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GROSS BETA RADIOACTIVITY OF THE ALGAE AT ENIWETOK ATOLL, 1954-1956

#9

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ABSTRACT

A study was made to determine the amounts of radioactivity in marine algae, water and lagoon bottom sand collected at Eniwetok Atoll during the period April 1954 to April 1956. The highest levels of beta radioactivity of algae collected after the detonation of a nuclear device (Nectar) were in algae from those islands closest to the site of detonation and in the downwind path of the fallout. With time after detonation, the decline of radioactivity in the algae at Belle Island was faster than can be accounted for on the basis of physical decay alone.

In March 1955, algae and bottom sand collected in the deeper waters (20 to 140 feet) of the lagoon, one half to two miles offshore, contained as much or more radioactivity than samples collected in the shallow water near shore.

The radioactive decay rates of algae samples collected from Leroy and Henry Islands were greater than those of algae from other islands, indicating that there was less residual contamination from previous detonations at these two islands.

Study of the radioactive decay rates of the algae at Belle Island showed that the radioactivity was decaying at a relatively low rate, which became slower with samples collected late in the survey. These observations indicate that the longer-lived isotopes were being taken up by the algae.

GROSS BETA RADIOACTIVITY OF THE ALGAE AT ENIWETOK ATOLL, 1954-1956

INTRODUCTION

Since the Operation Crossroads tests at Bikini Atoll in 1946, the Laboratory of Radiation Biology, University of Washington, has been investigating the effects of radiations released by nuclear detonations upon living organisms. The amounts of radioactivity detected in aquatic and terrestrial organisms and the effects of the nuclear detonations on these organisms were studied in 1946[1], 1947[2], 1948[3], 1949[4], and 1952[5]. These studies took place either shortly after a detonation or at a later date, often as much as a year or more after a nuclear test. Thus, there were gaps in the knowledge of the interim periods. Consequently, a series of investigations was initiated by this Laboratory, in which a year's continuous study was made of the effects of nuclear detonations on biological organisms. This study was done in conjunction with the 1954 weapons tests at the Eniwetok Test Site. The results of the investigations on the following organisms have already been reported: reef fish[12], land crabs[9], and invertebrates[8].

The study of the marine algae constituted an integral part of this program. The main objectives were to determine the rate of decline of radioactivity of several genera of algae and to determine whether these algae were selectively absorbing fission products released by the nuclear detonations. Other objectives were to determine the geographical distribution of radioactivity and to determine the variability in the levels of radioactivity in the same species.

METHODS

The following collections of algae were made: (1) samples of several genera of algae and of sea water from the intertidal zones at Belle Island (Fig. 1) at varying intervals of time before and after a nuclear detonation on an adjacent island; (2) samples of three genera of algae in the shallow water near eight other islands of the atoll at approximately monthly intervals; (3) samples of algae and bottom sand from the deeper waters of the lagoon off seven islands.

The samples were prepared at the Eniwetok Marine Biological Laboratory for further processing at the Laboratory of Radiation Biology, University of Washington, Seattle. The samples of algae were dry ashed for counting in an internal gas-flow counting chamber. The methods used in the preparation of samples for radioassay are described in this Laboratory's report, UWFL-43[7] and the procedures for counting are outlined in WT-616[5] (UWFL-33). The samples of sea water were placed on 1 1/2-inch stainless steel planchets and dried under an infrared lamp

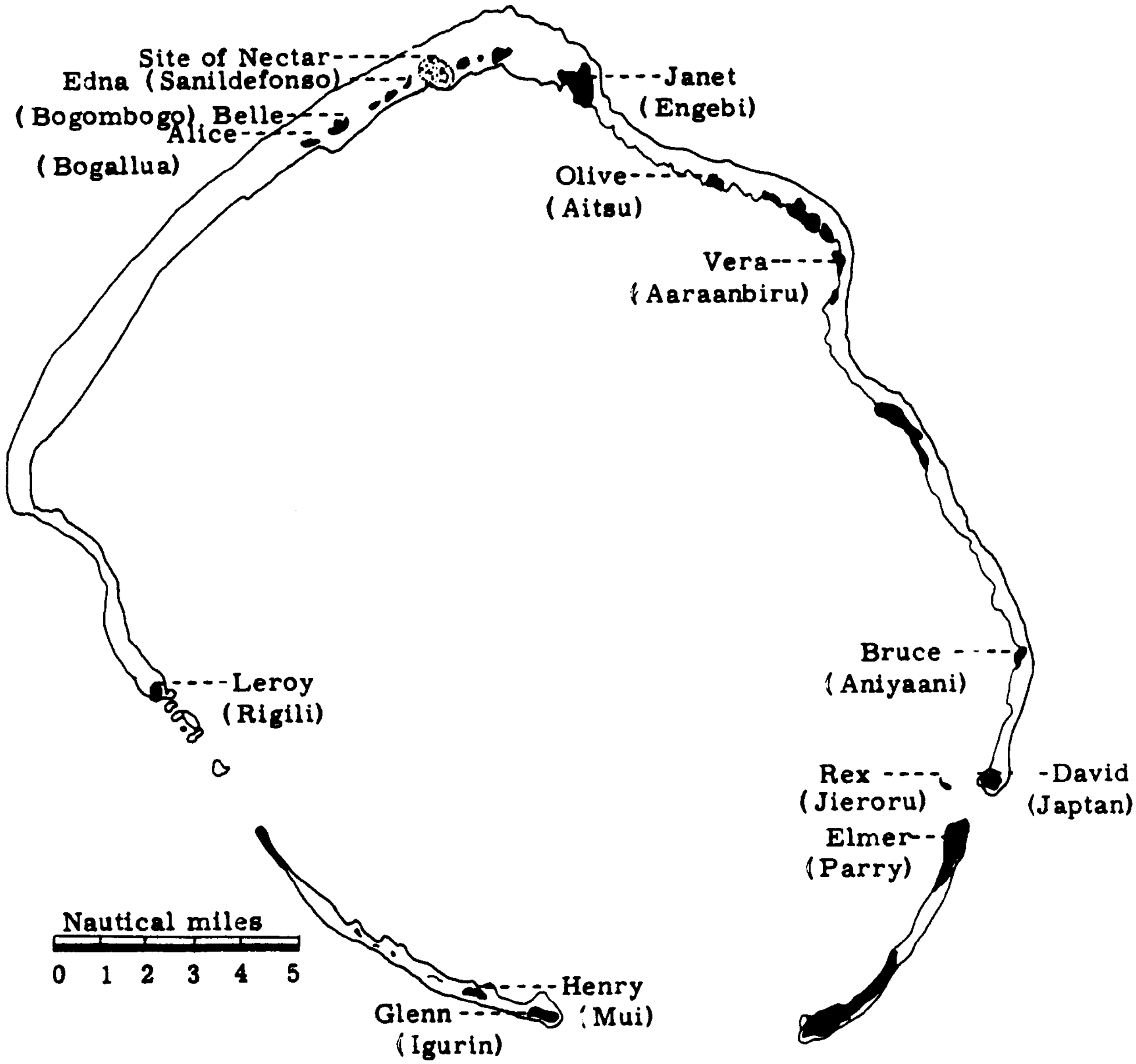

Fig. 1. Eniwetok Atoll showing the islands where collections were made, April 1954 to April 1956.

before counting. The samples of bottom sand were dried in an oven at 96° C, and 100-mg portions of the dried material were spread on a planchet and dry ashed before counting. The counts of radioactivity were corrected to the date of collection; the factors used to correct for radioactive decay (decay factor) for all but three of the samples were based on a soil sample collected on May 15, 1954, at Belle Island. For the early collections decay factors as high as 16.2 were used, whereas for the last collection a decay factor of only 1.02 was applied. Corrections also were made for self-absorption, backscatter (0.77), geometry (2.00), and coincidence for those samples used in determining absolute amounts of radioactivity. Only the correction factor for coincidence was applied to samples used for determining radioactive decay.

The amounts of radioactivity are expressed in microcuries per kilogram ($\mu c/kg$) of wet tissue for the algae samples, in $\mu c/kg$ of dry matter for the sand samples, and in disintegrations per minute per milliliter (d/m/ml) for the water samples.

The rates of radioactive decay of individual samples of algae, sand, and water were determined by counting the samples on at least three different dates. The decay of mixed fission products approximates a linear log-log relationship for the period involved in this study[10].

The rate of decline of radioactivity in some biological samples from Rongelap Atoll also has been observed to follow a similar pattern[6]. Therefore, the decay and decline slopes were plotted logarithmically.

RESULTS

Studies at Belle Island

A. Rate of Decline of Radioactivity in the Algae

In order to determine the levels of radioactivity in several genera of algae during the period from April 1954 to April 1956, samples were collected on thirty-six different dates, three of these before the test of May 14, 1954. The results of these surveys are summarized in Table 1, and a log-log presentation of the average decline in radioactivity is illustrated in Figure 2. The values plotted are based on the average of seventeen samples for each date after May 14, 1954. The individual rates of decline for representatives of six genera of algae (*Halimeda*, *Caulerpa*, *Spyridia*, *Dictyota*, *Lyngbya*, and *Udotea*) were found to be approximately the same.

The radioactivity in the samples collected before May 14, 1954, was due to the residual radioactivity of the 1952 test series at Eniwetok Atoll (Operation Castle) plus some airborne contamination from the early tests

Table 1. Radioactivity of the algae at Bogombogo Island (Belle) April 1954 to April 1956 expressed in $\mu c/kg$ of wet tissue.

Date	Halimeda	Dictyota	Caulerpa	Lyngbya	Spyridia	Udotea	Codium	Microdictyon	Miscellaneous
1954									
4/15	.90					3.8	.78		.72[1]
4/22	.78	2.4	1.5	4.6		1.9			
4/25					2.4				1.6[2]
5/15	2,400		2,600						
5/16	770	5,000	810		3,900	3,500			
5/17	780	1,100	1,200		670		500		
5/18	740	210	840						
5/19	330	420	1,200						3,200[2]
5/20	380	510			1,300				
5/21	280	630							
5/22	250	450	260		520	790	160	180	
5/26	99	120							110[3]
5/28	120	110							
6/1	30	61					25		
6/4	40	76							
6/7	26	38							
6/11	12	37							
6/19	43	56	22	54	150	62		24	17[1] 43[4]
6/25	11	17							
7/1	3.9	24							
7/8	9.9	46							
7/15	10	40							
7/22	16	50							
7/29	9.7	56							
8/5	12	12	18	55		52		60	

1. Rhipilia 2. Asparagopsis 3. Enteromorpha 4. Bryopsis

Table 1. - continued

Date	Halimeda	Dictyota	Caulerpa	Lyngbya	Spyridia	Udotea	Codium	Microdictyon	Miscellaneous
1954									
8/12	6.1	11							
8/19	2.9	14							
9/7	3.1	16		16	37	14			
10/5	1.6		5.1	5.8	10	5.8		5.6	8.6[5]
11/2	.85		1.0	4.0	2.0	2.0	.94	2.4	2.5[6]
11/30	.45	.62	.75			1.1		2.4	
1955									
1/18	.92		.62			1.2		3.7	.74[3] .20[7]
2/9	.13				3.6	.83			2.2[8]
3/21	.49		.33	3.6	.99		.32	.48	.32[1]; 1.5[4]; .44[9]; .76[10]
11/1	.081		.26		.22	.35	.19		
1956									
4/26	.084						.074	.16	

1. Rhipilia 3. Enteromorpha 4. Bryopsis 5. Dictyosphaeria 6. Jania 7. Valonia 8. Liagora 9. Laurencia 10. Nostoc.

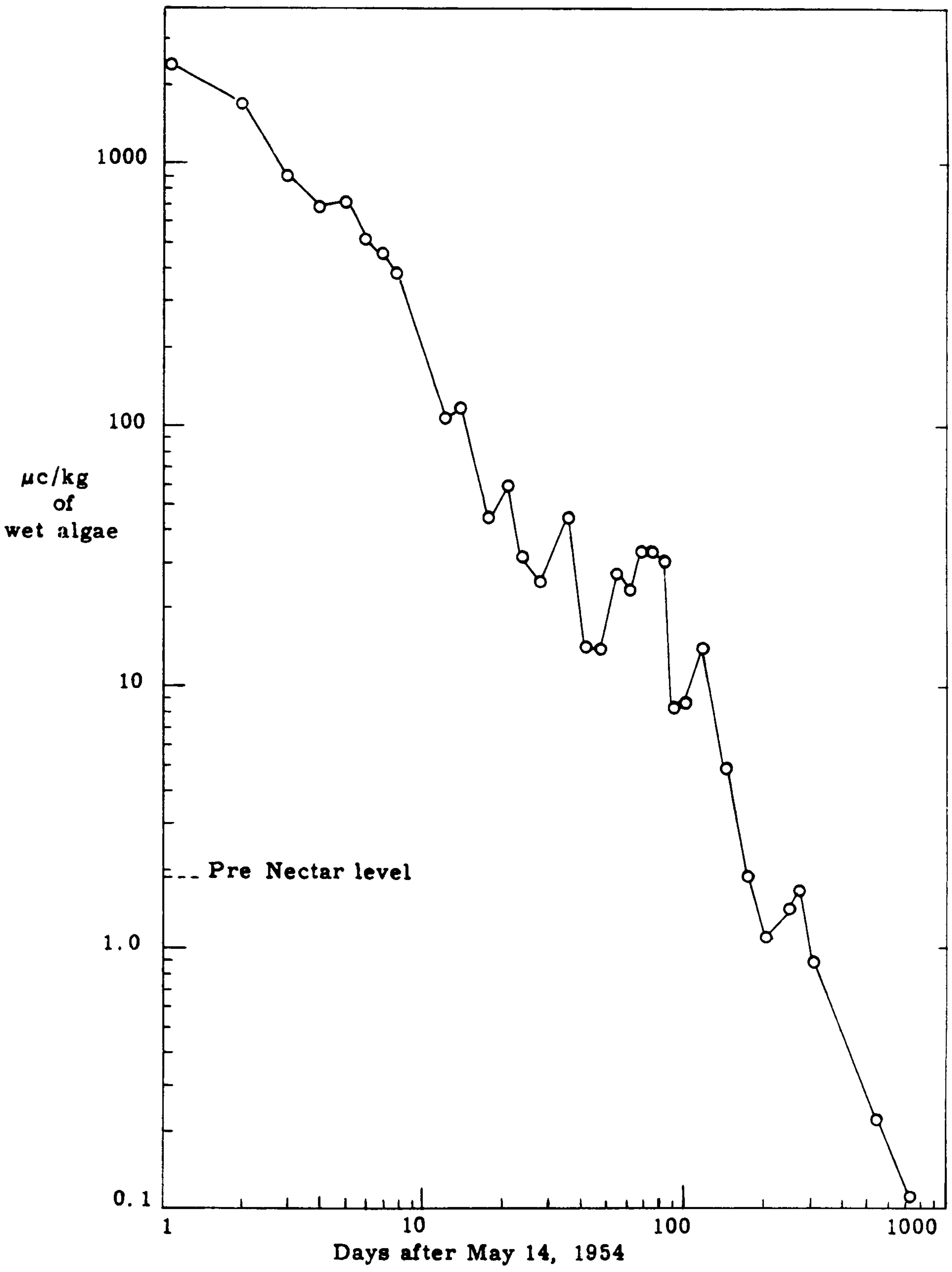

Fig. 2. Rate of decline of radioactivity of the algae at Belle Island, Eniwetok Atoll, from May 15, 1954 to April 26, 1956.

of the 1954 series at Bikini Atoll.

The levels of radioactivity of the algae immediately following the test averaged 2,500 $\mu c/kg$ of wet tissue but declined rapidly, thus the level from previous experiments (1.9 $\mu c/kg$) was reached in about 170 days. At the conclusion of the study in April 1956, the average level was 0.10 $\mu c/kg$ of wet tissue. The trend for the period was one of general decline of radioactivity, although there was some deviation from this pattern.

B. Rate of Decline of Radioactivity in the Sea Water

The amounts of radioactivity in the sea water collected in the same area as the algae are given in Table 2. In recording the results of the radioactivity in the water, the data are reported in d/m/ml instead of $\mu c/kg$ because of the very low levels found. On the first day after the test, the radioactivity in the water averaged 2,200 d/m/ml but it declined rapidly, so that on the last collection dates it was indistinguishable from the background level. A logarithmic plot of the decline in radioactivity is shown in Figure 3, and it can be seen that the rate is approximately the same as that for the algae, even though the levels in the algae were approximately one thousand times greater.

From May 15, 1954 to May 19, 1954, the ratio of radioactivity in the algae to that in the water increased from 2,500 to 14,000, which indicates that the algae were concentrating radioactive material even though

Table 2. Average radioactivity of intertidal water at Belle Island, Eniwetok Atoll, May 15, 1954 to April 26, 1956, expressed in d/m/l ± 0.95 counting error.

Date			
5-15-54	2300	±	240
5-16	640	±	85
5-17	200	±	59
5-18	130	±	46
5-19	120	±	37
5-21	540	±	39
5-22	2800	±	104
5-26	170	±	18
5-28	140	±	15
6-1	430	±	12
6-4	92	±	9.6
6-7	140	±	10
6-9	280	±	13
6-11	72	±	7.8
6-19	320	±	12
6-25	54	±	7.1
7-1	20	±	5.3
7-8	93	±	7.2
7-15	46	±	5.8
8-5	22	±	4.7
9-7	14	±	3.6
10-5	16	±	3.6
11-2	8.0	±	2.8
2-9-55	1.5	±	2.6
2-12-55	5.4	±	2.8
3-21-55	0.57	±	2.9
11-1-55	0	±	2.4
4-26-56	1.5	±	.58

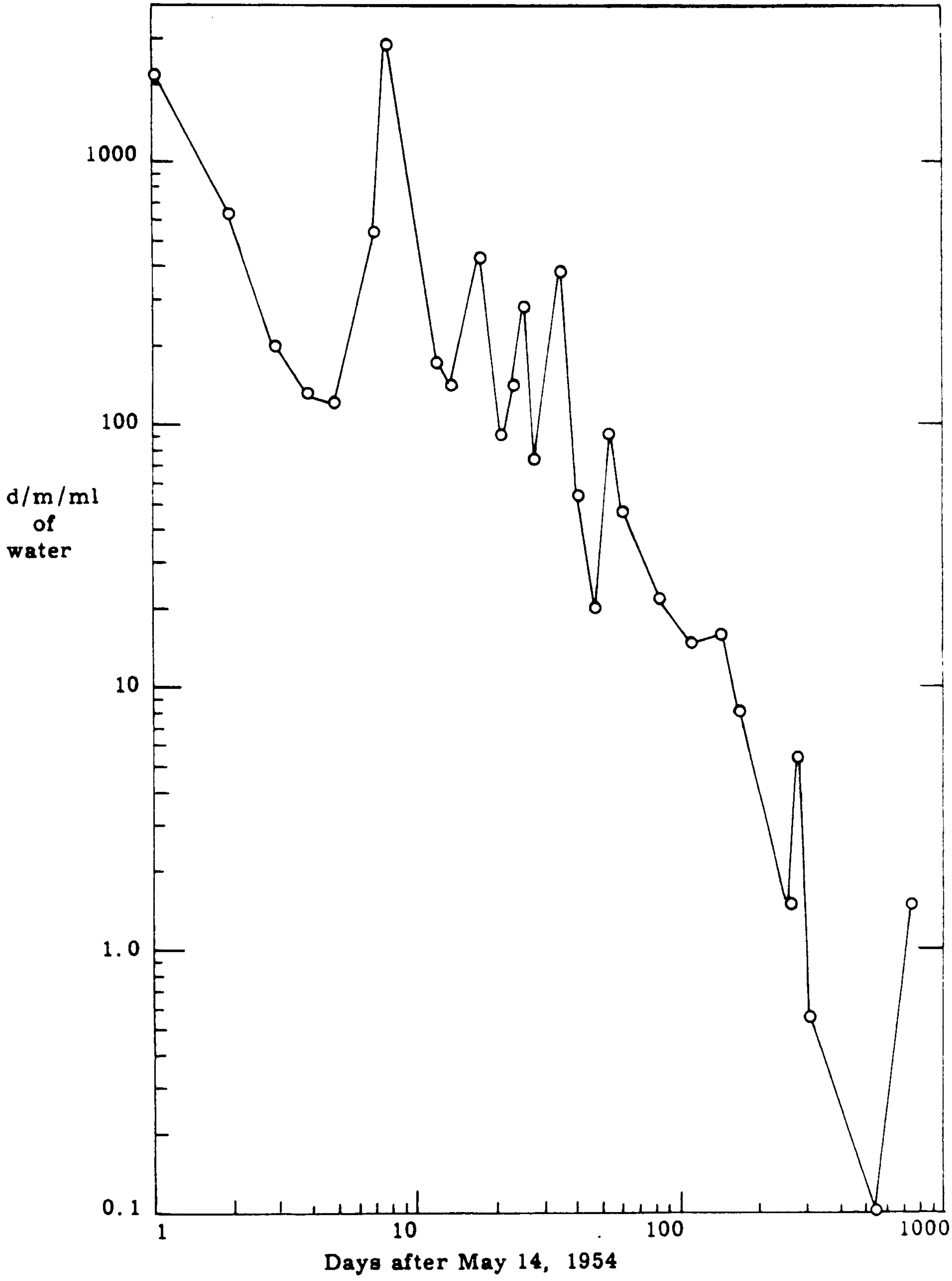

Fig. 3. Rate of decline of radioactivity of the intertidal water at Belle Island, Eniwetok Atoll, from May 15, 1954 to April 26, 1956.

the supply was diminishing.

C. Geographical Distribution of Radioactivity in the Algae

Intertidal zone. The average levels of radioactivity of specimens of three genera of algae, *Caulerpa*, *Lyngbya*, and *Halimeda*, collected in the intertidal zones of eight islands of the atoll at intervals from April 1954 to April 1956 are given in Table 3.

Before May 14, 1954, the highest levels were found in algae samples from Vera Island (35 $\mu c/kg$) and Olive Island (21 $\mu c/kg$), the lowest at Elmer Island (0.26 $\mu c/kg$) and Leroy Island (0.28 $\mu c/kg$), and intermediate levels at the other four islands. The rapid radioactive decay in the samples from Vera and Olive Islands and the data from the survey for gamma radioactivity at Vera Island showed that fallout from the March 1954 tests at Bikini Atoll had contaminated this area of the atoll.

After May 14, 1954, the highest initial values were found in the algae from Leroy Island and the lowest in those from Elmer Island. The levels of radioactivity in the algae from the northern half of the atoll were generally higher than those from the southern islands. Over the period of study this pattern remained much the same. The levels of radioactivity of the algae collected at Belle Island were similar to those collected at Alice Island (one mile away) and Vera Island (ten miles away).

Table 3. Radioactivity in three species of algae collected at eight islands of Eniwetok Atoll from April 1954 to April 1956, expressed in $\mu c/kg$ of wet tissue.

Date of collection	Alga	Island: Bruce	Vera	Olive	Alice	Leroy	Henry	Elmer	Janet
4/1954	Halimeda	1.5	5.7	3.7	1.2	.98	.92	.40	2.4
	Caulerpa		3.1		4.6	.28	.91	.26	
	Lyngyba	.69	35.	21.	.74	2.5			
6/3/54	Halimeda	64.	37.	16.	26.	500.	8.3	12.	64.
	Caulerpa		130.	77.	69.	34.	12.	6.9	17.
	Lyngyba	28.			190.	350.	39.		
6/21/54	Halimeda		44.	11.	17.	400.	8.3	45.	5.0
	Caulerpa		70.	26.	19.	12.	37.	9.1	17.
	Lyngyba	50.		32.	15.	160.			
7/20/54	Halimeda	10.	7.6	4.2	6.1	33.	9.6	3.2	4.6
	Caulerpa					3.7	7.1	5 7	
	Lyngbya	15.	15.	7.9	69.	56.			8.1
9/15/54	Halimeda		1.4	1.1	1.4	16.	.29	.24	1.7
	Caulerpa	1.4	2.5		7.4	1.6	.67	.46	1.6
	Lyngyba	.98		1.3		12.		2.0	
10/21/54	Halimeda		.45	1.5	1.7	2.8	.22	.64	.82
	Caulerpa	.68	.96		1.6	.50	.40	.53	2.1
	Lyngbya	.95		1.1	4.0	1.8	.59	.79	2.2

Table 3. - continued

Date of collection	Alga	Island: Bruce	Vera	Olive	Alice	Leroy	Henry	Elmer	Janet
11/17/54	Halimeda		.22	.40	.29	.88	.24		.19
	Caulerpa	.053	.57			.031	.090	.22	
	Lyngyba	2.8	5.2	6.4		.47	3.0	.33	
12/17/54	Halimeda		1.0	.25	.29	1.3	.11		.36
	Caulerpa	.17	.039			.16			
	Lyngyba		3.1						3.2
2/11/55	Halimeda	.12	.21	.26	.19	.51	074		
	Caulerpa	.22				.25	.15		
	Lyngyba					1.7			
3/18/55	Lyngyba								.47
10/30/55	Halimeda					.092	.047	.022	.14
	Caulerpa					.040	.034	.035	
	Lyngyba	.083				.17			.21
4/25/56	Halimeda		.070						.14
	Caulerpa		.13						.26
	Lyngyba		.32			.084			.023

At Belle Island the amounts of radioactivity in specimens of algae from different areas of the intertidal zone (Fig. 4) collected on the same day were compared. An example is presented in Table 4.

Table 4. Gross beta activity of four species of algae collected from different areas of Belle Island on May 22, 1954. Values are expressed as thousands of d/m/g of wet tissue at time of collection.

Species	Area				
	E-1	E-2	F-1	F-2	G
Halimeda opuntia	478	375	633	674	621
Caulerpa urvilliana	735	-	704	455	503
Udotea indica	-	2040	1320	1170	2060
Microdictyon sp.	-	361	208	285	593

This table and similar data from other collection dates showed that the radioactivity of the algae from different areas was essentially the same.

The variability in the radioactivity of five to ten specimens of Halimeda sp. from the same area was also determined for eighteen collections. The coefficient of variation, C (C = standard deviation ÷ mean), varied from 12 to 65 per cent, the average being 35 per cent, an indication of great variability in the amounts of radioactivity in the samples collected from the same area. Similar conclusions were reached

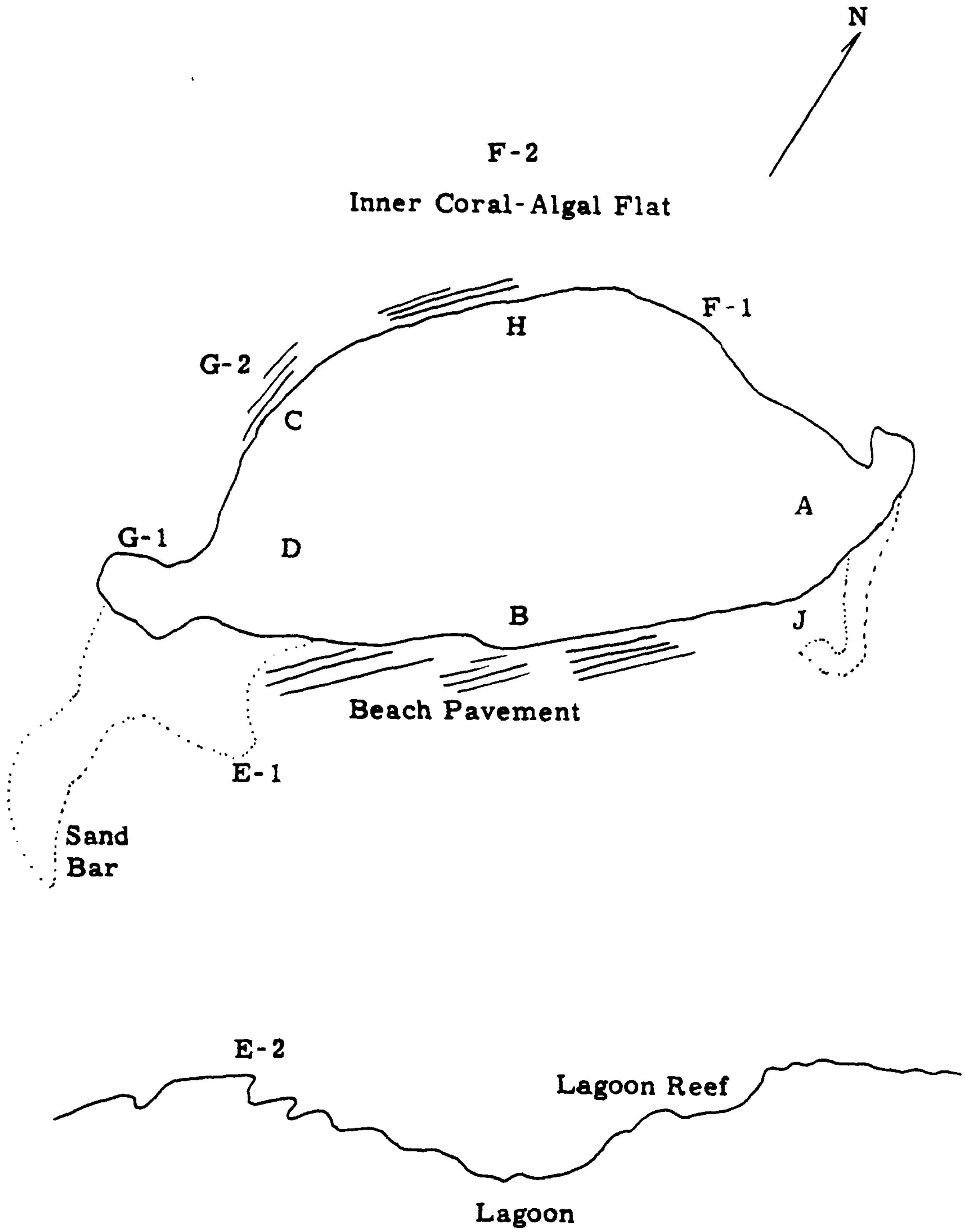

Fig. 4. Diagram of Belle Island, Eniwetok Atoll, showing the areas of collection.

concerning the variability in three collections of H. stuposa, each involving ten portions of the same plant.

Deep waters of the lagoon. A summary of the results of the radioactivity of nine deep-water collections of bottom sand and fourteen deep-water collections of algae is given in Table 5. The values of radioactivity for the bottom sand are expressed in $\mu c/kg$ of dry weight because they are more reliable than those based on wet weight. Consequently, when the radioactivity of the coral sand and algae were compared, conversion factors were applied to the values for the algae to convert them to a dry weight basis. The conversion factors are given in Table 5.

The results show that in the southern end of the lagoon (Rex Island) the radioactivity of the algae and bottom sand was high in June 1954, but much lower (in the algae) in August and September, 1954, (Elmer Island) and in March 1955 (Elmer, Glenn, and Leroy Islands). In the northern end of the atoll, however, the levels of radioactivity in the algae and sand were high in March 1955, especially in the vicinity of the detonation (Edna Island). In the lagoon off Janet and Vera Islands the radioactivity of the bottom sand was also high at this time.

A comparison of the radioactivities of the deep-water algae and the shallow-water algae is given in Table 6. In three of the four cases where comparisons can be made, the deep-water algae contained higher levels of radioactivity than did the shallow-water algae. Further study would be necessary to determine the consistency of this relationship and to develop

Table 5. Radioactivity in algae and sand from the deep waters of Eniwetok lagoon.

Station and water depth (feet)	Date of collection	Algae	μc/kg dry weight Alga*	Sand	Ratio**
Rex Is. 45	6/6/54	Lyngbya majuscula	155.		
Rex Is. 60	6/16/54	Lyngbya majuscula	434.	5.4	80.
		Lyngbya sp., Dictyota sp. mixture	464.		86.
Elmer Is. 50	8/8/54	Halimeda sp.	48.		
Elmer Is. 135	9/4/54	Halimeda gigas	2.25		
		Halimeda orientalis	13.5		
		Caulerpa racemosa	2.39		
Elmer Is. 140	9/9/54	Halimeda opuntia	12.9		
		Halimeda monile	4.8		
		Halimeda gigas	6.6		
		Lyngbya majuscula	11.4		
Elmer Is. 140	9/11/54	Caulerpa racemosa	0.99		
Janet Is. 20	3/2/55	Polysiphonia sp.	3.10	9.8	.32
		Asparagopsis taxiformis	3.51		0.36
		Halimeda opuntia	1.98		0.20
Elmer Is. 90	3/4/55	Halimeda gigas	0.20	0.43	0.47
		Halimeda opuntia	0.78		1.8
		Polysiphonia sp.	3.96		9.2
		Lyngbya sp.	2.98		6.9
Edna Is. 60	3/8/55	Halimeda lacunulis	66.	550.	0.12
		Halimeda gigas	96.		0.18
		Halimeda opuntia	150.		0.27
		Polysiphonia sp.	430.		0.73
Vera Is. 20	3/9/55	Halimeda opuntia	0.72	0.58	1.2

* Multiplication factors used to convert wet weight to dry weight

Asparagopsis	6.5	Lyngbya	3.1
Caulerpa	5.7	Padina	6.1
Dictyota	4.7	Polysiphonia	4.3
Halimeda	3.0	Udotea	3.1

** $\frac{\text{Radioactivity in algae}}{\text{Radioactivity in sand}}$

Table 5. - continued

Station and water depth (feet)	Date of collection	Algae	μc/kg dry weight		Ratio**
			Alga*	Sand	
Vera Is. 80	3/11/55	Halimeda monile, Halimeda opuntia	0.60	2.9	0.21
		Padina Commersonii, Dictyota sp. mixture	4.27		1.5
Elmer Is. 100	3/14/55	Caulerpa racemosa	0.86	0.18	4.8
		Halimeda gigas	0.36		2.0
		Halimeda opuntia	0.99		5.5
Glenn Is. 50	3/16/55	Halimeda monile	0.36	0.53	0.68
		Dictyota sp.	3.15		5.9
		Lyngbya majuscula	0.81		1.5
Leroy Is. 60	3/16/55	Halimeda monile	1.11	1.5	0.74
		Dictyota sp.	3.71		2.5
		Asparagopsis taxiformis	3.06		2.0

* Multiplication factors used to convert wet weight to dry weight

Asparagopsis	6.5	Lyngbya	3.1
Caulerpa	5.7	Padina	6.1
Dictyota	4.7	Polysiphonia	4.3
Halimeda	3.0	Udotea	3.1

** $\frac{\text{Radioactivity in algae}}{\text{Radioactivity in sand}}$

an understanding of the methods of distribution of radioactivity in the lagoon.

Table 6. Gross beta activity of the algae collected from the deep and shallow waters of Eniwetok Atoll, expressed in $\mu c/kg$ of wet tissue.

Island	Date of collection	Species	Deep water	Shallow water
Rex	6-6-54	*Lyngbya majuscula*	50	
	6-16-54	" "	130	
Bruce	6-3-54	" "		28
	6-21-54	" "		50
Elmer	9-4-54	*Halimeda* spp.	2.6	
	9-9-54	" "	2.7	
	9-15-54	" "		0.24
Vera	2-11-55	*Halimeda* sp.		0.21
	3-9-55	" "	0.24	
	3-11-55	*Halimeda* spp.	0.20	
Edna	3-8-55	" "	35	1.2

The radioactive materials adhering to the bottom sand of the lagoon are constantly undergoing mixing and diffusion into the adjacent water. Therefore, the amount of radioactivity in the sand may be directly related to that in the water and indirectly to that in the algae. The ratio for the relationship of the radioactivity in the algae to that in the sand, $\frac{\text{amount of radioactivity in the algae}}{\text{amount of radioactivity in the sand}}$, was used to determine whether the algae had concentrated radioactive materials from the water. The results, given in Table 5, show that the ratio varied with the species of algae and with the location of the collection site in the atoll. In general the ratio was highest for the fleshy algae such as Lyngbya and Polysiphonia and lowest for the coralline alga, Halimeda. The highest ratios or concentration factors (80 to 86) were obtained from the samples collected shortly after the detonation in the southern portion of the atoll (Fig. 1). Approximately one half of the samples had ratios greater than unity, indicating a concentration of radioactivity by these algae.

Comparison of Radioactive Decay Rates

The radioactive decay rates of four genera of algae collected at Belle Island on different dates were determined and compared with each other and with the decay rates of water samples obtained from the same areas in order to determine whether there were any differences in the radioisotopic content of the samples. For algae of the following genera, Halimeda, Caulerpa, and Spyridia, the decay rates decreased with time after the test of May 14, 1954, from a slope of -1.3 to -1.0 (Table 7). For Udotea, a semi-calcareous alga, the slopes fluctuated between -0.8 and -1.5. In July and November, 1954, at least, it appears as though Udotea contained radionuclide mixtures different from those taken up by the other algae.

The decay of algae collected in May and June, 1954, was slower than the decay of water samples collected during the same period of time in the same localities, indicating that the algae had selected some of the longer-lived radionuclides. Unpublished results of radiochemical analyses have shown that Ce^{144}-Pr^{144}, Zr^{95}-Nb^{95}, and Ru^{106}-Rh^{106} are the predominant radionuclides present in algae samples collected shortly after a nuclear detonation.

The decay rate of water samples collected in July and September, 1954, was slower than that for the algae, but because of the high percentage counting error in the last counts of radioactivity in water samples, these data are in doubt.

Table 7. Decay rates of algae and intertidal water collected at Belle Island, May 1954 to March 1955, expressed as the negative slopes of logarithmic plots: $A_t = A_1 t^{-x}$.

Dates of collection

	1954						1955		
Sample	5/16-22	6/1-19	7/5	9/7	10/5	11/30	1/18	2/9	3/21
Halimeda	1.3*	1.3		1.3	1.3	1.1	1.3	1.0	
Caulerpa					1.2	1.1	1.1		1.0
Spyridia	1.2*	1.2		1.2	1.1			1.2	1.0
Udotea	1.2*	1.3*	1.5*	1.2*	1.2*	0.8*	1.2	1.2	
Intertidal water	1.8* 1.2	1.8*	1.0*	1.1					

*Two or more samples with identical slopes

A_t = Activity at day t

A_1 = Activity at day 1

t = Time in days

-x = Slope

Table 8. Decay rates of algae collected at Eniwetok Atoll, June 1954 to February 1955, expressed as the negative slopes of logarithmic plots.

Island \ Date collected	Halimeda				Lyngbya				Caulerpa			
	6/54	7/54	10/54	2/55	6/54	7/54	10/54	2/55	6/54	7/54	10/54	2/55
Leroy	1.7	1.5	2.6	2.2	1.8	1.5	2.4	3.3	2.1		2.7	2.5
	1.6	2.5	2.5		1.6	2.5			2.1			
Henry	1.7	1.9	2.0	1.4	1.6		2.2		1.6	2.0	2.2	2.0
	1.6				1.2				1.5		2.2	
Elmer	1.4	1.5	1.4				1.8		1.2	1.0	1.5	
	1.4								1.4			
Bruce	1.3	1.5		1.3	1.5	2.0	1.7				1.3	1.0
Vera	1.4	1.6	1.1	1.1		1.8			1.3		1.3	
			1.2									
Olive	1.5	1.8	1.2	1.2		1.1	1.1		1.4			
Janet	1.1	1.3	1.2				1.1		1.1		1.0	
			1.1									
Alice	1.2	1.4	1.2	1.0	1.0	1.1	1.2		1.2		1.2	

The decay rates of algae from the intertidal zones of eight islands are given in Table 8. In general the decay rates for the different species collected at one island were the same. It was found, however, that the decay rates varied depending on the date of collection. The radioactivity in the algae collected at Henry and Leroy Islands decayed faster than that in the algae collected at other islands (Table 9).

Table 9. Summary of the decay rates of algae collected on four dates at Leroy and Henry Islands, and at six other islands combined, expressed as the negative slopes of logarithmic plots.

Date of collection	Leroy Is.	Henry Is.	Other islands
6/3/54	1.8	1.5	1.3
7/20/54	2.0	2.0	1.5
10/54	2.6	2.3	1.3
2/55	2.7	1.7	1.1

From these data it appears that the algae at Leroy and Henry Islands absorbed radionuclides with relatively short half lives. A similar conclusion was reached with samples of invertebrates collected at the same time[8]. These observations indicate that the residual contamination from previous detonations accounted for less of the radioactivity at these islands than it did at the islands in the northern end of the atoll.

The radioactive decay of algae and sand collected in the bottom of the lagoon was the same at all stations tested. The decay rates of deep-water algae were similar to those of shallow-water samples. These data indicate that the radionuclides found in the sand were the same as those in the deep-water and shallow-water algae.

DISCUSSION

The algae samples collected one to two days after the nuclear detonation of May 14, 1954, contained the highest amounts of radioactivity of the samples collected during the survey. The radioactivity of the later samples diminished at a rate faster than can be accounted for by the decay of mixed fission products ($t^{-1.2}$)[10], indicating that factors other than physical decay were responsible for the diminution of radioactivity in the samples with time after detonation. One of the factors involved, undoubtedly, was the loss of radioactivity in the sea water in which the algae were growing. The radioactivity of the water was much lower per unit weight than that of the algae, but the rate of loss of radioactivity was approximately the same, which indicates that the amount of radioactivity in the algae was dependent upon that in the water. Since the water in the vicinity of Belle Island was highly radioactive immediately after detonation, the mixing of uncontaminated water from the ocean and less contaminated water from the southern portions of the lagoon would tend to lower the radioactive content of the water surrounding Belle Island, and, consequently, the radioactive content of the algae living in this water. Thus the radioactivity in the algae would tend to decrease with time at a rate faster than would be expected by the process of radioactive decay alone.

Variability in the radioactivity present in the algae was found to be high, even in samples from the same clump of algae. Thus, in comparing the relative amounts of radioactivity in samples from different locations or of different species, it is important to consider the amount of variation that is usually encountered and not place undue importance on slight variations in radioactivity. It was found that the different genera of algae at Belle Island contained essentially the same levels of radioactivity regardless of where they were collected. The radioactivity of the algae at different islands of Eniwetok Atoll, however, varied from island to island, those islands closest to and in the downwind path of the fallout having the highest levels of radioactivity during the period of the survey.

Study of radioactive decay rates of the algae and water at Belle Island showed that the radioactivity in the algae was decaying at a relatively slow rate and that this rate became slower with samples collected later in the survey. These observations indicate that the longer-lived radioisotopes were being taken up by the algae. This is in agreement with the results of studies in which ion-exchange techniques and gamma spectrum analyses were used (to be published later). These results show that the radioisotopes Ce^{144}-Pr^{144}, Zr^{95}-Nb^{95}, and Ru^{106}-Rh^{106} are the most common ones present in algae collected shortly after a nuclear detonation. Others, such as Y^{91}, Co^{60}, Co^{58}, Eu^{155}, Ba^{140}-La^{140}, and I^{131} [11] have been found, but only in isolated instances, and sometimes in very low amounts

The rate of decay of radioactivity in the samples of algae collected at Leroy and Henry Islands was faster than that at other islands of the atoll. Samples collected in February 1955 (nine months after detonation) decayed at rates much faster than would be expected on the basis of mixed fission product decay, an indication that these algae must have been concentrating short-lived radioisotopes. The identity of these radioisotopes is not known, nor is it known why the algae in these two areas should take up short-lived isotopes and algae at other islands take up different ones.

Studies of the levels of radioactivity of the algae and bottom sediment at different locations in the lagoon at Eniwetok Atoll showed that high amounts of radioactivity can be expected at depths up to 140 feet at any location in the atoll months after a nuclear detonation. The radioactivity present in the bottom of the lagoon, miles from the site of detonation, could be deposited there either by direct fallout or by transport by water currents. Once the radioactivity is deposited on the bottom of the lagoon after settling out of the water, it probably remains near its deposition site.

SUMMARY

The rate of decline of radioactivity in the algae at Eniwetok Atoll was studied for a period of two years after the detonation of May 14, 1954 (Nectar). The average pre-Nectar level at Belle Island (Bogombogo) was 1.9 μc/kg of wet tissue; this level was attributed to radioactive contamination from the tests at Bikini Atoll in March 1954. After the Nectar test the average level in the algae built up to 2500 μc/kg on May 15, 1956, then declined to 0.10 μc/kg on April 26, 1956. A logarithmic plot of the levels at each date of collection gave a negative slope of approximately 1.5; this slope probably could be used to estimate the average level of radioactivity of the algae at any future date up to about four years after the Nectar detonation. The rate of decline of radioactivity in water samples collected in the same areas as the algae samples paralleled that of the algae, but the levels were much lower.

Comparison of radioactive decay rates of individual algae collected at Belle Island showed that Udotea, a semicalcareous alga, had selected radionuclide mixtures different from the ones taken up by other algae.

Decay rates of algae and water samples collected at Belle Island showed that for the first two months after detonation the algae had selected some of the longer-lived isotopes from the water.

There were no differences in the amounts of radioactivity in the algae collected at different parts of Belle Island, but there were differences in the amounts in the algae collected at different islands of

Eniwetok Atoll. In general those islands closest to the site of detonation and in the downwind path of the fallout contained the highest levels of radioactivity.

In March 1955, algae and bottom sand collected in the deep water (20 to 140 feet) of the lagoon one half to two miles offshore contained as much or more radioactivity than samples collected in the shallow water near shore. The ratios of amounts of radioactivity in the sand and algae showed indirectly that the algae were concentrating radioactive material from the neighboring water. Comparison of decay rates of sand and algae from the deep water showed that there was no selective absorption of radionuclides by the algae.

Algae at Leroy and Henry Islands absorbed radionuclides with shorter half lives than those absorbed by algae at the other islands of Eniwetok Atoll, an indication that there was less residual contamination from previous detonations at these two islands than there was at other sites examined.

In general, certain genera of algae (*Spyridia*, *Lyngbya*, and *Udotea*) contained more radioactivity than others, while some (*Halimeda*, *Caulerpa*, and *Codium*) usually contained the least. There was no apparent relationship between the amount of radioactivity in an alga and its structure, habitat, or phylogenetic relationships.

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