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THE HALF-TIME OF CESIUM-137 IN MAN¹

T.F. McCraw

÷ . part of participation in the Federal Radiation Council Working Group and Ad Hoc Pa + on Strontium and Cesium Radionuclides that and data on the half-time of cesium-137 a met were reviewed. The purpose of this The was to collect data on measured values e. e. .um-137 half-time that could be employed, with other material, to support the and of an assumed value of biological half-life : whole body and bone marrow dose calculatio.13.

This report represents (1) collected data on measured values of cesium-137 half-time in man, (2) a suggested model for expressing cer or -137 half-time as a function of age, and (b) an inates of doses and body burdens for a satake of cesium-137 and for intake of -37 in milk, using an assumed pattern 🕐 🔅k consumption by various ages.

mportant consideration in determining the stand bone marrow radiation dose c an exposed population from internal cesium-137 is the effective half-time of this radionuclide in man. Should there be a different biological half-time for cesium-137 in various age groups within a population and an effective half-time³ which varies as a function of age, it will be necessary to consider this factor in determining doses to the population and in determining which age group in the population will receive the highest exposure from a con-

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Available data

Table 1 lists data from the literature. The symbol T_b will be used to represent the biological half-time of cesium-137 in man. Where possible, the range of observed values for each group of individuals studied is included.

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BY H.R. SCHHIDT, DATE: 6-16-94 D.R. GILSON QUED

AUTHORITY: DOE/SA-20

Discussion of data

Rather than present individual measurements of T, for each subject, many investigators have reported an average value with an indication of the range of observed values. Considering the lower limits of the range of values for "adults" (unweighted for number of subjects) for all investigators where a range was given, the average value for the lower limits is about 78 days. The average value for the upper limits is about 122 days, and the overall average is about 98 days for these data.

The unweighted mean of the "Body Radioactivity Measurements and Excretion or Dietary Analysis" data from Rundo's summary is 110 days. The "Body Radioactivity Measurements" give an unweighted mean of 108 days. The "Excretion or Dietary Analysis" data give an unweighted mean of 114 days. Thus, the two techniques appear to give results which are in close agreement.

The data collected on T_b for groups of subjects are presented graphically in figure 1. Also plotted are individual values for 6- and 8-yearold girls and for two infants (Rundo), and values for three young women and two infants (Bengtsson et al.). In order to display the data for "adults", it has been assumed that this age group consists of those about 20 to 25 years of age and older, and the elderly are assumed to be over 60 years of age.

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for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virginia 22151 (Oc-tober 1, 1965). Price \$7.00. ¹ Mr. McCraw is a Health Physicist with the Division of Operational Safety, Atomic Energy Commission, Germantown, Maryland. ² For cesium 137 in man, the radiological half-time is so long (about 11,000 days) and the biological half-time is so short (of the order of 100 days or less) that for purposes of this report, the effective half-time can be considered equal to the biological half-time.

Group	Age (years)	To (days)	Range (days)* I	
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	adults adult	4 135 4 150	110-147	
•	adulte adulte	4 122 4 75	109-148 54-114	
*	eduite	- 109 	79-133 56-129	
5	adults Bout	• 125 • 188	92-157	
• •	jetella "Alista -	• 110 • 56	53-60	
	- advite	• 170 • 97	140-200 53-140	
, '	adults	• 71 • 76		
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ndult ndult	46 49	84 136	=	
ngos: Mintr	32 Elderly women	73 101		
	alderly son	57	±17	

Small fraction for one subject. Small fraction diminated Major fraction eliminated Sody radion tivity measureme

-retion of dietary analysis

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romponent component

F. in table 1 and from figure 1, it is seen that much of the data on T, are for "adults",





and that investigators have reported halftimes, for adult groups, of about one day for a small fraction of the cesium-137 intake (about 10 percent) and values between about 60 ann 180 days for the major portion of the intag While part of the difference in values from various investigators may lie in the realm of factors of instrumentation, calibration, laboratory technique, etc., the measured values generally appear to represent real differences among individuals. The range of values obtained by a single investigator for a group of subjects must involve many biological and environmental factors for which there is little information. No attempt will be made to identify these factors except for the possible influence of age on the biological half-time of cesium-137 in man (age may be an indirect factor).

The data are meager, but figure 1 suggests that the value of T_b for those groups unde about 20 to 25 years of age decreases with a and that T_b may be as low as 6 to 7 day for infants a few days old. For the four infantin figure 1, the average value is about 15 days which agrees with Pendleton's average of 1th days for five infants.

One additional feature in the data is possible significant. For the age groups reported, t investigator (from the available reports) has reported a value of T_b greater than 70 days f groups under 25 years of age or a value ! than about 50 to 60 days for groups over years of age.

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Guarded statements by s() investigators indicate reservation in specifying trends in the data, such as dationships between Th and age, sex, or speci- Rupda has said, "If there is a change of half life with age then it presumably starts at birth and increases steadily until a adulthood is reached" (1). Other investigators indicate a stronger support for a relationship between T_b and age. Bengtsson et al. state "Fng results also confirm that biological halfwhile for cesium increases with age" (12). Onstead et al. report that in their studies involving more than 6,000 individuals, "... our findings suggest that, within a single species, biological half-life is dependent on age" (17).

In referencing the use of 100 days for the sit logical half-life of cesium in man, the December 1964 report to the Federal Radiation Council by the National Academy of Sciences Advisory Committee, entitled "Implications to Man of Irradiation by Internally Deposited Strontium-89, Strontium-90, and Cesium-137" (78) contains the following:

"This value is almost certainly too large for children, perhaps by a factor of three 4.5 five."

The Federal Radiation Council, in its Report No. 7, (19) stated:

"The data for persons younger than 25 years suggest that the biological half-life before maturity may be a function of age. Biological half-lives of about 20 days or less have been reported for infants. For this report a value of 30 days is used as the biological half-life of cesium-137 in infants."

A value of 30 days for infants appears to be a conservative assumption since the available data for infants show values close to, but below, this value.

Boni's value of 81 days, which is applicable for adults ?? to 40 years of age, is in close sgreement with the average value of the lower limit for adults for all investigators of 78 days. However, there are little data for ages within the category specified as "adults" to determine if there is a trend of change in T, as a function of age above about 25 years. The average value for adults for all investigators, those that specified a range of values and those that did not, is 101 days. The most data for an early wudy for all ages in a population group are for

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the Marshallese per \bigcirc with a value of 70 days reported (5).

The data of Miettinen suggest an average value of about 70 days for the ages 16 through 75 years. Lists of "age limits" indicate most of these individuals were less than 50 years of age. Whether the inclusion of individuals of ages down to 16 years has the effect of lowering the average value of T_b for these groups compared to data on groups of "adults" presented by Rundo and Hansen and others, is not known. Possibly other biological and environmental factors are more important.

Model development

Considering the available values of T_{h} for the entire range of ages in the population, the trend that is suggested for T_{h} and age may be presented graphically. The solid line in figure 2 is drawn to account for the apparent rapid change of T_{h} with age for those less than about 25 years of age, to provide an average value of about 80 days for younger adults as suggested by Boni's measurements, and to provide an average value for adults over 25 years of age of about 100 days. Considering all age 'groups, the solid line in figure 2 develops an average T_{h} for all ages of about 75 days.



Figure 2. Biological half-time versus age

The three segments of figure 2 may be approximated by:

$$T_{b} = 12.8 (x^{1} + e^{-x})$$
 (1)

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where:

 $T_b = biological half life (years)$ x = age (years) The dotted curve in figure 1 nows that the fit is good for all ages. While this expression does not provide for estimating effective halftimes of cesium-137 for individuals, it does provide a close approximation to averages of successive values of cesium-137 retention for process of subjects.

section a FRC Report No. 7 (19) that relates whole body and bone marrow in rads to whole body and bone marro

$$D = \frac{I_t}{W} \times 0.03 \times 1.44 \ [12.8 \ (x^1 + e^{-x})]$$
$$D = \frac{0.55}{W} \ I_t \ (x^1 + e^{-x}) \ W$$
(2)

4048(n+1+1)

D = total dose (rads) $I_t = total intake of ^{137}Cs (microcuries)$ W = body weight (kilograms) x = age of exposed group (years)

This equation applies where it can be assumed that body weight, W, does not change significantly suring exposure.

is the intake of concern is through the dietary pathway of pasture-cow-milk-man, the total intake of cesium-137 for an acute contaninating event can be expressed in terms of the maximum daily intake. (See "Estimates of the Concentration of Strontium-89, Strontium-90, and Cesium-137 in Milk as a Function of Time", Report of Special Ad Hoc Committee of Federal Radiation Council, Radiological Health Data, July 1965.

$$I_1 \sim 32 I_m$$
 (3)

where:

 $I_m = maximum$ daily intake of $137C_a$

For the case of a single acute deposition of cesium-137 on pasturage, the total dose may be estimated from:

$$D = \frac{17.6 \ I_m \ (x^{i} + e^{-x})}{W}$$
(4)

For those less than about 10 years of age, most of this dose will have been received within about 1 year.



Figure 3. Body weight versus age (average for male and female)

Model application—dosc estimates

Figure 3 gives the average male and female body weights in kilograms from birth to 80 years. The average values of body weight for various ages are generally not the same for male and female; however, the differences in weight are not large. For these body weights and using the generalized expression for dose, figure 4 presents the total whole body and bone marrow dose as a function of age for a total intake of 1.0 microcurie of cesium-137. The doses in figure 4 would also be obtained using equation (4) and a maximum daily cesium-137 intake in milk of 1/32 microcurie or 31 nanocuries from an acute deposition of cesium-137.



Figure 4. Total whole body and bone marrow dose from internal cesium-137 versus age (an assumed total intake of 1 µCi ¹³⁷Cs)



Figure 4 indicates that v⁻¹ the use of this smodel for biological half-ti __, the highest and icwest doses for all ages from a given intake of cesium-137 differ by a factor of about two. This occurs even though body weights vary by a "factor of about 20, and biological half-times vary by a factor of about 10. For the younger ages, those sess than 1 year of age receive the singhest dose. Those 70 to 80 years of age may receive a comparable dose. However, definitive data for ages greater than 50 are not available and the model suggested may not be really representative for ages over 50 years.

Again, if one assumes that the dietary item or interest is whole milk, the doses in figure 4 can be modified by a pattern of intake for milk. "Table 2 presents data on average at-home milk consumption as a function of age. Values of verage consumption in table 2 were developed from a percentage distribution of milk intake ty age (Radiological Health Data, January 1963). This study of at-home milk consumption was conducted throughout the United States in July 1962. Since the study did not include consumption of whole milk outside the home. consumption may be underestimated for those ages consuming whole milk away from home. Table 2 also presents the average consumption by each age group relative to consumption by mains less than 1 year of age (the intake normalization factor). The average consumption for males less than one year of age is seen to be 17.8 ounces per day. This is approximately one-half liter per day (16.9 oz/day).

Table	2. A	verag	e d ai l	ly fres	sh who	de milk
COI	isum	ption a	at hor	ne in	U.S.*	

Age (ynars)	Average co (fluid o	nsumption sunces)	No con- sumption (percent)	Normalization factor consumption/<1 year male consumption		
	Male	Female		Male	Female	
<1	17.8 17.8 16.0 16.3 11.8 9.8 8.7 8.3 7.6 8.1 8.1 8.6	16.3 16.9 14.5 12.7 10.2 7.5 6.8 5.7 5.7 5.7 5.7 5.9 6.8	38.0 15.9 20.5 25.0 35.1 39.1 37.5 39.1 42.0 40.9 35.4	1.0 1.0 .95 .95 .92 .92 .92 .55 .55 .49 .47 .43 .45 .45	.92 .95 .81 .72 .58 .42 .38 .42 .33 .33 .33 .33 .33	

* Average communition values and normalization factors developed from report on "National Food Consumption Survey" in Radiological Health Data, Vol 1V. No. 1, January 1963.

The doses in figure 4, averaged for each age group, have been modified by the normalization factors in table 2 to illustrate the effects that

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a pattern of milk consumption may have on dose. The result be shown in figure 5.





The influence of the pattern of milk consumption in table 2 is to reduce the average doses for most ages relative to the doses in figure 4.

The sex-related differences in milk consumption cause males to receive higher average doses than females for all ages. The difference in dose between ages receiving the highest and lowest values is a factor of about four for male and about five for female, and males less than 1 year of age receive the highest dose.

The yearly dose that would be received by various age *groups* from a continuing daily intake of cesium-137 may be estimated by determining the average cesium-137 body burden during the year and using the following:

$$\mathbf{D}_{r} = \frac{\mathbf{B}/\mathbf{W}}{\mathbf{85.7}} \tag{5}$$

• where:

 D_r = dose rate (rads per year)

B = average body burden (nanocuries)and W = body weight (kilograms)

The determination of average body burden for a continuing intake of cesium-137 is described in the following section (see equation (9) and figure 7).

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Model application-body bu n estimates

For acute ingestion of cesium-137 (ingestion over a period of a few days), estimated average body burdens can be determined as a function citize after ingestion for the exposed population from:

$$B_{t} = \frac{B_{o}}{1000} e^{-.691 t/Tb}$$
 (6)

where

B = body burdens (nanocuries)

B.= initial body burden,

= total intake in picocuries assuming 100 percent absorption,

t = time after ingestion (days),

 $T_h = biological half-time (days),$

 $= 12.8 (x^{i} + e^{-x})$

War is a age (years).

Conversely for acute ingestion, the total interm of the estimated for various age groups is their average body burdens are known at some time after ingestion.

For ingestion of cesium-137 that decreases with time, average body burdens within the population may be estimated as a function of time from:

$$B_{t} = \frac{R_{o}}{1000 (\lambda_{i} - \lambda_{b})} (e^{-\lambda_{b}t} - e^{-\lambda_{i}t})$$
(7)

where

 $\hat{\mathbf{x}}_c = \text{initial rate of intake (picocuries per day),}$ $\lambda_b = \text{biological decay constant}$

 $=.693/12.8(x^{1}+e^{-x}),$

 $\lambda_i = intake \ decay \ constant = .693/T_i$

T = half-time for intake after maximum concontration (days)

right Report No. 7 (19) indicates that for an acute deposition on pasturage, the total cesium-137 intake from milk may be 32 times the intake on the day of the maximum concentration in milk (assuming the same amount of milk is consumed each day). The portion of the total intake occurring prior to maximum concentration is about 16 percent of the total intake. The intake occurring after maximum concentration is about 27 times the maximum. Therefore, 27 days may be considered the mean time of cesiun.-137 in milk following maximum concentration. The half-time for intake after maxiyaum concentration is:

$$T_1 = 27 \times 0.693 \sim 18$$
 days.

For acute deposition of cesium-137 on pasturage utilized by any cows, it has been estimated that the maximum concentration in milk will occur about 6 days following deposition. The average body burden for various ages resulting from such changing levels in milk may be approximated by:

- 1. Assuming total milk intake prior to maximum concentration is an acute intake using equation (6).
- Assuming an additional intake using the maximum daily intake as R. in equation (7).

The estimated body burden from milk consumption will be the burden from equation (6), plus the burden from equation (7). Contributions to total body burden from other contaminated foods will be additive. Figure 6 presents the body burden for males 1 year of age, for an acute deposition on pasturage, where the maximum concentration of cesium-137 in milk reached a level of 2,000 pCi/liter. Figure 6 indicates that maximum burden will be reached in about 25 days for this age group.





Other assumptions regarding the pattern of milk consumption versus age may apply for various portions of the U.S. population. Body burdens for the milk consumption pattern in table 1 may be underestimated for the ages consuming quantities of milk away from home.

For a continuing intake of cesium-137 (intake that occurs over a period of years), estimates of average body burdens within a population can be developed from the following:

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$$\mathbf{B} = \mathbf{R} \mathbf{T}_{\mathbf{m}} \mathbf{A}_{\mathbf{f}} / \mathbf{I} \mathbf{C}$$

(8)

where.

 $\mathbf{B} = body$ surden (nanocuries)

B = rate of intake of ¹³⁷Cs (picocuries per day) $T_{a} =$ oiological mean time (days),

 $A_f = absorption$ factor, assumed to be 1.0.

With biological mean time expressed as a function of age, equation (8) becomes:

$$B = 0.018 R (x^{1} + e^{-x})$$
 (9)

where:

x = age (vears)

Equation (9) may be used, for example, to estimate the average body burdens of cesium-337 in the U.S. population from milk consumption. The U.S. Public Health Service pasteurized milk network results for 1963 and 1964 averaged 114 and 109 pCi/liter, respectively (20, 21).

These data indicate that the average level of cesium-137 in U.S. milk supplies has decreased slowly over the past 2 years. Considering the small change in these levels, it can be assumed that the various age groups in the population are in equilibrium with the cesium-137 levels in milk they consume for the portion of their body burden due to milk intake, and their average body burdens for 1964 may be determined from an average value of daily cesium-137 intake.

If it is assumed that milk ingestion for males less than 1 year of age resulted in an average intak of 55 pCi/day during 1964, and using the cormalization factors in table 2 to estimate milk consumption by other age groups in the population, estimated body burdens may be determined from equation (9). The resulting values are shown in figure 7.

The dose to males less than 1 year of age from at-home milk consumption, using equation (5), is about 0.002 rad or 2.0 millirads in 1964. The point should be stressed that these estimates apply only to that portion of the cesium-137 body burgens of the U.S. population due to milk consumption at home. The contribution to body burden and whole body dose from milk consumption outside the home and from other items of the diet are additive.



Figure 7. Estimated cesium-137 body burdens from milk consumption for U.S. population in 1964

For cesium-137 in U.S. milk supplies, estimates of cesium-137 body burden in figure 7 indicate that males 15 to 20 years of age had the highest levels; those less than 1 year of age, male and female, had the lowest levels; and females of all ages had a lower average level than males of the same age.

Summary

The observations of biological half-time for cesium-137 in man indicate that half-time is a function of age. The average biological halftimes for cesium-137 from birth through adult life vary by a factor of about 10. A simple mathematical expression has been presented which relates half-time of retention of cesium-137 and age. Though the model is crude, it has utility in predictions of doses and body burdens from cesium-137 for various ages within an exposed population. Additional measurements of cesium-137 retention are needed, particularly for younger age groups, to further refine the model and to improve prediction capability. More data are also needed for the elderly.

The combination of changes in half-time and body weight results in a dose variation, for a given cesium-137 intake, from birth through adult life, of a factor of about two. The addition of assumptions regarding patterns of milk intake as a function of age and resultant cesium-137 intake leads to a different distribution of dose with age than is found for a fixed intake

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for all ages. For the assumed p. rn of intake of cesium-137 in milk, the dose varies within the range of ages from birth through adult life by a factor of four to five, with males less than 1 sear of age receiving the highest dose.

Seran acute contaminating event, the time ere anisoum cesium-137 body burden is a funcage. Maximum body burdens from milk consumption may occur in about 25 days after an acute contaminating event for those exspected to receive the highest dose; i.e., those test than 1 year of age.

it is estimated that for a long-term, slowly changing intake of cesium-137, such as ocsurred from use of fresh whole milk supplies by the U.S. population in 1964, males 15 to 20 is a of age had the highest body burdens; time less than 1 year of age, male and female, 'owest body burdens; and females of it to and lower body burdens than males of The Same age.

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