Estimation of $^{137}$Cs Body Burden in Japanese

I. The Ratio of $^{137}$Cs Excreted in the Urine to that in the Total Excreta Following the Continuous Intake of $^{137}$Cs in Fall-Out

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The ratio of $^{137}$Cs excreted in the urine to that in the total excreta, namely, $f_u$ value, was determined for a group of 10 Japanese male adults in continuous intake of fall-out $^{137}$Cs. The ratio averaged 0.88, ranging from 0.83 to 0.92 and was very close to those reported previously. Additionally, the ratios for Ca and stable Sr were also determined and found as 0.36 and 0.15 respectively for the same subjects.

INTRODUCTION

The present fall-out from nuclear tests still gives rise to an appreciable internal dose due to $^{137}$Cs to Japanese. The waste from the atomic power establishment may also bring a chance to expose the public to $^{137}$Cs. In order to estimate the potential hazard of the low but continuous exposure to $^{137}$Cs from these sources, $^{137}$Cs body burden of the public must be determined precisely. The whole-body counting technique is the most reliable method for this purpose. However, in Japan, it is necessary to develop a dependable method in place of the whole-body counting because of a limited number of whole-body counter available for the measurement of the public.

A compartment model well explains the relationship between the $^{137}$Cs level of the total body and that in the total excreta or intake, which is expressed with the following equation:

$$-\frac{d}{dt}Q(t) = -\lambda Q(t) + I(t) \quad (1)$$

where $Q(t)$ and $I(t)$ are respectively the body burden and the intake of $^{137}$Cs at time, and $\lambda$ is the rate constant of elimination of $^{137}$Cs from the total body. $\lambda Q(t)$ is, therefore, equivalent to the excretion, $E(t)$. The body burden is consequently expressed with the equation (2), where $f_u$ is the ratio of $^{137}$Cs content in the daily urine to that of total excreta, and $E_u(t)$ is the amount of $^{137}$Cs excreted in the urine. $T$ is
the biological half-life of $^{137}$Cs for the total body.

$$Q(t) = \frac{1}{f_u} \cdot E_u(t) \cdot \frac{T}{\ln 2} \quad (2)$$

Accordingly, a successful estimation of the body burden can be given by the urinary assay of $^{137}$Cs if the values of $f_u$ and $T$ are correctly known. It was already indicated that the body burden, $Q(t)$, was estimated to be 120 times as much as $E_u(t)$ for Japanese in most period of decreasing tendency in the daily intakes of $^{137}$Cs. A further investigation, however, indicated that 130 was better and more reasonable than 120 to estimate $^{137}$Cs body burden.

The present work indicates both the average and the distribution of $f_u$ as to $^{137}$Cs for 10 male subjects and summarizes the values for normal Japanese reported previously. In addition, the $f_u$ values of both Ca and stable Sr are reported for the same individuals. They will be useful to estimate the body burden due to $^{90}$Sr which is another notorious radionuclide in fall-out.

**MATERIALS AND METHODS**

Ten male researchers in the National Institute of Radiological Sciences, served as the subjects voluntarily. They were apparently healthy and doing their normal works. Their physiques, ages and average amount of excreta are given in Table 1. The day-to-day samples of the feces and the urine were separately collected from each subject in the period of 3 consecutive days in November 1968. Around the period $^{137}$Cs in the total diet in or near Chiba was in a decreasing tendency.

The sample was ignited below 450°C in a muffle furnace, and $^{137}$Cs in the ash was determined radiochemically: after the coprecipitation of $^{137}$Cs on ammonium

| Subject | Age (year) | Weight (kg) | Height (cm) | Vol. of urine (ml) | Ash of urine (g) | Weight of feces (g) | Ash of feces (g) |
|---------|------------|-------------|-------------|-------------------|-----------------|---------------------|-----------------|
| 1       | 30         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 2       | 31         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 3       | 32         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 4       | 33         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 5       | 34         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 6       | 35         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 7       | 36         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 8       | 37         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 9       | 38         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| 10      | 39         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| Average | 33         | 56.8        | 167.4       | 137.0             | 21.0            | 143.0               | 3.9             |
| S.D.    | 6          | 8.2         | 6.8         | 310               | 4.2             | 70.1                | 1.0             |
molybdophosphate, $^{137}$Cs was finally separated in the form of platinic cesium chloride and the radioactivity was measured. The samples over 3 consecutive days' ash of feces of each subject were respectively put together, and 10 composite samples with enough amount of $^{137}$Cs for measurement by a low background gas flow G.M. counter were prepared for the group of this subjects. $^{137}$Cs in each sample of the daily urine in the 3 consecutive days was separately analyzed for the individual subjects.

In contrast with $^{137}$Cs, both Ca and stable Sr are mainly excreted into feces. The 3 consecutive days' ash of urine were, therefore, joined for the individual subjects separately after half the daily sample had been taken to analyze $^{134}$Cs. While, a known amount of the ash of feces excreted daily was separately analyzed for the individual subjects. Ca contents determined by the atomic absorption spectrometry were lower than that determined by the titration with EDTA. The results by the atomic absorption spectrometry were, however, taken in the present study because the measurement was less interfered with co-existing materials in the sample than the titration method. The loss of Ca and Sr in the analytical processes were corrected radiochemically by adding $^{40}$Ca and $^{88}$Sr to the sample.

RESULTS AND DISCUSSION

Table 2 shows the average of $^{137}$Cs in the urine, feces and total excreta in the 3 consecutive days, and the $f_u$ values for individual subjects. The averages of these values for the group are also presented in the same table. The $f_u$ values for the individuals were so close to each other that the coefficient of variance was about 3 percent of the average.

| Subject | Urine (pCi/day) | Feces (pCi/day) | Total excreta (pCi/day) | $f_u$ (%) |
|---------|----------------|----------------|-------------------------|-----------|
| 1       | 29.6           | 2.6            | 32.2                    | 92        |
| 2       | 29.3           | 2.9            | 32.2                    | 91        |
| 3       | 52.1           | 8.7            | 60.8                    | 86        |
| 4       | 23.3           | 2.9            | 26.2                    | 90        |
| 5       | 33.7           | 5.2            | 38.9                    | 87        |
| 6       | 23.5           | 2.9            | 26.5                    | 89        |
| 7       | 41.0           | 6.5            | 47.5                    | 86        |
| 8       | 22.9           | 4.6            | 27.5                    | 83        |
| 9       | 21.1           | 3.1            | 24.1                    | 88        |
| 10      | 26.9           | 4.5            | 31.5                    | 85        |
| Average | 30.7           | 4.1            | 35.1                    | 88        |
| S.D.    | 9.4            | 2.0            | 11.2                    | 3         |
The average for the group of 0.88 is in good agreement with the values for Japanese male adults reported by Fujita et al. Some of them were observed in the increasing period and the rest in the decreasing period as to $^{137}$Cs intake. The values were reported 0.82 for the former and 0.87 and 0.81 for the latter. Moreover, the values observed in the United States were 0.85,17,18 and no significant difference existed among the values observed in the two distant countries.

Figure 1 indicates the distribution of the $f_u$ values for individuals in the United States and Europe19-22 and for Japanese2-5 including the present result. More than 70% of the $f_u$ values distributed between 0.75 and 0.9 in either of the two ethnically different nations, although the K intake is much lower for Japanese.6-15,17,18,20,24,26 It can be concluded by these facts that the $f_u$ value of $^{137}$Cs must be a physiological constant with the average of 85 to 90 in terms of percentage and that no trophic level of K can contribute to change the value. The finding by Ward and Johnson25 supports the present conclusion.

Fig. 1. Distribution of the $f_u$ values for individual male adult subjects.
Left: the distribution for individuals in the United States and Europe.
Right: the distribution for individuals of Japanese. Both of them include some $f_u$ values which were determined in the period after the termination of initial fast excretion of $^{137}$Cs following a single administration.

Tables 3 and 4 indicate the $f_u$ and other values for Ca and stable Sr. The $f_u$ values are 36 and 15 in terms of percentage on the average for Ca and stable Sr, respectively. The distributions around the averages are comparable with each other in two elements but much larger than the distribution for $^{137}$Cs. The differences of
average f_u values and the distributions among Ca, stable Sr and 137Cs can be ascribed to the difference of their gastrointestinal absorption, that is, 100, 60 and 30 in terms of percentage for 137Cs, Ca and stable Sr in the descending order. In other words almost all of 137Cs in the excreta must come from the metabolic pool. While, a fairly large part of Ca and stable Sr in ingested foodstuff can be unabsorbed through the intestinal tract and excreted into feces. The part will vary day by day and also among individual subjects depending on their dietary habits.

### Table 3

| Subject | Urine (mg/day) | Feces (mg/day) | Total excreta (mg/day) | f_u (%) |
|---------|----------------|----------------|------------------------|---------|
| 1       | 186            | 173            | 359                    | 52      |
| 2       | 186            | 243            | 429                    | 43      |
| 3       | 200            | 387            | 587                    | 34      |
| 4       | 183            | 320            | 503                    | 36      |
| 5       | 96             | 432            | 528                    | 18      |
| 6       | 140            | 288            | 428                    | 33      |
| 7       | 270            | 448            | 718                    | 38      |
| 8       | 167            | 316            | 433                    | 35      |
| 9       | 174            | 150            | 324                    | 54      |
| 10      | 89             | 453            | 542                    | 16      |
| Average | 169            | 321            | 490                    | 36      |
| S.D.    | 52             | 109            | 115                    | 12      |

### Table 4

| Subject | Urine (mg/day) | Feces (mg/day) | Total excreta (mg/day) | f_u (%) |
|---------|----------------|----------------|------------------------|---------|
| 1       | 0.15           | 0.73           | 0.88                   | 17      |
| 2       | 0.32           | 1.03           | 1.34                   | 24      |
| 3       | 0.15           | 1.01           | 1.16                   | 13      |
| 4       | 0.19           | 1.00           | 1.12                   | 16      |
| 5       | 0.21           | 1.19           | 1.40                   | 15      |
| 6       | 0.08           | 0.75           | 0.83                   | 10      |
| 7       | 0.13           | 1.43           | 1.56                   | 8       |
| 8       | 0.23           | 0.68           | 0.91                   | 25      |
| 9       | 0.14           | 0.75           | 0.90                   | 16      |
| 10      | 0.10           | 1.19           | 1.29                   | 7       |
| Average | 0.17           | 0.98           | 1.15                   | 15      |
| S.D.    | 0.07           | 0.25           | 0.26                   | 6       |
Table 5 indicates the comparison of the values as to excretion between the present work and ICRP publication 23. It is impressive that the weight of ash of feces is much lighter in the present work than in the literature, nevertheless the weights of raw material are about the same between them. The same tendency as the relation of weight of excreta is also clear in the amount of Ca excreted into the urine and the feces. The amount of total excretion of Ca is found in this work a half of that by the ICRP value. The excreted amount of Ca in this work, however, well balances with the intake by Japanese, that is, about 540 mg per day for the individual living in Tokyo or its neighbouring districts though the amount is still in an increasing tendency. The rather low amount of Ca intake by Japanese, therefore, supports the present result because the element should be in equilibrium between the body and the intake in the adult subjects.

Table 5
Comparison of the values as to excretion obtained in the present study and those for the reference man

|                         | The present study\(^a\) | Reference man |
|-------------------------|-------------------------|---------------|
| Volume of urine (ml)    | 1370 ± 310              | 1400          |
| Weight of ash of urine (g) | 21.0 ± 4.2            | 17            |
| Weight of feces (g)     | 143 ± 70                | 135           |
| Weight of ash of feces (g) | 3.9 ± 1.0              | 0.18          |
| Ca in urine (g)         | 0.17 ± 0.05             | 0.32 ± 0.11   |
| Ca in feces (g)         | 0.32 ± 0.11             | 0.74          |
| \(f_u\) value for Ca (%)| 36 ± 12                 | 20\(^b\)      |
| Sr in urine (mg)        | 0.17 ± 0.07             | 0.34          |
| Sr in feces (mg)        | 0.98 ± 0.25             | 1.5           |
| \(f_u\) value for Sr (%)| 15 ± 6                 | 18\(^b\)      |
| \(f_u\) value for \(^{137}\)Cs (%) | 88 ± 3               |               |

\(a\) Rounded due to the convenience to compare with those for the reference man.

\(b\) Calculated from the values for the reference man by the present author.

As to stable Sr excretion, the total amount in Japanese is about a half of the ICRP's value again but this time the urinary excretion by Japanese is a half of the ICRP's value in contrast with the case of Ca excretion. In terms of ratio to Ca, Stable Sr was excreted relatively more into the feces in Japanese than in the reference man of ICRP.

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