RATIONAL REFERENCE LEVELS FOR PACIFIC COAST RADIOACTIVE POLLUTION STUDIES SUPPLIED BY SAMPLES FROM NORTHERN BAJA CALIFORNIA

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RESUMEN

El aumento de la población y el uso creciente de la energía nuclear producen contaminación radioactiva en las aguas próximas a las costas. En la Institución Scripps se efectúan estudios para estimar lo objetable que esto pueda llegar a ser en el sur de California y en Baja California.

Entre Ensenada y Santa Bárbara existe un vórtice costero permanente (contracorriente) que provoca la dispersión de contaminantes, ya que las aguas oceánicas vienen primero hacia la costa cerca de Ensenada para luego deslizarse rumbo al norte. Por lo tanto, para determinar si la contaminación ha alcanzado o no a la planta marina o a un animal, o a un sedimento recogidos cerca de San Diego, Los Angeles o Santa Bárbara, se deben hacer comparaciones analíticas con muestras idénticas recogidas cerca de Ensenada, donde la costa está bañada directamente con aguas oceánicas más limpias.

Sin embargo, deben también considerarse muchos otros factores antes de demostrar científicamente la existencia de rastros anteriores de contaminación radioactiva en la costa. El océano contiene radioactividad y también cantidades medibles de desechos radioactivos de las pruebas de armamentos. Aun en el océano abierto, los niveles radioactivos están cambiando continuamente; por lo tanto, para estimar qué cantidad de radioactividad existía antes de tener efecto la contaminación, se debe tomar en cuenta el registro del desecho producido por las pruebas del armamento y también considerar qué factores físicos, químicos o biológicos actuán en la redistribución de este desecho en el océano. En este trabajo deben incluirse todas las ramas de la Oceanografía.

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ABSTRACT

Radioactive pollution may be expected in coastal waters as the result of increased populations and use of nuclear fuels. Studies to estimate how objectionable these may become in the future near southern California and Baja California are being made at the Scripps Institution. Between Ensenada and Santa Barbara lies a permanent coastal eddy (countercurrent) that strongly influences dispersal of pollutants, oceanic water first coming toward shore near Ensenada and then sweeping northward. Therefore to determine whether or not pollution has reached a marine plant or an animal or sediment collected near San Diego, Los Angeles, or Santa Barbara, analytical comparisons must be made with identical samples collected near Ensenada where the coast is most directly contacted with cleaner oceanic waters.

However, many other factors also must be considered before early traces of a coastal radioactive pollution can be demonstrated scientifically. The ocean contains natural radioactivities in small amounts and also measurable amounts of radioactive refuse from weapons tests. Even in the open ocean, radioactive backgrounds are continually changing. Therefore, to estimate what radioactivity was present before a contamination took place, one must refer to the past history of weapons fallout and must consider what factors, physical, chemical or biological, act to redistribute this fallout in the ocean. All branches of oceanography must be enlisted.

INTRODUCTION

Background levels of radioactivity in the marine environment along the Pacific Coast are at present extremely low. However, these certainly will rise along with the growth of coastal populations and with the increased use of nuclear energy. It would be desirable to anticipate where and how fast concentrations of artificial radioactivities will reach unacceptable levels in coastal water. Successful prediction of this sort requires knowing how the ocean responds, in given regions, to specific inputs. Fortunately, some of the fate of a large class of radioactive pollutants that must be faced in the future may be inferred from careful studies of the behavior of certain constituents of nuclear fallout that have entered the ocean during the past 20 years.

Distributions and trends of fallout radioactivities along the coasts of California and Baja California have been studied for many years at Scripps Institution of Oceanography using specialized techniques. A completely satisfactory model for predicting coastal behavior, or even oceanic behavior, toward pollutants has yet to be derived; partly because of the large scales of the phenomena involved, and partly because of the difficult character of measurements that have been required. On the other hand, important factors are now understood and some of these will be reviewed in this paper. It is hoped that members of the Mexican Geophysical Union may find of some interest the reasons for our choice of waters of northern Baja California for obtaining reference standards for demonstrating small radioactive anomalies in other environments along the Pacific Coast. This choice has involved consideration of the whole Pacific, its major currents, reactions at continental boundaries, and also the characteristic behaviors of certain marine plants and animals. In addition, account had to be taken of the history of global fallout.

From these and other considerations, it becomes clear that the coastal region near Ensenada is more directly exposed to truly oceanic waters than are those other regions lying further north where larger populations are now growing and where significant pollutions must first be anticipated. Samples from the coastal environments of northern Baja California therefore can provide the most rational reference specimens for making comparisons with samples from other coastal regions suspected of receiving local pollutions.

USE OF THE FALLOUT RECORDS

One objective at Scripps has been to learn how the ocean may behave toward certain classes of pollutants by studying records of global fallout inputs, oceanographic data on oceanic motion, and by carefully measuring the changing concentrations of certain fallout constituents in sea water and in marine organisms. Records of fallout (Volchok 1966, Volchok and Kleinman 1971) are most commonly presented in terms of either of two relatively long lived radioactive fission products, ^{90}Sr (28 years) or ^{137}Cs (30 years). The latter activity generally is the one more easy to determine in marine samples, but concentrations in sea water of one of these usually can be estimated from the other. Figure 1 graphically summarizes temporal trends that have been reported for global fallout in terms of the annual inputs of ^{90}Sr over the whole area of the Northern Hemisphere. Inputs of ^{137}Cs (in kilocuries per year) were approximately 50% higher than the ^{90}Sr inputs depicted.

EFFECTS OF MOTIONS OF THE OCEAN

Figure 1 was derived from soil samplings, so it represents primarily the monthly fallout increments that have accumulated on the land surfaces averaged over the hemisphere. In the ocean, however, each increment, as time passes, will be diluted, mixed downward, and also carried laterally by currents and eddies. In addition, global fallout rates vary with latitude as well as with time. Presumably, these follow the same input pattern over the ocean that has been observed on land where it has been found that roughly 10 times as much fallout arrives near latitude 45°N as near the equator in a given period. Thus, the concentration that has accumulated at the surface in any region of the ocean depends upon currents as well as upon the character of past inputs. The amount of lateral distortion of the fallout input pattern, of course, will depend upon the time spent in the upper layers where currents are rapid. This depends in turn upon the rate of physical decay of the nuclide in question, and upon those physical, chemical, and biological factors that act to deplete it from the layer and carry it downward.

It is only recently that strong evidence has come to light showing that large amounts of chemically passive and soluble constituents of fallout may be retained in the upper oceanic layers for decades over wide areas of the Pacific. Because of this, it is now clear that full account must be taken, when we are concerned about present radiological background conditions along the Pacific Coast, of fallout inputs that have occurred as early as 1958 and as far away as Japan.

PHYSICAL SURVEYING BY SHIPS

The ocean is so large that it is difficult to sample it in detail sufficient to delineate much of its motions. Nevertheless, enough surface water samples have now been collected along the tracks of ships crossing the N. Pacific. These samples have been analyzed for traces of fallout radiocesium (^{137}Cs) to suggest that contaminations may remain near the sea surface long enough to be displaced many thousands of miles. For example, the results of one 1966 oceanographic survey supporting this is summarized in Figure 2 where the ^{137}Cs concentrations found between San Diego and Honolulu and also between Honolulu and Adak have been plotted alongo the ship's course. Concentration levels are plotted graphically as amplitudes (to the right-hand) relative to the track. Some generalized surface currents reported for the N. Pacific (Department of Commerce 1961) also have been added to this figure and also has been added a solid line (AC) representing a trajectory suggesting a route that might be taken by surface water masses in being transported from latitudes near 45°N, where fallout has been most intense, into the subtropical regions near 20°N. A period of roughly two years may be estimated for a journey such as this.

An interpretation of the distribution observed in 1966 along the ship's path (Folsom *et al* 1968) between San Diego and Adak is facilitated by consideration of the concentration distributions that can be predicted for a hypothetical ocean having no surface currents. Therefore, in Figure 2, along the 160°E meridian has been plotted a graphical representation of the variation with latitude of ^{137}Cs concentration in this hypothetic "frozen" 1966 ocean that can be computed from amounts of fallout reported to have accumulated on terrestrial areas at several different latitudes. For this computation, of course, it is necessary to choose a depth to which the fallout penetrated; in this figure a 100 meter depth of uniform mixing was assumed. Concentrations, as before, are plotted graphically from the right-hand of the (arbitrary) zero line, the 160°E meridian. A similar concentration profile would, of course, be expected along all other longitudinal parallels in a fixed ocean.

A comparison between the concentrations predicted for the non moving ocean and concentrations actually observed in 1966, considered together with the supposed average directions of average motion of surface currents depicted in Figure 2, strongly suggests that much of the nuclear products that fell so intensely in northern latitudes had, by 1966, moved into latitudes of southern California and northern Baja California. The core of the California Current west of San

Diego was at that time carrying fallout in concentrations far higher than reported for any other region of the N. E. Pacific, concentrations much higher than any attributable to local fallout alone. As indicated in Figure 2, the 1966 concentrations of ^{137}Cs west of California increased rapidly with distance from shore. Therefore, measurements near shore gave little indication of what was occurring beyond in the open ocean. What is more important to coastal pollution studies, changes that would take place near the coast during the next few years could hardly have been anticipated without some knowledge of the large amount of northern fallout that was passing by in the California Current.

Table 1 illustrates that there were gradients showing higher offshore concentrations of other fallout nuclides also, including those of plutonium and strontium.

OCEANIC FALLOUT PERSISTENCE STUDIES

Little was known about persistence of fallout in upper layers of the Pacific. Therefore, after 1964, numerous water samples were collected and analyzed for ^{137}Cs and other fallout nuclides. In addition, samples of tissues of a well-known oceanic fish were collected every summer in a consistent manner. The N. Pacific albacore tuna migrates every year across the central N. Pacific (Otsu and Uchida 1963) and may be sampled in the commercial fisheries near California. By comparing changing concentrations of fish tissues and also changing concentrations of fallout in sea water samples that were believed to be typical of the albacore's oceanic habitat, an estimate could be made of the time that was required for depletion of fallout from oceanic waters west of California. The "cleanup" rate was much slower than had been anticipated.

Figure 3 depicts the ^{137}Cs concentration trends in two classes of tissue and in sea water samples from their supposed recent environments (Hodge *et al* 1973). These, and other measurements, strongly suggest that after 1965 ^{137}Cs concentrations decreased to half value in about 10 years.

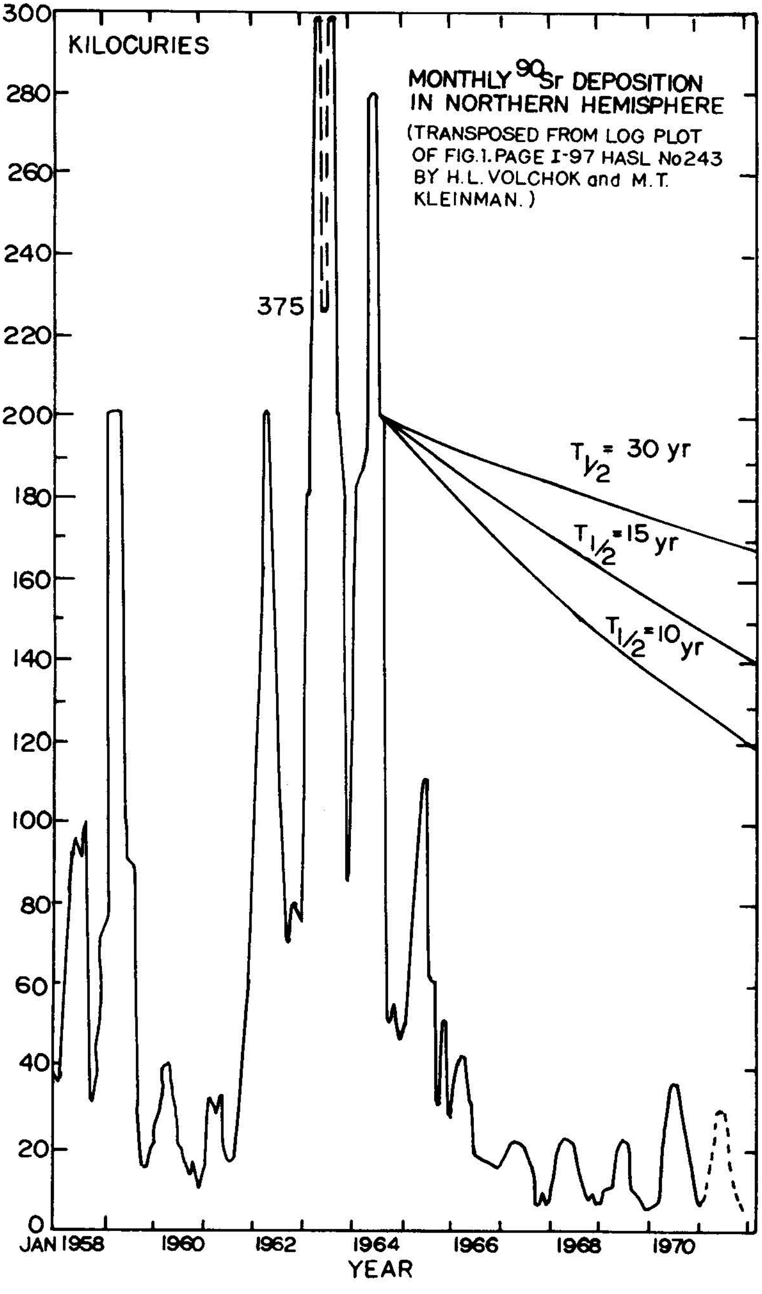
These observations that the depletion of fallout in oceanic waters west of California was very slow gave warning that certain classes of pollutants may persist for long periods in surface layers of certain regions of the ocean. However, it is difficult to separate, even for the oceanic case, the parts played by downward losses and the lateral losses (or gains) caused by surface currents. Whenever modeling is attempted, it is soon found that fallout which has entered the ocean many years earlier, may have to be taken into consideration. To suggest how very large the time scale must be in an oceanic model, three hypothetical attenuation lines have been added to Figure 1. For example, an attenuation at the rate of half value in 10 years may make remanents of inputs that arrived in 1962 far more significant thant recent fallout. On the other hand, much of the apparent persistence of the fallout in the California Current may be found to be owing merely to advection of higher concentrations from the north.

ESTABLISHING COASTAL BACKGROUNDS

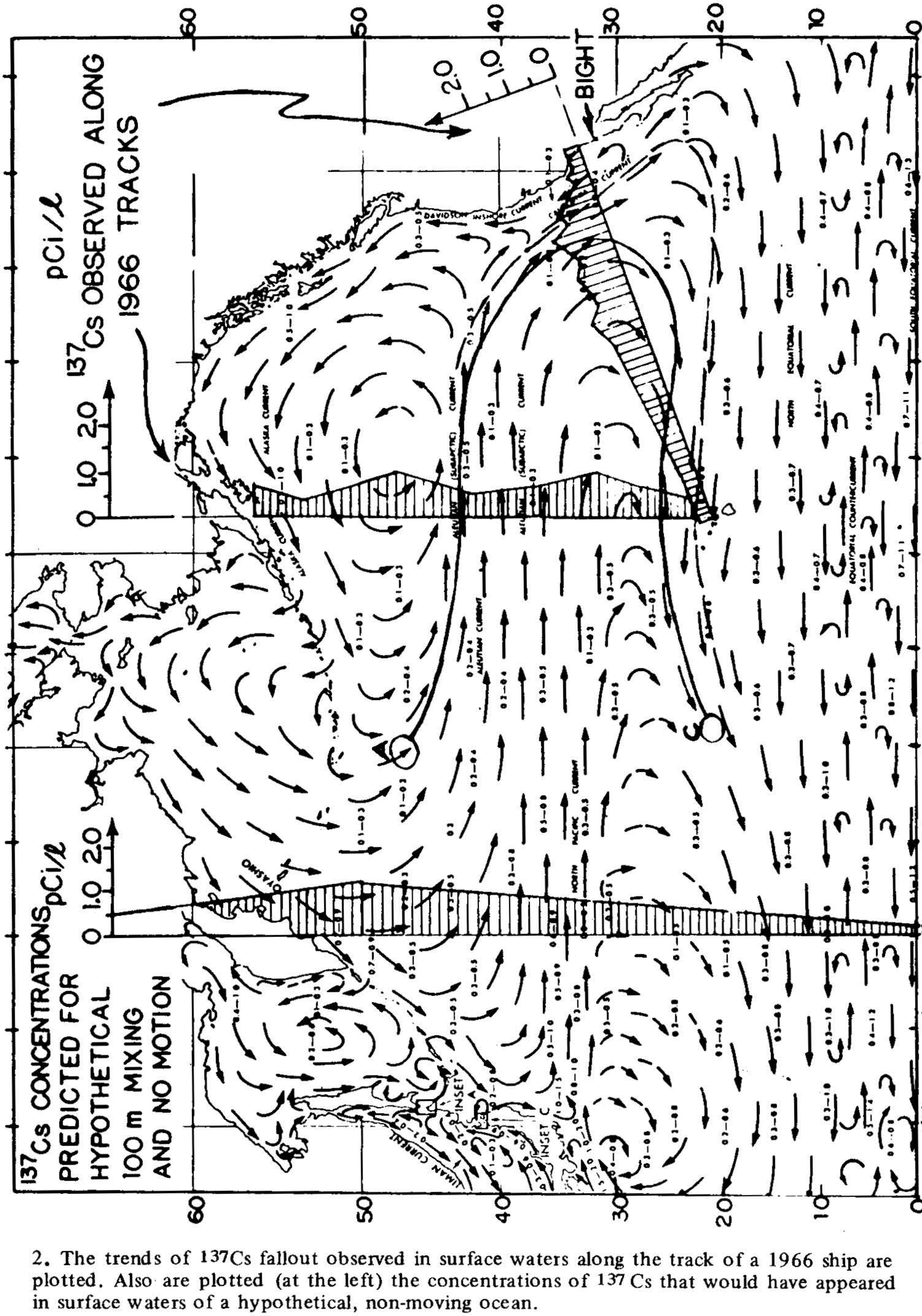
Numerous factors, for example variations of fallout concentrations with depth, cannot be discussed here, but unfortunately do complicate the prediction of oceanic concentration changes. Near shore, still more factors enter so that resort, ultimately, must be made to direct comparisons of appropriate samples taken from different coastal environments. Nevertheless, advantage can be taken of offshore information such as described above provided an understanding can be gained of factors underlying coastal concentration, transporting, and mixing processes. Fortunately, these phenomena are now being studied intensely in the coastal region from northern Baja California to Point Conception, California by the Southern California Coastal Research Project (1973). It is now evident that a large offshore eddy usually persists in this region moving counterclockwise so as to direct the near shore water northward as sketched in the large scale map shown in Figure 4. Because of this eddy the region near Ensenada tends to receive the fresher oceanic water in comparison with coastal water moving past the more northern cities. Thus, samples of water, plants, and animals collected say at Punta Banda near Ensenada must be expected to reflect environmental conditions that are more closely rated to oceanic conditions than prevail along shores of the populated regions near San Diego, Los Angeles or Santa Barbara. Therefore, it is most reasonable to obtain appropriate specimens collected in northern Baja California for estimating what contemporary background conditions might prevail in the ocean beyond influence of local contaminations.

Table 2 illustrates this point by comparing concentrations of ^{65}Zn in mussels and barnacles collected along the coast (Folsom 1965). This is a short-lived nuclide suspected of global fallout origin (Folsom *et al* 1971) that for years has been carried southward by the California Current. The higher concentrations listed for samples collected along the coast of Baja California are consistent with the physical evidence given above that oceanic waters enter the coastal region most readily just south of the border.

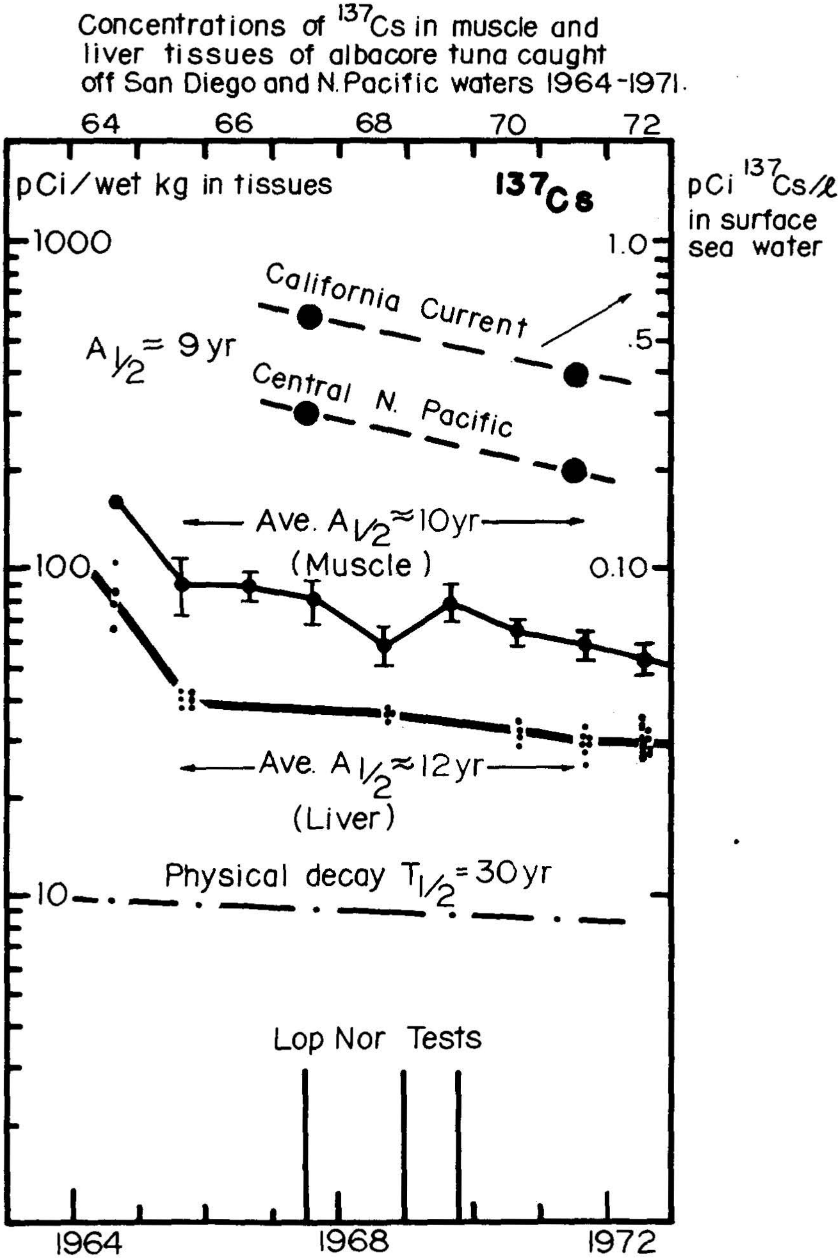
Finally, Table 3 lists concentrations of three metallic fallout nuclides that are intensely concentrated by certain coastal organisms, organisms that may often serve conveniently as indicators of changes in coastal environmental conditions (Hodge and Folsom 1973). In this case, samples from Baja California were not available for use as reference standars. However, suitable samples were collected at La Jolla so as to be compared with similar samples collected at a coastal point near the nuclear power plant at San Onofre. La Jolla lies about 70 km south of San Onofre, that is, in a direction toward Baja California. Table 3 illustrates that the "upstream" samples (La Jolla reference samples) had accumulated much less of all three nuclides. In fact, La Jolla levels were consistent with offshore oceanic fallout levels typical in 1970 and 1971. Comparisons of concentrations in the reference samples and the samples collected near the power plant left little doubt that small amounts of ^{60}Co, ^{58}Co and ^{110m}Ag had recently come into the local coastal environment presumably from the power plant.



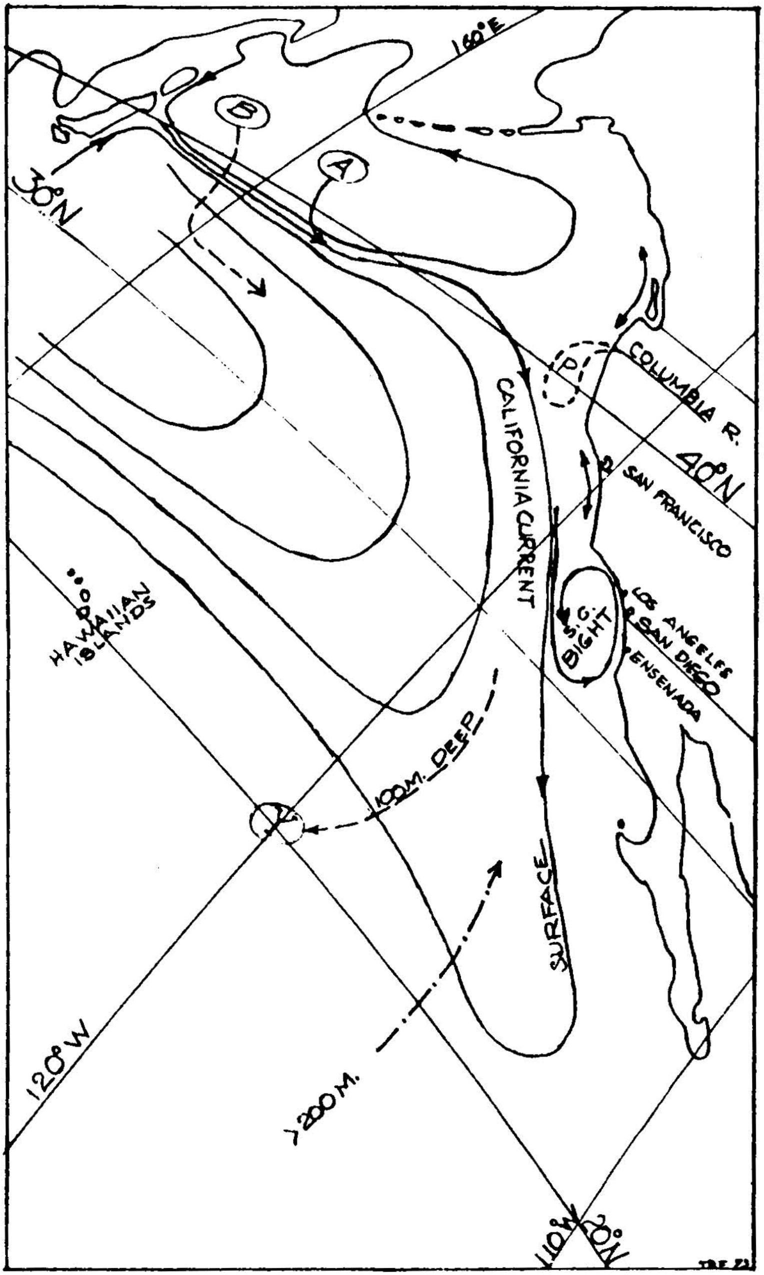
1. Reported trends of global fallout in terms of the amount of ^{90}Sr (kilocuries) deposited per month averaged over the N. Hemisphere. The amount of ^{137}Cs fallout is roughly 50% greater. Three hypothetical attenuation lines have been added with rates that are appropriate in considerations of retention of oceanic surface pollutions.



2. The trends of 137Cs fallout observed in surface waters along the track of a 1966 ship are plotted. Also are plotted (at the left) the concentrations of 137 Cs that would have appeared in surface waters of a hypothetical, non-moving ocean.



3. Trends of 137 Cs concentrations observed in tissues of oceanic albacore tunas, also trends for sea water samples collected in the N. Pacific where these tunas live.



4. A large-scaled map summarizing currents controlling fallout concentrations west of Ensenada, San Diego, and Los Angeles. A large semi-permanent eddy is shown in the coastal foreground, the Southern California Bight Eddy. This eddy generally directs inshore waters northward from Baja California where oceanic waters most closely approach the coast.

CONCLUSION

In future years, after much more nuclear fuel is used near San Diego, it may be impossible to resort to reference samples from coastal regions such as La Jolla. The last source of good reference specimens may be the coast of Baja California.

Table 1. Variations in concentrations of ^{239}Pu, ^{90}Sr, and ^{137}Cs observed in surface water going westward from California in 1964 (crossing the Southern California Bight region). Notice the maxima 300-700 miles offshore at this period

		pCi/ℓ sea water		
Station	*Miles from coast*	^{239}Pu*	^{90}Sr	^{137}Cs
Scripps Pier	0 (La Jolla)	0.0004	–	0.12-0.46
815-475	30 (S. of Pt. Arguello)	0.0011	0.055	0.09
762-50	10 (N. of Pt. Arguello)	0.0011	0.097	0.16
80.70	100 (W. of Pt. Arguello)	0.0014	0.19	0.27
70.120	300 (W. of Pt. Arguello)	0.0015	0.37	0.59
60.190	700 (W. of Pt. Arguello)	0.00316	0.57	0.66
60.200	720 (W. of Pt. Arguello)	0.00259	–	–
"November"	1100 (1400 W. of San Diego at latitude 30°N)	0.0030	0.37	0.48

* Folsom *et al* (1966).

Table 2. Environmental variations of a fallout nuclide, ^{65}Zn, observed in sessile marine organisms collected along the shores of the California Bight region.*
Notice that concentrations are highest in northern Baja California

A. ^{65}Zn in *Mytilus Californianus* (black mussel)

		pCi/kg wet	
Location	*Latitude (°N)*	*May 1963*	*February 1964*
Pt. Dume, Ca.	34.0	50	–
Santa Monica, Ca.	34.0	23	–
Laguna Beach, Ca.	33.5	34	–
Oceanside, Ca.	33.3	26	–
Solana Beach, Ca.	33.0	21	–
La Jolla, Ca. (Scripps)	32.9	48	32
Pacific Beach, Ca.	32.8	50	–
Pta. Banda, B. C.	32.0	133	–
Pta. Calaveras, B. C.	31.4	–	106
Pta. de Cabra, B. C.	31.3	105	–
Cabo Colnett, B. C.	30.6	–	125
Pta. Baja, B. C.	29.9	–	82
Pta. San Carlos, B. C.	29.6	–	50

B. ^{65}Zn in *Pollicipes polymerus* (gooseneck barnacle)

		pCi/kg wet
Location	*Latitude (°N)*	*February 1964*
La Jolla, Ca. (Scripps)	32.9	30
Pta. Banda, B. C.	32.0	81
Pta. Calaveras, B. C.	31.4	120
Cabo Colnett, B. C.	30.6	94

* Sampled and analyzed by David R. Young (in Folsom 1965).

Table 3. Small coastal disposals of artificial radioactivities from the San Onofre Nuclear Power Plant evidenced by relatively high concentrations in selected marine organisms collected locally.*

		*pCi/kg wet weight***		
Sample	*Date Collected*	^{60}Co *(5.3 yr)*	^{58}Co *(72 d)*	^{110m}Ag *(270 d)*
Sea hare	12/12/70	85	2 260	114
(*Aplysia*	3/10/71	63	734	78
californica)	6/22/71	16	87	16
a shell-less	10/4/71	45	125	49
mollusc collected	1/7/72	7	12	12
near San Onofre	12/18/72	34	64	195
collected near La Jolla	6/22/71	2	<1	<1
Agar Agar	12/12/70	24	313	35
(*Gelidium sp.*) a red	3/10/71	5	44	6
alga collected near	11/2/71	4	11	13
San Onofre				
collected near La Jolla	6/22/71	5	<1	<1
Surf grass	3/10/71	31	426	42
(*Phyllospadix sp.*) a	11/2/71	21	42	25
flowering plant col-	1/17/72	9	15	14
lected near San Onofre	12/18/72	58	160	85
collected near La Jolla	3/10/71	9	<1	<1

* For comparison, concentrations are given for the same species collected at La Jolla, Ca., 70 km away.

** Counting errors of measurements are 10% or better. Half-lives of these three artificial nuclides are given in parentheses. Other nuclides also have been detected.

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