特別掲載

Determination of Thorium Amount in Thorotrast Patients

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トロトラスト患者体内トリウム量の決定

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トロトラスト投与患者の臓器吸収線量推定には，臓器中の ^{232}Th 量を知ることは勿論であるが，それと同時にトリウム系列の各核種の ^{232}Th に対する放射能比を知る必要がある．この論文では，トロトラスト投与によりもっとも多く障害の誘発される部位である肝臓と脾臓についてのこれらの値を決定した．well type scintillation spectrometerと gridded ionization chamberで測つた組織からのγ線およびα線のエネルギースペクトルを解析することにより，半減期の比較的長い核種の^{232}Thに対する放射能比を求めた．また ^{232}Th とその娘核種の臓器中および全身の負荷量をwhole-body counterにより，11名のトロトラスト患者について決定し，同時にその臓器の平均収線量を推定した．

Since a colloidal solution of thorium dioxide had come into market by Hyden as a trademark of "Thorotrast" in 1931, it was used extensively as a contrast medium in hepatolienography, angiography, etc. until 1945. In Japan, it was used mainly in angiography for wounded soldiers in the China Affair.

Thorotrast contains 24 to 25 per cent thorium dioxide. A diameter of granules of thorium dioxide ranges from 30 to 100 Å[1]. After injection, Thorotrast is deposited in the reticuloendothelial system, chiefly in the liver and the spleen, where the granules of thorium dioxide remain indefinitely and form aggregates. Radiation from the aggregates continues to irradiate tissues for a long time, the chronic radiation causing a lesion in tissues. Jaffe[2], Weiser[3] and others[4)5)] had warned that thorium might induce a late hazard in man who had received it. Since 1940 an immediate hazard and the late one, particularly retarded carcinogenic effect, have been reported[6]. Most of carcinomas are liver carcinoma, whose mean latent period is about 20 years[7)~9)]. A group of patients who received Thorotrast, as well as a group of radium painters, are interesting objects for finding a relationship between the hazard due to the chronic radiation and the dosage absorbed in tissues.

Knowledges of distribution and elimination of Th-232 and its daughters in the human body are important for an estimation of the dosage absorbed in tissues due to radiations from thorium decay series. This series has eleven kinds of radioactive elements, whose physical properties are given in Table 1. A behaviour of Th-232 and its daughters in the human body, that is, their distribution and elimination, has hitherto been searched for by some of workers with only a few data obtained. Therefore, it is necessary for us to confirm the behaviour in more details. The present paper intends to give much to the currently available

Table 1 Physical properties of thorium decay series. Figures in parenthesis show a relative abundance to total Th-232 radiation.

Nuclide	Decay Constant	Mean Alpha-Ray Energy	Principal Beta-Ray Energy	Principal Gamma-Ray Energy
	per year	MeV	MeV	MeV
Th- 232	0.495×10^{-10}	4.00 (1.00)	—	—
Ra- 228	0.119	—	0.012 (1.00)	—
Ac- 228	0.990×10^{3}	—	1.15 (0.53)	0.338 (0.09) 0.908 (0.25)
Th- 228	0.363	5.39 (1.00)	—	—
Ra- 224	0.695×10^{2}	5.66 (1.00)	—	0.241 (0.046)
Rn- 220	0.424×10^{6}	6.28 (1.00)	—	—
Po- 216	0.138×10^{9}	6.77 (1.00)	—	—
Pb- 212	0.573×10^{3}	—	0.331 (0.88)	0.239 (0.80)
Bi- 212	0.603×10^{4}	6.05 (0.36)	2.25 (0.64)	—
Po- 212	0.729×10^{14}	8.78 (0.64)	—	—
Tl- 208	0.117×10^{6}	—	1.8 (0.36)	0.583 (0.28) 2.62 (0.35)

informations concerning the behaviour of Th-232 and its daughters in the liver and the spleen to which the hazards of the Thorotrast patients are centering.

An activity ratio between Th-232 and its daughters in the liver and the spleen except for elements having a very short half life was determined with a NaI (Tl) scintillation spectrometer and a gridded ionization chamber. A distribution and body burden of Th-232 and its daughters in the living man were determined *in vivo* in eleven Thorotrast patients with a whole body counter, and a mean dosage absorbed in the liver and the spleen was also estimated.

Experimental Procedures and Results

I. *In Vitro* Measurement

Gamma-rays from three (Ac-228, Pb-212 and Tl-208) of eleven radioactive elements and alpha-rays from two (Th-232 and Th-228) of them make it possible to estimate the activity ratio between them in living tissues.

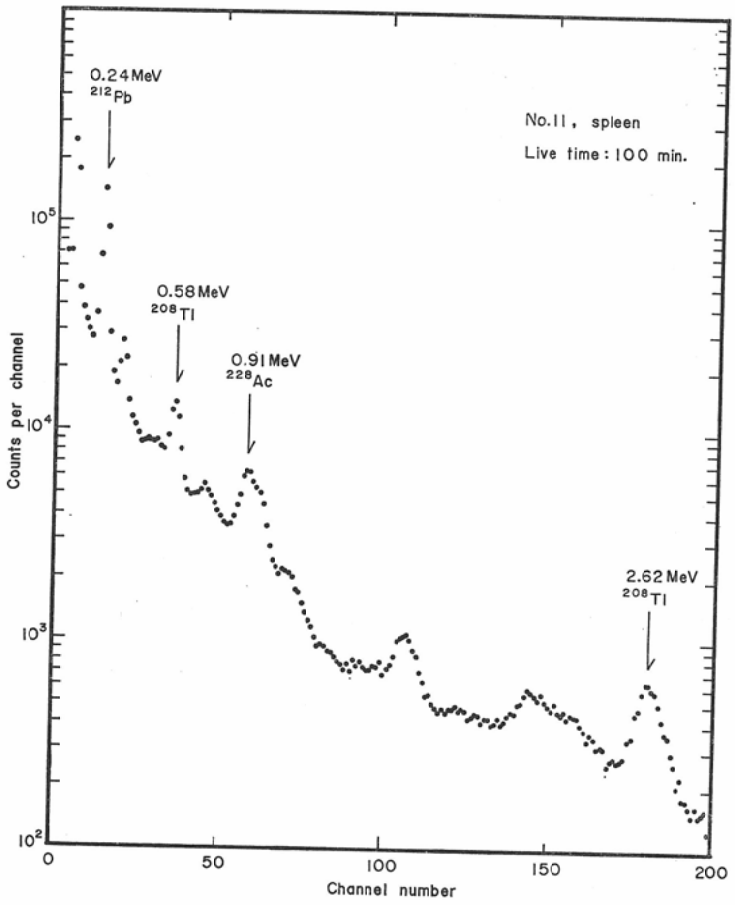
1. An activity ratio of Ra-224 to Th-228

Tissue samples, weighing about 3 g, prepared within a few days after the death of patients were sealed in a polyethylene test tube (1.5 cmϕ × 5 cm) and an activity of the samples was analyzed with a scintillation spectrometer at various times until Th-228 reached radioactive equilibrium with its daughters. The scintillation spectrometer consists of a 2″ × $1\frac{3}{4}$″ NaI (Tl) well type scintillator and a 2″ ϕ photomultiplier tube. Pulses from the photomultiplier tube were fed into a 400-channel pulse height analyzer.

Fig. 1 shows a gamma-ray spectrum of the spleen of case 11. A growth of an activity ratio of Pb-212 to Th-228, A, was obtained from a photopeak energy band from 0.14 to 0.26 MeV after subtraction of the Compton contribution due to more energetic photons. Since Ra-224 reaches radioactive equilibrium with its daughters in a day or two, this growth after this time can be approximately given by

$$A=\frac{\text{(Activity of Pb-212)}}{\text{(Activity of Th-228)}}=1-(1-\alpha)\,e^{-0.190t} \qquad t \text{ in days,} \qquad (1)$$

Fig. 1. The gamma-ray spectrum of thorium in the spleen of case 11.



where α is an activity ratio of Ra-224 to Th-228 in tissues just before Thorotrast patients die ($t = 0$). Measurements for three samples of the liver and the spleen are shown in Fig. 2 with the growth curves calculated from the equation (1) for various values of α. The results showed that a mean of the activity ratio of Ra-224 to Th-228 in living tissues was 0.70 for three samples: that is, about 30 per cent of an amount of Ra-224 produced in these organs was washed out through the circulatory system. The value of this activity ratio agreed well with that of Rundo[10], Parr[11], Kaul[12] and Oberhausen et al[13]. each.

2. An activity ratio of Th-228 to Ac-228 (or Ra-228)

As shown in Fig. 2, Th-228 reaches radioactive equilibrium with its daughters in a month. At equilibrium, an activity ratio of Tl-208 to Ac-228 is equal to that of Th-228 to Ac-228, or to that of Th-228 to Ra-228, because a half life of Ac-228 is very short.

An activity of a tissue material, weighing about 3 g, prepared within a month after death was measured with the same instrument as mentioned in I-1. A calibration of the activity of Tl-208 and Ac-228 in tissues was made with an aged thorium source of $Th(NO_3)_4 6H_2O$ prepared 58 years ago, which is nearly completely at radioactive equilibrium. The activity of Tl-208 in the samples was evaluated from a photopeak energy band from 2.48 to 2.76 MeV and that of Ac-228 from a photopeak energy band from

Fig. 2. The activity ratio of Ra-224 to Th-228.

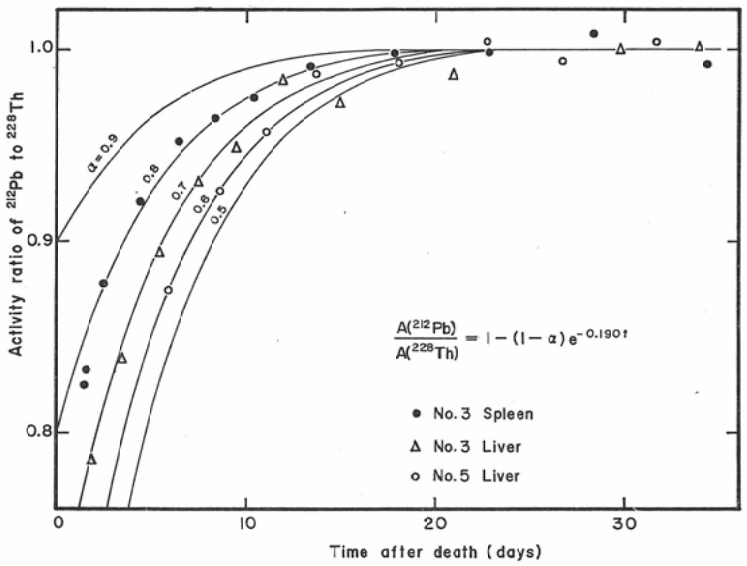


Table 2 The activity ratio of Ra-224, Th-228 and Ra-228 to their parents in the liver (L.) and the spleen (S.).

Case	Activity Ratio					
	A (Ra-224) / *A* (Th-228)		*A* (Th-228) / *A* (Ra-228)		*A* (Ra-228) / *A* (Th-232)	
	L	S	L	S	L	S
1	···	···	···	···	0.559	0.409
2	···	···	···	···	0.541	0.513
3	···	···	···	···	0.561	0.626
4	···	···	···	···	0.607	0.665
5	···	···	0.842	0.874	0.367	0.330
6	···	···	···	···	0.267	0.412
7	···	···	0.829	···	0.350	···
8	···	···	0.805	0.940	0.418	0.380
9	0.7	0.8	0.935	0.940	0.422	0.383
10	0.6	···	0.906	···	···	···
11	···	···	0.889	0.933	0.511	0.418
Average	0.70±0.06		0.890± 0.016		0.460± 0.025	

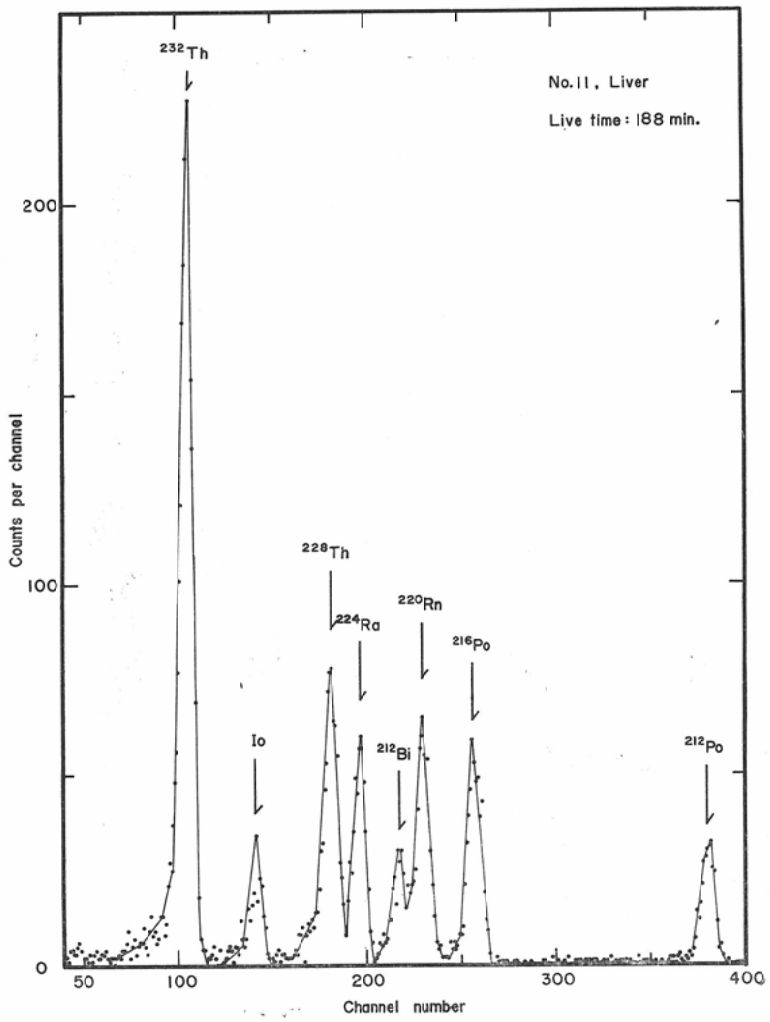
0.79 to 1.02 MeV after subtraction of the Compton contribution due to more energetic photons.

Fourth and 5th columns of Table 2 show the activity ratio of Th-228 to Ac-228 (or Ra-228), whose mean value was 0.89 for ten samples. This indicates that 11 per cent of an amount of Th-228 produced in the liver and the spleen was washed out by the blood stream. The value of this activity ratio was in good agreement with that of Rundo[11], Hursh[14], Miller[15] and Kaul[12] each.

3. An activity ratio of Ra-228 to Th-232

Ra-228 emits only beta-rays with low energy, and this makes a measurement of its activity difficult. An activity ratio of Ra-228 to Th-232 was estimated by means of an indirect method mentioned in the pre-

Fig. 3. The alpha-ray spectrum of thorium in the liver of case 2.



vious paper[16]. From a ratio of Th-228 counts to Th-232 counts, this activity ratio was deduced on the assumption that the biological elimination from the organ follows a simple exponential law. The ratio of Th-228 counts to Th-232 counts was measured from an alpha-energy spectrum obtained with a gridded ionization chamber. The chamber is connected with a rotary pump and a tank containing a PR-gas. A collecting electrode of the chamber is connected with an amplifier fed into a 400-channel pulse height analyzer. A tissue material was cremated without any chemical treatment. About 20 mg of the ash was suspended in water. Some volume of the suspension in agitation was sucked up with an injector and dropped on a sample metal disk to dry. The metal disk was placed in the chamber, being served as a negative electrode.

Fig. 3 shows the alpha-energy spectrum of thorium in the liver of case 11. First of all, an effective decay constant of Ra-228 was numerically estimated from the ratio of Th-228 counts to Th-232 counts with due regard to the activity ratio of Th-228 to Ra-228 obtained in the previous section (I-2). Then the acti-

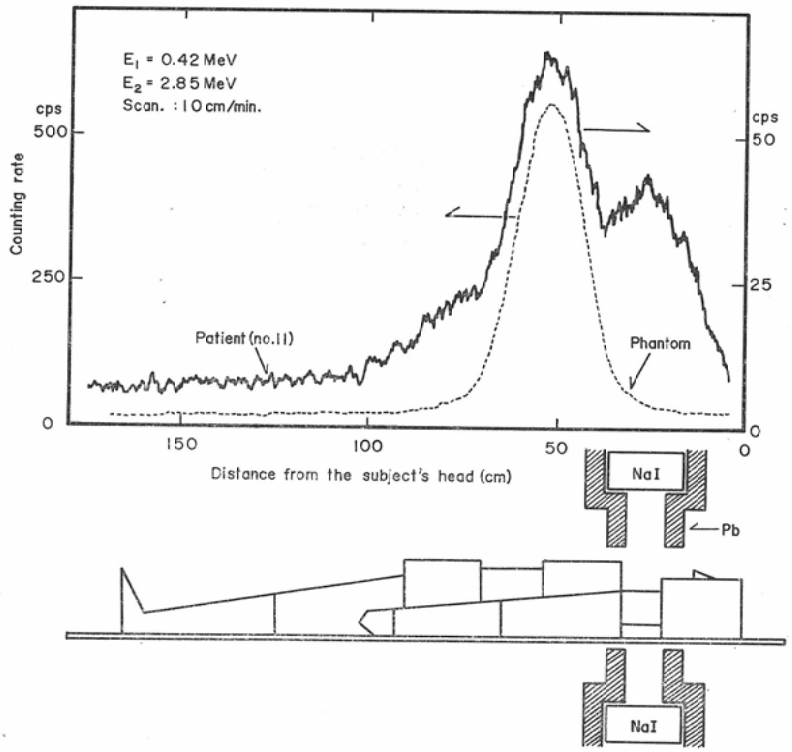
vity ratio of Ra-228 to Th-232 was obtained by dividing the physical decay constant of Ra-228 by the effective decay constant, because the activity ratio between Th-232 and its daughters appear to be in a steady state in the liver and the spleen of patients, who had been living for a long time after injection of Thorotrast. The results are shown in 6th and 7th columns of Table 2. That is, a mean of the activity ratio of Ra-228 to Th-232 was 0.46, which shows that about 54 per cent of an amount of Ra-228 produced in the liver and the spleen was washed out through the circulatory system. Though the values of the activity ratio of Ra-228 to Th-232 dispersed in a fairly wide range, its mean value, 0.460, was in good agreement with that of Miller[15] by an alpha- and a gamma-spectrometry and that of Hursh[14] by a radiochemistry and alpha-analysis. But this ratio is somewhat lower than that obtained by Rundo[10] by means of a growth of a gamma-counting rate and that of Unnewehr et al.[17]

II. *In Vivo* Measurement

A distribution and body burden of Th-232 and its daughters were measured for eleven Thorotrast patients with a whole body counter at the National Institute of Radiological Sciences[18].

The patients were selected from a roster of wounded soldiers who received Thorotrast. The patients rested on a bed (lucite, 1 cm thick) in an iron room of 20 cm thickness lined with 3 mm lead-plate inside and measurement was made with two 20 cmϕ × 10 cm NaI (Tl) crystal detectors. These crystal detectors have removable collimaters (lead, 5 cm thick), and are placed facing each other above and below the bed. The detector units can automatically be scanned along a long axis of the human body. Output from the two detectors is summed up and amplified before pulse hight sorting with a 256-channel analyzer.

Fig. 4. The distriburion of thorium in patient 11 and Remab phantom with the whole body counter.



An activity in the patients was determined with reference to Remab phantom (Alderson Research Labs., Inc., U.S.A.) in which models of the liver, the spleen, the lung and other organs and a natural human skeletons are incorporated. An aged thorium of Th $(NO_3)_4 6H_2O$ prepared 58 years ago was poured into the models of the liver (3.78 g of Th-232) and the spleen (0.80 g of Th-232) of the phantom, and the rest was filled up with water.

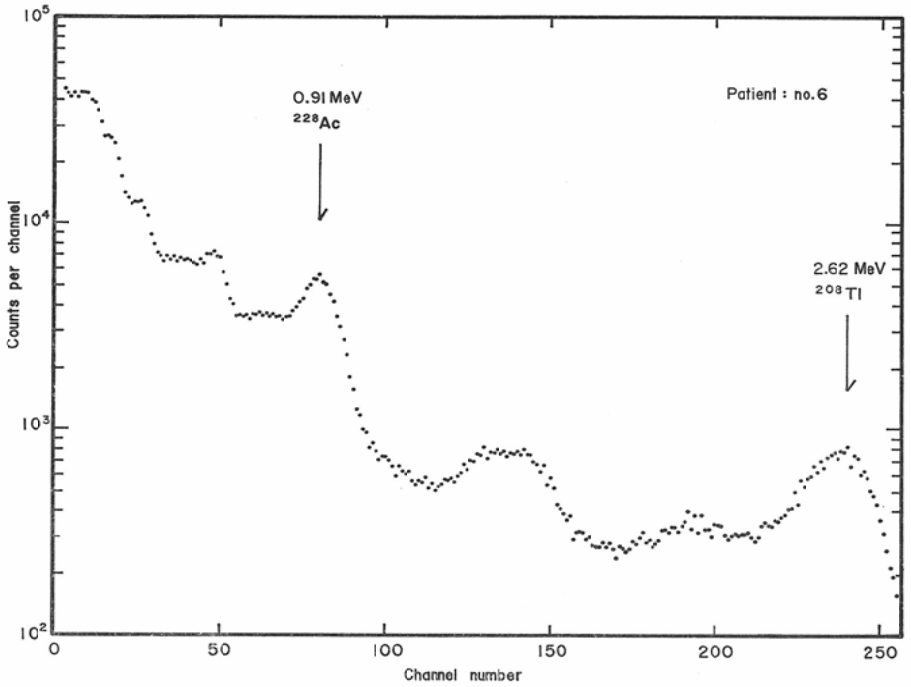
1. A distribution of thorium in Thorotrast patients.

A rough scheme of a distribution of thorium in Thorotrast patients was obtained by means of a profile scanning. Surfaces of the two detectors with the lead collimator of a slit width 10 cm were set at 39 cm above and 18 cm below the bed. An activity was measured with gamma-rays of an energy region from 0.42 to 2.85 MeV at a scanning speed of 10 cm per minute. Fig. 4 shows the profile scanning of patient 11 and Remab phantom. A maximum counting rate appeared at a distance of about 55 cm from the subject's head in ten of eleven patients, but in patient 1, the maximum counting rate was not found. This site corresponded to that of the liver and the spleen. In a region from 70 to 100 cm, a decrease of the counting rate following the maximum peak was gradual as compared with that of Remab phantom. This may be attributed to an activity of Th-232 and its daughters deposited in the abdominal lymphnodes and in the pelvis. In three cases, a peak appeared at about 25 cm distant from the subject's head, and this site corresponded to that of the neck, where these patients have had a perivascular Thorotrast deposit. Though a thorium amount in the liver and the spleen is impossible to estimate from the profile scanning, it may be supposed that a major portion of thorium injected is evidently deposited in the liver and the spleen.

2. A body burden of Th-232

The patients were set in a supine position for 30 minutes. Two crystal detectors were coaxially posi-

Fig. 5. A gamma-ray spectrum of patient 6 with the whole body counter.



tioned at 35 cm above and 15 cm below the bed respectively, and a position of the axis of them was set on the liver and the spleen according to an instruction of a physician. Fig. 5 shows a gamma-ray spectrum of patient 6. The activity of Tl-208 was evaluated from a photopeak energy band from 2.44 to 2.82 MeV, and that of Ac-228 from the band from 0.82 to 1.08 MeV after subtraction of the Compton contribution due to more energetic photons. The activity of Th-232 was estimated by dividing the activity of Ac-228 by a factor of 0.46, which is the activity ratio of Ac-228 to Th-232 obtained in the previous section (I-2). The results are shown in 5th, 6th and 7th columns of Table 3.

Table 3 Thorium body burden and dose absorbed in the liver (L) and the spleen (S).

Patient	Injected Amount	Time After Injection	Perivascular Thorotrast Deposit	Total Tl-208 Content in the Liver and the Spleen	Total Ac-228 Content in the Liver and the Spleen	Total Th-232 Content in the Liver and the Spleen	Th-232 Body Burden	Activity Ratio of Tl-208 to Ac-228	Th-232 Content Ratio of the Liver to the Spleen	Th-232 Content in the Liver and the Spleen	Dose
	cc (g)*	yeras		μCi	μCi	g	g			g	rad/week
1	5(1.1)	28	···	0.000	0.000	0.00	0.00	···	···	L : ··· S : ···	L : ··· S : ···
2	8(1.7)	28	···	0.025	0.056	1.10	1.43	0.440	3.4	L : 0.85 S : 0.25	L : 0.34 S : 0.97
3	10(2.2)	28	neck a little	0.018	0.027	0.52	0.68	0.689	4.0	L : 0.42 S : 0.10	L : 0.17 S : 0.39
4	10(2.2)	28	···	0.023	0.032	0.62	0.81	0.713	3.6	L : 0.49 S : 0.13	L : 0.20 S : 0.51
5	10(2.2)	27	···	0.042	0.046	0.89	1.16	0.914	7.5	L : 0.79 S : 0.10	L : 0.32 S : 0.39
6	15(3.3)	26	···	0.136	0.180	3.53	4.59	0.756	4.1	L : 2.84 S : 0.69	L : 1.15 S : 2.68
7	15(3.3)	26	neck onsiderable	0.117	0.133	2.60	3.38	0.882	6.0	L : 2.23 S : 0.37	L : 0.90 S : 1.44
8	20(4.4)	27	···	0.064	0.087	1.70	2.21	0.742	4.1	L : 1.37 S : 0.33	L : 0.55 S : 1.28
9	20(4.4)	28	···	0.295	0.391	3.22	4.19	0.832	3.8	L : 2.55 S : 0.67	L : 1.03 S : 2.61
10	25(5.5)	28	···	0.157	0.207	4.06	5.28	0.756	4.0	L : 3.25 S : 0.81	L : 1.32 S : 3.15
11	36(7.9)	25	neck cosiderable	0.174	0.218	4.26	5.54	0.800	7.2	L : 3.74 S : 0.52	L : 1.51 S : 2.02

*: the injected amounts of Th-232 deduced from an amount of Thorotrast recorded in the roster.

Analyzing the tissue and bone samples in only one case, Kaul[19] has shown that about 70 per cent of an amount of administered Thorotrast is deposited in the liver and the spleen. Rundo[20] has reported the results on the same lines. When this value was adopted, the total body burden of Th-232 was estimated to be such as shown in 8th column of Table 3. Figures in parentheses in 2nd column of this table are injected amounts of Th-232, which were deduced from an amount of Thorotrast recorded in the roster. Unfortunately, these values discorded with those obtained in our measurement. This difference may be attributed to an existance of the perivascular Thorotrast deposit in the site of the Thorotrast injection and/or to a probable fault of a statement in the roster. For instance, in our experiment with the whole body counter and in the roentgenography, it was found that in patient 1 no thorium existed within an experimental error in his body, though the roster recorded that 5 cc of Thorotrast had been injected to him.

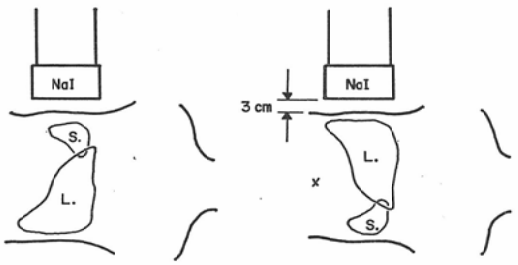
3. An activity ratio of Tl-208 to Ac-228 (or Ra-228)

An activity ratio of Tl-208 to Ac-228 (Ra-228) was easily deduced from the activity of Tl-208 and Ac-228 obtained in the previous section. These values are shown in 9th column of Table 3. This ratio averaged 0.752, which means that 25 per cent of daughters from Th-228 to Tl-208 was eliminated from the human body. This value was fairly lower than that expected from the *in vitro* measurement.

4. A ratio of thorium content in the liver to that in the spleen

An attempt was made to determine a ratio of Tl-208 activity in the liver to that in the spleen with an upper NaI (Tl) crystal detector without a collimator. Measurement was made for 10 minutes in patients in two recumbent postures on their right (a spleen side) and left (a liver side) sides. The crystal detector was placed over the liver-spleen region at a distance of 3 cm from the skin of the patient, as shown in Fig. 6.

Fig. 6. Two positions of a detector in relation to the liver-spleen region in determing the ratio of thorium content in the liver (L.) to that the spleen (S.).



The activity of Tl-208 in the liver and the spleen may be given as a first approximation by simultaneous linear equations as follows,

$$X(L) = a \cdot C(L) + b \cdot C(S)$$
$$X(S) = c \cdot C(L) + d \cdot C(S), \qquad (2)$$

where $X(L)$ and $X(S)$ are the activity of Tl-208 in the liver and the spleen, and $C(L)$ and $C(S)$ are the counting rate of Tl-208 gamma-rays in the postures of the liver side and the spleen side respectively. The counting rate of Tl-208 was obtained from a photopeak band from 2.44 to 2.82 MeV. Coefficients in the equations were determined with Remab phantom. Consequently the ratio of Tl-208 activity in the liver to that in the spleen was derived from the above equations as follows,

$$R = \frac{X(L)}{X(S)} = \frac{6.27 \cdot C(L) - 0.65 \cdot C(S)}{3.43 \cdot C(L) - 1.55 \cdot C(S)} \qquad (3)$$

The results of this ratio are shown in 10th column of Table 3. A mean of this ratio was 4.84 for 10 patients. The profile scanning showed that two patients of nos. 7 and 11 had a considerable amount of the perivascular Thorotrast deposit in the region of the neck, which seems to have affected the counting rate of Tl-208 gamma-rays in this measurement. When these cases are excluded, the mean value of this ratio becomes 4.4. Since an activity ratio of Tl-208 to Th-232 in the liver is considered to be equal to that in the spleen, the ratio of the amount of Th-232 in the liver to that in the spleen is considered to be 4.4. This ratio shows that the Th-232 amounts in the liver and the spleen are 81 and 19 per cent of the total amount in the liver and the spleen. The amounts in the liver and the spleen are shown in 11th column of

Table 3. This ratio agreed well with that of Rundo[20], who has estimated it to be 4.2. But this ratio discorded with that of Kaul et al[21]., who have estimated it to be 2.8 both by making *in vivo* measurement before and after a splenectomy and by measuring section samples.

Discussion

Results obtained with *in vitro* and *in vivo* measurements are summarized in Table 4. Since patients who supplied tissue samples had been living for a fairly long time after Thorotrast injection in comparison with a half life of the daughters of Th-232, it seems very probable that the figures in Table 4 are steady state values in the living organs. Though the biological elimination in the early stage after Thorotrast administration is not expressed by a simple exponential function, the elimination in the late stage (in the steady state) may be expressed by that function.

Table 4 The activity ratio and the biological half life

Nuclide	Activity Ratio to its Parent	Activity Ratio to Th-232	Effective Decay Constant	Biological Decay Constant	Biological Half Life
			per year	per year	
Th- 232	...	1.000	0.00165	0.00165	> 420 y
Ra- 228	0.460	0.460	0.274	0.155	4.47 y
Ac- 228	(1.000)	(0.460)	990	...	...
Th- 228	0.890	0.409	0.408	0.045	15.4 y
Ra- 224	0.70	0.287	99.3	29.8	8.5 d
Tl- 208	0.753 *	0.35	...	...	...

*: the activity ratio of Tl-208 to Ac-228

In order to compare the elimination rates between Th-232 and its daughters from the liver and the spleen, the biological decay constant for these organs was estimated on the assumption that the biological elimination from those organs follows a simple exponential law. The biological decay constant of a given element is deduced from the activity ratio, A, of this element to its parent as follows,

$$A=\frac{N\bullet\lambda_{phy}}{N\bullet\lambda_{eff}}=\frac{\lambda_{phy}}{\lambda_{phy}+\lambda_{biol}},$$

$$T_{biol}=\frac{0.693}{\lambda_{biol}}, \qquad (4)$$

where N is the number of atoms of this element, λ_{phy}, λ_{biol} and λ_{eff} are the physical, biological and effective decay constants respectively, and T_{biol} is a biological half life of this element. These decay constants and half life calculated from the equation (4) are given in Table 4. In this table, the values of Th-232 are those of Hursh et al[22]., and the only available ones which they obtained on the elimination of Th-232 from the human body of only two Thorotrast patients. Taking account of tissue analyses, Hursh et al. have concluded that an injected patient would essentially retain 100 per cent of the injected dose.

It is interesting that there exists a great difference in the biological half life both between Th-232 and Th-228 and between Ra-228 and Ra-224. The difference between Ra-228 and Ra-224 is explained by a possibility that Ra-228 produced in the granules may be bound in and around the granules and that Ra-224 may behave like free ions in the body. An excretion rate of radium salts from the body has been reported by many researchers, whereas reports of that from the liver and the spleen has been only a few. A comparison between our results and those of the excretion rate of radium salts from the body is possible

by studies of Marinelli et al[23]. and Kaul[19] concerning thorium amounts in bone; an amount of Ra-224 transfered to the bone from other organs is very small, as compared with that of Ra-224 washed out from the liver and the spleen, and then it is thought that an amount of Ra-224 excreted from the liver and the spleen may be equal to that of Ra-224 excreted from the human body in a steady state. Norris et al[24]. have reported an excretion of radium chloride in the patients subjected to the multiple intravenous injection at weekly intervals and in dogs subjected to a single dose. Their results allowed us to estimate the biological half life to be about 10 days from the radium retention of 4 cases within 30 days after the last administration and from that of the dogs. These values accorded with our results of Ra-224, which suggests that Ra-224 produced in the liver and the spleen act as if it has been injected intravenously as a radium salt and that Ra-228 produced in the thorium granules is physically trapped in the granules and a disintegration to its daughter in this granules is very probable. The difference in the biological half life between Th-232 and Th-228 may also be explained by a physical property of these nuclei. Parr[25] has elucidated this difference in the behaviour both between Ra-isotopes and between Th-isotopes by an energy of a recoiling nucleus at alpha- and beta-disintegrations.

Since about 90 per cent of energy dissipated in tissues by the radiations emitted from the Thorotrast aggregates is carried by alpha-rays, the dosage due to alpha-rays in the liver and the spleen of ten patients was estimated by using the our data of the activity ratio between Th-232 and its daughters and by adopting the following assumptions: 1) 10 per cent of Rn-220 is eliminated from the liver and the spleen[26]; 2) no daughters of Rn-220 are eliminated from these organs; 3) a weight of the liver and that of the spleen are 1200 g and 125 g respectively; and 4) a self-absorption of the Thorotrast aggregates made of the granules of thorium dioxide is 0.5[27]. The dose rate estimated is shown in 12th column of Table 3. Since an atrophy of the liver and the spleen is seen in most cases, it is likely to be underestimated. Furthermore, since a maximum range of alpha-particles emitted from thorium decay series is about 90 μ in water, the dose centers in a vicinity of the aggregates. For example, an average dose rate in tissues within a maximum range of alpha-particles from the surface of aggregates with a diameter of 30 μ is 20 rad/week[27]. Therefore, in fibrous tissues where the aggregates are distributed densely, the dose rate may be considerably higher than that when averged over a whole organ.

Summary

1. The activity ratio between Th-232 and its daughters in the liver and the spleen was determined by using autopsy materials.

2. The amount of Th-232 and its daughters in the liver and the spleen was measured in eleven patients with the whole body counter.

3. The ratio of Th-232 amount in the liver to that in the spleen was determined with *in vivo* measurement.

4. The dosage in the liver and the spleen of the Thorotrast patients was estimated by using the data obtained.

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