724007

*Health Physics* Pergamon Press 1962. Vol. 8, pp. 201–205. Printed in Northern Ireland

# LONG-TERM RETENTION OF RADIOCESIUM BY MAN*

C. R. RICHMOND, J. E. FURCHNER and W. H. LANGHAM
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico

(*Received* 21 *November* 1961)

**Abstract**—The Los Alamos $4\pi$ liquid scintillation counter (Humco 1) was used to measure whole-body retention of radiocesium in four adult male subjects. Two subjects were measured for about 550 days and one for 940 days. The whole-body retention data were reduced into two-component exponential equations by a curve-fitting method programmed for an IBM Model 704 computer. The biological half-time of the important retention component ranged from 110 to 147 days, with a mean value of ~135 days, for the four subjects. Standard deviations are given for the retention parameters. Results of other investigators are presented.

## INTRODUCTION

BECAUSE $Cs^{137}$ is produced in high yield from both uranium and plutonium fission, one must consider its potential hazard to man as a by-product of large-scale power production and other peaceful uses of nuclear energy. Resumption of atmospheric testing of nuclear weapons has also rekindled interest in $Cs^{137}$. In view of the importance of radiocesium as a contaminant and the scarcity of data on its metabolism by man, computer methods were employed to determine the best values for the parameters which describe biological retention by four human subjects. Whole-body retention data were obtained for about 550 days in two subjects and for 950 days in another.

## METHODS AND MATERIALS

Retention of radiocesium in male adults after a single oral administration was studied using whole-body counting techniques for both $Cs^{134}$ (subjects HMCs-1† and HMCs-4) and $Cs^{137}$ (subjects HMCs-2 and HMCs-3). The $4\pi$ liquid scintillation detector (Humco I) has been described previously by ANDERSON *et al.* [1] Since the subjects were all in good health and free from illness during the experimental period, they were considered normal. No attempts were made to alter their regular feeding habits. An overnight fast was observed by all subjects prior to radionuclide administration.

By using appropriate standards, the whole-body activity at any time could be expressed as a percentage of the administered activity, corrected for physical decay (i.e. biological retention). Details of these procedures and graphic analysis of the incomplete retention data were reported previously.[2]

An iterative least-square curve-fitting procedure, programmed for an IBM Model 704 computer, was used to fit the retention data as a function of time. Details[3] and application[4] of this procedure have been reported.

## RESULTS

Table 1 gives age and weight of subjects, chemical form and activity of the radionuclide administered, duration of experiments, and number of measurements. Preliminary graphic analysis of the retention data for each subject suggested a biological retention function of the following form:

$$R_t = \sum_{i}^{2} [a_i e^{-k_i t}]$$

where $R_t$ is the percentage retention at any day $t$, and $a_i$ and $k_i$ are the intercept and rate constants, respectively. No more than two

* Work performed under the auspices of the U.S. Atomic Energy Commission.

† The code for designating cases indicates species, sex, nuclide, and case number (e.g. HMCs-2 indicates that the first human subject receiving cesium was a male).



A-00607
Human Studies Project
1169702
REPOSITORY MMES-ORNL
COLLECTION Snyder's Files
BOX No. 3
FOLDER Cs Reports

*Table 1. Details of individual experiments on retention of radiocesium by male human subjects*

| | Subject | | | |
|---|---|---|---|---|
| | HMCs-1 | HMCs-2 | HMCs-3 | HMCs-4 |
| Age (years) | 33 | 35 | 37 | 27 |
| Weight (kg) | 81.8 | 77.3 | 57.0 | 68.2 |
| Form administered | $Cs^{134}Cl$ | $Cs^{137}Cl$ | $Cs^{137}Cl$ | $Cs^{134}Cl$ |
| Activity administered ($\mu$c) | ~1 | <1 | <1 | 1.4 |
| Duration of experiment (days) | 106 | 543 | 555 | 940 |
| Number of measurements | 25 | 47 | 47 | 94 |

exponentials were required to describe whole-body retention of radiocesium, even though one subject (HMCs-4) was measured until the lower limit of the detecting system was approached. This suggests that no additional components are needed to describe the long-term retention of cesium by man.

Table 2 gives the parameters of the "best-fit" biological retention equations for each subject and for the pooled data. Exceptionally good agreement among the intercept constants and reasonably good agreement among the rate constants exist for each component. These data show that the second component (i.e. second term in the retention equation) is the more important with regard to radiation dose because of the large intercept values and relatively long half-time. For example, the contribution of the second component to the total area ($t_0$ to $t_\infty$) under the effective retention function,

$$R_{t\ \mathrm{eff}} = a_1 e^{-(k_1+\lambda)t} + a_2 e^{-(k_2+\lambda)t}$$

for the pooled data is more than 99 per cent. As this area is proportional to radiation dose, it becomes apparent that the first component can be ignored when considering radiation dose calculations. Table 3 gives the standard deviations for the intercept and rate constants of the second component of each retention equation. The largest standard deviations are for subject HMCs-1, who was measured for only 106 days. Values for all other cases are in good agreement and smaller than those for HMCs-1.

Fig. 1 shows experimental data for subject HMCs-2, plotted with a graph of the best-fit biological retention equation derived by the

*Table 2. Parameters of biological retention functions* for four normal male subjects given radiocesium*

| | Subject | | | | |
|---|---|---|---|---|---|
| | HMCs-1 | HMCs-2 | HMCs-3 | HMCs-4 | Pooled data |
| $a_1$ | 14.95 | 12.19 | 12.89 | 10.62 | 13.34 |
| $(k_1 \times 10^1)$ | −4.9782 | −4.7560 | −6.1444 | −6.9400 | −4.9880 |
| $T_b$ | 1.39 | 1.46 | 1.13 | 1.00 | 1.39 |
| $a_2$ | 84.58 | 87.93 | 86.99 | 89.59 | 86.69 |
| $(k_2 \times 10^3)$ | −6.2920 | −5.2823 | −5.9778 | −4.7222 | −5.1749 |
| $T_b$ | 110.16 | 131.22 | 115.95 | 146.79 | 133.95 |

*From $R_t = a_1 e^{-k_1 t} + a_2 e^{-k_2 t}$, where $R_t$ is the percentage of administered amount present at any day $t$, $e$ is the base of natural logarithms, and $a$ and $k$ of each term are the intercept and rate constant, respectively. Respective units of $a$, $k$ and $T_b$ are percentage, days$^{-1}$ and days.

1169703

*Table 3. Standard deviations of intercept and rate constants for second component of biological retention functions*

| Subject | $a_2 \pm \sigma$ | $k_2 \pm \sigma$ |
|---|---|---|
| HMCs-1 | 84.58 ± 1.33 | $-6.29 \times 10^{-3} \pm 4.11 \times 10^{-4}$ |
| HMCs-2 | 87.93 ± 0.58 | $-5.28 \times 10^{-3} \pm 4.35 \times 10^{-5}$ |
| HMCs-3 | 86.99 ± 0.67 | $-5.98 \times 10^{-3} \pm 5.29 \times 10^{-5}$ |
| HMCs-4 | 89.59 ± 0.52 | $-4.72 \times 10^{-3} \pm 3.17 \times 10^{-5}$ |
| Pooled data | 86.69 ± 0.83 | $-5.17 \times 10^{-3} \pm 6.24 \times 10^{-5}$ |

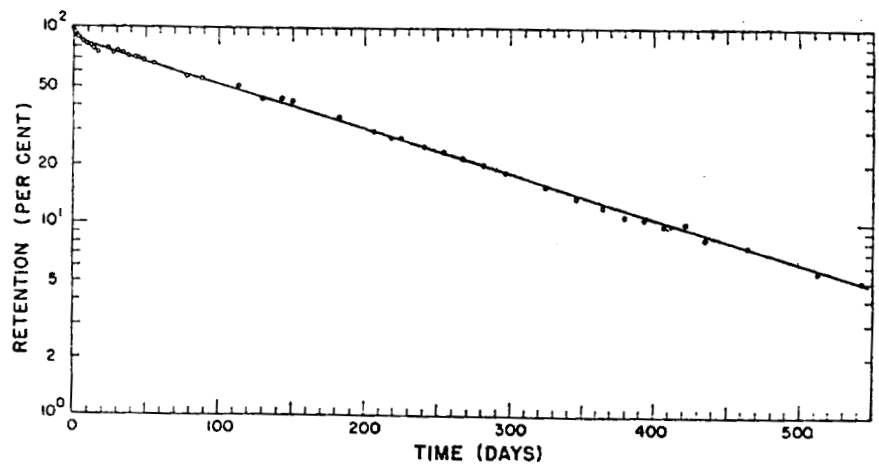


FIG. 1. Biological retention of $Cs^{137}$ by a normal adult male subject (HMCs-2).

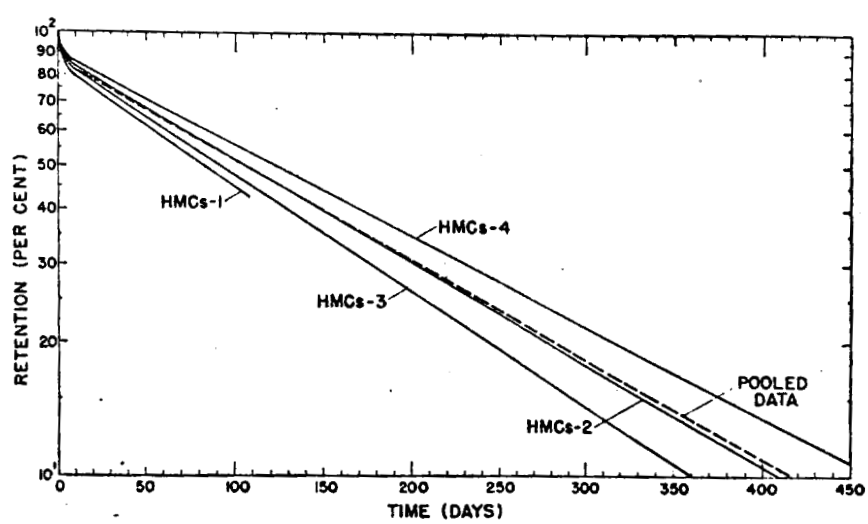


FIG. 2. Computer-derived biological retention functions for four normal male subjects given radio-cesium.

1169704

computer. Fig. 2 plots the biological retention equations derived by computer analysis for the pooled data and for individual subjects. For convenience, retention curves are shown to only 10 per cent of the original burden. Other workers[5] also reported only two components in the $Cs^{137}$ retention functions for two subjects measured for approximately 200 days.

## DISCUSSION

Biological retention of radiocesium can be described more accurately by the sum of two exponential components than by a single or composite power function. The biological half-time of the component of interest (i.e. that with the smaller rate constant) ranges from 110 to 147 days, with a mean value of ~135 days, for a group of four normal male subjects. Combined use of a whole body counting facility and a curve-fitting procedure programmed for the IBM Model 704 computer provides the best objective estimates of both the retention functions and the variance of the parameters which describe retention.

Several estimates of the biological half-time of $Cs^{137}$ in man have been calculated from excretion data obtained from contaminated subjects. ANDERSON *et al.*[6] estimated a value of 145 days based on the $Cs^{137}$ content of a 52-man-day urine sample collected from six men. These workers assumed a mean body burden of 0.005 $\mu c$ $Cs^{137}$ and a urinary-to-fecal $Cs^{137}$ excretion ratio of 4. MILLER and STEINGRABER[7] reported half-times of 92.5 and 157 days for two Marshallese subjects contaminated in 1954. These admittedly crude estimates were based on the $Cs^{137}$ content per gram of potassium in excreta samples. It was assumed that the subjects excreted 0.5 and 2 g of potassium per day in the feces and urine, respectively. WOODWARD *et al.*[8] reported a half-time of 110 days for Marshallese subjects, based on four pooled urine samples collected over a 180-day period.

Other estimates of the biological half-time of $Cs^{137}$ in man have been obtained from whole-body counting experiments. Tentative results[2] on the four subjects reported here indicated a mean half-time of about 143 days for the component with the smaller rate constant. STEWART *et al.*[9] reported that excretion from the $Cs^{137}$-contaminated human subject could be described by a composite expression of either the exponential or power-function type. It was the authors' opinion that the exponential model had more practical usefulness in describing the experimental data, since more than one power function would be necessary to describe the retention process. Radiocesium retention data obtained at this Laboratory were not describable by power functions.

MCNEIL and GREEN[10] reported effective half-times of 110, 115 and 119 days for three accidentally contaminated subjects. Measurements were made with a 5-in. NaI crystal in a room shielded with 8-in.-thick steel walls. Although the subjects were followed for 140 days, the actual number of measurements per man were 4, 2 and 8, respectively. MILLER[11] estimated a value of about 110 days for two subjects accidentally contaminated with $Cs^{134}$ and measured for 60 days. OBERHAUSEN[12] reported a biological half-time of ~144 days for one $Cs^{137}$-contaminated male. Several measurements were made with the Landstuhl $2\pi$ liquid scintillation detector to obtain this result.

Despite the small number of observations and the large number of factors, such as age and dietary state, which almost certainly contribute to variations in $Cs^{137}$ turnover among subjects, it is encouraging that reported half-times vary by less than a factor of 2.

## SUMMARY

Whole-body retention of radiocesium was measured in four normal adult male subjects by means of a $4\pi$ liquid scintillation counter (Humco I). Two subjects were measured for 550 days and another for 940 days. A computer method was used to derive the biological retention equations for each subject. Although whole-body retention can be described by the sum of two exponential components, one component can be ignored for most biological considerations The biological half-time of the component of interest (i. e. that with the smaller rate constant) ranges from 110 to 147 days, with a mean value of ~135 days, for the four subjects. Findings of other investigators are summarized.

1169705

.t excretion from
. subject could be
›ression of either
:ion type. It was
ponential model
:n describing the
. than one power
to describe the
:n retention data
:e not describable

eported effective
.9 days for three
ojects. Measure-
. NaI crystal in
:hick steel walls.
:ollowed for 140
:easurements per
:vely. MILLER[11]
.10 days for two
:nated with $Cs^{134}$
OBERHAUSEN[12]
:e of ~144 days
male. Several
:th the Landstuhl
or to obtain this

f observations and
such as age and
:rtainly contribute
:r among subjects,
:d half-times vary

radiocesium was
:ult male subjects
:ntillation counter
:ere measured for
days. A computer
:e biological reten-
:. Although whole-
ped by the sum of
s, one component
:ical considerations
the component of
aller rate constant)
with a mean value
subjects. Findings
:mmarized.

*Acknowledgments*—The authors acknowledge the valuable counsel and assistance of W. LESTOURGEON (Group. T-1) in deriving the parameters to the biological retention functions. We are indebted also to the co-operation of the subjects reported in this study.

## ADDENDUM

Since the preparation of this paper, several additional measurements of the biological half-life of radiocesium have become available. LIDÉN [*Acta Radiol.* **56,** 237 (1961)] refers to a 74 day biological half-life obtained from one male Scandinavian subject following intravenous administration. This subject was studied for 7 months at the University of Lund. ROWE and VAN DILLA (personal communication) recently obtained a 150 day biological half-life for one accidentally contaminated male subject at this Laboratory. Twenty measurements were made over a 597 day period in the whole-body counting (NaI crystal) facility.

## REFERENCES

1. E. C. ANDERSON, R. L. SCHUCH, J. D. PERRINGS and W. H. LANGHAM, *Nucleonics* **14,** No. 1, 26 (1956).
2. C. R. RICHMOND, *Los Alamos Scientific Laboratory Rep.* LA-2207 (1958).
3. R. H. MOORE and R. K. ZEIGLER, *Los Alamos Scientific Laboratory Rep.* LA-2367 (1960).
4. C. R. RICHMOND and J. E. FURCHNER, *Health Phys.* **6,** 36 (1961).
5. R. C. MCCALL, Personal communication.
6. E. C. ANDERSON, R. L. SCHUCH. W. R. FISHER and W. H. LANGHAM, *Science* **125,** 1273 (1957).
7. C. E. MILLER and O. J. STEINGRABER, *Semi-annual Rep. of the Radiological Physics Division, Argonne National Laboratory* ANL-5755 pp. 53–57 (1957).
8. K. T. WOODWARD, A. G. SCHRODT, J. E. ANDERSON, H. A. CLAYPOOL and J. B. HARTGERING, Division of Nuclear Medicine, Walter Reed Army Institute of Research, DASA-1180 (1960).
9. C. G. STEWART, E. VOGT, A. J. W. HITCHMAN and N. JUPE, *Proceedings of the Second Conference on the Peaceful Uses of Atomic Energy, Geneva,* 1958, P/15, p. 220. United Nations, New York (1958); see also: *Progr. Nucl. Energy, Ser. VII, Med. Sci.* **2,** 39 (1959).
10. K. G. MCNEILL and R. M. GREEN, *Canad. J. Phys.* **37,** 528 (1959).
11. C. E. MILLER, *Argonne National Laboratory Rep.* ANL-5596 (1956).
12. E. OBERHAUSEN, *Proceedings of the University of New Mexico Conference on Organic Scintillation Detectors,* pp. 286–292. U.S. Atomic Energy Commission, Office of Technical Information TID-7612 (1961).

1169706