Body Burdens of Cesium-137 and Potassium-40 in the Japanese Population

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日本人体内のカリウム—40およびセシウム—137量の測定

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日本人約 2,000名を対象とし，ヒューマン・カウンタによる体内のカリウム—40およびセシウム— 137の量を測定した．被検者の年令は6～87才におよび，年令ならびに性別を考慮して選択した．測定はほぼ2カ年にわたつて行なわれたので，その間のセシウム— 137体内の減少を考慮のうえ，必要な補正を行なつた．

データは，年令別・性別数値として表わした．カリウム量は，全身体内量（g），濃度（g/kg—体重，g/g-LBM）として求め，セシウム— 137量は，濃度（g/kg—体重，g/g—カリウム）として求めた．

測定によつて得られた値から，カリウム—40およびセシウム— 137による国民遺伝有意線量（1967年8月時点の体内量を基準として）を試算し，それぞれ，20.61 mrem/年，および0.49 mrem/年の値を得た．

The radioactive nuclides in human body are roughly classified into two groups. The one is naturally existed radioactive nuclides, and the other is radioactive nuclides of fallout from the nuclear fission of large scale such as tests of nuclear weapon. The quantitative estimation of these nuclides is not only indispensable for the practice of whole-body monitoring, but also essential in the field of radiological science.

In the present study, body burdens of cesium-137 and potassium-40 in the Japanese population were measured with a whole-body counter. The size of sample measured has been about 2000 persons overing the age distribution. Cesium-137 was selected as a presentative of long-lived gamma-emitting nuclides in radioactive fallout. Potassium-40 is one of four naturally existing elements (^{226}Ra, ^{238}U, ^{232}Th and ^{40}K) which contribute to natural background radiation.

Since the gamma-rays of ^{137}Cs can readily be measured in human body by use of the whole-body counter, many data have been adduced on the level of ^{137}Cs in order to ascertain its distribution in the world and its attendant potential radiation hazard[1)2)3)4)7)11)].

Naturally existing ^{40}K is normally the most abundant gamma-emitting radioisotope in human body, and always shows up as a distinct peak in the whole-body counter. Because natural potassium contains ^{40}K in a constant ratio, 0.0119%, potassium content in human body can be measured by means of whole-body counting of ^{40}K. Statistical survey on whole-body ^{40}K content in the population make a valuable contribution to the field of physiology as well as radiological health.

There exists a considerable literature on ^{137}Cs or ^{40}K body burdens in the population, but little work has been done to measure to body burdens on a large number of Japanese. The present study was designed to measure ^{137}Cs and ^{40}K body burdens on the subjects which were selected with due consideration for age and sex. In addition to the primary objective above mentioned, considerable attension is denoted to the genetically significant dose from these radioactive nuclides.

Method

The subjects, ranging in age from 6 to 87 years, had already lived in Tokyo district for more than three years before being measured. It can seen in Table 1 that sex and age evently distributed among the subjects measured. These people are all in good health and have not been exposed to radioactive contamination in the course of their normal work or medical treatment.

Each subject was inquired on personal history (occupational history, social history, habits etc.) using a check-sheet in advance of the whole-body counting. Biometrics were made on height, body weight, abdominal thickness, and others.

Body-burdens of ^{137}Cs in the population reflect the variable level of fallout from previous nuclear weapon tests. It is necessary to make a correction because the whole-body counting of the subjects com-

Table 1. Number, age and of subjects

Age	Sex	Number of Subjects
6— 8 yr.	M (Male)	53
	F (Female)	52
9—11	M	61
	F	61
12—14	M	80
	F	63
15—17	M	66
	F	54
18—20	M	60
	F	60
21—23	M	98
	F	62
24—29	M	65
	F	60
30—39	M	66
	F	84
40—49	M	56
	F	90
50—59	M	56
	F	60
60—69	M	62
	F	58
70—	M	38
	F	54
Total	M	761
	F	758
	M+F	1519

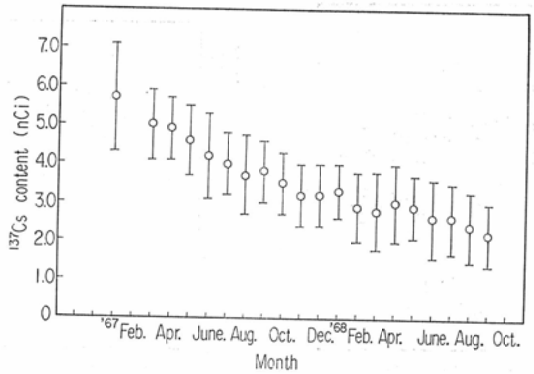

Fig. 1. Change of whole-body content of cesium-137, Jan. 1967–Sept. 1968
The bars indicate 2 S.D.

menced in January, 1967 and completed in September, 1968. Each measured value was corrected to estimated level in August, 1967. To obtain correction factors, the decreasing rate of body burdens of ^{137}Cs, periodically repeated measurements were made on 15 subjects with a narrow range of height and body weight. As indicated in Figure 1 the ^{137}Cs body burdens decreased by 49% from January 1967 to September, 1968.

Measurements of ^{137}Cs and ^{40}K in the subjects were obtained with the whole-body counter of the University of Tokyo[5]. The counter is equipped with sodium iodide and plastic scintillation detectors. In this study, four 50 × 50 × 15 cm plastic scintillation detectors were used. The two channels used on the plastic system for analysis encompassed energy bands of 0.11–0.66 Mev for ^{137}Cs and 0.66–1.72 Mev for ^{40}K.

The skinfold measurements were made with a skinfold caliper of Keys'type. Fat content and lean body mass, LBM, were calculated from skinfold-thickness by Keys and Brozek's formula[6], and Suzuki and Nagamine's formula[8].

The physical structure of the subject has a great influence on the efficiency of whole-body counting. In order to avoid the influence, the measured value was corrected by means of the factor which is quantitatively related to body weight and chest thickness.

Results and Discussion

The potassium content was expressed in terms of the following three ways: whole body content, grams per body weight, and grams per lean body mass. These values have been plotted against the age of the subjects in Figures.

As indicated in Figure 2 the whole-body content of potassium reached a peak at the age of 18–21 years and is followed by a slight decline. The relation between potassium content per kilogram body weight and age is given in Figure 3. The difference in potassium concentration, gr/Kg-body weight, between male and female is smaller than in whole body content. As shown by the solid line in Figure 3 the increase in the potassium concentration of male exhibits from 12 years old till 20. On the other hand, the result of female does not show the same trend as in male. The discrepancy between male and female seems to have arisen from the difference in body fat content. The marked difference of body fat content

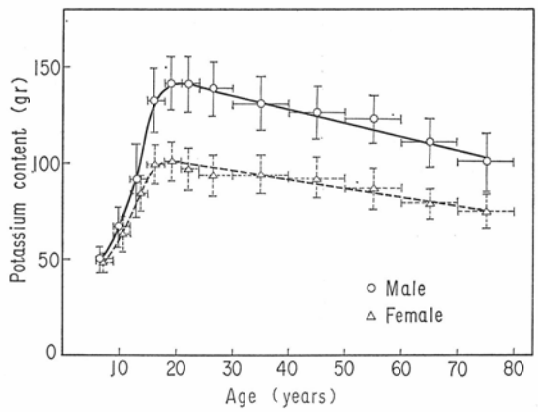

Fig. 2. Average potassium content in human body as a function of age Vertical bars indicate 2 S.D.
Horizontal bars indicate the range of ages.

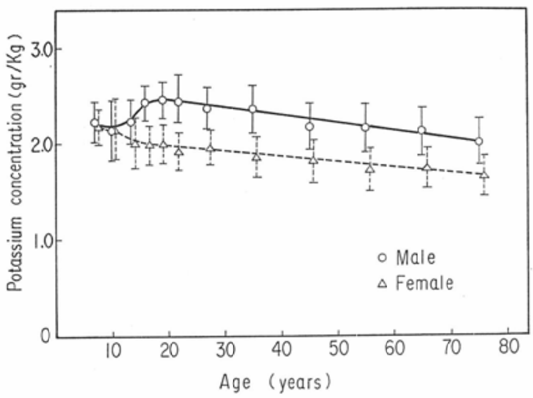

Fig. 3. Average potassium concentration (gr/Kg-body weight) in human body as a function of age
The bars indicate 2 S.D.

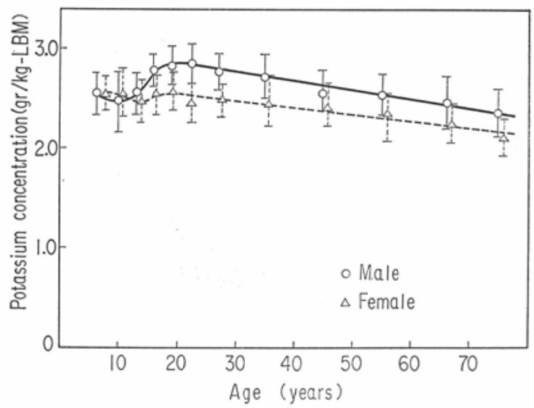

Fig. 4. Average potassium concentration (per LBM) as a function of age
The bars indicate 2 S.D.

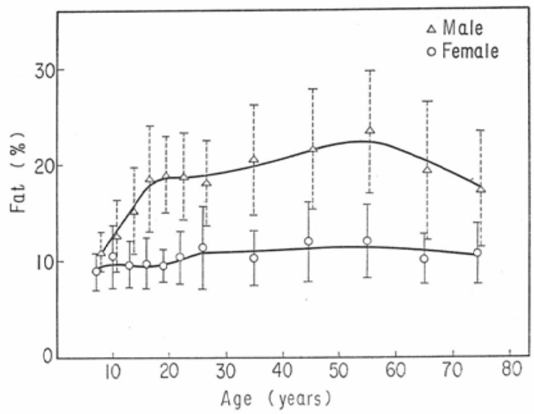

Fig. 5. Average fat content as a function of age The bars indicate 2 S.D.

between male and female is presented in Figure 5. It is clearly evident from the figure that the fat content affects in directly the measured value of potassium per body weight. In order to avoid the effect of the fat content value, the potassium concentration is recorded as grams potassium per kilogram lean body mass. The result obtained with this method are illustrated graphycally in Figure 4. It was found that there was little difference between both sexes about the values of potassium per kilogram lean body mass.

The body burdens of ^{137}Cs were expressed as radioactivities per kilogram body weight (pCi/Kg-body weight) and per gram potassium (pCi/gr-K). Figure 6 and 7 are the histograms to illustrate the frequency distribution of ^{137}Cs concentration. What is evident from these figures is considerable variation among individuals in the concentration of ^{137}Cs. The frequency takes a maximum value in 41–45 pCi/Kg-body weight or 21–25 pCi/g-K. The correlations of ^{137}Cs concentration with age and sex are given in Figures 8

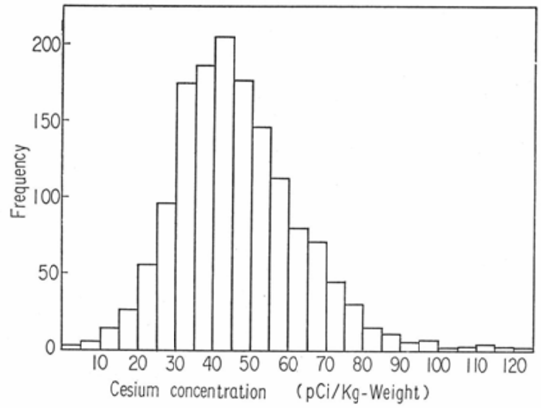

Fig. 6. Cesium-137 concentration (pCi/Kg-body weight) in human body

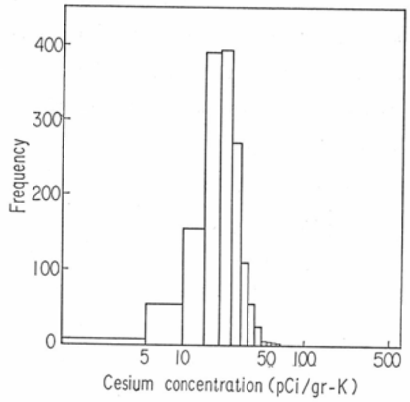

Fig. 7. Cesium-137 concentration (pCi/gr-potassium) in human body

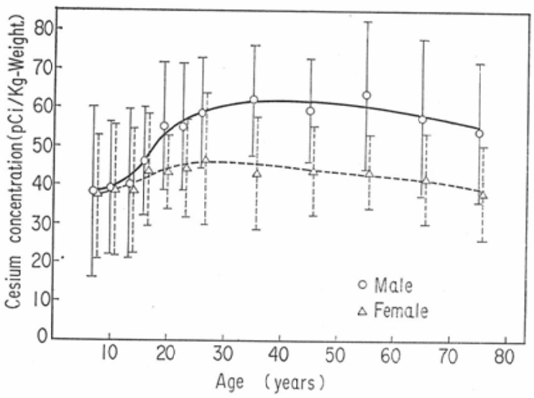

Fig. 8. Average cesium-137 concentration (pCi/gK-body weight) as a function of age
The bars indicate 2 S.D.

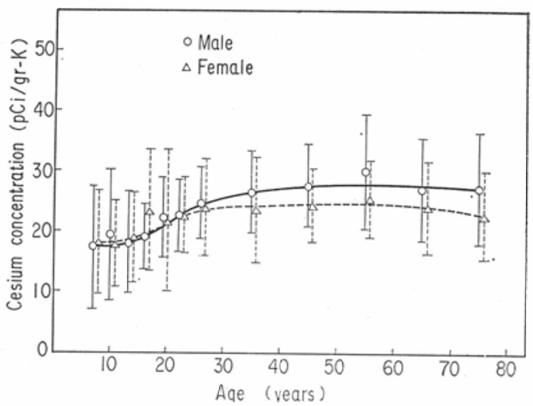

Fig. 9. Average cesium-137 concentration (pCi/gr-potassium) as a function of age
The bars indicate 2 S.D.

and 9. Figure 8 shows that the amount of ^{137}Cs per kilogram body weight differs with sex in adult age. On the other hand, Figure 9 represents little or no dependence of the amount of ^{137}Cs per gram potassium upon sex. The significant correlation was not observed between ^{137}Cs concentration and age within the limits of the results shown in these figures.

It is a important problem to calculate genetically significant dose delivered from ^{40}K and ^{137}Cs body burdens in groups of population. The genetically significant dose is calculated using the formula[10]:

$$\text{G.S.D.}\frac{\sum_k \left(\overset{(F)}{Nk}\ \overset{(F)}{wk}\ \overset{(F)}{dk} + \overset{(M)}{Nd}\ \overset{(M)}{wk}\ \overset{(M)}{dk}\right)}{\sum_k \left(\overset{(F)}{Nk}\ \overset{(F)}{wk} + \overset{(M)}{Nk}\ \overset{(M)}{wk}\right)}$$

Where

G.S.D. = (annual) genetically significant dose, mrem/yr,

Nk = (annual) number of individuals of age-class k,

wk = future number of children expected by an individual of age-class k,

dk = gonad dose of an individual of age-class k, mrem/yr,

(F) and (M) denote "female" and "male" respectively. In order to solve this equation, Nk and wk quoted from Vital Statistics in 1965[12].

The following assumptions have been made in calculation of annual gonad dose, dk.

(a) Potassium-40 and cesium-137 distribute uniformly in whole body.

(b) The dose to gonads is equivalent to the whole body dose.

(c) The total body burdens of these nuclides are constant throughout the year.

(d) The concentrations of ^{40}K and ^{137}Cs in children under five years old are equal to the valudes in six to eight years old.

(e) The values in August, 1967 are used for the calculation of the dose from ^{137}Cs body burdens.

(f) The regional differences of the body burdens are negligible, and the values estimated for Tokyo district residents are regarded as the mean value of the Japanese.

The values of dk are obtained from the following equations:

$dk(^{40}K) = 9.4\ Qi(^{40}K)$ mrem/yr

$dk(^{137}Cs) = 11.0 \times 10^{-3}\ Qi(^{137}Cs)$ mrem/yr

The value of effective absorbed energy per disintegration, ε (Mev/decay), is indispensable to calculation of whole body dose. In this study, the value, ε, given in Report of ICRP Committee II was used without consideration of age[9]. The genetically significant doses delivered to Japanese population from ^{40}K and ^{137}Cs body burdens were calculated as 20.61 ± 0.50 mrem/yr and 0.49 ± 0.05 mrem/yr respectively.

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