Arh. hig. rada, *19* (1968) 513.

COMPARISON OF THE DISTRIBUTION OF ^{47}Ca, ^{85}Sr, ^{133}Ba AND ^{223}Ra FOLLOWING INTRAVENOUS INJECTION INTO A HEALTHY MAN

G. E. Harrison

Medical Research Council, Radiobiological Research Unit, Harwell, Didcot, Berkshire, England

(Received for publication August 28, 1968)

A healthy 60 year-old man was given ^{47}Ca, ^{85}Sr, ^{133}Ba and ^{223}Ra intravenously so that the metabolism of each nuclide could be compared in the same individual.

Serial blood samples were taken for 7 days after each injection and separate collections of urine and faeces continued for over three months. The metabolism of ^{133}Ba and ^{223}Ra was very similar so that Ba may be regarded as a good short-term tracer for Ra. Differences in the metabolism of ^{47}Ca and ^{85}Sr were quite marked.

The whole body counting of ^{85}Sr was continued for 1 year and for ^{133}Ba is still continuing. Marked difference in the long-term retention of these nuclides have been observed.

Further information has been obtained on the long-term body retention of radon in the same subject following an accidental contamination with ^{226}Ra. From 17 to 27 years after the contamination, the body retention of radon has been shown to be decreasing exponentially with a half-life of about 7$^{1}/_{2}$ years.

Biologically, as well as chemically, the four alkaline earths calcium, strontium, barium and radium behave similarly. Thus they are all absorbed from the gastro-intestinal tract and are transferred from blood to bone by similar physico-chemical processes. However certain organs discriminate between Ca and Sr and marked differences have been observed in their metabolism (1, 2, 3, 4). Many comparisons of the distribution of radioactive Ca and Sr have been made both in man and in experimental animals (5, 6) and the metabolism of radioactive Ba and of Ra has been studied in laboratory animals (7, 8, 9, 10). No intercomparison of the distribution of the four elements has been made however, in man. Such comparisons are of importance not only in respect of their relative biological toxicity but also in the assessment of the degree to which one radionuclide behaves as a tracer for the others.

In the present experiment, a healthy 60 year old man was given ^{47}Ca, ^{85}Sr, ^{133}Ba and ^{223} Ra intravenously so that the metabolism of each could be compared in the same subject. Ideally, the four nuclides would have been injected simultaneously to avoid temporal changes in the subject, but this procedure would have made interpretation of the radioactivity measurements quite difficult. The four injections were therefore given in succession over a period of 10 weeks allowing a period of 2 to 3 weeks between successive injections.

Serial blood samples were taken over the first 7 or 8 days after each injection and separate daily collection of urine and fæces continued for over 4 months.

In addition to the initial period of rapid equilibrium between blood, soft-tissue and bone and the removal of each nuclide from the body during the first few weeks after injection the present account includes measurements made by Dr. J. Rundo of the Health Physics Division, Atomic Energy Research Establishment at Harwell of the whole body radioactivity for each nuclide after injection. For ^{85}Sr it was possible to continue these measurements for 1 year, for ^{133}Ba the measurements are still in progres $3^1/_2$ years after the administration. The change in the whole body retention of these nuclides with time will therefore be presented.

It should be added that in planning the experiment the experimental procedures and the expected tissue-doses were discussed by the subject with his medical and scientific colleagues.

In September 1940 the same subject became contaminated with ^{226}Ra as a result of an inhalation exposure. Body retention measurements of the radon retained have been made over the last 11 years. These body measurements will also be presented so that the short and long term retention of Ra can be compared in the same subject.

1. METHOD

1.1 *Administration of the nuclides*

Weighed samples containing 2 to 5 μCi of each carrier-free nuclide were made up to 10 ml in isotonic saline. After sterilization, 4 ml of each solution was injected into the anticubital vein of the right arm. The remainder (6 ml) was used for the preparation of radioactive standards. The physical characteristics and the amount of each nuclide injected are given in Table 1.

Table 1

Characteristics of the radionuclides and the amounts injected

Nuclide	Half Life	Radiation emitted	Principal γ ray		Injection μCi	Date of injection
			Energy MeV	% abundance		
^{47}Ca and ^{47}Sc	4.7d	β γ	1.31	77	1.94	26.ii.65
^{85}Sr	65 d	γ	0.51	100	0.54	9.ii.65
^{133}Ba	10y	γ	0.36	70	2.25	12.i.65
^{233}Ra and daughters	11.7d	α β γ	0.27	~20	0.72	23.iii.65

1.2 *Collection and radioactive assay of biological samples*

(i) *Blood.* 20 ml of blood were taken from the anticubital vein of the left arm into 1 mg of heparin of low Sr content (11) at about 10 min, 3 and 12 hours, 1, 2, 3, 4, 6 and 8 days after each injection. The count-rate in the principal photopeak of ^{47}Ca, ^{85}Sr or ^{133}Ba from 10 ml of separated plasma was compared with the count-rate in the respective photopeak from a standard solution of the given nuclide by means of a γ-ray spectrometer. For ^{223}Ra, a known amount of ^{133}Ba was added to the 10 ml of separated plasma and the plasma was then dried and thermally ashed. The ash was dissolved in a minimum amount of dilute HCl, and after the addition of about 1 mg of stable Ba as carrier, Ra and Ba were precipitated as sulphates. The insoluble sulphates were plated and the α-activity due to ^{223}Ra was compared at radioactive equilibrium with that of a standard ^{223}Ra preparation. The overall chemical recovery was estimated from the recovery of ^{133}Ba in the separated samples.

(ii) *Urine.* For the first 7 or 8 days after each injection samples of acidified urine were assayed for ^{47}Ca, ^{85}Sr, ^{133}Ba and ^{223}Ra by γ-ray spectrometry. Later urine samples were dried and ashed before the radioactive assays. To obtain greater precision in the ^{223}Ra measurements on collections made after the first week, the bulked urines were dried, ashed and dissolved in HCl. A known tracer amount of ^{133}Ba was added, and the solutions were chemically treated to remove fall-out ^{90}Sr, ^{95}Zr and ^{137}Cs present in the urine. ^{223}Ra and the ^{133}Ba marker were precipitated as chromates, plated, and the total β-particle activity in the plated sample was compared with that from a ^{223}Ra standard at equilibrium on an anti-coincidence counter. Corrections were made for chemical recovery (from the ^{133}Ba count-rate), radioactive decay and the interference of ^{133}Ba in the observed β-particle count-rate. By this procedure it was possible to follow the ^{223}Ra activity in bulked urine collections up to 3 weeks after the injection.

(iii) *Fæces.* These were collected daily, dried and thermally ashed. As for urine, ^{47}Ca, ^{85}Sr, ^{133}Ba and ^{223}Ra in the ashed samples were estimated by γ-ray spectrometry. For collections made after the first week the β-particle activity due to ^{223}Ra and its daughter products was determined by anti-coincidence counting, exactly as for urine.

(iv) *Saliva and seminal fluid.* Measurements were made of the concentrations of each radioactive nuclide in saliva and seminal fluid collected at about 2 hours after each injection.

1.3 *Whole body radioactivity*

The whole body radioactivity measurements were made at Harwell by Dr. J. Rundo and a full report of these will appear elsewhere. In principle, the net count-rate in a selected photopeak of each radionuclide injected was compared with that from a standard source of the nuclide after correction for the natural body ^{40}K and fall-out ^{137}Cs in the subject. It has already been stated that the subject was also contaminated with ^{226}Ra so that γ-rays from the decay products RaC, RaC′, formed part of his γ-ray spectrum. The whole body measurements were continued until the physical decay of each nuclide made accurate observations impossible. In practice, the observations were continued for 30 days for ^{47}Ca, 400 days for ^{85}Sr, about 30 days for ^{223}Ra and for ^{133}Ba they are still in progress.

1.4 *Stable Ca, Sr and Ba*

Ca concentrations in plasma and the Ca excreted per week in urine and fæces were determined by flame-spectrophotometry. The corresponding quantities for Sr and Ba were determined by activation analysis (12).

2. RESULTS

The plasma concentration of each nuclide at various times after injection is shown in Figure 1. It will be seen that there is similarity between the plasma concentrations of ^{47}Ca and ^{85}Sr and between ^{133}Ba and ^{223}Ra, the latter pair falling much more rapidly with time than the former. Ten minutes after the intravenous dose, the plasma concentration was between 6 and 7 per cent dose per litre for ^{47}Ca, ^{85}Sr and ^{133}Ba. The apparently low value observed for the plasma concentration of ^{223}Ra was not due to an error in counting but may have been due to an error in sampling.

Table 2

Concentration of radioactivity in saliva and seminal fluid

Hours after administration	^{47}Ca		^{85}Sr		^{233}Ba		^{223}Ra	
	Saliva	Seminal fluid	Saliva	Seminal fluid	Saliva	Seminal fluid	Saliva	Seminal fluid
2	2.2	2.0	3.0	2.1	0.33	—	0.43	1.0
	(3.4)		(3.4)		(1.5)		(1.5)	
6					0.22	0.81		
					(0.5)			

The standard deviation due to counting was < 10 per cent of the observed concentrations.

Figures given in parentheses are the interpolated contemporary plasma concentrations.

Table 2 shows the concentrations of the respective nuclides in saliva and seminal fluid. For comparison the respective contemporary plasma concentrations are given in parentheses. The concentrations of ^{47}Ca and

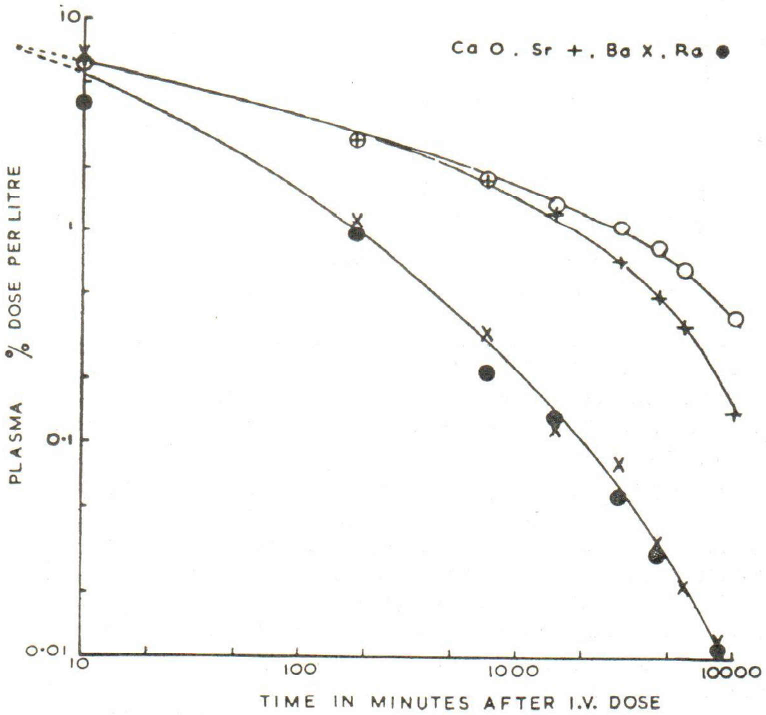

Fig. 1. *Plasma concentration of nuclides at various times after injection*

^{85}Sr in saliva and seminal fluid approximated to 0.6 times the plasma concentrations. Figure 2 gives the cumulative urinary excretion of each nuclide over the first 30 days after the dose. It will be seen

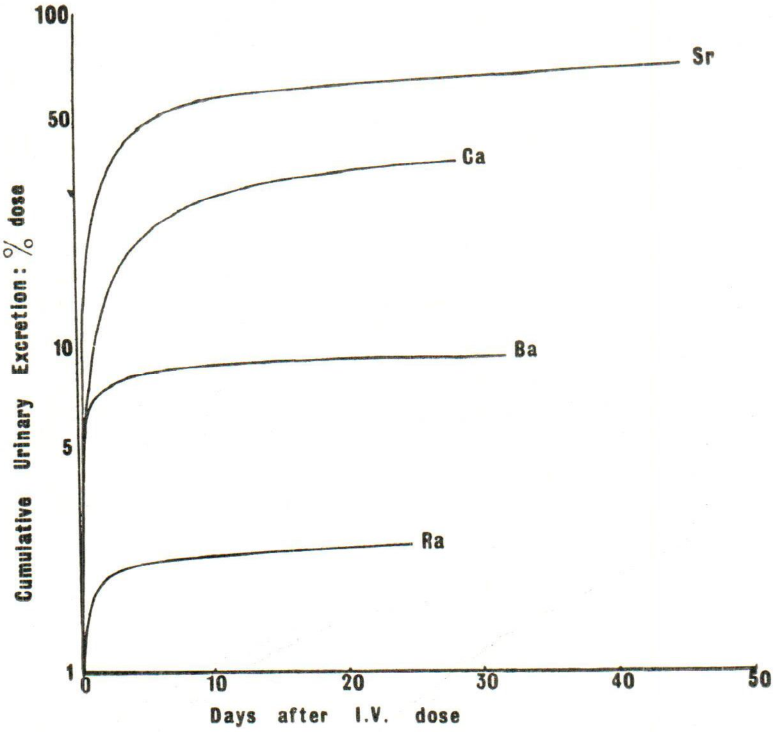

Fig. 2. *Cumulative urinary excretion of each nuclide*

that a fraction of the injected dose excreted in the urine is greatest for ^{85}Sr a result of the renal discrimination against Sr. The urinary excretion of Ba and Ra is however much less than that of Ca and Sr. In fact the urinary excretion of Ra is only $^1/_{30}$th that of Sr, three weeks after the injection.

The total excretion (urine plus fæcal) is shown in Figure 3. A notable feature is that, over the first few days after the administration of each nuclide, the ratio of the cumulative fæcal excretion, F, to the cumulative urinary excretion, U, increased to a constant value of 0.52 for Ca, 0.24 for Sr, 9.0 for Ba and 36.0 for Ra (13) which may be regarded as the ratio of the intestinal to the renal clearance of the particular nuclide.

Three weeks after administration of ^{223}Ra and 4 weeks after that of ^{133}Ba, the urinary excretion of these nuclides was so small that direct measurement, even on bulked samples, was not possible. However, the fæcal output of ^{223}Ra and ^{133}Ba was measured up to 60 or 70 days. The urinary excretion after 3 or 4 weeks was calculated, therefore, from the product of the fæcal excretion and the constant ratio of urinary to fæcal excretion for each nuclide.

Table 3

Body retention of four nuclides expressed as the difference between percentage administered and the percentage excreted

Days after administration	^{47}Ca	^{85}Sr	^{133}Ba	^{233}Ra
1	91.8	[illegible].3	71.0	81.5
2	85.3	[illegible]5.3	42.5	79.9
3	78.1	56.7	27.1	37.5
4	74.0	47.7	24.2	25.0
5	69.4	42.4	20.3	20.5
6	65.9	38.3	16.7	18.0
7	63.5	36.2	16.6	16.5
8	61.2	33.8	14.1	15.3
9	59.4	32.1	13.0	14.6
10	57.9	31.2	12.3	13.7
15	52.0	26.7	10.5	11.4
20	48.6	24.4	9.2	9.9
25	45.9	23.1	8.5	9.0*
30	—	22.3	7.8*	8.3*
40	—	21.2	6.8*	7.0*
50	—	—	6.3*	6.3*
60	—	—	6.0*	5.5*
70	—	—	5.8*	—

* Calculated from faecal excretion and the constant ratio of faecal to urinary excretion.

Table 3 gives the body retention derived from the excretion data i. e. the amount administered minus amount excreted. At 25 days after each injection, the retention of ^{47}Ca was about double that of ^{85}Sr and 5 times that of ^{133}Ba or ^{223}Ra.

Table 4

Mean plasma concentrations and mean weekly urinary and faecal excretion rates for stable Ca, Sr and Ba during the experiment

Mean plasma concentration ppm		Mean urinary output per week	Mean faecal excretion per week
Ca	96	1.9 g	7.1 g
Sr	0.022	1.5 mg	11.3 mg
Ba	0.003	0.15 mg	4.1 mg

Table 4 gives the mean plasma concentration and the mean weekly urinary and fæcal excretions of stable Ca, Sr and Ba. The excretion rates will depend on the dietary intake which was not constant over the

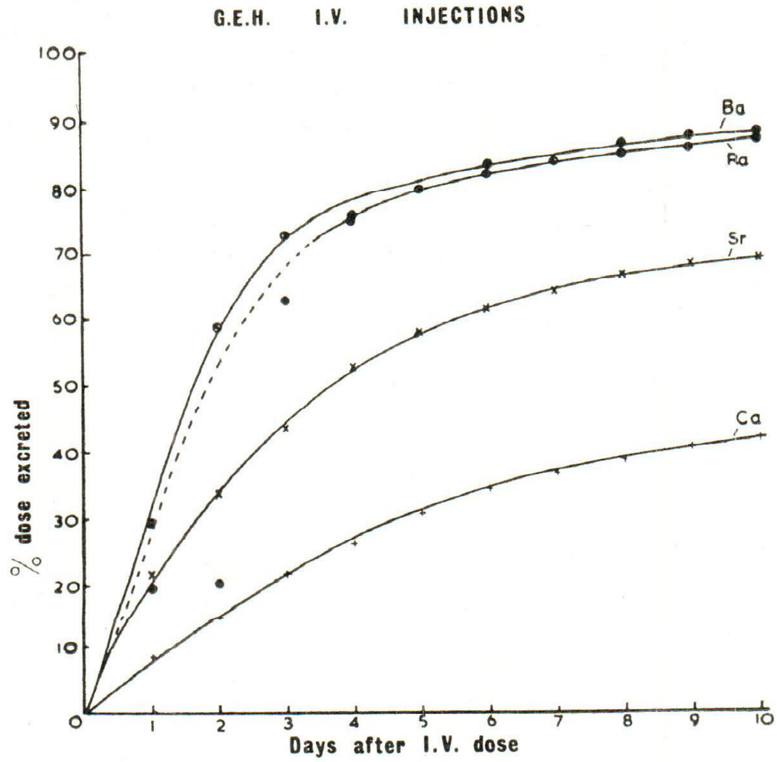

Fig. 3. *Total excretion of each nuclide*

experiment. Obviously the ratio of fæcal to urinary excretion of a stable element must be greater than the value for an injected radioactive nuclide, since the fæcal excretion of the former includes an exogenous fraction.

Whole body radioactivity

Figure 4 gives the complete results for the body retentions of ^{47}Ca and ^{223}Ra, and the retentions for the first 120 days of ^{85}Sr and ^{133}Ba. The body retentions for all nuclides derived from the excretion data agreed quite closely with that obtained from the whole-body measurements. For ^{47}Ca no attempt has been made to derive a biological half-life, $T^{1}/_{2}$, or a power law index of the retention, b.[14] For ^{223}Ra the body retentions

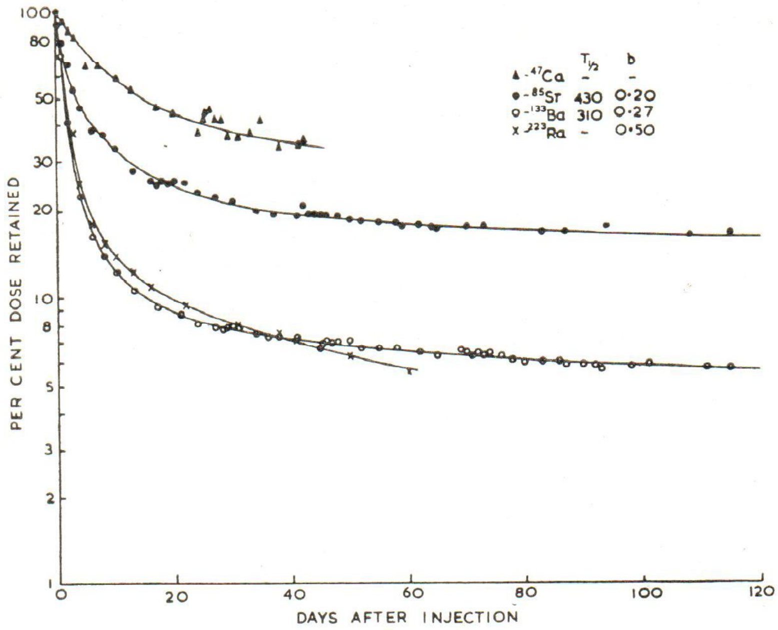

Fig. 4. *Whole body retention of nuclides with biological half life (T 1/2) and power index b*

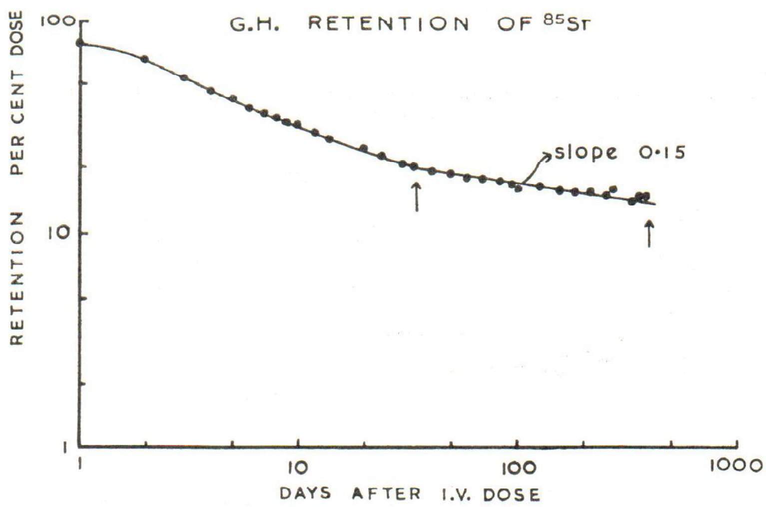

Fig. 5. *Complete whole body retention measurements for* ^{85}*Sr*

fitted a power law retention quite closely so that the slope of the log retention, log time relationship was 0.5 in close agreement with that originally derived by *Norris* (14) for Ra in man.

Figure 5 gives the complete results for ^{85}Sr. It will be seen that from about 30 to 400 days the body retention measurements fit a power law relationship:

$$R = R_1 \ t^{-b} \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (1)$$

where b $\sim$ 0.15.

Figure 6 gives the results for the whole body retention of ^{133}Ba to date. The power law relationship fits the observations from about 20 to 400 days but thereafter there is a significant deviation.

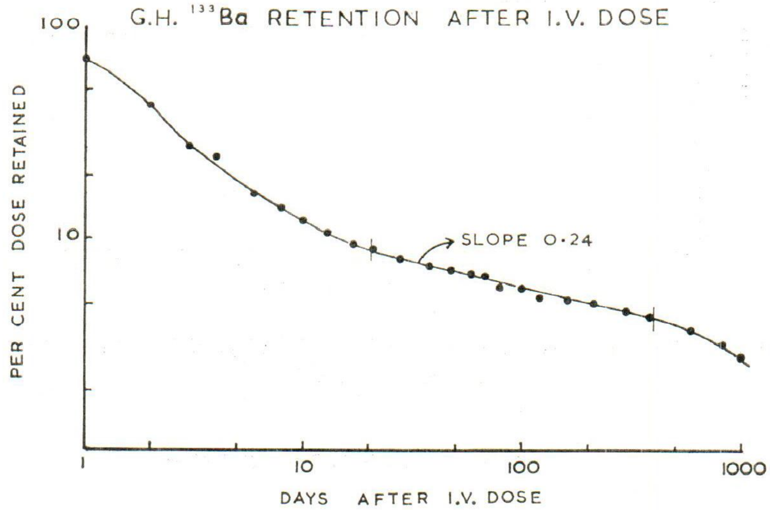

Fig. 6. *Log-log plot of whole body retention measurements for ^{133}Ba up to 1000 days after injection*

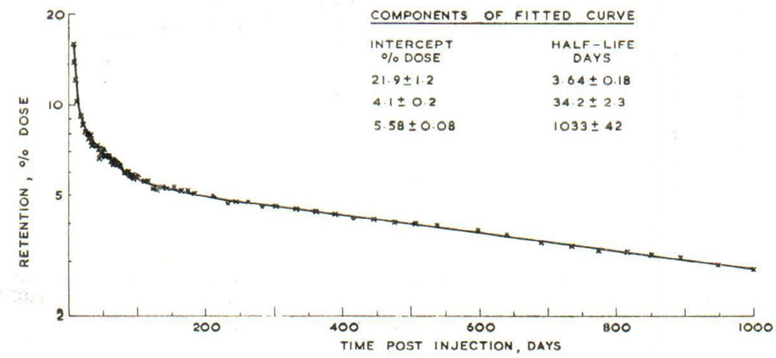

Fig. 7. *Log-linear plot of whole body retention measurements for ^{133} Ba*

Figure 7 shows the same observations plotted as a log-linear relationship. In fact, from 6 to 1000 days the whole body retention of Ba, R, can be represented by the relationship (15):

$$R = 22e^{-\frac{0.693t}{3.6}} + 4.1e^{-\frac{0.693t}{34}} + 5.6e^{-\frac{0.693t}{1033}}$$

From 150 to 1000 days the log Rt, t, relationship is linear.

Radium 226

The body content of radon from 1957 to 1968 for the same subject is shown in Figure 8. In each year repeated observations of the radon content were made and the figure shows the mean values for each year,

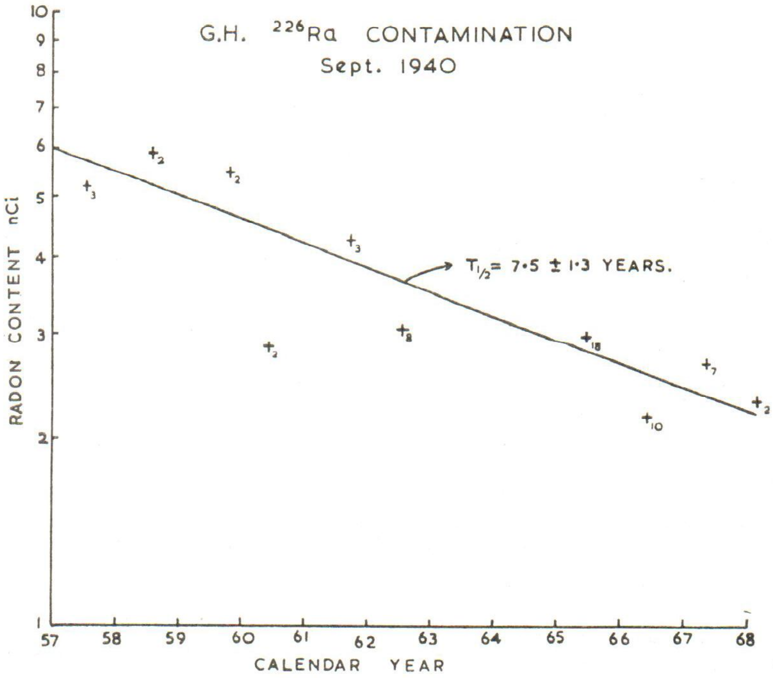

Fig. 8. *Body content of radon from 1957 to 1968 following Ra contamination of subject in September 1940*

the numbers indicating the number of observations in each year. The straight line relationship between the log retention and time was fitted by computer to give $T^{1}/_{2} = 7.5 \pm 1.3$ years.

3. DISCUSSION

3.1 *Extra-cellular fluid content*

Similarity between the curves for plasma concentration of each nuclide against time (Figure 1) prompts extrapolation of the curves to intersection at t ~ 5 min and at a common plasma concentration of 7.2 per cent dose per litre. This plasma concentration may be regarded as a measure of the initial body space into which the four injected nuclides were dispersed. The volume of this space is given by the activity injected (100 per cent) divided by 7.2 = 13.9 litres which may be regarded as the volume of the total extra-cellular fluid. (E. C. F.) If this space remains constant, the percentage of the injected activity in the E. C. F. at any time is given by 13.9 × plasma concentration.

3.2 *Tissue content*

The tissue content of each nuclide = 100 minus [urinary plus fæcal excretion plus the activity in the E. C. F.] all quantities being expressed as the percentage of the amount of the nuclide injected. The fæcal »excretion« shortly after each injection may be derived from the urinary excretion multiplied by the asymptotic value of F/U reached a few days after each injection.

Table 5 gives the results of this calculation over the first 48 hours after the injections. It will be seen that the derived tissue content reached a maximum during the first 2 days after each injection. By plotting the tissue content against time after injection, the maximum for Ca (67 per cent) is found to occur at about 20 hours when the E. C. F. content of the ^{47}Ca was 22.2 per cent; for Sr (56 per cent) also at 20 hours after injection when the E. C. F. content was 18.6 per cent; for ^{133}Ba (55 per cent) at about 1½ hours when the E. C. F. content was about 24 per cent, and for Ra (62 per cent) also at about 1½ hours after injection when the E. C. F. content was again 24 per cent.

If we assume that there is radioactive equilibrium at the time of the maximum tissue concentration between E. C. F. and the other constituents of tissue, we may equate the specific activities of the tissue and E. C. F. The E. C. F. content is given by 13.9 × (the plasma concentration of the element). Table 4 gives the mean plasma concentration of stable Ca, Sr and Ba during the experiment so that, for Ca we may write:

$$\frac{67}{x} = \frac{22.2}{13.9 \times 0.096} = 4.0$$

where x is the tissue content for Ca in grammes. The corresponding tissue content for Sr is 1.0 mg and for Ba 0.095 mg. For adult man, the total body Ca is about 1070 g and the corresponding values for Sr and Ba are 300 mg (16) and 30 mg (17). Thus the ratio of the calculated tissue content to total body content is 0.37 per cent for Ca, 0.33 per cent for Sr and 0.38 per cent for Ba. That this ratio should be approximately constant for the three alkaline earths is interesting.

Table 5

Calculated tissue and E. C. F. content of each nuclide at various times after administration

Hours after admini-stration	^{47}Ca E. C. F.	^{47}Ca Urine	^{47}Ca Faeces (0.52 × urine)	^{47}Ca Tissue	^{85}Sr E. C. F.	^{85}Sr Urine	^{85}Sr Faeces (0.24 × urine)	^{85}Sr Tissue
1	57.0	6.7	0.4	41.9	57.0	3.2	0.8	39.0
2	47.2	1.1	0.6	51.1	47.2	4.6	1.1	47.1
5	36.4	2.3	1.2	60.1	35.0	9.7	2.3	53.0
10	28.9	4.0	2.1	65.0	26.4	14.8	3.5	55.3
24	20.6	8.3	4.3	66.8	16.7	21.7	5.2	56.4
36	17.0	11.3	5.9	65.8	12.8	27.7	6.6	52.9
48	14.7	13.9	7.2	64.2	10.3	32.0	7.7	50.0

Hours after admini-stration	^{133}Ba E. C. F.	^{133}Ba Urine	^{133}Ba Faeces (9.0 × urine)	^{133}Ba Tissue	^{223}Ra E. C. F.	^{223}Ra Urine	^{223}Ra Faeces (36.0 × urine)	^{223}Ra Tissue
0.5	44.4	1.0	9.0	45.6	44.4	0.2	7.2	48.2
1	30.3	1.7	15.3	52.7	30.3	0.3	10.8	58.6
2	19.4	2.7	24.3	53.6	19.4	0.5	18.0	62.1
5	9.4	4.4	39.6	46.6	9.4	0.9	32.4	57.3
10	5.1	5.4	48.6	40.9	5.1	1.3	46.8	46.8
24	2.2	6.8	62.0	29.0	2.2	1.8	64.8	31.2
36	1.4	7.3	65.7	25.6	1.4	1.9	68.3	28.4
48	0.9	7.6	68.5	23.0	0.9	2.0	72.0	25.1

3.3 *Similarities and difference in the distribution of the four nuclides*

It is significant that the maximum tissue content of both ^{133}Ba and ^{223}Ra was reached in the first hour or so after injection compared with about 20 hours for ^{47}Ca and ^{85}Sr. This relatively rapid deposition of the heavier nuclides in tissue may be associated with their preferential binding to protein. Comparison of the initial binding of the four nuclides to adult rat bone *in vitro* (18) showed that the bone retention of ^{133}Ba and ^{223}Ra was double that of ^{45}Ca and ^{85}Sr and that, although the initial uptake was partly reversible for the latter pair, it was almost completely irreversible for the former.

The total excretion (urinary plus fæcal) of ^{47}Ca over the first 2 days (Fig. 3) differs from that of ^{85}Sr mainly on account of the difference in the renal clearance of the two nuclides and this also accounts for most of the divergence in the plasma concentrations of the two nuclides shown in the Fig. 1. For ^{133}Ba and ^{223}Ra, however, excretion following intravenous administration is mainly via the bowel, the ratio of the intestinal to the renal clearance being 9 for ^{133}Ba and 36 for ^{223}Ra. The relatively high permeability of the gastro-intestinal wall to ^{133}Ba and ^{223}Ra compared with that to ^{47}Ca and ^{85}Sr has been demonstrated for rats in this laboratory (19). Thus, 10 min after an injection, about 17 per cent of the ^{223}Ra injected and 12 per cent of ^{133}Ba was in the gut wall or gut contents compared with only 3 per cent for ^{47}Ca and 4 per cent of ^{85}Sr. In fact, following intravenous administration, the main route of excretion for Sr is via the kidney, whereas for the next member of the alkaline earths, Ba, the main route of excretion is intestinal. This interesting result is worthy of further investigation.

One of the most notable results of the present study is the close approach of plasma concentration and body retention for ^{133}Ba and ^{223}Ra (Fig. 1 and Table 3). In adult man, it would appear that valid inferences on the short-term retention of Ra could be obtained from a study of the turnover of Ba. The turnover of the ^{47}Ca and ^{85}Sr following intravenous administration showed appreciable differences, so that Sr cannot be regarded as a good marker for Ca. In fact, 48 hours after injection, the derived tissue content for ^{85}Sr was about 50 per cent and for ^{47}Ca 65 per cent of the amount administered compared with 24 per cent for both ^{133}Ba and ^{223}Ra (Table 3).

3.4 *Long-term retention of ^{133}Ba and ^{226}Ra*

From Figure 7 it is evident that a single exponential represents the body content of ^{133}Ba from about 150 to 1000 days. Measurements of this are still in progress and it is too early to say if the half life of 1033 days for this component of the retention will be maintained for the next few years.

That the time-retention relationship for radon retained from 17 to 28 years after contamination, in the same subject, fits a single exponential is of considerable interest. It is usually assumed that radon retention follows a power law (20, 21):

$$\text{Per cent radon retained} = 5.8\ t^{0.18} \quad \text{. . . . .} \quad (2)$$

where t is the time in days after injection. It follows that for the time span of the present measurements, the change in the radon retained would be about 8 per cent. This would correspondingly reduce the observed biological half-life of 7.5 years. The same formula (2) may be used to convert the ordinate of Figure 8 to radium retained, the multiplying factor being about 3.3, i. e. the body content of radium in January 1957 would be 19.8 nCi.

It might be expected that the biological half-life of retained Ra is greater than that for Ba in view of the potentially higher R. B. E. of radiation from the former. Thus if the Ra deposited in bone is potentially more toxic to the local cell population than ^{133}Ba, the long-term turnover of Ra could be less than that for ^{133}Ba.

Miller and *Finkel* (22) have shown that the radium retention in patients who received radium injections at the Elgin State Hospital in 1931 could be represented by a single exponential with $T^{1}/_{2}$ from 9 to 21 years. However in the assessment of body retention (a) there was a considerable time lapse between the early measurement of these patients at Elgin and the measurements subsequently made at Chicago; (b) changes in the method of assessing the body content of Ra undoubtedly took place during the time they were studied, even at Chicago; (c) the doses ranged from 90 to 300 μCi.

3.5 *Assessment of original ^{226}Ra contamination*.

If we assume that the body content of Ra from 1 year after the contamination (September 1941) to January 1957 was exponential then,

$$3.3 \times 6 = R_1 \, e^{-\frac{0.693 \times 15^1/_4}{7.5}} \quad \text{or} \quad R_1 = 80 \text{ nCi}$$

where R_1 is the body content at 1 year.

If we also assume that from 1 day to 1 year the body content follows the power law $r = r_1 t^{-0.5}$

where $r = R_1$ = body burden at 1 year = 365 days

and r_1 = body burden at 1 day after contamination then $r_1 = 80 \times \sqrt{365} = 80 \times 19.1 = 1.5$ μCi.

ACKNOWLEDGEMENT

Special thanks are due to Dr. J. Rundo for the whole body measurements which he made of the four nuclides.

References

1. *Barnes, D. W. H., Bishop, M., Harrison, G. E., Sutton, A.:* Int. J. Radiat. Biol., *3* (1961) 637.
2. *Comar, C. L.:* Transfer of Calcium and Strontium across Biological Membranes, 1963, p. 405.
3. *Kshirsagar, S. G., Lloyd, E., Vaughan, J.:* Brit. J. Radiol., *39* (1966) 131.

4. *Shimmins, J. G., Smith, D. A., Nordin, B. E. C., Burkinshaw, L.*: Strontium Metabolism, Academic Press, London, New York, 1967, 149.
5. *Comar, C. L., Wasserman, R. H.*: Mineral Metabolism, Vol. 2A, Academic Press, New York, 1964, 523.
6. *Gran, F. C., Nicolaysen, R.*: Radio-Strontium Deposition in Humans, Scandinavian Univ. Books, Norway, 1964.
7. *Domanski, T. M., Depczyk, D., Liniecki, J.*: Physics Med. Biol., *11* (1966) 461.
8. *Norris, W. P., Kisieleski, W.*: Cold Spring Harb. Symp. quant. Biol., *13* (1948) 164.
9. *Sansom, B. F., Garner, R. J.*: Biochem. J., *99* (1966) 677.
10. *Nelson, N. S., Rust, J. H.*: Internat. Symp. on Radioecological Concentration Processes, Pergamon Press, London, 1967, 573.
11. *Harrison, G. E., Sutton, A.*: Nature, *197* (1963) 809.
12. *Carr, T. E. F., Sutton, A.*: Symp. on Nuclear Activation Techniques in the Life Sciences, I. A. E. A., Vienna, 1967, 445.
13. *Harrison, G. E., Carr, T. E. F., Sutton, A.*: Nature, *209* (1966) 526.
14. *Norris, W. P., Tyler, S. A., Brues, A. M.*: Science, *128* (1958) 456.
15. *Rundo, J.*: Int. J. Radiat. Biol., *13* (1967) 301.
16. *Bryant, F. J., Loutit, J. F.*: Proc. R. Soc. B *159* (1964) 449.
17. *Henderson, E. H., Parker, A., Webb, M. S. W.*: Atomic Energy Research Estab.: Report No. R4035, 1962 (London H. M. S. O.).
18. *Harrison, G. E., Howells, G. R., Pollard, J.*: Calc. Tiss. Res., *1* (1967) 105.
19. *Carr, T. E. F.*: unpublished results, 1967.
20. *Mays, C. W., Van Dilla, M. A., Floyd, R. L., Arnold, J. S.*: Radiat. Res., *8* (1958) 480.
21. *Mays, C. W., Cochran, T. H., Jee, W. S. S.*: Health Phys., *9* (1963) 615.
22. *Miller, C. E., Finkel, A. J.*: Argonne Nat. Lab. Report No. ANL-7217 (1965) p. 77.

Sadržaj

USPOREDBA RASPODJELE ^{47}Ca, ^{85}Sr, ^{133}Ba i ^{223}Ra U ZDRAVA ČOVJEKA NAKON INTRAVENOZNE INJEKCIJE

Zdravi 60-godišnji muškarac primio je intravenozno ^{47}Ca, ^{85}Sr, ^{133}Ba i ^{223}Ra da bi se mogao promatrati metabolizam tih radionuklida u istom ispitaniku.

Serijski uzorci krvi uzimani su 7 dana nakon svake injekcije a skupljanje urina i fekalija nastavljeno je kroz period od preko 3 mjeseca.

Ustanovljeno je da je metabolizam ^{133}Ba i ^{223}Ra vrlo sličan, tako da Ba možemo smatrati dobrim kratkoživućim obilježivačem za Ra. Razlike u metabolizmu ^{47}Ca i ^{85}Sr bile su vrlo očite.

Određivanje ^{85}Sr u cijelom tijelu vršeno je u toku cijele godine, a određivanje aktivnosti ^{133}Ba se još i sada nastavlja. Zamijećene su značajne razlike u kasnijoj fazi retencije ovih radionuklida.

Pored toga prikazani su i novi rezultati o kasnoj retenciji radona u tijelu istog ispitanika nakon akcidentalne kontaminacije ^{226}Ra. Tjelesna retencija radona između 17 i 27 godina nakon kontaminacije pada eksponencijalno s vremenom poluraspada od 7,5 godina.

Primljeno 28. VIII 1968.

Savjet za medicinska istraživanja,
Istraživačka radiobiološka jedinica,
Harwell, Didcot, Berkshire, Engleska