

## ROENTGEN RAY FLUORESCENCE METHOD FOR DETERMINATION OF IODINE IN TISSUE

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A variety of methods have been used for determination of a stable iodine in the tissues (EDHOLM & JACOBSON 1959, HEEDMAN & JACOBSON 1964, JACOBSON 1953, KRANER et coll. 1973, OLDENDORF et coll. 1974). Almost all of these methods are based on transmission of gamma or roentgen rays, giving only the amount of iodine per unit area. In clinical research it would be of more value to know the true concentration of iodine. Such a method, based on measurement of the fluorescent roentgen rays of iodine, is published by KAUFMAN et coll. (1973). The method requires special high resolution equipment, such as semiconductor detectors and multi-channel analyzers. Difficulty in accounting for the absorption of radiation due to tissues overlying the measuring site constitutes a drawback encountered in other methods (HOFFER et coll. 1968).

A method is now presented which permits the measurement of the concentration of iodine in organs using only the apparatus normally available in hospitals. The results are independent of the tissue layers surrounding the measuring site.

### Method

The technique is based on the use of two roentgen beams, of which one excites the K roentgen rays of iodine while the other does not. The beams are collimated on the measuring site containing iodine and the resulting radiation is monitored with a

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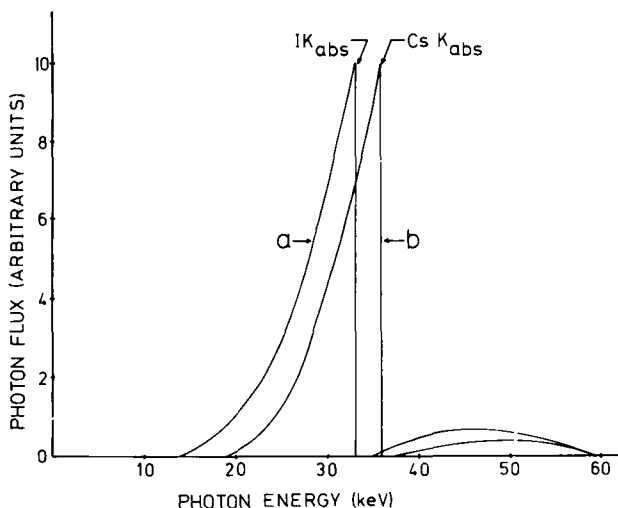


Fig. 1. Spectra of the two roentgen beams after modifying the primary radiation of the radiation source with critical absorbers. a) Low energy beam obtained with a 192 mg/cm<sup>2</sup> iodine absorber. b) High energy beam obtained with a 246 mg/cm<sup>2</sup> cesium absorber.

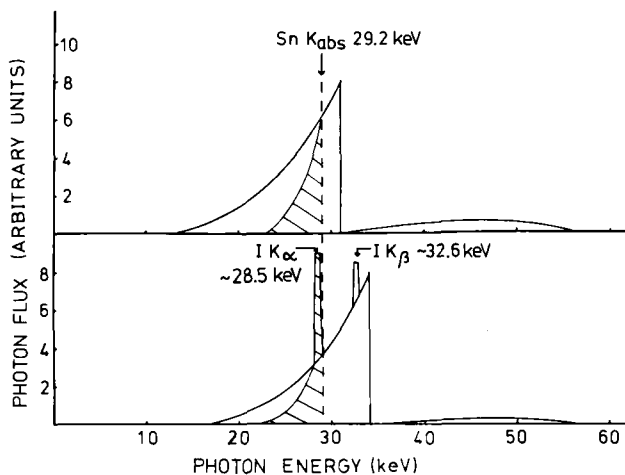


Fig. 2. Spectra of the emitted radiations from the volume to be analyzed at an angle of 90° with the incoming radiation. a) (Upper diagram) Spectrum provoked by the low energy beam. b) (Lower diagram) Spectrum provoked by high energy beam. The hatched parts of the spectra are formed when the emitted photons are passed through a tin absorber. These photons are then measured with a NaI-detector, and the counting rates are used to calculate the iodine concentration.

radiation detector. One beam produces mainly fluorescent and scattered photons whereas the other only scattered photons. The ratio of the counting rates obtained with the two beams is used for determining the iodine concentration.

A single roentgen tube serves as the source of both beams, which are obtained by the appropriate use of critical absorbers. The low energy beam is produced by means of an iodine-absorber and the high energy beam by a cesium-absorber. The spectra of the two beams (Fig. 1) were constructed by the polydiscrete roentgen ray attenuation method (PUUMALAINEN et coll. 1976).

The calculated spectra of the emitted radiation from the measuring site appear in Fig. 2. The spectrum in Fig. 2 a is calculated for the low energy beam, and that in Fig. 2 b for the high one. These spectra describe the outgoing fluorescence and scattered radiation at an angle of 90°. The spectrum in Fig. 2 b contains in addition

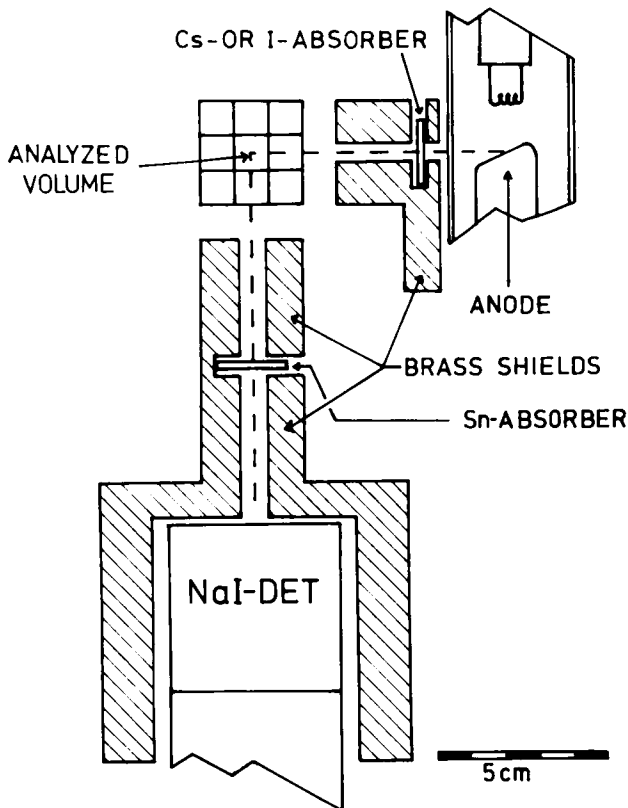


Fig. 3. Experimental arrangement for testing the roentgen ray fluorescence method.

to scattered radiation, the characteristic roentgen rays to be analyzed. Fig. 2 also shows the absorption edge of a tin absorber. This absorber, placed in front of the detector, is used to modify the spectra of the emitted photons in such a way that the difference between the measured counting rates is primarily due to iodine present at the measuring site.

Assuming that the average photon energy of both beams is equal ( $E_K(\text{Cs}) \approx E_K(\text{I}) \approx 34 \text{ keV}$ ), the ratio of the photon fluxes is independent of the attenuation in the target material. The spectrum provoked by the low energy beam contains only scattered radiation. Let  $N_1$  be the number of photons detected. The spectrum provoked by the high energy beam contains, in addition to scattered radiation, the characteristic roentgen rays to be analyzed. The number of photons detected in this case is

$$N_2 = N_I + N_s \quad (1)$$

where  $N_I$  = the number of registered characteristic roentgen rays corresponding to the concentration of iodine

$N_s$  = the number of registered scattered photons.

For dilute iodine solutions it may be written

$$N_1 = kC_I \quad (2)$$

where  $C_I$  = the concentration of iodine

$k$  = proportionality constant.

Combining equations (1) and (2) the ratio of the numbers  $N_2$  and  $N_1$  is given by

$$\frac{N_2}{N_1} = aC_I + b \quad (3)$$

where  $a(=k/N_1)$  and  $b(=N_s/N_1)$  are constants.

In the same manner, with pure water as a sample, it may be written

$$\frac{N_2^0}{N_1^0} \approx b \left( = \frac{N_s}{N_1} \right) \quad (4)$$

Using equations (3) and (4) the concentration of iodine may be obtained by

$$C_I = c \left( \frac{N_2/N_1}{N_2^0/N_1^0} - 1 \right) \quad (5)$$

where  $c = \text{proportionality constant} (= N_1 N_2^0 / k N_1^0)$

A quantity  $\delta$  is defined as

$$\delta = \frac{C_I}{c} \quad (6)$$

or alternatively

$$\delta = \frac{N_2/N_1}{N_2^0/N_1^0} - 1 \quad (7)$$

The expressions (6) and (7) show that iodine concentration is proportional to  $\delta$  and by measuring the numbers of photons  $N_1$ ,  $N_2$ ,  $N_1^0$  and  $N_2^0$  the value of  $\delta$  can be calculated.

*Experimental arrangement.* The experimental arrangement is illustrated in Fig. 3. Photons falling into an energy interval of 30 to 35 keV were counted with a collimated 5 cm × 5 cm NaI(Tl) detector. The roentgen source was a Philips generator with an AC voltage of 59 kV, and 1 mA. The primary voltage of the generator was stabilized using two Philips constant voltage stabilizers (type PE 1402/11). The absorber used to modify the primary radiation was placed inside a collimator, on the side of the tube. The diameter of the beam at the target site was 8 mm. An area of 8 mm in diameter was recorded by the detector through the collimator. The detector absorber was placed inside this collimator. The beam absorbers used were a 0.82 mm thick KI tablet (192 mg/cm<sup>2</sup> iodine) for the low energy beam, and a 0.80 mm CsCl

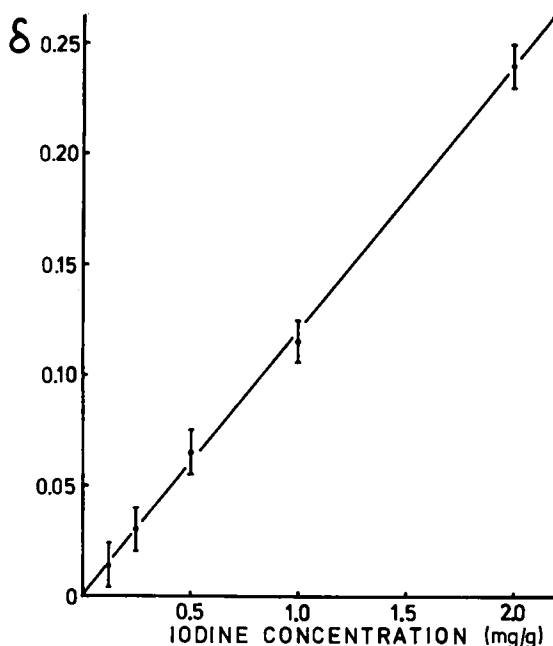


Fig. 4. Measured  $\delta$  values ( $\pm 1$  SD) as a function of the iodine concentration.

tablet (246 mg/cm<sup>2</sup> cesium) for the high energy beam. The detector absorber was a 0.11 mm thick tin plate.

The samples were KI solutions contained in 1 cm<sup>3</sup> plastic cubes with 0.1 mm thick walls. Concentrations varied from 0 to 2 mg/g. Irradiation time was 1 min per beam.

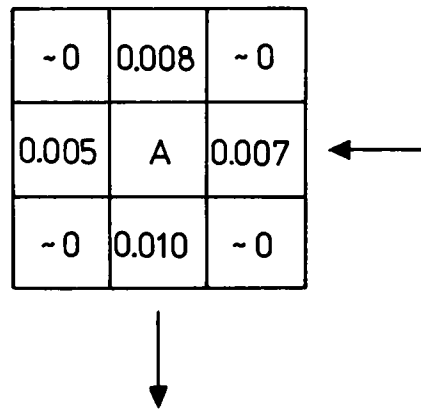
*Accuracy and sensitivity.* The quantity  $\delta$  as a function of the iodine concentration appears in Fig. 4.

A change of 1 mg/g in iodine concentration caused a change of about 0.12 in  $\delta$ . Taking into account the total counts of these one minute measurements, the accuracy due to statistical variations was estimated to  $\pm 0.1$  mg/g.

The effect of iodine outside the volume to be investigated was analyzed by placing at different points around the sample cube A (Fig. 5), another cube containing 1 mg iodine per g, and determining  $\delta$  for each position. In each measurement the sample cube contained pure water. The results appear in Fig. 5.

The greatest error was caused with the cube placed closest to the detector. For zero-concentration in the sample an increase by 0.01 of the  $\delta$  value corresponds to an error of only 0.08 mg/g. At sites which were not seen by the detector and roentgen generator, i.e. at the corners of the cube, the concentrations had no effect on the  $\delta$  value. Finally, the zero-concentration sample was put in the middle of a 3 cm  $\times$  3 cm  $\times$  3 cm cube, which contained 1 mg iodine per g. The  $\delta$  value obtained was 0.03, corresponding to a systematic error of 0.25 mg iodine per g.

Fig. 5. Experimental arrangement to test the effect of iodine content in surrounding tissue(s) on the  $\delta$  value. The arrows indicate the incoming and emitted photons. The incident beam is objected to the sample cube A filled with water. Another cube containing 1 mg iodine per  $\text{cm}^3$  was placed in different sites around the cube A. The numbers denote the yielded  $\delta$  values, respectively. Concentrations at the corners of the cube had practically no effect on the  $\delta$  value.



*Phantom measurements.* Thyroid phantom measurements were carried out in order to analyze the sensitivity of the method to differences in absorption due to different constituents surrounding the analyzing site.

The structure of the phantom appears in Fig. 6. In order to perform patient measurements an angle of  $120^\circ$  was preferred to the right angle between the incoming beams and the measured radiation. Two series of measurements were made, one with the phantom filled with water (water around KI solution), and the other with the phantom empty (without water around KI solution). Measurements with the water-filled phantom yielded identical calibration lines, i.e.  $\delta$  versus concentration, as in the previous measurements. With the empty phantom the measurements gave iodine concentrations which were uniformly about 10 per cent too high when determined using the calibration obtained earlier. In practical terms, this means that changes in fatty tissue/muscular tissue ratio have negligible effect on the determination of the iodine concentration.

*Radiation dosimetry.* The exposure at the measured site was determined for both beams using a Philips dosimeter (type 37470). In both irradiations the exposure rate was about 0.5 R/min.

### Discussion

From the present measurements it appeared that the overall efficiency of the method can be further improved. Possibilities for developments depend mainly on the radiation source available. A more intense source, e.g. a 10 mA DC generator, would allow the use of thicker critical absorbers. This, in turn, would produce sharper and narrower lines for the spectra of the two beams. The overlapping part of these spectra would then be considerably smaller. The general shape of a roentgen ray spectrum generated by a DC potential generator is more advantageous and would make the use of high potentials, such as 59 kV, superfluous and therefore the elimination of the high energy part of the spectra would become easier and more efficient

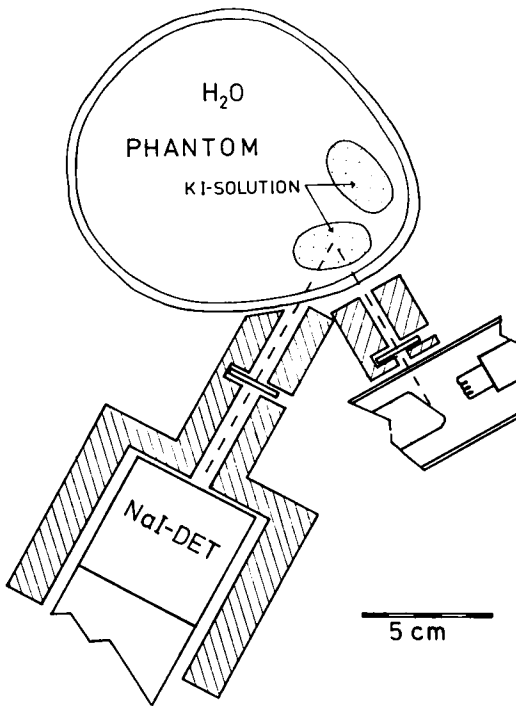


Fig. 6. Structure of the phantom. An angle of  $120^\circ$  was used between the incoming and outgoing radiation.

simply by decreasing the potential. This would be very useful since the high energy parts cannot be further reduced with the absorber in front of the detector. If, for instance, a DC generator with a current of 10 mA, and potential of about 50 kV were used, it would be easy to achieve the values of  $\delta$  improved by a factor of about 10. This means that  $N_2$  in formula (7) increases with respect to  $N_1$ ,  $N_1^0$  and  $N_2^0$ . A considerably smaller radiation exposure would then be needed to achieve the same accuracy,  $\pm 0.1$  mg/g, as is now obtained using a total exposure of 1 R. Another way to decrease the radiation exposure is to enlarge the detector collimator.

The employed generator had no cooling system and hence it could not be operated continuously. This situation caused additional stability problems. The stability of the primary roentgen ray intensity was monitored with a separate NaI-detector recording air-scattered photons from the generator through a 1.5 mm CsCl absorber. This procedure showed that it is essential that the temperature of the generator is constant for both irradiations. The cooling time between successive irradiations was 10 min. With the use of stabilizers for the supply current of the generator no intensity corrections were needed. The total count rates were of the order of  $10^5$  counts per irradiation of 1 min.

Expressions (1) and (2) have paid no attention to coherently scattered radiation present at low energies. However, the approximate theory is accurate enough since the coherent photons represent about one per cent of the scattered radiation at most.

The  $\delta$  value was not sensitive to smaller changes in the absorption, i.e. to the change in the fatty tissue/muscular tissue ratio. It is, however, advisable to keep the distance between the collimator and the object surface constant. This is best achieved by using an elastic water bag between the two collimators and the analyzed surface. This ensures that the absorption lengths remain constant in a material with a density of about 1 g/cm<sup>3</sup>.

The sensitivity of the present method permits the measurement of the iodine content of the thyroid nodules. By enlarging the collimators the amount of total iodine in the thyroid can also be measured. With slight modifications the method may be applied for the assessment of the distribution of iodine containing radiographic contrast media within different organs.

### SUMMARY

A roentgen ray fluorescence method was developed for the quantitative determination of iodine concentration in tissue. The method is based on the use of two beams, of which one excites the K roentgen rays of iodine, while the other does not. The concentration of iodine was determined from the difference between the counting rates of the fluorescent and the scattered radiation. The measurements were carried out with standard equipment consisting of a generator, a NaI(Tl)-detector and a scaler. An accuracy of 0.1 mg I per g was obtained with the radiation exposure of about 1 R.

### ZUSAMMENFASSUNG

Eine Röntgenfluoreszenz Methode wurde zur quantitativen Bestimmung von Jodkonzentration im Gewebe entwickelt. Die Methode ist auf zwei Strahlenbündeln basiert, eines mit K-Strahlen des Jods und eines ohne. Die Konzentration von Jod wurde durch die Differenz der Zählrate der Fluoreszenzstrahlung und der Streustrahlung bestimmt. Die Messungen wurden mit einer Standardausrüstung, einem Generator, ein NaI(Tl)-Detektor und einem Scaler, durchgeführt. Eine Genauigkeit von 0,1 mg I per g wurde erreicht bei einer Bestrahlung von etwa 1 R.

### RÉSUMÉ

Une méthode de fluorescence de rayons de Roentgen a été mise au point pour la détermination quantitative de la concentration d'iode dans les tissus. Cette méthode est basée sur l'utilisation de deux rayonnements dont l'un excite les rayons de Roentgen K de l'iode alors que l'autre ne les excite pas. La concentration de l'iode a été déterminée à partir de la différence entre les taux de comptage du rayonnement fluorescent et du rayonnement diffusé. Ces mesures ont été effectuées avec un équipement standard consistant en un générateur, un détecteur à NaI(Tl) et une échelle. Les auteurs ont obtenu une précision de 0,1 mg d'iode par gramme avec une exposition aux radiations d'environ 1 R.

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