(Academic Press, New York, 1956), p. 447.
35. D. B. Cater, *Proc. Roy. Soc. London* **B155**, 136 (1961).
36. H. A. Krebs and L. V. Eggleston, *Biochem. J.* **82**, 134 (1962).
37. G. Serlupi-Crescenti, unpublished data.
38. R. Lemberg and J. W. Legge, *Hematin Compounds and Bile Pigments* (Interscience, New York, 1949).
39. B. Chance and C. M. Connelly, unpublished data.
40. M. Klingenberg, W. Slenczka, E. Ritt, *Biochem. Z.* **332**, 47 (1959).
41. G. E. Glock and P. McLean, *Biochem. J.* **61**, 388 (1955).
42. M. Klingenberg, personal communication.
42a. W. N. Aldridge, *Ciba Foundation on Enzymes and Drug Action* (Churchill, London, 1962), p. 155.
43. Unpublished data.
43a. D. K. Hill, *J. Physiol.* **107**, 479 (1948).
44. P. W. Davies and D. W. Bronk, *Federation Proc.* **16**, 689 (1957).
45. P. W. Davies, personal communication.
46. R. P. Davis and M. Canessa-Fischer, *Abstracta* (53rd Annual Meeting of the American Society for Clinical Investigation, Atlantic City, May 1961), p. 15; M. Canessa-Fischer, C. M. Edelman, Jr., R. P. Davis, *Federation Proc.* **21**, 148 (1962).
47. Dr. Blake Reeves participated in early phases of the development of the microfluorometer and Dr. J. Ramirez applied it to a study of excised heart strips. Dr. Hans Rasmussen and Dr. Ulla Fugmann applied the method to excised frog skin and toad bladder. Dr. Richard Keynes participated in applications of microfluorometry to the excised electric organ of *Electrophorus*. Dr. Serlupi-Crescenti applied the spectrofluorometer to excised liver diaphragm and the brown fat body. Dr. Frans Jobsis participated in experiments on renal artery perfusions of rat kidney. Dr. William Masland carried out the brain operations. Victor Legallais contributed the excellent designs of the spectrophotometer and microfluorometer. We are grateful to our colleagues for thoughtful criticism of this manuscript and for many useful suggestions. This work has been supported in part through grants from the National Science Foundation, the U.S. Public Health Service, and the Army Chemical Center. Dr. Peter Cohen is a member of the department of anaesthesiology and is supported under training grant 2G-215C4 from the U.S. Public Health Service.

Cesium-137 in Man

Fallout was decreasing at a rate equivalent to a half-life of 1 year before testing was resumed.

Charles O. Onstead, Erich Oberhausen, Frank V. Keary

The results of our measurements of the cesium-137 level in 1000 individuals living in Germany were reported in an earlier publication (*1*). We made these measurements in Landstuhl, Germany, during the period June through December 1959, with the aid of the two-π liquid scintillation whole-body counter designed by Anderson and his coworkers (*2*). The program was continued, and by 1 September 1961, levels in more than 6000 individuals living in Germany, whose average diet is shown in Table 1, had been measured. The large number of measurements makes possible a thorough study of the influence of age and sex, as well as diet, on the cesium-137 content in the human body. Because cesium and potassium are chemically similar, and because earlier work (*1, 3*) had revealed that the concentration of potassium in the human body is dependent on age and sex, we expected to find that levels of cesium-137 are age- and sex-dependent. Our studies also enabled us to follow the cesium-137 content of the general population up to the time that atmospheric testing of nuclear weapons was resumed by the Soviet Union. Various investigators (*4–6*) have reported a relatively steady increase in the cesium-137 levels during the period 1956 through 1959. This was to have been expected, since testing of fallout-producing nuclear weapons continued until the latter half of 1958. It was realized that, pending the resumption of testing, fallout, and consequently the cesium-137 content in the human being, would eventually begin to decrease. The factor primarily responsible for determining the rate of decrease is the length of time the fission products remain in the stratosphere. In a recent article, Rundo (*6*) reported that the cesium-137 content in the human being has been decreasing since December 1959. His study was based on regular measurement levels in 11 individuals. No conclusions were reached regarding the rate of the decrease.

With our more voluminous material, an attempt was made to follow the changing concentration of cesium-137 in man by studying the average findings in the general population. It was necessary to establish correction factors for sex and age, since the average cesium-137 values were found to be dependent, to a certain extent, on sex and age as well as on time. Figures 1 and 2 demonstrate the relationship of levels of cesium-137 to age for males and females of our study, as indicated by measurements made between 1 July 1959 and 1 September 1961. These results are not corrected for variations in the cesium-137 content in man which occurred over this long period. This may account for the distance of some of the points from the curves.

It is evident from Fig. 1 that the cesium-137 content per kilogram of body weight is age-dependent. Since the ratio is much lower for children than for adults, the dose rate from this isotope is correspondingly lower for children.

Assimilation, by the body, of cesium and of potassium differs with sex and age, as indicated in Fig. 2. The fact that the ratio of cesium-137 to potassium is much lower in children than in adults indicates that children discriminate against cesium in favor of potassium, whereas, as other workers have found (*5*), adults discriminate against potassium in favor of cesium. At an age of about 22 years, the ratio of cesium-137 to potassium reaches a constant figure; thereafter it is independent of age. However, the ratio remains lower in females than in males. We investigated the possibility that this variation could have been caused by a systematic error in our measurements or calculations but found no discrepancies. Since the findings are statistically valid, it must be concluded that the ratio of cesium-137 to potassium varies with sex and varies between child and adult. Since potassium, and presumably cesium, are primarily intracellular constituents of the human body, it may be said that certain groups of cells keep changing their discrimination patterns with respect to these two elements until the individual is 22. This conclusion,

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however, presupposes that the resorption of potassium and cesium from the gastrointestinal tract is identical for all age groups, and that the cesium-to-potassium ratio is the same in the diets of children and of adults. Ott (*7*) showed that the biological half-life of cesium-137 varies considerably in animals of different species, and our findings suggest that, within a single species, biological half-life is dependent on age.

The difficulties encountered in determining the monthly changes in the cesium-137 content of the general population are evident in Figs. 1 and 2. If the monthly average for all subjects studied were plotted, the picture would be inaccurate because of differences in age. Furthermore, the ratio of men to women in the study would also influence the average. In order to overcome these difficulties, the following procedures were followed. In determining monthly averages of cesium-137 in micromicrocuries per gram of potassium, only the data for subjects 22 or older were considered. All results for females were multiplied by a factor of 1.145, since, as shown in Fig. 2, the average values for females were lower by this factor than the average values for males. Determination of the monthly averages for cesium-137 in micromicrocuries per kilogram of body weight presented an additional problem, since this ratio is not constant after the age of 22, but decreases with increasing age. As Fig. 1 reveals, the age-dependence of the ratio may be considered to be linear after the age of 22. By calculating a straight line for the slope and applying correction factors to all the results, it was possible to correct all results on the basis of ratios for a 22-year-old male.

The corrected monthly averages for cesium-137 (in micromicrocuries per kilogram of body weight and per gram of potassium) are plotted semilogarithmically in Fig. 3. In these curves, variations in the cesium-137 concentration which result from differences in age and sex are eliminated. As one would expect, the curves are similar. From the time of our first measurements in June 1959 until March 1960, neither an increasing nor a decreasing trend is detectable. However, beginning in March 1960 and continuing thereafter, there is an obvious decrease in both curves. On the semilogarithmic graph, the lines, which were calculated by the least-square method, represent the constantly decreasing level of cesium-137. The half-life for this decrease in cesium-137 was found to be 11.3 months for

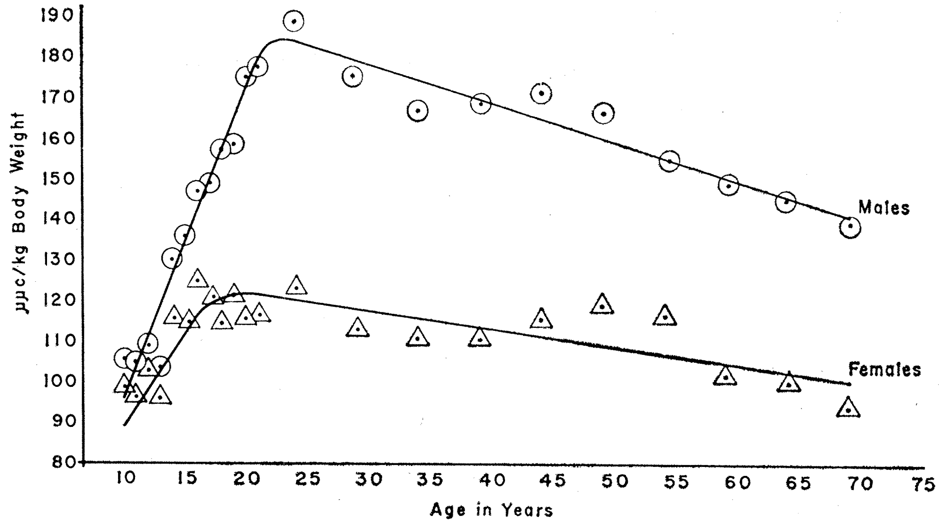

Fig. 1. Age- and sex-dependency of the amount of cesium-137 per kilogram of body weight.

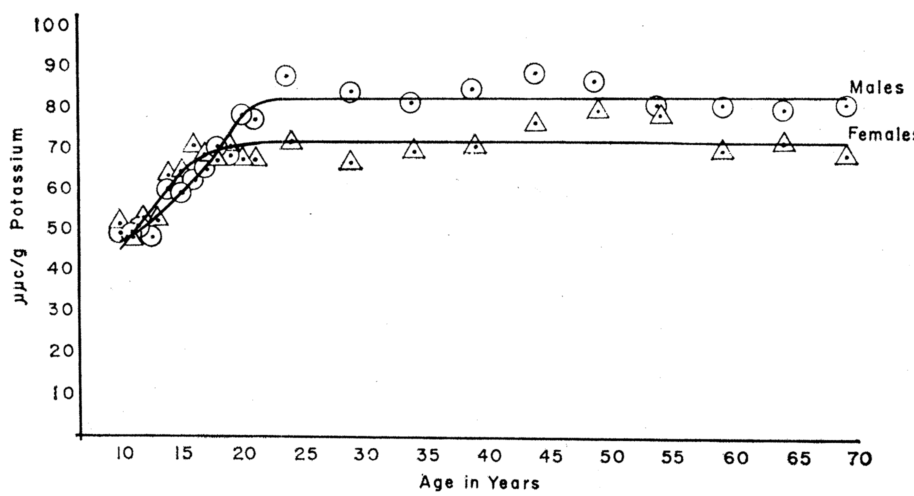

Fig. 2. Age- and sex-dependency of the amount of cesium-137 per gram of body potassium.

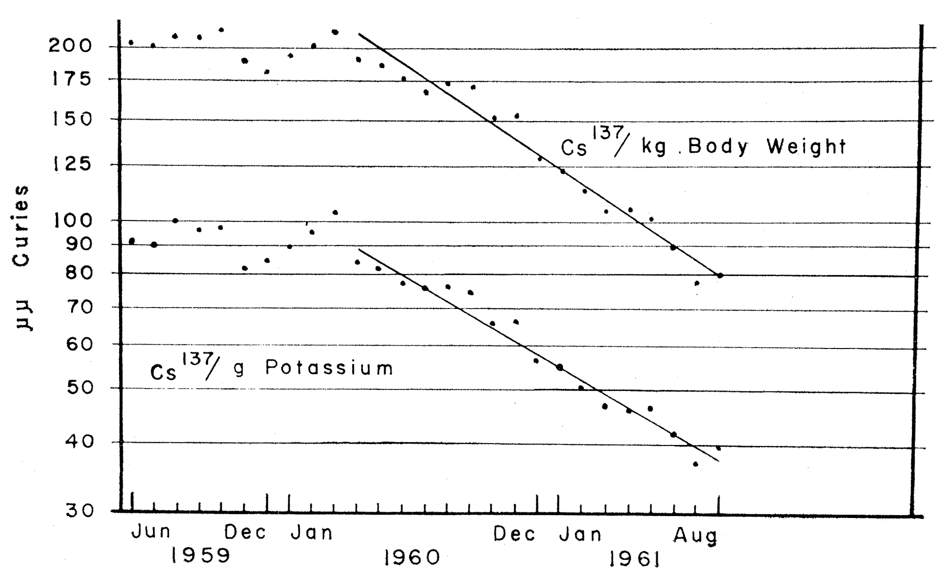

Fig. 3. Corrected monthly averages for amounts of cesium-137 per kilogram of body weight and per gram of body potassium.

Table 1. The average diet of subjects of the study. [*Statistisches Jahrbuch fuer die Bundesrepublik Deutschland*, 1960]

Component	Amount (kg per yr per person)
Bread	82.5
Vegetables	189.1
Fruits	97.2
Meat	53.3
Pork	28.9
Beef	17.7
Poultry	3.1
Other	3.6
Milk	122.9
Dairy products	14.5
Eggs	12.5
Fish	6.5

the ratio of cesium-137 to body weight and 12.7 months for the ratio of cesium-137 to potassium. These findings are in good agreement with one another, despite the necessity for making the corrections discussed previously.

The question of the significance and exact meaning of such a half-life for cesium-137 in man arises. It has been shown (*8*) that, after a single administration of cesium-137, the rate of elimination from the human body is exponential, the effective half-life being approximately 140 days. If we assume that the cesium activity in man's food also decreases exponentially, we can estimate the daily changes in the cesium content in man from the following formula:

$$\frac{dN}{dt} = Ke^{-\lambda_1 t} - N\lambda_2 \qquad (1)$$

where N is the cesium-137 content in man; K is the daily uptake of cesium-137 in food when the cesium-137 content in man is maximal; λ_1 is $0.693/(T_{1/2})_1$, where $(T_{1/2})_1$ is the half-life for the decrease in cesium-137 in food; and λ_2 is $0.693/(T_{1/2})_2$, where $(T_{1/2})_2$ is the effective half-life for cesium-137 in man.

Integration of Eq. 1 gives:

$$N = No\, e^{-\lambda_2 t} + \frac{K}{\lambda_2 - \lambda_1}\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right) \quad (2)$$

where No is the period when the cesium-137 content in man was maximal (1 July 1959 to 1 September 1961).

Since, at the time of maximum cesium-137 content, the amount present in the human body remained constant for several months, the following relationship also exists:

$$\frac{dNo}{dt} = K - No\,\lambda_2 = 0 \qquad (3)$$

where $No = K/\lambda_2$.

Insertion of Eq. 3 into Eq. 2 gives:

$$N = \frac{K}{\lambda_2 - \lambda_1}\, e^{-\lambda_1 t} - \frac{K}{\lambda_2(\lambda_2 - \lambda_1)}\, e^{-\lambda_2 t} \quad (4)$$

Since, in our case, $\lambda_2 > \lambda_1$ and $K/(\lambda_2 - \lambda_1) > K/\lambda_2\,(\lambda_2 - \lambda_1)$, a good approximation of the cesium-137 content in man a few months after the beginning of the decrease in cesium-137 can be expressed as follows:

$$N = \frac{K}{\lambda_2 - \lambda_1}\, e^{-\lambda_1 t}$$

Therefore, the half-life, as determined by our measurements, represents the rate of decrease of cesium-137 in the human diet.

By measuring levels in animal foodstuffs, Pfau and Kallistratos (*9*) proved that the portion of plants which grows above ground contains more cesium-137 than the portion which grows below the surface. This is explained by the fact that, above ground, plants take up cesium through absorption or adsorption or both. This explanation is in agreement with findings of Nishita (*10*), who determined that the cesium uptake through the roots of a plant is of minor importance. It appears, therefore, that the cesium-137 in human food comes mainly from the cesium-137 in plants exposed to fallout during their period of growth. Cesium-137 enters the human body directly from these plants, or indirectly through meat and dairy products.

Since the cesium-137 in plants comes directly from fallout rather than through uptake through their roots, and since, as reported by Hood and Comar (*11*), the effective half-life of cesium-137 in cows is less than 1 month, it can be assumed that only a few months elapse between the time fallout products reach the earth's surface and the time cesium-137 enters the human body.

Therefore, the results of our measurements of the cesium-137 content in man indicate that, as of 1 September 1961, fallout in Western Europe was decreasing, and had a half-life of approximately 12 months. Martell and Drevinsky (*12*) estimate a fallout half-life of a few months for debris injected into the polar stratosphere, and of 3.5 to 7 years for debris from the higher equatorial injections. The half-life found by us is an average value; this half-life would have been expected to lengthen as the fallout from the higher equatorial stratosphere became predominant. This phenomenon will not be observed, however, since atmospheric testing of nuclear weapons has been resumed. Seasonal fluctuations, as reported recently by Parker and Crookall (*13*), are not evident, because the time, even though brief, required for the passage of cesium-137 through plants and animals to man does tend to obscure sharp variations in the rate of fallout.

References and Notes

1. C. O. Onstead, E. Oberhausen, F. V. Keary, *Atompraxis* **6**, 337 (1960).
2. E. C. Anderson, F. N. Hayes, R. D. Hiebert, *Nucleonics* **16**, No. 8, 106 (1958).
3. E. C. Anderson and W. H. Langham, *Science* **130**, 713 (1959); T. H. Allen, E. C. Anderson, W. H. Langham, *J. Gerontol.* **14**, 348 (1960).
4. C. E. Miller and L. D. Marinelli, *Science* **124**, 122 (1956).
5. W. H. Langham and E. C. Anderson, *Health Phys.* **2**, 30 (1959).
6. J. Rundo, *Nature* **188**, 703 (1960).
7. D. G. Ott, "Advances in liquid scintillation counting," paper presented at the 4th Conference on Radioactive Isotopes in Agriculture, Oklahoma State University, Stillwater, 2 Apr. 1960.
8. K. T. Woodward, C. R. Richmond, W. C. Langham, paper presented at a meeting of the Health Physics Society, June 1956.
9. A. Pfau and G. Kallistratos, *Atompraxis* **6**, 422 (1960).
10. H. Nishita, *Soil Sci.* **81**, No. 317 (1956).
11. S. L. Hood and C. L. Comar, *Arch. Biochem. Biophys.* **45**, 423 (1953).
12. E. A. Martell and P. J. Drevinsky, *Science* **132**, 1523 (1960).
13. R. P. Parker and J. O. Crookall, *Nature* **190**, 574 (1961).