pass of from 1 to 30,000 cy/sec, on to a dual-beam oscilloscope. Short light stimuli, with a duration of the order of 10 μsec, were provided by a Grass photostimulator. Longer stimuli were provided by a 6-volt tungsten filament lamp. The entire retina was illuminated.

With the advance of the microelectrode, the sudden appearance of deflections of brief duration and uniform amplitude that were modifiable by light was taken as evidence that an active unit was being sampled. By this criterion, from two to six fibers were sampled in a single penetration of the nerve. An individual fiber could be observed for periods lasting from a few seconds to 90 min. In all instances the polarity of the responses was positive with respect to the gross electrode. The responses were sharply peaked. Their amplitude ranged from 0.05 to 0.3 mv, and their duration at the baseline was about 0.6 msec. In most cases the uniform amplitude of the responses recorded from a given site indicated that a single unit was being sampled, though occasionally responses of two amplitudes, suggesting simultaneous recording of two units, were observed.

Figure 1*A* shows records obtained from three fibers of different response types. In each instance the top record, showing the spontaneous activity, and the two lower records, showing the responses to a prolonged light stimulus, were taken in close temporal sequence. Fibers were observed that responded only to the "on" of the light, others that responded only to the "off," and still others that responded both to the "on" and the "off." This is consistent with observations made in vivo (*4*). Almost all fibers showed a rather high level of spontaneous activity. As shown in Fig. 1*A*, the spontaneous activity of the "on" fibers was diminished during the latent period between onset of the illumination and the burst of responses, and the spontaneous activity of the "off" fibers was diminished throughout the period of illumination. At occasional sites, deflections were recorded that could not be modified by light, though in all other respects they were identical to the spontaneous activity recorded from fibers responsive to light.

Figure 1*B* shows the response of an "on" fiber to a short (about 10 μsec) light stimulus, varying in intensity from about 130 to about 10^6 ft-ca. As intensity increased over this range, latency diminished by a factor of 2, but the number of evoked discharges did not change.

Figure 1*C* shows the multiple responses sometimes observed after short stimuli of low intensity. Though the successive intervals between discharges, or pairs of discharges, were not equal, they were reproducible from stimulus to stimulus. The number of response groups and the lengths of the intervals between them changed with the intensity of the stimulus. At higher intensities only the first group of discharges remained. It is possible that these multiple responses are related to the rhythmic activity observed in the cortex of man after photic stimulation (*5*).

Since several important features of electrical activity—the level of spontaneous discharge, the response of different types of fibers, the occurrence of multiple discharges—are revealed only by the microelectrode, it should be a useful addition to gross electrodes in experiments correlating the function of nervous tissue with metabolism and with changes in the chemical milieu (*6*).

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Strontium-90 and Cesium-137 in North American Milk

Abstract. The strontium-90 and cesium-137 concentrations in powdered milk in North America vary roughly with the specific activity of rain. The Sr^{90}/Cs^{137} ratios in over 800 powdered milk samples taken from 60 stations in North America from 1957–60 have a standard deviation of only 44 percent.

Powdered milk samples taken on a weekly basis from 1957 to 1960 at some 60 stations scattered over North America have been analyzed for Sr^{90} and Cs^{137}. The network was maintained by the Los Alamos Scientific Laboratory (*1*), and the Cs^{137} analyses were performed there. The Sr^{90} analyses were done under the supervision of the geochemistry laboratory, Columbia University (*2*). The raw data have been given in various reports by the Health and Safety Laboratory of the Atomic Energy Commission (*3*), and the Cs^{137} data from 1957–1958 have been discussed by Langham and Anderson (*4*) and by Anderson (*5*).

This program was designed to give information on the following subjects: (i) the average Sr^{90} and Cs^{137} levels in the North American diet, (ii) the mechanism by which these isotopes enter plant tissue and milk, and (iii) the relation of Cs^{137} and Sr^{90} concentrations.

It has been shown in a variety of studies (*6*) that the Sr^{90} concentration in Western diet is about 1.2 times the concentration in milk in micromicrocuries of Sr^{90} per gram of calcium. Since milk is the easiest food to sample in a comprehensive manner, it is the best food to monitor. The average values provided by the U.S. Public Health Service's networks for testing powdered milk and liquid milk are given in Table 1. There is no systematic difference between the Sr^{90} concentration in powdered and liquid milk from the same general area. The data are grouped by half years, rainfall, and geography. From these data the Sr^{90} concentration in the average North American diet is calculated for each year. The concentration of Sr^{90} in the diet increased each year from 1957 through 1959, but it appears that it will drop to nearly half the 1959 value in 1960. Similar results for Cs^{137} are shown in the lower part of Table 1.

The relative contribution to the concentration of Cs^{137} and Sr^{90} in plants by direct absorption from rain and by absorption through the soil is of great importance since it determines the concentration of these fission products in the diet in the long-term situation. R. S. Russell and his co-workers (*7*) have conducted experiments which suggest that for the typical milk-producing pasture in Britain, only 20 percent of the Sr^{90} in the plants under the fallout conditions up to 1958 was introduced through the soil. They assumed that absorption from the soil is the same for the vertical profile produced by fallout as if the Sr^{90} is homogenized in the upper 4 in. of soil.

The maintenance of the milk networks of the Los Alamos Scientific Laboratory and the Public Health Service through 1961 should answer this question empirically for the North American continent as a whole. The specific activity of Sr^{90} in rain in the spring of 1960 was down from that in 1959 by a factor of about 5, whereas the total cumulative deposit had only increased by 5 to 10 percent. Thus the milk levels in the summer of 1960 should give for the continent the first estimate of the relative contribution from these sources. Although the data

Table 1. Summary of Sr^{90} and Cs^{137} in North American milk. The numbers in parentheses indicate the number of stations.

Sector	Annual rainfall (in.)	1957		1958		1959		1960		Percent of population
		First half	Year	First half	Year	First half	Year	First half	Year	
		Sr^{90} in micromicrocuries per gram of Ca								
Eastern U.S.	40–60	6.0 (12)	6.5 (32)	7.5 (27)	8.7 (78)	15.8 (27)	11.2 (47)	11.0 (54)		0.46
Northwest coast	40–60	5.2 (8)	4.6 (16)	7.5 (8)	6.8 (19)	13.0 (7)	11.7 (11)	10.8 (9)		0.06
Midwest	20–40	6.5 (16)	6.4 (35)	6.4 (32)	7.5 (87)	10.4 (26)	9.8 (47)	10.5 (67)		0.38
Plains states	10–20	4.6 (10)	6.1 (28)	8.8 (21)	8.7 (63)	11.6 (28)	11.4 (48)	9.1 (50)		0.09
West and Southwest	irrigation	2.2 (13)	2.5 (25)	2.8 (14)	3.4 (28)	9.1 (5)	6.0 (10)	3.5 (19)		0.01
North American av. weighted for population			6.2		8.1		10.7		~7	
North American total diet (est.)			7.4		9.7		12.7		~8	
		Cs^{137} in micromicrocuries per gram of K								
Eastern U.S.	40–60		51 (54)		61 (84)		86 (56)		76 (1)	0.46
Northwest coast	40–60		41 (38)		53 (45)		100 (16)		—	0.06
Midwest	20–40		46 (57)		53 (137)		61 (61)		38 (1)	0.38
Plains states	10–20		47 (45)		51 (89)		60 (45)		55 (4)	0.09
West and Southwest	irrigation		29 (59)		29 (69)		34 (11)		—	0.01
North American av. weighted for population			49.1		56.7		74.3			

are as yet quite limited, the results for the second quarter of 1960 (8.8 $\mu\mu$c of Sr^{90} per gram of Ca) show milk values down by a factor of 2 since 1959 (17.6 $\mu\mu$c of Sr^{90} per gram of Ca). This would suggest that at least half of the Sr^{90} in milk has been a result of direct absorption.

There are some other effects which show that direct absorption was quite important even prior to 1960. The first of these is that the Sr^{89}/Sr^{90} ratio in the milk was about half of that in the rain and much higher than that in the soil. The Sr^{89}/Sr^{90} ratios suggested a mean delay time of 2 mo from the time the Sr^{90} fell in the rain and its entry into the milk. This could result from an equal contribution of very recent (1 mo) Sr^{90} directly from rain mixed with old Sr^{90} from the soil which carried virtually no Sr^{89}. A second point is that the Cs^{137} and Sr^{90} concentrations in milk vary closely with the specific activity of the rain. Figure 1 gives these measurements for the Burlington, Wash., station as well as the average quarterly specific activity of the rain. The concentration of these fission products in the milk is essentially independent of the total rainfall. This same relation holds for the average continental values. Third, Langham and Anderson (*4*) showed that the Cs^{137} values in milk of the plains states are very sensitive to deposition of fresh fission products from Nevada tests. This, coupled with the strong bonding of cesium to the soil and its difficulty of passing to the plant through the roots, suggests that the Cs^{137} absorption occurs largely in the upper parts of the plants, directly from rain. The uniform Sr^{90}/Cs^{137} ratios over a wide variety of conditions indicate that the same mechanism holds for Sr^{90} as well.

When all of the milk data are available for the second and third quarters of 1960, it should be possible to make a fairly reliable prediction of the relative importance of the rate and cumulative factors for the North American continent as a whole.

In the event of a nuclear disaster of local or global dimensions it is desirable to be able to monitor large quantities of food for the long-lived isotopes, Cs^{137} and Sr^{90} in particular. Since the Cs^{137} assay may be done in a matter of minutes with a Los Alamos Scientific Laboratory type of counter, and since the Sr^{90} determination requires many days, it is of interest to determine the accuracy with which the Sr^{90} concentration may be estimated from a Cs^{137} measurement. Powdered milk is ideal in this regard, for it is relatively simple to handle and it may be representative of a large area.

In order to determine the accuracy of such a procedure, the ratios of Sr^{90} per gram of calcium to Cs^{137} per gram of potassium were calculated for all samples of the Los Alamos Scientific Laboratory network for which these data were currently available. The total number of samples was about 800. The North American average over 50 stations and 4 yr was

$$\frac{\mu\mu c\ Sr^{90}/g\ Ca}{\mu\mu c\ Cs^{137}/g\ K} = 0.17$$

with a standard error on this mean of ± 0.02. The *standard deviation* based on the entire array was 44 percent of the mean. Thus a single determination of the Cs^{137} content of a randomly selected powdered milk sample taken anywhere in the United States will give the Sr^{90} concentration well within a factor of 2 in accuracy at the 95-percent confidence level. Such accuracy is

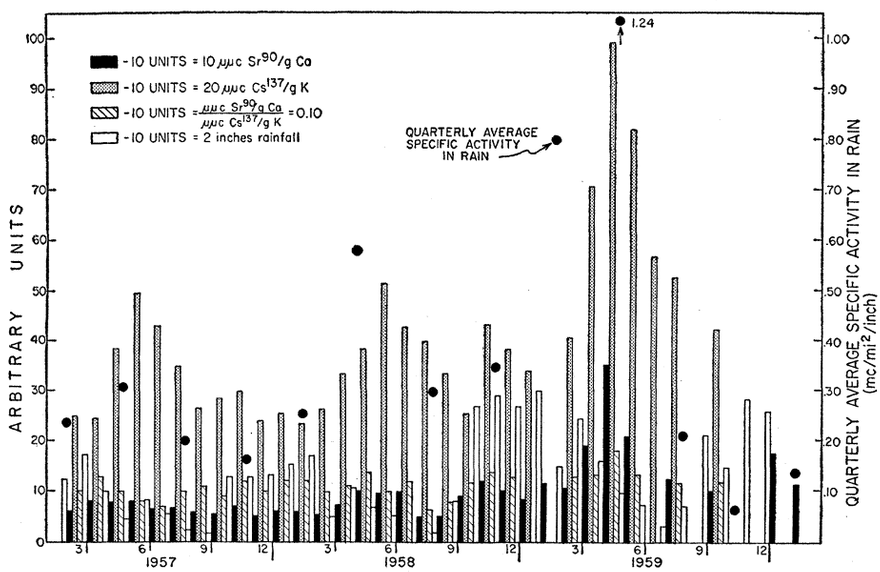

Fig. 1. Comparison of concentrations of cesium-137 and strontium-90 in milk with total rainfall and specific activity of rain at Burlington, Washington, 1957–60.

Table 2. Standard deviations of the average ratios of Sr^{90} to Cs^{137} for five representative stations in North America.

Station	Annual rainfall (in.)	Av. ratio, Sr^{90}/Cs^{137}	Standard deviation (%)
Burlington, Wash.	40–60	0.11	23
Tipton, Calif.	irrigation	0.115	42
St. Albans, Vt.	40–60	0.13	30
Aberdeen, Miss.	40–60	0.27	18
Springfield, Mo.	20–40	0.22	30
			Av. 29

entirely adequate for large-scale monitoring purposes. Presumably the same value would hold for the rest of the Western world and might hold for the whole world. Limited data from a world-wide network of about 15 stations are concordant with this assumption.

A further question, however, is whether the accuracy of the estimate can be improved if the sampling is restricted in some way. First, the standard deviation was calculated for five representative stations for the entire 4-yr period. The results are shown in Table 2.

The combination of the analytical errors probably yields a standard deviation of the ratio of about 15 percent. The average deviation of 29 percent for these five representative stations therefore seems to show a real variation in this ratio in the samples, but it is clear that the estimate of the Sr^{90} concentration from a Cs^{137} assay can be improved if some history is available on the particular station. It can also be observed from these data that the average Sr^{90}/Cs^{137} ratio for a given station remained within the standard deviation from year to year. This suggests that over this period there was no marked difference in the character of the fallout or the relative routes of entry of Cs^{137} and Sr^{90} into grass.

There are significant and reproducible differences in the average Sr^{90}/Cs^{137} ratio between the stations in each group. Thus in the eastern sector, where rainfall is 40 to 60 in. annually, Aberdeen, Miss., has an average ratio of 0.27, whereas St. Albans, Vt., has about 0.15. In the Midwest 20 to 40 in. area, the highest consistent station is Springfield, Mo., with 0.22, and the lowest is LaGrange, Tex., with 0.13. There is no systematic difference with latitude or, within the station variation, with rainfall. Thus the average values for the different groups, each with their standard error of the mean, are: East (40–60 in.), 0.19 ± 0.02; northwest coast (40–60 in.), 0.14 ± 0.02; Midwest (20–40 in.), 0.19 ± 0.02; High Plains states (10–20 in.), 0.19 ± 0.03; West and Southwest (irrigation), 0.14 ± 0.03.

The differences in the average ratio of Sr^{90} to Cs^{137} between individual stations (as much as a factor of 2) appear to be real, but the reason for these differences is as yet obscure.

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2. This article is Lamont Geological Observatory Contribution No. 487. The phase of the investigation carried out at the Lamont Geological Observatory was supported by the U.S. Atomic Energy Commission under contract AT(30-1)-1656. Rieta Slakter Hirshman was in charge of the Lamont analytical program, and Homer McFadden assisted in the laboratory. Various commercial laboratories analyzed most of the samples under contract with the Health and Safety Laboratory of the U.S. Atomic Energy Commission. These included Controls for Radiation, Inc., Isotopes, Inc., Nuclear Science and Engineering Corp., and Tracerlab.
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Transport of Oxygen through Hemoglobin Solutions

Abstract. An expression is derived for the steady-state diffusion rate of oxygen through a solution or suspension of oxygen-carrying particles. Several special cases of interest are discussed and compared with the data of Hemmingsen and Scholander. Their observed dependence of the rate of specific oxygen transport on pressure and *p*H is consistent with the present expression.

The discovery by Scholander (*1*) that oxygen diffuses through hemoglobin solution many times faster than nitrogen has stimulated considerable interest (*2*). More recently, Hemmingsen and Scholander (*3*) showed that this specific transport of oxygen is abolished when the liquid film is opposed by a slight back pressure of oxygen. These investigators also pointed out the need for a unified theory to explain all of their data. In the present report, a simple general expression is derived which not only accounts for their results but which may also be useful as a quantitative guide for further experimental work in this direction.

Consider the portion of liquid enclosed in an imaginary cylinder in the diffusion layer as depicted by the broken line in Fig. 1. Let the axis of the cylinder be parallel to the x-axis, which represents the direction of diffusion, and let A and $x_1 - x_2$ represent, respectively, the cross-sectional area and length of this imaginary cylinder. We have, for the concentration C_i of bound O_2 inside the oxygen-carrying particles:

$$C_i \equiv f(p) = cpL'/L \qquad (1)$$

where c is the concentration of total hemoglobin or myoglobin inside the oxygen-carrying particles; p is the partial pressure of O_2; $L' = dL/dp$; and for myoglobin, $L = 1 + Kp$, and for hemoglobin, $L = 1 + K_1p + K_1K_2p^2 + K_1K_2K_3p^3 + K_1K_2K_3K_4p^4$; and K, K_1, K_2, K_3, and K_4 are equilibrium constants for oxygenation reactions (*4*).

Also, for the concentration C_o of dissolved O_2 in water outside the particles, we have

$$C_o = kp \qquad (2)$$

and for the concentration C_p of dissolved O_2 in the particles, we have

$$C_p = k'p \qquad (3)$$

where k and k' are the Henry's law constants.

Differentiating Eq. 1 with respect to p gives

$$f'(p) \equiv df(p)/dp = c(pLL'' + LL' - pL'^2)/L^2 \qquad (4)$$

where $L'' \equiv dL'/dp$.

The steady-state diffusion rate of oxygen molecules in the x-direction, averaged over the entire volume of the imaginary cylinder, is

$$q = \frac{-1}{A(x_2 - x_1)}\left[\int_{v_o} D_o k \frac{\partial p}{\partial x}\,dv + \int_{v_i} (D_i + D_p)\left\{f'(p) + k'\right\}\frac{\partial p}{\partial x}\,dv\right] \qquad (5)$$

where D_o, D_i, and D_p represent, respectively, the diffusion coefficient of dissolved O_2 outside the oxygen-carrying particles, that inside the particles, and the diffusion coefficient of the particles themselves. The integration of the first term in Eq. 5 is to be carried out over the total volume, v_o, of the imaginary cylinder outside the particles, and the integration of the second term is over the total volume, v_i, inside the particles.