

# World-wide distribution of Strontium-90 and its uptake in man

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Objekttyp: **Article**

Zeitschrift: **Bulletin der Schweizerischen Akademie der Medizinischen Wissenschaften = Bulletin de l'Académie Suisse des Sciences Medicales = Bollettino dell' Accademia Svizzera delle Scienze Mediche**

Band (Jahr): **14 (1958)**

Heft 5-6: **Symposium sur les effets nocifs de faibles doses de radiation : éléments physiques et aspects biologiques = Symposium über schädliche Wirkungen schwacher Strahlendosen : physikalische Grundlagen und biologische Aspekte = Symposium on noxious effects of low level radiation : physical elements and biological aspects**

PDF erstellt am: **21.07.2024**

Persistenter Link: <https://doi.org/10.5169/seals-307384>

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## **World-wide Distribution of Strontium-90 and its Uptake in Man<sup>1</sup>**

*By J. Laurence Kulp, Professor of Geochemistry*

### *Introduction*

With the first identification of Sr<sup>90</sup> in foodstuffs and human bone in 1953 it became evident that a thorough understanding of the movement and uptake of Sr<sup>90</sup> in man was essential while the concentrations were still small. The research program at Columbia University has been directed primarily at the actual distribution of Sr<sup>90</sup> in the world population. In addition studies have been made of the geochemical and biochemical mechanisms that are involved in the movement of the Sr<sup>90</sup> from the atmosphere to the human skeleton. Previous results of this program including the analytical and radiometric techniques have been described elsewhere (1-4).

The ultimate objective of this research is to be able to predict with considerable accuracy the average Sr<sup>90</sup> content and the nature of the distribution around this average for any segment of the world population at any time in the future given a certain pattern of nuclear testing. This then will provide the basic data for the medical scientists who must assess the potential hazard.

The important parameters for such predictions are:

1. The quantity of fission introduced into the atmosphere with specification of time, altitude and location.
2. Rate and mechanism of transfer from stratosphere to troposphere.
3. Mean annual rainfall distribution.
4. The local diet, particularly with regard to the calcium-rich components.
5. Place of origin of foodstuffs in diet.
6. Discrimination factor between strontium and calcium from food to bone.

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<sup>1</sup> Lamont Geological Observatory cont. No 299.

7. Age of the individual.

8. Distribution of common strontium and  $\text{Sr}^{90}$  in present groups of the population.

With these factors in hand it then becomes possible to predict for any given program of nuclear testing how much  $\text{Sr}^{90}$ , for example, a 12-year-old boy in Bangkok, New York, Cape Town, or the Amazon jungle would have on the average in 1978 and the distribution curve for 12-year-olds at each locality.

*Libby and Stewart* (5) have summarized the current knowledge on the atmospheric problems. It is clear that the least well-defined factors at present are the quantity of  $\text{Sr}^{90}$  in the stratosphere, the mean residence time in the stratosphere, and the total world fallout. If the reasonable assumption is made that the bulk of the fallout in the North Temperate Zone is from atomic debris which a) did not enter the stratosphere or b) has a short residence time in the stratosphere (because of the northerly latitude in which it was injected), then these factors can be ignored. In this case the total fission produced can be compared directly with the current food levels.

The existing data on fallout show a rough correlation with integrated rainfall for a restricted latitude zone. Once on the ground, the  $\text{Sr}^{90}$  remains in the top few inches of the soil and the concentration available for plants and eventually man is primarily determined by the exchangeable calcium content of the soil. The soil-plant relationship is extremely complex due to the sharp vertical gradient of  $\text{Sr}^{90}$  in the ground; hence this step in the transfer of  $\text{Sr}^{90}$  is not readily subject to quantitative treatment. On the other hand, the discrimination factors from grass to milk and from food to human bone are now fairly well known, so that food analyses permit accurate estimates of bone levels.

It is the purpose of this paper to report the present bone levels, to compare these with fallout and diet and to indicate on the basis of these data what certain future levels may be.

### *$\text{Sr}^{90}$ in Human Bone*

Autopsy samples of human bone are now being received from about 30 stations in a world-wide network (fig. 1). Already several thousand have been or are being analyzed. Samples have been rather evenly distributed with regard to age. An attempt has also been made to obtain a maximum spread in geographic and dietary setting but the restriction in the location of medical centers has limited the samples largely to urban populations.



### *Skeletal Averages from Single Bones*

Since most of the samples are a single bone (normally rib, vertebrae or femur), it is necessary to establish the correction factors which relate a particular bone type to the whole skeleton. Experiments have been conducted (table 1) using 1. single dose Sr<sup>85</sup> spike in terminal patients,

Table 1  
Distribution of Sr<sup>90</sup> in Adult Skeleton

| Method                                | Investigator             | Vertebrae skeleton | Rib skeleton | Long bone skeleton |
|---------------------------------------|--------------------------|--------------------|--------------|--------------------|
| Sr <sup>85</sup> spike, autopsy       | Schulert et al. (1958)   | 4.8 ± 0.4          | 2.0 ± 0.2    | 0.68 ± 0.06        |
| Sr <sup>90</sup> , N.Y. 1956 cadavers | Schulert and Kulp (1958) | 3.3 ± 0.3          | 2.0 ± 0.3    | 0.86 ± 0.13        |
| Common strontium                      | Thurber et al. (1958)    | 0.9 ± 0.1          | 0.9 ± 0.1    | 1.0 ± 0.1          |

2. actual Sr<sup>90</sup> distribution among adult bones, and 3. common strontium distribution. Within the experimental error common strontium is uniformly distributed in the skeleton. This should be the situation for Sr<sup>90</sup> 1. if a uniform diet is ingested for a lifetime, and 2. in young children who are building bone nearly in equilibrium with the diet. The Sr<sup>90</sup> dose to adults who are merely exchanging, not building, bone at a slow rate approaches the Sr<sup>85</sup> experiment.

These results are used to correct analyses of individual bones to whole skeletons in the case of adults. No correction is made for children whose bones most closely approximate uniform distribution. Preliminary Sr<sup>90</sup> results on a few children's skeletons confirm this procedure.

### *Present Levels*

The bone data for 1956-57 are summarized in table 2. Note that the adult levels from 20 years and up are essentially constant, independent of age. The Northern Hemisphere averages about twice that of the Southern Hemisphere. The entire world average at the end of 1956 was about 0.2 μμc Sr<sup>90</sup>/g Ca.

### *Age Effect*

The data for the U.S. and Western Europe are shown in fig. 2. The solid curve is calculated using the following five assumptions:

a) The Sr<sup>90</sup> content in the diet of the U.S. and western Europe is known from the milk and food analyses made by the *Harwell* group, the Health and Safety Laboratory of the U.S. Atomic Energy Commission, and the Geochemical Laboratory at Columbia University (2).

Table 2

## World-wide Distribution of Strontium-90 in Man - July 1, 1956 to June 30, 1957

(All values are given in micromicrocuries of strontium-90 per gram of calcium normalized to the whole skeleton. The figures in parentheses give the number of samples in the category)

| Location      | Age at death (years) |           |           |           |           |           |           |           |                    |  |
|---------------|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------------------|--|
|               | 0-4                  | 5-9       | 10-19     | 20-29     | 30-39     | 40-49     | 50-59     | 60-80     | 20-80<br>(average) |  |
| North America | 0.67 (30)            | 0.69 (17) | 0.38 (15) | 0.07 (14) | 0.06 (9)  | 0.08 (16) | 0.05 (5)  | 0.07 (18) | 0.070 (62)         |  |
| South America | 0.16 (3)             | 0.20 (1)  | 0.19 (5)  | 0.03 (5)  | 0.02 (2)  | 0.03 (2)  | 0.06 (3)  | 0.01 (1)  | 0.034 (13)         |  |
| Europe        | 0.65 (2)             | 0.34 (4)  | 0.34 (9)  | 0.06 (20) | 0.07 (4)  | 0.04 (6)  | 0.06 (1)  | 0.08 (2)  | 0.059 (33)         |  |
| Africa        |                      |           | 0.06 (2)  | 0.03 (2)  | 0.03 (3)  | 0.04 (4)  |           |           | 0.035 (9)          |  |
| Asia          | 0.93 (1)             | 0.12 (2)  | 0.32 (2)  | 0.06 (8)  | 0.04 (6)  | 0.12 (8)  | 0.06 (5)  | 0.05 (5)  | 0.070 (32)         |  |
| Australia     | 0.75 (3)             | 0.60 (2)  |           |           | 0.03 (3)  | 0.03 (4)  | 0.03 (3)  |           | 0.030 (10)         |  |
| Entire world  | 0.64 (39)            | 0.57 (26) | 0.30 (33) | 0.059(49) | 0.047(27) | 0.070(40) | 0.052(17) | 0.065(26) | 0.060 (159)        |  |

World average = 0.20

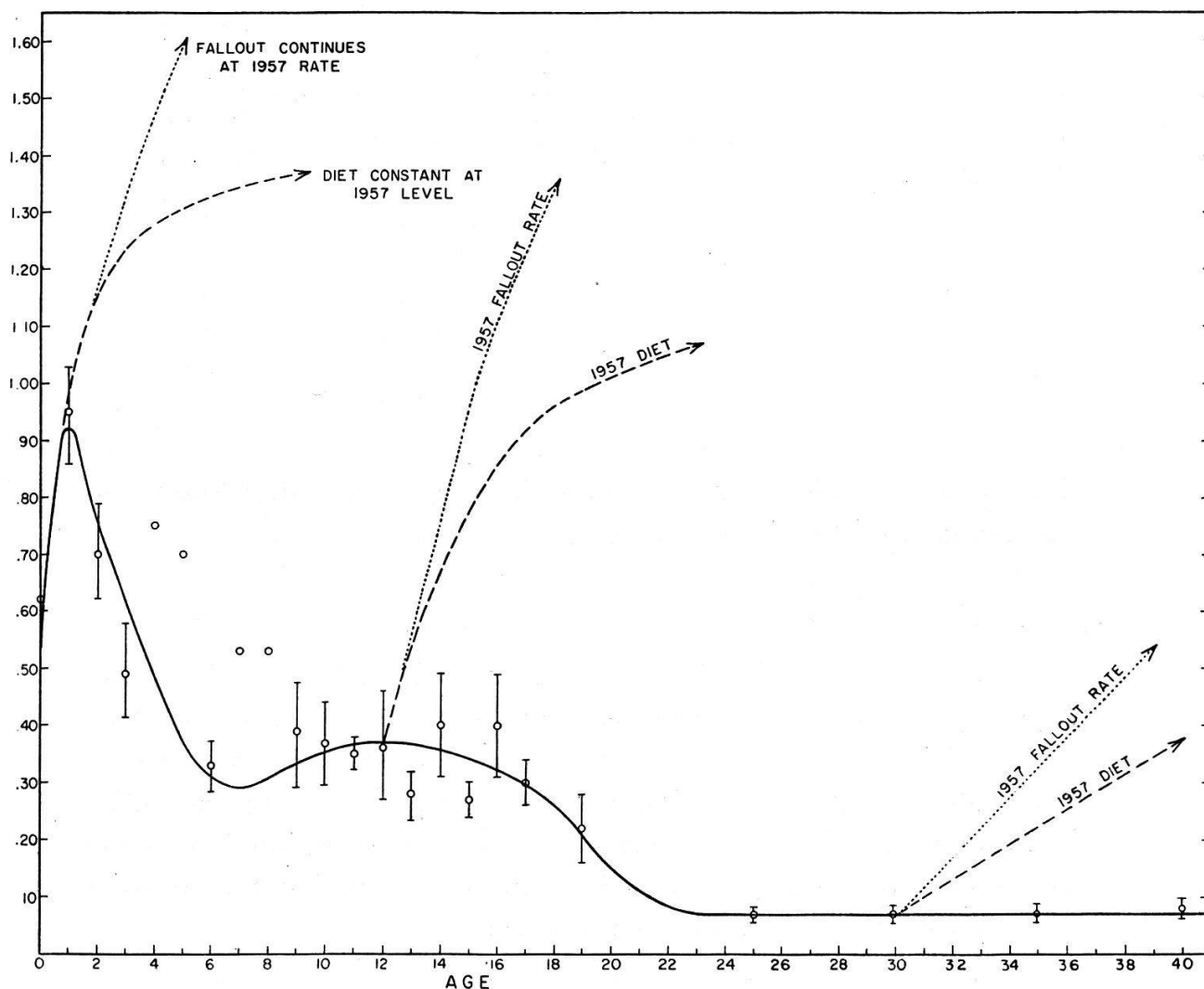


Fig. 2. Theoretical and observed  $Sr^{90}$  level in northern hemisphere bone at end of 1956.

b) The discrimination factor between food and bone is 4 (table 3 and reference 6).

c) The yearly deposition of calcium in children from birth to 20 years is that given by *Mitchell* et al. (7).

d) The fetal protective factor is 2 (8).

e) The rate of exchange of calcium in adults is about 2 per cent per year.

The experimental points follow the theoretical curve with the exception of four ages (4, 5, 7 and 8) each set of which contained one very high value (1.5 to 2.4  $\mu\mu c$   $Sr^{90}/g$  Ca). It is expected that an improved fit will be obtained or more samples become available.

The highest concentration occurs in 1-year-olds in the present state of strong disequilibrium. The minimum around age 6 is a reflection of the bone growth curve. It is evident that for purposes of examining

**Table 3**  
Sr/Ca Discrimination – Food to Bone

| Species | Investigator           | Method                          | $\frac{\text{Sr/Ca food}}{\text{Sr/Ca bone}}$ |
|---------|------------------------|---------------------------------|---|
| Rat     | Comar et al. (1956)    | $\text{Sr}^{85}/\text{Ca}^{45}$ | 3.7   |
|         | Macdonald (1956)       | Sr/Ca                           | 3.7   |
| Sheep   | Bryant et al. (1956)   | Sr/Ca                           | 4.2   |
|         |                        | $\text{Sr}^{90}/\text{Ca}$      | 4.3   |
| Man     | Schulert et al. (1957) | $\text{Sr}^{85}/\text{Ca}^{45}$ | 4.0   |
|         |                        | $\text{Sr}^{90}/\text{Ca}$      | 4.0   |

distribution in a population nearly at equilibrium with its diet, the 14- to 18-year group would be best.

*Growth Curves for Next Five Years*

Prediction curves are also drawn for people who in March of 1958 are 1, 12, and 30 years old, respectively. The curves show their average skeletal level in the next 5 years on two assumptions: a) that atomic tests stop today and that the stratospheric fallout just equals the radioactive decay of the  $\text{Sr}^{90}$  in the atmosphere-geosphere-biosphere reservoir; b) that the fallout rate on northeast U.S. and England of  $10 \text{ mc}/\text{mi}^2/\text{year}$  observed during 1957 continues at this rate.

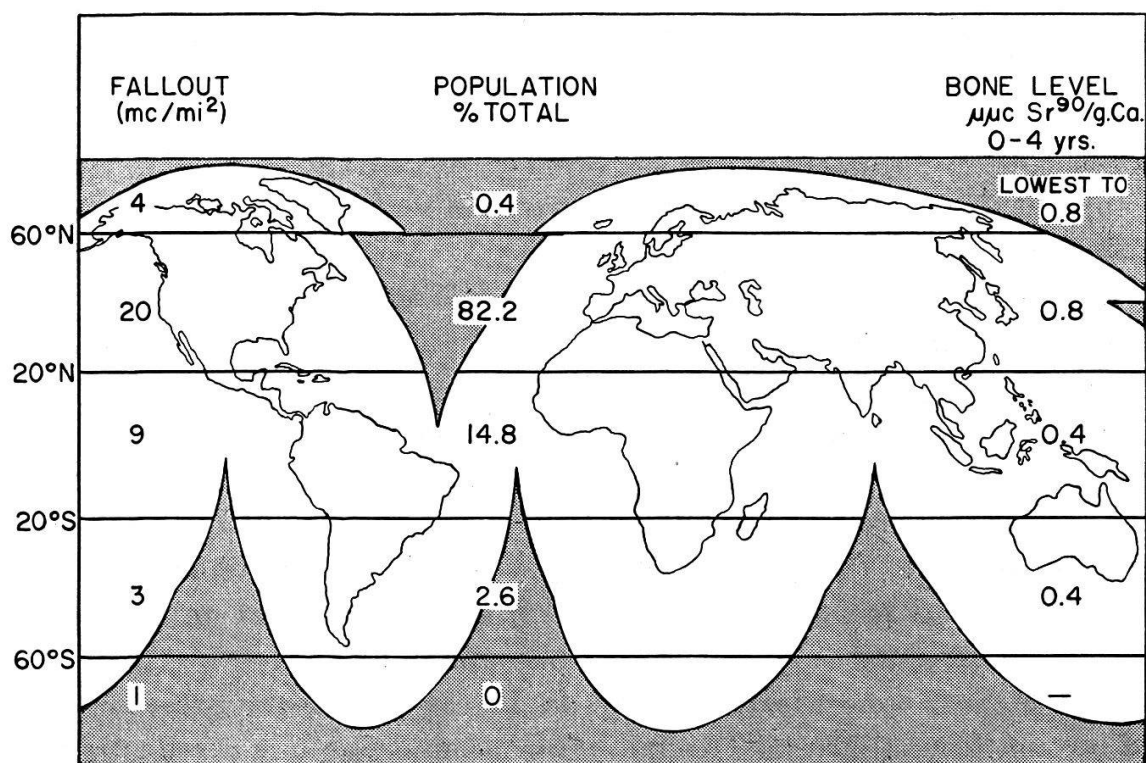


Fig. 3. Latitude effect March 1958 (Equal Area Projection).



### Latitude and Time

Comparison of estimated fallout of Sr<sup>90</sup> in mc/mi<sup>2</sup>, population and bone level for various latitude sectors are shown in fig. 3. It appears that the bone levels in the Southern Temperate Zone may be held up somewhat from food from the Northern Hemisphere.

The increase in the Sr<sup>90</sup> content with time is most clearly displayed by analyses of average diet and a large number of total body ash samples from New York City (fig. 4).

In passing it might be noted that radium analyses (table 4) on these unusual total body samples and composites of bones from the worldwide collection network give the most complete picture of natural radium levels in the human population so far and that the effective radiation to the bones of young children from Sr<sup>90</sup> now exceeds the radium dose by about a factor of 3. On the other hand the Sr<sup>90</sup> dose is still a small fraction of the total dose from natural background. This work will be reported in detail elsewhere (9).

### Distribution in the World Population

The distribution of radium and common strontium in the whole body ash of New York City cadavers is approximately normal<sup>1</sup> with a standard

Table 4  
Radium in Human Bone

| Investigator                       | Locality                    | Ra content of ash (10-14 g Ra/g) |                |           |
|------------------------------------|-----------------------------|----------------------------------|----------------|-----------|
|                                    |                             | Average                          | Number samples | Range     |
| Krebs (1942)                       | Germany                     | 500.0                            | 18             | <30-1800  |
| Hursh and Gates (1950)             | 9 states                    | 5.0                              | 27             | 1.9 - 9.0 |
| Palmer and Queen (1956)            | 18 states<br>11 countries   | 1.6                              | 50             | 0.6 - 5.0 |
| Muth et al. (1957)                 | Frankfurt                   | 13.0                             | 14             | 5.0 -31.0 |
| Kulp and Eckelmann (1957)          | 8 countries                 | 1.4                              | 21             | 0.13- 4.0 |
| Walton, Kologrivov, Kulp<br>(1958) | N.Y. City<br>cadavers       | 0.9                              | 150            | 0.24- 5.3 |
|                                    | 20 countries<br>(composite) | 1.2                              | 200            | 0.35- 3.6 |

*Best Estimate:*

World average radium burden 0.03  $\mu\mu\text{c/g Ca}$   
Northern Hemisphere Sr<sup>90</sup> (0-5 years) March 1958 0.80  $\mu\mu\text{c/g Ca}$

<sup>1</sup> Recent data on many additional samples indicate a distribution that is closer to lognormal than normal. These will be published subsequently in Walton et al. (9) and Thurber et al. (6)

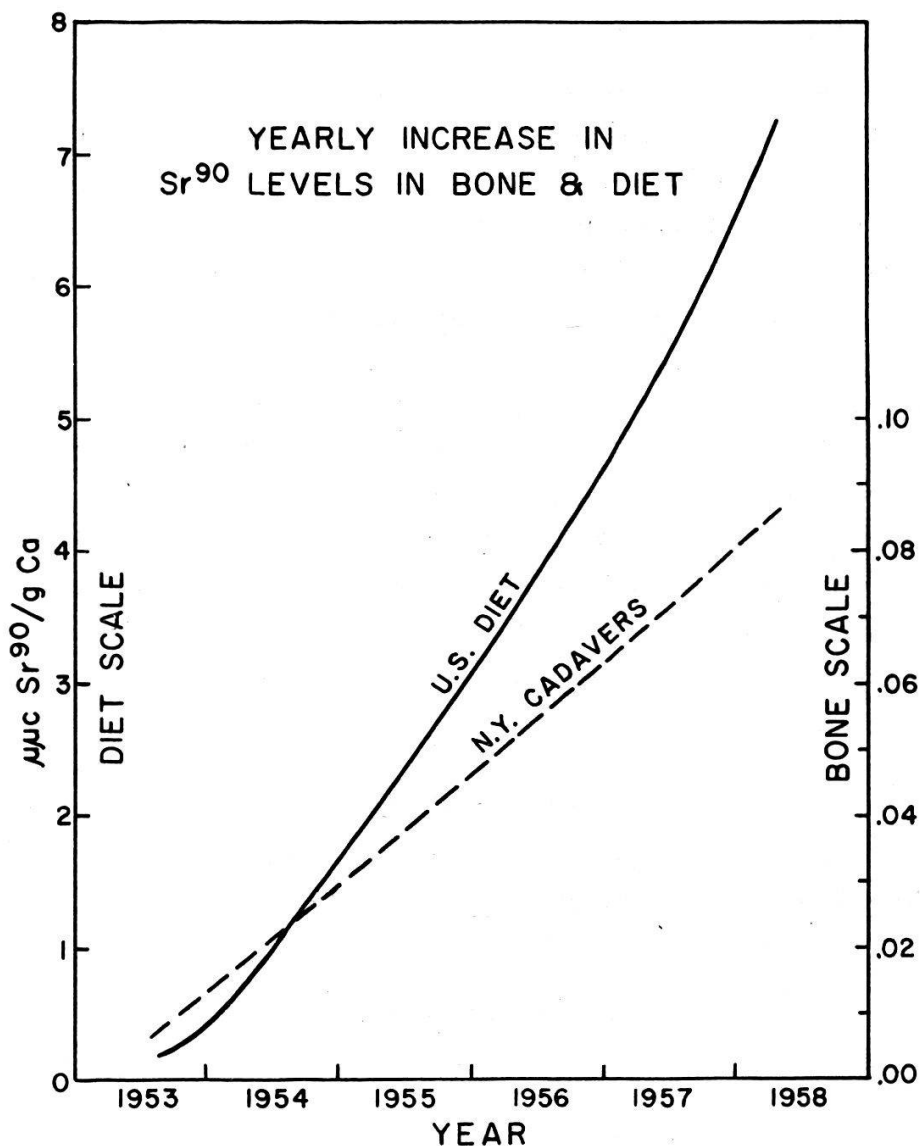


Fig. 4.

deviation of 30 to 35 per cent of the mean. Fig. 5 shows these relations as well as the present histograms for Sr<sup>90</sup> distribution in Northern Hemisphere teenagers and the New York whole skeleton samples. Since the human bone even for children is far out of equilibrium with the diet, it is not surprising that the spread is somewhat larger for the Sr<sup>90</sup> than the common strontium or the radium. It would be expected, however, that if the concentration of Sr<sup>90</sup> in the diet becomes constant, the Sr<sup>90</sup> distribution in all urban centers as well as those suburban and rural areas of western culture which experience the pooling of food should approach that of common strontium. It can therefore be concluded that the monitoring of the Sr<sup>90</sup> concentration in food and bone at a limited number of centers should ultimately permit definition of the average content and the distribution of Sr<sup>90</sup> in a large fraction (possibly 80 to 90 per cent) of the world's population.

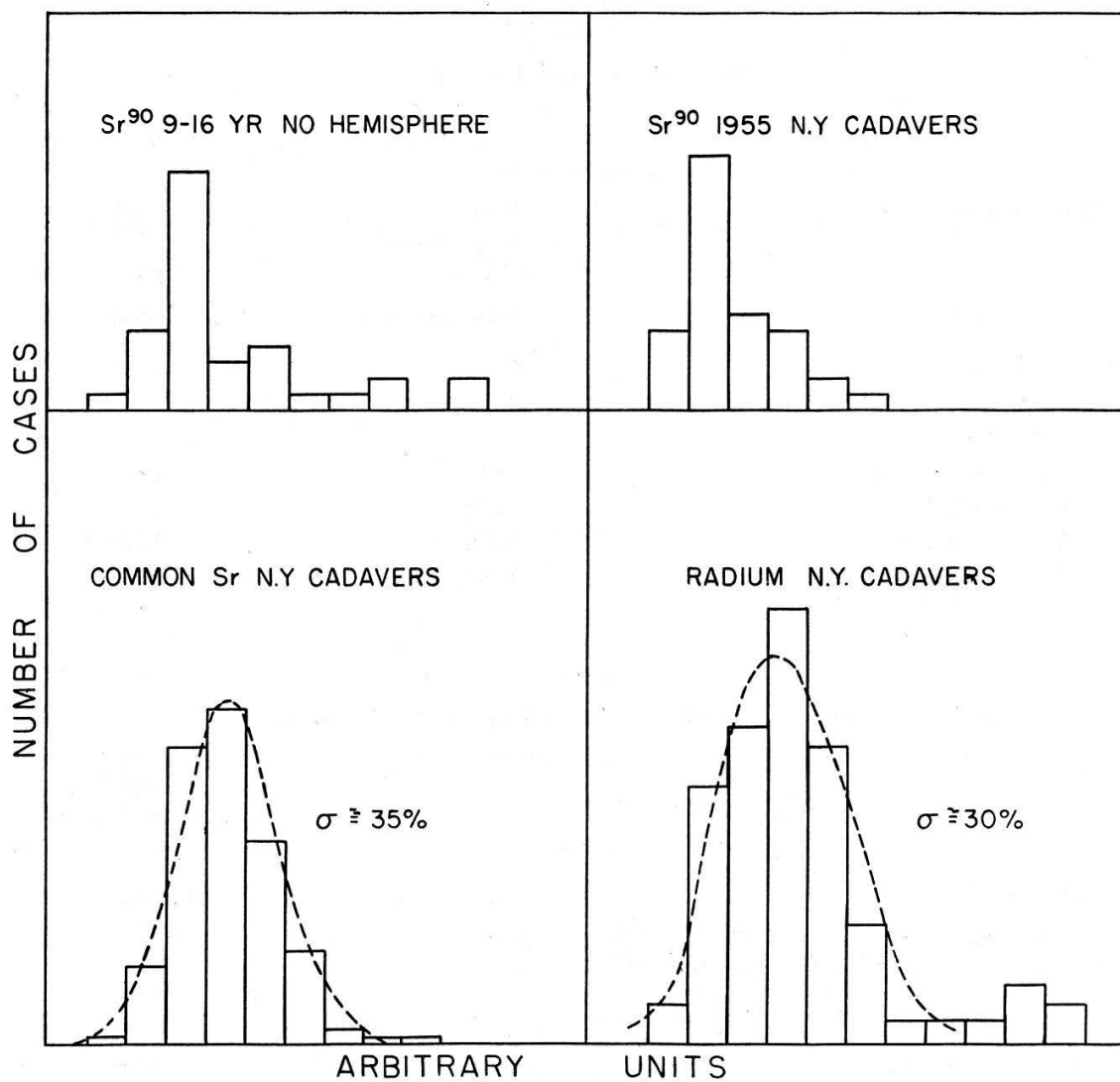


Fig. 5.

Widespread spot sampling of foods and milk in the U.S., adjacent to many of the bone stations, and in a north-south section through Central and South America shows that serious anomalies are rare. Table 5 shows the average Sr<sup>90</sup> in the diet of most of the U.S. and United Kingdom in 1957. In addition, the important anomalies that have been discovered by the Harwell investigators (10), the New York Operations Office (11) and the Lamont laboratory are summarized. It is evident that a limited number of localities in the North Temperate belt have sufficiently low calcium content in the soil to raise the milk level by about a factor of 2 above the average. The Mandan samples are output from a powdered milk plant and the Kentucky samples represent liquid milk from two counties. Assuming that this milk is consumed locally it may be concluded that the people who may experience this level will be considerably under 0.1 per cent of the population.

The Ecuadorian yuca represents the major calcium food for the iso-

Table 5  
Sr<sup>90</sup> in Diet and Food 1957

| Region                         | Food         | $\mu\mu\text{c Sr}^{90}/\text{g Ca}$ |
|--------------------------------|--------------|--------------------------------------|
| United States . . . . .        | Milk         | 6.1                                  |
|                                | Vegetables   | 8.7                                  |
|                                | Cereals      | 13.5                                 |
|                                | Average diet | 6.6                                  |
| United Kingdom . . . . .       | Milk         | ~7.0                                 |
| High localities                |              |                                      |
| Mandan, South Dakota . . . . . | Milk         | 17.0                                 |
| Londonderry, U.K. . . . .      | Milk         | 10.0                                 |
| Kentucky . . . . .             | Milk         | 14.0                                 |
| Eastern Ecuador . . . . .      | Yuca         | 40.0                                 |

Table 6  
Present and Predicted Bone Levels of Strontium-90

| Situation or condition                                     | Level<br>( $\mu\mu\text{c Sr}^{90}/\text{g Ca}$ ) |
|--|---|
| Industrial MPC* . . . . .                                  | 1000  |
| Large-population or young-children MPC . . . . .           | 100   |
| Average background radiation equivalent . . . . .          | 50  |
| March 1958 Averages  |   |
| World . . . . .  | 0.25  |
| North American children (0 to 4 years) . . . . .           | 0.85  |
| North American adults . . . . .                            | 0.09  |
| Predicted equilibrium value, North America . . . . .       | 1.7   |
| Predicted equilibrium value, Southern Hemisphere . . . . . | 0.8   |
| Futures Averages   |   |
| No further testing   |   |
| Children (0-4) Northeast U.S. 1978 . . . . .               | 1.5   |
| Adults Northern Hemisphere . . . . .                       | 0.6   |
| Continuous fallout of 10 mc/mi <sup>2</sup> /year          |   |
| Population in Northern Hemisphere (A.D. 2100) . . . . .    | ~20.0   |

\* Maximum permissible concentration recommended by the International Committee on Radiation Protection.

lated jungle Indians of the Upper Amazon Basin. The high Sr<sup>90</sup> concentration is due to the severe leaching of the calcium from the soil under the high temperature, high rainfall conditions. The fallout is essentially normal for the latitude and the rainfall (i.e. 5 mc/mi<sup>2</sup>). It is concluded that the equilibrium bone level for this relatively small segment of the world population (certainly less than 0.01 per cent) is now 5 to 10  $\mu\mu\text{c}$

$\text{Sr}^{90}/\text{g Ca}$ . Further work is being done to define the  $\text{Sr}^{90}$  level and population of the primitive people who live under such conditions of diet.

#### *Future Levels*

The present and predicted average bone levels of  $\text{Sr}^{90}$  are low compared to the average background radiation and the current maximum permissible concentrations recommended by the International Committee on Radiation Protection.

If there is no further testing it is assumed that the stratospheric drip will just equal the radioactive decay of  $\text{Sr}^{90}$ . If the fallout in the Southern Temperate Zone is representative of the long-term stratospheric fallout the above assumption appears warranted. Under these conditions young children will reach  $1.5 \mu\mu\text{c Sr}^{90}/\text{g Ca}$  and adults about  $0.6 \mu\mu\text{c Sr}^{90}/\text{g Ca}$  by 1978.

If testing continues of such a character and at such locations to produce a steady fallout of  $10 \text{ mc}/\text{mi}^2/\text{year}$  as has occurred in much of the North Temperate Zone in 1957 equilibrium would be approached about 2100 A.D. with a population burden of about  $20 \mu\mu\text{c Sr}^{90}/\text{g Ca}$ . Presumably the population average should reach  $10 \mu\mu\text{c Sr}^{90}/\text{g Ca}$  before the year 2000 A.D.

It is concluded that the distribution of  $\text{Sr}^{90}$  in the world population and the mechanisms by which it proceeds from a nuclear test to human bone are now fairly well known. Although the present level of  $\text{Sr}^{90}$  produces only a small increment to the radiation dose from natural background sources, the problem is not trivial. Continued testing requires vigilant monitoring and a more precise definition of each important factor which affects the uptake of  $\text{Sr}^{90}$  in man. It should also be noted that such studies will provide the basic scientific data for controlling the environment in the event of a reactor accident.

#### *Summary*

The  $\text{Sr}^{90}$  concentration in the bones of young children in the Northern Hemisphere is about  $1 \mu\mu\text{c}$  per gram of calcium. The level in adults is about ten times lower and is independent of age. People in the Southern Hemisphere carry a burden about half of that in the Northern Hemisphere. Results from a world-wide network of sampling stations, which have already supplied thousands of samples, are interpreted in terms of diet, latitude and time. The common strontium and radium concentrations in people in an urban area appear to be normally distributed with a standard deviation of 30 to 35 per cent of the mean. This should be the case for  $\text{Sr}^{90}$  as equilibrium with the diet is approached. The distribu-

tion curve for the entire world population is discussed. Future  $\text{Sr}^{90}$  concentrations in human bone are predicted taking various assumptions on the rate and kind of nuclear testing.

### *Zusammenfassung*

Der  $\text{Sr}^{90}$ -Gehalt des Kleinkindknochens beträgt in der nördlichen Hemisphäre etwa  $1 \mu\mu\text{c}$  pro g Calcium. Der Gehalt bei Erwachsenen ist ungefähr 10mal kleiner und vom Alter unabhängig. Die Bevölkerung der südlichen Hemisphäre weist einen halb so großen Strontiumgehalt auf als jene der nördlichen Hemisphäre. Ergebnisse eines über die ganze Erde verstreuten Netzes von Versuchsstationen, welche bereits Tausende von Proben eingebracht haben, werden unter Berücksichtigung von Diät, geographischer Breite und Zeit gedeutet.

Die gewöhnliche Strontium- und Radiumkonzentration bei Menschen eines Stadtgebietes scheint bei einer Standardabweichung von etwa 30–35% vom Mittel eine normale Verteilung aufzuweisen. Dasselbe sollte für  $\text{Sr}^{90}$  der Fall sein, da der Gleichgewichtszustand mit der Diät beinahe erreicht ist. Es wird der Versuch gemacht, für die Bevölkerung der ganzen Erde eine Verteilungskurve zu berechnen. Diese Erhebungen werden mit der natürlichen Umgebungsstrahlung verglichen. Zum Schluß werden die zu erwartenden  $\text{Sr}^{90}$ -Konzentrationen im menschlichen Knochen an Hand von Vermutungen über die künftige Zahl und Art der Kernversuche erwogen und abgeschätzt.

### *Résumé*

La concentration du  $\text{Sr}^{90}$  dans les os de jeunes enfants de l'hémisphère nord est d'environ  $1 \mu\mu\text{c}$  par g de calcium. La teneur chez les adultes est environ dix fois plus faible, elle est indépendante de l'âge. Les populations de l'hémisphère sud ont une teneur d'environ la moitié de celles de l'hémisphère nord. Les résultats livrés par tout un réseau mondial de stations de prélèvement et d'étude ont déjà donné des milliers d'épreuves, qui seront interprétées en fonction de la latitude, du temps et du type d'alimentation. La concentration du Sr et du radium des gens d'une population urbaine semble montrer une variabilité normale avec une déviation standard de la moyenne d'environ 30–35%. Ceci devrait être le cas également pour  $\text{Sr}^{90}$  puisque l'équilibre avec la diète est à peu près atteint. Les efforts actuels tendent à calculer la courbe de distribution pour la population du globe toute entière. Les moyennes obtenues seront comparées aux irradiations provenant de sources naturelles. On essaie enfin de prévoir la concentration du  $\text{Sr}^{90}$  dans le sque-

lette humain sur la base de suppositions concernant la fréquence et le genre d'expériences futures d'explosions nucléaires.

This research is being supported by the Division of Biology and Medicine of the U.S. Atomic Energy Commission. The encouragement, support, and criticism of *W. F. Libby*, of *C. L. Dunham*, Forrest Western, *H. D. Bruner*, and *W. D. Claus* of the Division of Biology and Medicine, and of *M. Eisenbud*, *J. H. Harley*, and *I. Whitney* of the New York Operations Office, are greatly appreciated. *Daniel Laszlo*, chief, Division of Neoplastic Diseases, Montefiore Hospital, has provided valuable counsel and assistance in biomedical aspects of the program. Other scientific contributions to the planning and interpretation of this work have been made by *H. L. Volchok*, of Isotopes, Inc.; *C. L. Comar*, of Oak Ridge National Laboratory; *Wright Langham*, of Los Alamos Scientific Laboratory; and *K. K. Turekian*, of Yale University, *Elizabeth Hodges*, *Edwin Peets*, and *Rieta Slakter* were key personnel in the carrying out of the technical phases of the investigation. They were assisted by *D. Walton*, *D. Tuck*, *J. Rippey*, *G. Markle*, *R. Alley*, and *W. Blake*. We wish to express our very great appreciation to the physicians who have co-operated so completely in this program, in many cases at real sacrifice in time and effort. Among those who have assisted us in essential sample procurement are: *D. Anderson*, *C. Brown*, *J. de Brux*, *W. Civen*, *E. Diago*, *M. Feo*, *T. Galindo*, *H. Hamperl*, *H. Hopps*, *E. Krieger*, *W. Leach*, *J. Legendre*, *J. Lowry*, *F. Margarey*, *H. Menezes*, *J. Montalvan*, *T. Potenza*, *M. Ravelo*, *G. Roach*, *D. Rosenberg*, *A. Stewart*, *W. Stewart*, *P. Tamura*, *G. Teilum*, *J. Thomson*, *C. Treip*, *E. Uehlinger*, *H. Ungar*, *G. Volante*, *S. Warren* and *Shu Yeh*.

1. *Kulp, J. L., Eckelmann, W. R., and Schulert, A. R.*: Strontium-90 in man. *Science* **125**, 219 (1957).
2. *Eckelmann, W. R., Kulp, J. L., and Schulert, A. R.*: Strontium-90 in man, II. *Science* **127**, 266 (1958).
3. *Volchok, H. L., Kulp, J. L., Eckelmann, W. R., and Gaetjen, J. E.*: Determination of  $\text{Sr}^{90}$  and  $\text{Ba}^{140}$  in bone, dairy products, vegetation, and soil. *N.Y. Acad. Sci. Ann.* **71**, 293 (1957).
4. *Volchok, H. L., and Kulp, J. L.*: Low-level beta counter for routine radiochemical measurements. *Nucleonics* **13**, 49 (1955).
5. Papers by *W. F. Libby* and *N. G. Stewart* presented at The Symposium on Radioactive Fallout, Swiss Academy of Medical Sciences, Lausanne, Switzerland, March 1958.
6. *Thurber, D. L., Kulp, J. L., Hodges, E., Gast, P. W., and Wampler, J. M.*: Strontium content of the human skeleton. *Science* (1958) (in press).
7. *Mitchell, H. H., et al.*: The chemical composition of the adult human body and its bearing on the biochemistry of growth. *J. Biol. Chem.* **158**, 625 (1945).
8. *Comar, C. L., Whitney, I. B., and Lengemann, F. W.*: Comparative utilization of dietary  $\text{Sr}^{90}$  and calcium by developing rat fetus and growing rat. *Proc. Soc. Exp. Biol. Med.* **88**, 232 (1955).
9. *Walton, A., Kologrivov, R., and Kulp, J. L.*: Radium content of human bone (to be submitted to Health Physics shortly).
10. *Bryant, F. J., Chamberlain, A. C., Morgan, A., and Spicer, G. S.*: Radiostrontium in Soil, Grass, Milk and Bone in the United Kingdom. AERE HP/R 2353, p. 23 (1957).
11. *Eisenbud, M.*: Hearings of the Joint Committee on Atomic Energy, May 27–June 7, 1957, p. 554. Government Printing Office, Washington, D.C.