

FALLOUT IN THE OCEAN

A Statement prepared for the Special Subcommittee  
on Radiation, Joint Committee on Atomic Energy,  
Congress of the United States for Public Hearings  
on Fallout from Nuclear Weapons Tests, May 5-8, 1959

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May 4, 1959

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### INTRODUCTION

The following discussion of fallout in the oceans is, for the most part, a discussion of local, not stratospheric fallout. Local fallout is defined as the fallout that occurs during the first day or two following the detonation of a nuclear device and within a few hundred miles of ground zero. Local fallout differs from stratospheric fallout in several important aspects.

In an area of local fallout the amount of fallout per unit area and the size of the fallout particles are considerably greater than in an area of stratospheric fallout only. For a surface explosion 65 to 85 per cent of the fallout may be local and for an underwater detonation local fallout may be even greater. Also, the chemical form and the percentage composition of the radioisotopes in the two areas may differ. For the megaton weapons fired in the Pacific the bulk of the fallout resides on particles of  $\text{CaO}$  or  $\text{Ca(OH)}_2$  or mixtures of  $\text{CaO}$ ,  $\text{Ca(OH)}_2$  and  $\text{CaCO}_3$  made by the great heat of the fireball acting on the coral of the islands and sea floor. A large amount also is carried on  $\text{NaCl}$  particles (Libby, 1956). The large particles of these compounds fall out locally and do not enter the stratosphere. As a consequence greater quantities and different species of

radioisotopes are found in a local fallout area as compared to an area with stratospheric fallout only.

In the following statement the order of presentation will be to discuss, first, the information about fallout in the ocean that has become available since the 1957 hearings and, secondly, the areas of future research.

The basic concept of the ability of marine plants and animals to concentrate from the ocean certain radioisotopes of fallout remains unchanged. Additional information since 1957 as a result of the analyses of more samples and of a more thorough search for the radioisotopes that are difficult to detect has led to the confirmation of some of the previous conclusions and to a modification of other conclusions. The comparison of results of radiological analyses can not be made superficially and requires that careful consideration be given to the following three factors: (1) the completeness of the analysis; (2) the time after fallout when the collection was made and when the analysis was done; and (3) the similarity of samples as to species and tissue.

The completeness of analysis depends to a great extent upon the capability of the detecting equipment and the selection of the proper radiochemical method. As no one instrument or single method of radiochemical analysis is adequate to determine the presence of all radioisotopes the presence of a radioisotope, even

in large amounts, may escape detection unless a combination of various methods is used. For example, the predominate radioisotope in the first analysis of the kidney of a giant clam from the Marshall Islands was found to be radiocobalt. However, a radioisotope of iron ( $\text{Fe}^{55}$ ) which emits a weak X-ray (see Table 1) was present but was not detected by the original gamma spectrum analysis. When the proper technique for identifying  $\text{Fe}^{55}$  was used, radioiron was found to be in greater abundance than radiocobalt (Table 2). Another example is that of the Taney plankton. Gamma spectrum analysis of a sample in November, 1957 confirmed the earlier finding that the major fission products were  $\text{Ce}^{144}$ - $\text{Pr}^{144}$  but also revealed an appreciable amount of  $\text{Co}^{60}$  (Lowman et al., 1958). Modification of techniques to meet the special requirements of an analysis is sometimes required. In order to accurately determine  $\text{Sr}^{90}$  in marine organisms, especially fish, a special technique was developed by Kawabata and Held (1958). As these special techniques develop and the detection equipment becomes more sensitive, more isotopes can be expected to be found or to be determined more accurately.

The time after fallout when the sample is collected demands consideration when the results of radiological analyses are being compared because the relative composition of the radioisotopes in a sample of mixed fission products is constantly changing (Table 1). It is obvious that the comparison of the relative radioisotopic

Table 1. Per cent abundance of fission products, radiation energy, half life, critical organ and maximum permissible concentration of fallout radioisotopes of biological interest

Fission products	(1)				(2,3)		(2,3)		Critical organ	MPC $\mu\text{c/ml}$
	Per cent abundance at:				Radiation energy, Mev		Half life			
	One week	One month	One year	Ten years	Beta	Gamma	Physical	Biological (for man)		
Sr <sup>89</sup>	2.1	6.7	2.7	---	1.46	none	51 days	3900 days	bone	0.00007
Sr <sup>90</sup>	---	---	1.8	21.8	.54	none	28 years	} 3900 "	bone	0.0000008
Y <sup>90</sup>	---	---	1.8	21.8	2.26	weak	64 hours			
Y <sup>91</sup>	2.4	7.6	3.9	---	1.54	1.22*	58 days	> 500 "	bone	0.2
Zr <sup>95</sup>	2.5	8.2	7.3	---	.36*	.72	65 days			
Nb <sup>95</sup>	---	4.1	15.	---	.16	.76	35 days	50 "	bone	0.004
Ru <sup>106</sup>	---	---	2.4	---	.04	none	1.0 years	} 20 "	kidneys	0.1
Rh <sup>106</sup>	---	---	2.4	---	3.5*	0.51*	30 secs.			
I <sup>131</sup>	6.3	3.7	---	---	.61*	.36*	8.1 days	180 "	thyroid	0.00003
Cs <sup>137</sup>	---	---	1.5	18.2	.51*	.66	27 years	} 17 "	muscle	0.0015
Ba <sup>137m</sup>	---	---	1.5	18.2	1T	.66	2.6 mins.			
Ba <sup>140</sup>	8.8	10.8	---	---	1.02*	.03*	13 days	} 200 "	bone	0.002
La <sup>140</sup>	9.4	12.5	---	---	1.36*	.33*	40 hours			
Ce <sup>144</sup>	---	2.0	26.5	---	.31*	.03*	285 days	} 500 "	bone	0.04
Pr <sup>144</sup>	---	2.0	26.5	---	2.97	.06*	17 months			
Pm <sup>147</sup>	---	---	5.7	15.8	.22	weak	2.6 years	>100 "	bone	1

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Table 1. - continued

Non-fission products	(1) Per cent abundance at:				(2,3) Radiation energy, Mev		(2,3) Half life		(4) Critical organ	(4,5) MPC $\mu\text{c/ml}$
	One week	One month	One year	Ten years	Beta	Gamma	Physical	Biological (for man)		
Mn <sup>54</sup>					EC	.84	290 days	5 days	liver	0.0013
Fe <sup>55</sup>					EC	none	2.6 years	65 "	blood	0.005
Fe <sup>59</sup>					.46*	1.1*	45 days	65 "	blood	0.0001
Co <sup>57</sup>					EC	.12*	270 days	8 "	liver	0.0072
Co <sup>58</sup>					B <sup>+</sup> =.47	.81	71 days	8 "	liver	0.0015
Co <sup>60</sup>					.31	1.17*	5.2 years	8 "	liver	0.02
Zn <sup>65</sup>					B <sup>+</sup> =.32	1.12	250 days	23 "	bone	0.06

\* and others

\*\* Maximum permissible concentration in drinking water based on the assumption that water consumption is 2200 ml per day and that water is the only source of radioisotopic contamination. Values can be directly extrapolated to grams of food when compensation is made for the difference between the daily intake of water and food

(1) Hunter and Ballou, 1951

(3) Kinsman, 1957

(5) Lowman, 1957

(2) Strominger et al, 1958

(4) NBS Handbook No. 52, 1953

composition of two samples has little meaning unless the age of the radioisotopes in the samples is approximately the same.

Thirdly, the comparison of results of analyses may require that the samples be alike as to species, tissue and even physiological function. Using the giant clam again as an example, there are species living in the tropical Pacific that acquire a large portion of their food by growing and harvesting Zooxanthellae within their own body. These clams have a large and specialized kidney which concentrates radiocobalt to a high degree. There are other giant clams in the Pacific that are not as dependent upon Zooxanthellae and do not have as specialized a kidney. In the clams with the less specialized kidney more radiozinc is found than radiocobalt and this finding is in agreement with laboratory experiments with less specialized clams (Chipman, 1958). Thus it would be inaccurate to make a generalization about the uptake of fallout radioisotopes by clams based upon the analysis of the unusual kidney of a highly specialized species which is common and important in only a limited part of the world.

The comparison of results of radiological analysis of marine organisms may be used to evaluate the health hazard to man associated with eating certain sea foods. (Man's concern about fallout in the ocean is primarily as to how it will affect his health and secondarily as to how it will affect his ocean resources). The health hazard problem will not be discussed here, other than to

say that to evaluate hazard, it is equally important to know both the amount and the species of radioisotope present. The variation in MPC values as given in Table 1 (the difference between  $\text{Sr}^{90}$  and  $\text{Pm}^{147}$  is greater than one million) points out the futility of estimating hazard without knowing the radioisotopes present, a practice that has been followed on occasion in the past.

Although it was stated above that most of the observations on fallout in the ocean have been of close-in fallout, the Woods Hole Oceanographic Institution is studying the distribution of five fallout radioisotopes-- $\text{Sr}^{90}$ ,  $\text{Sb}^{125}$ ,  $\text{Cs}^{137}$ ,  $\text{Ce}^{144}$  and  $\text{Pm}^{147}$ -- in the Atlantic Ocean, an area far removed from close-in fallout. Because the amount of these radioisotopes in Atlantic Ocean waters is minute, large samples and special separation methods are required and the number of samples processed is relatively small. The minute weight of fallout that is added to the ocean can be determined by calculating the amount of an isotope in terms of weight units rather than in units of radioactivity. Using  $\text{Sr}^{90}$  as an example and assuming that the radioactivity from  $\text{Sr}^{90}$  is 30 disintegrations per minute per 100 liters of water--the highest value found in the Atlantic (Bowen and Sugihara, 1957)-- the amount of  $\text{Sr}^{90}$  in the 100 liters of water is calculated to be  $10^{-13}$  grams. Since there is one gram of stable strontium in 100 liters of water the dilution of the stable strontium by the radioactive strontium is of the order of one part in ten trillion. Therefore,

it is evident that although the presence of a radioisotope from fallout can be detected easily by radiological methods the weight of the isotope is much less than can be detected by the most sensitive balance.

For certain areas of the Atlantic Ocean the amount of  $\text{Sr}^{90}$  delivered per unit area of sea surface has been calculated from the determination of  $\text{Sr}^{90}$  in the surface layer and the depth of that layer. From analyses of the 1956 and 1957 data the amount of  $\text{Sr}^{90}$  in surface waters was generally greater than for land areas at comparable latitudes (Libby, 1956) and varied by a factor of five between extremes (Bowen and Sugihara, 1957). The  $\text{Sr}^{90}$  values for surface waters from the shelf area were the highest of any area and ranged from 6.3 to 30.0 disintegrations per minute per 100 liters of water. Begeman and Libby (1957) report the same general sort of variation in the analyses of Atlantic water for bomb tritium. Further study will indicate whether the fivefold variation of  $\text{Sr}^{90}$  in surface waters is an artifact or the result of some factor in the circulatory system that prevents the surface waters from becoming thoroughly mixed. In deep ocean water, below 800 meters, the values for  $\text{Sr}^{90}$  were less than 10 per cent of the surface values.

Selection of the other four radioisotopes-- $\text{Sb}^{125}$ ,  $\text{Cs}^{137}$ ,  $\text{Ce}^{144}$  and  $\text{Pm}^{147}$ --was based on the fact that their relatively long half lives and relatively high yields in fission gave promise that

detectable amounts would be found, and that their chemical behavior was well enough known to permit a meaningful analysis of the data when obtained (Bowen and Sugihara, 1958). Too few samples have been analyzed so far to permit a reliable interpretation of the results.

Although  $\text{Sr}^{90}$  may be more abundant in the Pacific Ocean in the vicinity of the Eniwetok Test Site than in the Atlantic Ocean the occurrence of  $\text{Sr}^{90}$  in the marine organisms of the Pacific is not common. The low levels of radiostrontium in fish and other marine organisms were pointed out in the 1957 hearings (Alexander, 1957; Revelle, 1957) and have been substantiated by additional analyses since that time. If radiostrontium is present in the marine biological samples it is usually in the samples collected during the first few days after fallout when many of the other fission products that are not found in samples collected at a later time are also present. The presence of a broad array of fission products in the samples immediately after fallout is believed to be, at least partially, an adsorption phenomenon. Radioisotopes are present in particulate form immediately after fallout and when in this form the most effective concentrators of activity are the mucous, ciliary and pseudopodial filterers (Schaefer, 1957). Lowman (1958) is also in agreement with the postulate that the major source of radioactive elements from fallout to marine zooplankton is through the uptake of particulate material.

In marine organisms collected a few weeks, months or years after fallout at a time when radiostrontium and other long-lived fission products would be expected to be present, radiostrontium has not been detected by the techniques used or is present at extremely low levels (Table 2). For conditions of equal fallout the  $\text{Sr}^{90}$ -calcium ratio which is the important factor in determining the hazard from  $\text{Sr}^{90}$  is a good deal less for pelagic fish than in such calcium-rich terrestrial food products as milk (Schaefer, 1958).

Although radiostrontium may not be present in marine organisms collected in the vicinity of the Eniwetok Test Site, radiostrontium is found in some of the plants and animals living on the atolls in the same area. From the limited information available at the time of the 1957 Hearings the inference was made that the plants and animals living on the coral atolls would not be expected to concentrate radiostrontium because of the high calcium content of the soils, a situation similar to that which occurs in the ocean. However, this is not true as some land plants and animals do accumulate  $\text{Sr}^{90}$  in measurable amounts--especially the coconut crabs (Held, 1957). Although calcium is abundant in the soils apparently only part of the calcium is in a chemical form which is available to the plants. This is a difficult matter to resolve in a quantitative manner but efforts are continuing in

that direction. Other radioisotopes that have been found in soil samples but not in marine organisms are antimony-125 and europium-155 (Palumbo and Lowman, 1958).

On page 526 of the report of the 1957 Hearings the suggestion was made that the concentration of various radioactive substances in different parts of marine organisms should be considered because there are marked differences and in the case of some marine organisms not only the flesh but the skin, viscera and bones are eaten. The data on one fish that was given is now supplemented by the results of counting 693 specimens collected over a period of 19 months at Eniwetok Atoll (Welanders, 1957). The average values by tissues for beta radioactivity based on the per cent of total radioactivity for the tissues counted are as follows:

skin	muscle	bone	liver	viscera
8%	1%	8%	23%	60%

Surveys to determine the geographical and biological distribution of fallout in the ocean during and after Operation Hardtack in 1958 were carried out in a similar fashion to the surveys for Operation Redwing in 1956 (Donaldson, 1956; Seymour, 1957). Plankton continues to be the most sensitive indicator of radioactivity in the sea with concentration factors ranging from one thousand to several thousand.

The distribution of fallout in the sea a month after the conclusion of the testing program can be defined from the

radioactivity in the plankton samples. The rate of movement can only be approximated because the origin of the fallout at any one sampling station is not known accurately in respect to either time or area. The origin may be any of many detonations that occur during the testing period which lasts for several months and for which the area of the original local fallout is only known within several hundred miles. In 1956, fallout, as indicated by the radioactivity of the plankton samples, was 800 miles west of Eniwetok one month after the end of the Redwing series but it is to be remembered that this fallout could have originated several months earlier at the beginning of the Redwing series. In 1958 at a comparable time in respect to the end of the test series fallout was detectable in the plankton 1100 miles west of Eniwetok. The best estimate of the westward rate of advance is about ten miles per day or slightly less. In 1958 a surface drogue placed a few miles west of Eniwetok moved 51 miles in 71 hours or about 17 miles per day. This rate of movement was for a short distance and is a measure of the surface current which would be expected to be faster than the rate of advance of fallout as measured by the radioactivity in plankton.

Radiochemical separations by ion exchange and precipitation techniques and gamma spectrum analyses were used to determine the radioisotopes present in the plankton samples. For the Redwing samples fission products, mainly  $Zr^{95}$ - $Nb^{95}$  and  $Ce^{144}$ - $Pr^{144}$

contributed an average of 29 per cent of the total radioactivity. The remaining 71 per cent was contributed by the non-fission radioisotopes  $Zn^{65}$ ,  $Co^{57,58,60}$ ,  $Fe^{55}$  and  $Mn^{54}$ . Radioactive zinc, cobalt, and iron accounted for averages of 24, 26 and 21 per cent, respectively, of the total radioactivity;  $Mn^{54}$  was present in trace amounts (Lowman, 1958). The results of analysis of four of the samples are given in Table 2.

In the Hardtack plankton samples the presence of radioactive tungsten ( $W^{185}$ ) was striking. Plankton samples with  $W^{185}$  were found in three areas and contributed as much as 83 per cent of the total radioactivity. Plankton taken outside of these areas did not contain radiotungsten nor was it found in any plankton samples collected three weeks later in the same area, corrected for the rate of advance, where  $W^{185}$  was found originally (Lowman, 1959). The assumption based on this and other evidence is that tungsten occurred as an external contaminant and that little was taken up biologically. The analyses of four of the 1958 plankton samples are also given in Table 2. The 1958 plankton sample was of fresher fallout material which accounts in part for the difference in the radioisotopic composition between the 1956 and 1958 plankton samples.

From the measurement of the radioactivity in plankton, fish and other organisms in the sea, it is evident that the organisms, especially plankton, play an important role in the translocation

and movement of radioisotopes in the sea. The ability of plankton organisms to rapidly acquire a large part of the radioactivity in the sea and to make diurnal vertical migrations from the relatively fast moving and well mixed surface layer of the ocean to the slow moving stratified water layers of the deeper ocean has been demonstrated. A study of the fundamental processes involved in the translocation of radioisotopes by a plankton population has been initiated and a report of the state of progress of this research was given at the second Geneva conference on the peaceful uses of atomic energy (Ketchum and Bowen, 1958).

In addition to the analyses to determine the radioisotopes present in plankton, similar analyses have been made of algae, clams, fish and many of the land plants and some of the land animals. A few of the analyses for algae, clams and fish are given in Table 2. The results as given in the Table are comparable from one sample to another only in a general way because the specimens have been collected from areas that have received fallout at various times ranging from a few days to ten years. Although the analyses of the land plants and animals are not given, there is a striking difference between the land and the sea in the biological distribution of the fission products and non-fission products (transition elements). In general the transition elements iron, zinc, cobalt and manganese are present in marine animals but in very

low amounts when present in marine plants or on the land. None of the radioactive transition elements or only low levels are present in island soil, in plants growing in the soil, or in the herbivorous field rats. However, in the plankton, the marine invertebrate filter feeders and omnivores, and in the fishes, the transition elements may contribute up to 100 per cent of the total radioactivity.

Other observations on the biological uptake of radioisotopes are as follows:

Of the long-lived fission product isotopes-- $\text{Sr}^{90}$ ,  $\text{Cs}^{137}$  and  $\text{Ce}^{144}$ --only  $\text{Ce}^{144}$  enters into the biological cycle in the marine environment to a significant extent. However, on land,  $\text{Sr}^{90}$  and  $\text{Cs}^{137}$  are taken up but  $\text{Ce}^{144}$  is not, to any great extent.

Of the gamma-emitting isotopes present in ten tissues of reef and lagoon fish the radioisotopic composition did not vary greatly from tissue to tissue except that radiocobalt was not found in the bone. Practically no fission products were found in fish. The transition elements ranked in order of abundance are radioiron, zinc, cobalt and manganese. Oceanic fish differ from reef and lagoon fish in that radiozinc ranks first in abundance in the former.

In comparison with fish, plankton have greater amounts of radiocobalt and lesser amounts of radioiron.

In order to be able to predict the future levels of radioactivity in the plants and animals of the Eniwetok Test Site area, the rate of decline has been determined for many organisms. The rate of decline is defined as the rate at which the radioactivity is decreasing in a given tissue, organ, or organism in its native environment (Held, 1957). The only constant factor is that of physical decay. Prediction of rate of decline would be extremely difficult by other than empirical means. The decline rates and decay rates for many organisms in various areas in the vicinity of the Eniwetok Test Site are reported by Bonham (1958).

In general the decay curves are steeper than the decay curve for mixed fission products which is generally expressed as being  $t^{-1.2}$ . The mean of about 100 decay curves was about  $t^{-1.5}$ . The greatest deviation from the mean was for muscle samples from birds and rats, for which the decay rate was much slower.

The decline rates were equal to or greater than the decay rate of  $t^{-1.2}$ . The difference between the decay rate for mixed fission products and the decay rate and decline rate of the biological samples means that the radioactivity is declining faster in plants and animals than it would from fallout that included the entire spectra of fission products. Reasons for this are that there is biological selectivity of the radioisotopes and other factors such as weathering. The decline in radioactivity of representative samples from just after the Nectar shot at Eniwetok

in 1954 to a time 700 days later is given in Table 3. That different tissues have different rates of decline is evidenced by the shift in relative positions of the samples in regard to radioactivity between the first and last collections.

Since the beginning of the series of weapons tests at Bikini and Eniwetok a program to determine the biological and geographical distribution of fallout in the vicinity of the test site has been a part of each test operation. The biological program of the Laboratory of Radiation Biology, University of Washington (formerly the Applied Fisheries Laboratory), since the the first operation at Bikini in 1946 has recently been reviewed by Donaldson (1959a). Other reports on radioactivity in the oceans and of biological programs associated with weapons testing programs are included in recent bibliographies by Davis (1958) and by Wallace (1958).

The fallout at Rongelap Atoll has received special attention. This is the one area in the world where fallout has been great enough to require that the population be evacuated. Although the level of radioactivity is now low and the natives can live safely at Rongelap, the area provides a wonderful opportunity for a study of radioisotopes in a natural environment. The history of the Rongelap studies follows.

Since the radioactive contamination of Rongelap Atoll on March 1, 1954, repeated studies have been made of the extent and distribution of the contamination. Eleven collections were made

Table 3. Decline in radioactivity of samples collected at Eniwetok immediately following and 700 days after the Nectar Shot, May 14, 1954.

Maximum value 1-3 days post-Nectar	700 days post-Nectar
d/m/g wet	d/m/g wet
10 <sup>7</sup> Plankton	
Bird feathers and skin	
10 <sup>7</sup> Algae	10 <sup>7</sup>
Snail liver	
Clam visceral mass	
" kidney	
10 <sup>6</sup> Beach sand	10 <sup>6</sup>
Fish gut	
Bird gut	
Sea cucumber gut	
Bird bone, kidney	
Coral	
Bird liver, lung	
Fish skin, bone	
10 <sup>5</sup> Sea cucumber muscle	10 <sup>5</sup>
Snail muscle	
Clam muscle	
Sea water	
10 <sup>4</sup> Fish muscle	10 <sup>4</sup>
	Snail liver
	Clam kidney
	Beach sand
	Snail muscle
	Fish liver
	Plankton
	Fish gut
	Sea cucumber gut
10 <sup>3</sup>	10 <sup>3</sup>
	Clam visceral mass
	Bird kidney, liver, lung
	Sea cucumber muscle
	Fish bone
	Algae
10 <sup>2</sup>	10 <sup>2</sup>
	Clam muscle
	Bird bone, skin
	Coral
	Fish skin
	Fish muscle
10	10
	Bird muscle
	Bird gut
1	1
	Sea water

by the Laboratory of Radiation Biology, University of Washington, between March 1954 and March 1959, and two collections by the Naval Radiological Defense Laboratory, February 1955 and February 1956. Analyses of some of the samples were made by the Health and Safety Laboratory of the Atomic Energy Commission. In addition, teams of medical experts have been conducting periodic medical examinations of the Rongelapese. The soils and biological monitoring data through 1956 have been summarized by Dunning (1957).

It was recognized that while monitoring of the biota for radioactive contamination is essential to an immediate estimate of potential hazards, the information so gained is limited in application. Understanding of the processes involved in the movement of radioisotopes throughout the physical and biological system of the atoll is essential if it is hoped to arrive at basic conclusions of broader applicability. From such basic conclusions it might then be possible to predict the consequences of future contamination of similar areas and possibly the development of practical methods of reducing radioisotopic levels in foods of the area. It was also recognized that the total ecology of the area should eventually be understood in as great detail as possible in order to understand the processes by which the radioisotopes move from the soil to plants and probably to the sea, from the lagoon bottom to the marine life and sea birds, thence back to the land. Obviously this is an ambitious concept involving many

disciplines. The implementation of such a concept deserves careful consideration of the area to be studied. Rongelap Atoll has a unique advantage since it has been contaminated only once by moderately high levels of fallout. Thus the time of origin is known without the confusion due to repeated contamination of the same area. There is what might be thought of as a disadvantage, the fact that atolls are not typical of continental situations. On the other hand, a glance at a map of the Pacific Ocean quickly shows that a large portion of the earth's surface is represented by atolls and other coralline islands.

Late in 1958 the University of Washington, Laboratory of Radiation Biology, under the direction of Professor Lauren R. Donaldson, was asked to institute a program of "radiation ecology" at Rongelap Atoll. The first expedition was made in March 1958 in cooperation with a medical team headed by Dr. Robert A. Conard of the Brookhaven National Laboratories. Since that time trips have been made in August-September, 1958 by the ecology group and March, 1959 by the medical and ecology groups.

It should be emphasized that radiation effects on the biota are too elusive to be profitably followed in the field. Deleterious effects are produced by a variety of agents which are not all known and are difficult to separate under field conditions. It has never been possible to determine with certainty that observed "abnormalities" of the biota in the vicinity of the

Eniwetok Test Site have been due to radiation effects. Indeed, the same "abnormalities" have been found in areas not subject to radioactive contamination. Consequently, studies aimed specifically at the determination of radiation effects can best be done under controlled laboratory conditions.

The emphasis at Rongelap Atoll has therefore been on mineral transport through the biota. This requires evaluation of the ~~stable~~ isotopes as well as the radioisotopes. The efforts of the first year have been concentrated on the land forms; however, collection and analysis of marine organisms have been made to provide a continuous record of radiation levels in different life forms. The marine phase is to be expanded during the coming year to include more extensive sampling of the lagoon bottom and waters.

None of the studies can be considered complete now or for some time to come. Some of the points that stand out most clearly thus far are as follows:

1. The general levels of radioactivity continue to decline more rapidly than would be expected from physical decay alone (there are certain exceptions such as the levels of  $\text{Sr}^{90}$  in coconut crabs).
2. Extensive sampling of soils shows clearly that the radioisotopes remain concentrated in the top inch or less.
3. Radioactive materials are found more uniformly mixed to a depth of several inches in lagoon sediments.

4. Collection of rain water which has percolated through undisturbed soil shows that  $\text{Cs}^{137}$ ,  $\text{Ru}^{106}$ - $\text{Rh}^{106}$ ,  $\text{Zr}^{95}$ - $\text{Nb}^{95}$ ,  $\text{Sb}^{125}$ , and  $\text{Ce}^{144}$  are being leached from the soil in very small but as yet undetermined amounts.
5.  $\text{Cs}^{137}$  is the principal long-lived fission product taken up by the plants. The  $\text{Cs}^{137}$  levels are higher in older leaves than in younger leaves.
6. There is a general potassium deficiency in the area. Fertilization experiments indicate that the potassium levels are associated with  $\text{Cs}^{137}$  uptake by the plants.
7. Variation in all types of soil and biological samples is commonly as great as by a factor of five for a given type sample taken in an area of less than one square mile.
8. Evaluation of calcium levels in the soil in terms of absolute levels of available calcium is very difficult. It is clear that although these are highly calcareous soils, available calcium represents a small fraction of the total calcium. This is important relative to  $\text{Sr}^{90}$  uptake.
9. In general  $\text{Cs}^{137}$  and  $\text{Sr}^{90}$  are the principal long-lived isotopes found in the land organisms while  $\text{Zn}^{65}$ ,  $\text{Co}^{60}$ ,  $\text{Mn}^{54}$  and  $\text{Fe}^{55}$  are found in the marine organisms.

The need for future studies on fallout in the ocean is in general similar to the needs for studies in the ocean related to

the disposal of high-level radioactive wastes. The Committee on Oceanography for the National Academy of Sciences has recommended a program in oceanography for the years 1960-70. Part of the program is for the study of radioactivity and has been planned with the expectation that the oceans may be used as a disposal area for high-level radioactive wastes. The section on "Radioactivity in the Ocean" from Chapter I of the report by the Committee on Oceanography of the National Academy of Sciences (1959) is included as an appendix to this report. Fulfillment of the recommended program also would provide answers to questions regarding fallout in the ocean.

A study that is in process and will be reported in the near future is the radiological analysis of 2700 tuna samples from the Western Pacific that were collected before, during and after the Hardtack series (Donaldson, 1959b).

The presence of fallout in the ocean provides a unique opportunity to study basic biological and physical processes in the sea. The addition of radioisotopes to the ocean, especially in the vicinity of the Eniwetok Test Site during a weapons testing program, provides tracers for the study of mineral metabolism and transport, or of the movement of ocean currents, or other important research problems. Fallout in the ocean provides a tool for a large-scale field experiment that cannot be duplicated elsewhere.

The assistance of Dr. Edward Held in the preparation of this report is acknowledged with pleasure.

## SUMMARY

The concepts on the uptake and concentration of fallout by marine organisms that were presented at the 1957 Hearings are basically unchanged. The greatest emphasis of recent studies has been to identify all of the radioisotopes in the samples.

The following observations in an area of local fallout, the Eniwetok Test Site, have been made:

(1) Of the three long-lived fission products,  $Cs^{137}$ ,  $Sr^{90}$  and  $Ce^{144}$ , only the latter is found in marine organisms. (If present,  $Sr^{90}$  occurs at low levels); by contrast  $Cs^{137}$  and  $Sr^{90}$  are found in land forms while  $Ce^{144}$  generally is not.

(2) Of the non-fission products radioisotopes of iron, zinc, cobalt and manganese were predominant in marine animals but were much less abundant in marine plants, land plants and land animals.

Radiostrontium as stratospheric or possibly intermediate fallout has been measured in the Atlantic Ocean. The data so far available indicates an amount in surface water greater than predicted, but the significance of the difference is questionable because of the limited number of samples.

The program at Rongelap Atoll has been enlarged to include basic studies of mineral transport and metabolism in addition to radiation monitoring.

The presence of fallout in the ocean provides a unique opportunity to study basic biological and physical processes in the sea. It is recommended that a research program be planned to take advantage of this opportunity.



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## APPENDIX

Radioactivity in the Oceans\*

The widespread use of nuclear energy for peaceful or military purposes necessitates studies to determine the effects of radioactive contamination upon the oceans and the life therein. The Committee on Effects of Atomic Radiation on Oceanography and Fisheries in its report to the National Academy of Sciences made certain general recommendations concerning national policy in this area. Both the Committee on Oceanography and the Committee on Effects of Atomic Radiation on Oceanography and Fisheries believe that more specific and detailed recommendations can now be made.

1. A single agency should be given the overall responsibility and authority for regulating the introduction of radioactive materials in the oceans. Monitoring of disposal sites should be done by some agency other than the regulating agency. It is recommended that either the Coast and Geodetic Survey or the Public Health Service be made responsible for engineering studies in and near disposal areas, for routine monitoring of disposal areas and their surroundings and for a continuing assessment of the effects on the environments of added radioactive materials.

2. Vigorous programs should be started for the purpose of determining the circulation and mixing processes which control the dispersion of introduced contaminants in coastal and estuarine environments and in the open ocean. These studies represent the major part of the proposed budget in this area.

3. A program should be pursued aimed at determining the inorganic transfer of radioactive elements from sea water to the sediments.

4. Studies should be made of the effects of living organisms on the distribution of radioactive elements introduced into the sea.

5. The genetic effects of radiation upon marine organisms should be studied.

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\* See "Literature Cited," (21)

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6. A variety of biological field experiments should be conducted utilizing radioisotopes.

7. The proposed budgets for the programs are given in tables 12 and 13. The greater part of the program should be financed by the Atomic Energy Commission.

Table 12. Radioactivity in the oceans -- Summary of budget estimates  
(Annual cost in 1958 dollars)

	Without ship time	Ship time	Total
Control and monitoring	370,000	---	370,000
Estuarine and coastal studies	1,920,000	880,000	2,800,000
Research in open ocean	1,000,000	400,000	1,400,000
Sedimentation processes	449,000 <sup>(1)</sup>	35,000	484,000 <sup>(2)</sup>
Effects of the biosphere	678,000	260,000	938,000
Genetic effects	100,000	---	100,000
Biological field experiments	100,000	---	100,000
<b>Total, 1st year</b>	<b>4,617,000</b>	<b>1,575,000</b>	<b>6,192,000</b>
<b>Total subsequent years</b> About 1/3 is now underway.	<b>4,432,000</b>	<b>1,575,000</b>	<b>6,007,000</b>
<b>Net cost of new program:</b>			
1st year	3,078,000	1,050,000	4,128,000
Subsequent years	2,954,000	1,050,000	4,004,000
If 2 large open sea tests are conducted, 1 in 1962 and 1 in 1966, the additional costs in those years will be	1,400,000	600,000	2,000,000
<b>Total in those years</b>	<b>4,354,000</b>	<b>1,650,000</b>	<b>6,004,000</b>

(1) \$264,000 after 1st year

(2) \$299,000 after 1st year

(Table 13. not included here)