes in true counting rates at the detector.

We determined that the minimum uncertainty in estimated iodine concentration for all detector and sample thicknesses occurred when counting losses were about 25% for the unfiltered beam. At higher counting rates, the loss of system sensitivity negated any gain in counting statistics. For our detector system and electronics, optimal source strengths (i.e., providing about 25%

**TABLE 2. COUNT RATE PER mCi Ce-139 SOURCE ACTIVITY (CPS  $\times 10^{-4}$ , NO DEADTIME LOSSES)\***

Sample thickness (cm)	NaI(Tl) detector thickness (mm)		
	0.1	0.3	1.0
1	8.31	20.7	23.8
2	3.35	8.55	9.90
3	1.56	3.93	4.54
4	0.73	2.02	2.34

\* Source-to-detector separation just sufficient to insert desired sample thickness, e.g., as in Fig. 2.



**Fig. 7.** Uncertainty in estimated iodine concentration, vs. sample thickness for different NaI(Tl) detector crystal thicknesses; ● = 0.1 mm, ○ = 0.3 mm, □ = 1.0 mm. Uncertainty is based on counting statistics of 200-sec measurements (100 sec/beam) and 1-mCi source, with negligible deadtime losses. Optimal system is 0.3- or 1.0-mm-thick detector with samples 2-3-cm thick.

counting losses) ranged from about 1-40 mCi, depending on the sample and detector thicknesses (Table 2). Optimal source strength for the combination of 0.3-mm-thick detector and 3-cm-thick sample was 5-10 mCi.

An experiment was performed to determine whether the theoretical values of  $\sigma_i$  predicted from considerations of counting statistics could be achieved in practice. Repeated measurements (ten or more) were made on 3-cm-thick samples using the 0.3-mm-thick NaI(Tl) detector, a 5-mCi Ce-139 source, and counting times ranging from 4 to 400 sec total, divided equally between filtered and unfiltered beam measurements. Samples were removed and replaced between individual measurements. Measurement uncertainties were in agreement with theoretical predictions down to  $\sigma_i \sim 5 \mu\text{g/ml}$  (400-sec counting times). It may be possible to reduce this uncertainty even further by using longer measurement times. However, the use of greater source strengths would provide only minor improvement because of the deadtime effects.

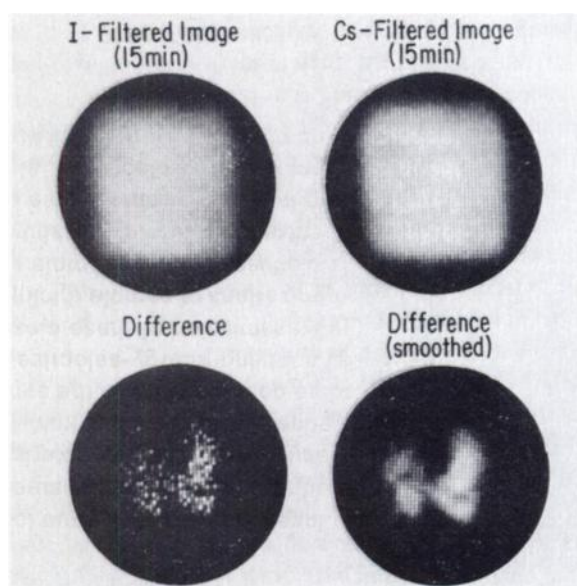
#### APPLICATIONS

An experiment was performed to evaluate potential clinical application of the Ce-139 technique. A 25-kg mongrel dog was injected with 1 ml/kg Conray 60, the dosage level normally used for IVP radiographic examinations in patients. Blood samples (10 ml) were withdrawn at 2 and 4 hr after injection, and iodine concentrations determined using 3-cm-thick samples, 0.3-mm-thick NaI(Tl) detectors, and 400-sec counting measurements per beam. Iodine concentrations were in

the 30-300  $\mu\text{g/ml}$  range. The concentration values were used to estimate glomerular filtration rate (GFR) by the method of Guesrey et al (11). The calculated value was  $112 \pm 6 \text{ ml/hr}$ . For comparison, the value determined from measurements on the same samples using the FEA (fluorescence) technique (300-sec counting time) was  $114 \pm 5 \text{ ml/hr}$ . The experiment demonstrates that the Ce-139 technique could be used to determine a patient's GFR in conjunction with an IVP radiographic examination. It could also be used to monitor blood levels of iodine in patients receiving repeated injections of contrast material for x-ray studies.

Because the Ce-139 absorption-edge technique can be used with NaI(Tl) detectors, there is at least the theoretical possibility of imaging stable iodine concentrations in vivo with an imaging instrument such as the Anger camera. Figure 8 shows images of the Picker thyroid phantom obtained on an Anger camera-computer system. A cesium-filtered beam rather than an unfiltered beam was used in this experiment, to balance the counting rates at the detector for the two images. Images obtained with the iodine- and cesium-filtered beams give no hint as to the presence of stable iodine. However, the difference image, especially when smoothed, outlines the distribution of stable iodine quite clearly.

Although an absorption-edge technique using lanthanum characteristic x-rays could be used to visualize stable iodine with an Anger camera, Ce-139, unfortunately, will not be a suitable radiation source for this application (Fig. 8). A 10-cm thickness of tissue-equivalent absorber placed over the thyroid phantom transmits a beam that consists primarily of 166-keV photons,



**FIG. 8.** Images of Picker thyroid phantom containing stable iodine, obtained using an Anger camera-computer system and Ce-139 technique. Concentration: 4 mg/ml. Source activity: 2 mCi.

with only a small residue of lanthanum x-rays. At the counting rates required to visualize stable thyroidal iodine in reasonable imaging times, the Anger camera would be overwhelmed by 166-keV radiation. Practical application of the absorption-edge technique to in vivo studies will require a lanthanum x-ray source with no high-energy contaminants.

#### DISCUSSION

The Ce-139 absorption-edge transmission technique can be used with NaI(Tl) detectors to measure concentrations of stable iodine, in vitro, to an uncertainty of about 5  $\mu\text{g}/\text{ml}$ , with total counting times of about 400 sec. The optimal sample thickness is about 3 cm, NaI(Tl) detector crystal thickness about 0.3 mm, and source activity about 5–10 mCi. Assuming that the smallest detectable iodine concentration is two or three times  $\sigma_i$ , the lower limit of detectability for the Ce-139 absorption-edge technique is about 10–15  $\mu\text{g}/\text{ml}$ . The upper limit of measurement is about 200 mg/ml for 1-cm-thick samples. The detection limits are adequate for measurement of blood levels of iodine in patients injected for x-ray contrast studies, e.g., for determination of GFR values in patients undergoing IVP studies.

Compared with absorption-edge techniques using filtered x-ray beams, the major advantage of the Ce-139 technique is the stability and compactness of the radiation source. No advantage would be gained from the greater output intensity that might be provided by an x-ray tube for in vitro applications, because deadtime losses in the detector and counting system are the limiting factors, rather than source intensity. One might also consider operating the PM tube in "current mode" to eliminate deadtime factors altogether. However, such a system would require extreme operating stability ( $\pm 0.01\%$ ) to achieve the same levels of precision obtained in our investigations using counting techniques.

In comparison with the FEA (fluorescence) technique, the Ce-139 absorption-edge technique uses a much smaller quantity of a much less hazardous radioactive material:  $\sim 10$  mCi Ce-139 as compared with  $\sim 1$  Ci Am-241. Note, however, that the activity used for the Ce-139 technique is limited by counting-rate losses, and not by an inherent requirement for less activity. Because the FEA technique can be employed with greater source strengths, it is capable of a much lower limit of detectable iodine concentration than the Ce-139 technique, perhaps by a factor of ten. An FEA system can also be used to assay elements other than iodine.

The Ce-139 technique does not require a semiconductor or other detector with exceptional energy resolution, and can be used with NaI(Tl) systems. The cost of electronic components for a Ce-139 system is modest—under \$5000 for the components outlined in Fig. 3, which is about the cost of the detector alone for an

FEA system. The components used for the Ce-139 technique could also find other uses in other standard systems in a nuclear medicine laboratory, e.g., as part of a thyroid uptake or probe counting system.

A major disadvantage of the Ce-139 technique is the requirement for periodic source replacement. Current cost is about \$3000 for a 30-mCi source. With adjustment of the source-to-detector distance to avoid excessive deadtime losses, a 30-mCi source would have a useful lifetime of four to five half-lives, or about 18–24 mo ( $T_{1/2} = 140$  days), resulting in a source replacement cost of about \$150/mo. Against this must be balanced the greater initial cost of an FEA system and the cost of continuous liquid-nitrogen maintenance.

The feasibility of visualizing stable iodine content using an Anger camera and lanthanum characteristic x-rays has been demonstrated. However, Ce-139 cannot be used as the source material for this application, because of its 166-keV gamma emission.

There are radionuclides other than Ce-139 that emit characteristic x-rays that could be used to measure concentrations of elements other than iodine. For example, Hg-197 emits characteristic  $K_{\alpha}$  x-rays of gold at 67.0 and 68.8 keV, which bracket the absorption edge of tantalum (67.4 keV). Perusal of the chart of the nuclides, however, does not reveal a very large number of potentially practical possibilities. Another approach would be to use a source containing two different radionuclides emitting characteristic x-rays of two different elements that bracket the absorption edge of a third element. Such systems will require further investigation.

#### FOOTNOTES

\* Type LE66, New England Nuclear, Cambridge, MA or Isotope Products Laboratories, Burbank, CA.

† Ultima/2, Ino-Tech, Inc., Madison, WI.

‡ Canberra Industries, Inc., Meriden, CT.

#### ACKNOWLEDGMENT

This work was supported by BRH Contract No. 223 76 6006 and by NIH Grant No. 5 GM22983. The technical assistance of Mr. Loren Niklason and Mr. Edwin Nakashima is gratefully acknowledged. I am also indebted to Dr. James Nelson for many helpful contributions to this project, to Drs. Gerry Hine and Ed Coleman for editorial advice, and especially to Mrs. Janie Thomas for her patient secretarial assistance in the preparation of this manuscript.

Portions of this paper were presented at the 25th Annual Meeting of the Society of Nuclear Medicine at Anaheim, CA, June 27–30, 1978.

#### REFERENCES

1. PALMER DW, DECONNINCK F, SWANN SJ, et al: Low cost intrathyroidal iodine quantification with a fluorescent scanner. *Radiology* 119: 733–735, 1976
2. KAUFMAN L, PRICE DC: *Medical Applications of Fluorescent Excitation Analysis*. Boca Raton, Florida, CRC Press, Inc., 1979

3. JACOBSON B: Dichromatic absorption radiography. Dichromography. *Acta Radiol* 39: 437-452, 1953
4. ROSE HA, FLICK DE: Assay of iodine content of thyroid extract by x-ray absorption edge analysis. *J Pharmacol Sci* 53: 1153-1156, 1964
5. ATKINS HL, HAUSER W, KRANER HW: Absorption edge transmission scanning. *Am J Roentgenol* 114:176-180, 1972
6. MISTRETTA CA, ORT MG, KELCZ F, et al: Absorption edge fluoroscopy using quasi-monoenergetic x-ray beams. *Invest Radiol* 8: 402-412, 1973
7. OLDENDORF WH, PHELPS ME, HOFFER PB, et al: An inherently stable system for measuring tissue iodine using its K-absorption edge. *Am J Roentgenol* 120: 583-588, 1974
8. DILLMAN LT, VON DER LAGE FC: Radionuclide decay schemes and nuclear parameters for use in radiation-dose estimation. MIRD Pamphlet No. 10, *J Nucl Med: Suppl* No 10, 90, 1975
9. HUBBELL JH: Photon cross sections, attenuation coefficients, and energy absorption coefficients from 10 keV to 100 Gev. Nat. Stand. Ref. Data Ser., Nat. Bur. Stand (U.S.) 29, 1969, pp 60, 64, 70
10. WICKS R, BLAU M: The effect of window fraction on the deadtime of Anger cameras: concise communication. *J Nucl Med* 18: 732-735, 1977
11. GUESRY P, KAUFMAN L, ORLOFF S, et al: Measurement of glomerular filtration rate by fluorescent excitation of non-radioactive meglumine iothalamate. *Clin Nephrol* 3: 134-138, 1975

**7TH ANNUAL WINTER MEETING  
THE SOCIETY OF NUCLEAR MEDICINE TECHNOLOGIST SECTION**

**Feb. 7-9, 1980**

**Galt Hotel**

**Louisville, Kentucky**

**FIRST CALL FOR ABSTRACTS-SCIENTIFIC PAPERS**

The Technologist Section of the Society of Nuclear Medicine announces the first call for abstracts for scientific papers for its 7th Annual Winter Meeting. Abstract forms may be obtained from: Diane Shepherd, SNM, 475 Park Ave. So., New York, NY 10016.

Completed abstracts (including the original with five copies, with supporting data) should be returned to:

Janice Brewster  
Episcopal Hospital  
Nuclear Medicine Dept.  
Front St. & Lehigh Ave.  
Philadelphia, PA 19125

Deadline for submission of abstracts-September 15, 1979

**FIRST CALL FOR ABSTRACTS-SCIENTIFIC EXHIBITS**

Completed abstracts (including the original and five copies, with supporting data) should be returned to:

David Phegley  
St. Louis University Hospital  
Nuclear Medicine Dept.  
1325 South Grand Blvd.  
St. Louis, MO 63104

Deadline for submission of abstracts-November 15, 1979