Estimation of $^{137}$Cs Body Burden in Japanese II.
The Biological Half-life

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(Received February 16, 1978; Revised version received June 24, 1978)

Caesium-$^{137}$/Biological Half-Life/Japanese

The biological half-life of $^{137}$Cs in the total body of human subjects was determined in 23 individuals of Japanese male adult in their normal works by measuring amount of $^{137}$Cs in both their total body and daily urine in the same period. For the group, the value was determined by averaging the half-lives for individuals, by comparing the mean body burden and the mean daily urinary excretion, or by applying a curve fitting method to the body burden estimate. The biological half-life averaged 86 days, ranging from 50 to 161 days. The averages of the biological half-lives for the group were 83, 87 and 82 days in the different periods of observation. By the curve fitting method, 85 days was found for the group. The biological half-life for the individuals depended on both body weight and age, to a lesser extent, of the subjects.

INTRODUCTION

ICRP 2 gives the biological half-life of 70 days to Cs distributing in the total body. However, the value was derived based on very limited number of subjects from some limited area. A lot of factors like age, sex and ethnic group may result in a different biological half-life and even economic status may contribute to the biological half-life because of possible difference in food consumption in both quality and quantity.

In fact, the available values of Cs biological half-life in the total body obtained thereafter indicated the rather wide distribution as indicated graphically later.

The biological half-life or half-time of an element is one of the most determining factors for estimation of internal radiation dose due to the radioisotopes. In accordance with the development of peaceful uses of atomic energy, therefore, it has become more important to study the average and the range of biological half-life of a radionuclide in man in order to estimate reasonably the internal radiation exposure of the public to the radioactive waste issued from an atomic energy establishment in operation or in preparation.

Fig. 1 shows the change of $^{137}$Cs body burdens of the group of male adults with time which included the subjects in the present work. The coefficient of variation averages roughly 30%. The biological half-life is one of the most responsible factors...
for $^{137}\text{Cs}$ body burden. Therefore, existence of rather large variation in the body burden suggests an appreciable difference of $^{137}\text{Cs}$ biological half-life between the subjects in the present group nevertheless all the subjects were male adults.

Consequently, in the present work, the effort was concentrated to obtain many biological half-lives of $^{137}\text{Cs}$ in normal Japanese male adults in order to estimate the range and the reasonable average. These are required to forecast the internal radiation dose due to radioesium by both peaceful uses of atomic energy and fall-out.

The biological half-life used in the present work means strictly the effective one for the major component in a two-component exponential function representing the total body retention after single administration of Cs because the physical half-life, 30 years, is long enough to allow the effective half-life to be the biological one. The major component has a longer half-life than the minor one.25

In view of its significance to the internal exposure from $^{137}\text{Cs}$, the longer half-life was estimated in the present work.

**MATERIALS AND METHODS**

The subjects measured their biological half-lives were 23 researchers in both the Institute of Public Health and the National Institute of Radiological Sciences, and joined the present work voluntarily. They were apparently healthy though not examined medically and engaged their normal activities during the period of 1964 to 1967.

Their body burdens of $^{137}\text{Cs}$ which were accumulated by the daily intake of food contaminated with fall-out, were periodically measured by the 2 whole-body counters at the National Institute of Radiological Sciences.

The excretion of $^{137}\text{Cs}$ in 24-hr urine was so fluctuated as much as 13\% in terms of coefficient of variation in the observation of 7 consecutive days as indicated in Table 1. The fluctuation decreased by the extention of period for the urine collection which was given in Table 2. Table 3 indicates age, body weight, height and average volume of daily urine for 5 male adults who joined the experiment of day-to-day fluctuation of $^{137}\text{Cs}$ urinary excretion. Based on these data, the biological half-life in the present work was computed by the analysis of the body burden and the averaged amount of $^{137}\text{Cs}$ in 3 consecutive days urine which fluctuated as much as 6\% in terms of coefficient of variation after April 1965.

The 24-hr urine samples were separately and daily collected from each of the subjects mainly for 3 consecutive days in the same period as the body burden measurement. Amount of $^{137}\text{Cs}$ in the urine was determined radiochemically following the procedures described in appendix.

The body burden and the daily urinary excretion of $^{137}\text{Cs}$ in almost equilibrium were used to determine the biological half-life. In the cases that the equilibrium states were attained a few times for a subject through the period of present work, the biological half-life was determined each of the periods and the average was represented in Table 4.
Table 1. Day-to-day fluctuation of the urinary excretion under the continuous ingestion of fall-out $^{137}$Cs

<table>
<thead>
<tr>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Coefficient of variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95</td>
<td>94</td>
<td>78</td>
<td>108</td>
<td>87</td>
<td>95</td>
<td>96</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>132</td>
<td>97</td>
<td>102</td>
<td>82</td>
<td>89</td>
<td>106</td>
<td>84</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>82</td>
<td>77</td>
<td>95</td>
<td>87</td>
<td>73</td>
<td>97</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
<td>84</td>
<td>75</td>
<td>80</td>
<td>71</td>
<td>96</td>
<td>79</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>108</td>
<td>113</td>
<td>98</td>
<td>87</td>
<td>79</td>
<td>95</td>
<td>12</td>
</tr>
</tbody>
</table>

Remarks: 1. This measurement was performed in March 1965.
2. All the subjects were male and did their normal works.

Table 2. The effect of urinary collection period on the fluctuation of mean urinary $^{210}$Cs excretion

<table>
<thead>
<tr>
<th>Subject</th>
<th>1-day urine</th>
<th>2-day urine</th>
<th>3-day urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10%</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>2</td>
<td>17%</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>3</td>
<td>13%</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>4</td>
<td>12%</td>
<td>7%</td>
<td>4%</td>
</tr>
<tr>
<td>5</td>
<td>12%</td>
<td>9%</td>
<td>10%</td>
</tr>
<tr>
<td>average</td>
<td>13%</td>
<td>8%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 3. Age, body weight, height and average volume of 7 consecutive days' urine for 5 male adults

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Body weight (kg)</th>
<th>Height (cm)</th>
<th>Average volume of urine (ml/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>58.0</td>
<td>171.5</td>
<td>1040</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>52.0</td>
<td>174.3</td>
<td>1440</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>48.5</td>
<td>163.5</td>
<td>1120</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>52.0</td>
<td>164.6</td>
<td>1640</td>
</tr>
<tr>
<td>5</td>
<td>31</td>
<td>58.5</td>
<td>167.1</td>
<td>1650</td>
</tr>
</tbody>
</table>

Remark: The same numbers are used to identify the subjects through Tables 1-3.

As a group, the half-life was determined with three different ways. The first is the arithmetic average of half-lives of the 23 individual subjects. Secondarily, it was computed from the average of body burden and that of urinary excretion determined for the group in which the subjects mentioned above were included. Equilibrium was attained 3 times for this group but the subjects composing of the group changed a little for each of the periods. The total number of subjects in this group were 43 in the period April to August 1964, 147 in the period January to October 1965 and 52 in
the period June 1966 to March 1967, and the biological half-lives determined in these periods were indicated in Table 4 as subjects 24, 25 and 26, respectively.

Table 4. Biological half-life of $^{137}$Cs in total body determined for 23 male adults of Japanese and the averages

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Body weight (kg)</th>
<th>$f_u$</th>
<th>Biological half-life (days)</th>
<th>Number of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>53.6</td>
<td>0.88*</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>53.7</td>
<td>0.88*</td>
<td>61</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>59.8</td>
<td>0.90</td>
<td>55</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>50.2</td>
<td>0.92</td>
<td>59**</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>47.6</td>
<td>0.88*</td>
<td>63</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>60.8</td>
<td>0.88*</td>
<td>64**</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>32</td>
<td>49.9</td>
<td>0.86</td>
<td>64**</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>22</td>
<td>50.3</td>
<td>0.88*</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>27</td>
<td>51.2</td>
<td>0.88*</td>
<td>71</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>49.6</td>
<td>0.88*</td>
<td>78**</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>24</td>
<td>55.5</td>
<td>0.88*</td>
<td>83</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>27</td>
<td>63.3</td>
<td>0.88*</td>
<td>84</td>
<td>11</td>
</tr>
<tr>
<td>13</td>
<td>23</td>
<td>59.3</td>
<td>0.88*</td>
<td>84</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>36</td>
<td>51.5</td>
<td>0.85</td>
<td>86</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>31</td>
<td>57.5</td>
<td>0.88*</td>
<td>88***</td>
<td>11</td>
</tr>
<tr>
<td>16</td>
<td>29</td>
<td>58.3</td>
<td>0.87</td>
<td>91**</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>31</td>
<td>54.4</td>
<td>0.88*</td>
<td>99</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>44</td>
<td>55.4</td>
<td>0.88*</td>
<td>103</td>
<td>7</td>
</tr>
<tr>
<td>19</td>
<td>32</td>
<td>70.0</td>
<td>0.88*</td>
<td>104</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>32</td>
<td>67.9</td>
<td>0.86</td>
<td>115**</td>
<td>13</td>
</tr>
<tr>
<td>21</td>
<td>24</td>
<td>85.0</td>
<td>0.88*</td>
<td>117</td>
<td>6</td>
</tr>
<tr>
<td>22</td>
<td>35</td>
<td>57.7</td>
<td>0.88*</td>
<td>138</td>
<td>15</td>
</tr>
<tr>
<td>23</td>
<td>33</td>
<td>59.9</td>
<td>0.88*</td>
<td>161</td>
<td>18</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>30±6</strong></td>
<td><strong>57.5±8.3</strong></td>
<td><strong>86±28</strong></td>
<td></td>
<td><strong>18</strong></td>
</tr>
<tr>
<td>24</td>
<td>28±7</td>
<td>54.8±4.2</td>
<td>0.88*</td>
<td>83±14</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>29±4</td>
<td>57.7±8.7</td>
<td>0.88*</td>
<td>87±10</td>
<td>10</td>
</tr>
<tr>
<td>26</td>
<td>31±4</td>
<td>56.4±7.2</td>
<td>0.88*</td>
<td>82±18</td>
<td>4</td>
</tr>
</tbody>
</table>

Remarks: 1. The symbols *, ** and *** mean the estimate for the male adult of Japanese, the average of biological half-lives obtained in 2 different periods and that in 3 different periods.

2. Subjects 24 to 26 are the data for the total number of 42 individuals in the period from April to August 1964, 147 individuals during the period January to October 1965 and 53 individuals in the period from June 1966 to March 1967, respectively.

The biological half-life was computed according to the idea of equivalent half-time by Lloyd et al., which is given by eq. (1).

$$T_{eq} = (1-a)T_L + aT_S$$  

where $T_{eq}$ is the equivalent half-time which can be determined in an equilibrium or
nearly equilibrium state in respect to $^{137}$Cs. The "$(1-a)$" and "$a$" are the intercepts for the major and the minor components of retention curve after single administration of unit amount of radiocesium, and their biological half-times are $T_L$ and $T_S$, respectively.

The "$a$" and $T_S$ are known as about 0.1 and shorter than a few days. Therefore, the second term in eq. (1) is negligibly small as compared to the first term. Consequently eq. (2) holds approximately.

$$T_L = \frac{1}{(1-a)} \cdot T_{eq} \tag{2}$$

While, eq. (3) indicates the relation of the body burden to the excretion of $^{137}$Cs by a compartment model.

$$E(t) = \lambda_{eq} \cdot Q(t) \tag{3}$$

where $E(t)$ and $Q(t)$ are the total excretion and the body burden of $^{137}$Cs at time $t$ and $\lambda_{eq}$ is the elimination constant of $^{137}$Cs from body.

If $^{137}$Cs in the urine is measured in place of $^{137}$Cs in the total excreta and $f_u$ which is the ratio of $^{137}$Cs excreted into the urine to the total excretion, is measured or can be estimated, eq. (2) turns to eq. (4) which is the final formula used in the present work. Eq. (4) was also used for calculation of biological half-life for individual subjects.

$$T_L = \frac{1}{(1-a)} \cdot \ln 2 \cdot \frac{Q(t)}{E_u(t)} \cdot f_u \tag{4}$$

In the present work, $Q(t)$ and $E_u(t)$ were measured repeatedly and the fairly constant quotients of $Q(t)/E_u(t)$ were averaged over the period indicated in Table 4. For some subjects, $f_u$ was measured but for the group and the subjects whose $f_u$ values were not determined, the average of $f_u$ determined for 10 male adults, namely 0.88, was used.

A rounded value of 0.9 was assumed for "$1-a$" because the reported values distributed around $0.88 \pm 0.05$, $N=23$. Another method is applied to the present group. Some arbitrarily chosen values of biological half-life were applied to a compartment model which was used to estimate the body burden from the daily intake, and the value to give the best fit to the observed body burden was taken as the most reliable biological half-life to this group. In this compartment model, each of the 2 components composing of the retention curve after single administration of $^{137}$Cs were assumed to have a component respectively with no exchange of $^{137}$Cs one another. If the period of concern was divided into some shorter periods, $^{137}$Cs daily intake could be approximated by an exponential of time in the period of the present work, which would be indicated separately. The equation used in the present work is as follows:
\[ Q(t) = a' I_0 \left( \frac{1}{\lambda_I + \lambda_s} e^{\lambda_I t} + \left( \frac{1}{\lambda_s} - \frac{1}{\lambda_I + \lambda_s} \right) e^{\lambda_s t} \right) \\
+ (1-a)' I_0 \left( \frac{1}{\lambda_I + \lambda_L} e^{\lambda_I t} + \left( \frac{1}{\lambda_L} - \frac{1}{\lambda_I + \lambda_L} \right) e^{\lambda_L t} \right) \]

(5)

Where \( I_0 \) and \( \lambda_I \) are the initial daily intake and the rate constant of \(^{137}\text{Cs}\) daily intake, \( \lambda_s \) and \( \lambda_L \) are the elimination constants from the minor and the major compartments, respectively.

\(^{137}\text{Cs}\) daily intake data were cited in part from Radioactivity Survey Data in Japan and in part the original data by the present author on which correction was made to estimate the complete intake of \(^{137}\text{Cs}\) based on balance of potassium excreted and ingested because amount of diet analysed to \(^{137}\text{Cs}\) intake, was far from the true intake. For these data, it will be discussed separately.

**RESULTS AND DISCUSSION**

Table 4 represents the biological half-lives for the individual subjects and their average, and the biological half-lives for the group determined in the various periods. Body weight, age, \( f_w \) value and number of measurement performed to determine the biological half-life for each of the individual subjects or for the group in each of the different periods, are also included in the same table.

The biological half-lives range from 50 to 161 days for the individual subjects and the average and 1 S.D. are 86 and 28 days respectively if normal distribution is assumed to the distribution of \(^{137}\text{Cs}\) biological half-life.

The biological half-lives as a group are indicated as subjects 24 to 26 in Table 4. From these values and the average for individual subjects, the biological half-life as a group averages 85 days with total error of 18 days in the present work. Moreover, the biological half-life of 85 days gives the best estimate of body burden to the observed one when eq. (5) is applied in the period of the present work.

In the present work, the error of biological half-life computed by eq. (4) is estimated about 20% in terms of relative median error if normal distribution is assumed for all of "1-\(a\)", \( Q(t) \), \( E_u(t) \) and \( f_w \).

Fujita et al. reported the biological half-lives for 5 male adults based on the observation in 8 periods of 5 days each for about 3.5 years. Some of the values, however, were determined in the increasing periods of \(^{137}\text{Cs}\) daily intake. In an increasing period, no constant value of \( \lambda_q \) in eq. (3) can be obtained which they used in computation of biological half-life since the minor component of \(^{137}\text{Cs}\) retention curve contributes more positively to the total excretion than to the body burden and the contribution changes with time as indicated in Fig. 2.

If their values in the not increasing periods of \(^{137}\text{Cs}\) intake only were taken, the range of 75 to 89 days and the average of 83 days with 1 S.D. of 6 days are computed for the major component in their subjects.
Fig. 1. Average $^{137}$Cs total body burden in a group with time.
Remark: The vertical lines express the 1 S.D.

Fig. 2. Change of ratio of the total body burden to the urinary excretion of $^{137}$Cs with time in some increasing tendencies of $^{137}$Cs intake.
Remarks: $\lambda_I = 0.0029$ /day, $I_0 = 16$ pCi/day ①
The value of $\lambda_I$ and $I_0$ were estimated as the representatives of the rate constant of increasing tendency as to daily intake and the initial daily intake by a male adult in or near Chiba city during the period September 1962 to December 1963 which were estimated by $^{137}$Cs in the pooled urine of junior high school students.
$\lambda_I = 0.0029$ /day, $I_0 = 160$ pCi/day ②
$\lambda_I = 0.029$ /day, $I_0 = 16$ pCi/day ③
Yamagata found 76 days as the equivalent biological half-life which corresponded to 84 days in terms of the biological half-life for major component, by neutron activation analysis of stable Cs in various human organs from autopsies collected in Tokyo and in the composite sample of total diet collected from 10 families chosen at random from a number of sites in Japan.14

In conclusion, 85 days with fluctuation of 18 days in terms of total error should be the reasonable estimate of $^{137}$Cs biological half-life for a group of Japanese which is composed of more than 5 subjects in the present time. This value is a little longer than that of the ICRP's, namely 70 days, which corresponds to 78 days for the major component.

The variation of biological half-lives between individual subjects is about 30% in terms of coefficient of variation in the present work and roughly same as that of body burden indicated in Fig. 1.

Fujita et al. reported the rather smaller variation than that in the present work.15 Their subjects had almost same body weight (54 to 56.5 kg at the start of observation and 56 to 62 kg at the end) and ate same diet in most period. While, the present subjects weighed 49.6 to 85.0 kg as indicated in Table 4 and had no restriction on their food. These may explain in part the larger variation of biological half-lives between the subjects in the present work than that in theirs.

Iinuma et al. found 70 and 82 days for 2 male adults,16 84 days for the former of them and 70 days for the different subject17 and 72 days for another subject after single administration of radiocesium. All the subjects were doing their normal works.

### Table 5. Biological half-life of Cs for the same subjects of Japanese determined by 2 different ways

<table>
<thead>
<tr>
<th>Subject *</th>
<th>Body weight (kg)</th>
<th>Age (years)</th>
<th>Biological half-life (days)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>49.3</td>
<td>31</td>
<td>68 ± 1</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>50.4</td>
<td>32</td>
<td>61 ± 2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>no data</td>
<td>33</td>
<td>about 70</td>
<td>B</td>
</tr>
<tr>
<td>15</td>
<td>57.8</td>
<td>31</td>
<td>94 ± 2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>57.3</td>
<td>31</td>
<td>81 ± 3</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>57.3</td>
<td>32</td>
<td>88 ± 2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>58.0</td>
<td>29</td>
<td>70.0</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>no data</td>
<td>32</td>
<td>about 84</td>
<td>B</td>
</tr>
<tr>
<td>18</td>
<td>56.9</td>
<td>44</td>
<td>102 ± 2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>53.8</td>
<td>44</td>
<td>103 ± 2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>no data</td>
<td>45</td>
<td>71.5 ± 5</td>
<td>B</td>
</tr>
</tbody>
</table>

Remarks: 1. A continuous ingestion of fall-out $^{137}$Cs
2. Single administration of radiocesium
3. The numbers to identify the subjects are same as those in Table 4.
In the present work, 3 of the 4 subjects were served by chance as the subjects (subjects 7, 15 and 18 in Table 4). The biological half-lives determined with the 2 different ways are summarized in Table 5. There is a little but inconsistent difference between the biological half-lives derived from the equivalent biological half-life and those by single administration of radiocesium for each of the subjects. This phenomenon was also found in some reports.\(^{10,12}\)

For 12 subjects identified with simbols * and ** in Table 4, their biological half-lives were measured in more than 2 periods of time and varied about 16% in terms of the ratio of range to average. The differences for subjects 7 and 15 are surely within this boundary of fluctuation but for the subject 18 the difference is too large to be explained by the fluctuation observed ordinarily.

Lloyd et al. found no seasonal change in the elimination rate of Cs in either the continuous or the single intake of radiocesium.\(^{12}\) While, Pendleton et al. also obtained a little different biological half-life for the same subjects in the interval of 2 years.\(^{13}\)

In the single dose experiment for the subject 18, radiocesium was given so sufficiently that the body burden measurement could not be disturbed by the day-to-day fluctuation of continuous ingestion of fall-out \(^{137}\)Cs. Therefore, the biological half-life is reliable. While, the body burden will be over-estimated in the period with heavy fall-out rate because whole-body counter detects any gamma-rays from the radionuclides in fall-out with energies very close to one from \(^{137}\)Cs and no way can be in practice performed to subtract the contribution by these radionuclides to amount of \(^{137}\)Cs body burden. Determination of \(^{137}\)Cs in the urine in the present work, however, was little disturbed by the change of fall-out rate because it was performed radiochemically. Therefore, over-estimated biological half-life may be computed by eq. (4) in the period with heavy fall-out rate. In order to investigate this point, the biological half-lives determined in and after the year of 1964 when the fall-out rate of \(^{137}\)Cs was in its peak and drastically decreased afterwards, were compared for 3 subjects (subjects 13, 18 and 23 in Table 4). The values for the subjects 13, 18 and 23 determined in 1964 are 82, 102 and 138 days, respectively and 86, 103 and 184 days are determined after 1964. There is no indication that the half-life determined in 1964 is longer than that determined later. Therefore, the reason causing the rather large difference between the biological half-lives determined by the 2 different methods for the subject 18 is unsolved.

Fig. 3 indicates the ratios of the body burden to the daily urinary excretion of \(^{137}\)Cs for 3 subjects (subjects 4, 16 and 20 in Table 4) over 2 years. Their biological half-lives are rather different each other. As indicated in Table 4, their body weights and biological half-lives average 67.9 kg and 115 days, 58.3 kg and 91 days and 50.5 kg and 59 days, respectively. This means that the relative values of \(^{137}\)Cs biological half-life for the individual subjects little change or is inherent to the subject in the adulthood.

This figure suggests the existance of weight dependency for \(^{137}\)Cs biological half-life. Eberhardt showed that the half-time increased as 6 times of 2/3 power of the
body weight. However, the relationship is not clear about the subjects with their body weights over 50 kg if the subjects are limited in an ethnic group.

McCraw indicated an increasing tendency of biological half-life in the age in his original figure which was obtained by summarizing the biological half-lives reported in various countries up to 1965. But in his text, he stated no age dependency for the subjects over 20 years old. Lloyd concluded that the biological half-life for Cs in humans could be considered as a function of age for juveniles and sex for adults but was not determined by the body mass, although both body mass and biological half-life were undoubtedly dependent upon some other common factor or factors. He indicated that for male subjects more than 20 years of age the correlation coefficient was r=0.29, DF=28, F=2.64 and 0.1<p<0.2, indicating little or no relationship between body mass and biological half-life.

While, for the 23 present individual subjects, the regression line of the biological half-life on the weight is as follows:

\[ y = 1.6x - 6.9 \]

where x is body weight in kg and y is biological half-life in day.

The correlation coefficient is r=0.49, degree of freedom DF=22, variance ratio F=6.602, and the probability that the correlation coefficient is different from zero by chance alone is p<0.05.

The correlation coefficient between the biological half-life and the age is 0.42 and the regression line of the biological half-life on the age is as follows:
\[ y = 0.47t + 72 \]

where \( t \) is age in years.

The \( F \) equals 4.519 and the probability that the correlation coefficient is different from zero by chance is \( p < 0.05 \).

Therefore, the biological half-life depends on both the body weight and the age, to a lesser extent, for the present male subjects nevertheless in their adulthood.

The present result is, therefore, rather characteristic.

One of the possible cause will be the difference in the quality of subjects. For example, if the present result is compared to that by Lloyd et al., the quality of subjects was more uniform in the present work than in theirs as to both races and working conditions of subjects although normal subjects only joined with either of the works. The biological half-life in average is \( 86 \pm 28 \) days in the present work and
105±25 days in theirs.

This suggests the difference of biological half-life between Japanese and people in the United States of America or the other population groups in the world.

Fig. 4 indicates the biological half-lives of various population groups in the world, which were determined for normal male adults in the groups of more than 5 subjects under continuous ingestion of 137Cs due to fall-out and the biological half-life for the major component was computed using eq. (4) by the present author when the equivalent one was given in the original report. The vertical lines in the figure indicate the averages for each of the population groups.

Fig. 5 represents the biological half-lives after administration of radiocesium in various population groups. The subjects were also normal male adults. The horizontal lines indicate 1 S.D.

There is same tendencies as to the averages of biological half-life for Japanese, for the people in the United Kingdom and for the people in the United States of America, of which data are rather plenty, between Fig. 4 and Fig. 5. The biological half-life for the people in the United States of America is longest and Japanese has the shortest half-life although each of them has rather large distribution. As to the distribution of biological half-life, the values for Japanese are closer each other than those of the people in both the United States of America and the United Kingdom.

Comparing the average of biological half-lives determined by eq. (4) and those by single administration of radiocesium, the latter correspond about 0.9 time as much as

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**Fig. 4.** Average biological half-lives of 137Cs in the total body determined for a group of over 5 male subjects in their normal works in the different countries.

**Remarks:**

1. The columns, a, b and c give the number of subjects whose biological half-lives were determined, the methods of determination and number of references, respectively. The mark + shows the data by the present work.

2. The marks A, B, C-1, C-2, C-3 and D refer to the following methods of determination:
   - A Single administration of radiocesium (whole-body counting)
   - B Curve fitting method, namely a least square method applied the compartment model of Cs retention to find the biological half-life which gives the best fit of actually observed body burden.
   - C Analysis of amount of 137Cs both in the urine, the total excreta or diet and in the total body.
     - C-1: Analysis of the urine and the whole-body counting
     - C-2: Analysis of the total excreta and the whole-body counting
     - C-3: Analysis of the diet and the whole-body counting
   - D: Activation analysis of stable Cs in the human tissues and the diet

3. -○- the average and the range
   - ○ average only
   - : the mean of averages in a country
   - * See in the text.
   - ** observation of 14 to 61 subjects in a quoter of year for 4 years
   - *** more than 15000 men for 4 years.
the former. Accumulation of plenty of data only will be possible to resolve this contradiction.

Nevertheless, the biological half-life determined in measurement of $^{137}$Cs in both the total body and urine or diet, is important to estimate both the initial burden and the internal dose for the subject exposed to radiocesium and the population dose with a reasonable range in the assessment of contamination of environment by radiocesium released from an atomic energy establishment because of scanty of the biological half-life determined by a single dose.

The average value may be taken 85 days with 20% of total error as a group and
the distribution for individuals ranges from 50 to 161 for male adults in their normal works in the present study.

This work is a part of thesis submitted to University of Tokyo, 1977.

ACKNOWLEDGMENT

The author is pleased to acknowledge his indebtedness to Dr. Y. Yoshizawa, Professor of University of Tokyo for his heartfelt encouragement and valuable suggestion through this series of work and his kindness of making correction of this manuscript. Grateful acknowledgment is also extended to Dr. T. Inuma, National Institute of Radiological Sciences for permission to use the whole body burden data obtained in corporation. Drs. N. Hosoya, A. Koizumi, M. Wada and S. Suzuki, University of Tokyo, gave useful comments to this work. The author would like to express his thanks to them.

The author also wishes to express his thanks to the following people: Messrs. T. Ishihara, Gunma University and S. Yashiro for their technical supports to measure body burden; the researchers in both the Institute of Public Health and the National Institute of Radiological Sciences who served willingly as the subjects for this work.

REFERENCE


30. L. Jeanmaire (1964) Note au sujet de deux types de contamination humaine par le $^{137}$Cs. ibid. 75-78.


Appendix Determination of $^{137}$Cs in a bulk of urine.

Urine

wet ashing on a water bath

$\rightarrow$ Conc. HNO$_3$ (1/5 as much as urine in vol.)

$\rightarrow$ Cs carrier (50 mg)

Decomposed urine

$\rightarrow$ Ammonium molybdophosphate (6.2 g)

stir for 15 min in room temp.

and stand for 24 hrs.

wash with 50 ml of 1:50 (v/v) HNO$_3$ and centrifuge

(repeat 3 times)

Coprecipitate of Cs on ammonium molybdophosphate

Precipitate

$\rightarrow$ 50 ml of 2N NaOH soln.

Solution

heat to drive out volatile bases

on a water bath

Dowex 50w--X-12 column

(H$^+$ type, 1 cm in diameter and 18 cm in height)

$\rightarrow$ 100 ml of 30% ethanol

effluent (discard)

$\rightarrow$ 100 ml of 0.5N HCl

$\rightarrow$ 100 ml of 3N HCl

Effluent

heat to dry

Residue

$\rightarrow$ 100 ml of demineralized water

Solution

$\rightarrow$ 2 ml of 10% platinic chloride solution after adjusting the pH to about 8 with NaOH soln.

Precipitate

Weigh and count the radioactivity with a low background counter and the result should be corrected for the self-absorption of $\beta$ ray by the sample as usual.