Application of “Thorium B” Labeled Red Corpuscles in Blood Volume Studies

By George Hevesy, M.D., and Gustav Nylin, M.D.

A new method for determining blood volume utilizing thorium B, which has advantages over the use of P₃², is described in detail. The problems of protecting the patient and operator from radiation activity are discussed in an appendix.

THE SUCCESSFUL application of radioactive indicators in physiology caused the early introduction of a radioactive component into the erythrocytes and their use in blood volume determinations. While this method has found application in animal experiments, it is not very suitable for determination of the blood volume of humans, since iron-labeled red corpuscles can only be obtained in vivo, and thus the application of this method depends on the availability of iron-labeled donors.

On the other hand the use of P₃² labeled red corpuscles has found a very extended application in blood volume determinations. This method necessitates incubation of the blood sample with radioactive phosphate for an appreciable time. It also requires centrifuging of blood samples and washing of red corpuscles, which consume much time.

An ideal radioactive method of clinical blood volume determination should fulfill the following conditions:

(a) The radioactive source should be available at a moment’s notice, and should not need replacement for some years.

(b) The rays emitted by the radioactive indicator should be easily measurable.

(c) No significant loss of the radioactive indicator by the red corpuscles should take place in the circulation in the course of the experiment.

(d) The half-life of the radioactive indicator should be sufficiently long, amounting to at least several minutes, to enable a trained nurse to carry out the radioactive measurements without difficulty. The half-life should, however, be shorter, and preferably appreciably shorter, than one day, since it may be necessary to repeat the blood volume determination after some time.

(e) Centrifugation of the injected or secured blood samples should not be necessary. It should suffice to compare the radioactivity of a known aliquot of the injected labeled blood, poured into a glass cuvette, or in dry state, with that of a sample secured after injection, in order to arrive at a correct figure for the circulating blood volume of the patient.

The present communication describes a method of blood volume determination which fulfills to some extent the above conditions. It is based on an observation that when oxygen carrying thoron is led through a blood sample, an appreciable part of the thoron decays within the sample, and its decay product thorium B (ThB) is almost entirely taken up by the corpuscles, from which it is released at a very slow rate.

METHOD

Radiothorium preparations are easily available. We applied a sample prepared according to the Hahn procedure and having the activity of 2 mg. of radium. It was obtained (price £7 per millicurie) from Harwell. Such a preparation is a copious source of thoron gas (thorium emanation). It is placed in a small glass vessel of a weighing glass type. Through the stopcock of the vessel two narrow glass tubes are inserted: through one, oxygen is led into the vessel, through the other, the thoron-loaded red corpuscles. From the Cardiovascular Clinic, Södersjukhuset, Stockholm, Sweden.

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* The uptake of ThB by red cells was studied at an early date by Behrens and Pachur (Arch. exp. Path. u. Pharmakol. 122: 319, 1927).
oxygen is led (for example, for 10 minutes) into the blood sample to be activated. The narrow glass cylinder containing the blood sample is placed in a small wash bottle. Since rubber strongly absorbs thoron, rubber tubing is kept at a minimum.

Thoron absorbed by the blood sample decays with a half-time of 55 seconds and is converted into ThB and its disintegration products. Within five minutes, all thoron absorbed by the blood decays, and the activity of the blood sample is now exclusively due to the presence of ThB and its disintegration products, the activity of ThB decaying with a half-time of 10.6 hours.

While the larger part, 10 ml., for example, of the active blood sample is reinjected into the human subject, whose blood volume we wish to determine, a small fraction is applied to prepare a standard sample. In preparing such a sample, we add, for example, 0.02 Gm. of active blood to 2 Gm. of inactive blood (or saline), hemolyze the sample by adding a few grams of saponin, and pour the hemolyzed blood into one of Zerahn's cuvettes, or preferably dry the sample and pour 100 mg. of the dry sample into an aluminium dish 1.2 cm. in diameter, or, if a larger blood sample is available, preferably into a dish of larger diameter. The activity of the standard sample is then compared with the activity of a blood sample secured, for example, 10 minutes after the injection of the active blood took place. This sample is hemolyzed as well, and treated similarly to the standard sample. It is of the greatest importance to compare the activity of dry blood samples having the same corpuscle/plasma ratio. This is facilitated by preparing the samples from hemolyzed blood.

**Thorium B and Its Disintegration Products**

Before describing the measurement of the activity of the ThB-labeled blood samples, it is appropriate to recapitulate our knowledge concerning the disintegration of the active deposit of thorium, and the radiation emitted which follows this disintegration.

The sequence of the radioactive disintegration products of radiothorium (RaTh) is shown in the following schema:

\[
\begin{align*}
\text{RaTh} & \rightarrow \text{ThN} \rightarrow \text{Tn} \rightarrow \text{ThA} \\
1.90 \text{ years} & \rightarrow 3.61 \text{ days} \rightarrow 55 \text{ sec.} \rightarrow 0.16 \text{ sec.}
\end{align*}
\]

\[
\begin{align*}
\text{ThB} & \rightarrow 65\% \text{ ThC}^- \rightarrow \text{ThC} \rightarrow \text{ThB} \\
60.5 \text{ min.} & \rightarrow 10.6 \text{ hrs.}
\end{align*}
\]

\[
\text{ThC}^- \rightarrow 3.1 \text{ min.} \rightarrow 0.16 \text{ sec.}
\]

\[
\text{ThB} \rightarrow 35\% \text{ ThC}^- \rightarrow \text{ThC} \rightarrow \text{ThB}
\]

Thoron B emits, as seen from the above schema, soft \(\beta\)-rays, which are half absorbed by a blood layer of 0.4 mm. thickness. The disintegration products of ThB, ThC and ThC\(^-\) emit 7.5 times and 4.8 times as penetrating \(\beta\)-rays as ThB. Furthermore, ThC and ThC\(^-\) emit \(\alpha\)-rays having a range of 31 \(\mu\), and ThC with a range of 56 \(\mu\), in dry blood; \(\gamma\)-rays are emitted as well. To what extent these radiations participate in producing ions in the Geiger tube, depends on the thickness of the layer, that of the window of the counter and the volume of the counter. The complexity of the radiation emitted by ThB and its disintegration products is in no way disturbing, as we are solely interested in the comparison of the activity of blood samples emitting the same complex type of radiation. When we use thin window counters, as applied when measuring the activity of C\(^14\), some of the strongly ionizing \(\alpha\)-rays emitted by the dry blood sample penetrate into the counter and contribute to the total number of counts produced. When we use glass cuvettes, however, these and other soft rays are stopped by the window of the cuvette; furthermore, these, and also harder rays, are partly absorbed by the water content of fresh blood. If we wish to administer a very restricted dose, we prefer to compare the activity of dry blood samples placed in an aluminium dish, and use thin window counters as when measuring the activity of C\(^14\).

The approximate half-value thickness of the \(\beta\)-rays emitted by ThB and its disintegration products in aluminium is as follows:

<table>
<thead>
<tr>
<th>Product</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ThB (lead isotope)</td>
<td>0.10 mm</td>
</tr>
<tr>
<td>ThC (bismuth isotope)</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>ThC(^-) (thallium isotope)</td>
<td>0.77 mm</td>
</tr>
</tbody>
</table>
Of the disintegration products of thoron, ThA decays in a half-time of 0.16 second and can thus be disregarded. ThB, which has a half-time of 10.6 hours, takes about 6 hours to come into exchange equilibrium with its disintegration products. This is a fact of importance in interpreting the activity figures obtained for ThB-labeled blood samples.

After leading thoron through the blood for 20 minutes, for example, the maximum ThC activity of the sample is not obtained until after the lapse of 200 minutes, as shown by table 1. In the succeeding 100 minutes, the activity decays by 3 per cent; later a decay with a half-time of 10.6 hours sets in; thus after the lapse of 21 hours, the activity is reduced to \( \frac{1}{4} \), after the lapse of 42 hours to \( \frac{1}{16} \) and after 63 hours to \( \frac{1}{64} \). These figures indicate the maximum fraction of the injected ThB still present in the organism. The actual fraction present is, however, lower than the figures stated, as some ThB is lost by excretion as well as by disintegration.

### Activation of Blood

We obtained the best results by the following procedure: Through 10 ml. of freshly drawn heparinized blood, an oxygen stream of about 30 ml. per minute pervolates for 20 minutes after it has passed through the vessel containing the radiothorium preparation. The tube containing the blood is placed in a small wash bottle. After leaving the wash bottle, the oxygen stream passes through four more wash bottles containing vegetable oil, which absorb all or most of the thoron still present in the oxygen stream. The activated blood is then gently shaken at room temperature for 30 minutes; 9 ml. are reinjected into the patient, a known aliquot of the rest being applied to prepare a standard sample as described above. We found it less advantageous to incubate blood at 37°C than at room temperature.

Instead of leading thoron containing oxygen through blood, we can dissolve the "active deposit" of thorium collected on the surface of a platinum foil in blood. Most of the ThB introduced into the blood accumulates in the corpuscles, though not to such a large extent as after thoron activation. After 30 minutes incubation at room temperature, about 6 per cent of the ThB is still found to be present in the plasma. When choosing this method of labeling red corpuscles we have, therefore, to replace the active by an inactive plasma before injecting the labeled blood. In the above experiments, the active deposit of thorium was collected* for 24 hours, on the surface of a platinum foil connected with the negative pole of a 220 volt (or preferably 300 volt) circuit. The platinum foil is then placed in the blood sample, which is gently shaken at room temperature for 10 minutes. The blood is then centrifuged, and the active plasma replaced by inactive plasma, before the blood is injected into the circulation.

### Evaluation of the Activity Figures

As already mentioned, we measure, besides the counts produced by the rays emitted by ThB, to a large extent those emitted by ThC and its disintegration products. Since prac-

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ically all ThB is taken up by the red corpuscles; the plasma does not contain this radioactive element; it contains, however, appreciable amounts of the bismuth isotope, ThC, which does not accumulate in erythrocytes. Some of the ThC present in the plasma of the injected blood escapes in the course of the experiment through the capillary wall, while the ThC present in the standard sample has no way of escape. The ratio between the activity of the standard sample and a secured sample shortly after securing the latter does not, therefore, afford a correct measure of the circulating blood volume, as indicated by the formula stated below. We can correct for the loss of ThC from the circulation during the experiment, or we can avoid such a correction by waiting for a few hours, until the ThC of the plasma, which has a half-life of one hour, has decayed.

But even in this case, when comparing the activity of different samples, we have to bear in mind that a decay of half of the ThB present takes place in the course of 10.6 hours.

In evaluating the results of the activity measurements, we can avoid correcting for the change in the activity with time by comparing the activity of the sample secured with that of the standard sample, provided both change their activity with time in the same way. If the secured sample has an initial activity of 200 counts per minute, for example, we will register, in the course of 10 minutes, almost 2000 counts. In fact, as the activity has decreased in 10 minutes from 200 to 197.8 counts per minute, we will measure only 1,987 counts in the course of 10 minutes or 198.7 per minute.

We now measure for one minute the standard sample, having 2,000 counts. The ratio between the activity of the standard sample and that of the secured sample works out then as $\frac{2000}{198.7} = 10.07$. If greater accuracy is wanted, we again measure for 10 minutes the secured sample which has now a mean activity of 196.4, and repeat this procedure. Thus the correct activity ratio between standard and secured sample works out as

$$\frac{2000}{\frac{198.7 + 196.4}{2}} = \frac{2000}{197.6} = 10.12$$

As the standard sample is prepared by diluting active with inactive blood, a strongly active standard sample can be easily obtained.

The measurement of the activity of such samples takes, in contrast to the secured samples, only a very few minutes. When applying an automatic sample changer, which shifts five secured samples and one standard sample at 10 minute intervals, and permits reading the counts on six independent telephone counters, the following correction for decay has to be made on the registered counts. Since counter 2 starts and finishes counting 10 minutes later than counter 1, and during this time 1.1 per cent of the ThB has decayed, the counts registered by counter 2 must be increased by 1.1 per cent of their value. Similarly the counts registered by counters 3, 4, 5 and 6 have to be increased by 2.2 per cent, 3.3 per cent, 4.4 per cent and 5.5 per cent, respectively, of their value, to make them comparable with the counts registered by counter 1.

We found it very convenient to place five secured and one standard sample in an automatic sample chamber which shifts the samples every 10 minutes and register—on six separate telephone counters—the counts produced during the night. Even blood samples of very restricted activity could be measured with satisfactory accuracy by this procedure, as seen in table 2.

The procedure cannot be used when the result is wanted urgently. In such cases we centrifuge the blood sample before injection, and replace the active by an inactive plasma, thereby removing the disturbing ThC present in plasma. Applying this procedure we can also obtain labeled red cells by dissolving ThB collected on the surface of a platinum foil, which is then placed into the blood sample. This type of activation of the blood sample takes only a few minutes.

Decaying actinium supplies emanation (acton) as well, which in turn produces in the blood sample AcB, which has the same chemical properties as ThB, and AcC which has the same chemical properties as ThC. While one half of the ThC present decays in one hour, the half-life of AcC is only 2.2 minutes, and this product correspondingly disappears from
the plasma of activated blood in a few minutes. We are at present investigating the possibility of applying AcB-labeled red corpuscles in circulation studies.

Calculation of the Blood Volume

If we inject $G$ Gm. of labeled blood, express the activity of the secured sample by $P$, that of the standard sample by $S$, and the dilution figure of the standard sample by $D$, the blood content of the human subject in Gm. $X$ works out as $X = \frac{SG}{PD}$. We then compare the activities of 100 mg. of dry blood of the secured and of the standard sample, or the activities of these samples after being poured into cuvettes. It is assumed that all ThB is concentrated in the corpuscles; in fact, about 1 to 2 per cent of the ThB content is located in the plasma. About four-fifths of this ThB leaves the circulation within a few minutes. Correspondingly, the above formula overestimates the blood content by about 1 per cent and should be replaced by

$$X = \frac{0.99 SG}{PD}$$

If, for example, $S = 2000$, $P = 200$, $G = 10$ Gm. and $D = 0.02$, $X$ works out as 4950 Gm.

Should we wish to compare the activity of cuvettes, one of which contains hemolyzed blood, while the other (the standard sample) contains a hemolyzed suspension of red corpuscles in saline, owing to the somewhat lower absorbing power of the latter sample for $\beta$-rays, we have to multiply the above formula by 0.95.

While Zerahn's cuvettes are most convenient for use in determining the circulating blood volume, the high water content of the 1.5 cm. of fresh blood placed in the cuvette absorbs much of the radiation of the sample. An activity five times as large is registered when measuring the activity of 100 mg. of dry blood as in the measurement of 1.5 ml. of fresh blood placed in Zerahn's cuvette.

Experimental Results

Figures 1, 2 and 3 demonstrate the change in the ThB content (activity) of the circulating blood with time. The third case investigated was one of polycythemia, in which the mixing of the injected and the circulating blood was probably slower than usual, as the maximum activity of the blood was reached after only five minutes. Figures 4, 5, 6 and 7 demonstrate the results of blood volume determinations carried out by using first ThB-labeled erythrocytes, then $\text{P}^{32}$-labeled red corpuscles.

When we carried out the experiments, the result of which is shown by figures 1 to 7, we
were not yet cognizant of the beneficial effect of a 30-minute incubation of the active blood previous to its injection. Nevertheless, the ThB label was found to be better preserved than
INJECTION OF WHOLE BLOOD LABELLED WITH P\textsuperscript{32}  

**1971 Dec 10th, 1951**

- Red blood corpuscles: 1080 g, 29.6 g/kg, 1000 cc, 26.8 cc/kg
- Plasma: 1002, 26.8, 1000, 26.8
- Circulating blood volume: 2082, 55.6, 2000, 55.6

**1977 Dec 17th, 1951**

- Red blood corpuscles: 1060 g, 28.8 g/kg, 2955 cc, 26.8 cc/kg
- Plasma: 1020, 27.3, 1000, 26.8
- Circulating blood volume: 2080, 55.3, 2000, 55.3

**Fig. 6.** Comparisons of data obtained by injections of thorium B labeled blood cells suspended in inactive plasma (above) and P\textsuperscript{32} labeled cells (below).

**INJECTION OF WHOLE BLOOD LABELLED WITH P\textsuperscript{32}**

**1977 Dec 17th, 1951**

- Red blood corpuscles: 2570 g, 27.6 g/kg, 2980 cc, 25.0 cc/kg
- Plasma: 2880, 30.3, 2820, 29.6
- Circulating blood volume: 5450, 57.3, 5200, 54.6

**Fig. 7.** Comparisons of data obtained by injections of thorium B labeled blood cells suspended in inactive plasma (above) and P\textsuperscript{32} labeled cells (below).
the P₃² label. Results of the experiment in which blood incubated for 30 minutes was injected, are seen in table 2.

In this experiment, in the course of 57 minutes, the ThB loss by the circulating blood was found to be —3.0 per cent, +1.3 per cent, +0.4 per cent, and 1.5 per cent, respectively, which compares with a loss of about +8 per cent in the case of P₃²-labeled red corpuscles. In the course of 24 hours, one-third to one-fourth of the ThB content of the red cells is given off, which compares with a 50 per cent loss of P₃² by the labeled erythrocytes.6

Table 2.—Change in the ThB Content of Circulating Blood with Time

<table>
<thead>
<tr>
<th>Time between injection and sampling in minutes</th>
<th>Activity of dry samples secured from human subjects (Counts per minute)</th>
<th>Relative activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>3    69.3 37.2 82.4 30.7 100 100 100 100</td>
<td>1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>5    72.5 37.6 82.5 30.6 104.2 100.1 99.7</td>
<td>1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>15   72.6 36.9 84.6 30.9 104.3 98.6 102.7 100.3</td>
<td>1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>30   71.8 38.1 84.9 41.3 103.4 102.4 103.2 104</td>
<td>1 2 3 4</td>
<td></td>
</tr>
<tr>
<td>60   71.4 35.7 82.1 39.1 102.9 99.7 98.8</td>
<td>1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>

Standard activity of dry samples secured from human subjects (Counts per minute)

<table>
<thead>
<tr>
<th>Time in minutes of passage of the thoron stream before incubation</th>
<th>Percentage of ThB present in plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>2.4</td>
</tr>
<tr>
<td>30</td>
<td>1.3</td>
</tr>
<tr>
<td>45</td>
<td>0.97</td>
</tr>
<tr>
<td>60</td>
<td>0.72</td>
</tr>
<tr>
<td>75</td>
<td>0.63</td>
</tr>
<tr>
<td>90</td>
<td>0.53</td>
</tr>
<tr>
<td>105</td>
<td>0.30</td>
</tr>
<tr>
<td>120</td>
<td>0.80</td>
</tr>
</tbody>
</table>

| 10                                                               | 1.6                                 |
| 30                                                               | 0.85                                |

| 10                                                               | 1.2                                 |
| 30                                                               | 0.86                                |
| 30                                                               | 0.76                                |

Table 3.—ThB Content of 1 Gm. of Fresh Plasma, Expressed in Percentage of the ThB Content of 1 Gm. of Fresh Corpuscles, after Incubation of the Active Blood for 20 Minutes at 37 C.

<table>
<thead>
<tr>
<th>Time in minutes of the passage of the thoron stream before incubation</th>
<th>Percentage of ThB present in plasma</th>
</tr>
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<tbody>
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<td>15</td>
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</tr>
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<td>120</td>
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</table>

| 10                                                               | 1.6                                 |
| 30                                                               | 0.85                                |

| 10                                                               | 1.2                                 |
| 30                                                               | 0.86                                |
| 30                                                               | 0.76                                |

Distribution of ThB Between RkD Corpuscles and Plasma

Immediately after leading thoron-charged oxygen for 20 minutes through a blood sample, the ThB content of 1 Gm. of fresh plasma is found to contain 4 per cent of that of 1 Gm. of red corpuscles. If we wish to avoid this restricted activity, we can replace the active plasma by inactive plasma, and inject the blood sample, the activity of which is now exclusively located in the erythrocytes. We can, however, reach almost the same result by incubating the active blood for about 20 minutes at 37 C. The percentage of ThB still present in the plasma after incubation is seen in table 3. The ThB content of the plasma can be strongly reduced by incubating the blood for 20 minutes, as seen in table 3.
In incubating active corpuscles with inactive plasma in vitro for 1 hour, 1 to 2 per cent of the ThB of the corpuscles enter the plasma phase.

**Loss of ThB by Injected Active Plasma**

ThB present in the injected plasma is lost at a remarkable rate, as shown by the figures of table 4 and in figure 8. Part of lost ThB penetrates the capillary wall, and part intrudes into the blood corpuscles.

In some of our experiments, we found the percentage incorporation of the injected plasma ThB in the circulating erythrocytes after the lapse of 3, 60 and 360 minutes, respectively, to be as high as 25, 40 and 45. These figures compare with 1, 5 and 9 for P32 infusion into the red corpuscles following injection of P32-labeled plasma.

**Summary**

1. Thorium B (ThB) is a disintegration product of the radioactive gas thoron. The procedure for preparation of ThB is described.

2. The advantages of ThB for blood volume determinations are that it accumulates to 99 per cent in red corpuscles, is released more slowly than radio phosphorus (loss less than 4 per cent in one hour) and has a half-time of 10.6 hours, which permits repeated determinations of blood volume. The radiation emitted by ThB is measured as easily as that of radioactive phosphorus.

3. The procedure for calculating blood volume is described in detail. In principle it consists in comparing the radioactivity of original whole blood samples with that of a sample removed from the patient after dilution. It requires no calculations of cell/plasma ratios; centrifugation is unnecessary.

**Acknowledgment**

The thanks of the authors are due to Miss Marianne Lindberg for her very valuable assistance.

**APPENDIX**

**Radiation Protection and Radiation Exposure**

Among the components of the active deposit of thorium, produced through decay of thorium emanation, is found thorium C⁻, which emits hard γ-rays. In view of the penetrating rays emitted by the radiothorium sample, the operator must be protected from the effect of this radiation. Placing the glass tube containing the sample in the center of a lead block 4.5 by 4.5 by 4.5 cm., reduces the intensity of the γ-rays emitted to about one-eighth, as 1.5 cm. of lead cuts down the radiation by half.

A still more effective precaution is to increase the distance between the sample and the operator. While the γ-radiation of radiothorium having the activity of 1 mg. of radium produces, at 1 cm. distance, a dose of 8.6 roentgen equivalent physicals (reps.) per hour, at a distance of 100 cm., only 1/10,000 of that dose is produced.

When passed through the blood sample, the oxygen still contains some thoron. Though, owing to the short lifetime of thoron, the activity released into the atmosphere is rather restricted, it is advisable to lead the oxygen stream which has already left the blood through an aggregate of wash bottles containing olive oil or some other vegetable oil, before releasing it into the atmosphere. While the distribution coefficient of thoron between water and air at 20° C. amounts only to 0.26, the corresponding figure for olive oil and air is as high as 25.

Radiation dosage is always an important consideration when applying radioactive indicators. Owing to the short half-life of ThB, the patient is exposed to radiation for a much shorter time than in administering P32, for example. This difference is partly offset by the fact that the disintegration products of ThB emit α-rays, which are, in the mammalian tissue, more effective in producing radiation effects than the less densely ionizing β- and γ-rays. The maximum number of reps. produced in the body of a human subject weighing 70 Kg. by ThB and its disintegration products having the activity of 1 mg. of radium is the following:

ThC emits α-particles having an energy of $9.42 \times 10^{-6}$ erg. A dose of 1 roentgen equivalent physical (rep.) corresponds to the absorption of 93 ergs/Gm. tissue. This dose is thus produced by $0.94 \times 10^{6}$ α-particles; 1 microcurie emits $3.2 \times 10^{5}$ α-particles per day, producing $3.4 \times 10^{2}$ rep. Assuming the weight of the
human subject to be 70 Kg., 4.8 × 10⁻³ rep. per gram are produced.

We stated above the number of α-particles emitted by 1 microcurie in the course of a day. The effective half-life of ThB is, however, only 0.31 day. Furthermore, 35 per cent of the ThC atoms disintegrate only under emission of α-particles. The number of reps, produced by the α-particles of ThC in equilibrium with 1 microcurie of ThB thus works out to 0.52 × 10⁻³ rep./Gm.

One microcurie of ThC, 65 per cent of which disintegrates under emission of α-particles has an energy of 1.46 × 10⁻⁴ erg, produces during its life-time 1.4 × 10⁻³ rep./Gm.

The biologic effect of the densely ionizing α-radiation is appreciably larger than that of β- or γ-radiation producing the same number of ions. To account for this difference, the notion of roentgen equivalent man (rem.) was introduced, replacing the notion of roentgen equivalent physical (rep.). For α-rays 1 rem = 20 reps. (or less), while for β- and γ-rays 1 rem. corresponds to 1 rep. In the course of the disintegration of 1 microcurie of ThB + ThC + ThC⁻ thus, the α-rays emitted produced not more than 4.0 × 10⁻² reps. We arrive at this figure by assuming that the whole amount of ThB administered decays in the body. In fact, some ThB is excreted previous to its disintegration.

The mean energy of the β-rays emitted by ThB and its disintegration products is 0.42 Mevs. or 6.7 × 10⁻⁷ ergs per particle. By a similar calculation, as described above, we conclude that the β-particles of 1 microcurie of ThB produce during its life-time an aggregate dose of 1.1 × 10⁻³ rep./Gm.

The upper limit of the radiation dose produced by the decay of the γ-rays of 1 microcurie of ThB and its disintegration products is obtained by assuming all γ-radiation emitted to be absorbed in the body. The mean energy of the γ-radiation emitted being 1.1 Mev., the number of reps. produced per day per Gm. body weight works out to 3.0 × 10⁻⁴. The upper limit of rem./Gm. produced by 1 microcurie of ThB + ThC + ThC⁻ decaying in the organism is thus 4.0 × 10⁻² + 1.1 × 10⁻⁴ + 3.0 × 10⁻⁴ = 4.4 × 10⁻². The dose actually produced lies quite appreciably below this figure. We applied in all our experiments less than 2 microcories of ThB. Thus the total maximum dose administered was below 8.8 × 10⁻² rem.

REFERENCES


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