RECEIVED BY DTIC NOV 3 1971

Invited Paper

Ecological Aspects of Plutonium Dissemination in Aquatic Environments;

What has Pu Data to tell us about other Transuranics*

Victor E. Noshkin

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts 02543

Presented at the 11th Hanford Biology Symposium, "The Biological Implications of the Transuranium Elements", Richland, Washington, 26-29 September 1971.

To be published in Health Physics, June 1972

* This work was supported by the United States Atomic Energy Commission under Contracts AT(30-1)-2174 and AT(30-1)-4275. This is Contribution Number 2734 from the Woods Hole Oceanographic Institution.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

100

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

The available data concerning the dissemination of plutonium and other transuranics in the aquatic environment are drawn together for appraisal. The most studied isotope has been ^{239}Pu derived from worldwide fallout. Essentially all the published work has been concerned with levels in the marine environment where plutonium is found widespread among planktonic, pelagic and benthic organisms. The concentrations are higher in organisms feeding on sediment or on surfaces than in those drawing largely on the water itself. Among the species where data are available are a variety of convenient "indicator organisms" for plutonium. There is some evidence that plutonium concentrations are increased in organisms of higher trophic levels. Bone and liver are major repositories for plutonium in marine vertebrates while muscle tissue of both marine vertebrates and invertebrates contain relatively lower concentrations. Plutonium is geochemically separated from both ^{90}Sr and ^{137}Cs in the water column and the sedimentation of ^{239}Pu may be more involved with biological processes than has been found for fallout rare earth isotopes. In marine sediments, as in soils, plutonium is more mobile than was originally expected. What little is known of the behavior of plutonium in the marine environment should be used conservatively to assess the behavior and distribution of new plutonium additions derived from sources other than fallout, and even more conservatively in predicting the impact of other transuranics in the aquatic environment. Considerably more understanding of the aquatic radioecology of several of the elements is a major priority especially since it now appears that when the relative biological effectiveness of alpha vs gamma or beta radiations is considered, fallout ^{239}Pu contributes more than fallout ^{90}Sr or ^{137}Cs to the artificial radiation exposure of many marine species.

INTRODUCTION

In 1961, Olafson and Larson,⁽¹⁾ reviewing "Plutonium, its Biology and Environmental Persistence", stated, "Perhaps no single element has ever been so intensively studied as has plutonium in the 19 years since the first microgram quantities of this, the first of the man-made elements, became available in the summer of 1942. Literally thousands of reports have been published on the physical and chemical properties of this element and its isotopes. Equally impressive is the number of reports concerning metabolism and toxicology of plutonium in animals". Since 1961, continued research on the properties of plutonium and other transuranium elements has been equally impressive and considerable new and necessary information has been derived from these more recent studies.

Unfortunately, however, no such attention has been given to plutonium uptake in nature. There have, indeed, been a few mammal and plant studies and other environmental considerations, mostly conducted at nuclear test site facilities; even fewer have been studies concerned with the behavior of plutonium in aquatic environments. Our knowledge in this field is limited principally to study of plutonium dissemination in the oceans, and is derived from only a few open-literature publications. Of these reports, the majority deal with the fate and behavior of fallout plutonium and the remainder are principally surveys of radioisotope releases from nuclear facilities. Plutonium, in such reports as these last, has been usually the element least emphasized. However, of all the transuranium elements, plutonium has been, by far, the element most intensively studied. The implication, hopefully, is clear. We know very little about the behavior of plutonium, relatively nothing of the behavior of the other transuranics in the ocean, and far less of the behavior and fate of the elements in fresh water environments. The electronic configuration (and consequently the oxidation state) of the lower transuranium elements is very sensitive to the chemical environment; geochemical behavior of these elements is, therefore, difficult to predict. Many of the radioeco-

logical patterns deduced from fallout studies may not necessarily be applicable to assessing the impact of other releases on the environment since both different chemical species and different physical forms of the elements may be involved.

We need only acknowledge the increased utilization of the transuranics in the nuclear industry to realize there is a great need to understand the bio-geochemical behavior of these elements in the aquatic environment. This growing use will increase the probability of waste production and environmental contamination. Consider, for example, the data shown in Table 1. The columns indicate the per cent increase above the previous year's output in both total mean alpha and beta activities discharged from Windscale to the Irish Sea during the period 1957-1967. Whereas beta releases have decreased in certain years, below the previous year's output, the alpha output has increased in every successive year. In order to accommodate the expansion of the U. K. nuclear industries, increase of the authorized alpha release limits has recently been requested. (3)

The principal modes of radioactive decay of many of the isotopes lead to the formation of other transuranium elements. After uptake of a parent isotope by an organism, for example, the distribution of the newly-formed daughter in the tissues may be quite different from the distribution encountered when the daughter element is assimilated directly from the environment. Davis, et al⁽⁴⁾ reported ^{239}Np concentrated in fresh water green algae to a level of 2.7×10^6 pCi/kg (wet weight). This sample was collected near Hanford in the late 50's. This quantity of ^{239}Np will decay in approximately 10 days to yield 0.7 pCi/kg (wet weight) ^{239}Pu , a level comparable to those presently found in many offshore marine organisms^(5,6). The fate of the ^{239}Pu so produced is unknown. In order to assess the ecological impact of the transuranium elements, questions as to the fate of an element introduced by radioactive decay must be considered.

Portions of the environmental survey for ^{239}Pu at Thule, following the 1968 B-52 aircraft disaster, were done by contouring the contamination levels, using detectors sensitive to the 60 kev photon from ^{241}Am . The ^{241}Am in the Thule debris resulted from the decay of ^{241}Pu , an impurity in the weapon material⁽⁷⁾. Although all possible precautions were, in this case, taken to account for the debris, one may question whether, in the future, under different circumstances, a procedure using one transuranic to detect or monitor another would always be adequate. Consider, for example, the ^{241}Am and $^{239}\text{Pu}/^{241}\text{Am}$ concentrations in Porphyra as a function of distance from the Windscale pipeline (Table 2)⁽³⁾. Whereas the ^{241}Am levels, in general, decreased with distance, the ^{239}Pu levels were more variable, reaching a peak value a few miles offshore but with relatively significant concentrations in samples 20 miles from the pipeline. Note that at both the discharge point and at a distance of 38 miles the levels of ^{239}Pu and ^{241}Am are similar. Using the distribution of ^{241}Am as a means of assessing the plutonium distribution would, in this case, fail. Clearly, either the bio-geochemical behavior of the two elements in the ocean must be significantly different or the releases of the two isotopes vary considerably with time to result in the levels observed.

What little knowledge we have gained in understanding the behavior of plutonium in the marine environment should be used conservatively to assess even the behavior and distributions of new plutonium additions, and even more conservatively in predicting the impact of other transuranium elements. Considerably more understanding of the marine radioecology of several of the elements is a major priority, especially since it now appears that when the relative biological effectiveness of alpha vs gamma or beta radiations is considered, fallout ^{239}Pu contributes more than fallout ^{90}Sr or ^{137}Cs to the artificial radiation exposure of many marine species^(5,6). It should be emphasized, of course, that present levels in the marine environment in no way represent a hazard to those species or ecosystems thus far observed⁽⁸⁾.

This review will consider some of the documented sources contributing transuranics to the aquatic environment and the ecological aspects of the most studied element - plutonium.

SOURCES OF TRANSURANIUM ELEMENTS REPORTED IN AQUATIC SAMPLES

Artificially produced isotopes of the transuranium elements have been and are being introduced to the waters of the world from a variety of sources.

Most of the ^{239}Pu , as well as several other transuranics, present in the environment has originated from both underwater and atmospheric nuclear tests. Plutonium 239 derived from the interaction of large neutron fluxes in nuclear explosions with the ^{238}U present in such nuclear devices, or from unfissioned core material, is a significant component of worldwide fallout (2-3% of the ^{90}Sr activity⁽²⁹⁾) and quantities have been reported in sea water^(9,10,11,12,13), sediments^(5,13,14,15), and organisms^(5,6,12,13,14,16). Little is known of the distribution of fallout levels in fresh water but currently research is being conducted by several laboratories in the United States to document the concentrations and distributions in several major fresh water bodies. Plutonium 238 (~5% of ^{239}Pu) derived from weapons testing has, in addition, been detected in many of the above marine samples^(5,10,11,12,13). Plutonium 240 is perhaps one-tenth the atomic abundance of ^{239}Pu in fallout⁽²⁾. No assessment of ^{240}Pu concentrations in the aquatic environment has been made however, since the energies of the alpha particles from ^{239}Pu and ^{240}Pu are not sufficiently different to be separated by alpha spectrometry, the detection technique most commonly used to assess environmental levels. It has, therefore, become customary to report fallout activities as the sum of the activities of ^{239}Pu and ^{240}Pu .

Quantities of transuranics were deposited in discrete marine environments near "surface and underwater burst" test sites. Eniwetok and Bikini atolls were the sites for 59 nuclear tests between 1946 and 1958. In 1952, following the first large scale

thermonuclear test (Ivy Mike), Diamond, et al⁽¹⁷⁾ were able to detect, in air filters, isobars of mass numbers 239-255. Following the Redwing test in 1956, Thomas, et al⁽¹⁸⁾ reported increased ^{239}Pu levels in a number of marine species near and distant from the test site. Welander⁽¹⁹⁾ resurveyed Bikini Atoll in 1964 and found significant plutonium levels in all sediment, plankton, algae, fish and sea bird samples analyzed. Neptunium 239 was the principal isotope present in marine plankton during the first 48 hours of the Rehoboth survey following testing at Eniwetok in 1958⁽²⁰⁾.

Transuranics above "background levels" are detected in aquatic samples obtained from the vicinity of fuel reprocessing facilities. Templeton and Preston⁽²¹⁾ reported increased levels of plutonium in sediment and invertebrates collected near the discharge area of the Windscale pipeline. Levels of plutonium in the seaweed, Fucus vesiculosus, depreciated from a maximum value, which persisted up to a distance of 10 miles from the pipeline, to "background levels" at approximately 100 miles. Plutonium-239, ^{241}Am and ^{242}Cm were detected in Porphyra collected from the vicinity of Windscale during 1968 and 1969^(3,22). Plutonium-238, ^{239}Pu , ^{241}Am , ^{242}Cm , and ^{244}Cm have been reported in either the interceptor composites or the lagoon receiving the discharge from the Nuclear Fuel Services, Inc. reprocessing facility^(23,24). Plutonium-238 and ^{239}Pu from this source have been detected in streams below the NFS discharge⁽²⁵⁾.

Accidents involving nuclear devices are another source from which transuranics are introduced to aquatic environments. Aakrog⁽¹³⁾ reported on the increased ^{239}Pu levels found in a variety of Arctic marine samples. This plutonium was released following the military aircraft disaster near Thule in 1968. Americium-241, released when the weapon broke up, was detected in many environmental samples as well⁽⁷⁾. Levels of ^{238}Pu were high relative to ^{239}Pu and exceeded the expected fallout ratio in many nearshore marine invertebrates and shallow waters collected in 1969 and 1970 near Cape Cod, Mass.⁽⁵⁾ The increased ^{238}Pu levels were derived from the deposition of a fraction of the 17 kCi of ^{238}Pu released to the atmosphere during the SNAP 9A burnup in 1964.

Transuranium elements are introduced into rivers and waters from laboratories involved in nuclear research and/or production or fabrication of nuclear material. Transuranium elements have been reported in Clinch River water⁽²⁶⁾. Plutonium has been detected in Sawmilk Creek at Argonne National Laboratory⁽²⁶⁾ and in the Greater Miami River downriver from Mound Laboratories⁽²⁶⁾. Neptunium-239 is found in the Savannah River, downriver from SRL⁽²⁶⁾ and was a significant component in the cooling waters of the Hanford reactors. The ^{239}Np from this latter source was detected as far as 260 miles downriver from the facilities at Hanford⁽²⁷⁾. Averaging the data which document the levels found in the river at Richland and Pasco over the period 1961-65⁽²⁸⁾, some 500 Ci/day were transported down the Columbia toward the Pacific. This quantity of ^{239}Np , over this 5-year period, produced by radioactive decay, some 0.1 Ci of ^{239}Pu which is now distributed downriver to and presumably into the offshore waters of Washington and Oregon. Production by radioactive decay is thus an extremely important source term for specific transuranium elements found in the aquatic environment.

PLUTONIUM IN THE AQUATIC ENVIRONMENT

Water

The analytical problems associated with the separation and detection of plutonium in seawater, organisms and sediments are discussed in references (5,6,9,10,12,13,15,30 and 31). Data for plutonium radiochemical blanks in aqueous samples and reagents has been presented and discussed by Bowen, et al⁽⁹⁾.

The available data for ^{239}Pu in seawater are shown in Table III. Other than the samples analyzed from the area of Bylot Sound by Aakrog⁽¹³⁾, the surface seawater concentrations in more recent years are universally less than 1 fCi/l. The 1963 value and the two 1964 values for the open Atlantic and Pacific, respectively, are higher; the years 1963 and 1964 being peak years for fallout delivery to the ocean surface. The three samples analyzed from the southern Atlantic are roughly half the value found in the North Atlantic. Both mid- and deep-Atlantic and Pacific waters contain measurable quantities of ^{239}Pu .

The characteristics of aqueous plutonium has been reviewed by Andelman and Rozzell⁽³²⁾. They conclude that both kinds of and distribution of sizes among colloidal plutonium species--which are affected by aging, changes in pH, fluctuations in ionic strength and variations in type and concentration of complexing agents--will influence the elements' fate and interactions with mineral or other suspended surfaces in natural waters. By whatever the mechanism, be it geochemical as proposed by Andelman and Rozzell⁽³²⁾ and by Bowen et al⁽⁹⁾, or biological as proposed by Bowen et al⁽⁹⁾, or a more complicated bio-geochemical process, plutonium added to the oceans from any source is rapidly depleted from surface and nearshore waters. Templeton and Preston⁽²¹⁾ found that over 80% of the plutonium released from Windscale was rapidly associated with particles nonfilterable through 1.2 μ m membrane filters. Aakrog⁽¹³⁾ reported that from sedimentation experiments carried out by Langham, 85-95% of the debris from the Thule disaster and associated plutonium oxide sank in the waters immediately and that only 1% was suspended as fine, nonfilterable particles in the water phase.

Bowen, et al⁽⁹⁾ have shown that the upper layers of the Atlantic ocean are deficient in ^{239}Pu compared to ^{90}Sr or ^{137}Cs . Fallout delivery/activity ratios, $^{239}\text{Pu}/^{90}\text{Sr}$, of about 2-3% are reduced to less than 1% in North Atlantic surface water. Miyake and Sugimura⁽¹¹⁾ also noted lower than expected $^{239}\text{Pu}/^{90}\text{Sr}$ ratios in two 1967 Pacific surface samples. One vertical profile of fallout ^{239}Pu concentrations in the Sargasso Sea⁽⁹⁾ was strikingly similar to the concentration profile of ^{144}Ce and ^{147}Pm as reported by Sugihara and Bowen⁽³³⁾ and Bowen and Sugihara⁽³⁴⁾ and it was suggested that ^{239}Pu , like the lanthanides, might be useful in tracing sedimentary processes.

Plutonium is highly concentrated by a number of marine species. Biological sedimentation, therefore, could be of major importance in moving plutonium, especially in the waters of the open ocean. Wong, et al⁽⁶⁾, however, concluded from a small amount of data that when using a mean concentration factor for ^{239}Pu of about 2000

for zooplankton, 330 changes of zooplankton populations would be required in the Atlantic Slope water to remove two-thirds of the ^{239}Pu , as observed, from the surface waters. Over the shelf, 1300 changes and in the Gulf Stream or Sargasso Sea, some 13,000 changes would be required. Since only 10-20 changes per year are likely, a higher ^{239}Pu concentration factor must be characteristic of some other member of the plankton population, not yet found, or other processes of an undefined nature play a major role in the removal of plutonium from the surface ocean. One such population, restricted however to the confines of the Sargasso Sea, is the Sargasso weed. The mean concentration factor found for *Sargassum* Sp. has a value of 2×10^4 (see Table VI). In recent years the weed population could have effectively scavenged some 30 nCi/km^2 of ^{239}Pu per year from the surface waters of the Sargasso Sea⁽⁵⁾.

Since the inventory of fallout ^{239}Pu in surface waters has been rapidly depleted over the years, there has been a relative increase in the $^{238}\text{Pu}/^{239}\text{Pu}$ ratio in surface waters. This increase has been particularly noticeable in inshore regions uncontaminated by local introductions⁽⁵⁾. The added quantities of ^{238}Pu in the environment are the result of deposition of quantities of the SNAP-9A debris.

As in marine waters, plutonium is rapidly depleted from fresh waters; Magno et al⁽²³⁾ observed that quantities of the plutonium isotopes released from the NFS reprocessing facility became insoluble and settled rapidly in the lagoon system which intercepts much of the discharge. Of the amount leaving the lagoons to the surrounding streams, 92% of the plutonium was found to be associated with suspended material⁽²³⁾. During 1970 the $^{238}\text{Pu}/^{239}\text{Pu}$ activity ratio in all stream waters below NFS was greater than one⁽²⁵⁾ and the average ^{239}Pu concentration was 0.7 pCi/l ⁽²⁵⁾, a value roughly 1000 times greater than the fallout levels found in inshore marine waters. The large difference in the ratio of $^{238}\text{Pu}/^{239}\text{Pu}$ in reprocessing waste compared to the fallout value, could provide a unique tag for investigating the distribution of these isotopes in the environment of the NFS site.

Sediments

To fully understand what role sediments and sedimentary particles have in the uptake and retention of plutonium, it is not only necessary to consider lithological and chemical differences in sediment type but also the organic content and biological activity in the sediment as well. Plutonium is removed from the water to sediments rapidly and increased levels have been observed in all aquatic sediments analyzed.

Table IV summarizes the ^{239}Pu levels reported in aquatic sediments. The data from reference 13 was obtained from both within and outside the impact zone of the B-52 crash at Thule in 1968. Considering the concentration relative to the surface area, the sediments of Bylot Sound contain more plutonium than any other aquatic environment for which data is presently available. It was expected that most of the debris that had not been removed during decontamination of the accident area would be found on the sea bottom near the impact area. The highest levels were, however, found in the sediments distant from the point of impact and bottom feeding bivalves as far as 15km from the point of impact showed plutonium levels two orders of magnitude above background. Plutonium was rapidly redistributed in the water either by physical or biological processes.

The three cores from Buzzards Bay, Mass., depict the fallout levels accumulated in shallow water, silty bay sediments. The concentrations in the beach sand are shown to illustrate the differences in retention of ^{239}Pu between extreme sediment types. The sandy deposits contain 30 to 40 times less ^{239}Pu per unit weight in the upper 3 cm of sediment than do the silty deposits of the Bay. The different ^{239}Pu deposition values noted, comparing the three cores, may be real and may relate to both the lithology and chemical differences of the sediment samples. However, the error associated with each core value is approximately 15%, and the differences noted may only be due to analytical precision. From the one core where measurements were made to 29 cm, 86% of the ^{239}Pu was found between the surface and 9 cm. Normalizing the two short cores by

this percentage yields an average of 2.3 ± 0.2 mCi/km² ²³⁹Pu deposited in Bay sediments. Hardy and Krey⁽³⁵⁾ have recently reported the total ²³⁹Pu in six selected soil samples from New York area sites collected in 1969 and 1970. The average ²³⁹Pu deposited, determined to depths of greater than 20 cm in the soils, was 2.3 ± 0.3 mCi/km². DeBortali and Gaglione⁽³⁶⁾ analyzed 11 soil profiles collected in 1966 and 1967 and reported a mean value of 2.1 ± 0.7 mCi/km² for ²³⁹Pu deposited in the surroundings of the Euratom Ispra establishment. Both average soil values are in good agreement especially when one considers that at the most only some 0.1 mCi/km² of ²³⁹Pu were deposited between 1967 and 1969⁽¹⁰⁾.

As has been found for ⁹⁰Sr little difference in ²³⁹Pu deposition is detected in selected soil, sampled globally, within the same 10° latitude band. Since Buzzards Bay is within the 40-50° latitude band, the soil deposition values can be directly compared to the sediments results. Fallout ²³⁹Pu has been almost completely depleted from the shallow water column and a substantial quantity of that deposited over the years has been retained in the sediment. It should be anticipated, regardless of the source, that those animals deriving material from near shore sedimentary deposits will be exposed to higher levels of ²³⁹Pu than those animals deriving food directly from the waters.

Plutonium is redistributed to considerable depth in marine deposits. Templeton and Preston⁽²¹⁾ found penetration in the order Pu > ¹³⁷Cs > ⁹⁰Sr > ¹⁰⁶Ru in sea bed deposits between the Windscale discharge outlet and St. Bees Head, England. Comparing the 15-23 cm depth section of a core to the top 5 cm they find a Pu ratio of 0.17. The value for ¹³⁷Cs was 0.08. In Fig. 1 is shown the fraction of the surface layer concentrations of ²³⁹Pu and ¹³⁷Cs as a function of depth in one shallow water core obtained from Buzzards Bay in 1970⁽¹⁵⁾. The order of penetration is opposite to that found by Templeton and Preston⁽²¹⁾. Comparing the Bay data⁽¹⁵⁾ with the same depth increments as used by Templeton and Preston⁽²¹⁾, the ²³⁹Pu value in the Buzzards Bay core is 0.04 while the ¹³⁷Cs value is 0.20.

The ^{137}Cs content in the Buzzards Bay core is less than 10% of the quantity deposited in the 40-50° latitude band, as estimated from soil and rainfall data. This supports the earlier observation; plutonium is depleted from the water column more rapidly than the more soluble ^{137}Cs .

Since the mean sedimentation rate in the Bay region is too low to account for the presence of both ^{239}Pu and ^{137}Cs at depth in the core, only two explanations can be proposed to account for its presence at depths. Chemical or biological reactions must be occurring at the sediment-water interface to produce changes in the interstitial waters and solid phases which are sufficiently large to induce redistribution of the plutonium and ^{137}Cs taken up by sedimenting material. The post depositional pattern could result either from molecular diffusion-sorption-desorption taking place in the bulk sediment, or biological reworking of the upper layers of sediments, or a combination of both these processes.

An as yet unexplained observation, which in fact may be more coincidental than real, is the similarity of the ^{239}Pu profile in marine sediment and in soil from both Brookhaven and Ispra.

In figure 2 are shown the fractions of the total activities as a function of depth intervals. The sediment values⁽⁵⁾ were normalized to Hardy and Krey's⁽³⁵⁾ increments while the Ispra data is shown as published⁽³⁶⁾. The vertical distributions indicate, although the profiles are very similar, that ^{239}Pu may penetrate marine sediments less rapidly than it penetrates continental soils. More work is required to confirm this observation and to clarify the mechanisms involved, but it is suggestive that the chemical properties of plutonium involved and the physical-chemical properties of the environment may be more important than biological reworking in controlling the process of vertical migration.

Invertebrates and Algae

It is clear from Tables III, V and VI that all marine invertebrates have higher levels of plutonium than are observed in their environment. When the concentration in the organism was not considered to be in equilibrium with the surrounding sea water, concentration factors were not computed by the references indicated and are therefore unavailable.

The similar concentration factor found for *Mytilus*, separated by both time (1964-1970) and environment (coastal Atlantic - coastal Pacific), suggests *Mytilus*, for the most part, regulates its plutonium content in relation to the concentration in water and is therefore an excellent biological indicator for plutonium levels in the environment. The $^{238}\text{Pu}/^{239}\text{Pu}$ activity ratio in *Mytilus* is more typical of that value found in the near shore waters rather than the isotopic value in bottom sediments of Cape Cod⁽⁵⁾. The mussel therefore probably feeds on recently formed suspensions within the water column rather than on aged resuspended or bottom detritus.

The starfish were collected as they were feeding on the mussel beds^(5, 6). The ^{239}Pu concentration, although different in each specimen, was about four times that found in the mussels upon which each was feeding. The $^{238}\text{Pu}/^{239}\text{Pu}$ activity ratio was the same as the average mussel value. It would appear that plutonium enters the starfish via the prey rather than from the environment. The similar isotopic ratio, and the fact that this pathway has been suggested for other radioisotopes found in the starfish, in addition to finding the starfish feeding on the prey, support this conclusion. These observations show that plutonium concentrations increase along this simple food chain.

The bottom feeding organisms are found to contain the highest concentrations in every environment sampled. *Mytilus* collected at the Windscale pipeline buoy showed a bottom to surface of buoy ^{239}Pu ratio of 28⁽²¹⁾. The decrease, surface to bottom, was thought to reflect the concentration of the suspended material available to the invertebrate at each level down the buoy⁽²¹⁾ but in addition emphasizes the rapid sedimentation rate of plutonium. Polychaetes collected from the Thule area contained 30,000 pCi of ^{239}Pu per kilogram fresh weight

and other bottom feeding bivalves contained levels of ^{239}Pu up to 76,000 pCi/kg⁽¹³⁾. The marine worm collected from Cape Cod waters is a nonselective deposit feeder and ingests quantities of sediment. Plutonium values were considerably higher in sediment than in the water and the low $^{238}\text{Pu}/^{239}\text{Pu}$ ratio found in the worm is similar to that ratio found in sediments⁽⁵⁾. Most of the plutonium found in *Nereis* is derived from material deposited on the sea floor.

The concentration of ^{239}Pu in the body of the scallop from Cape Cod is slightly higher than the mussel. The plutonium isotope ratio is more similar to that found in the sediment rather than the water, which suggests a sedimentary source for the element. The adductor muscle, that part commonly consumed in large quantities by man, contained levels of plutonium significantly lower than the rest of the body. As in higher order animals⁽⁶⁾ plutonium is not highly concentrated in muscle tissue. These results confirm an earlier observation by Ward⁽³⁹⁾ who found the concentration factor for plutonium in lobster shell two orders of magnitude higher than in meat.

Sea plants, as well, appear to be sensitive indicators of environmental ^{239}Pu levels. Quite surprising, and as yet unexplained, is the relatively higher affinity for ^{239}Pu in North Atlantic Sargassum. Considering that this weed is transported in quantities out of the Sargasso Sea, a significant quantity of plutonium can be transferred from one water mass to another. If, as it has been found for ^{144}Ce ⁽⁴⁰⁾, surface adsorption plays a relatively insignificant part in the accumulation of radionuclides by sargassum, the plant must be rapidly fixing the radionuclide internally.

Fish

In Table VII are shown plutonium concentration values for selected organs and total sample of marine vertebrates. Concentration factors were, in addition, obtained from the literature and are reproduced in Table VIII. Concentration factors were computed only when the concentrations found were considered to be in equilibrium with sea water.

As shown for marine invertebrates, plutonium is not highly concentrated in muscle tissue. The plutonium levels in all organs and total fish in samples obtained

near test sites and in Greenland are orders of magnitude higher than those found in open ocean samples where the plutonium levels were derived from total fallout delivered.

Wong et al⁽⁶⁾ found (and it has been confirmed by additional data⁽³⁸⁾; see Table VII) that the cartilaginous skeleton of sharks concentrates much less plutonium than do the better calcified skeletons of the bony fish. The concentrations in the backbone of the latter are roughly a factor of ten higher than in the sharks. In the sharks, however, where the skeleton is a less available repository for plutonium, the liver concentration was higher than in any of the bony fish analyzed from the open ocean. In bottom feeding fish, such as the tautog and flounder, the high gut contents are reflected in the two highest liver plutonium concentrations. Although "sorting" among plutonium repositories probably accounts for its distribution, relative to the path of uptake, the "sorting" by marine vertebrates must be quite complicated and different from both man and other mammals.

The ratio of the mean concentration factors, $^{90}\text{Sr}/^{239}\text{Pu}$ and $^{137}\text{Cs}/^{239}\text{Pu}$ shown in Table VIII for the gut contents resembles those values found in invertebrates ($^{137}\text{Cs}/^{239}\text{Pu} = 0.07$; $^{90}\text{Sr}/^{239}\text{Pu} = .04$ ⁽³⁸⁾) and in the upper few centimeters of shallow water sediments ($^{137}\text{Cs}/^{239}\text{Pu} = .034$; $^{90}\text{Sr}/^{239}\text{Pu} = .005$ ⁽¹⁵⁾) more than the ratios in other fish tissue. The activity levels observed in the guts of the bottom feeding fish could then be explained if bottom sediment of only a few percent of the wet weight were present in the samples analyzed. Regardless of the area, bottom feeding fish do however, tend to concentrate more plutonium than those fish such as the blue fin tuna, bonito or sea scorpion which only rarely feed about the bottom.

Plutonium appears to be immobilized in the gut wall as soon as absorbed and is discriminated against in other tissues in favor of ^{90}Sr and ^{137}Cs . However, one should exercise care in extrapolating the concentration factors presented herein to make predictions of the body burden several years hence since, like in other vertebrates,⁽³⁷⁾ plutonium levels in fish may increase with time.

In addition to whatever concern the present levels of plutonium are when consideration is given to radiation exposure to fish, it appears at this time that, while fish flesh

does not represent an important vector transferring environmental plutonium into human food chains, there are aspects of fish ecology and physiology that result in reconcentration of plutonium in the rarely-eaten parts of the organisms. Therefore, such food items as anchovies, sardines, canned salmon, etc., which are consumed whole, and fish protein concentrate, whose useage as a food supplement will increase in future years, will represent important transfer vectors of plutonium into humans via the food chain.

REFERENCES

1. J. H. Olafson and K. H. Larson. In Radioecology (Edited by V. Schultz and A. W. Klement, Jr), pp. 633-639. Reinhold, New York (1963).
2. A. B. Joseph, P. Gustafson, N. R. Russell, E. A. Schuert, H. L. Volchok and A. Tamplin, in Radioactivity in the Marine Environment (Edited by A. H. Seymour) NAS-NRC, Washington, pp. 6-41. (1971).
3. N. T. Mitchell. Ministry of Agriculture, Fisheries & Food, Fisheries Radiobiological Laboratory, March. T. R. FRL 7 (1971).
4. J. J. Davis, R. W. Perkins, R. F. Palmer, W. C. Hanson and J. F. Cline, 2nd U. N. Conf. on Peaceful Use of Atomic Energy 18, 423-428 (1958).
5. V. E. Noshkin, V. T. Bowen, K. M. Wong and J. C. Burke, Plutonium in North Atlantic Ocean organisms; ecological relationships, in Proc. 3rd National Symposium on Radioecology, held at Oak Ridge, Tenn., May 1971. In press.
6. *K. M. Wong, J. C. Burke and V. T. Bowen, in Proc. 5th Ann. Health Phys. Soc. Midyear Topical Symposium, pp. 529-539 (1970).
7. W. K. McRaney, in USAF Nuclear Safety, AFRP-122, 65(2): 45-51 (1970).
8. W. L. Templeton, R. E. Nakatini and E. Held, in Radioactivity in the Marine Environment (Edited by A. H. Seymour), NAS-NRC, Washington, pp. 223-239 (1971).
9. *V. T. Bowen, K. M. Wong and V. E. Noshkin, J. Mar. Res. 29, 1-10 (1971).
10. Y. Miyake, Y. Katsuragi and Y. Sugimura, J. Geophys. Res. 75, 2329-2330 (1970).
11. Y. Miyake and Y. Sugimura, Pap. Meteorol. Geophys. Tokyo, no. 19, 481-485 (1968).
12. K. C. Pillai, R. C. Smith and T. R. Folsom, Nature, 203, 568-571 (1964).
13. A. Aarkrog, Health Phys. 20, 31-47 (1971).
14. *K. M. Wong, V. E. Noshkin, L. Surprenant and V. T. Bowen, U. S. AEC Document HASL-227, pp. I-25 to I-33 (1970).

15. V. E. Noshkin and V. T. Bowen, Fallout radionuclides in near shore sediments, in preparation (1971).
16. K. M. Wong, V. F. Hodge and T. R. Folsom, presented at the Environmental Plutonium Symposium, Los Alamos Scientific Lab, Aug. 4-5, 1971.
17. H. Diamond, P. R. Fields, C. S. Stevens, M. H. Studier, S. M. Fried, M. G. Ingram, D. C. Hess, G. L. Pyle, J. F. Mech, W. M. Manning, A. Ghiorso, S. G. Thompson, G. H. Higgins and G. T. Seaborg, Phys. Rev. 119, 2000-2004 (1960).
18. C. W. Thomas, D. L. Reid and L. F. Lust, U. S. AEC Document HW-58674, 81 pp. (1958).
19. A. D. Welander, in Symposium on Radioecology (Edited by Daniel J. Nelson and Francis C. Evans), U. S. AEC Document CONF-670503, pp. 346-354 (1969).
20. F. G. Lowman, in IAEA Publication, Disposal of Radioactive Wastes, Conf. Proceedings, Monaco, Nov. 16-21, 1959, pp. 105-138 (1960).
21. W. L. Templeton and A. Preston, in IAEA Publication, "Disposal of Radioactive Waters into Seas, Oceans and Surface Waters", pp. 267-289 (1966).
22. N. T. Mitchell. Ministry of Agriculture, Fisheries and Food, Fisheries Radio-biological Laboratory, Nov. T. R. FRL 5 (1969).
23. P. Magno, T. Reavey and J. Apedianakis, in Proc. 5th Ann. Health Phys. Soc. Midyear Topical Symposium, pp. 208-220 (1970).
24. W. J. Kelleher, Radiol. Health Data Rep., 10, 329-339 (1969).
25. W. G. Bentley, 1970 Annual Report of Environmental Radiation in New York State, State of N. Y., Dept. of Environmental Conservation, June 18, 1971.
26. Radiological Health Data and Reports, Environmental labels of radioactivity at Atomic Energy Commission installations, for example, data in Vol. 8, #8; Vol. 9, #7; Vol. 8, #11; Vol. 9, #6; Vol. 9, #9; Vol. 11, #10 (1967-1970).
27. A. H. Seymour and G. B. Lewis, U. S. AEC Document UWFL-86, 73 pp. (1964).
28. R. F. Foster, U. S. AEC Document BNWL-316, 34 pp. (1966).

29. H. L. Volchok and P. W. Krey, U. S. AEC Document HASL-224, pp. 1-14 to 1-27 (1970).
30. K. M. Wong, Radiochemical determination of plutonium in seawater, sediments and marine organisms, Anal. Chim. Acta, in press (1971).
31. K. M. Wong, V. E. Noshkin and V. T. Bowen, in IAEA Publication, Reference Methods for Marine Radioactivity Studies (Edited by Y. Nishiwaki and R. Fukai), pp. 119-127 (1970).
32. J. B. Andelman and T. C. Rozzell, in Advances in Chemistry Series, No. 93, "Radionuclides in the Environment", American Chemical Soc., pp. 118-137 (1970).
33. T. T. Sugihara and V. T. Bowen, in IAEA Publication, Radioisotopes in the Physical Sciences and Industry 1, 57-65 (1962).
34. V. T. Bowen and T. T. Sugihara, J. Mar. Res. 23(2), 123-146 (1965).
35. E. P. Hardy and P. W. Krey, "Determining the accumulated deposit of radionuclides by soil sampling and analysis", presented at "Environmental Plutonium Symposium", Los Alamos Scientific Lab, Aug. 4-5, 1971.
36. M. C. deBortali and P. Gaglione, Health Phys. 17, 701-710 (1969).
37. E. M. Romney, H. M. Mork and K. H. Larson, Health Physics 19, 487 (1970).
38. V. E. Noshkin, unpublished data.
39. E. E. Ward, Nature 209, 625-626 (1966).
40. J. E. Simek, J. A. Davis and C. E. Day, III, in Symposium on Radioecology (Edited by Daniel J. Nelson and Francis C. Evans), U. S. AEC Document Conf.-670503, pp. 505-598 (1969).

* Absolute plutonium values in this review differ from those in the original papers so indicated. Restandardization indicated the original standards used for detector calibration were in error, hence all plutonium values were corrected using a constant factor. These corrections were made with the permission of the authors.

Table 1 - Mean Activity Discharge Rate to the Irish Sea from Windscale Chemical Reprocessing Plant, U. K. - % Change in Release Rate over Previous Year Mean/Month (Data from Ref. 2)

% Change		
Year	Total Beta	Total Alpha
1958	+27.5	+8.3
1959	+11.9	+7.7
1960	-15.6	+21.4
1961	-38.4	+63.2
1962	- 6.0	+39.6
1963	+ 7.4	+22.6
1964	+25.7	+23.6
1965	- 9.8	+43.8
1966	+19.8	+44.4
1967	+10.2	+63.1

Table II - Am²⁴¹ and Pu²³⁹ concentrations in Porphyra in the vicinity of Windscale, 1969 (Data from Ref. 3)

Distance from Pipeline (km)	Am ²⁴¹ pc/gm (wet weight)	Pu ²³⁹ /Am ²⁴¹
0.0	1.0	1.0
1.4	0.7	4.9
1.9	0.8	2.5
3.1	0.7	1.9
3.7	1.1	1.9
5.6	0.4	2.3
5.6	0.8	3.6
8.0	1.1	0.7
10.0	0.6	1.3
10.9	0.2	1.5
14.3	0.3	1.7
20.1	0.7	4.1
38.0	0.2	1.0

Table III -- Plutonium-239 in Sea Water

Year	No. of Samples	Depth (meters)	Location	Median Value		Ref.
				fCi/l *	range	
1963	1	0	44°N, 41°W	1.4		(9)
1964	4	0	(32°N, 117°W) Scripps Pier	0.4	0.3- 0.5	(12)
1964	2	0	27-30°N, 129-140°W	2.4	2.0- 3.0	(12)
1967	1	0	56°N, 51°W	0.9		(9)
1967	10	0	24-44°N, 133-150°W	0.4	0.1- 1.4	(11)
1967	3	0	(35°N, 140°E) Jogashima Pier	0.8	0.6- 1.2	(11)
1968	10	0-100	0-31°N, 67°W-03°E	0.7	0.3- 1.8	(9)
1968	3	0-100	18-28°S, 07°E	0.4	0.3- 0.5	(9)
1968	11	0-70	54-56°N, 10-13°E	1.0	0.1- 3.0	(13)
1968	4	2	Thule, impact area	5.8	4.0-12.0	(13)
1968	8	30-100	Bylot Sound	5.5	2.0-67.0	(13)
1968	6	0-2	Control Zone, Greenland	3.8	1.0-26.0	(13)
1969	2	0	36-37°N, 70°W-0°E	0.9	0.6- 1.5	(9)
1968-69	7	300-700	0-39°N, 63°W-6°E	1.2	0.4- 3.0	(9)
1968-69	7	1000-4500	25-27°N, 67°W-0°E	0.2	-0.1- 0.4	(9)
1968	2	1000-3000	33°N, 143°E	0.3	0.2- 0.3	(11)
1971	?	0	Scripps Pier	0.7	?	(16)

* femtocurie/liter

Table IV - Plutonium-239 in Aquatic Sediments

<u>Year</u>	<u>pCi/g dry</u>	<u>mCi/km²</u>	<u>Location and Notes</u>	<u>Reference</u>
<u>Marine Sediments</u>				
1964	8.0		Bikini Atoll	19
1968	1.3	3.9	Outside impact area of 1968, B-52 diaster	13
1968	16	135.0	1 km from point of impact, Bylot Sound	13
1970	.06 (0-3 cm)	2.2 (0- 9 cm)	Buzzards Bay, Mass.	15
1970	.04 (0-3 cm)	2.5 (0-29 cm)	Buzzards Bay, Mass.	15
1970	.02 (0-3 cm)	1.6 (0- 9 cm)	Buzzards Bay, Mass.	15
1970-71	.0011 (0-3 cm)		Average of 5 samples of beach sand from vicinity of Buzzards Bay, Mass.	5, 15
<u>Fresh Water Sediments</u>				
1967	39.3 (total Pu)		January-Waste lagoon #3 at NFS facility.	35
1967	4.7		September - from above site	
1967	0.03		June - Cattaraugus Creek offsite NFS	

Table V -- Plutonium 239 Concentrations in Marine Invertebrates and Algae.
(²³⁸Pu, ¹³⁷Cs and ⁹⁰Sr concentrations shown when given in reference indicated)

Organism	Tissue	Collection date	Location	Mean pCi kg wet	$\frac{^{238}\text{Pu}}{^{239}\text{Pu}}$	$\frac{^{137}\text{Cs}}{^{239}\text{Pu}}$	$\frac{^{90}\text{Sr}}{^{239}\text{Pu}}$	Reference
Blue Mussel (<i>Mytilus edulis</i>)	body	1970	Cape Cod	0.26	.099	18.3	2.1	5
	shell	1970	Cape Cod	0.42	.088	1.1		5
Brown Mussel (<i>Modiolus modiolus</i>)	body	1970	Cape Cod	0.29	.071	15.0	2.0	5
<i>Mytilus californianus</i>	body	1964	Calif. coast	0.22				12
Softshell Clam (<i>Mya arenaria</i>)	body	1970	Cape Cod	0.37		27.0		5
Oyster (<i>Ostrea virginica</i>)	body	1970	Cape Cod	0.11		20.0		5
Scallop (<i>Pecten irradians</i>)	adductor	1970	Cape Cod	0.02		600		5
	body	1970	Cape Cod	0.49	.049	6		5
	shell	1970	Cape Cod	0.52	.058			5
Whelk (<i>Busycon corina</i>)	body	1970		0.12				5
	shell	1970	Cape Cod	0.25	.093	2		5
Moonshell (<i>Lunatia heros</i>)	body	1970	Cape Cod	0.57	.046	4.7		5
	shell	1970	Cape Cod	0.59		0		5
Starfish (<i>Asterias forbesi</i>)	body	1970	Cape Cod	0.87	.087	1.2	11.9	5
Marine Worm	body	1970	Cape Cod	3.50	.056	1.2		5
Sponge (<i>Clathria delicata</i>)	body	1970	Cape Cod	1.80	.074	1.5		5
Blue Mussel (<i>Mytilus edulis</i>)	body	1964	Windscale Area	2450				21
Bivalves (mixed)	body	1968	Thule, Zone II	40	.020			13
Bivalves (mixed)	body	1968	Thule, Zone I	8000	.018			13
Bivalves (mixed)	body	1968	Danish Inner Water	7				13
Crustacea	body	1968	Thule	95	.022			13
	shell	1968	Thule	330	.021			13
Crustacea	body	1968	Danish Inner Water	1.5				13

Table V -- Plutonium 239 Concentrations in Marine Invertebrates (Continued)
 (^{238}Pu , ^{137}Cs and ^{90}Sr concentrations shown when given in reference indicated)

Organism	Tissue	Collection date	Location	Mean $\frac{\text{pCi}}{\text{kg wet}}$	$\frac{^{238}\text{Pu}}{^{239}\text{Pu}}$	$\frac{^{137}\text{Cs}}{^{239}\text{Pu}}$	$\frac{^{90}\text{Sr}}{^{239}\text{Pu}}$	Reference
Zooplankton (Mixed)		1950	Calif. coast	.023				12
Zooplankton (Mixed)		1961	Atlantic	2.03				6
Zooplankton (Mixed)		1964	Calif. coast	1.08				12
Zooplankton (Mixed)		1964	Enyu Is.	700 *				19
Zooplankton (Mixed)		1964	Romurikku Is.	11000*				19
Zooplankton (Mixed)		1968	Thule	4.8				13
Salpa		1958	Atlantic	1.40				6
Algae								
**Mixed (4 samples)		1964	Pacific coast	0.47				12
**Mixed (7 samples)		1964	Thule	16.0				13
**Mixed (19 samples)		1971	Pacific coast	0.64				16
**Mixed (6 samples)		1970-71	Cape Cod	0.53				5
**Mixed (3 samples)		1964	Bikini	2530*				19
Sargassum Sp (6 samples)		1965-70	Atlantic	20.7				5
Sargassum Sp (2 samples)		1971	Pacific coast	0.28				16
Porphyra		1969	Windscale Vicinity	1470				3

*pCi/dry weight

**refer to reference for species

Table VI - Plutonium 239 Concentration Factors in Marine Invertebrates and Algae.

Organism	Tissue	Collection date	Location	Mean Value	Range	Reference
Blue Mussel	body	1970	Cape Cod	300 (7)**	250-350	5
Mussel	body	1964	Calif. coast	260 (2)	230-290	12
Brown Mussel	body	1970	Cape Cod	340 (1)		5
Blue Mussel	shell	1970	Cape Cod	490 (3)		5
Soft Shell Clam	body	1970	Cape Cod	440 (1)		5
Oyster	body	1970	Cape Cod	130 (2)	100-160	5
Scallop	adductor	1970	Cape Cod	24 (2)	10-37	5
	body	1970	Cape Cod	520 (3)	410-690	5
	shell	1970	Cape Cod	600 (1)		5
Whelk	body	1970	Cape Cod	140 (1)		5
	shell	1970	Cape Cod	300 (1)		5
Moonshell	body	1970	Cape Cod	660 (1)		5
	shell	1970	Cape Cod	690 (1)		5
Starfish	body	1970	Cape Cod	1020 (1)		5
Brittle Star	body	1970	Cape Cod	760 (1)		5
Marine Worm	body	1970	Cape Cod	4100 (1)		5
Sponge	body	1970	Cape Cod	2100 (1)		5
Bivalves (mixed)	body	1968	Danish Inner Waters	8235 (?)*		13
Crustacea	body	1968	Danish Inner Waters	1765 (5)	1060-4471*	13
Zooplankton		1961	Atlantic	2300 (1)		6
		1964	Calif. coast	2590 (1)		12
Salpa		1958	Atlantic	1567 (3)	900-2400	6
Algae		1964	Pacific coast	1020 (4)	660-1570	12
		1971	Pacific coast	890 (19)	260-3500	16
		1970-71	Cape Cod	620 (6)	100-1600	5
Sargassum Sp.		1965-71	Atlantic	21000 (6)	3000-100,000	5
Sargassum Sp.		1971	Pacific coast	390 (2)	325-450	16

*computed using an average open ocean seawater value of .00085 pCi/ka ** Number of samples in parenthesis

Table VII -- Plutonium 239 in Marine Vertebrates
pCi/kg Wet or Fresh Weight

Species	Collection		Backbone	Liver	Gut	Muscle	Total animal**	Reference
	Year	Location						
Surgeon Fish	1957	Guam	140			70		18
Bat Fish	1957	Guam	340	230		20		18
Mackeral Tuna	1957	Guam	110	350		20		18
Snapper	1964	Bikini		7000*				19
Surgeonfish	1964	Bikini					7500*	19
Damselfish	1964	Bikini					1200*	19
Bonito (<i>Sarda lineolata</i>)	1964	Calif. coast					.001	12
Sea Scorpion	1968	Thule	1.3				0.9-14	13
Polar Cod	1968	Thule					19-230	13
Greenland Halibut	1968	Thule					260-470	13
Liparidae and Lycodidae	1968	Thule					35-40	13
Blue Shark (<i>Prionace glauca</i>)	1970	Cape Hatteras	0.02-.03	0.1-0.2		.001-.005		6
Mako Shark (<i>Isurus oxyrinchus</i>)	1971	Cape Hatteras	0.01-.04			.01		38
Dusky Shark (<i>Carcharhinus obsurus</i>)	1971	Cape Hatteras	0.05			.003		38
Blue Fin Tuna (<i>Thunnus thynnus</i>)	1970	Cape Cod	0.1			.003		6
Blue Fish (<i>Pomatomus saltatrix</i>)	1969	Cape Cod	0.6	.03		.005		6
Stripped Bass (<i>Morone saxatilis</i>)	1970	Cape Cod	0.2	.02	0.04	.005		6
Tautog (<i>Tautoga ovitis</i>)	1970	Cape Cod	0.6	.07	0.8			6
Blackback Flounder (<i>Pseudopleuronectes Americanus</i>)	1970	Cape Cod	0.05	.06	1.2	.002		6
Marine Protein Concentrate	1970						0.23	38

* pCi/gm dry weight

** Range of values given when more than one sample analyzed

Table VIII -- Plutonium 239 Concentration Factors in Marine Vertebrates

<u>Species</u>	<u>Backbone</u>	<u>Liver</u>	<u>Gut</u>	<u>Muscle</u>	<u>Total Animal</u>	<u>Reference</u>
Blue Shark	21	175		4		6
Mako Shark	29			13		38
Dusky Shark	49					38
Blue Fin Tuna	90			2		6
Blue Fish	570	26		5		6
Bass	160	14	36	4		6
Flounder	50	57	1060	1		6
Tautog	510	64	730			6
Bonito					3	12
<u>Mean Concentration Factor Ratios</u>						
$^{90}\text{Sr}/^{239}\text{Pu}$	0.7	0.2	.08			38
$^{137}\text{Cs}/^{239}\text{Pu}$		0.9	.08	81		38

Figure 1 - Vertical Profile of ^{239}Pu and ^{137}Cs in Marine Sediment

from Buzzards Bay, Mass.

41°33'50"N; 70°42'33"W

30 June 1970 in 12m of water

Fraction of (0-1cm) ^{239}Pu activity (dpm/gm dry weight)

Figure 2 - Depth fraction of total ^{239}Pu activity
in core as a function of depth in Buzzards Bay sediment,
Brookhaven and Ispra soils

Fraction of total ^{239}Pu in soil or sediment core