DISTRIBUTION OF MAN-MADE RADIOACTIVITY IN THE NORTH PACIFIC THROUGH SUMMER 1955

By

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ABSTRACT

The radioactivity which originated from the Bikini and Eniwetok tests in the spring of 1954 was transported mainly to the west, then to the north toward the coast of Japan, and finally down south along the Kuroshio Current by summer 1955. Activity in contaminated areas where activity in sea water was greater than 0.1 $\mu\mu$c of Sr^{90}/l averaged 4.2×10^6, 1.9×10^7 and 2.7×10^7 km^2 respectively in June 1954, March–April 1955, and August–September 1955. In spring 1955 the activity extended down to about 600 m below the surface. Vertical distribution of radionuclides might be influenced less by vertical migration and decomposition of marine life than by physical mixing. A horizontal eddy diffusion coefficient of 0.8–1.4×10^9 was obtained from the time change of distribution of radioactivity in the ocean.

Large scale contamination of the ocean due to man-made radioactivity was confirmed during the first Japanese Bikini Expedition (Miyake, *et al.*, 1954), conducted aboard the observation ship Shunkotsu-maru in May and June 1954. This expedition was undertaken about one month after Castle Test at the Bikini-Eniwetok proving ground in spring 1954. In sea water, maximum activity of 91,000 dpm/l was found 450 km west of Bikini, and activity of more than 1,000 dpm/l was distributed as far as 2,000 km WNW of Bikini along the North Equatorial Current. In plankton the highest value was 800,000 dpm/g wet weight.

From 25 February to 3 May 1955, the U.S. Atomic Energy Commission, in co-operation with Scripps Institution of Oceanography and the Applied Fisheries Laboratory of the University of Washington (U.S. Atomic Energy Comm., 1956), carried out a transoceanic expedition in the Pacific aboard the U.S. Coast Guard Cutter Taney for the purpose of measuring radioactivity. Results showed that lower activity than that observed previously, ranging from 0 to 570 dpm/l in sea water and from 3 to 340 dpm/g wet weight in plankton, was diffused over a larger area than before. The highest

activity was located off the coast of Luzon Island in the Philippines, and some activity still remained in water along the North Equatorial Current. In summer 1955, the North Pacific Expedition (NORPAC), carried out through international co-operation of Canada, Japan and United States, found that slight (0–30 dpm/l) but wide-spread activity remained in the water in a large part of the western North Pacific, maximum activity being observed along the Kuroshio Current off the coast of Japan.

Again, from May to July 1956, about ten nuclear tests at the Bikini and Eniwetok area brought about further contamination in the Pacific. According to results of the second Japanese Bikini Expedition (Fisheries Agency, Japan, 1956), conducted from 26 May to 30 June 1956, the activity in sea water was lower than that in 1954 by a factor of ten. These lower values resulted from the facts that the observations were made during an earlier stage of the test series and that the observation points were located more than 900 km from the test site as compared to those in 1954. Also, most of the explosions took place at a higher altitude than in 1954, which diminished the direct contamination of the sea surface. However, note that considerable activity was found not only along the North Equatorial Current but also in the region of the Equatorial Counter Current, where little activity had been observed in 1954. According to observations, there was a remarkable correlation between the activity of falling dust on the deck and in the sea. Therefore, contamination of the sea water in May and June 1956 may well have been due mainly to direct fall-out of air-borne dust rather than to transport of contaminated sea water from the test area by ocean currents.

In July and August 1956, the Equatorial Pacific Expedition (EQUAPAC), undertaken by oceanographers of Canada, France, Japan and United States, found that radioactivity was concentrated in the sea area of 5–15° N and 145–165° E. The highest activity, 193 dpm/l (evaluated one year after sampling), was found near 10° N, 160° E. Only a trace of fission product was detected either in the area south of the Equator or east of 180° W. In September 1956 a survey of radioactivity was made by the U.S. Atomic Energy Commission in collaboration with the Applied Fisheries Laboratory of the University of Washington (U.S. Atomic Energy Comm., 1957) in an area bounded by 09° and 15° N and approximately 145° and 166° E. The highest value for water activity was 19,000 dpm/l,

TABLE I. RADIOACTIVE CONTAMINATION IN NORTH PACIFIC WATERS (1954–1955)
UNIT: $\mu\mu c$ Sr^{90}/l

	Period	*Contaminated Area where Activity was* $>0.1\,\mu\mu c/l$	*Maximum Activity Observed* ($\mu\mu c/l$)	*Maximum Average Activity of Water Column* ($\mu\mu c/l$)	*Average Activity as* Sr^{90} ($\mu\mu c/l$)	*Total Amount of* Sr^{90} (*mega C*)
First Shunkotsu Expedition	31 May–30 June 1954	4.2×10^6	194* 11°05′ N 160°12′ E 80 m	45* down to 100 m	7* down to 100 m	2.6 + X
Operation Troll	9 March–13 April 1955	1.9×10^7	3.9 21°30′ N 124°45′ E 0 m	1.8 down to 400 m	0.4 down to 400 m	3
Norpac Expedition	August–September 1955	2.7×10^7	0.5 28°25′ N 129° E 0 m	0.5 down to 500 m	(>0.1) 0.2 (<0.1) 0.03 down to 500 m	3**

* Except near the test site.

** In which 0.1 Mega Curie of Sr^{90} is attributed to fall-out. Contribution of fall-out may be about 0.5 Mega Curie at present, which is equivalent to 0.02–0.1 $\mu\mu c/l$ according to depth of contaminated layer.

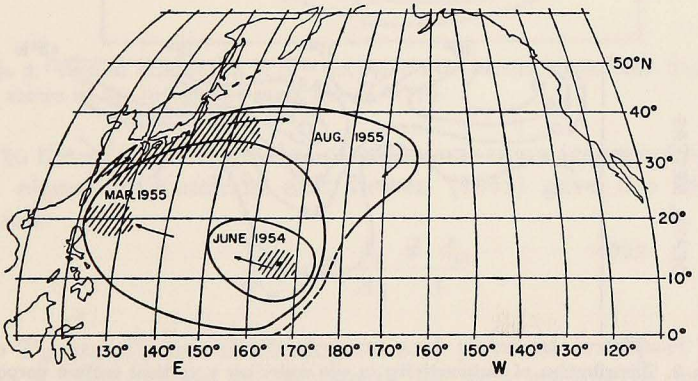

Figure 1. Radioactive contamination in the North Pacific. Shaded areas represent those of maximum contamination.

between Eniwetok and Ujelang, and the lowest value was 48 dpm/l, northeast of Bikini; the highest value in plankton, 21,000 dpm/g wet weight, was found about 1,300 km north of Eniwetok, and the lowest value, 27 dpm/g, was obtained near Guam.

In this study of radioactive contamination in the North Pacific through summer 1955, the activity in sea water was converted to the value of Strontium-90 (assuming that Hunter-Ballou's table is applicable) in order to make the activities comparable with each other. Results are summarized in Table I and Fig. 1. As shown in Fig. 1, the activity which flowed out from Bikini was transported mainly to the west, then to the north toward the coast of Japan, and finally down south along the Kuroshio Current. Note that the contaminated area is located mainly in the western half of the North Pacific.

Vertical distribution of radioactivity in sea water is shown in Figs. 2 and 3. Fig. 2 shows that in June 1954 it was limited to the mixed layer above the thermocline. In March 1955, however, the activity extended down to about 600 m below the surface, the thermocline being present at a depth of 75 m.

According to Steemann Nielsen (1952), organic productivity in the sea, expressed as grams of fixed carbon per square meter, is 0.2 g C/day/m^2 or 73 g C/year/m^2 in the tropical Pacific. If the thickness of the euphotic zone is assumed to be 100 m, then the rate of formation of organic matter in a year is only 0.7 mg C/l or about 2.7 mg/l of planktonic organisms. Assuming that the enrichment factor of radionuclides in marine organisms is 10^3, the

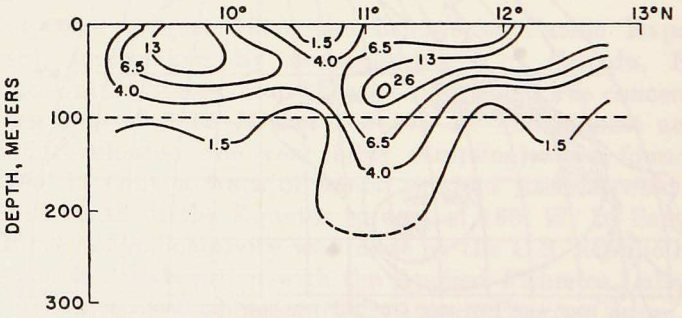

Figure 2. Distribution of radioactivity in sea water on a vertical section perpendicular to the North Equatorial Current along a line 570 km west of the Bikini Atoll, June 1954. The thermocline is shown as the broken line (unit, $\mu\mu c$ of Sr^{90}/l).

fraction of activity in organisms is only 0.3 % of that in sea water. Therefore, decomposition of sinking marine life may not be the cause of contamination of sea water below the thermocline.

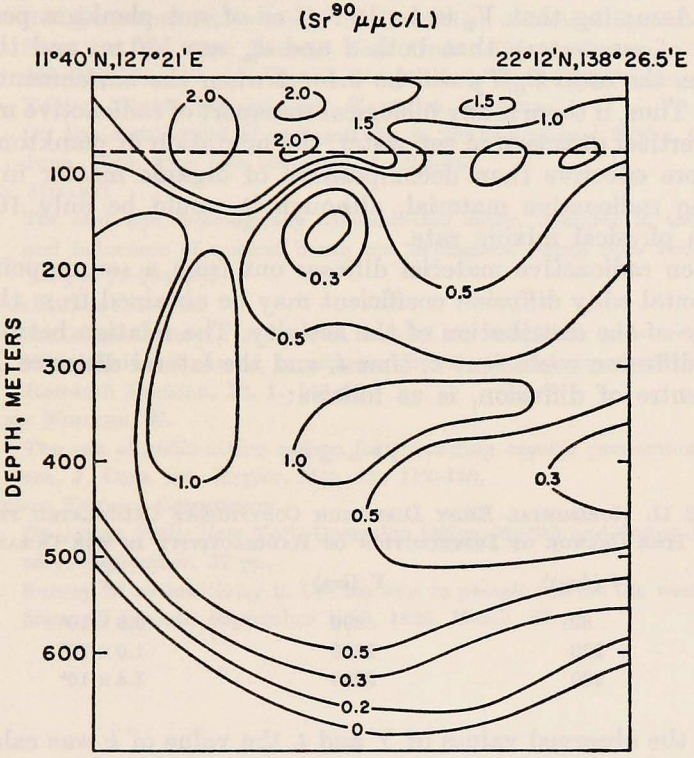

Figure 3. Vertical distribution of Sr^{90} in the North Pacific, March 1955. The thermocline is shown as the broken line (unit, $\mu\mu c$ of Sr^{90}/l).

As to the effect of migration of organisms upon transport of easily labile elements, Ketchum and Bowen (1958) gave the following equation:

$$\frac{T_B}{T_P} = V_0 \frac{f_0}{A_z} \cdot \frac{d \cdot d_m}{t},$$

where T_B and T_P are the biological and physical transport respectively; V_0 the volume of organisms per unit volume of water; f_0 the ratio of concentration of the element in the organism to the

total concentration in the water; A_z the vertical coefficient of eddy diffusion; d the depth of the gradient zone; d_m the distance over which the organism migrates; and t the period of migration. Miyoshi (1956) gave about 5 to 10 cm²/sec as the value of A_z near the Bikini area. Assuming that V_0 is 1×10^{-6} (1 cc of wet plankton per cubic meter of sea water), that both d and d_m are 100 m, and that t is 10^5 sec, the ratio T_B/T_P will be 0.1–0.2 when the enrichment factor is 10^3. Thus, if there is any biological transport of radioactive material in a vertical direction in sea water, the migration of plankton might be more effective than decomposition of organic matter in transporting radioactive material, although it would be only 10–20 % of the physical mixing rate.

When radioactive material diffuses out from a source point, the horizontal eddy diffusion coefficient may be obtained from the time change of the distribution of the activity. The relation between the eddy diffusion coefficient k, time t, and the lateral distance Y from the centre of diffusion, is as follows:

$$Y^2 = 2\,kt.$$

TABLE II. Horizontal Eddy Diffusion Coefficient Calculated from the Time Change of Distribution of Radioactivity in the Ocean

t (*days*)	Y (*km*)	k
60	890	0.8×10^9
270	2100	1.0×10^9
420	3200	1.4×10^9

From the observed values of Y and t, the value of k was calculated and is given in Table II.

According to Inoue (1950), the horizontal eddy diffusion coefficient k for oceanic turbulence may be expressed as follows:

$$k = 0.01\,L^{4/3} \qquad (10^{10}\text{ cm} > L > 10\text{ cm}),$$

where L is the magnitude of diffusion phenomena in the ocean.

By putting the value of k into the above equation, $\log L = 8.1-8.4$ was obtained, which corresponds with the observed value of $\log Y = 7.9-8.5$.

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