difficult to assess but we do feel that tag returns, especially from Latin American areas, have increased since the initiation of this reward program.

CONCLUSIONS

The returns of tagged fish from many of these experiments, especially those during 1957, are yet incomplete, and estimates of mortality rates, tag dispersion and the geographical distribution of sub-populations in the fishery are not yet possible. It can be said, however, that,

1. Improvements in the original plastic loop tag for tunas, in handling techniques and the establishment of a reward program have resulted in considerable increases in the rates of tag return for both yellowfin and skipjack tunas.
2. The results of the testing of the plastic dart tag are still inconclusive but it appears that the tag visibility is poor in the American fishery and may result in high losses of recovered but undetected tagged fish.

LITERATURE CITED

BLACK, EDGAR C.
1958. Hyperactivity as a lethal factor in fish. J. Fish. Res. Bd. Canada, 15 (4), pp. 573-586.

WILSON, ROBERT C.
1953. Tuna marking, a progress report. Calif. Fish and Game, Vol. 39, No. 4, pp. 429-442.

YAMASHITA, DANIEL T. AND KENNETH D. WALDRON
1958. An all-plastic dart type fish tag. Calif. Fish and Game, Vol. 44, No. 4, pp. 311-317.

Accumulation of Radioactive Materials by Fishery Organisms

WALTER A. CHIPMAN
Radiobiological Investigations
U. S. Fish and Wildlife Service

WE ARE NOW LIVING in a period in which there is tremendous expansion in the use of atomic energy. There is great interest in possible hazards to man of the radioactivity associated with the release of the energy of the atom. Of considerable concern is the contamination of man's environment with radioactive materials. Such materials added to the atmosphere, soil, and natural waters may be taken in by man and levels of radioactivity may be built up in the body sufficient to be damaging. In marine environments radioactive contaminants may accumulate in seafood organisms and affect their utilization or availability.

In discussing radioactive materials we need to consider that these materials are radioactive isotopes of chemical elements. In most cases the atoms that compose a chemical element differ in mass and those of like mass members, the isotopes, are present in definite ratios. For instance carbon, wherever it is found in nature, is composed almost 99 per cent of carbon atoms of mass number 12 and about one per cent of carbon atoms of mass number 13. With the advent of man-made isotopes of carbon with other mass numbers, for example carbon-14, which is radioactive, it is possible to have carbon compounds in which the isotopic ratio is changed by inclusion of radioactive atoms. For the most part, the chemical and physiological processes of the body make use of elements to form compounds without discrimination as to their isotopic composition. Thus a radioisotope may be incorporated into the body tissues of marine plants and animals if present in their environment.

Living tissues accumulate chemical elements to different degrees. It is well known that certain elements, such as calcium and strontium, are concentrated in skeletal structures, such as bone and shell. Other elements are present in greater amounts in certain soft tissues and organs. Although maximum levels of concentration of an element exist, the elements composing the compounds of the body are constantly being replaced. Some compounds are broken down and reformed rapidly; others only slowly. If radioactive isotopes are included with the other isotopes of the element involved in the metabolism of marine organisms, an accumulation of radioactivity can result.

Radioisotopes may be added to a marine environment from the use of nuclear weapons and from the various operations required for the use of nuclear reactors. Some disposal may be made in coastal waters of a variety of radioisotopes used in industry, research, and medicine. They may be grouped into two general categories based on their origin. One includes the fission products resulting from the fission of uranium-235 and the other the radionuclides of elements produced from induced nuclear changes, generally from neutron bombardment resulting from the fission process.

Contamination of a marine environment from nuclear warfare can be from fission products and from induced radionuclides. Although there was an addition of fission products to the sea water from the testing of nuclear weapons in the Pacific Ocean, large contributions to the total radioactivity of certain fish were found to be from the non-fission product, zinc-65, and of certain molluscs from cobalt-60 (Weiss *et al.*, 1956). Many other induced radionuclides were also present in the fish and shellfish.

In the normal operations concerned with the use of nuclear reactors only insignificant amounts of radioactive materials are released to natural waters. Many reactors are cooled with water and the primary coolant water may contain radioactive materials. These may be radioisotopes of the elements normally present in water or present as corrosion products. They become radioactive from close association with the high neutron flux of the reactor core. Some fission products may be present if ruptures occur in the coverings of fuel elements. However, generally the primary coolant is contained within a closed system in which the heat is transferred through heat exchangers to a secondary coolant. Only through leaks within the heat exchangers would radioactive materials be passed to the secondary coolant. Small amounts of fission products are included in the waste effluents of chemical plants engaged in the reprocessing of irradiated and spent fuels. In a few instances low-level radioactive wastes from such plants are released into coastal waters.

It is the purpose of this paper to discuss the accumulation of radioactivity by marine fish and shellfish when fission product radionuclides and other radioisotopes are present in sea water.

For the most part the discussion is based on the experimental work of the

Radiobiological Investigations of the Bureau of Commercial Fisheries carried on at the Beaufort, North Carolina, laboratory. Some of the findings were described previously (Chipman, 1958) and details of many of the results are reported in the scientific literature or will be published shortly.

Accumulation of Fission Products

We may first consider the accumulation of radioisotopes of the fission products. We have measured the uptake of radioactivity by plankton, fish, and shellfish following the addition of mixed fission products of nearly one year of age to sea water or administered in foods. We have made radiological analyses of the accumulated radioactivity to determine the radioisotopes responsible for the activity. In order to further understand accumulation patterns, we have tested the uptake and accumulation of several of the individual radionuclides of such mixtures.

Table 1 shows some of the radionuclides produced in the fission of uranium that may be considered as biologically important and the per cent they contribute to the total radioactivity after different periods of time. The great majority of those having a significant contribution from twenty days up to about one year of age are those of the rare earth elements or those having chemical characteristics similar to rare earths. The importance of strontium-90 and cesium-137 in aged fission products is apparent.

TABLE 1

Per cent of Total Radioactivity Contributed by Certain Fission Products of Biological Interest at Different Times After Fission.[1]

	20 days	90 days	1 year	3 years	10 years	20 years
Sr^{89}	5.0	10.5	2.7	—	—	—
Sr^{90}-Y^{90}	—	—	3.7	17.4	44.0	48.0
Y^{91}	5.6	12.5	3.8	—	—	—
Zr^{95}	5.9	14.7	7.2	—	—	—
Nb^{95}	2.3	18.0	14.7	—	—	—
Mo^{99}	1.3	—	—	—	—	—
Ru^{103m}	4.4	7.2	0.8	—	—	—
Rh^{103}	4.2	7.0	0.8	—	—	—
Ru^{106}-Rh^{106}	—	—	4.9	6.0	—	—
I^{131}	5.6	—	—	—	—	—
I^{132}	1.1	—	—	—	—	—
Cs^{137}-Ba^{137m}	—	—	2.9	13.6	36.0	45.0
La^{140}	13.9	1.8	—	—	—	—
Ba^{140}	12.0	1.6	—	—	—	—
Ce^{141}	9.7	8.5	—	—	—	—
Pr^{143}	12.0	11.2	2.6	—	—	—
Ce^{144}-Pr^{144}	2.6	12.0	52.8	42.0	—	—
Nd^{147}	5.0	—	—	—	—	—
Pm^{147}	—	—	5.7	19.0	16.0	3.4
Sm^{151}	—	—	—	1.1	2.5	2.6

[1]Adapted from data of Hunter and Ballou (1951). Reference, Chipman (1958).

The availability of radionuclides for uptake by marine fish and shellfish is dependent in part on their chemical nature and physical state when present in the sea water. When fission products of about one year of age are added to sea water, the greater part of the radioactivity will be present in the form of particles. As seen in Table 2, only radioisotopes of strontium and cesium remain as the important fission products of mixtures of this age in solution. The nature of the ruthenium compounds is difficult to predict, but in our tests we had precipitation of ruthenium when employing ruthenium-106 at the pH of sea water.

Not only may there be a formation of particles, but there is also a marked adsorption of many radionuclides to the surfaces of particles. There is a great abundance of particles in natural sea water, especially in certain inshore waters. This adsorption of radionuclides to both living and non-living particles in sea water is of considerable significance in discussing the fate of radioactivity added to marine environments.

Accumulation by plankton

In the sea the primary concentrators, the photosynthetic plants, take chemical elements directly from the water. For the most part, these plants are the minute single-celled algae, the phytoplankton. Because of their small size they offer tremendously large surfaces for adsorption. An accumulation of radioactive materials by these forms may be passed to marine animals through the food webs of the sea.

In the Pacific Ocean following the testing of nuclear weapons, high radioactivity was found in the plankton, the nannoplankton samples having higher radioactivity than those composed of larger organisms (Harley, 1956).

TABLE 2

PROBABLE STATE OF CERTAIN FISSION PRODUCTS WHEN PRESENT IN SEA WATER

Particulate	Solution
yttrium-91	strontium-89
zirconium-95	strontium-90
niobium-95	ruthenium-103*
praseodymium-143	ruthenium-106*
cerium-144	cesium-137
promethium-147	

*Questionable

In laboratory culture planktonic algae rapidly take up radioactivity when fission products are added to the sea water medium. In a very short time nearly all the radioactivity of added mixed fission products is associated with the cells. In tests with separated fission products we found very great accumulation of some radionuclides. These would thus be available in concentrated amounts for passage through the food webs to marine animals. There was great accumulation of ruthenium-106. The rare earth radionuclide, cerium-144, was accumulated many thousands of times above sea water concentrations as shown from the concentration factors listed in Table 3. Radioisotopes of yttrium are markedly concentrated. The experiments indicate that much of the accumulation of many radionuclides is related to surface areas.

Marine algae may be of little importance in passing certain radionuclides to animals. These include the radioisotopes of strontium and of cesium. As seen in the concentration factors listed in Table 4, marine species of phytoplankton do not concentrate cesium-137 appreciably. Although some species concentrate strontium, many take up only small amounts of radiostrontium added to the sea water in which they are grown (Rice, 1956).

With few exceptions the fishes and many other animals are not equipped to feed directly on phytoplankton. They depend on other forms which possess mechanisms which allow this type of feeding. An important group of phyto-

TABLE 3

CONCENTRATION FACTORS OF Ce^{144} FOR VARIOUS SPECIES OF PLANKTONIC ALGAE, CALCULATED ON A WET WEIGHT BASIS

Algae	Number of times over sea water concentration After 0.5 hours	After 24 hours
Carteria	314	2422
Platymonas	1843	2127
Nitzschia	518	1970
Thallassiosira	2610	3346
Amphidinium klebsi	3001	4498
Porphyridium	802	3344

TABLE 4

CONCENTRATION OF CESIUM BY MARINE ALGAE.[1]

Algae	Concentration factor[2]
Bacillariaceae	
Nitzschia closterium	1.2
Amphora sp.	1.5
Nitzschia sp.	1.7
Chlorophyceae	
Chlamydomonas sp.	1.3
Carteria sp.	1.3
Chlorella sp.	2.4
Pyramimonas sp.	2.6
Nannochloris atomus	3.1
Rhodophyceae	
Porphyridium cruentum	1.3

[1]Boroughs, Chipman, and Rice (1957).
[2]The concentration factor is reported as the ratio of Cs^{137} in the algae (wet weight) to that in an equivalent weight of sea water at an apparent steady-state condition.

plankton feeders is the small animal plankton. These are eaten by small fishes which may serve as food for others still larger.

We have observed that marine copepods and other filter-feeding zooplankton forms do rapidly become radioactive when exposed to sea water in which are suspended radioactive phytoplankton cells and other radioactive particles.

The copepod, *Tigropus californicus,* removed nearly all the radioactive cerium available in the sea water and food giving the animal a high concentration over the water. Likewise, brine shrimp feeding on *Nannochloris* cells containing ruthenium-106 became radioactive from their water filtration. Apparent high concentration factors can result when such accumulation of radioactive food particles can be collected from large volumes of water.

As regards the fission product radionuclides present as particles or associated with the phytoplankton food, the great majority are those poorly absorbed from the digestive tract. Consequently, the accumulation of radioactivity by the filtering zooplankton is related to the presence of radioactive particles on the filtering mechanisms and concentrated within the digestive tract. They fail to accumulate significant amounts of fission product radionuclides in their bodies. When the radioactive particles are no longer available, the accumulated radioactivity of the zooplankton forms is rapidly lost, depending on the time for the clearing of the digestive tract. An example of the rapid loss of accumulated cerium-144 by copepods is shown in Table 5. The accumulation was due almost entirely to a concentration of particles.

TABLE 5
RETENTION OF CERIUM-144 BY THE COPEPOD, *Tigropus californicus* (AVERAGE OF 22 INDIVIDUALS)

Days	Activity c.p.m./copepod	Per cent remaining
0	7103	100
1	227	3.2
2	123	1.7

Zooplankton may accumulate radionuclides present in the water in solution. If accumulated to any marked extent, appreciable concentrations may be passed to fishes using these forms as food. Two important fission product radionuclides that may be considered in this connection are strontium-90 and cesium-137. Both are readily taken up from the water and both pass quickly into the body from the digestive tract.

A few species of zooplankton have calcareous structures and may concentrate strontium. Many species do not. We have measured concentration factors for radiostrontium of about one for the copepod, *Tigropus,* and less than one for the brine shrimp, *Artemia* (Figure 1). When phytoplankton food is present, however, a concentration of particles filtered from the water with concentrations of strontium may give an apparent concentration factor somewhat greater than one, particularly if the factor is calculated per unit volume of water disregarding the abundance of phytoplankton cells. Cesium-137 is slowly concentrated through a slow accumulation (Figure 1).

From the foregoing we can see that the zooplankton become radioactive from an accumulation of radionuclides from fission product mixtures, but that they can pass the accumulated radionuclides farther up the food web only while these are within the digestive tract, for the greater part of the radioactivity is due to those that are poorly absorbed from the digestive tract. A concentration of radiocesium in their bodies may permit the transfer of the accumulated radionuclides of cesium to small fish using zooplankton forms as food.

Accumulation by shellfish

Oysters, clams, and scallops are important fisheries organisms which filter large volumes of water and feed on the filtered material. As may be expected, the story of the accumulation of radionuclides of fission product mixtures present in sea water in the form of particles is exactly the same as that of the accumulation by the small animal plankton forms. They concentrate radioactive particles markedly. Often the greater part of the measured accumulation is due to association of particles with body surfaces and their presence in the organs and structures connected with the digestive tract. A great number of

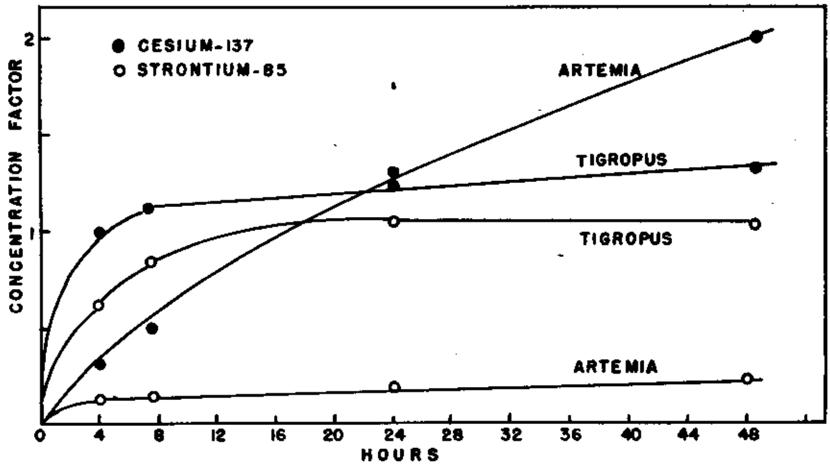

FIGURE 1. Accumulation of cesium-137 and strontium-85 by the copepod, *Tigropus californicus*, and the brine shrimp, *Artemia salina*, maintained in filtered sea water containing the isotope.

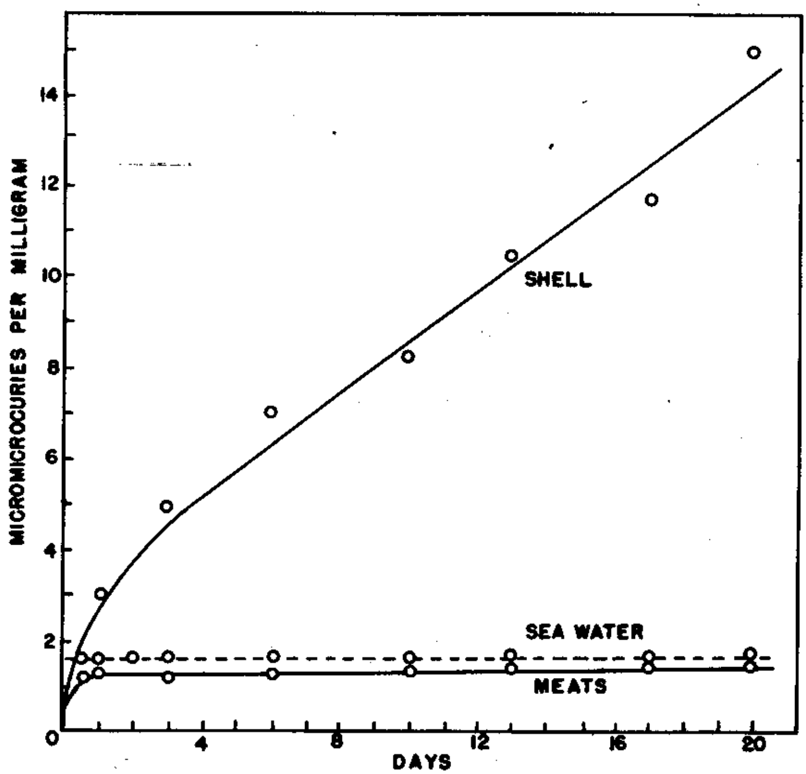

FIGURE 2. Uptake of strontium-85 by young hard clams, *Mercenaria mercenaria*.

fission product radionuclides are not absorbed readily from the tract and are not accumulated or concentrated in body tissues and structures. However, such an accumulation of radioactive particles may be important for purposes of passage through food webs and to man. The fact that man eats the whole soft tissues of oysters and clams allows for the ingestion of many radionuclides that may not be metabolized and incorporated into the tissues of these shellfish.

Strontium radioisotopes are taken up by oysters, clams, and scallops. Uptake is primarily from the water, for there is no great accumulation in their food. The strontium is concentrated in their shells. There is no concentration of strontium in the soft tissues. Figure 2 shows the accumulation of radiostrontium in the shells and meats of hard clams. A concentration factor of less than one over that of the water was found for the meats. Aside from accumulation from the formation of new shell, there is an uptake of considerable magnitude by shells separated from the meats. This accumulation of radioactivity by shells may be of interest in view of the fact that shells are placed on the bottom by oystermen as cultch for the attachment of the young oyster spat.

Cesium-137 is accumulated to relatively high levels by the soft tissues of shellfish. There is a more rapid uptake by the soft tissues other than muscle, but the highest concentrations are reached in time by the muscles. An example of this differential uptake is shown in Figure 3, which shows the accumulation of cesium-137 by scallops. In ten days the concentration in the adductor muscle of scallops was ten times that of the water and increasing. Actually, the uptake continues for very long periods of time.

We have found that clams concentrate cesium-137 to a greater extent than do oysters, which is in agreement with the difference in their body structure

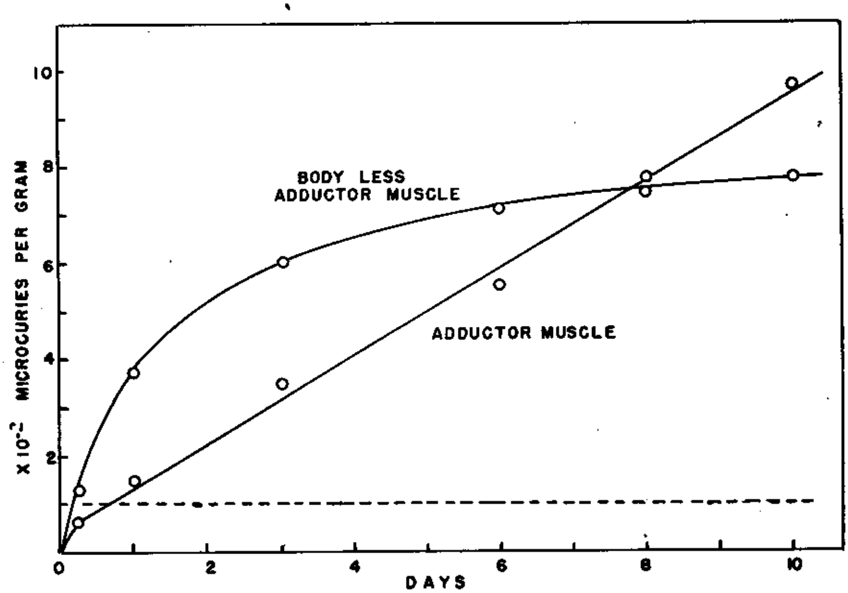

FIGURE 3. Uptake of cesium-137 by the body tissues of the bay scallop, *Pecten irradians*.

as regards muscle tissue. As far as the hazards to humans is concerned from the ingestion of cesium from shellfish, the most hazardous is the scallop, since only the adductor muscle is eaten. Clams would be more hazardous than oysters.

Only small amounts of the radioactivity of mixed fission products administered entered the body tissues of edible crabs and shrimps. Of that that did enter, the greater part was present in the internal organs. Daily oral doses to the blue crab resulted in a gradual accumulation of radioactivity in the shell and in the edible muscle.

In crustacean shellfish, there is an accumulation of strontium radioisotopes in the shell and other calcified structures. Molting results in the loss of the concentrated radioactivity. We have found no concentration of radiostrontium in the muscles.

The radioisotope of mixed fission products that seems to be of most importance in regard to its accumulation by shellfish is cesium-137. It is concentrated to relatively high levels in the edible meats. In the practice of "heading" of shrimp for market, the accumulated radioactivity of the internal organs and a major part of the shell is discarded. However, relatively high concentrations of radioactive cesium would be present in the marketed portion.

Accumulation by fish

Marine fish, like the invertebrates, take up only small amounts of most of the radionuclides of fission products when taken into the digestive tract. Since the greater part of the radioactivity of a mixture of about a year of age is due to radionuclides of the rare earths and others poorly absorbed through the intestinal wall, very little of the accumulated radioactivity of fish is due to these radionuclides. Table 6 shows the loss of fission product radioactivity from bluefish and croakers at various times after oral administration and the small amounts taken up by the tissues. Croakers given the rare earth radionuclide,

TABLE 6

PER CENT OF ORAL DOSE OF FISSION PRODUCT MIXTURE PRESENT IN FISH AFTER DIFFERENT PERIODS OF TIME

(TEST WITH MFP-1 OF AGE 143-151; 196-199 WITH CROAKERS, AND MFP-1 OF AGE 216 DAYS WITH BLUEFISH)

	Hours after dose	Per cent of oral dose remaining: Digestive tract	Body	Total fish
Bluefish (individually)	½	100	0	100
	1	90	6	96
	2	76	2	78
	4	(16	(2	(18
		(14	(5	(19
	8	3	1	4
Croakers (average of 3)	3	43	14	57
	6	56	7	63
	28	5	4	9
	69	2	0.8	2.8
	137	0.4	1.6	2.0

cerium-144, by pipette into the stomach had only about three or four per cent of the radioactivity of the dose in their tissues. Menhaden fed phytoplankton cells containing ruthenium-106 took up only about one per cent of the radionuclide (Table 7).

TABLE 7

RADIOACTIVITY OF MENHADEN AFTER FEEDING ON PHYTOPLANKTON CELLS CONTAINING Ru^{106}

(TISSUES OF 5 FISH ANALYZED FOR EACH OBSERVATION)

Time in hours	Per cent of dose: Gills	Digestive tract and contents	Remainder of fish	Total in fish
0	0.64	92.39	0.76	93.79
2	0.05	80.09	1.00	81.14
4	1.13	21.15	0.53	22.81
8	0.06	7.99	0.34	8.39
16	0.08	8.50	0.56	9.14
32	0.02	5.23	0.22	5.47
64	0.02	1.48	0.26	1.76
128	0.01	0.05	0.25	0.31

Although only a small amount of the total radioactivity enters the body of the fish, certain radionuclides are taken up rapidly, and these are markedly concentrated in the fish tissues, particularly in the skeletal structures. Table 8 shows the body distribution of the radioactivity of mixed fission products in bluefish four hours after administration. There was considerable radioactivity in the internal organs and in bone and scales. Repeated daily doses of mixed fission products to fish resulted in marked concentration of strontium-90 in the bones and scales, and a gradual accumulation of radioactivity in the body muscles. The latter was due to the uptake of cesium-137. The greater part of the radioactivity of the internal organs was due to rare earth radionuclides.

TABLE 8

DISTRIBUTION OF RADIOACTIVITY IN THE BODY OF BLUEFISH 4 HOURS AFTER ORAL DOSE

(FIVE PER CENT OF DOSE IN BODY. β ACTIVITY MEASURED DAY AFTER ADMINISTRATION)

Part or organ	Gross β radioactivity: Per cent of total fish	d.p.s./gm.
Body less digestive tract and internal organs	96.4	331
Muscle		41
Bone		463
Integument		539
Liver	2.0	858
Internal organs other than digestive tract and liver	1.6	438

d.p.s.—disintegrations per second

However, we have found from repeated doses of the rare earth, cerium-144, to croakers that, although the radionuclide is rapidly concentrated in the liver, the greatest accumulation is ultimately in bone.

There is no concentration of strontium radioisotopes in the edible body muscles of marine fishes. Continuous exposure of small mullets to strontium-85 for thirty days (Figure 4) resulted in a concentration factor over water of only 4.6. In these the greater part of the weight of the fish was due to body muscles, while the greater part of the radioactivity was from accumulation in bone and scales. The body muscles of the killifish (*Fundulus heteroclitus*) had a concentration factor for strontium-85 of only 0.15 after exposure of the fish to the isotope in sea water for thirty-two days (Figure 5).

Cesium-137 is accumulated in the edible fish flesh and significantly high concentrations can result. The rate of accumulation in internal organs is more rapid than by muscle tissues, but the long-continued uptake by muscles of this radionuclide of long physical half-life can be of great importance when continuously available for uptake. The accumulation of cesium-137 in the body

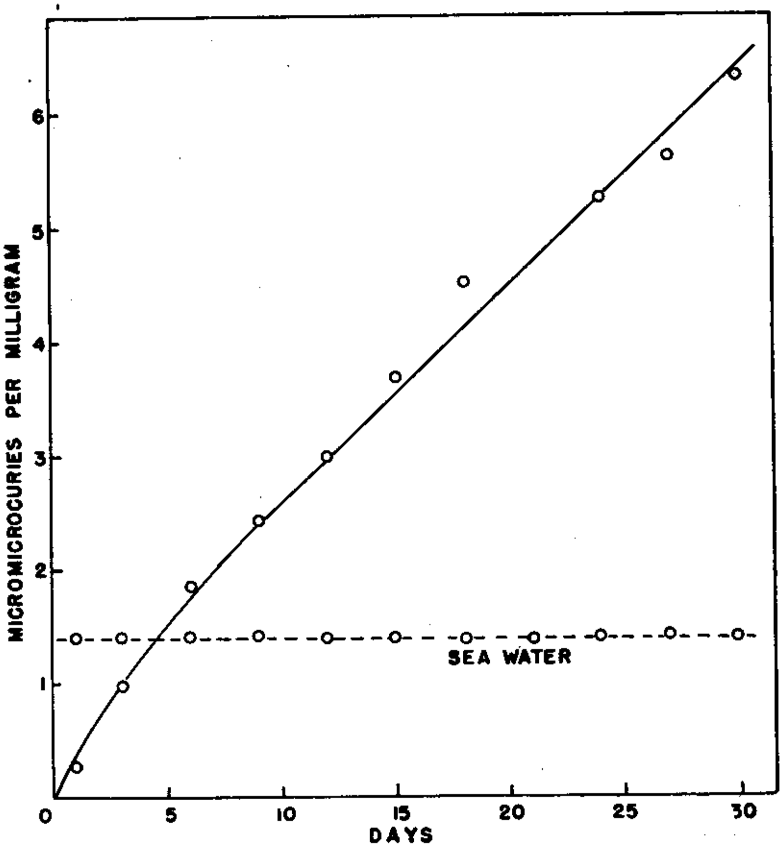

FIGURE 4. Uptake of strontium-85 by young mullets, *Mugil cephalus*.

muscles of *Fundulus* is shown in Figure 6. Accumulation was still continuing after an exposure of seventy-two days when the concentration was about thirty-five times that of the water. Fish continuously bathed in sea water containing cesium-137 and eating foods that contain concentrations of the nuclide would gradually accumulate relatively high concentrations in the edible flesh.

Accumulation of Other Radionuclides

Besides the radionuclides of fission product mixtures, we need consider accumulation of certain of the trace elements of sea water. Included in this category are isotopes of iron, manganese, copper, cobalt, and zinc. To date two of these, radiozinc and radiocobalt, have been studied in our laboratory. A report (Chipman *et al.*, 1958) has been made of the accumulation of radioactive zinc.

When zinc-65 or cobalt-57 are added to sea water in which marine phyto-

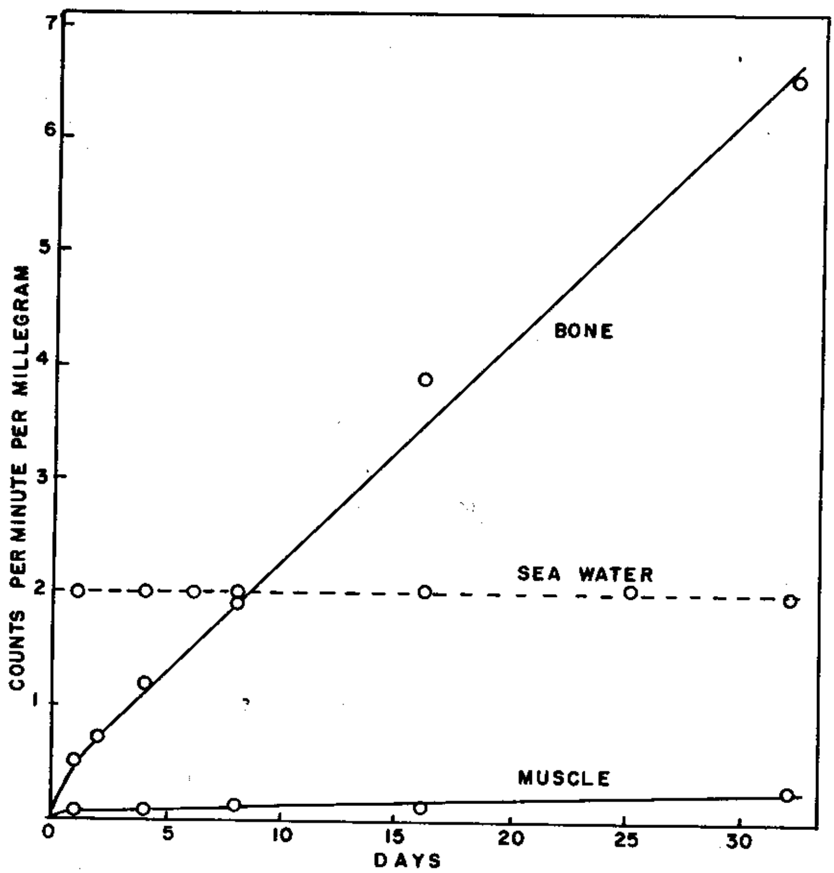

Figure 5. Accumulation of strontium-85 in muscle and bone of the killifish, *Fundulus heteroclitus*.

plankton cells are suspended, there is rapid and extensive uptake of the radionuclides. A species of *Nitzschia* was found to concentrate zinc many thousands of times over sea water concentrations. Likewise, phytoplankton cells accumulated cobalt-57 very markedly. It is obvious that, if radioactive zinc or cobalt were added to the sea, high concentrations would be found in phytoplankton and could be passed to animals using these cells as food.

Although these metals are present in sea water in low concentrations, they are markedly accumulated by marine animals. Tests made of the accumulation of radiozinc and radiocobalt by copepods demonstrated that both are taken up rapidly and to high concentrations, the radiozinc being accumulated to levels over 200 times that of the water in 48 hours with the accumulation continuing. In the same length of time radiocobalt concentration was about fifty times that of the water. Oysters, clams, and scallops concentrate large amounts of zinc, thousands of times more than the sea water. They also concentrate cobalt very markedly. Marine fish were found to take zinc-65 into the body tissues very rapidly with accumulation in the bone, integument, and muscle tissues. High concentrations of zinc-65 were present in the internal organs, notably in the kidneys.

It is apparent that the radioisotopes of the trace metals, zinc and cobalt, added to sea water are quickly taken up and concentrated to high levels by the biota. They are readily transferred through the food web, being passed through the lining of the digestive tract very promptly and accumulated to high levels in the body tissues. Pollution of estuaries or coastal waters with significant amounts of these could create hazardous situations affecting the utilization of our seafood resources.

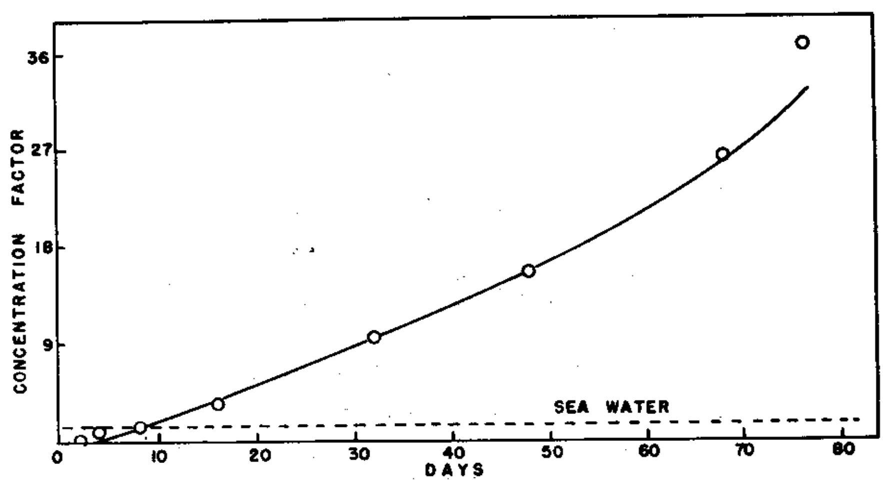

FIGURE 6. Accumulation of cesium-137 in the body muscles of the killifish, *Fundulus heteroclitus*.

LITERATURE CITED

BOROUGHS, HOWARD, WALTER A. CHIPMAN, AND THEODORE R. RICE
1957. Laboratory experiments on the uptake, accumulation and loss of radionuclides by marine organisms. *In* The Effects of Atomic Radiation on Oceanography and Fisheries, Publication No. 551, National Academy of Sciences—National Research Council, Washington, pp. 80-87.

CHIPMAN, WALTER A.
1958. Biological accumulation of radioactive materials. Proceedings of the First Texas Conference on Uses of Atomic Energy, pp. 36-41. Special Publication of the Agricultural and Mechanical College of Texas, College Station, Texas.

CHIPMAN, WALTER A., THEODORE R. RICE, AND THOMAS J. PRICE
1958. Uptake and accumulation of radioactive zinc by marine plankton, fish, and shellfish. Fishery Bull. 135, Fishery Bull. Fish and Wildlife Service, *58:* 279-292.

HARLEY, JOHN E. (Editor).
1956. Operation Troll. N. Y. Operations Office, U. S. Atomic Energy Commission, Document NYO4656, 37 pp.

RICE, T. R.
1956. The accumulation and exchange of strontium by marine planktonic algae. Limnology and Oceanography *1:*123-138.

WEISS, H. V., S. H. COHN, W. H. SHIPMAN, AND J. K. GONG.
1956. Residual contamination of plants, animals, soil, and water of the Marshall Islands two years following Operation Castle fallout. Research and Development Report, U.S.N.R.D.L.—455, U. S. Naval Radiological Defense Laboratory, San Francisco 24, California, 55 pp.

DISCUSSION

Biological Session

Discussion Leader: K. M. RAE
Discussion Panel: EUGENIE CLARK, WALTER GRESH
R. WINSTON MENZEL, PAUL S. GALTSOFF

Parasites and Fishery Problems

WILLIAM J. HARGIS, JR.

Q. Gresh: How do you answer the public when they ask you whether they should eat wormy fish?

A. Hargis: I would say that if they cook the fish they are not harmful. I advise never to eat uncooked fish.

Q. Galtsoff: I wonder why you completely disregarded the distinction between pathogens and commensals.

A. Hargis: The problem of classifying the symbiotic relationship is difficult, and I wanted to restrict the discussion specifically