APARTADO DEL ACTA RADIOLÓGICA INTERAMERICANA
VOLUMEN VII Nº 3-4 1957

Radioiodine Uptake Measurement

MARSHALL BRUCER, M. D.[1]

DURING the past decade radioiodine uptake measurements have become a very popular and widely used procedure. Currently the largest portion of the total number of shipments of radioisotopes that are made from Oak Ridge are radioiodine. This totals a little less than one curie per month. It is estimated that about two thirds of about 6000 shipments per month are ultimately used for thyroid radioiodine uptake measurements. About 1800 physicians are doing thyroid radioiodine studies in the United States alone. The procedure is therefore an important one but its reliability has been questioned.

At a meeting in Oak Ridge in 1953, a group of internists discussed the validity of these measurements and set up a committee to study the problem. This is known as the Thyroid Uptake Calibration Committee of ORINS. The committee set out initially to answer one question: Is there a significant variation in thyroid uptage measurements as currently perfomed throughout the world? Even before the surveywas complete, the answer to this question was obvious. Variation in thyroid uptake measurements among laboratories is significant. This paper is a report on the survey and the extension of the committee's work toward a method of calibration.

There are many reasons for believing that measurements of thyroid uptake might show considerable variation. Almost every physician is using a different combination of standards, instruments, distances, techniques, and formulas for measuring thyroid uptake. The standards currently in use range from point sources to milk-bottle-sized containers. The instruments used range from Geiger-Muller end-window tubes hastily connected with outmoded scalers to the newest scintillation crystals on automatic scanners. When the various methods used for calculating thyroid uptake are surveyed, there should be no question of variation of results. The surprising thing is that there is any useful unanimity of opinion.

[1] Chairman, The Medical Division Oak Ridke Instituteof Nuclear Studies Oak Ridge, Tennessee. (Under Contract with the United States Atomic Energy Comission.)

By 1950 the National Bureau of Standards in the United States in cooperation with many other national bureaus had been able to calibrate a sample of iodine with a high degree of precision. This intercalibration was on the basis of purely physical techniques and was a laboratory procedure. The committee decided in 1954 that one of the reasons for the wide variation in results was the lack of a similar intercalibration standard that met clinical requirements. It was felt that a clinical intercalibration procedure, which would be adaptable to all the various techniques in use, was necessary. Such a clinical intercalibration demanded the use of a long-lived isotope. The short half life of radioactive iodine was one of the main deterrents to clinical intercalibration.

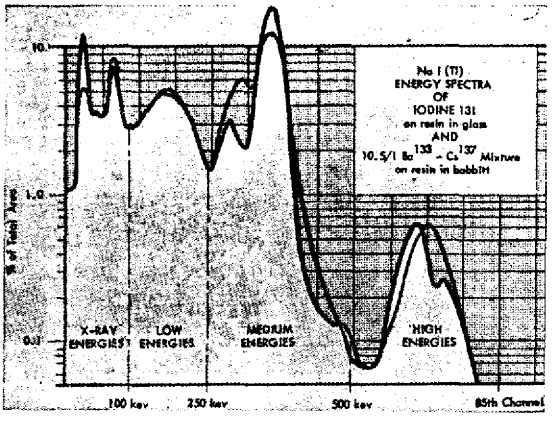


Fig. 1. Comparison of the sodium iodide spectra of iodine 131 and mock-iodine.

A long-lived gamma emitter can be made to simulate the gamma-ray spectrum from iodine 131. This material is now called mock-iodine and consists of the proper mixture of barium 133 and cesium 137. In Fig. 1 the sodium iodide spectra of iodine 131 and mock-iodine are compared. In this figure it is seen that when radioactive iodine is "viewed" by a sodium iodide crystal, it emits a number of gamma photons of different energies. An arbitrary division has been made on the spectrum to divide the energies emitted into four classifications. The X-ray energies are arbitrarily defined as anything under 100 kev; the low energies are defined as those up to 250 kev; the medium energies are those up to 500 kev; and the high energies are the rest of the spectrum. The high-energy peak shown in the spectrum consists of two gamma photons that are not very important

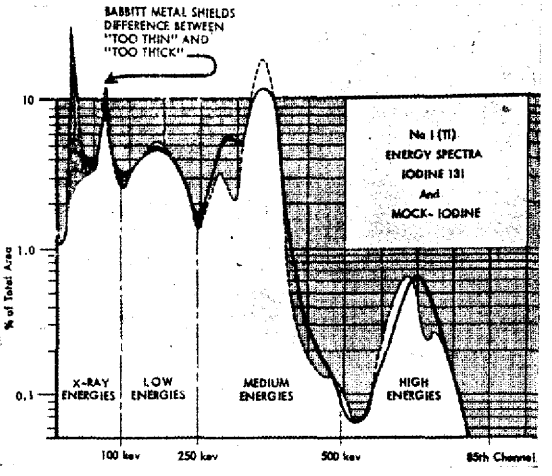


Fig. 2. The results of interposing succesive layers of babbit metal between raw mock-iodine and the detecting crystal.

in thyroid uptake measurements because they contribute so little to the total number of counts recorded by most instruments. The medium-energy peaks are the most prominent in the iodine spectrum. The low energy peak consists mostly of Compton scattered radiation. The peaks in the range arbitrarily called X-rays energies consist both of photons emitted by the iodine and scatter from interactions in both the instruments and the surroounding media. The mock-iodine spectrum matches this iodine spectrum remarkably well. The high-energy peak is slightly higher but this will not be picked up by any instruments except complex spectrometers, which are seldom used for thyroid radioiodine uptake measurements. The medium-energy peaks show the major difference between iodine and mock-iodine. There is too much of the 280 kev radiation and too little of the 360 kev radiation in mock-iodine.

Since all instruments except spectrometers integrate the two peaks, it has been experimentally determined that the difference in this portion of the spectrum causes 2 to 4 per cent difference in the comparative measurement of iodine and mock-iodine by most instruments. In the X-ray portion of the spectrum there is slightly too much of the 80 kev peak and slghtly too little of the 35 kev peak. This causes another 2 to 4 per cent difference in the comparative measurement of iodine and mock-iodine (which may or may not cancel out the medium-energy difference depending upon the instrument used). It has been empirically determined that in a wide variety of instruments, the difference in the measurement of iodine and mock-iodine is from 0 to 5 per cent

When the mock-iodine is used in its raw state, both the barium 133 and the cesium 137 contribute entirely too large a proportion of the very low-energy X rays, however, this can be corrected by partially shielding,the raw mock-iodine with a medium Z metal. Figure 2 shows the results when successive layers of babbit metal (a tin-antimony mixture) are interposed between the mock-iodine and the detecting crystal. The very low energies decrease very fast. The higher energies are almost unaffected. Thus when the correct thickness of babbit metal shields the mock-iodine, a compromise absorption is obtained. It has been found empirically that a 0.82 mm thickness of babbit metal is the best compromise filter the raw mock-iodine. All the mock-iodine sources are therefore manufactured and used in a container made of babbit metal.

Since barium 133 and cesium 137 have widely different half lives, the mock-iodine does not have a true half life. It does, however, have a useful life about 10 years. In Fig. 3 the method of arriving at this useful life is illustrated. The ideal mixture of barium 133 and cesium 137 has been shown to be 10.5 units of barium 133 to 1 unit of cesium 137. A millicurie measure is used for the cesium, but since the decay scheme of barium 133 is unknown, an arbitrary millicurie had to be defined for barium 133.

The barium 133 decays with a half life of about 9.5 years. The cesium 137 decays with a half life of about 33 years. Neither of these half lives is exactly known but they

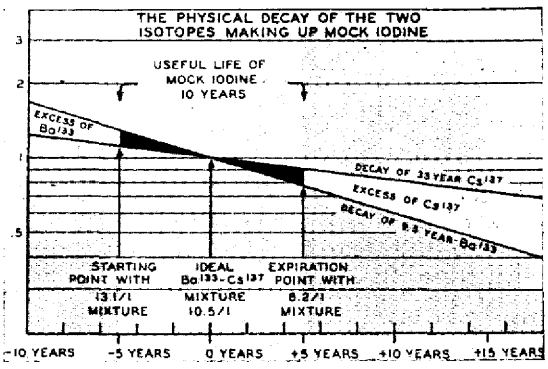


FIG. 3. The method of arriving at the useful life of mock-iodine

are approximately true. If one starts out with a mixture containing an excess of barium, the decay will extend through the ideal mixture and will eventually show an excess of cesium 137. Many different mixtures of barium and cesium were made up on an experimental basis and were empirically compared with identical iodine 131 source. It was found that, with some kinds of instrumentation, when there was an excess of barium 133 (much greater than a 15 to 1 ratio) significant differences in the comparison of mock-iodine with iodine 131 began to appear. When the mixtures contained too little barium 133 (much less than a ratio of 8 barium 133 to 1 cesium 137) variations again appeared in the comparison with iodine 131 with different kinds of instrumentation. Therefore, an arbitrary cut-off point was made with a starting mixture of 13.1 to 1, which represented a 5-year decay period before the ideal mixture was reached. An expiration point was arbitrarily set up at a mixture of 8.2 to 1, which represented 5 years of decay after the mixture had gone through the ideal

point. Thus the useful life of mock-iodine is 10 years. A 15 or 20 year period could easily have been set up that would meet the requirements, of most instrumentation. It is felt, however, that for calibration purposes, what instrumentation is used (excepting spectrometers) the results from measuring any iodine sample should be about the same as the result from measuring an identical mock-iodine sample.

THE RELATIVE PROPORTIONS OF LOW, MEDIUM AND HIGH ENERGIES IN Ba^{133}—Cs^{137} MIXTURES MAKING UP MOCK IODINE

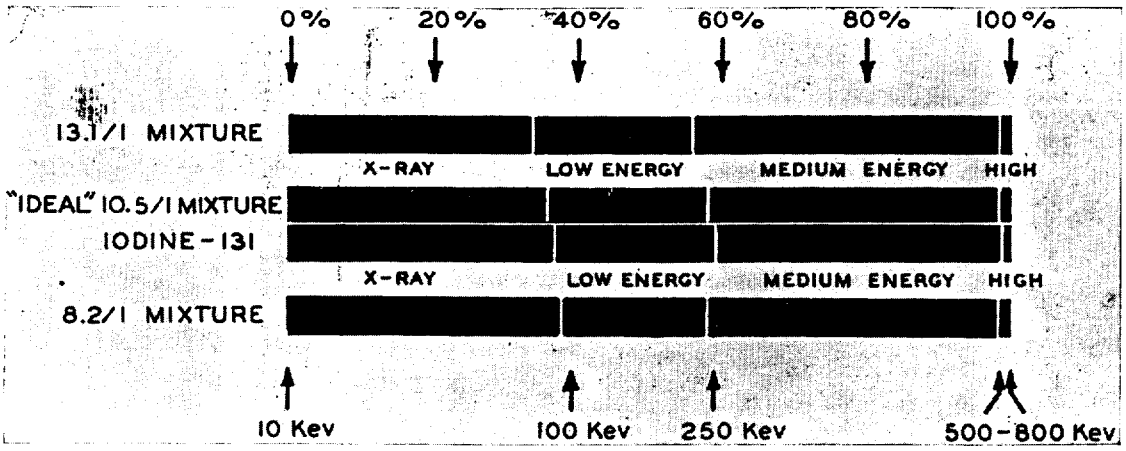


FIG. 1. The expected differences between iodine 131 and mock-iodine at the extremes of the accepted intercalibration mixture.

the accuracy of the 10 year period should be in excess of the accuray that is obtainable with most instrumentation.

In Fig 4 the differences that can be expected between iodine 131 and mock-iodine at the extremes of the accepted intercalibration mixture are shown by dividing the spectrum into 4 energy regions. It is seen that not quite 40 per cent the total energy emitted from iodine 131 is in the arbitrarily defined X-ray region. There is a slightly lower percentage in the X-ray region with the 13.1/1 starting mixture and there is a slightly greater percentage in the 8.2/1 expiration mixture. About 20 per cent of the energy from iodine 131 is in the low-energy region. Another 40 per cent is in the medium region. The mock-iodine mixtures have about the same distribution of energy. Only about 1-1/2 per cent of the distribution is in the high-energy region. Thus it can be seen that mock-iodine matches the gamma-ray spectrum of iodine 131, and no matter

It was necessary to suspend the mock-iodine in extended sources of a variety of shapes in order to mimic clinical conditions. To do this the mock-iodine was suspended on an ion-exchange resin. The ion-exchange resin is a tissue-like, unit-density material that not only matches soft tissues but also tightly binds the isotopes so that their use, even when the containers are broken, is relatively safe. After the material was bound on the ion-exchange resin, it was measured in small lots, against samples calibrated by the National Bureau of Standards in a high-pressure ionization chamber. These small lots of active material were then mixed with large amounts or small amounts of inactive resin to obtain a uniform dispersion of activity throughout any required volume of material.

The mock-iodine was then put into a calibration manikin. A great deal of trouble was taken to math as exactly as possible a simulated clinical condition. The manikin

consisted of the upper half of a body that was completely filled with a body-background radiation. A simulated thyroid gland, filled with either a higher or lower amount of mock-iodine, was placed in the neck region. A small thigh section was included with the manikin and also a set of nine 100 per cent dose standards. These 100 per cent dose standards ranged from the size of a gelatin capsule to that of a 100 cc paper cup and very closely simulated most of the types of "100 per cent dose standards" that were used in clinical practice.

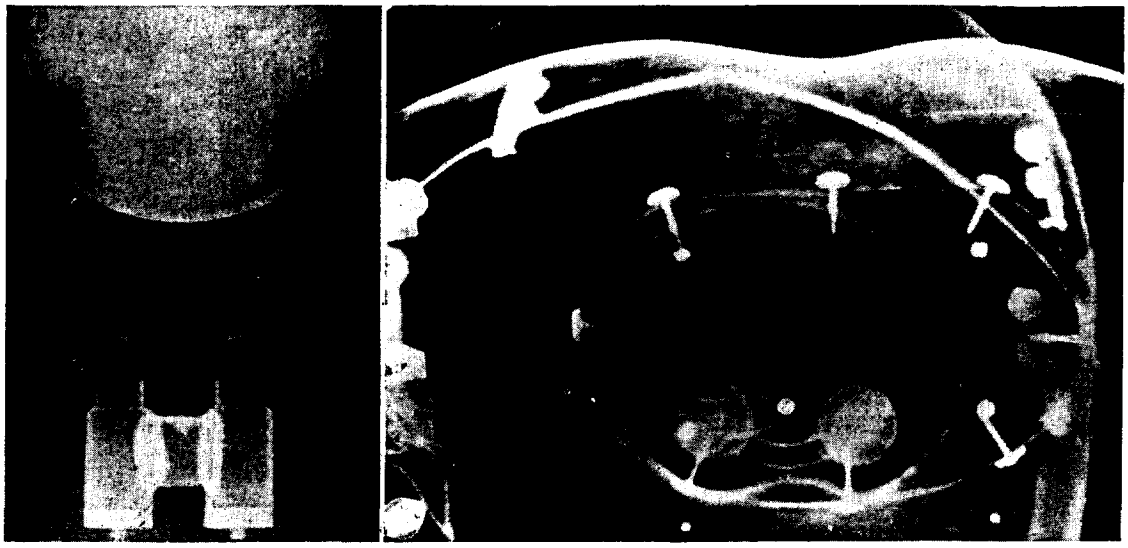


FIG. 5. X rays of a manikin to show the shape and position of the babbit metal thyroid.

Figure 5 shows an X ray of one of the completed manikins illustrating the positioning of the babbit metal thyroid in the manikin. In the survey manikins, a 25 ml volume thyroid was simulated with two lateral lobes and a median lobe. The simulated thyroid was placed in a position forward in the neck closely simulating the anatomical position of the true thyroid gland.

Six manikins were originally made for the survey. Nineteen manikins have now been made, plus one additional one for training purposes and two for more complex problems of scanning. The six survey manikins were divided into euthyroid, hypothyroid, and hyperthyroid simulated activities. For each type a 10 microcurie and a 50 microcurie total dose was made. The figures shown in Table 1 are the nominal uptakes of the manikins. They are not the true figures. The true calibrations of the uptakes of these manikins have been destroyed since it was not the purpose of the survey to determine that some methods were correct and sowe were incorrect. This is a much more complex problem and will be taken up in the third phase of the calibration program. For the survey, all that was wanted was to determine whether there was or was not a variation in the way in which physicians measured thyroid uptake.

Table 2 shows the results of the survey to date. More than 200 laboratories have participated in the test. The answers given from the laboratories ranged from an 8 per cent uptake to a 154 per cent uptake. Well over 90 per cent of the laboratories were more than 10 percentage points off the true answer. Any of the manikins could have been diagnosed in the laboratories in the United States and England as either hyperthyroid, hypothyroid or euthyroid. Since some of the best research laboratories in the United States and England were included in this survey,

and since their results were no better than those laboratories in which only routine procedure are followed, the situation is one that is an immediate cause for concern. There is a reason for questioning much of the literature that has been published on thyroid uptake, but not all. Many of the articles concern only relative differences. Frequently, although one laboratory may have given an answer both laboratories would have been able to duplicate their own answer. Results in any one laboratory were usually reproducible but the error was not neecssarily consistent from high uptakes to low uptakes.

A simulated urine sample was included in the standards'kit. Only a portion of the laboratories did routine urine examinations, but here also the variation of results was considerable. Another question that was answered by some of the laboratories was in the absolute determination of the number of microcuries in the 100 per cent sample. Here the results were remarkably accurate. It is apparent, therefore, that in most clinical laboratories, where they are sufficiently well equipped to do absolute calibrations on a small sample, the results are usually accurate. When, however, they are asked to measure

TABLE 1 MANIKINS

	NAME	STANDARD METOD UPTAKE	DOSE		HALF BODY BACKGROUND
Eu-Thyroid	Euphemia	65 %	50 uc		2.4 %
	Ibis	57 %	10 uc		1.5 %
	*Lulu	71 %	20 uc		2.5 %
	**Drusilla	56 %	11 uc		2.5 %
	**Hortense	62 %	50 uc		2.0 %
Eu-Thyroid	Chloe	27 %	50 uc		5.0 %
	Moira	33 %	20 uc		3.5 %
	Ophelia	36 %	1 uc		5.0 %
	Terry Toma	38 %	100 uc	(50 %)	2.5 %
	*Abigail	42 %	100 uc	(50 %)	3.0 %
	**Bridget	33 %	11 uc		4.5 %
	**Jezebel	20 %	10 uc		3.5 %
Low-Thyroid	Grenadine	7 %	50 uc		20.0 %
	Katrinka	6 %	10 uc		15.0 %
	*Felicia	7 %	10 uc		22.0 %
	**Nabby	12 %	20 uc		25.0 %
Well-Type	Pandora	(65 %)	10 uc		2.5 %
	Queenie	(35 %)	10 uc		5.0 %
	Rhoda	(9 %)	10 uc		20.0 %

(Each Well-Type manikin has has three interchangeable Thyroid glands of 50 cc, 25 cc, and 15 cc volumes)

Scanning:

Bonnie Boleyn – thyroid 10 uc, blood vessels 2 uc each, spinal colum 5 uc, metastases 1 uc each

Anne Boleyn – thyroid 25 uc, blood vessels 2 uc each, spinal colum 5 uc, metastases 1 uc each

* Available for one month loan
** Available for six months loan

an extended source in a simulated clinical condition, most laboratories are not able to achieve a result that is even reasonably accurate.

It was not intended that the work of the Thyroid Uptake Calibration Committee be confined only to the determination of the variation in thyroid uptake measurements. This was only the first phase of the program. A second phase has been set up that is concerned with the determination of why there was a variation and what factors influenced the measurement. Included in the second phase is the determination of whether it is possible to set up an intercalibration program that could be fairly universally followed and would be acceptable to most workers in the field. The third phase of the program will then be to initiate an intercalibration program.

The determination of the causes for variation with different instrumentation has been a complex study. It involves such things as investigating the variations due to different detectors, counting systems, distances, filtrations, size and shape of standards, variations in body background, scatter background, and a host of other causes for variance. A detailed explanation of each of these variances would be too long for this paper, but an illustration can be given of one of the major causes for variation. This involves the changes in the spectrum of energies emitted from the body from the standards when iodine 131 is distributed throughout an extended body.

A point source of iodine gives off many gamma photons ranging from an 80 kev to a 722 kev gamma photon. It gives these off in definite proportions. When the iodine is distributed in an extended source, each of these gamma photons has a different probability of absorption and scatter. Further, the higher-energy protons will tend to interact with the surrounding media with a Compton interaction that will cause the production of a spectrum of degraded energies. The very low energies will tend to interact with a photoelectric absorption.

TABLE 2

DISTRIBUTION OF RUSULTS OF ORINS THYROID UPTAKE CALIBRATION SURVEY

First Phase (250 Laboratories)

Measured % Uptake	Hyperthyroid Manikins	Hypothyroid Manikins	Hypothyroid Manikins
0 - 10	1 %	0	44 %
10 - 20	0	3 %	46 %
20 - 30	0	13 %	5 %
30 - 40	2 %	57 %	2 %
40 - 50	2 %	17 %	2 %
50 - 60	9 %	7 %	0 %
60 - 70	15 %	3 %	0
70 - 80	35 %	0	0
80 - 90	17 %	0	0
90 - 100	10 %	0	0
100 - 110	3 %	0	0
110 - 120	2 %	0	1 %
120 - 130	2 %	0	0
130 +	1 %	—	0

Different measuring instruments have different sensitivities to different portions of the spectrum. A thin-walled Geiger-Muller tube, for example, has a very high sensitivity for the lower-energy radiation and a decreased sensitivity for the high-energy radiation. A thick-walled Geiger-Muller tube has a different energy-sensitivity. The energy-sensitivity of a scintillation crystal will depend upon its size, shape, material, and the way in which it is canned. Even the size, shape, and the material of the collimating system will change the spectral sensitivity of the counting system. Therefore, a given amount of iodine 131 existing as a point source in air will give a different number of counts with differnt systems of detection. When this given amount of iodine distributed in a small gelatin capsule, the number of counts will change when the gelatin capsule is put into different kinds of phantoms. When the iodine is distributed in the thyroid gland in a neck, it will give a still different number of counts. One of the methods of investigating how the detector will respond to these differences in

absorption and scatter is to look at the shape of the spectrum.

Figure 6 shows the pulse-height spectrum from an iodine 131 point source. Superimposed over this is the pulse-height spectrum from a patient's neck in which a thyroid gland was present. These two spectra are arbitrarily normalized at the 640 peak, and the spectrum is smoothed to show only the major peaks. When the point-source spectrum is subtracted from the extended source spectrum, it is possible to illustrate the differences that have occurred by drawing out what can be called a first-order difference spectrum In (Fig 6) this differente spectrum shows that there is a great excess of low-energy radiation produced in the patient's neck. There is some absorption of the 640 kev peak but, it should be remembered, the differences that might occur in the 640 kev peak disappear on the graph because the two spectra have been normalized at this point.

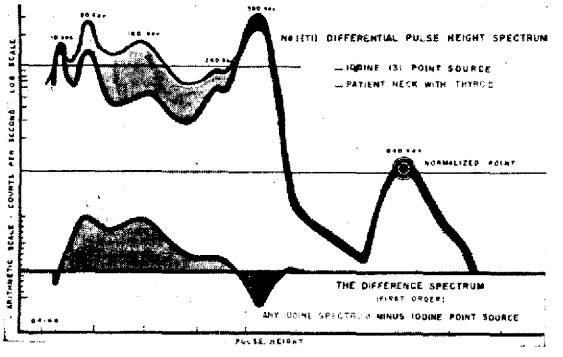


FIG. 6. Pulse-height spectrum of a patient's neck superimposed over the pulse-height spectrum from an iodine 131 point source to give a first-order difference spectrum.

With the shape of this difference spectrum kept in mind, we can look at what happens when the size and shape of the 100 per cent total dose standards that are commonly used is varied. Figure 7 shows the selection of 100 per cent total dose standards used in the survey manikin kit. These range from a very small capsule containing 0.4 ml of iodine 131 solution, to a paper cup containing 100 ml of iodine 131 solution The size and shape of these nine standards closely simulate most of the standards that are in current use.

The effect of the size and shape of these standards is shown in (Fig 8). When a 5 cc test-tube sample is used as the base line

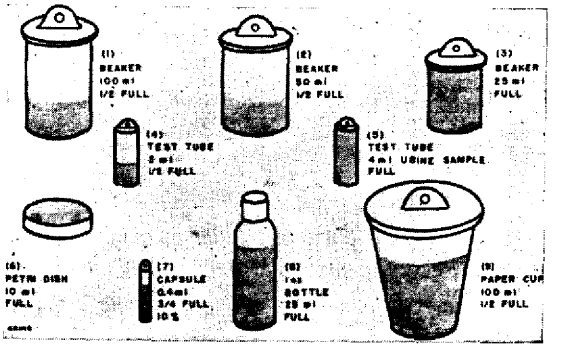


FIG. 7. The 100 per cent total dose standards used in the survey manikin kit.

for comparison, there is very little change in its difference spectrum and that of the large and small beakers and the paper cup. However, when the test-tube sample is compared with a commonly used gelatin capsule (in two different kinds of phantoms) it is seen that there is a tremendous change in the difference spectra. It is interesting that none of these spectra even closely resemble the spectrum from a patient's neck. Therefore, when one is using any of these standards in air, or even many of the very carefully constructed neck-shaped phantoms, one is not comparing the same things, and the 100 per cent dose standard is not truly a standard. During the course of our investigation of these spectra, we had almost reached the conclusion that a phantom for the patient's neck could not be designed. Recently, however, a method has been devised that makes it appear that such a phantom can be designed but that the specifications will have to be exceedingly strict. A number of these phantoms have been made for clinical trial by the Thyroid Uptake Calibration Committee and they now being sold commercially.

In order to investigate the potential acceptance of a calibration method, a large series of instruments has been set up in Oak Ridge. Most of the methods of doing thyroid uptake measurements can now be duplicated in Oak Ridge, and the methods of intercalibration can be tested on a fixed-geometry training table. This allows for the substitution of various manikins and standards in a fixed geometry with three representative types of instrumentation. A series of conferences has been held so that those who have participated in the survey can calibrate their own instrumentation.

To assit in the calibration problem a series of calibration kits has been designed. The calibration kits contain the long-life mock-iodine; and when used in conjunction with a carefully designed phantom, the spectrum emitted by the calibration elements will be within the range of the spectra emitted by the necks of patients. Two simulated thyroid glands are included, one at 5 and one at 50 microcuries. Five mock-testtubes with activities ranging from 50 to 0.01 microcuries and 5 simulated capsules with activities ranging from 10 to 0.001 microcuries are included. Thus, it is possible to intercalibrate almost all kinds of instrumentation from highly sensitive well-scintillation counters to very insensitive thin-walled Geiger-Muller tube external counters. (Narrow-window spectrometers are always an exception when mock-iodine is used.)

Over a two-year period Dr. Hirotake Kakehi, from Chiba University, Tokyo, Japan, used nineteen different kinds of thyroid uptake measuring equipment in Oak Ridge to investigate the problems of thyroid uptake measurement. The results of this very extensive investigation showed that there were a number of major sources of error that were always present in every kind of thyroid uptake measurement. Figure 9 shows a template that was devised to illustrate almost all of the methods of doing thyroid uptake. In every thyroid uptake measurement a patient is used. This patient cannot be standardized in any way; however, a selection of patients can afford a reasonable kind of standardization. The kinds of patient in which the newly divised standard technique is valid are only those in which the thyroid gland is in its usual anatomical position and in which the thyroid gland is of reasonable size. The words "usual" and "reasonable" are used in order to cut out of consideration sublingual thyroid tissue, substernal thyroid glands, or metastases in the range of "vision" of the detector. The word "usual size" is defined as follows: Any thyroid gland that can be completely hidden by a 4″ by 4″ square thyroid eclipse shield is considered to be of usual size.

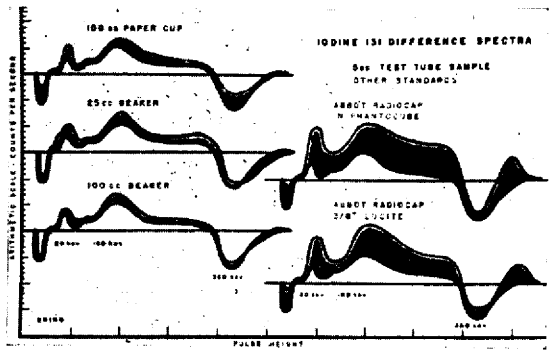


FIG. 8. The first order difference spectra of various standards compared.

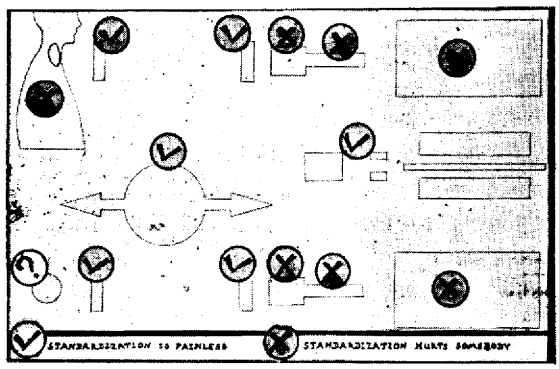


FIG. 9. Template for investigating methods of doing thyroid uptake and the individual sources of error contained therein. Reading from left to right on the upper row are the patient, the "B"-filter, the "A"-filter, the collimator, detector, and the scaler. Any method of standardization must include statements on hall of these individual pieces of a calibration method.

Well over 95 per cent of patients presenting themselves to a physician for a thyroid uptake measurement will meet this requirement. In those patients where the thyroid tissue is spread over an area greater than 4″ by 4″, the standard intercalibration technique will not be accurate.

Almost all the methods of doing thyroid uptake measurements use some kind of filtration. Two very different kinds have been used. These have been separated as follows: The term "A-filter" is used when a piece of material is purposely interposed between the patient and the detector but is kept in a position very close to the detector. The term "B-filter" (or thyroid eclipsing shield, or a filter in the B position) is used when a piece of material is interposed between the patient and the detector but is put very close to the patient's neck.

Every method of doing thyroid uptake uses a detector, and this detector must be considered in two parts. First of all is the detector itself, and this can be any kind of Geiger-Muller tube, or inonization chamber, or electroscope, or gamma-ray-sensitive crystal. The detector is usually placed within some sort of shield and collimator arrangement. Some kind of counting signal is always attached to the detector. In some laboratories this may be a very complex spectrometer or it may be a simple scaling device. In some laboratories very simple rate meters are in use and are giving very acurate results. In some laboratories very complex electronic systems have been devised and are giving very inaccurate results.

Every method of doing uptake includes some kind of measurement of a standard. In a few laboratories this standard is measured once for a particular instrument and the instrument is said to be calibrated for measuring thyroid uptake directly. Usually these methods have ben highly inaccurate, but this is because the instruments themselves are inaccurate and not because the method is necessarily a poor one.

All the methods interpose a distance between the neck of the patient and the detector is placed on the surface of the neck it may be called zero distance, but there is still space between the tube and the source of activity. Measurement of distance is a most important part of the thyroid uptake technique.

All the persons doing thyroid uptake measurements apply some sort of formula for calculating the final result. In order to simplify the survey and for teaching thyroid uptake techniques, we have adopted a standard formulary to describe thyroid measurements. The following system of symbols is used:

P = the measurement taken over the patient's neck with no interposed filters.

P_A = the measurement over the patient's neck with an "A-filter" placed very close to the detector.

P_B = the measurement taken over the patient's neck with a thyroid eclipsing shield placed very close to the patient's neck.

S = the measurement taken over the standard in or out of the phantom. Such items as the distance, the type of scaler, the type of detector, are listed as footnotes to the formula.

Many different kinds of formulas were found in use during the thyroid uptake calibration survey. In fact, no laboratory was found that was using exactly the same method as any other laboratory. A simplified generalization, however could be made for four specific kinds of formula. These are as follows:

The O formula: $$TU = \frac{P - RB}{S - RB}$$

In this "no-filter" formula the thyroid uptake was measured without any filtration, but a room background measurement was made

and was subtracted from both the measurement over the patient and the measuremnt over the standard.

$$\text{The A formula:} \qquad TU = \frac{P_A - RB_A}{S_A - RB_A}$$

In this formula an "A-filter", usually a thin piece of lead, was interposed between the patient's neck and the detector but was placed very close to the detector.

$$\text{The B formula:} \qquad TU = \frac{P - P_B}{S - S_B}$$

In this formula a thyroid eclipsing shield was used. These may have been of many different sizes and shapes but were always placed very close to the patient's neck and usually at a distance from the detector. Here a measurement was taken over the patient without a filter and another measurement was taken with the filter in place. The measurement with the filter was substracted from the measurement without the filter. This results in a kind of body-background correction.

$$\text{The AB formula:} \qquad TU = \frac{P_A - P_{AB}}{S_A - S_{AB}}$$

This is the formula that was devised after extensive study. It is a method that has been used in very few laboratories but is the formula that showed the best answers under all

Another very common formula was used to measure thyroid uptake. It was a formula that involved the subtraction of a thig measurement or of some other kind of measurement to correct for body background. The results from laboratories using the thigh correction and similar results with this kind of a body-background correction in the ORINS laboratory were so exceedingly poor that this method has been dropped from all further consideration. Another method that was very commonly used was a very simple one in which no correction was made for body background or for room background. Since this method is so similar to the 0 formula method. it was dropped from any further consideration.

In many laboratories, very complex formulas interposed factors (or even fudge factors) that sometimes resulted in very accurate thyroid uptake measurements. In most instances these fudge factors were valid only for certain kinds of patients, usually the very high thyroid-uptake, very low bodyback-ground patients. In a number of instances very complex formulas were intimately associated with very complex and unusual designs of instruments. Since these instruments were available to very few laboratories (and most persons doing thyroid uptake measurement could not even dream of obtaining them), these complex formulas were dropped from further consideration.

With the four type-formulas applied to almost every kind of instrumentation under almost every kind of thyroid uptake circumstance and in many different kinds of patients, it was found that a generalized statement of error could be made.

Among those persons who used instruments in which there was a high degree of control of the spectrum (and this includes all the spectrometers and also those instruments that had good discriminator control) the degree fo control over the spectrum accounted for the lion's share of the variation in thyroid uptake measurements under any one circumstance. Where the spectrometer control excluded all scattered radiation, the results of the measurement were usually very good. Where the spectrometer control included scattered radiation, the results of the measurement were invariably very poor. About three quarters of the error could be accounted for on the basis of the control of the spectrum seen by the detector.

Even with very good spectrometer control it is possible to make significant errors in the thyroid uptake. The most significant factor is the adoption of an improper phantom. One of the primary things that a phantom

does is to distort the spectrum of radioactivity so that the detector sees a different kind of radiation from what it would see if the source were in free air. If the phantom distorts the spectrum in a manner different from the way the neck distorts the spectrum, then the measurements of the total number of counts detected will be different. Therefore, the phantom must be designed to give off a spectrum similar to that of the patient's neck.. The misuse of phantoms and the use of improperly designed phantoms accounts for about one quarter of the potential error in those laboratories where spectrometers are used for thyroid uptake.

In some laboratories formulas have been devised with very careful attention to detail so that measurements on all of their hyperthyroid patients are correctly calibrated to a reasonable answer. However, when a hypothyroid patient with a high body background is inserted into this system of measurement, a very false answer is achieved. The use of queer and unusual formulas accounts for a significant portion of the error in those laboratories where spectrometers are used for thyroid uptake.

Among those persons who used spectrometer it was unusual that the size, shape, or kind of standard caused any error. Usually the laboratories sufficiently advanced to use a spectrometer made very good calibrations of their standards. The only argument that would ensue in a laboratory using a spectrometer would be the argument on the estimate of absolute microcurie values.

But very few laboratories used a spectrometer for the measurement of thyroid uptake. Most laboratories used instruments in which there was no possible control over the spectrum seen by the instrument. In these laboratories the major source of error in thyroid uptake measurements was in the use of an improperly designed phantom or the use of no phantom at all. The phantom design alone accounts for the largest portion, about 50 per cent, of the error. Even when a standard phantom is used, however, it is still possible to make considerable error in the thyroid uptake measurement. It would appear that the formula used to determine the per cent uptake in the neck accounts for the next largest portion-about 25 per cent. With many instruments the size and shape of the 100 per cent total dose standard is very important. Those persons who used a very small standard, for example a gelatin capsule in air, invariably gave very incorrect answers. Those persons who used very large standards, for example 100 cc of water in a paper cup, usually gave fairly accurate answers in the high-thyroid, low body-background type of patient. They invariably, however, had very incorrect answers in the low-thyroid, high body-background type of patient. The size and shape of the standard appears to account for about 20 per cent of the error when all types of machines are taken into consideration.

Most of the other elements of variation accounted for a very small portion of the error in thyroid uptake measurement. For example, the area covered by the filters, the type of collimation, the distance used, the thickness of various filters, the materials used in manufacturing the filter — all of these factors were relatively minor. The distance factor, however, brought up a different question. In many laboratories the most important single source of error was the sloppiness with which the distance was measured. Almost any distance, provided it is neither too close nor too far from the patient, can be used adequately to measure thyroid uptake. However, the distance between the detector and the patient and the detector and the standard must be either identical or in a precisely constant ratio. This is a very critical measurement and is one that is not appreciated by most of the technicians who are doing thyroid uptake measurement. During the survey of thyroid uptake measurments it was found that many laboratories did not use any device for determining distance.

To illustrate in summary form the effects of many of these variables in thyroid uptake measurement Fig. 10 shows the combination of all the factors. One kind of instrument was used, the Mediac, to measure two different manikins. One was a high-thyroid, low body-background manikin; and the other was a low-thyroid, high body-background manikin. In the measurement of thyroid uptake the four standard formulas were used; the O formula (without any filtration), the A formula (with an "A" filter only), the B formula (with a thyroid eclipsing shield only), and the AB formula. Three different kinds of phantoms were used. One was the most shallow possible kind of phantom; and one, the standard phantom, was a phantom in which the spectrum of emission from the source matched the spectrum of emission from the patient's neck. The measurements were made at five different distances (from 20 to 60 centimeters from the surface of the patient's neck to the surface of the detector). It can be seen from this figure that when a very shallow phantom is used, there is a tendency for a very wide range of answers. When the too-deep phantom is used in the hig-thyroid type of patient, all the answers are far too high. When a standard phantom is used, except where there is no filtration, usually a reasonably good answer is given.

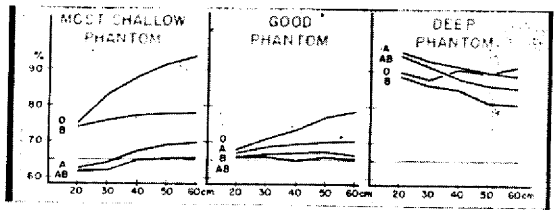
The results in the low-thyroid, high body-background patient illustrate the value of the thyroid eclipsing shield or "B-filter". Even where the phantom is improperly designed, if a thyroid eclipsing shield is used, the result is within reason.

An important question is, how accurate can a thyroid uptake measurement be under ideal conditions? In running through a very large series of measurements on many different instruments and many different manikins, it was found that with exceptionally stable equipment it is possible to measure the thyroid uptake within about 3 percentages point of accuracy. If the thyroid uptake is close to 90 per cent, then this is a very small errorr. It was found that the actual amount of error was highly related to the thyroid uptake, and therefore the error is given in percentage points of uptake rather than in per cent error. This 3 percentage points of accuracy, however, is possible only

TUC-RANK ORDER IMPORTANCE

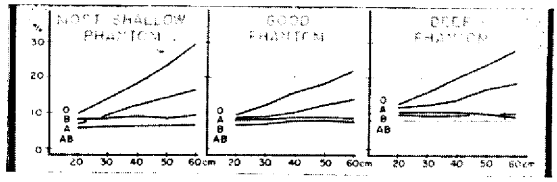
A		B	
WITH SPECTROMETER CONTROL		WITHOUT SPECTROMETER CONTROL	
The spectrum	80 %	The phantom	50 %
The phantom	20 %	The formula	25 %
The formula	10 %	The standard	20 %
The standard (for absolute values only)		The filter area*	2 %
		The collimation*	2 %
		The distance*	1 %
		The filter thickness*	1 %

* Be reasonable



Hi-thyroid, lo-boadybackground patient

AND FORMULA HAVE BEEN STANDARDIZED
DISTANCE, PHANTOM, STANDARD, FILTERS



Lo-Thyroid, Hi-Bodybackground patient

FIG. 10. Summary of the effects of many variables in thyroid uptake measurement.

under ideal conditions of artifical manikins and easily controlled geometry. When patients are used, this accuracy cannot be achieved. It would appear however, that with any instruments and with any kind of patient it is possible to achieve well within 10 percentage points of accuracy and probably, if care is taken, 5 percentage points of ac-

curacy, if the AB formula and a properly designed phantom are used. It is felt that this ± 5 percentage points of accuracy in the thyroid uptake measurement is sufficient for all clinical conditions. A standardized technique is therefore recommended for all routine thyroid uptake measurements. This standardized technique is the measurement of thyroid uptake with the AB formula system and a standard phantom at a distance of 10 inches. With any instrumentation it is possible to measure thyroid uptake within ± 5 percentage points of the correct figure in a patient with any thyroid uptake and with any body background Two restrictions are put on this statement: the thyroid must be eclipsed by a 4″ by 4″ "B-filter" and must be in a known position.

It should be noted here that the calibration program is so far concerned only with the physical measurements. When the art of measuring the radioiodine activity in the thyroid gland has progressed to the point where physicians all over the world are talking the same physical language, then it will be necessary to extend the investigations to the much more difficult problem of the biological sources of error. Eventually, there will have to be considered the more serious problem of the clinical interpretation of thyroid uptake measurements.

SUMMARY

This paper is a report on the survey and the extension of the work carried out by the Thyroid Radioiodine Uptake Calibration Committee of the Oak Ridge Institute of Nuclear Studies toward a method of calibration.

The variation in thyroid uptake measurements among laboratories is significant because of the use of different combination of standards, instruments, distances, techniques and formulas.

It was felt that a clinical intercalibration procedure adaptable to all the various techniques in use was necessary.

The program of the Committee presented three phases:

1) Determination of the variation in thyroid radioiodine uptake measurement.
2) Determination of why there was a variation, of what factors influenced the measurements and of whether it is possible to set up an intercalibration program that could be fairly universally followed and would be acceptable to most workers in the field.
3) To initiate an intercalibration program for the Radioiodine Uptake Measurement.

RESUMEN

Se presenta un informe de la revisión y extensión del trabajo realizado por la Comisión del Instituto de Estudios Nucleares de Oak Ridge para la Medición de la Captación Tiróidea del Yodo Radioactivo.

La variación existente entre las medidas obtenidas por diferentes laboratorios es notable, debido al empleo de distinta combinación de 'standards', instrumentos, distancias, técnicas y fórmulas.

Se sintió la necesidad de hallar un procedimiento clínico de calibración adaptable a todas las técnicas en uso.

El programa de la Comisión tenía tres fases:

1) Determinación de la variación en la medición de la captación tiróidea del yodo radioactivo.
2) Determinación de las causas de la variación, qué factores influenciaban estas mediciones y la posibilidad de establecer un programa de calibración que pueda ser aplicado lo más universalmente posible y que sea aceptable para la mayoría de los que trabajan en este campo.

5) Iniciar un programa de intercalibración de la captación tiróidea del yodo radioactivo.

RESUMO

Apresenta-se um infôrme da revisão e extensão do trabalho realizado pela Commissão do Instituto de Estudos Nucleares de Oak Ridge de Medição da Captação Tiróidea de Iodine em busca de um método exacto de medição.

A variação existente entre as medidas obtidas por diferentes laboratorios é notavel, devido ao emprego de diferente combinação de 'standards', instrumentos, distancias, técnicas e fórmulas.

Sentio-se a necessidade de encontrar um procedimiento clínico de calibração adaptavel a todas as técnicas em uso.

O programa da Commissão tinha tres fases:

1) Determinação da variação na medição da captação tiróidea de radioiodine.
2) Determinação das causas desta variação, fatores que influenciavan estas medições e a possibilidade de estabelecer um programa de calibração que possa ser aplicado o mais universalmente possível e que seja aceitavel para a maioría dos que trabalham neste campo.
3) Iniciar um programa de intercalibração da captação tiróidea de iodine.

M. Brucer, M. D.
Oak Ridge Inst. of Nuclear Studies
P.O. Box 117, Oak Ridge, Tennessee.

RÉSUMÉ

On présente un rapport de la revision et de l'extension du travail réalisé par la Commission de Mesure de Captation Tyroïdienne de iodine de l'Institut d'Etudes Nucléaires de Oak Ridge, à la recherche d'une méthode exacte de mesure.

La différence existente entre les mesures obtenues par les différents laboratoires est considérable à cause de l'emploi d'une combinaison différente de "standards", d'instruments, de distances, de techniques et de formules.

On éprouva le besoin de trouver un procédé clinique de calibration, adaptable à toutes les techniques en usage.

Le programme de la Commission avait trois phases:

1) Détermination de la variation dans la mesure de la captation tyroïdienne de iodine.
2) Détermination des causes de cette variation, facteurs qui agissent sur ces mesures et possibilité d'établir un programe de calibration susceptible d'être universellement appliqué et acceptable pour la majorité de ceux qui travaillent dans ce domaine.
3) Initation d'un programme d'intercalibration de la captation tyroïdienne de iodine.

COMPAÑÍA IMPRESORA ARGENTINA S. A.
Alsina 2049 – Buenos Aires

Two Ways to Estimate Thyroid Dose from Radioiodine in Fallout

By GORDON M. DUNNING

Division of Biology and Medicine
U. S. Atomic Energy Commission
Washington, D. C.

reprinted from NUCLEONICS

Feb. 1956, Vol. 14, No. 2, Pgs. 38–41

By GORDON M. DUNNING
Division of Biology and Medicine
U. S. Atomic Energy Commission
Washington, D. C.

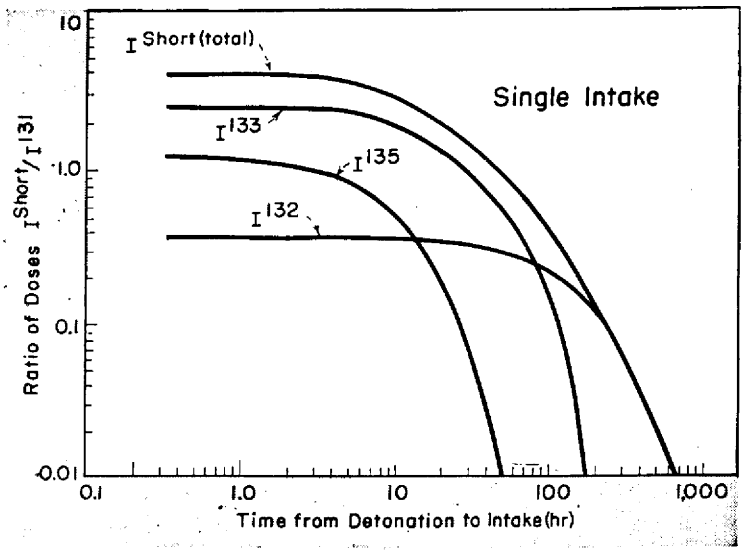


FIG. 1. Approximate ratio of infinity dose to thyroid from short-lived radioiodine isotopes and I^{131} for case of single intake. See Table 2 for sample calculation of these curves

Two Ways to Estimate

Thyroid Dose from Radioiodine in Fallout

CALCULATING RADIATION DOSE from fallout presents unique problems. One of these is how to estimate thyroid dose from intake of the radioisotopes of iodine found in fallout material. Because of uncertainties in the relevant variables, the calculations cannot be made with the precision that is possible in a laboratory or clinical situation. However, it is often essential to make such estimates, even though admittedly based on limited data.

There is disagreement as to the principal mode of entry into the body of the radioactive I contained in fallout, i.e., inhalation or ingestion. For low-yield detonations, such as in Nevada, relatively higher concentrations of fallout material are found in the air for only a matter of a few hours with essentially all of calculated intake by inhalation completed within 24 hours for nearby communities.

When the detonations occur at the Pacific proving ground the activity in the air may persist for somewhat longer times in the U. S. Thus, for relatively early, short exposures the amount of intake by inhalation may be comparable to that by ingestion. However, if one considers normal ingestion for a continuing period, it would appear this is by far the dominant factor. This is especially true for grazing animals. In fact, field experiments near the Nevada test site showed there was little I in the thyroid of rabbits, who were restrained so that they could not ingest any material but could continue to inhale during and after fallout.

The problem of dosage calculations is complicated by the presence, at early times after detonation, of short-lived I isotopes in addition to I^{131} and by tellurium precursors for several.

The general approach given below for these problems is to calculate the dose from I^{131} and its precursors and then add to this the contribution from the short-lived isotopes of I and their precursors. Due to relative abundance or short half-lives the only isotopes of concern here are: I^{131}, I^{132}, I^{133}, I^{135}, Te^{131m}, Te^{131}, Te^{132}, and Te^{133}. Their properties are given in Table 1.

Calculating Dose

The precise calculation of I^{131} intake to the thyroid is difficult because of

a. Uncertainties of the percentage of intake into body that reaches the thyroid.
b. The tellurium precursors that result in the absolute activity of the I^{131} in the environment remaining roughly constant for about a day followed by a period of increasing decay rate until the precursors no longer play a significant role and the decay rate then becomes that of I^{131}.

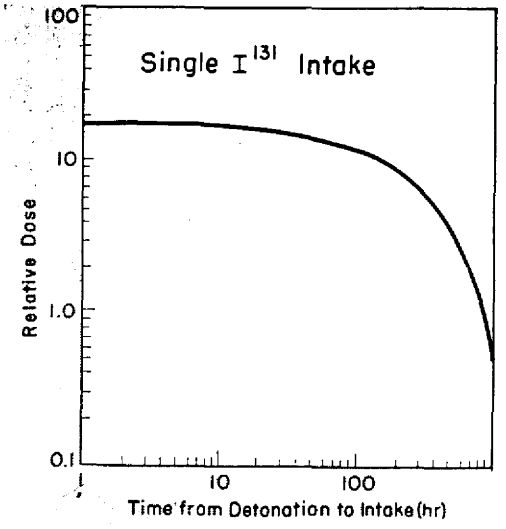


FIG. 2. Approximate infinity dose to thyroid from single intake of the I^{131} and its tellurium precursors from 10,000 fissions. This figure is used with Table 3 in the preparation of Fig. 3

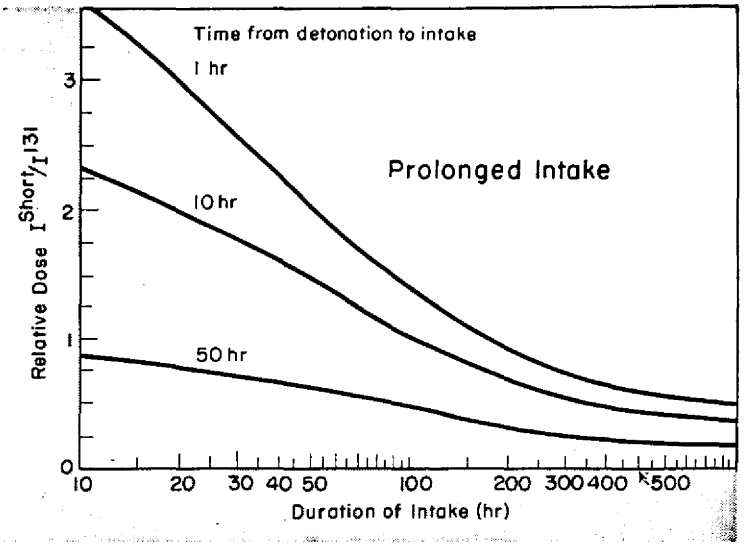


FIG. 3. Approximate relative infinity dose to thyroid from short-lived I isotopes and I^{131} for case of prolonged intake. See Table 3 for sample calculation of these curves

When ingestion or inhalation of radioactive fallout material occurs, it is important to be able to estimate the dose received. Here, for the case of radioiodine, is a procedure for determining the thyroid dose given present activity or initial intake

c. The intake, along with the I^{131}, of Te^{131m}, a part of which will disintegrate within the body to I^{131}.

To estimate the original rate of intake of I^{131} from a known activity in the thyroid at a later date, one can extrapolate according to the physical and biological decays of I^{131} only. This method ignores intake factor **b** and thus overestimates the original intake; it also ignores factor **c** and thus underestimates the original intake. The extent to which these affect the answer depends upon time of original intake after detonation and the duration of intake. However, estimates of the effects of ignoring these two factors indicate that the over-all error would not be any greater than other inherent uncertainties.

The exact steps are given in the following sections. The symbols are defined at the head of page 40. Two examples are given on pages 40 and 41.

1. Initial rate of intake of I^{131}, R_0. Assume that the rate of intake decreases according to the physical decay of the isotope. Then activity in the thyroid changes with time thusly

$$\frac{dA}{dt} = R_0 e^{-\lambda_r t} - (\lambda_r + \lambda_b)A$$

TABLE 1—Isotopes Important to Thyroid Uptake

Mass number	*Atomic number* 51 (*Sb*)	52 (*Te*)	53 (*I*)	54 (*Xe*)	55 (*Cs*)
131		30 hr ↓ 25 min →	8.0 day →	stable	
132	~5 min →	77 hr →	2.4 hr →	stable	
133	<10 min →	60 min →	21 hr →	5.3 day →	stable
134	<10 min →	43 min →	50.8 min →	stable	
135		<1 min →	6.7 hr ↗ 15.3 min (~10%) ↘ 9.2 hr →	2.1 × 10^6 yr →	stable

Symbols Used

$A = A(t)$ = activity in thyroid (μc/gm)
R_0 = initial rate of intake of thyroidal I^{131} (μc/gm/day)
λ_r = radiological (physical) decay constant
λ_b = biological decay constant
t = time
E = average energy of beta particles (Mev)
K = 55 R_0E (a constant)
D_s = infinity dose (reps) to thyroid from single I intake
D_t = total infinity dose (rep) to thyroid from continual intake from $t = 0$ to $t = \infty$.

TABLE 2—Sample Calculations for Figure 1

A Radio-isotope	*B* Half-life (hr)	*C* Activity[a] (dpm/10,000 fissions)	*D* Number of atoms present per 10,000 fissions	*E* Atoms of iodine reaching thyroid per 10,000 fissions	*F* Average beta energy (Mev)	*G* Max. rel. energies to thyroid ($E \times F$)[b]	*H* Ratio[c] $\frac{I^{Short}\ Energy}{I^{131}\ Energy}$
I^{131}	192	0.014	230	57.5[d]	0.20	11.5	
Te^{131}	30	0.019	49.4	9.9[e]	0.20	1.9	
Te^{131m}	0.42	1.5	54.3	13.6[f]	0.20	2.7	
I^{132}	2.4	0.026	5.4	0.3[g]	0.52	0.16	0.01
Te^{132}	77	0.056	374	11.2[h]	0.52	5.8	0.36
I^{133}	21	0.14	255	48.5[i]	0.45	21.8	1.35
Te^{133}	1	2.6	226	43.0[j]	0.45	19.4	1.20
I^{135}	6.7	0.88	512	61.6[k]	0.30	18.5	1.15
I(all short-lived)							~4.07

[a] Based on Hunter and Ballou tables (*1*).

[b] The biological fate of the isotopes of iodine is the same. Thus, the same proportions of the total number of atoms of each are taken into the thyroid and then eliminated according to the biological characteristics of the animal. The loss of an atom of a short-lived isotope means a greater loss of energy to the thyroid than does the loss of an I^{131}. However, it is to be expected that the biological half-life of animal thyroids will be much greater than the radiological half-life of even the longest short-lived radioiodine isotope (I^{133} with 21-hr half-life) so that essentially all of these energies will be delivered to the thyroid. For cases where the biological decay constant, λ_b, is significantly large compared with the radiological decay constant, λ_r of I^{131}, (0.0036 hr^{-1}), then the values for energies of I^{131} (including Te^{131} and Te^{131m} precursors) given in column *G* should be multiplied by the factor $\lambda_r/(\lambda_r + \lambda_b)$ and likewise the values for the relative energies in column *H* for the short-lived isotopes should be multiplied by the factor $(\lambda_r + \lambda_b)/\lambda_r$.

[c] All of the iodine atoms reaching the thyroid will disintegrate there. Corrections may be necessary according to footnote *b*.

[d] 25% of the I^{131} atoms taken into the blood reach the thyroid.

[e] 20% of Te^{131m} taken into the body reaches the thyroid, i.e., about 80% would have disintegrated to Te^{131} while in the gut of which all disintegrates to I^{131} of which 25% reaches the thyroid.

[f] All of the Te^{131} atoms taken into the body will disintegrate to I^{131} of which 25% will reach the thyroid.

[g] 6% of the I^{132} taken into the body reaches the thyroid. The biological half-life of I in the blood of humans may be about 7 hr (*2*). According to available data to date (*3*) the biological half-life of I in the blood of sheep may be 10–12 hr for the first day, followed by a flattening out of the curve. The proportion of activity reaching the thyroid may be estimated as $\frac{1}{4}\lambda_B/(\lambda_B + \lambda_r)$. The values in Table 1 are based on human data (7-hr biological half-life of iodine in the blood). These also give approximate values for sheep. Assuming a biological half-life of iodine in the blood of sheep of 11 hours over a period of 22 hours only, the ratios given in Fig. 1 differ for sheep as follows: I^{132}, about 30% too high; I^{133}, 10% too low; I^{135}, 10% too low. The ratio of doses from individual short-lived iodine isotopes indicated in Fig. 1 suggests that the ratio of the total short-lived isotopes to I^{131} may be underestimated for sheep by a few per cent in the early times after detonation. At later times the I^{132} contribution predominates, but also the ratio of infinity doses from the total short-lived isotopes to I^{131} has decreased significantly. Thus, the method suggested here may give a fair approximation of the total infinity doses for sheep.

[h] 3% of the Te^{132} intake reaches the thyroid as I^{132}, i.e., 50% would disintegrate to I^{132} while in the gut of which 6% will be deposited in the thyroid per footnote *g*.

[i] 19% of the I^{133} taken into the body will be deposited in the thyroid; 25% would be deposited normally, but about 25% of these atoms will decay before deposition[g].

[j] All of the Te^{133} taken in will disintegrate into I^{133} while within the body of which 19% will reach the thyroid according to footnote *i*.

[k] 12% of the I^{135} intake will be deposited in the thyroid; 25% would be deposited normally, but about 50% will decay before deposition according to footnote *g*.

This has the solution

$$A = \frac{R_0}{\lambda_b}\left(e^{-\lambda_r t} - e^{-(\lambda_r+\lambda_b)t}\right) \qquad (1)$$

Thus, analyzing the thyroid for its I^{131} activity, A, at any time, t, one can figure back to the initial rate of intake, R_0.

2. Infinity I^{131} dose. The dose to infinity from I^{131} intake on the first day is

$$D_s = K\int_0^\infty e^{-(\lambda_r+\lambda_b)t}\,dt$$
$$= K/(\lambda_r + \lambda_b)$$

The infinity dose from a continuing intake that decreases according to the radiological decay is then given by

$$D_t = K/\lambda_r + \lambda_b\int_0^\infty e^{-\lambda_r t}\,dt$$
$$D_t = K/(\lambda_r + \lambda_b)\lambda_r \qquad (2)$$

3. Doses from short-lived isotopes. The additional dose to the thyroid from short-lived isotopes of iodine resulting from a *single* intake is summarized in Fig. 1. A sample of the calculations used to construct Fig. 1 is given in Table 2 at left.

In the case of grazing animals, however, the period of intake may start at different times after detonation and extend for varying periods of time. An estimation of additional doses to the thyroid from short-lived isotopes of iodine under these conditions is summarized in Fig. 3. A sample of the calculations used to construct Fig. 3 is given in Table 3.

Example: Sheep Ingestion

About 3½ hours after the nuclear detonation at the Nevada Test Site on May 19, 1953, fallout occurred in an area around Cedar City, Utah, where sheep were grazing. On June 15 some of these sheep were sacrificed and on July 8 the I^{131} concentrations were measured in specimens of their thyroids. The highest measured I^{131} concentrations on July 8 were about 5×10^{-2} μc/gm (c.f. *3*). What might have been the total radiation dose to the thyroids of these sheep from all of the isotopes of radioiodine?

First calculate the I^{131} dose, then the dose from short-lived isotopes. Determine the initial rate of intake of I^{131} activity per gram, R_0 from Eq. 1

$$A = (R_0/\lambda_b)[e^{-\lambda_r t} - e^{-(\lambda_r+\lambda_b)t}]$$

In this case A_b = 0.37 μc/gm when sacrificed June 15. (Working back

from July 8 measurement.)

t = 27 days (May 19–June 15)

λ_r = 0.0866 day^{-1}

λ_b = 0.0204 day^{-1}*

Thus

$$0.37 = \frac{R_0}{0.0204}\left[e^{-(0.0866)27} - e^{-(0.107)27}\right]$$

R_0 = 0.189 μc/gram/day.

Now we determine the infinity I^{131} dose using Eq. 2.

$$D_{t\infty} = K/\lambda_r(\lambda_r + \lambda_b)$$

where: $K = 55\ R_0E = 55(0.189)(0.2) = 2.08$

Thus $D_{t\infty}$ = 224 reps is the infinity I^{131} dose.

To estimate the dose from short-lived isotopes of I enter Fig. 3 with these parameters:

start of intake = 3.5 hr
duration of intake = infinity.

The graph indicates a ratio of approximately 0.45.

But this is uncorrected for biological decay, i.e., it is based on the assumption that the biological decay constant for the thyroid is significantly less than the physical decay constant. It is necessary to correct this ratio by multiplying by the factor†

$$(\lambda_r + \lambda_b)/\lambda_r = 1.24.$$
$$0.45 \times 1.24 = 0.557$$

The infinity dose to the thyroid from short-lived isotopes of iodine is this fraction of the I^{131} dose

$$224 \times 0.557 = 125 \text{ rep.}$$

Thus the total infinite dose is 224 + 125 $\cong$ 350 rep.

This is not considered dangerous. Experimental studies with sheep at Hanford Atomic Products Operation suggest that about 16,000 reps are required to produce minimal changes in the thyroid cellular structure and about 50,000 reps to produce definite cell damage and hypothyroidism.

BIBLIOGRAPHY

1. H. F. Hunter, N. E. Ballou, NUCLEONICS 9, No. 5, C-2 (1951)
2. J. B. Stanbury, et al. "Endemic Goiter." Harvard University Monograph in Medicine and Public Health No. 12 (Harvard University Press, 1954)
3. L. Van Middlesworth, NUCLEONICS 12, No. 9 (1954)
4. H. Kornberg, private communication (1955)

* Biological half-life in sheep thyroids is about 34 days (4).

† See footnote *b* Table 2.

EXAMPLE: Human Inhalation

On May 19, 1953 the highest concentration of activity in the air due to fallout that has ever been recorded in the U. S., outside the Nevada Test Site, occurred at St. George, Utah. It amounted to about 1.3 μc/m^3 averaged over 24 hours. The total radiation dose to the thyroids of the people at St. George from inhalation of the isotopes of I is estimated to be 0.302 rep as shown in the following tabular calculation.

Estimate of Radiation Doses to Thyroid of Humans From Inhalation

Time after detonation (hr)	*Average fission-product activity (μc/meter^3)*	*Fission-product activity originally retained (μc)*[a]	*Fraction of fission product that is I^{131}*[b] *%*	*I^{131} activity reaching thyroid (millic)*	*Infinity I^{131} dose to thyroid (rep)*[d]	*Added dose from short-lived I isotopes*[e] *(rep)*	*Total infinity dose (rep)*
2–7	4.0	12.4	0.16	5.00	0.0304	0.121	0.155
7–10	2.3	4.3	0.35	3.77	0.0230	0.074	0.097
10–14	0.62	1.56	0.47	1.80	0.0110	0.030	0.041
14–18	0.043	0.104	0.7	0.19	0.0012	0.003	0.004
18–30	0.014	0.105	1.1	0.29	0.0018	0.003	0.005
						Tota	0.302 rep

[a] Based on 0.83-meter^3/hr air intake and assuming that 75% of the activity will be initially retained either in the lungs or find its way into the gastrointestinal tract.

[b] Based on assumption that 75% of initial intake of both Te precursors of I^{131} will remain within body until decayed to I^{131}.

[c] Assuming 25% of initial retention of I^{131} (either in lungs or gastrointestinal tract) reaches the thyroid.

[d] Initial dose rate = (55)(0.2)(μc of I^{131} per gram of tissue) in reps per day. Infinite dose = Initial dose rate/$(\lambda_r + \lambda_b)$.

[e] From Fig. 1. Multiply these ratios by $(\lambda_r + \lambda_b)/\lambda_r$ for I^{131} in man.

TABLE 3—Sample Calculations for Figure 3

A	B	C	D	E	F	G
Periods of intake (hours after detonation)	*Relative mean I^{131} energy intake × hours in period*[a]	*Cumulative I^{131} energy intake*	*Mean of ratios of energies I^{Short} I^{131}*[b]	*Relative energy I^{Short} (Columns B × D)*	*Cumulative I^{Short} energies intake*	*Ratio of total energies I^{Short} I^{131} for infinite thyroid dose intake from 1st hour to end of period indicated (Column F ÷ C)*[c]
1–11	160	160	3.6	575	575	3.6
11–21	158	318	2.3	364	939	2.95
21–31	150	468	1.6	240	1,179	2.52
31–41	146	614	1.3	190	1,369	2.23
41–51	140	754	1.0	140	1,509	2.0
51–61	135	889	0.84	115	1,624	1.83
61–71	130	1,019	0.70	91	1,715	1.68
71–81	125	1,144	0.55	69	1,784	1.56
81–91	120	1,264	0.46	55	1,839	1.45
91–101	115	1,379	0.40	46	1,885	1.37
101–201	920	2,299	0.20	184	2,069	0.900
201–301	650	2,949	0.08	52	2,121	0.718
301–401	470	3,419	0.042	19	2,140	0.626
401–601	600	4,019	0.02	12	2,152	0.535
601–801	280	4,299	0.0095	3	2,155	0.500
801–1,001	140	4,439	0.005	1	2,156	0.484

[a] Based on Fig. 2.

[b] From Fig. 1.

[c] This is uncorrected for biological decay as described in footnote *b*, Table 1. For cases where biological decay in the thyroid is significant for I^{131}, multiply last column *G* by the factor $(\lambda_r + \lambda_b)/\lambda_r$.

Printed in U.S.A.

Activity and Thyroid Dose from Radioiodines

by RONALD L. KATHREN, *Lawrence Radiation Laboratory, Livermore, Calif.*

RADIOIODINES ARE PRODUCED both directly from fission and as daughters of other fission nuclides. Thus the fraction of total iodine activity contributed by a given iodine nuclide will change with time. Since the total energy release and specific activity differ for each fission radioiodine, it is important to know the proportions of these nuclides so that biological hazards can be assessed more accurately.

The figure provides the means of determining the relative activity of the various fission radioiodines as a function of time after fission. The curves are based on thermal fission of U^{235} and are plotted from data given by Bolles and Ballou (*1*). Several individual points on each curve were confirmed by calculations based on the fission-product yield data of Katcoff (*2*). Because of the short half-lives of I^{136}–I^{140} and their precursors, they are not included in the figure. Similarly I^{128}–I^{130} are excluded because of their low fission yields.

The relative dose contribution can be determined by multiplying the relative activity by the dose constant for the nuclide under consideration. This dose constant R, expressed in terms of the total integrated thyroid dose in rads/μc uptake, is determined by the expression derived below and based on the body-burden equations of the International Commission on Radiation Protection (*3*, *4*):

$$R = \int_0^t \frac{k_1 k_2 E}{k_3 m} e^{-\lambda t}\, dt$$

$$R = \frac{k_1 k_2 E}{k_3 m \lambda} (1 - e^{-\lambda t})$$

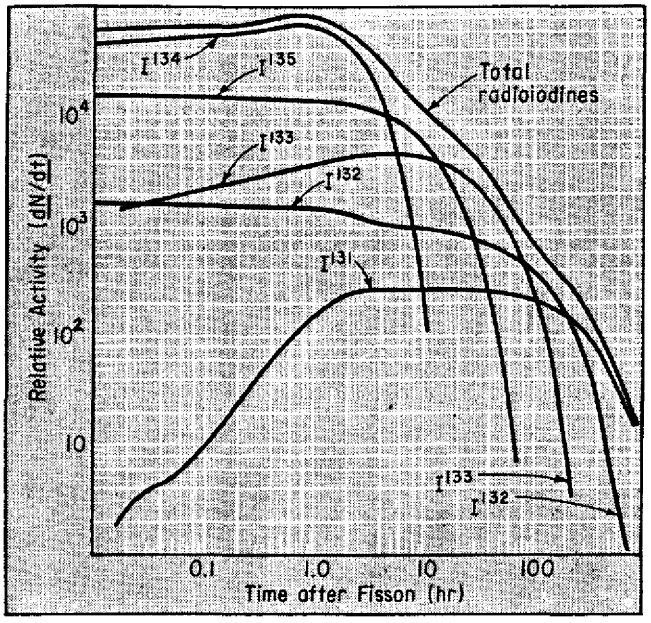
or, as $t \rightarrow \infty$,

$$R = \frac{k_1 k_2 E}{k_3 m \lambda}$$

in which k_1 is a constant equal to 1.33×10^8 disintegrations/hr/μc, k_2 is a constant equal to 1.6×10^{-6} ergs/Mev, k_3 is a constant equal to 100 ergs/gm/rad, E is the effective absorbed energy per disintegration in Mev, m is the mass of the critical organ in gm, λ is the effective decay constant in reciprocal hours and t is the time in hours after deposition.

This equation simplifies to $R = 0.15\,ET$, in which T is the half-life in hours. Values for E, m and T are given by the International Commission on Radiation Protection (*3*). The total integrated thyroid doses in rad/μc of uptake can be calculated and are:

I^{131}: 6.3 rads
I^{132}: 0.23 rad
I^{133}: 1.8 rads
I^{134}: 0.11 rad
I^{135}: 0.54 rad



RELATIVE ACTIVITY from radioiodines following fission of U^{235}

This data can be used to determine maximum permissible concentrations for mixtures of gaseous-fission iodines and thyroid doses following inhalation or ingestion. The method can also be used to determine the isotopic proportions of the various radioiodines from fallout in milk and other foods.

REFERENCES

1. N. C. Bolles, N. E. Ballou, USNRDL-456 (1956)
2. S. Katcoff, NUCLEONICS **16**, No. 4, 78 (1958)
3. International Commission on Radiation Protection, Committee II Report, *Health Phys.* **3**, 1 (1960)
4. R. L. Kathren et al., UCRL-7456 (Appendix) (1963); *Health Phys.* **10** (1964)

* * *

Work done under the auspices of the U. S. Atomic Energy Commission.

Ronald L. Kathren, who holds degrees from UCLA and the University of Pittsburgh, has been associated with the Radiation Safety Section of the Lawrence Radiation Laboratory for the past two years. His major interests and activities are in the areas of personnel dosimetry and health-physics instrumentation.