Short Papers and Notes

FISSION PRODUCT CONCENTRATIONS IN THE CHUKCHI SEA

Studies of the circulation of the Arctic Ocean[1,2,3] emphasize the significance of a supply of northwestern Pacific surface water flowing northward through the Bering Strait and along the eastern side of the Chukchi Sea into the Arctic Ocean. The authors cited agree in estimating this Pacific supply to be close to 40,000 km.[3] per year.

Analyses of bomb-test fallout in the western Pacific by Y. Miyake and co-workers[4,5] have consistently shown these waters to be higher than those of the north Atlantic,[6,7,8] in both strontium-90 and cesium-137. Miyake has attributed these high values to close-in fallout from the various Pacific tests; his conclusion is clearly supported both by his own studies[9] and those of others[10] in the Bikini area and by informed statements[11] that as much as 70 per cent of the fission product yield was deposited as close-in fallout during U.S. Pacific tests.

Combining the two sets of observations cited above appeared to promise both direct determination of the mass transport into the Arctic Ocean, through the Chukchi Sea, and this providing a basis for tracer studies of current patterns and of mixing rates in the Arctic Ocean itself. Through the good offices of Dr. Allyn H. Seymour, various expeditions mounted by the Laboratory of Radiation Biology, University of Washington, have obtained for us water samples in this area during 1959, 1961 and 1962; through the co-operation of Dr. F. Hagemann of Argonne National Laboratory, we obtained a sample collected just north of the Chukchi Sea in 1960, by the U.S.C.G.C. Northwind. In Table 1 are summarized the analytical and oceanographical data from these samples.

Two additional samples, collected from under the ice in the Arctic Ocean, are of interest in this discussion; they were analyzed for strontium-90 only, as shown in Table 2.

The analytical procedures used derive from those previously described[12]; a description of our present modifications is being prepared for publication elsewhere.

Discussion

Strontium-90

The data available for the Pacific, and applicable to a consideration of the Chukchi Sea, derive from two separate Japanese investigations.[4,5,13,14] The first group has reported results for surface samples taken in 1957 in the area from 41°57' to 46°00'N. and from 146° to 170°E.; strontium-90 values ranged from 130 to 500 disintegrations per minute per 100 litres. Two years later, in the area from 33°04' to 42°N. and from 144°08' to 149°26'E., strontium-90 ranged from 180 to 500 in the same units. Miyake's values are all from samples taken in August or September. In 1959 Higano[14] found strontium-90 concentrations in the area about 35°N. 140°E. ranging from 110 to 190; the samples, however, were taken in February, June and July. In 1960 and 1961 (unfortunately, no closer dating of the samples was published), Higano[14] found strontium-90 values ranging from 50 to 90, in the area 15° to 35°N., and 130°W. to 140°E.

Considering the highly non-uniform patterns of radioisotope distribution in the Pacific, described both by Miyake[9] and by Harley[10] as well as in the summary of Pacific Ocean gross beta radioactivity distributed by HASL[15], it is not possible to argue that the data reported by Miyake and Higano are in disagreement. The values are, however, considerably higher than those we have obtained for North Atlantic samples (ranging from 14 to 22 d.p.min./100 l. in 1959, about 18 in 1960, and from 11 to 24 in 1961 — ref. 8 and to be published). The Pacific data are perfectly consistent with the idea that at some time following an equatorial test series, irregular masses of water labelled by close-in fallout have passed northward through the Pacific. The routes via the Kuroshio,

across to the Gulf of Alaska and so to the Bering Sea, or more directly by transfer from the Kuroshio to the northeastward directed arm of the Oyashio[16] cannot be discriminated by the data available, nor can the areas or volumes represented be defined.

derive the depth of uniform mixing required in the water column to represent these accumulated deliveries; depths range from 45 m. for the Point Barrow figure to 90 m. for Palmer. Considering the spread of the values for land delivery, we see that these

Table 1. Fission product concentrations in the Chukchi Sea.

Collec. date	Lat. N.	Long. W.	Water depth m.	Sample depth m.	Sample T:°C.	Sample salin. %₀₀	dis. per min. per 100 l.*		
							^{90}Sr	^{144}Ce†	^{147}Pm†
Aug.30, 1959	66° 40′	168° 58′	32	0	5.86	32.295	21.6 ± 0.9	23 ± 1	6.9 ± 0.4
Aug.30, 1959	66° 40′	168° 58′	32	5	5.85	32.310	21 ± 0.7	33 ± 1	69 ± 4
Aug.26, 1960	71° 40′	156° 38′	70	7	—	—	35 ± 1.6	—	—
Aug.19, 1961	68° 03′	165° 45′	—	0	—	—	42 ± 2.2	9.3 ± 0.5	8.8 ± 0.9
Aug.26, 1961	67° 58′	165° 52′	32	30	—	—	40 ± 1.8	15.7 ± 0.8	8 ± 0.8
May 8, 1962	67° 58′	165° 52′	32	0	−1.75	32.162	58 ± 4	—	—
May 8, 1962	67° 58′	165° 52′	32	30	−1.75	—	50 ± 4	—	—

*Confidence limits are 2 sigma based on counting statistics, replication of duplicates and error estimates for chemical processing.
†Corrected for radioactive decay since collection date.

Table 2. Arctic Ocean fallout.

Collection date	Position	Sample depth	dis. per min. per 100 l. ^{90}Sr
Sept. 11, 1957	about 86° 30′ N. 180° W.	3 m. below ice	2.3 ± 0.4
Apr. 6, 1958	80° 17′ N. 112° 50′ W.	5 m. below ice	5.3 ± 0.5

It is evident that we have not obtained samples from the Chukchi Sea equivalent to the highly contaminated water masses reported by Miyake and Higano in 1957 and 1959. In fact the samples collected for us in 1959 are within the range, for the same year, of North Atlantic surface samples, contaminated only by world-wide fallout (ref. 8 and to be published). Comparison of our 1959 values with those for land-delivery in Alaska[17] is of interest. Integrated profiles of carefully selected soils indicated by mid-1959 a total delivery of 9500 d.p.min. ^{90}Sr per m.^{2} at Point Barrow, of 16400 at Fairbanks, and of 18900 at Palmer. Dividing these values by our concentration figures, we

depths correspond quite well to the apparent average depth of the Chukchi Sea (taken below as 55 m.).

The values for the Chukchi Sea for 1960 and 1961, however, fit a quite different picture. In the Pacific, Higano[14] found surface concentrations either uniform or diminishing during most of 1960 and 1961. In the Atlantic also, our data indicate that the rate of fallout had diminished during the test moratorium to a level that did not balance the rate of down mixing. On land the soil analyses at Point Barrow, Palmer, and Fairbanks, as elsewhere[18], show an increase in ^{90}Sr (1959-1960) less than the 10 per cent relative standard deviation of the analytical method. The Chukchi

Sea increase, by 65 per cent to August 1960 and by about 100 per cent to August 1961, can hardly have been produced except by inflow of water directly contaminated during a previous test series.

We cannot disprove the possibility of this having been Arctic Ocean water, contaminated by close-in fallout from the Russian test series; we do, however, discount this possibility as supported by no collateral data whatever, whereas the North Pacific as a source is suggested by the hydrographic picture, as well as by the analytical data from Japan and by our understanding of fallout patterns during the U.S. equatorial test series. Machta has also reported[19] that the Russian tests of 1958, 1961, and 1962 yielded "no significant local fallout".

Rough estimates of the volume of the Chukchi Sea south of the 70th parallel, using depths from U.S. Hydrographic Office chart 2560, are about 2×10^4 km.^{3} Clearly a volume this small may be expected to be extremely sensitive to the effects of a current transporting about 4×10^4 km.^{3}/year. We would expect neither appreciable dilution in specific ^{90}Sr activity, of north Pacific water flowing through, nor any appreciable retention within the basin, once the source water mass had moved away from the Bering Strait area. Coachman and Barnes[3], however, on the basis of temperature and salinity data, conclude that the northward flowing Bering Sea water mixes in the Chukchi Sea with Siberian Shelf water, in proportions so that the outflow enters the Beaufort Sea gyral as a 4 or 5 to 1 dilution of Bering Sea water with arctic water from the Siberian Shelf. Applying this conclusion to the 1960 sample from northwest of Point Barrow, indicates that the Bering Sea water must initially have had a ^{90}Sr concentration approximating 80-95 d.p.min./100 l., if the 1959 Chukchi values can be taken as representing the diluent concentration, or of 120 to 150, if our 1957 and 1958 Arctic Ocean values, modified to include subsequent fallout, are taken. Either of these values is within the range indicated by the

northwest Pacific values published by Miyake and by Higano.

It is, unfortunately, not clear from the analysis of Coachman and Barnes, where are the major areas for mixing of Bering Sea and Siberian Shelf water. From the temperature and salinity data on our 1959 Chukchi samples, falling about mid-point of the envelope of properties found by *Brown Bear*[3] in the Bering Strait that year, we conclude the area of mixing to be north of 66°40′N. Unfortunately, no temperature and salinity data are available for our 1960 and 1961 samples; these properties for the 1962 samples, however, lie below the salinity range found by *Brown Bear*[3] somewhat west and north of the mouth of Kotzebue Sound. It appears to us likely that the 1962 samples represent Bering water diluted slightly with fresh water from runoff into Kotzebue Sound. If this conclusion is extended to include the 1961 samples, the apparent ^{90}Sr of the source water falls within the range of north Pacific samples reported by Higano for 1960-1961.

The ^{90}Sr of our Chukchi samples from spring 1962 falls within the range reported by Aarkrog[20] for shallow water samples from comparable latitudes both about Denmark and about Greenland. His Danish values, where depths for mixing approach those of our samples (25-35 m.), range in early spring from 50-95 d.p.min./100 l. Our own analyses of surface water (to be published) at 56°30′N., 51°00′W. range about 16 d.p.min./100 l. at the same period; the depth of mixing is not known, but was certainly greater than in the Chukchi Sea, or in Aarkrog's Danish or Greenland sampling areas. From the Faeroes, which we take to be bathed in open ocean water, Aarkrog reports 22 d.p.min./ 100 l. in late spring. A possibly extreme case of downmixing, we observed in February 1962 at 57°40′N., 48°00′W.: the ^{90}Sr at surface, 100, 300, 500, and 800 m. was essentially uniform, averaging 12.4 ± 1 d.p.min./100 l. (to be published); the water column was isopycnal to approximately 800 m.

We do not, however, believe that the increase shown by our Chukchi samples

between August 1961 and May 1962 can be attributed to recent winter and spring fallout in that area. These samples were collected under the winter ice cover, which had become established in 1961 before the increase in fallout began; the supply of fresh fallout would, then, have had to be delivered below the southern limit of winter ice, in an area of greater mixing depth, and, following Coachman and Barnes[3], too remote to have reached Kotzebue Sound by May, at the diminished rate of flow under the ice. Any reasonable extension of these arguments within the frame of reference of available data for fallout concentrations at high latitudes appears to us to indicate that North Pacific water entering the Bering Sea in late fall and winter 1962 must still have shown higher ^{90}Sr concentrations than known for the Atlantic.

Lanthanides

We have previously published[21] arguments and evidence that the lanthanide radioisotopes are removed from sea water during passage over shallow areas. In the Chukchi Sea, no increase in cerium-144 or promethium-147 concentration in water samples (Table 1) took place from 1959 to 1961, comparable to the 100 per cent rise in ^{90}Sr concentration. A series of mud samples from this area have been analyzed by gamma spectrometry[22]. The average ^{144}Ce content reported for the series is 0.6 ± 0.2 pc./g. We calculate, assuming the samples to represent the upper 2 or 3 cm. of sediment, and assuming biological and physical mixing to be effective over the upper 5 or 6 cm.[23], this corresponds to about 10^5 d.p.m./ m.², total ^{144}Ce accumulation. If all the ^{90}Sr in the 1959 water samples is assigned to the 1958 test series, the ratio, ^{144}Ce : ^{90}Sr $= 20$ (from ref. 24) for "typical weapon" production modified by one year decay, indicates about 2×10^5 d.p.min. ^{144}Ce per m.²; of this about 10 per cent is still in the water column. In a shallow sea of this sort, as on the Bahamas Banks[21], 90 per cent of the inflowing lanthanide radioactivity may well be expected to have reached

the sediment. Considering the uncertainties involved in the sampling coverage, in the analytical data, and in the calculations of total sediment content, agreement within a factor of two is excellent. For this area the total sediment content of lanthanide radioisotopes may well be a good indicator of the total through-put of fallout-labelled water. Analysis of samples of sediment taken in subsequent years may be quite illuminating, especially of a series from south to north along the course of the inflowing Pacific water.

Unfortunately, the mud samples analyzed[22] showed only ^{144}Ce, of the possible gamma emitting fallout nuclides. Even though the 1-year post-test ratio ^{144}Ce : ^{106}Ru should approximate 2 (ref. 24), Seymour reports that no value exceeded 10 pc. ^{106}Ru per sample. For the one case for which we can estimate sample size, this corresponds to a ratio ^{144}Ce : ^{106}Ru of more than 5.

The Irish Sea studies[25,26] indicate rapid transfer of the chain ^{106}Ru - ^{106}Rh to the sediment. In the absence of north Pacific data, we cannot judge how probable is differential removal of ^{106}Ru from ^{144}Ce. Higano's 1960-61 samples[14] show ^{144}Ce : ^{90}Sr ranging somewhat below 1 for samples spotted over the whole north Pacific; the ratio from our more northerly Atlantic surface waters from the same period (to be published) shows greater variation, most values lying between 4 and 6.

Conclusions

The changing fallout concentrations in the Chukchi Sea from 1959 to 1962 fully confirm the flow patterns inferred from temperature-salinity data, only if the source waters are assumed to have exhibited strontium-90 concentrations within the ranges reported for the northwestern Pacific by Miyake and by Higano.

It seems evident that a detailed survey of the cerium and ruthenium radioactivity in sediments from the Aleutian Arc northward across the Chukchi Shelf, would provide the basis for construction of an integrated pattern of rates and distributions of northward

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flow through this area.

Study of the strontium-90 concentrations in the Arctic Ocean may be expected to help to clarify the patterns and rates of circulation in this difficult area.

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PINGOS IN THE YUKON-KUSKOK-WIM DELTA, ALASKA: THEIR PLANT SUCCESSION AND USE BY MINK*

The Yukon-Kuskokwim delta of southwestern Alaska is a triangular piece of land lying between the Yukon and Kuskokwim rivers (Fig. 1). Almost 90 per cent of this delta is a subarctic lowland with numerous ponds and lakes ranging in size from a few yards to more than 15 miles in length. This plain has developed on unconsolidated surficial deposits of silt, sand, gravel, and organic materials[1]. Relative relief rarely exceeds 100 ft. and is mostly 10 ft. or less. The remaining area is occupied by isolated volcanic outcrops. Highest altitudes occur in the Kusilvak Mountains, which rise from almost sea-level to 2,450 ft.[1]

This delta is the largest area of homogeneous mink habitat in Alaska, producing an average of 18,000 pelts a year. In 1960 and 1961 a study was conducted to obtain information about the ecology, management, and economic importance of mink in this area. Further investigations of pingos were made in 1963.

The area lies in the zone of discontinuous permafrost, but permafrost was found in all habitats suitable for mink. The perennially frozen ground was found to have an indirect influence on mink because of its direct influence on vegetation, thaw lakes and pingos.

In the extensive low-lying areas of the delta, around the villages of Nunapitchuk and Kasigluk (60°53'N. 162°30'W.) pingos play an important role in the ecology of mink by providing the majority of sites suitable for natal dens. The area around these villages is a large expanse of low swampy and marshy terrain. Banks of the numerous lakes and streams are low and often a stand of emergent vegetation, with one or more channels winding through it, is the only separation between one lake and another. The area between these villages and Nelson Island (approximately 65 miles to the west) gives the impression of having been occupied by a shallow body of water. It is in this area that pingos are most abundant and much used by mink as den sites.

Independent studies of maps of this area by D. M. Hopkins and W. H. Condon of the U.S. Geological Survey has led them to believe that during early