PASSAGE OF FISSION PRODUCTS THROUGH THE SKIN OF TUNA

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ABSTRACT

Passage of the radioactive isotopes, strontium-89, cesium-137, and ruthenium-106, through the skin of the little tunny, Euthynnus alletteratus, was measured by using pieces of skin separating two sea waters, one of which contained the isotope. The diffusion of these isotopes through the tissues under the skin of iced fish was observed after a number of days of contact with the skin surface.

Cesium entered the fish through the skin very readily and ruthenium scarcely at all. Except for cesium, diffusion through the fish tissues was slow.

After 4 days contact of the skin with the radioactive solutions, the activity from cesium of the deep muscle tissues was equal to that on the skin surface. On the other hand, after 8 days the activity of the deep tissues was only 4 percent of the skin-surface activity for strontium-89 and one percent for ruthenium-106.

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In relation to "fallout" from nuclear-bomb tests, it is of interest to measure the amounts of radioactive isotopes known to be present in mixtures of fission products which would pass through the skin of fish held under refrigeration on fishing vessels. Presumably, radioactive materials contaminating the skin of such fish could enter and spread through the tissues thus contaminating the whole fish. The present study intended to test this assumption, considers the penetration of radioactive strontium, cesium, and ruthenium common products of nuclear fission, through the skin of the little tunny, Euthynnus alletteratus (Rafinesque), and their diffusion through the tissues.

It is accepted generally that the skin of marine fishes is relatively impermeable. This might be expected in such a group in which the osmotic pressure of the blood is below that of sea water. Discussions of the literature regarding the permeability of the skin of various species of fish are presented by Bond (1933) and by Wunder (1936). In dead fish, however, penetration of salts through the tissues is a process of diffusion which varies in rate depending on a number of factors. The rate of penetration of sodium chloride is low, resulting in small quantities in the tissues of tuna held in cold brine for as long as almost two months, according to the work of Land and Farber (1939) and of Godsil (1940). The factors regulating salt penetration into fish during brine freezing were considered by Bolston and Pottinger (1954), but as far as could be ascertained, no work has been reported on the penetration of radioactive ions through the skin of fish in storage. The radioactivity of the tissues of tuna contaminated with radioactive fall-out material or in fish from water containing this material has been measured, including autoradiographs of the various tissues (Tsujii, personal communication), but published accounts are not available.

Accordingly the following experiments were undertaken. Miss Maureen Downey assisted in the preparation of samples and in measurement of their radioactivity.

MATERIALS AND METHODS

The tuna were obtained by offshore trolling. After capture they were "iced down" and brought to the laboratory where they were kept iced and refrigerated until they were used for the experiments 8 to 20 hours after being caught.

The isotopes employed were $Sr^{89, 90}$ added to the sea water as strontium chloride; Cs^{137}-Ba^{137}, added as cesium chloride; and Ru^{106}-Rh^{106}, added as ruthenium trichloride in acid solution. The radioactive materials were obtained from the Oak Ridge National Laboratory under allocation by the Atomic Energy Commission.

The presence of the radioactive daughters, Ba^{137} and Rh^{106} did not affect the measurements since they are both of very short half-life and secular equilibrium is reached in a very short time.

There was a small amount of Sr^{90} present with the Sr^{89}. This was taken into consideration in the experiments with due allowance made for the return to secular equilibrium between the Sr^{90} and its daughter, Y^{90}. It is recognized that both radioisotopes of strontium were present, although reference is made throughout the paper only to Sr^{89}.

In the first series of experiments, cut pieces of skin of the little tunny were placed across the mouths of large plastic test tubes of which the bottom portion had been cut off, and the skin tightly held in place by winding thread around the lip of the tubes. Sea water containing strontium-89, cesium-137, or ruthenium-106 was placed in the tubes and the mounted skin immersed in a beaker of the same sea water, to which no isotopes had been added. The beakers with their tubes were kept in a domestic-type refrigerator at about 38°F. It was not convenient to arrange for continuous stirring. The outer surface of the skin faced the inside of the tube containing the radioactive sea water. The volumes were 30 ml. inside the tube and 100 ml. outside. Samples of the water were removed periodically, dried in a stainless-steel planchet under a heat lamp, and their radioactivity measured at a fixed distance below a glass Geiger-Müller tube of 30 mg./cm^2. thickness in a horizontal lead shield.

The percentage of equilibrium reached after intervals of time was calculated using the radioactivity expected from dilution of the one liquid with the other if there were no membrane separating the two.

In the second series of experiments, circular absorbent cellulose pads, 47 mm. in diameter, were soaked in sea water to which were added various concentrations of strontium-89, cesium-137, or ruthenium-106. These pads were then placed in contact with the skin of the iced fish. They were usually placed just above the lateral line with two pads on each side of the fish and covered with the concave side of a watch glass held in place by a heavy rubber band. The fish were again iced, and the container of crushed ice and fish was placed in a refrigerator. Care was taken to prevent the fish from becoming immersed in ice water. Periodically a fish was taken and the area under the pads dissected, care being taken to prevent contamination from the cutting. Measurements then were made of the surface radioactivity of the skin, of the muscle layer directly beneath, and of muscle tissues below this at thicknesses from 5 to 8 mm. The deep muscle was close to the backbone.

For the radiological measurements, the skin or muscle tissue was enclosed in a cellaphane envelope and placed under an aluminum plate having a hole 12 mm. in diameter so that the area to be counted on each sample would be constant. The plate was held a fixed distance below a glass Geiger-Müller tube with walls 30 mg./cm^2. thick for counting.

PASSAGE OF ISOTOPES THROUGH THE SKIN

Strontium-89

To observe the passage of strontium-89 through the skin of tuna, a series of six tubes was prepared with the skin fastened over one end. The sea water inside the tubes contained added strontium-89 to give concentrations of 0.01, 0.05, or 0.25 μc per ml. The increases in radioactivity of the sea water in the beakers in which the tubes and skins were immersed were measured after 1, 2, 4, 6, and 8 days, during which time the containers were refrigerated. With passage of the isotope through the skin, the specific activity of the sea water on the inside surface of the skin should equal that on the outside. Knowing the expected radioactivity from dilution, the percentages of equilibrium reached with time were calculated. The averages of the different tubes are listed in table 1.

Sea water contains appreciable amounts of strontium, and the addition of the radioactive isotope did not significantly increase the total strontium of the water outside the skin. It can be assumed that strontium moved across the membrane with an approach to isotopic equilibrium. The fact that the experiments were tried with different specific activities has no particular meaning in this instance. The approach to equilibrium on the inside of the fish skin was slow. It was only 7 percent complete in one day, and 48 percent complete in 6 days.

Cesium-137

Observations were made of the passage of cesium-137 through the fish skin in a similar manner to those employing strontium-89. However, in these the isotope was added to give strengths of 0.1 and 1 μc per ml. for convenience in radioactivity measurement. A series of 4 tubes were used at these strengths. The percentage equilibrium reached after 2, 4, 6, and 8 days is shown in table 1.

In 2 days the sea water on the inside surface of the skin was 51 percent of equilibrium with that outside. This increase in radioactivity continued and reached 92 percent in 8 days. It seems that the fish skin offered only a slight barrier to the passage of cesium and that entrance was rapid as compared to that of strontium.

It should be pointed out that sea water contains only very little cesium (about 2 gamma per liter) and that the addition of the cesium-137 increased the total cesium outside the skin considerably, about 150 times in the higher concentration used. There was therefore a marked gradient for the forcing of cesium across the membrane. This did not exist for total strontium in the tests previously described. In the case of strontium, only the isotopic ratio was altered.

Ruthenium-106

Sea water, to which had been added ruthenium-106 to give concentrations of 0.05 μc or 0.01 μc per ml., was placed in series of 4 tubes and in contact with the outside surfaces of the skin. The sea water in the beakers in contact with the inside surfaces increased slightly in radioactivity from passage of the isotope through the skin. The average of the percentage equilibrium reached between the two solutions after 2, 4, and 6 days is shown in table 1.

Ruthenium-106 did not pass through the fish skin to any great extent. Equilibrium was 17 percent complete at 6 days. There appeared to be a passage of a small amount which was not increased appreciably with time.

There is no information on the ruthenium content of natural sea water. Undoubtedly it is extremely small. There was, therefore, an increase in the total ruthenium outside the tubes.

Ruthenium salts are quite insoluble in water. With the addition of ruthenium trichloride to the sea water there was considerable hydration. It is doubtful if there was much ionic ruthenium outside the membrane and there were particles present as a fine precipitate. The ruthenium-106 gradually leaves the sea water and is adsorbed on various surfaces after such an addition as was made in these tests.

PENETRATION OF ISOTOPES INTO THE MUSCLE TISSUES

Strontium-89

Three series of experiments with observations made in duplicate were performed in which pads soaked in sea-water solutions of Sr-89 were placed against the skin of the fish and the radioactivity of the tissues underneath were measured. Strengths of solutions in which the pads were soaked varied in their specific activity. The solutions contained .01 μc, .05 μc, and 0.25 μc of strontium-89 per ml.

The activity at the skin surface varied in the different observations. There was of course more radioactivity in the deeper muscles when solutions of higher specific activity were employed. The results of measurements of penetration can best be expressed as the percentage of the radioactivity of the skin found in the tissue underneath. Table 2 gives the relative radioactivities of the muscle layers when the activity at the skin surface due to the Sr-89 is considered as 100 percent.

There was a gradual diffusion of the isotope through the tissues, the specific activity in the tissues gradually increasing with time. However, this diffusion was relatively slow only a very small percentage was present in the deep muscles after 8 days.

Cesium-137

Similar experiments to those carried on with strontium-89 were completed with cesium-137. The pads were soaked in solutions containing 0.1 μc and 1 μc cesium-137 per ml. Observations were made of the radioactivity of the tissues under the skin after 2, 4, and 8 days and the results are presented in table 2.

Although the cesium-137 solution was carrier-free, there was an appreciable amount of cesium added to the sea water in relation to that normally present. There was likely, therefore, a gradient from the skin inward.

The results of the experiments using cesium-137 show a very marked entry of cesium-137 into the fish body and diffusion into the muscles underneath. After a short time the muscle tissues contained considerably more of the nuclide than was present at the skin surface. The deep muscles near the backbone have as much radioactivity as the skin surface after 4 days of contact with the soaked pad.

Ruthenium-106

The tests with ruthenium-106 were carried on in a similar manner to those previously described. The pads were soaked in sea water to which had been added ruthenium-rhodium-106 to give a microcurie strength of 0.05 μc and 0.01 μc ruthenium per ml. Undoubtedly, there was hydration when the material was added to the sea water. The average radioactivity found in the tissues, expressed as percentages of the skin surfaces, is also given in table 2.

In these experiments with ruthenium, there was considerable radioactivity at the skin surface from contact with the solution in the pad. However, very little activity entered and the radioactivity of the muscle tissue just under the skin averaged only 11 percent of that of the skin surface after 8 days of contact with the pads. Muscle tissues deeper than those next to the skin had virtually no radioactive ruthenium.

SUMMARY

1 The radioactive isotopes, strontium-89, cesium-137, and ruthenium-106 in sea water in contact with the external surface of pieces of the skin of the little tunny, Euthynnus alletteratus, pass through to the inner surface. The passage of these elements differs, cesium entering very readily and ruthenium scarcely at all.

2 When these isotopes are in contact with the skin of iced tunny, they enter and diffuse into the muscle tissues beneath. Except for cesium, diffusion through the fish tissues is slow. The cesium-137 content of even the deep muscle tissue was equal to the amount at the skin surface after 4 days in which the isotope was in contact with the skin. The deep muscles had only 4 percent of the radioactivity of the strontium-89 of the skin surfaces after 8 days of contact of the skin with this isotope. These tissues had 1 percent of the ruthenium-106 radioactivity of the skin surface after 8 days of contact.

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Table 1.--Approach to complete equilibrium between two sea waters separated by a piece of skin of the little tunny. The water outside the skin contained radioactive strontium, cesium, or ruthenium.

(Averages of tests at different specific activities)

Days	Percentage of equilibrium		
	Sr-89	Cs-137	Ru-106
1	7	-	-
2	18	51	9
4	33	65	13
6	48	82	17
8	-	92	-

Table 2.--Relative radioactivity of tissues beneath the skin of little tunny following contact of the skin with sea water solutions of strontium-89. Activity of skin surface as 100.

(Average of duplicate tests in 3 series of experiments)

Tissue	Percentage of skin surface Radioactivity after designated time			
	2 days	4 days	6 days	8 days
Strontium-89				
Skin surface	100	100	100	100
Muscle tissue under skin	22	31	36	29
Intermediate muscle tissue	-	12	9	27
Deep muscle tissue	0	0	1	4
Cesium-137				
Skin surface	100	100	-	100
Muscle tissue under skin	121	139	-	159
Intermediate muscle tissue	43	109	-	148
Deep muscle tissue	13	103	-	95
Ruthenium-106				
Skin surface	100	100	-	100
Muscle tissue under skin	3	13	-	11
Intermediate muscle tissue	0	1	-	9
Deep muscle tissue	0	1	-	1