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## *RADIOACTIVE FALLOUT PARTICULARLY FROM THE RUSSIAN OCTOBER SERIES*

BY W. F. LIBBY

GEOPHYSICAL LABORATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON, D.C., AND U.S. ATOMIC ENERGY COMMISSION

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*Introduction.*—Radioactive fallout has been extensively studied and reported upon[23, 25, 26, 30] and, in general, although certain questions remain unanswered, the broad characteristics of its behavior have been established.

The stratosphere, the top fifth of the atmosphere lying above about 40,000 feet, plays an extremely important role. In fact, the fallout from megaton yield weapons occurs very largely from it while the troposphere is the medium which disseminates the fallout from kiloton detonations; thus, speaking broadly, stratospheric debris is from H-bomb detonations and tropospheric fallout is from A-bombs. It is not that the yield of the detonation is determinative, but rather that the altitude to which the fireball rises determines the fallout rates. The megaton yield fireballs are so enormous that they stabilize at levels only above the tropopause—the imaginary boundary layer dividing the upper part of the atmosphere, the stratosphere, from the lower part, the troposphere—while the kiloton yield fireballs stabilize below the tropopause. The tropopause normally occurs at something like 35,000 to 55,000 feet altitude, although it depends on season and location. In other words, low yield bombs fired in the stratosphere would be expected to give the same fallout rates as high yield weapons do when fired in the troposphere—or on the surface. There is some small part of the fallout for megaton yield explosions which does not reach the stratosphere.

The stratospheric debris descends very slowly unless, of course, it is attached to particles so large as to fall in the first few hours, as in the case of surface bursts. This paper is concerned only with the worldwide fallout—that is, the fallout which does not occur in the first few hours—and excludes the local fallout which constitutes the famous elliptical pattern which is so hazardous because of the intensity of its radiation at early times but which, in test operations, is carefully restricted to test areas. It should be noted that the local fallout is a principal hazard in the case of nuclear war. Most serious attention should be paid to it in civilian defense programs.

The worldwide fallout from the stratosphere occurs at a slow rate. The rate of descent of the tiny particles produced by the detonations is so small that something like five years appears to be the average time those from equatorial shots spend before descending to the ground, corresponding to an average annual rate of about twenty per cent of the amount in the stratosphere at any given time.

A principal point of this paper is to present evidence for the theory of Dr. E. A. Martell[1] that shots conducted in polar latitudes have a much shorter stratospheric residence—of about one year. This earlier precipitation of Russian debris has reduced the estimated residence time for equatorial fallout to five years because the method is to compare the observed fallout rate with the stratospheric inventory which necessarily becomes smaller by the earlier subtraction of the Russian polar debris.

It is not clear as to just how the tiny stratospheric particles do finally descend. It seems possible that the general mixing of the stratospheric air with the tropospheric air, which occurs as the tropopause shifts up and down with the season as well as what is brought about by the jet streams, constitute the main mechanisms. The descent of the stratospheric fallout apparently is never due to gravity but rather to the bulk mixing of stratospheric air with tropospheric air which brings the radioactive fallout particles down from the stratosphere into the troposphere where the weather finally takes over. This mechanism makes the percentage rate the same for all particles too small to fall of their own weight—and the same as would be expected for gases, providing some means of rapidly removing the gases from the troposphere exists, so the reverse process of troposphere to stratosphere transfer would not confuse the issue.

The worldwide fallout from the stratosphere descends very slowly, corresponding to residence times of 1 to 5 years depending on latitude, whereas the troposphere has a mean residence time of only one month with the air in the lower 10,000 feet being washed clean on the average about every three days. Between 10,000 feet and the tropopause, which is at something like 35,000 north of 30°N and at about 55,000 feet in equatorial regions between 30°S and 30°N, the residence time is perhaps 45 days for a half time for the troposphere as a whole of about one month. This short time means that radioactive fallout which is injected into the troposphere is restricted to the general latitude of the detonations for the reason that the residence time is so short that it doesn't have time to mix appreciably latitudinally. Similarly, the 1 year residence time for polar stratospheric debris means that it falls out mainly in the Northern Hemisphere because the inter-hemispheric mixing time appears to be longer.

The principal mechanism for precipitation of fallout is rain. Apparently, the tiny fallout particles hit cloud droplets and stick to them, because the particles are so small (perhaps a few hundred atomic diameters) and thus are subject to the violent random jiggling due to collisions with air molecules, the Brownian motion. In fact, for a particle one micron in diameter, Greenfield[2] calculates that the mean residence time in a typical cloud of water droplets of 20 microns diameter would be between 50 and 300 hours, that for a particle of 0.04 micron diameter it would be between 30 and 60 hours, and that for a particle of 0.01 micron diameter it would be between 15 and 20 hours. The theory calculates the diffusion due to the Brownian motion and says that it is in this way that the fallout particles and the

cloud droplets occur. Of course, once the fallout particle is taken into a droplet it is likely to be carried along with the normal weather processes from which rains result.

There is essentially no worldwide fallout in the absence of rainfall; i.e., in desert regions—except for a little that sticks to tree leaves, blades of grass, and surfaces in general, by the same type of mechanism Greenfield describes in the case of clouds. Thus it is that the moisture in the troposphere assures the short lifetime of the tropospheric worldwide fallout particles and, that stratospheric air which contains essentially no moisture* has a much longer residence time. When stratospheric air finally does descend into the troposphere, the tropospheric moisture proceeds to clean it up by the Greenfield mechanism of accretion on to cloud droplets. Actual samples of cloud droplets taken at Mt. Washington, New Hampshire,[3] have shown strontium-90 content per unit volume of water so derived in good agreement with those observed for rain in the same general area. Also, Suess[4] reports that at La Jolla (California) where there is little rain, an open tub, collecting sea spray at the end of a pier, showed strontium-90 content in general keeping with the theory. Of course, the same jiggly diffusive motion which brings the tiny fallout particles into contact with the droplets in a cloud will make contact with leaves of grass and trees, etc., possible as one does observe as previously mentioned.

*Russian October Fallout.*—The intensive series of bomb tests fired by the USSR during last October (1958) affords a unique opportunity to test whether stratospheric radioactive fallout from injections made at polar latitudes differs appreciably in distribution or fallout rates from that due to equatorial explosions, such as the United States and United Kingdom have fired. The Russian October series is estimated, on the basis of assumptions previously described,[5] to have added about 12.5 to 15 megatons† equivalent of fission products to the stratosphere, whereas the previous inventory on the same basis was about 18 megatons equivalent, if we anticipate the result, demonstrated later, that polar debris falls out in about 1 year instead of 5. The Russian addition amounted to a sudden increase of about 150 per cent in the Northern Hemisphere, if we take the previous stratospheric burden to have been uniformly distributed. In addition to the suggestion of Martell[1] that nuclear explosions conducted in the polar latitudes and which inject radioactive fallout into the stratosphere may have a stratospheric residence time of about one year, a time much shorter than for those tests conducted in equatorial latitudes,[5] the Department of Defense[6] has tentatively concluded on the basis of data which it has collected, together with the Atomic Energy Commission's stratospheric balloon data, that the residence time for Polar shots is about one year or less and that equatorial debris has a residence time of about three years.

L. Machta[7] has emphasized that the well-established nonuniformity of the total fallout in the Northern Hemisphere with a peak in the middle latitudes might be due to a natural characteristic of the circulation of the stratosphere which concentrates stratospheric fallout in these latitudes. The author[5] has pointed out the fact that major test sites in the United States and the USSR lie in these latitudes and that tropospheric fallout from these sites which, because it is airborne only one month or so on the average and, consequently has relatively little chance to spread in the North-South direction, could contribute a band of early fallout around the earth in the general latitude of the test site which might account for a large part of the peak. Comparison of foreign with domestic soil strontium-90 data shown in

Table 1 demonstrates that the United States has about 15 mc/mi² more strontium-90 than foreign countries in the same latitudes. This shows that a part of the United States fallout was tropospheric and specifically due to tests in Nevada. The

TABLE 1

U.S. AND FOREIGN SOIL $Sr^{90}$ CONTENTS[3, 8, 9]

| | October, 1956 mc/mi² | October, 1958 mc/mi² |
|---|---|---|
| United States Average | 17.3 | 47 |
| Foreign 20–50°N Average | 6.7 | 30–33* |
| Difference (U.S.—Foreign) | 10.6 | 14 to 17 |

* Foreign samples for 1958 were collected in spring and summer so correlation to October was made by rain data.

data continue to raise the old question as to whether this excess of the Northern Hemisphere over the Southern Hemisphere could all be due to tropospheric debris or might be due in one way or another to stratospheric fallout.

Study of the soil data, together with recent rain data, indicates that the true situation probably lies in a combination of Dr. Martell's theory, Dr. Machta's theory, and a part of the author's model.

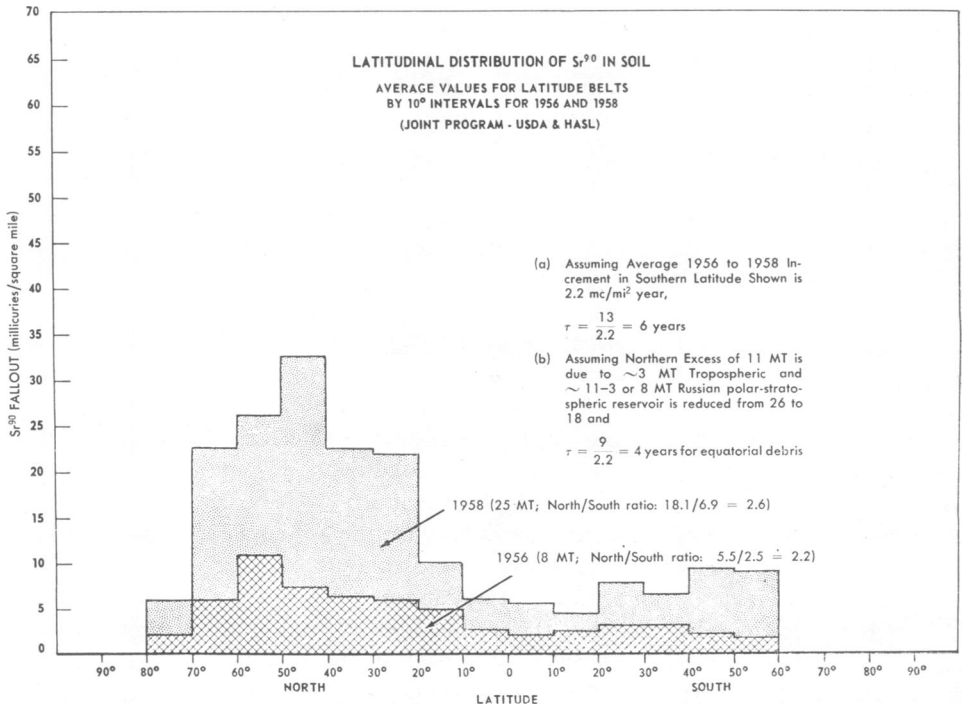


FIG. 1.—Latitudinal distribution of strontium-90 in soil.

Figure 1 presents both the 1956 and 1958 soil data collected from foreign countries by Dr. Lyle T. Alexander[8–9] in the spring and early summer of both years as analyzed by HCl extraction. The 1958 data show that there was a total deposit of about 25 megatons fission energy equivalent of strontium-90 of which about 18 megatons were in the Northern Hemisphere and 7 megatons in the Southern

Hemisphere and that in the Southern Hemisphere where presumably only stratospheric fallout occurred, the rate was 2.2 megatons per year which gives an apparent residence time of about 5 years when compared with the calculated stratospheric inventory of 18 to 22 megatons in that period.

Assuming that the stratospheric fallout in the two hemispheres would be symmetrical for material injected near the equator, that is for the strontium-90 produced by the United States and the United Kingdom megaton test explosions (as indicated

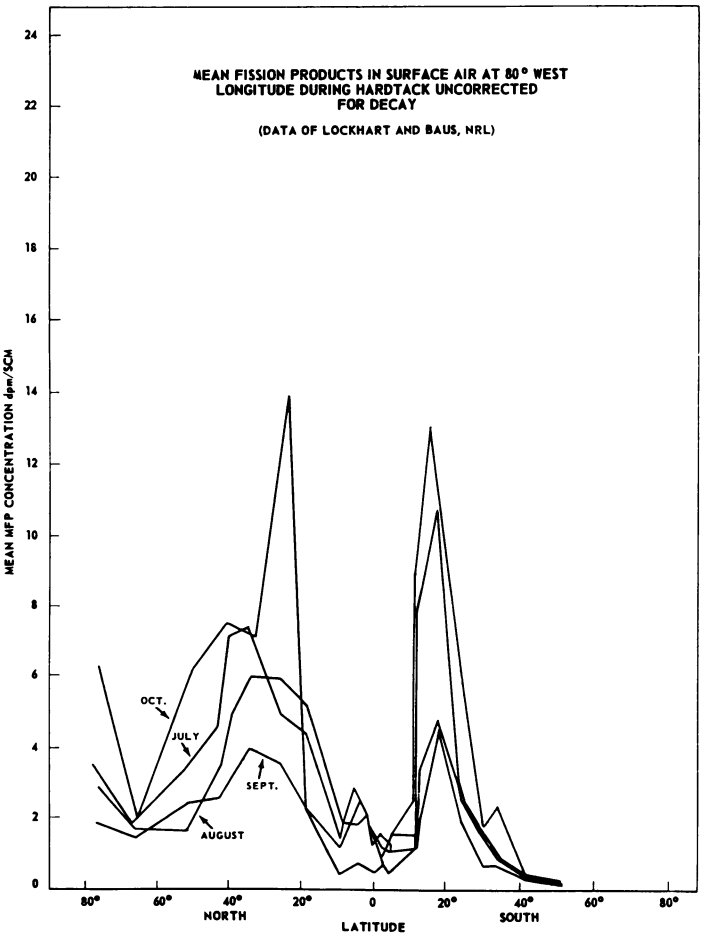


FIG. 2.—Mean fission product content of surface air during Operation Hardtack in 1958.

later by direct observation during Operation Hardtack, cf. Fig. 2) an excess of 11 megatons remain in the Northern Hemisphere. The question is whether this could be due to tropospheric fallout from test sites upwind or whether this must be due in part at least either to preferential leakage from the stratosphere in this latitude (Dr. Machta) or to Russian polar debris which, according to Dr. Martell, would preferentially settle in the Northern Latitudes because it would come down in a time so short, one year or less, that it would not have had time to spread into the Southern Hemisphere.

In the absence of firm direct measurements, an estimate of the stratospheric content is made by adding the amount of radioactivity which is injected, subtracting for the fallout and radioactive decay and calculating by difference. In this way numbers are derived which can be used to compare with the information that is available on stratospheric content and to calculate residence times from the observed fallout rates. Certain empirical rules have been used to estimate the injection numbers. These are:

A. Division between local and worldwide fallout:
   (1) Air shots—no local fallout—100% worldwide

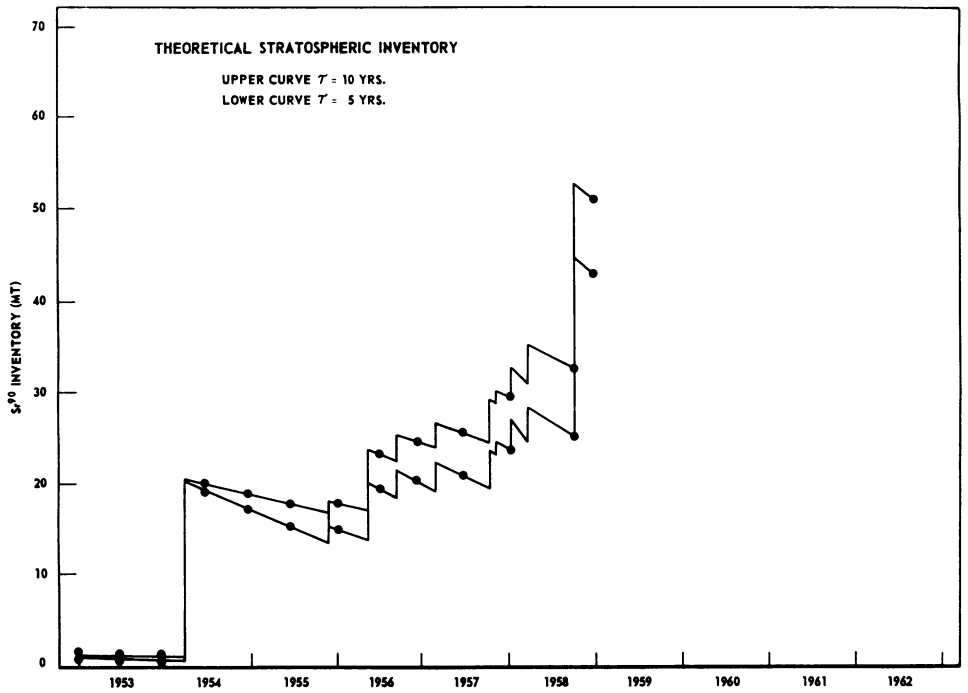


FIG. 3.—Theoretical estimates of strontium-90 in the stratosphere. Two curves are given, one for 10-year half residence time, the other for 5-year half residence time.

   (2) Surface shots on ground—80% local fallout—20% worldwide
   (3) Surface shots on water—20% local fallout—80% worldwide

B. Division of worldwide fallout between stratosphere and troposphere:
   (1) Megaton yields—99% in stratosphere—1% in troposphere
   (2) Kiloton yields—100% in troposphere

Figure 3 gives the stratospheric inventory for strontium-90 as deduced in this manner up to January 1, 1959, calculated on the basis of two assumed residence times—5 and 10 years and neglecting the Martell theory of shorter residence time for Polar shots.

The totality of nuclear releases to date, together with some over-all mention of the firing conditions is given in Tables 2, 3, and 4.

TABLE 2

UNITED STATES AND UNITED KINGDOM NUCLEAR EVENTS
(Yield in Kilotons)

| Year | Total Fission Yield | Total Fission Yield from Events, the Total Yield of Which Was 1 MT or Greater |
|---|---|---|
| 1945 | 60 | |
| 1946 | 40 | |
| 1948 | 100 | |
| 1951 | 500 | |
| 1952–1954 | 37,000 | 36,000 |
| 1955 | 200 | |
| 1956 | 9,000 | 8,000 |
| 1957–1958 | 19,000 | 14,000 |

TABLE 3

SOVIET NUCLEAR EVENTS
(Yield in Kilotons)

| Inclusive | Total Fission Yield* |
|---|---|
| 1945–1951 | 60 |
| 1952–1954 | 500 |
| 1955–1956 | 4,000 |
| 1957–1958 | 21,000 |

TABLE 4

UNITED STATES, UNITED KINGDOM, AND SOVIET NUCLEAR EVENTS
(Yield in Kilotons)

| | Fission Yield* | | | Total Yield | |
|---|---|---|---|---|---|
| Inclusive Years | Air Burst | Ground Surface Burst | Water Surface Burst | Air Burst | Surface Burst |
| 1945–1951 | 190 | 550 | 20 | 190 | 570 |
| 1952–1954 | 1,000 | 15,000 | 22,000 | 1,000 | 59,000 |
| 1955–1956 | 5,600 | 1,500 | 6,000 | 11,000 | 17,000 |
| 1957–1958 | 31,000 | 4,400 | 4,600 | 57,000 | 28,000 |

* A value of 50% has been arbitrarily selected for the fission to total yield ratio for all Soviet thermonuclear tests. As indicated in the tables, 50% is about the average fission to total yield ratio for all U.S./U.K. thermonuclear tests.

Anticipating for the moment the result for which we present evidence presently, namely that Martell's theory is essentially correct, one then should subtract from the 11 megatons excess in the spring of 1958 in the Northern Hemisphere approximately 3 megatons estimated tropospheric fallout from the Northern Latitude test sites to find an excess of some 8 megatons from Russian Polar debris. Now having set aside some 8 megatons of Russian Polar stratospheric injection from the general worldwide stratospheric pool of 26 megatons given in Figure 3, the rate of uniform worldwide fallout observed in the years between 1956 and 1958, 2.2 megatons per year in the Southern Hemisphere on the average, is to be compared with 18 megatons and in this way we calculate that the stratospheric residence time for equatorial injections is between 4 and 5 years, corresponding to a half-life of about 3 years on the average.

In order to study the general rate of spread of the Russian October debris we present in Figure 2 the data of the Naval Research Laboratory (L. B. Lockhart[31]) on the concentration of radioactive fallout mixed fission products at a variety of positions along the eightieth western meridian, for the months in the late summer and early fall of last year when the Pacific Operations were being conducted and terminated and in Figure 4 the analogous results for November, 1958 through

February, 1959 showing the fallout from the Russian October test series. The data in Figure 2 indicate that the equatorial material spreads into both hemispheres in a roughly symmetrical manner. Thus we see that the stratospheric content of equatorially injected fission products in the Southern Hemisphere should not be too greatly different from that in the Northern Hemisphere. Figure 4, on the other hand, shows clearly that this does not happen for Polar debris in the first four

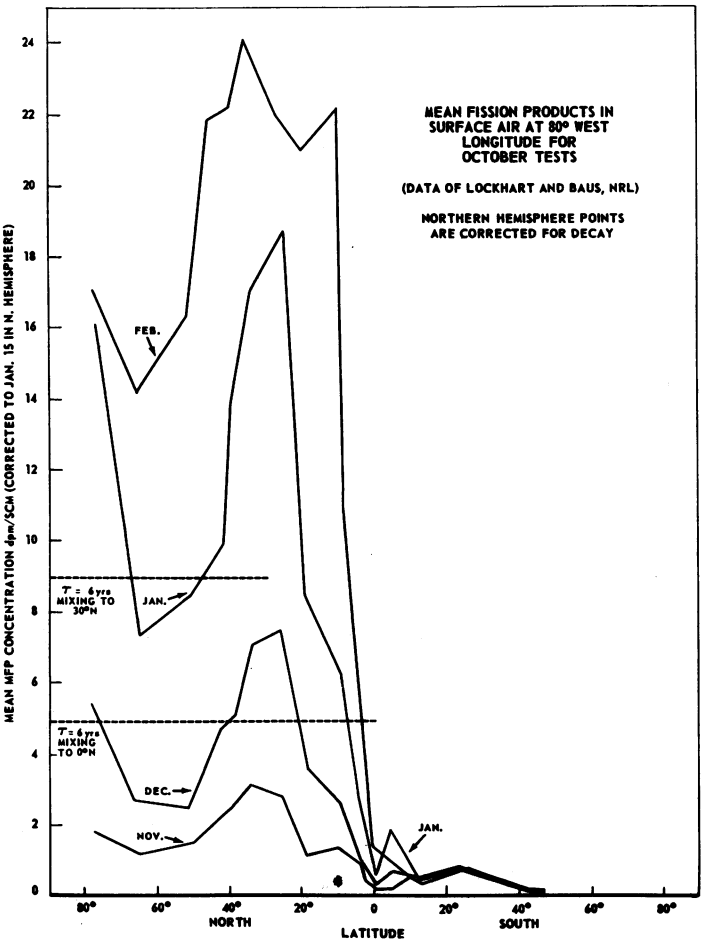


FIG. 4.—Mean fission product content of surface air following Russian October 1958 test series.

months at least, but that mixing seems to have occurred as far south as the equator and to have essentially stopped there up to that time.

Figure 5 shows the data for the stratospheric content of strontium-90 as taken between 50,000 and 90,000 feet altitude in the period November, 1956 to November, 1958 by the ASHCAN balloon borne air filter project. The average concentrations in the 50,000 foot to 90,000 foot altitudes range were 24 ± 2.2 dpm/1,000 SCP at Sao Paulo, Brazil, and 26 ± 2.5 at Minneapolis and 32 ± 4.3 at San Angelo, Texas. From these it seems that the Southern Hemisphere stratosphere may not have been

appreciably lower than the Northern Hemisphere in this period. This conclusion must be taken with reserve, however, since the data themselves show poor internal consistency as regards the $Cs^{137}/Sr^{90}$ ratio and because of the fact that there is only one station in the Southern Hemisphere.

In order to observe the fallout from the Russian October series promptly and with adequate accuracy, the standard procedure of strontium-90 fallout analysis was changed to allow up-to-date analyses of rainfall occurring during the extremely

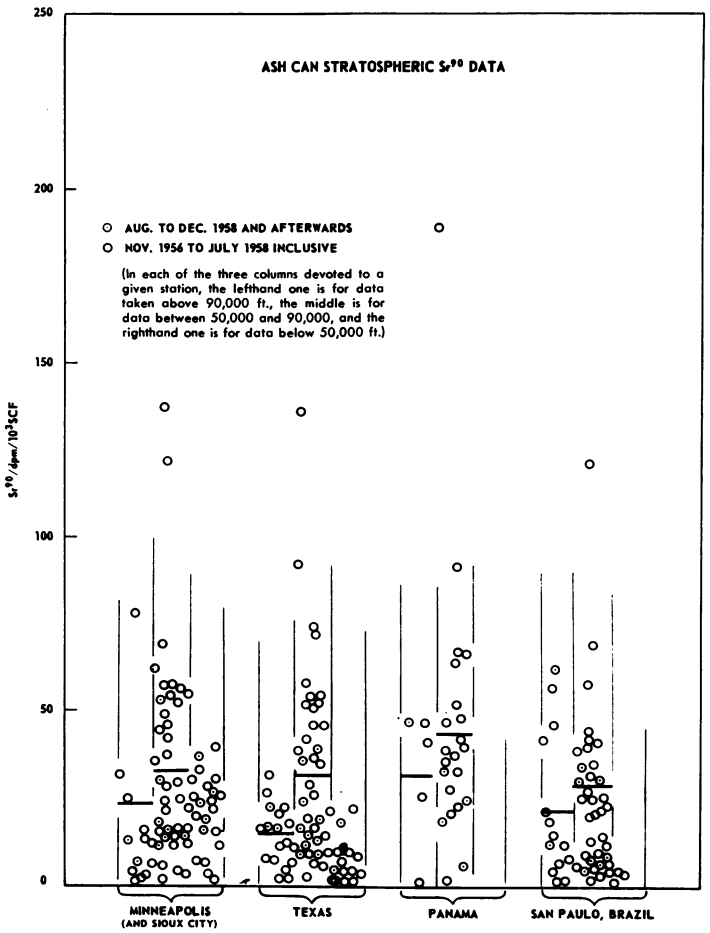


FIG. 5.—Strontium-90 content of stratospheric air.

crucial periods of March, April, and May of 1959. The change consisted in a reliance on the smoothness of the curve of the ratio of $Sr^{89}/Sr^{90}$ (Fig. 6) versus time in view of the fact that no nuclear explosions have been fired recently and the use of the knowledge of this ratio by extrapolation of the curve to allow one to calculate the strontium-90 fallout from a measurement of the total radioactive strontium ($Sr^{89} + Sr^{90}$) in a rainfall sample. This measurement can be made quickly. In this way the data in Figure 7 for rain collected at the Geophysical Laboratory in Washington, D.C. have been obtained and are given in detail in Table 5. They

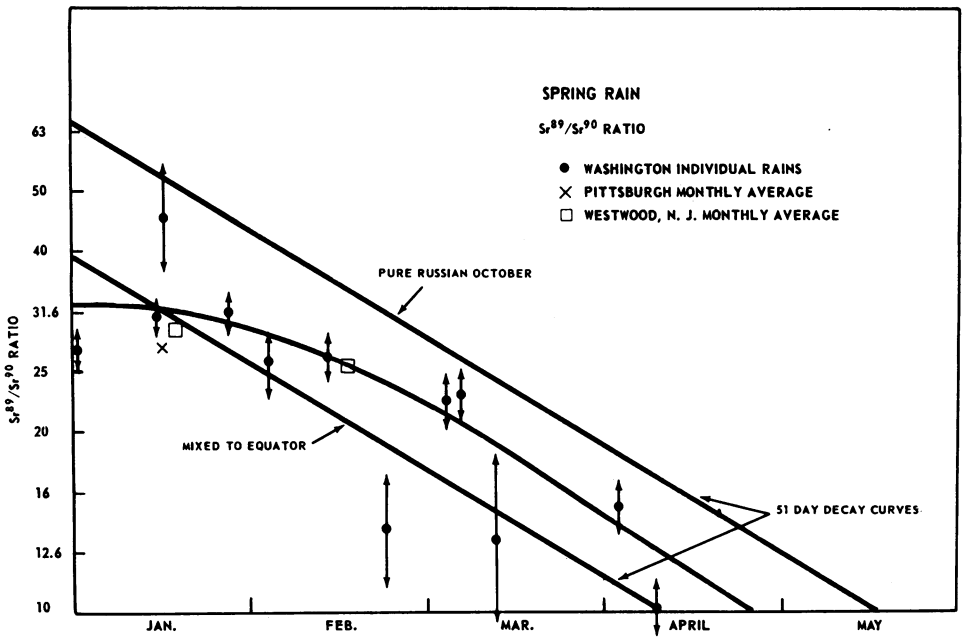


FIG. 6.—Ratio of strontium-89 to strontium-90 in rainwater samples. The samples were collected in the spring of 1959.

## TABLE 5

### SUMMARY OF WASHINGTON RUSSIAN OCTOBER DATA

| Date | Rainfall | $Sr^{89}$ dpm/l on Date | $Sr^{90}$ dpm/l | $Sr^{89}/Sr^{90}$ | $Sr^{90}$ Rate $\mu c/mi^2/in.$ | Incremental $Sr^{90}$ $\mu c/mi^2$ | Total $Sr^{90}$ $mc/mi^2$ |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 0.88 | 203 ± 1.7 | 7.4 ± 0.4 | 27.6 ± 1.7 | 222 ± 14 | 196 ± 11 | 0.20 |
| Jan. 14–15 | 0.12 | 890 ± 9 | 28.6 ± 1.3 | 31.2 ± 2 | 860 ± 37 | 104 ± 5 | 0.30 |
| Jan. 15–16 | 0.34 | 2,230 ± 65 | 48.6 ± 9.3 | 45.9 ± 9 | 1,460 ± 280 | 496 ± 96 | 0.80 |
| Jan. 20 | 0.33 | 639 ± 55 | | (31) | | (202) | 1.00 |
| Jan. 21–22 | 0.42 | | | (31) | | (202) | 1.20 |
| Jan. 26–27 | 0.76 | 1,450 ± 13 | 45 ± 2 | 31.8 ± 1.9 | 1,365 ± 60 | 1,040 ± 46 | 2.24 |
| Feb. 3–4 | 0.43 | 259 ± 3 | 10.1 ± 1.1 | 25.7 ± 3 | 303 ± 33 | 131 ± 14 | 2.37 |
| Feb. 12–14 | 0.75 | 722 ± 15 | 27.1 ± 1.7 | 26.7 ± 2 | 815 ± 51 | 611 ± 28 | 2.98 |
| Feb. 23 | 0.18 | 1,085 ± 40 | 80 ± 14 | 13.9 ± 3 | 2,140 ± 420 | 434 ± 76 | 3.42 |
| Mar. 4–5 | Trace | 950 ± 40 | 42 ± 4 | 22.6 ± 2.4 | 1,260 ± 126 | | |
| Mar. 5–6 | 1.13 | 724 ± 203 | 32.4 ± 2.6 | 23 ± 2 | 974 ± 78 | 1,104 ± 88 | 4.52 |
| Mar. 11–12 | 0.52 | 446 ± 25 | 35 ± 13 | 13 ± 5 | 1,050 ± 390 | 544 ± 203 | 5.06 |
| Mar. 27 | 0.44 | 580 ± 30 | | (13) | | (585) | 5.65 |
| Mar. 30 | 0.30 | 636 ± 36 | | (13) | | (436) | 6.09 |
| Apr. 2 6 A.M. to 1 P.M. | 0.29 | 276 ± 50 | 23.4 ± 2 | 15.3 ± 1.3 | 700 ± 60 | 519 ± 44 | 6.60 |
| Apr. 2 1 P.M. to 5 P.M. | 0.45 | 397 ± 17 | | | | | |
| Apr. 3–4 | 0.69 | 236 ± 16 | | (13) | | (378) | 6.98 |
| Apr. 9–10 | 0.31 | 550 ± 50 | 51.5 ± 3.7 | 10 ± 1 | 1,545 ± 110 | 479 ± 35 | 7.46 |
| Apr. 10–12 | 1.17 | 232 ± 13 | | (12) | | (688) | 8.15 |
| Apr. 19–20 | 0.12 | 1,337 ± 27 | | (11) | | (440) | 8.59 |
| Apr. 27–28 | 0.65 | 553 ± 55 | | (10) | | (1000) | 9.59 |
| Apr. 28–29 | 0.48 | 380 ± 20 | 50.5 ± 15 | 7.6 ± 2.3 | | 730 ± 216 | 10.32 |
| May 2–3 | 0.11 | | | | | (150) | 10.47 |
| May 12–13 | 0.12 | | | | | (180) | 10.65 |
| May 13 | 1.05 | 120 ± 5 | | (8) | | (430) | 11.08 |

The numbers in parenthesis are derived by taking the curve as drawn in Figure 6, calculating from it the expected strontium-89/strontium-90 ratio and using the observed total strontium activity in the sample of rainfall involved to calculate the strontium-90 contribution, and thus to calculate the total fallout in the storm in question.

show an average fallout rate over the last five months of about 2.3 millicuries of strontium-90 per square mile per month, a rate which can only be explained by the Russian October fallout coming down with about a 1-year residence time as Dr. Martell had suggested. Data from Bedford, Massachusetts,[10] Pittsburgh, Pennsylvania,[11] and Westwood, New Jersey,[12] are included in the figure to show the

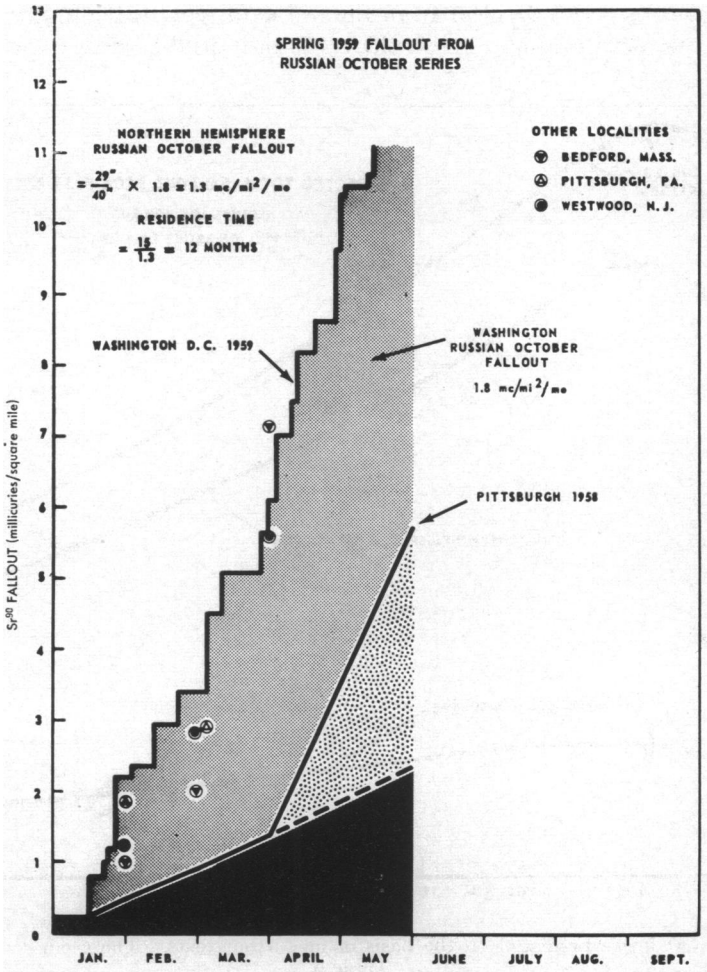


FIG. 7.—Fallout in the spring of 1959 attributed to the Russian October 1958 tests. This chart is based primarily on rainwater samples collected in Washington, D. C., in the spring of 1959. Since corresponding samples had not been collected in Washington in 1958 it was necessary to base the correction curve on 1959 samples from Pittsburgh. After allowing for the difference in rainfall at the two sites, the 1959 data for Pittsburgh are expected to agree with the corresponding Washington data.

general agreement. The mean residence time is calculated, as shown in Figure 7, by subtracting the 1958 rate for Pittsburgh after removing the April, 1958 rise which it showed, presumably due to the Russian tests at the end of February, 1958, and multiplying by the ratio of the mean annual rainfall to that for Washington. Thus we see that there is a difference in residence time for polar and equatorial shots

injecting into the stratosphere and we consequently are led to speculate as to its cause and as to whether the residence time for intermediate latitudes would be intermediate between 1 and 5 years.

The question of the Machta theory of extra rapid stratospheric fallout rates in the middle latitudes remains not completely settled in the author's opinion. However, one point is certainly clear from the soil data seen in Figure 1: the rate of fallout in equatorial latitudes is less than it is in latitudes away from the equator

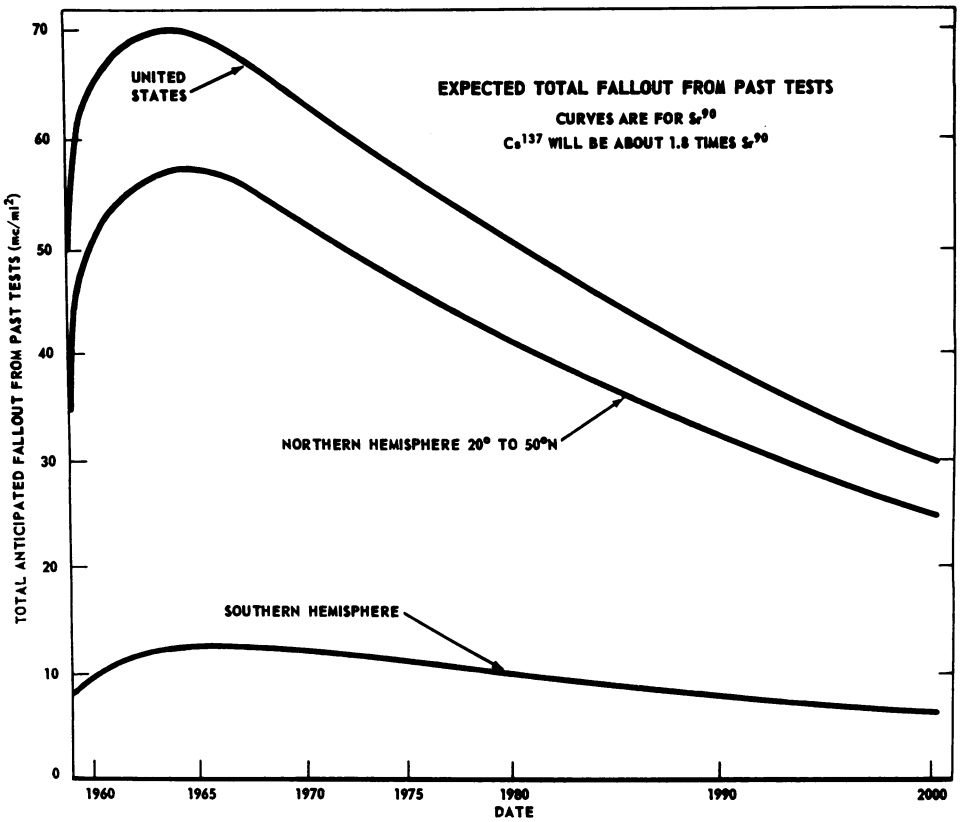


FIG. 8.—Fallout levels predicted on the basis of no further tests. These curves are based on Table 6.

and this is an essential point of Machta-Brewer theory. So it would seem that this feature is correct. Also, the short 1-year residence time for polar injections is in general in keeping with the Machta-Brewer Model of rising stratospheric air in equatorial regions and falling stratospheric air elsewhere, particularly in Polar regions.

*Future Fallout Expected from Past Tests.*—Using the results of Table 1 showing the U.S. to have about 15 mc/mi$^2$ more strontium-90 than equivalent latitudes in other countries and taking the latitudinal profile in these foreign countries as roughly characteristic of Polar stratospheric fallout even though we believe some 3 megatons equivalent of the total excess of 11 in the Northern Hemisphere as of the summer of

1958 had tropospheric origin, we can predict the future fallout to be expected from past tests.

Neglecting for the moment the past and taking only the future beginning January 1, 1959, there are two terms—the Russian October and the worldwide reservoir. Then the total future deposition in the Northern Hemisphere $t$ years after January 1, 1959 would be expected to be

$$[9(1 - e^{-t/5}) + (12.5 \text{ to } 15)(1 - e^{-t})]e^{-t/40}$$

in megatons fission equivalent (or in millicuries of strontium-90 per square mile if spread uniformly), the first term being the uniform stratospheric fallout with a residence time of 5 years and the second being the Russian October with a mean residence time of 1 year. The final factor is for the radioactive decay of the strontium-90.

For any given latitudinal belt the prediction is obtained by using the soil data profile of Figure 1 and adding for the Nevada extra contribution for the U.S. Thus we obtain the results shown in Figure 8 and Table 6. Since the soil data in

TABLE 6

PREDICTED FUTURE FALLOUT STRONTIUM-90 LEVELS FROM PAST TESTS
(millicuries per square mile)

| Year | Average U.S. | Average, Foreign 20°N to 50°N | Average, Southern Hemisphere |
|---|---|---|---|
| 1959 | 50 | 35 | 8 |
| 1960 | 64 | 50 | 10 |
| 1965 | 70 | 57 | 13 |
| 1970 | 64 | 52 | 12 |
| 1975 | 57 | 47 | 11 |
| 1980 | 51 | 42 | 10 |
| 1990 | 39 | 33 | 8 |
| 2000 | 31 | 25 | 6 |

Figure 1 apply to samples taken in the early months of 1958, a correction derived from the rain pot data is made to January 1, 1959. This brings the worldwide fallout (exclusive of the U.S. excess) up to about 30 megatons.

For example, the U.S. average future strontium-90 total fallout in mc/mi² should be obtained from

$$F(t) = [15 + 35 + 9 \times (1 - e^{-t/5}) + (12.5 \text{ to } 15) \times 22/11(1 - e^{-t})]e^{-t/40}$$

In this, the first number 15 is the average U.S. excess from Table 1, the second is the estimated mean in the 20° to 50°N latitude band as of January 1, 1959. The third term is the worldwide fallout using only the 9 megatons that will be expected in the Northern Hemisphere and the fourth is the Russian October term. The asymmetry factor of 22/11 is taken from Figure 1 as the ratio of the average observed fallout in the 20° to 50° band, less the 7 mc/mi² of uniform worldwide, to the hemisphere-wide average of 18 mc/mi² less the 7 mc/mi² also, or 11 mc/mi².

*Bomb Carbon-14 and Tritium.*—As pointed out earlier,[5] the neutrons escaping from a nuclear device during a nuclear explosion in air will make carbon-14 almost quantitatively just as the cosmic ray produced neutrons do in the genesis of natural radiocarbon. As stated previously, as of January 1, 1958, an estimated $10^{28}$ carbon-14 atoms had been injected into the atmosphere, mostly in the stratosphere. The present total figure should be higher in approximate proportion to the total

estimated yields. This is to be compared with a normal stratospheric carbon-14 content of about $9 \times 10^{27}$ carbon-14 atoms so the stratospheric carbon-14 content should have been about doubled.

Data on the rise in carbon-14 content of the troposphere and living matter are given in Figures 9 and 10 and the recent literature.[4, 13–19] From these it is clear that the carbon-14 descent from the stratosphere is not out of keeping with a residence time of several years, possibly five, although our knowledge of the stratospheric reservoir content is imperfect.

The similarity between the rises observed in the Northern and Southern Hemispheres suggest a short latitudinal mixing time of the order of two years or less as pointed out by Fergusson[18] with the Suess fossil fuel $CO_2$ effect, and Broecker and

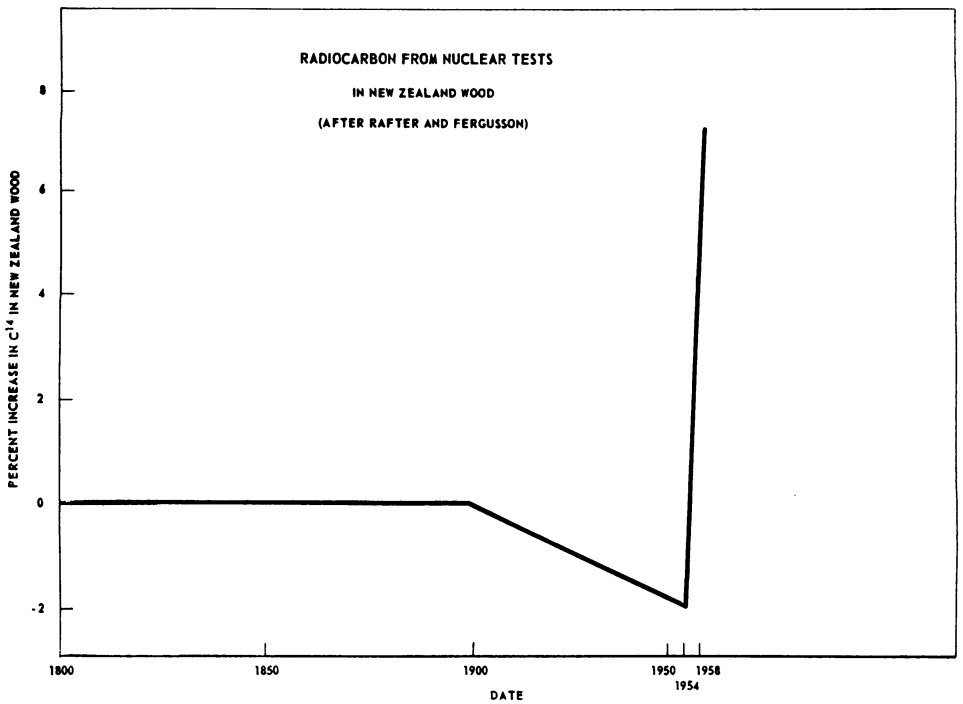


FIG. 9.—Effect of radiocarbon from nuclear tests on the radiocarbon content of wood. Decrease prior to 1954 is attributed to combustion of fossil fuels; increase after 1954 to nuclear tests.

Walton[14] with the bomb carbon-14. The estimates of the amount by which bomb carbon-14 will raise the general carbon-14 level when complete mixing with the oceans has occurred has risen from 0.3 to about 0.4 or 0.5 per cent now due to the firings during 1958.

Of course, in the short time range before the deep ocean mixes, the concentration of radiocarbon in the biosphere will rise as the stratospheric material descends. If the total exchangeable carbon reservoir in the top layer of the ocean and the troposphere and biosphere is X times that in the stratosphere and the present carbon-14 increases in the stratosphere is, say 200 per cent, then we must expect 200/X per cent as the eventual increase in the troposphere, biosphere, and top ocean. Since X is about 14 we should then expect an increase of about 14 per cent

which would last for several years. If the mixing with the top ocean is slow relative to the mixing of the atmosphere there may be a rise above this value for a few years after which it will settle back and gradually, over a matter of several centuries, fall to the 0.4 to 0.5 per cent value, depending on the time required to mix with the deep ocean. Subsequent to this it will decay with its 5,600 year half-life.

The movement of the bomb carbon-14 should help considerably in solving the remaining mysteries of atmospheric mixing patterns and storage times.

Several points about the biological effects of this carbon-14 have been made in recent publications.[20-22]

As has been remarked previously, all of the hydrogen bombs release a considerable

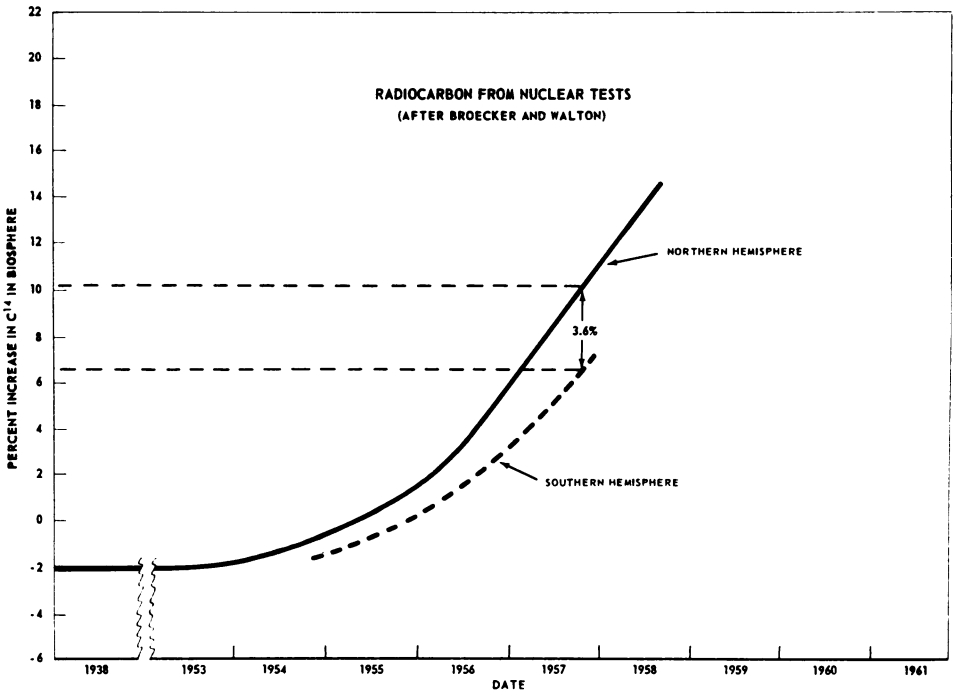


FIG. 10.—Effect of radiocarbon from nuclear tests on the radiocarbon content of the biosphere.

amount of tritium but because the devices previously have always been fired in the troposphere only a part of the radioactive water formed from this tritium has remained in the stratosphere. This is because a large quantity of water is incorporated in the fireball under these conditions with the result that when the fireball rises into the stratosphere and cools it makes the familiar white cloud consisting of rather large ice crystals which fall rather quickly and thus carry a considerable part of the tritium back to the troposphere again. This did not happen for the two devices fired over Johnson Island in the stratosphere in August, 1958 and, therefore, we can expect a relatively large increase at this time in the stratospheric tritium water content over that the cosmic rays have put into the stratosphere *naturally*. The quantities produced by the bombs could well raise this *natural* level several hundred fold.

The stratosphere is so low in moisture (a fair estimate seems to be about 10 milligrams per square centimeter of the earth's surface for the entire stratosphere as compared to something like 2 to 3 grams per square centimeter for the troposphere) that the concentration of the cosmic ray tritium in the stratospheric moisture should be very high, something like in the inverse ratio of the water concentrations, together with an additional factor for the 5 year storage time of the cosmic ray produced tritium.

In substance, the hydrogen bombs fired over Johnson Island made tritium water in large quantities in the stratosphere and it is to be expected if the simple uniform model for equatorial injections is correct, that the rains all over the world will show a stratospheric tritium drip as well as the stratospheric strontium-90-cesium-137 fission product drips which have been occurring for years. But this stratospheric tritium drip probably will have had its zero time in August of 1958 since earlier tropospheric firings probably added relatively less. This tritium should be useful in studying the normal hydrological cycles of the atmosphere and hydrosphere and the circulation patterns of the oceans. So it is with real interest that we look forward to the next few months of rainfall to determine the mechanism by which moisture in the top part of the world's atmosphere mixes with the lower stratosphere and with the troposphere and the land and ocean waters. This may prove to be an important contribution to meteorology and geophysics if it develops as expected.

A further point is that the Russian October shots having been fired in cold dry Polar air may have left more in the stratosphere than other tropospheric explosions and this coupled with the shorter residence time of the Martell theory should add appreciably to the Johnson Island tritium water fallout in the Northern Hemisphere.

A crude theory based on the assumption that about half of the water in the ice crystals in the equatorial stratospheric clouds evaporates before the crystals fall down into the troposphere and using a yield of tritium proportional to the fusion yields from Tables 2, 3, and 4, and assuming Martell's theory is correct for Polar shots, predicts a value of 800 to 1,000 tritium units ($10^{-18}$ T's per H atom) for rain in the Northern Hemisphere in the spring and summer of 1959. This, though a level entirely safe from a health standpoint, makes the measurement of tritium contained in rain and surface water at such levels relatively simple.

* The total water in the stratosphere is about 0.01 gm/cm$^2$ or less, while that in the troposphere is about 2 gm/cm$^2$, 200 times as much.

† It is useful to note that 1 megaton fission spread uniformly worldwide gives $^1/_2$ mc $Sr^{90}$/mi$^2$ or if restricted to one hemisphere and spread uniformly gives 1 mc/mi$^2$.

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# *GENETIC RECOMBINATION BETWEEN ESCHERICHIA COLI AND SALMONELLA TYPHIMURIUM**

BY L. S. BARON, W. F. CAREY, AND W. M. SPILMAN

DIVISION OF IMMUNOLOGY, WALTER REED ARMY INSTITUTE OF RESEARCH, WASHINGTON, D.C.

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*Introduction.*—The phenomenon of genetic recombination by sexual mating in bacteria, described by Tatum and Lederberg[1] has been investigated intensively by Lederberg *et al.*[2] and many other workers. These classical studies were carried out almost entirely with the K-12 strain of *Escherichia coli*, although comparable results were obtained with a small number of other strains of *E. coli*.[3,4]

In further studies, Cavalli[5] found that the frequency of recombination could be greatly increased by using a highly fertile mutant of the K-12 strain. Additional high frequency of recombination (Hfr) strains of K-12 have been isolated in a number of laboratories.[6,7] The concept of compatibility among certain K-12 derivatives has led to a detailed description of the fertility factor (F), so that it is now understood that mating consists of a unilateral contribution of genetic material from the Hfr or the $F^+$ strain to the recipient Hfr, $F^-$ or $F^+$ organism.[8–11]

In an attempt to demonstrate recombination between diverse species of bacteria, Zinder and Lederberg[12] discovered another mode of genetic transfer involving bacteriophage particles as vectors of genetic material. Intensive investigation of this phenomenon, referred to as genetic transduction, was undertaken by Stocker *et al.*,[13] Lederberg and Edwards,[14] and Zinder,[15] using the phage PLT-22. Studies of additional bacterial viruses competent in transduction have been reported by Baron *et al.*,[16] Spilman *et al.*,[17] Sakai and Iseki,[18] Lennox,[19] and Morse *et al.*[20] Many of these results have dealt with the phage-mediated transfer of genetic material between different species of bacteria and even organisms classified in different genera have been altered by a suitable phage.[19]

Genetic recombination between bacteria of different genera, however, has only recently been reported by Luria and Burrous[21] with the demonstration of mating between *E. coli* K-12 and various species of Shigella. The results of these workers have indicated the presence of the same fertility system in Shigella species as is known to exist in the *E. coli* mating strains. Attempts at recombination of *E. coli* with Salmonella species by a number of workers, however, have been uniformly negative.