

Penetration of ^{90}Sr and ^{137}Cs in deep layers of the Pacific and vertical diffusion rate of deep water

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ABSTRACT

Vertical penetration of Sr 90 and Cs 137 down to 5,000 m depth was confirmed in the western North Pacific. Surface values of these radionuclides range from 0.6 to 3.1 $\mu\text{C}/\text{L}$ for Sr-90 and from 0.8 to 4.8 $\mu\text{C}/\text{L}$ for Cs-137, while at 5,000 m depth both nuclides of about 0.1 $\mu\text{C}/\text{L}$ were determined. From the vertical variation in the concentration of radio-nuclides, the vertical diffusion coefficient from 200 m to 4,000 m depth was calculated and the value of 200 was obtained. Time required to attain practically a homogeneous vertical distribution of substances which is put in the western part of the north Pacific Ocean would be a few hundred years.

1. Determination of ^{90}Sr and ^{137}Cs in deep waters.

The vertical penetration of artificial radioactivity in the open ocean was first observed in June 1954 by Miyake, Sugiura and Kameda (1954) near Bikini area in the Pacific. They observed considerable activity from the surface to the depth of about 100 m depth. Most of the activity was confined to the mixed layer above the thermocline. A half year later, however, the survey carried out aboard the US Coast Cutter Taney (Operation Troll, USAEC, Harley, editor, 1956) found that the radioactivity had arrived at about 1,000 m depth below the sea surface (see also Miyake and Saruhashi, 1958). In the Atlantic, Bowen (1960) studied the vertical distribution of Sr-90 both north and south of the equator. He found that an average

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concentration from the depth of 300–700 m of about half the surface value. Appreciable concentration of Sr-90 was present at 1,000–1,200 m, but no activity was detected below 4,000 m.

The study of artificial radioactivity in the Pacific has been undertaken by the present authors for several years and some of analytical results regarding surface values of Sr-90 and Cs-137 were already published (Miyake *et al*, 1960, 1961). Recently determination of Sr-90 and Cs-137 in deep waters was done in our laboratory results of which showed the vertical penetration of these radionuclides down to 5,000 m depth.

The detailed procedure of radiochemical analyses of Sr-90 and Cs-137 in sea water were already described. Sr-90 was precipitated from sea water as strontium nitrate while Cs-137 was separated by its adsorption on the solid ammonium phosphomolybdate. Deep water samples were collected with Van Dorn type water sampler aboard the research vessel M. S. Ryofu-maru (1,200 tons) which belongs to Japan Meteorological Agency. From 50 to 100 liters of each sample was subjected to the radiochemical analysis.

The measurement of beta activity of Sr-90 was done with a thin wall type counter of 0.5 cpm back ground. In order to check the Sr-90 value, beta activity of Y-90 was also measured after milking when a gas flow counter of back ground 0.8 cpm was employed. The agreement between β ray measurements of Sr-90 and Y-90 was satisfactory. The measurement of activity of Cs-137 was performed with a gamma ray spectrometer equipped with a sodium iodide scintillator (2"×2") at the energy range from 0.52 to 0.80 Mev. The Cs-137 standard supplied by the Japan National Electrotechnical Laboratory (10⁴ dps/ml) was used as a references by preparing dilute solutions of given activities from the original standard solution. Contamination from reagents and other radionuclides was negligible.

Results of determination of Sr-90 and Cs-137 in deep waters collected at various points in the western part of the North Pacific down to 8,000 m were summarized in Table 1 and Fig. 1.

Table 1 Sr-90 and Cs-137 in deep waters (North Pacific)

Sample No.	Date	Location		Depth m	Sr-90 $\mu\mu\text{c}/\text{l}$	Cs-137 $\mu\mu\text{c}/\text{l}$	Cs-137/Sr-90
586 D	1958-11-11	15°01.5' N	134°58' E	3,000	0.1 ₂ ± 0.0 ₂	0.1 ₉ ± 0.1 ₀	1.6
587 D	11-15	00°02.5'	136°00'	3,000	0.1 ₄ ± 0.0 ₂	0.3 ₀ ± 0.1 ₃	2.1
588 D	8-7	29°51.5'	131°56.7'	1,000	0.6 ₀ ± 0.0 ₅	0.6 ₀ ± 0.2 ₀	1.0
589 D	11-7	29°55'	134°52'	3,000	0.6 ₀ ± 0.0 ₅	0.6 ₀ ± 0.2 ₀	1.0
594 D-1	1959-9-13	40°22'	144°34'	3,000	0.1 ₂ ± 0.0 ₂	0.1 ₈ ± 0.0 ₈	1.5
594 D-2	9-13	40°23'	144°31'	6,000	0.0	0.0	
595 D-1	9-15	40°38'	147°19'	2,100	0.2 ₁ ± 0.0 ₂	0.4 ₅ ± 0.1 ₀	2.1
595 D-2	9-15	40°35'	147°15'	5,000	0.1 ₃ ± 0.0 ₂	0.1 ₂ ± 0.0 ₂	0.9
597 D	3-14	11°11'	142°20'	3,000	0.2 ₀ ± 0.0 ₂	0.1 ₈ ± 0.1 ₀	0.9
601 D	1960-5-23	29°59'	144°29'	4,000	0.0 ₇ ± 0.0 ₁	0.1 ₀ ± 0.0 ₇	1.4
602 D	5-28	30°10'	142°33'	8,000	0.0	0.0	
							Av. 1.4

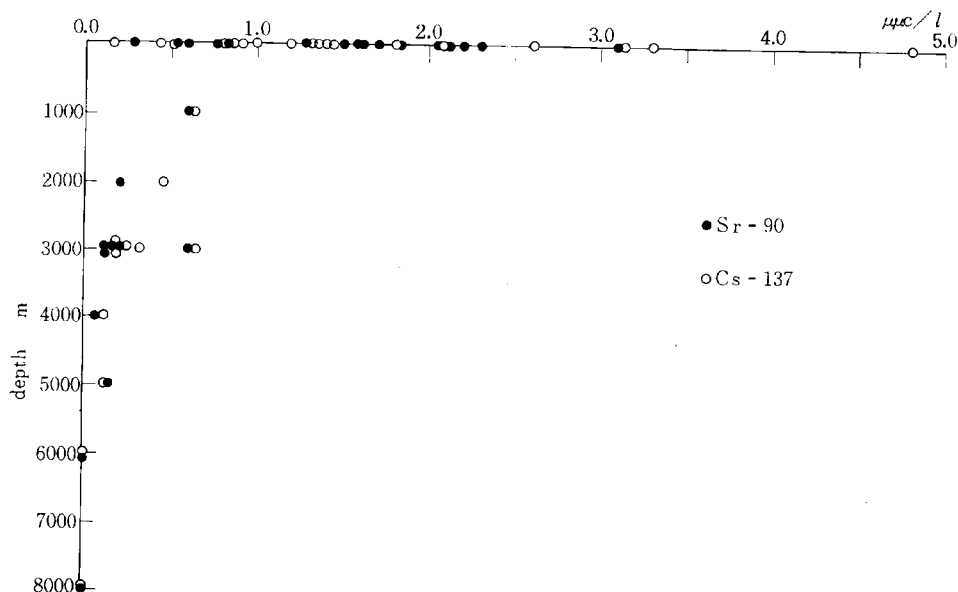


Fig. 1 Vertical distribution of Sr-90 and Cs-137 in sea water

The locations of collecting deep water samples are given in Fig. 2. As shown in the Table 1 both Sr-90 and Cs-137 were found through the depth of 5,000 m while no activity was detected below 6,000 m. The vertical gradient in the radionuclide concentration was larger near the surface which indicates the difficulty of penetration of the nuclides through the thermocline into the deep layer, while it was much smaller in the deeper layer showing the faster mixing rate. It is also to be noticed that the ratio of Cs-137 to Sr-90 was 1.4 on an average which is about the same to that in surface water. The reason of the lower ratio of Cs-137/Sr-90 in sea water than that in fallout (1.5–2.9) was discussed already in the previous paper (Miyake, Saruhashi, Katsuragi and Kanazawa, 1961).

2. Estimation of vertical diffusion rate of sea water.

In regard to penetration of substances dissolved in sea surface water into deeper layers, there are three possible processes, (1) physical mixing, (2) sinking of particulated matter both inorganic and organic, (3) biological transport.

Since both the strontium and the cesium are present in oceanic waters as true ionic solutions, the process of sinking of particulated matter can be ignored. As to the biological process, Ketchum and Bowen (1958) discussed about the effect of migration of organisms on the vertical transport of easily labile elements which are apt to be concentrated in living matters. However, as it is well known that the enrichment factors of the strontium and the cesium in marine organisms from sea water are low, biological transport may not be effective for these radionuclides. In addition, the same ratio of Cs-137 and Sr-90 in deep water as that in surface water suggests

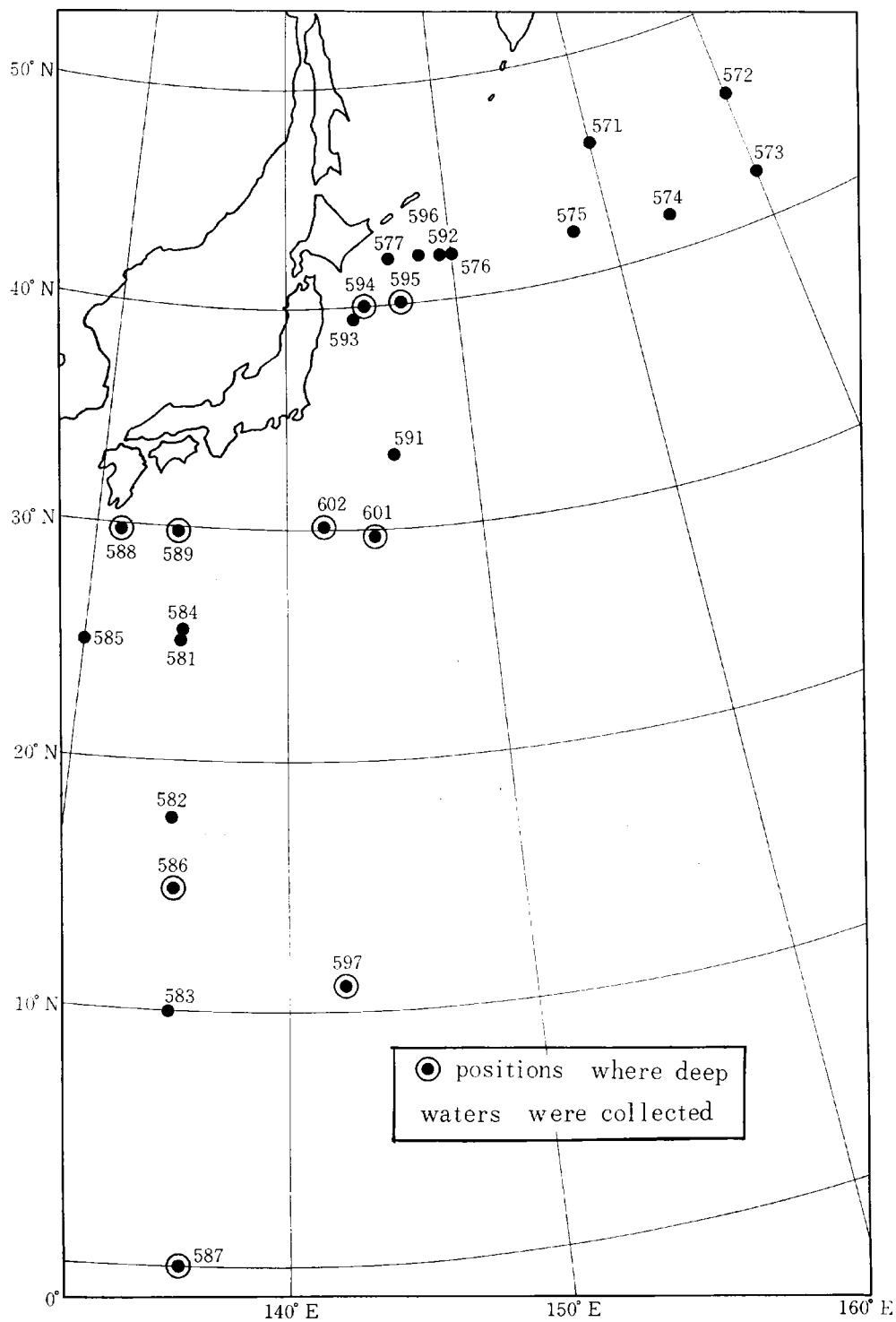


Fig. 2 Locations of collection of water samples for Sr-90 and Cs 137

that there has been no biological separation of both nuclides. Thus, penetration of radionuclides into the deep may be attributable to mainly to the physical mixing process.

Assuming that the horizontal distribution is approximately the same in wide area of the ocean and the main process of penetration of radionuclides into the deep is the turbulent mixing due to the vertical eddy diffusion of water masses, the averaged eddy diffusion coefficient between the bottom of the thermocline (200 m) and 4,000 m which is the mean depth of the oceans was calculated by using the well-known equation,

$$C = \frac{C_0}{\sqrt{\pi Dt}} e^{-Z^2/4Dt} \dots\dots\dots(1)$$

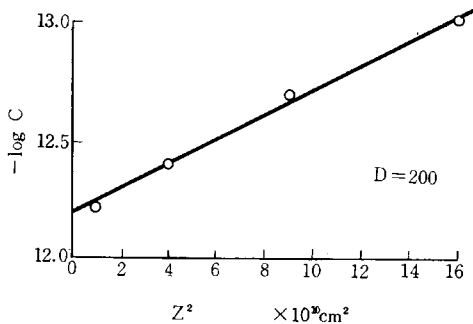


Fig. 3 Relation between Z² and log C in Equation 1.

in which D is the eddy diffusion coefficient on the vertical direction, Z, the depth, t, the time. C₀ is the total amount of radio-nuclide which is added near the surface layer at t=0, C is the concentration of either Sr-90 or Cs-137 at t=t and Z=Z. By plotting log C against Z², a straight line was obtained (Fig. 3). From the inclination of the straight line the eddy diffusion coefficient D can be calculated. The result of calculation showed that the average eddy diffusion coefficient on the vertical

direction in the ocean between 200 m and 4,000 m is 200 assuming that the time t is three years after the deposition of radio-active materials.

On the other hand, using all the observational data by Harley *et al* (1956), with respect to beta activity in sea water the vertical diffusion coefficient between 100 m and 1,000 m in the tropical area of the western Pacific was also estimated by employing the same equation above. The result of calculation gave the value of D=40.

Concerning the D value in the mixed layer by using the beta activity data obtained by Miyake *et al* (1955), Miyoshi (1956) gave about 5 to 10 for Bikini and its surrounding area. According to Sverdrup *et al* (1942) D is 30 to 80 from the surface to 200 m in Kuroshio region. In the same region Suda (1936) gave the value of 7 to 90 between the surface layer and 400 m depth. D value obtained by Sr-90 and Cs-137 tracers for the depth of 200 m to 4,000 m is much larger than these estimations. However, as it is believed that the eddy diffusivity increases generally with decreasing vertical stability, it may not be unreasonable that the mean D value increases with increasing depth.

A similar suggestion of increasing eddy diffusivity with depth was also given by Koczy (1958) in relation to his study on the diffusion of radium from the deep

sea floor.

By employing the D value of 200, the time change in the vertical distribution of non-radioactive materials which is put into 200 m layer was calculated as shown in Table 2 and Fig. 4. As seen in the table and the figure, the time required to attain practically a homogeneous, vertical distribution in the western part of the North Pacific Ocean would be a few hundred years.

Table 2 Time change of vertical distribution through diffusion

	Depth m		
	200	2000	4000
3 yrs	1	0.58	0.11
10 "	1	0.83	0.47
100 "	1	0.98	0.93
500 "	1	0.99 ₆	0.98 ₅
700 "	1	0.99 ₇	0.98 ₈

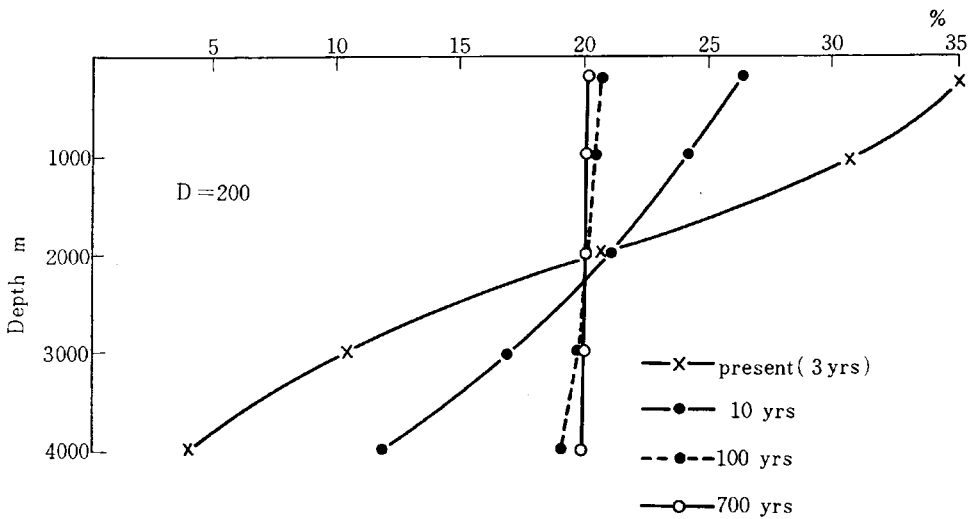


Fig. 4 Time change of vertical distribution through diffusion

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