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By
Kelshaw Bonham

January 6, 1958

Applied Fisheries Laboratory
University of Washington
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Lauren R. Donaldson
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ABSTRACT

The trend in beta radioactivity as measured with methane flow counters over a period of about two years is shown, starting with the 1954 Castle series of nuclear detonations, up to but not including the series of 1956. The results are presented as graphs each showing the logarithm of the radioactivity of an organism or of a particular tissue of an organism, related to the logarithm of the time after the date of detonation, when nearly all of the radioactivity was assumed to have originated.

Invertebrates are considered in greatest detail, and other organisms and materials are included for comparison: island soil, beach sand, sea water, plankton, algae, land plants, reef fish, birds, and rats.

It is proposed for most organisms studied that after a period varying with the organism up to two to four weeks following detonation, a maximum level of radioactivity in the field samples collected is attained, followed by a decline approaching linearity on log-log plots with slopes over the major portion of the two-year period that can be represented as the negative exponent of the time after detonation. These decline slopes varied greatly with different localities and organisms, reaching a maximum of > 3.

A few decay rates of individual samples of each organism or material are included for comparison, and these generally were equal to, or less steep than, the declines, suggesting that for some organisms or tissues, the level of radioactivity in the environment decreases more rapidly than can be accounted for solely by physical decay while for others the rate of decline can be accounted for solely by the rate of physical decay. Dilution by natural water currents and rain is presumed to account for the many cases of more rapid decline than decay.

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RADIOACTIVITY OF INVERTEBRATES AND OTHER ORGANISMS AT ENIWETOK ATOLL DURING 1954-55

Introduction

Levels of radioactivity in living forms have been determined at almost all of the Pacific Proving Ground tests, both immediately before and shortly after the detonations, as well as at occasional relatively great intervals of a year or more later (UWFL-33, 42, and 43).

The present study traces the trends in the beta radioactivity of invertebrates by means of repeated observations from shortly before the Nectar detonation (May 14, 1954) for a period of nearly two years. For comparison with the invertebrates similar observations on other substances and organisms are included, using some information given more fully in reports by other members of the Applied Fisheries Laboratory who deal with their problems from different points of view. Palumbo (1957) reported on the radioactivity in algae and land plants. Held (1957) studied the trends of radioactivity in the land hermit crab and discovered the preponderance of radiostrontium in the exoskeleton. Welander (1957) described the trends of radioactivity for the reef fishes of Belle Island. Lowman, Palumbo, and South (1957) reported the identity of the radioactive non-fission products remaining in certain samples collected in 1954-55 and in 1956 as determined in late 1956 and early 1957.

Although the emphasis of the present paper is on invertebrates, certain data from many of the other areas are brought together here in order to compare the trends in levels of radioactivity in a unified form and by as nearly identical methods as is practicable. It should be possible in this way to observe the general pattern of change of radioactivity in living and non-living materials, and to detect divergences from the pattern. Study of the trends in this manner has proved useful in pointing out materials of interest for radioisotopic analysis by gamma-ray spectrometry.

A comparison of the rate at which levels of activity in organisms of the same species change with the passage of time, herein termed decline, with the rate of physical decay, should indicate changes in availability of the radioactivity to the organism concerned. If decline is more rapid than decay a reduction of activity in the environment beyond that caused solely by physical decay is suggested, and conversely, a steeper decay than decline suggests either an increase in availability in the environment or an accumulation or concentration of radioactivity by the organism. Equality of decay and decline suggests that uptake and excretion of radioisotopes have reached an equilibrium with the environment. It will be shown that cases in which physical decay progressed more rapidly than did the rate of decline over the same period of time were rare or lacking.

METHODS

Radioactivity of common substances and organisms at Eniwetok Atoll was evaluated in two ways, first by concentrated study involving many organisms collected frequently at one island, Belle, and second, by less intensive study at several islands around the atoll in order to elucidate the geographical distribution of the activity.

Belle Island (Fig. 1) was the major collecting and observation site, except for rats, for which it was Janet Island. Collections were made on April 15, 1954 at Belle before the Nectar test, almost daily for the week after, and at increasing intervals later. The second aspect of the study, at several islands, involved pre-Nectar collections in April and May, and nine to ten post-Nectar collections, usually expedited by helicopter, at intervals increasing from one to nine months, at which time six islands, Henry, Leroy, Alice, Olive, Vera, and Bruce were visited. The remaining two islands, Janet and Elmer, were sampled at approximately the same times in connection with other studies.

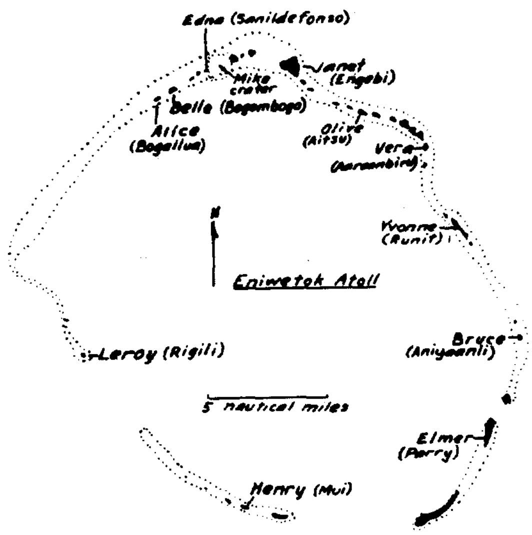

Fig. 1. Map of Eniwetok Atoll

Survey meter readings were taken frequently at Belle, but on only about half of the visits to other islands. The Juno meter was used for high (Table 2) levels of activity and the Geiger counter (Nuclear, MX-5) for low levels. Several spots were usually monitored with the instrument one inch from the ground and with the shield both open and closed. Similar readings three feet from the ground were taken less frequently and are not included.

For the distributional study on the various islands a handful of island soil from the top inch, intertidal beach sand, a few milliliters of sea water, algae, and three sea cucumbers were taken. Periodic trips by M-boat around the periphery of the lagoon, a mile or two centrally from the islands, served for sampling sea water, plankton, and pelagic fish by rod and reel. Plankton tows usually lasted from 15 to 30 minutes at from one to two knots per hour using two 1/2-meter nets, fine (No.20 of 173 mesh/inch) and coarse (No.6 of 74 mesh/inch) towed simultaneously from either side of the M-boat. Large jellyfish, if present were removed and the samples preserved by adding formalin to make 5%.

At Belle Island, the invertebrates usually sampled were the killer clam Tridacna, the spider snail Lambis, the land hermit crab Coenobita, the black sea cucumber Holothuria atra, and the branching corals Acropora, Porites, Pocillopora, and Heliopora. Fish, and aquatic invertebrates were usually collected along the north or ocean side, algae on the lagoon and ocean sides, land plants in the central portion, land hermit crabs among the bushes of the north edge, and terns nearby. Rats were obtained centrally on Janet Island.

Invertebrates and fish were collected at low tide when possible. Biological specimens were put on ice in insulated containers and transported to the laboratory at Elmer Island for immediate preparation or for freezing until time was available for dissection.

Soil samples were dried and packaged for shipment. Five-milliliter samples of sea water were dried on 1 1/2-inch stainless steel plates and ashed, except that in 1956, 100-milliliter samples were used because of the low level of the activity. These were treated with sodium carbonate to remove potassium (K^{40} contributes about 0.6 disintegrations per minute per milliliter), and then filtered, and the precipitate used for counting. Radiocesium is also lost by treatment with sodium carbonate (UWFL-46: 10).

Plankton was prepared by filtering and removing as much as 1-2 grams to the 1 1/2-inch counting plates, drying, and ashing. From occasional poor tows the wet sample weight was as low as 0.1 gram.

Portions usually sampled from the invertebrates were: from clams, mantle, adductor muscle, gill, kidney, visceral mass, and shell; from spider snails, mantle, muscle of foot, terminal portions of liver and gut, visceral mass, and shell; from the land hermit crab, gill, digestive gland or liver, gut, carapace, and muscle of leg; from sea cucumbers, gonad when sufficiently plentiful, gut and contents, muscle of the body wall, and body wall or integument with or without attached muscle; and from coral the terminal portions of small branches. Shell samples of clams and snails were usually taken from the thin edge to include periostracum.

The term gut as used in this report implies any portion of the digestive tract not more specifically designated and includes the contents.

Sample size was influenced somewhat by the nature of the sample and the amount of radioactivity present. When activity was low, larger samples were used. Between 50 and 200 milligrams of ash were usually considered desirable, but weights ranged widely, from less than 10 to more than 1000 milligrams. Shell and gut with sandy content were more lightly sampled on a wet weight basis than soft tissues.

Weighed samples of tissues in pliofilm bags were dried overnight at 100° C and sent to the Applied Fisheries Laboratory in Seattle for processing, which was usually accomplished about a month after collecting.

In processing, the samples in pliofilm bags were applied to the plates (1 1/2-inch stainless steel, previously weighed), ashed overnight at 500° - 550° C, slurried with alcohol, and dried. The plated ash received a few drops of Formvar dissolved in ethylene dichloride (up to 1 mg dry equivalent) to affix the ash to the plate. The plates were then weighed, and counted in methane gas-flow counters.

Except in the case of rats, counts were corrected back to date of collection using the decay rate of island soil (plate 7542) collected May 15, 1954 at Belle (Fig. 5, p. 11). For rats the decay correction was based upon the individual decay rate for each plate.

Self-absorption correction factors were based upon land soil collected June 7, 1954 at Edna, the decay curve of which (plate 9170) appears in Figure 5, page 11. Within seven months after Nectar an increase in average energy necessitated a reduction in the self-absorption correction factor for the later counting. The following tabulation illustrates these changes.

Ash weight	Self-absorption correction factor for counting	
in mg/plate	Before November 1, 1954	After November 1, 1954
3	1.0	1.0
10	1.1	1.1
30	1.4	1.3
100	2.0	1.6
300	2.9	1.9
1000	4.3	2.5

Geometry and backscatter for the counters and plates used required a combined correction factor of 1.54. Coincidence correction factors were determined and applied for the counters employed. For the decay curves plate counts were used, corrected only for coincidence.

Applying these correction factors gave values in disintegrations per minute per gram (d/m/g) of wet tissue as of the date of collection. Processing techniques are further discussed in UWFL-43 and WT-616. Three significant figures were retained throughout the calculations, finally being rounded to two. After plotting d/m/g against time the ordinate was in some graphs calibrated also in microcuries per kilogram (uc/kg), assuming 1 uc to equal 2.2×10^6 d/m.

The Nectar test (May 14, 1954) was used as the date of origin except where otherwise indicated, but earlier shots also contributed radioactivity to the samples studied. Especially the Bikini (March 1, 1954) shot contributed greatly to some of the samples. Residual long-lived products from earlier detonations prior to 1954 rendered the curves less steep than they would have been as a result of the 1954 series alone.

The trends of activity as related to time are of two kinds, the physical decay of individual samples, and the rate of change in activity of a certain type of sample at a certain locality. To distinguish it from physical decay, the latter trend will be referred to in this report as decline.

Results are shown as graphs of the relationship of logarithm of radioactivity to logarithm of time of collection after detonation. The date of origin used may deviate somewhat from detonation day or the true origin without markedly affecting linearity of the plot over the period of study. The slope is changed according to the date of origin selected, but if the same origin is used for both decay and decline, the two may be compared.

Hunter and Ballou (1951) show on logarithmic plot the theoretical decay of mixed slow-neutron-initiated fission products of U-235 over a period from 1 to 1000 days as a slightly curving line with a predominantly downward curvature (concave below) and a general slope varying from -1.0 to -1.7, averaging -1.2 (Fig. 2). A similar presentation of the trends of radioactivity observed in the present study facilitates comparison with this curve and within the study itself.

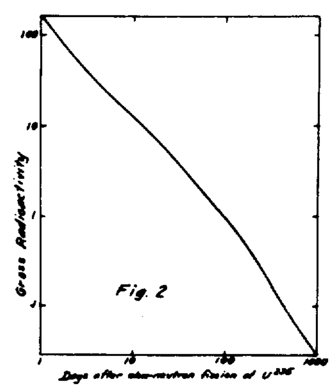

Fig. 2. Mixed fission product decay, gross beta. (After Hunter and Ballou).

In log-log graphs it will be convenient to speak of slopes or rates of decline and decay as becoming more or less steep with the passage of time, and when the terms steepening or leveling are applied to the trends, the log-log relationship is implied. A single half life when plotted semilogarithmically gives a straight line, while on the same plot a mixture of half lives results in a line of increasing steepness.

In the declines shown as straight lines on log-log plots possible fluctuations of a cyclic nature attributable to season or other variables are ignored.

RESULTS

Plan of presentation

For each of the ten primary subjects of investigation (survey meter readings, soil, water, plankton, algae, land plants, invertebrates, fish, birds, and rats), the trends or declines are shown graphically, and in some cases also in tabular form. For all subjects the regressions along with relevant data are brought together in Table 1. Where available the pre-Nectar level appears near the left edge of the decline graph as either a short horizontal bar or wedge.

For the straight lines depicting the declines where linearity appears to prevail, the time span involved is stipulated in Table 1 as well as being shown by the abscissal range of the lines in the graphs.

For conversion between microcuries and disintegrations per minute the following relationship was employed:

$$1 \text{ uc} = 2.2 \times 10^6 \text{ d/m}.$$

The log-log regression line is determined by its slope and y-intercept on day number 1, according to the relationship:

$$Y = at^b,$$

where Y is the amount of radioactivity at time t in days after assumed detonation day, and a is the y-intercept expressed in units of radioactivity of the regression line of slope b on day number 1. For example, the second entry in Table 1, survey meter readings at Belle, graphed in Figure 3, involved observations on 16 days over the period 5-540 days after Nectar. The regression was

$$Y = 2.5 \times 10^3 \; t^{-1.14} \text{ mr/hr},$$

with a correlation of -.971, which is far beyond the 1% level of P.

Along with decline data, available decays for as nearly simultaneous periods as possible are presented for comparison. Decays start later than declines because declines were corrected back to date of collection, while decays are for the actual dates of counting.

On the decay graphs the ordinate represents gross beta plus the negligible alpha and gamma activity that would be detected.

Decay curves even on the same graph are not comparable to one another as to absolute levels, because of vertical shifting to obtain compact presentation, but may be compared as to slope.

Table 1. Relationship of amount of radioactivity to time after detonation in 1954 at Eniwetok Atoll.

Subject	Locality	Detonation date to which referred	Time span involved, days after detonation	Units of radio-activity	Day #1 intercept of regression	Log-log decline rate, negative	n, days sampled	Correlation coeff. r, neg	P in %
Survey meter, shield closed, 1"	Belle	5/14/54	1-311	mr/hr	5.6×10^{2}	1.06	19	.988	<<1
Survey meter, shield open, 1"	Belle	5/14/54	5-540	mr/hr	2.5×10^{3}	1.14	16	.971	<<1
Island soil, top inch	Alice	"	22-270	μc/kg dry	2.8×10^{4}	1.39	8	.866	<1
" " " "	Belle	"	1-710	" "	1.3×10^{4}	1.06	13	.987	<<1
" " " "	Janet	"	22-710	" "	8.7×10^{2}	.87	10	.606	6
" " " "	Olive	"	22-270	" "	6.0×10^{3}	1.60	8	.762	4
" " " "	Vera	"	22-270	" "	1.1×10^{2}	.64	9	.610	7
" " " "	Bruce	"	22-270	" "	1.1×10^{3}	1.69	8	.985	<<1
" " " "	Elmer	"	22-710	" "	1.4×10^{2}	1.47	5	.982	<1
" " " "	Henry	"	22-710	" "	2.8×10^{2}	1.44	10	.815	<1
" " " "	Leroy	"	22-540	" "	3.7×10^{1}	.92	9	.643	7
Beach sand, intertidal	Alice	"	22-270	" "	3.0×10^{2}	.84	8	.816	2
" " "	Janet	"	22-710	" "	1.6×10^{2}	.79	10	.594	8
" " "	Olive	"	22-270	" "	1.0×10^{2}	.84	8	.617	>10
" " "	Vera	"	22-710	" "	2.1×10^{1}	.60	9	.717	4
" " "	Bruce	"	22-270	" "	8.0×10^{2}	1.36	8	.841	<1
" " "	Elmer	"	22-710	" "	3.7×10^{2}	1.23	5	.838	8
" " "	Henry	"	22-710	" "	5.2×10^{3}	1.88	10	.890	<<1
" " "	Leroy	"	22-540	" "	1.2×10^{3}	1.39	9	.915	<1
Sea water	Alice	"	38-220	d/min/ml	6.6×10^{3}	1.57	3	.976	>10
" ", ocean side	Belle	"	1-720	"	3.4×10^{3}	1.28	19	.871	<<1
" " lagoon reef	"	"	42-540	"	8.5×10^{5}	2.91	10	.944	<<1
" " plankton station	"	"	5-310	"	7.7×10^{5}	2.30	10	.985	<<1
" "	Edna	"	50-270	"	2.4×10^{5}	1.80	3	.947	>5
" "	Flora	"	5-26	"	5.4×10^{4}	1.8	2	--	-
" "	Janet	"	38-710	"	1.8×10^{4}	1.80	6	.913	1
" "	Olive	"	38-270	"	5.9×10^{3}	1.47	4	.991	1
" "	Vera	"	26-720	"	2.3×10^{5}	2.22	11	.924	<<1
" "	Bruce	"	38-720	"	1.9×10^{5}	2.14	5	.998	<1
" "	Deep Entr.	"	33-720	"	1.2×10^{5}	2.13	9	.896	<1
" "	Wide Pass.	"	26-310	"	7.8×10^{5}	2.40	9	.965	<<1
" "	Henry	"	38-270	"	2.2×10^{4}	1.66	4	.951	5
" "	Leroy	"	5-310	"	8.6×10^{5}	2.41	12	.986	<<1
" " except Belle ocean	All above	"	5-720	"	3.0×10^{5}	2.24	91	.935	<<1
" "	All	"	1-720	"	3.9×10^{4}	1.76	110	.991	<<1
Plankton	Belle	"	5-530	d/m/g wet	4.0×10^{8}	1.85	12	.955	<<1
"	"	"	"	" ash	1.8×10^{6}	1.52	12	.965	<<1
"	Mike crater	"	5-200	" wet	5.0×10^{7}	1.15	3	.998	4
"	" "	"	"	" ash	3.2×10^{5}	1.00	3	.975	>10
"	Vera	"	26-530	" wet	3.1×10^{6}	1.04	10	.515	>10
"	"	"	"	" ash	8.8×10^{4}	1.09	10	.608	7
"	Deep Entr.	"	33-710	" wet	7.9×10^{8}	2.15	13	.761	<1
"	" "	"	"	" ash	6.2×10^{6}	1.93	13	.748	<1
"	Wide Pass.	"	26-310	" wet	3.4×10^{9}	2.61	10	.840	<1
"	" "	"	"	" ash	3.4×10^{7}	2.37	10	.871	<1
"	Leroy	"	5-530	" wet	5.2×10^{8}	2.23	12	.947	<<1
"	"	"	"	" ash	2.6×10^{6}	1.90	12	.943	<<1
"	All six	"	5-710	" wet	2.8×10^{8}	1.96	60	.833	<<1
"	" "	"	"	" ash	2.2×10^{6}	1.74	60	.849	<<1
<u>Halimeda</u> (calcareous algae)	Alice	"	20-270	uc/kg wet	2.1×10^{4}	2.02	8	.963	<<1
"	Belle	"	20-710	" "	5.5×10^{4}	2.13	9	.965	<<1
"	Janet	"	20-710	" "	5.0×10^{3}	1.69	9	.947	<<1
"	Olive	"	20-270	" "	5.4×10^{3}	1.76	8	.970	<<1
"	Vera	"	20-710	" "	3.2×10^{4}	2.06	9	.954	<<1
"	Bruce	"	20-270	" "	2.0×10^{5}	2.50	3	.982	>5
"	Elmer	"	20-530	" "	3.2×10^{4}	2.28	7	.927	<1
"	Henry	"	20-530	" "	9.0×10^{3}	2.00	9	.938	<<1
"	Leroy	"	20-530	" "	1.0×10^{6}	2.91	9	.979	<<1
Land plants, green leaves	Belle	"	3-710	d/m/g wet	7.6×10^{6}	1.63	114	.883	<<1
<u>Acropora</u> (coral, tips)	Belle	"	36-710	" "	2.7×10^{8}	2.23	11	.976	<<1
Clam (<u>Tridacna</u>), kidney	Belle	"	1-710	" "	9.4×10^{5}	.71	29	.950	<<1
" " visceral mass	"	"	1-710	" "	2.0×10^{6}	1.07	29	.866	<<1
" " gill	"	"	1-710	" "	5.6×10^{5}	.96	29	.963	<<1
" " shell	"	"	1-710	" "	3.3×10^{5}	.99	25	.899	<<1
" " mantle	"	"	1-710	" "	2.0×10^{5}	.94	29	.961	<<1
" " muscle	"	"	1-710	" "	7.3×10^{4}	.90	29	.967	<<1

Eniwetok Atoll.

Corre- lation coeff. r, neg	P in %
.988	<<1
.971	<<1
.866	<1
.987	<<1
.606	6
.762	4
.610	7
.985	<<1
.982	<1
.815	<1
.643	7
.816	2
.594	8
.617	>10
.717	4
.841	<1
838	8
890	<<1
915	<1
976	>10
871	<<1
944	<<1
985	<<1
947	>5
--	-
13	1
91	1
24	<<1
98	<1
96	<1
65	<<1
51	5
36	<<1
55	<<1
1	<<1
5	<<1
5	<<1
8	4
5	>10
5	>10
3	7
1	<1
3	<1
)	<1
1	<1
7	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	>5
	<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1
	<<1

Table 1, continued.

Subject	Locality	Detonation date to which referred	Time span involved, days after detonation	Units of radio-activity	Day #1 intercept of regression	Log-log decline rate, negative	n, days sampled	Correlation coeff. r, neg	P in %
Spider snail (*Lambis*), liver	"	"	8-540	" "	2.5×10^7	1.10	9	.887	<1
" " " gut	"	"	8-310	" "	6.1×10^6	.93	9	.959	<<1
" " " mantle	"	"	8-310	" "	5.4×10^5	.62	8	.828	2
" " " muscle	"	"	8-540	" "	2.1×10^5	.64	10	.930	<<1
" " " shell	"	"	8-310	" "	9.1×10^5	1.18	9	.926	<<1
Hermit crab *Coenobita*, carapace	"	"	3-710	" "	9.0×10^6	1.05	30	.950	<<1
" " " muscle	"	"	3-710	" "	2.7×10^5	.95	30	.940	<<1
" " " liver	"	"	3-540	" "	5.3×10^6	1.28	29	.986	<<1
" " " gut	"	"	3-305	" "	2.4×10^7	1.46	28	.950	<<1
" " " gill	"	"	3-305	" "	1.8×10^6	1.32	28	.983	<<1
Sea cucumber *H. atra* gonad	Alice	"	39-710	" "	5.0×10^7	1.73	8	.908	<1
" " " gut	"	"	"	" "	3.1×10^6	1.14	8	.837	1
" " " muscle	"	"	"	" "	2.2×10^7	1.65	8	.980	<<1
" " " integument	"	"	"	" "	9.1×10^7	2.06	8	.980	<<1
" " *H. atra* gonad	Belle	"	36-540	" "	5.2×10^7	1.64	10	.931	<<1
" " " gut	"	"	"	" "	6.2×10^6	1.15	10	.939	<<1
" " " muscle	"	"	"	" "	2.6×10^7	1.67	10	.926	<<1
" " " integument	"	"	"	" "	7.8×10^7	2.01	10	.956	<<1
" " *H. atra* gonad	Janet	"	38-710	" "	4.6×10^7	1.93	7	.933	<<1
" " " gut	"	"	"	" "	2.6×10^7	1.65	7	.893	<1
" " " muscle	"	"	"	" "	2.5×10^7	1.86	6	.986	<1
" " " integument	"	"	"	" "	3.8×10^7	2.02	7	.987	<<1
" " *H. atra* gonad	Olive	"	21-280	" "	1.8×10^6	1.13	8	.817	<2
" " " gut	"	"	"	" "	1.6×10^6	1.13	8	.919	<1
" " " muscle	"	"	"	" "	5.5×10^5	1.16	8	.984	<<1
" " " integument	"	"	"	" "	4.4×10^5	1.06	8	.878	1
" " *H. atra* gonad	Vera	"	39-710	" "	6.8×10^7	1.84	8	.914	<<1
" " " gut	"	"	"	" "	1.3×10^8	1.82	8	.969	<<1
" " " muscle	"	"	"	" "	4.8×10^7	1.99	8	.913	<<1
" " " integument	"	"	"	" "	1.8×10^8	2.24	8	.976	<<1
" " *H. atra* gonad	Bruce	"	39-710	" "	5.9×10^7	1.85	9	.903	<<1
" " " gut	"	"	"	" "	1.6×10^8	2.04	9	.974	<<1
" " " muscle	"	"	39-540	" "	3.2×10^6	1.48	8	.907	<<1
" " " integument	"	"	39-710	" "	3.9×10^7	1.94	9	.961	<<1
" " *H. atra* gonad	Elmer	"	41-710	" "	2.0×10^6	1.43	8	.918	<<1
" " " gut	"	"	"	" "	3.7×10^7	1.87	8	.965	<<1
" " " muscle	"	"	"	" "	1.6×10^6	1.45	7	.953	<<1
" " " integument	"	"	"	" "	4.6×10^6	1.65	8	.943	<<1
" " miscel. gonad	Henry	"	39-710	" "	7.3×10^6	1.66	9	.841	<1
" " " gut	"	"	"	" "	5.4×10^7	1.97	9	.943	<<1
" " " muscle	"	"	"	" "	7.9×10^6	1.71	8	.872	<1
" " " integument	"	"	"	" "	1.4×10^8	2.19	9	.846	<1
" " miscel. gonad	Leroy	"	125-710	" "	4.9×10^9	2.75	7	.916	<1
" " " gut	"	"	"	" "	5.0×10^9	2.54	7	.932	<1
" " " muscle	"	"	"	" "	4.4×10^{13}	4.16	7	.914	<1
" " " integument	"	"	"	" "	5.1×10^{12}	3.74	7	.883	<1
Fish, all species skin	Belle	"	13-311	" "	2.5×10^7	1.90	21	.965	<<1
" " " gut	"	"	13-311	" "	2.0×10^7	1.43	21	.936	<<1
" " " muscle	"	"	13-710	" "	6.7×10^5	1.49	23	.969	<<1
" " " bone	"	"	13-540	" "	1.5×10^7	1.77	22	.990	<<1
" " " liver	"	"	13-710	" "	4.9×10^6	1.18	23	.930	<<1
Tern, mostly fairy, feathers	Belle	"	14-305	" "	7.0×10^5	1.25	17	.941	<<1
" " " muscle	"	"	"	" "	1.6×10^6	1.57	17	.926	<<1
" " " bone	"	"	"	" "	2.1×10^6	1.56	17	.833	<<1
" " " lung	"	"	"	" "	1.4×10^6	1.21	17	.814	<<1
" " " liver	"	"	"	" "	2.4×10^6	1.31	17	.859	<<1
" " " kidney	"	"	"	" "	3.2×10^6	1.35	17	.854	<<1
" " " gut	"	"	"	" "	2.5×10^8	2.40	17	.971	<<1
" " " all tissues	"	"	"	" "	7.7×10^6	1.63	17	.953	<<1
Rat, fur and skin	Janet	3/1/54	121-380	" "	2.3×10^5	1.15	14	.739	<1
" muscle	"	"	77-600	" "	9.8×10^4	.89	17	.711	<1
" bone	"	"	"	" "	1.3×10^7	1.49	17	.922	<<1
" lung	"	"	77-380	" "	2.7×10^6	1.59	16	.843	<<1
" liver	"	"	77-600	" "	7.8×10^4	.76	17	.578	2-3
" kidney	"	"	"	" "	5.2×10^5	1.12	16	.684	<1
" gut	"	"	77-380	" "	9.8×10^8	2.56	16	.896	<<1

Survey meter readings

Table 2 gives survey meter readings at nine islands, of which Edna, adjacent to the site of the Nectar detonation (Mike crater), was highest, with 600 mr/hr on June 7, 1954.

Figure 3 shows the series of readings at Belle with meter one inch from the ground, the shield both open and closed. Slopes of the two regression lines, -1.14 and -1.06 (Table 1) do not differ significantly. The slope is approximately that of mixed fission product decay, assuming there was a slight leveling influence due to detonations prior to 1954.

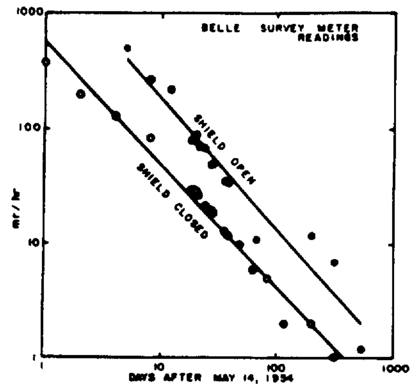

Fig. 3

Table 2. Survey meter readings in milliroentgens per hour at one inch from the ground on various islands of Eniwetok Atoll in 1954-55. Values above 20, with Juno, others with Geiger counter. Shield open except at Belle, first column, for which, shield closed.

Date	Alice	Belle		Daisy	Edna	Janet	Olive	Vera	Henry	Leroy
5/15/54		375								
16		200								
18		130								
19			500							
22		85	270							
26			220							
6/1/54		30	80							
2		30	80							
3		29	90			20	5	6		
4		27	70							
7		22	70	60	600					
10		20	50							
11		19	50							
18		13	35							
21	40	12	34		400	14	4	4	0	
7/1/54		10								
14				13						
15		6								
20	18		11			12	.7	0	.3	.1
8/5/54		5								
17	11				180					
9/7/54		2								
11/17/54	.7						.3	0	.12	.10
30		2	12							
12/9/54					20					
2/11/55	.8				16		.18	.2		.15
3/21/55		1	7							
11/1/55			1.2		3					

Island soil

Figure 4 shows the decline for island soil as well as the only two observations for beach sand at Belle. The slope for island soil of -1.06 (Table 1) corresponded closely with that of survey meter readings.

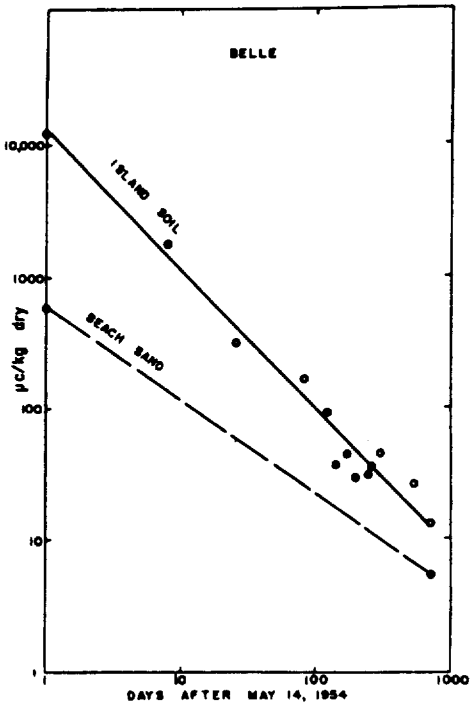

Fig. 4

From an initial level on the first day of 13 millicuries per kilogram, the island soil declined fairly regularly for a period of two years. The dip at 130-200 days is reflected in the decline curves for land hermit crab but is not apparent in the data for green leaves of plants on Belle.

Figure 5 shows the decay of samples of island soil from Belle (plate 7542) and from Edna (plate 9170), and of intertidal beach sand from Henry (plate 9711A). A slope of -1.2 is included for comparison.

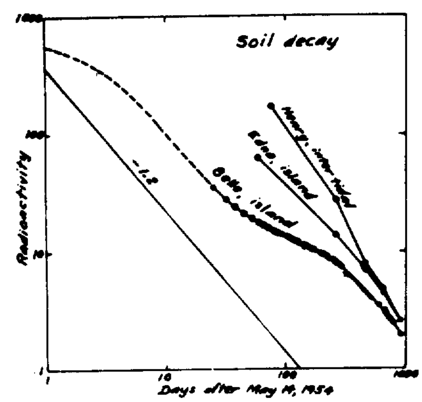

Fig. 5

The Belle island soil decay curve is for plate number 7542 which served as the basis for computation of the decay correction factors for converting values back to date of collection. The same factors were used for all types of material except rats collected post-Nectar at Eniwetok Atoll. The dashed, early portion of the curve is not a straight line because it was originally extrapolated on semi-log paper.

For comparison, Figure 6 shows the decay of the sample of lagoon bottom sand dredged November 7, 1952 off Tilda (northwest of Vera). This decay was used for calculation of decay correction factors for the collections following the Mike test in 1952(Donaldson 1953:25), and for 20-1000 days its similarity to the theoretical curve of Figure 2 is striking. It was practically uninfluenced by residues from previous detonations. The more pronounced flexures in the curve for Belle island soil, as well as its generally more gradual slope are the result of the influence of the Mike test residues superimposed upon the Nectar test effect.

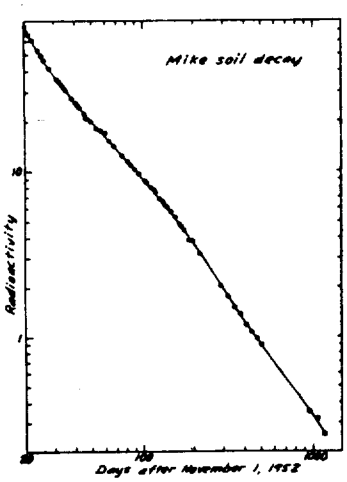

Fig. 6

Figure 7 shows island soil decline slopes at sites other than Belle. Pre-Nectar levels are indicated by short horizontal bars at the left edges of the graphs. Except at Bruce and Elmer, the points are widely scattered and the trends poorly defined. Variations in exact location of sample taking, changes of personnel, and the use of single samples contributed to this variability.

Levels of radioactivity were much higher at the northern than at the southern localities.

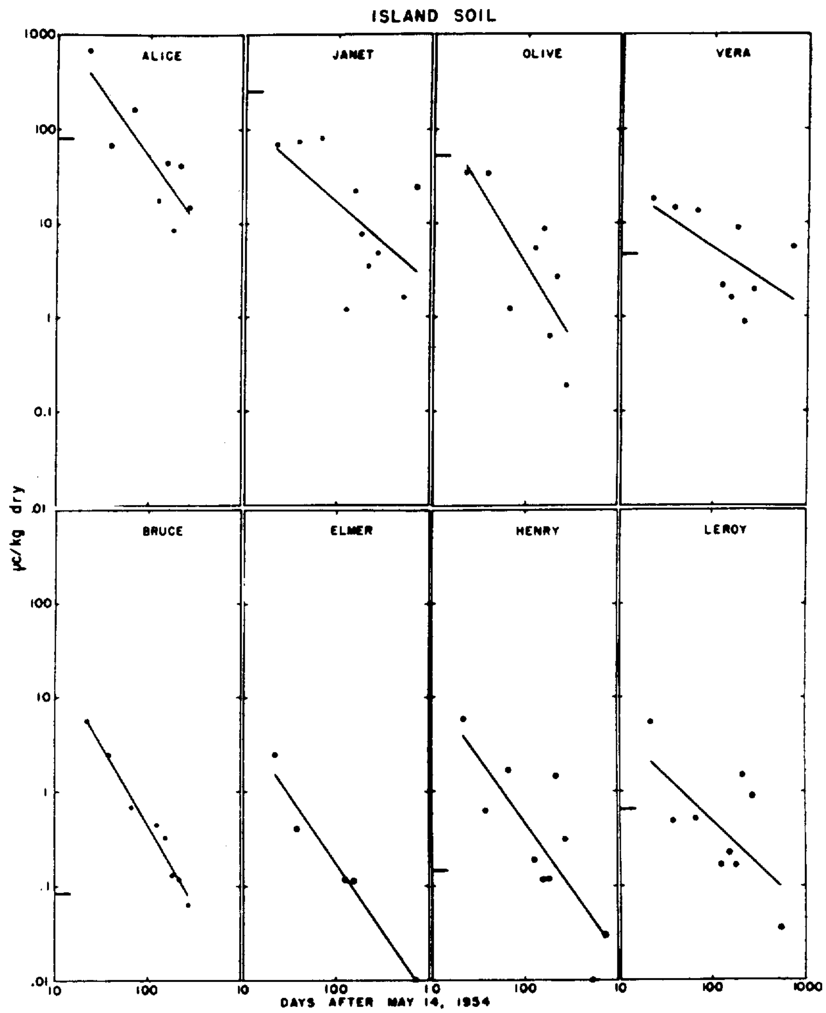

Fig. 7

Table 3 gives decay slopes of island soil samples from various islands over a time span of from one or two months to more than two years. Slopes ranged from -0.6 to -1.3, averaging -0.9 ± 0.02.

Since the five soil decay curves with more than two points are fairly straight lines, 2-point slopes were used to expand the scope of observations. The period of time covered by the decays is close to that of the declines. Table 3 shows that declines were steeper than decays except at Janet where decays were steeper, and at Vera where decay and decline were equal.

Table 3. Island soil decay rates with decline rates for comparison.

Locality	Plate number	Date of collection	Days after May 14, 1954, range	No. of times plate counted	Slope, negative: Decay, Plate	Decay, Locality, mean	Decline from Table 1
Alice	7597	6-3-54	50-540	2	.85	.9	1.4
"	7597A	"	50-540	2	1.05		
"	7597B	"	50-540	2	1.01		
Belle	7542	5-15-54	25-910	70	.7	.7	1.06
"	7543	"	49-870	4	.64		
"	9189	6-19-54	49-440	2	.62		
Edna	9170	6-7-54	49-910	5	1.2	1.2	
Janet	7595	6-3-54	49-870	2	1.27	1.3	.87
Olive	7593A	6-3-54	49-870	2	1.21	1.2	1.6
"	7593B	"	48-870	2	1.28		
Vera	7591B	6-3-54	48-870	2	.60	.6	.64
"	7591	"	49-870	2	.68		
Bruce	7587	"	50-870	2	.90	1.0	1.69
"	9196A	6-21-54	75-870	2	1.03		
"	9196B	"	75-870	2	1.21		
Elmer	9153	6-3-54	49-870	2	.78	.8	1.47
Henry	9151	"	49-870	3	.90	.9	1.44
Leroy	7599	"	48-870	4	.62	.6	.92
"	7599A	"	48-870	2	.57		

Table 4. Decay rates of intertidal beach sand, with declines from Table 1 for comparison.

Locality	Plate number	Date of collection	Days after May 14, 1954, range	No. of times plate counted	Slope, negative: Decay, Plate	Decay, Locality, mean	Decline from Table 1
Alice	9707A	6-21-54	76-870	2	.88	.9	.84
"	9707	"	"	2	.92		
Belle	7541	5-15-54	48-870	2	1.13	1.2	.7
"	7541A	"	47-870	2	1.14		
"	7541B	"	57-870	2	1.29		
Janet	9705	6-21-54	76-870	2	.80	.8	.79
Olive	9703B	"	74-870	2	1.16	.8	.84
"	7594	6-3-54	49-540	2	.96		
"	7594A	"	48-540	2	.65		
"	7594B	"	49-540	2	.55		
Vera	7592	6-3-54	49-540	2	.80	.9	.60
"	7592A	"	48-540	2	.40		
"	7592B	"	48-540	2	.70		
"	9701	6-21-54	76-870	2	.76		
"	9701A	"	75-870	2	1.23		
"	9701B	"	75-870	2	1.28		
Bruce	7588	6-3-54	49-540	2	1.00	1.5	1.36
"	7588B	"	48-540	2	.83		
"	9197	6-21-54	75-870	2	2.1		
"	9197A	"	75-870	2	2.2		
"	9197B	"	75-870	2	2.0		
Henry	9711A	6-21-54	78-910	5	1.7	1.7	1.88
Leroy	9709	"	76-870	2	2.2	2.2	1.39
"	9709A	"	76-870	2	2.0		

Beach sand

Intertidal beach sand at Belle was sampled only twice, at the first and the last of the experimental period (Fig. 4). These sparse data suggest a considerably lower initial level than for island soil, and a somewhat lower decline rate of -0.7.

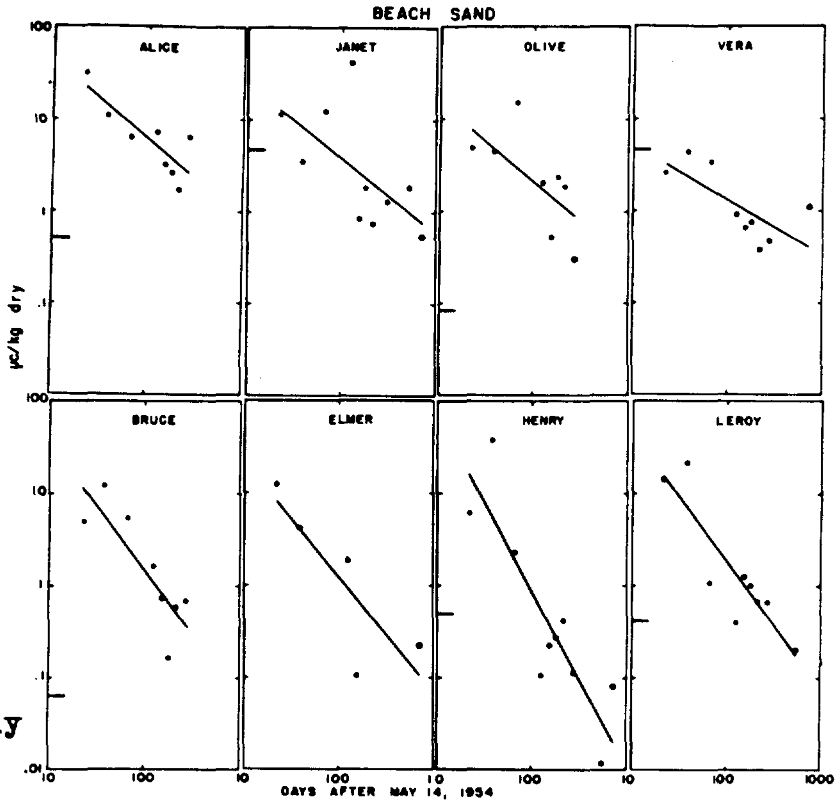

Fig. 8

Figure 8 shows beach sand declines for eight islands, and pre-Nectar levels except at Elmer. As with island soil there was great variability, possibly because of the continual shifting of the sand. The northern islands were only slightly more radioactive than the southern islands, but the declines at the southern islands, especially Henry and Leroy, tended to be steeper than at the northern islands.

The slower decline at northern than at southern islands is probably caused by a greater residue of radioactivity from previous detonations (higher pre-Nectar levels) at northern localities, possibly associated with the water currents.

The decays for beach sand are given in Table 4, page 13. Except for Henry (Fig. 5), these are based upon only two points. Beach sand decays were appreciably steeper at the southern than at the northern islands. The relationship between the slopes of declines and decays was inconsistent. At Henry decline slightly exceeded decay. At Leroy decays were steeper than declines, and at other localities differences were negligible. In general, decays were steeper than declines, although not convincingly so.

Sea water

Sea water sampling was most extensive at Belle as Table 5 shows. Data from plankton stations at Belle, lagoon reef, and ocean reef are presented separately, while at other localities all of the data for an island are combined.

Table 5. Radioactivity of sea water samples expressed as disintegrations per minute per milliliter (d/m/ml). The value indicates two samples except where the number of samples follows the parenthesis.

Day	Date	Belle Plankton station	Belle Lagoon reef	Belle Ocean reef	Alice	Edna	Flora crater	Janet	Olive	Vera	Bruce	Deep Entr.	Wide Pass.	Henry	Leroy
1	5/15/54			2500											
2	16			590											
3	17			200											
4	18			123(1											
5	19	25,000		117			3400								15,000
7	21			540											
8	22			2800											
12	26			170											
14	28			139											
18	6/1/54			430											
21	4			93											
24	7			137			170			84			320		510
26	9	273													
28	11			72								129(4			
33	16														
36	19			320	21			21	27	36	67			57	66
38	21														
42	25		54												
48	7/1/54		20												
50	3					350(4				62		7.2	46		60
53	6	97													
55	8		93												
60	13					80(8									
62	15		46							22		5.4	18		36
74	27	24													
76	29		40												
83	8/5/54		3.7												
116	9/7/54		14							16		20	18		16
140	10/1/54	18													
144	5			17											
165	26							2.1							
172	11/2/54			7.6(1						3.6		3.4	2.8		2.2
176	6	3.1			2.5			1.1	2.8	1.4	3.1			3.1	2.0
187	17											1.3	1.7		3.3
203	12/3/54	3.7						.86	2.6	.43(4	2.0	2.2	3.3	1.7	1.3(4
217	17	2.0			1.0				1.2	.54(3	1.2	.30(1	.59(1	3.6	.80(3
274	2/12/55	5.0(1	.41(1	2.6(1		10		2.6		2.8(1		-.56(1	.80(1		.91(1
311	3/21/55	1.1(1	.57(1	.57(1											
536	11/1/55		.021												
713	4/26/56			.075				.062		.043	.12	.072			

Additional data: 6/21/54, Yvonne, 31, and Elmer, 40; 7/14/54, Daisy, 83(6.

Figure 9 shows the declines for sea water at 12 localities. Variability was moderate except for the low values of early points for the ocean reef at Belle. The slopes were steeper than for meter readings, soil, or beach sand at most localities. At Belle, omitting the early ocean reef collections, the slopes

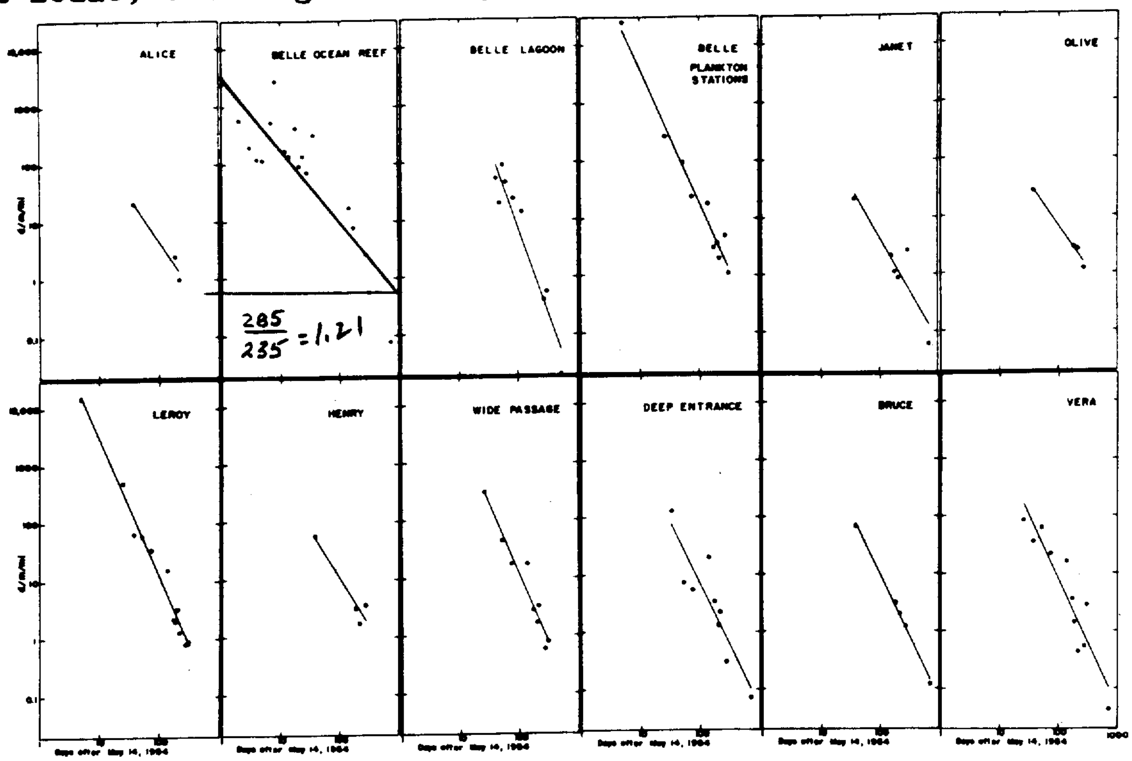

Fig. 9

were as steep as at Leroy, in contrast to the declines for sea cucumbers, beach sand, and algae, which were much steeper at Leroy.

Figure 10 is a scatter diagram of the sea water decline data of Table 5. The "Belle, outer" regression line is the same as that of Figure 9, Belle ocean reef. The regression for all data combined is shown as well as the steepest line for all data other than that of Belle, outer. The data for the sea water sampling at Eniwetok Atoll exclusive of Belle ocean reef give a decline slope of about -2.2.

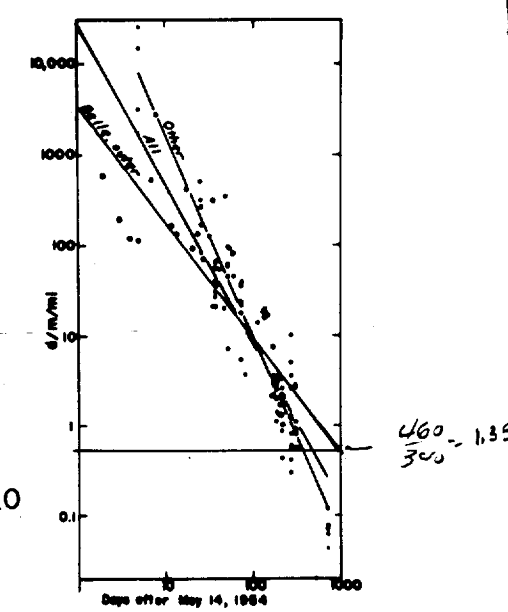

Fig. 10

The decays for sea water are given in Table 6 and Figure 11. Counting errors were large because of the low levels of nearly all of the later counts. The contribution to the radioactivity by K^{40} was compensated for by subtracting 1 from each count per minute per 5 milliliter plate. One count per minute per plate was equivalent to 3 d/m/plate, because the correction factor for geometry, back scatter, and self absorption was approximately 3.

Table 6. Decay rates of sea water samples collected at Eniwetok Atoll in May, June, and July 1954, with corresponding decline rates from Table 1 for comparison. Data for Fig. 11.

Curve number	Plate numbers	Locality	Time span in days after 5/14/54, of decay slope	Slope, negative: Decay	Slope, negative: Decline, from Table 1
1	7567-68	Belle, ocean side	33-630	1.3	1.28
2	7569-70	" " "	33-630	1.5	1.28
3	7575-76	" plankton station	55-910	1.3	2.30
4	7585-86	" ocean side	39-630	1.5	1.28
5	9803-04	" lagoon side	100-500	1.0	2.91
6	9793-94	Wide Passage	100-300	1.2	2.40
7	7572	Leroy plankton sta.	55-940	1.5	2.41
8	9161	" " "	49-940	1.5	2.41
9	9795-96	" " "	100-300	1.4	2.41

The data of Table 6 for the 9 sea water decays are graphed in Figure 11. With the exception of Belle, ocean side (curves 1, 2, and 4) where decline was unusually gradual because of low early values, declines were steeper than decays.

The decay curves tend to level terminally, even after subtraction of the activity due to K^{40}.

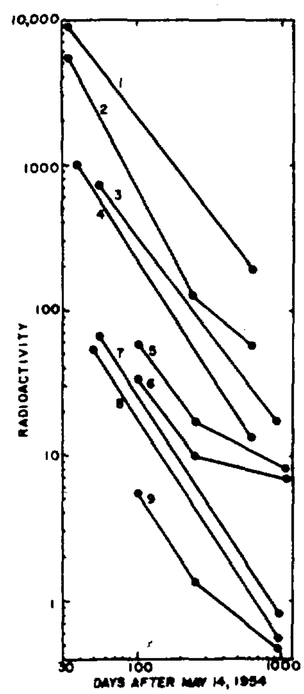

Fig. 11

Plankton

Amounts of radioactivity per unit of wet weight of plankton in samples from each tow appear in Table 7, and on the basis of ash weight, in Table 8. This dual analysis is intended to evaluate the appropriateness of the wet basis as compared to the ash basis in considering the radioactivity of plankton. Where simultaneous fine and coarse mesh tows

Table 7. Gross beta radioactivity of plankton samples in thousands of d/m/g of wet weight at Eniwetok Atoll in 1954-56.

Date	Belle Net mesh			Mike crater Net mesh			Vera Net mesh			Deep Entrance Net mesh			Wide Passage Net mesh			Leroy Net mesh		
	#6	?	#20	#6	?	#20	#6	?	#20	#6	?	#20	#6	?	#20	#6	?	#20
5/6&7/54		12.5			13.6			8.2									2.3	
5/19/54	10900		12900	4170		12800										5000		6500
6/9/54	801		2990	670		1360	900		400				220			660		370
6/16/54											185							
7/6/54	274		287				3.1		15	18.6		38	41		42	56		49
7/27/54		148						3.2			211			123			113	
		84						6.0			54			190			62	
9/1/54	81		58				33		9.1	19.5		33	63		39	30		2.5
10/1&2/54	12		33				1.1		32	4.2		7.6	77		12	17		2.5
11/6/54	46		150				103		250	236		216	8.7		6.3	29		21
11/26/54				121		163				5.8		6.1						
				60		180												
11/27/54				61		72				38		30						
				220		121				53		56						
12/3/54	12.7		30							6.6		5.8	.84		1.01	11.5		6.2
12/17/54	19.6		109				24		67	68		52	21		2.8	2.3		10.8
2/12/55	3.8						4.7			2.3			.34			.52		
3/16/55														.27			.37	
3/21/55	7.0						7.8			12.6								
	10						32			25								
10/29/55		.83						.53			.47						.091	
		3.4						2.2			.32						.22	
											.11							
											.41							
4/27/56										.034	.083							

Additional "? mesh": on 5/6-8/54, Janet 9.6, Yvonne 1.8, Bruce 2.0, Elmer 2.5, and Henry 3.4; on 4/27/56, Bruce 0.73 and 0.49.

Table 8. Gross beta radioactivity of plankton samples in thousands of d/m/g of ash weight at Eniwetok Atoll in 1954-56.

Date	Belle Net mesh			Mike crater Net mesh			Vera Net mesh			Deep Entrance Net mesh			Wide Passage Net mesh			Leroy Net mesh		
	#6	?	#20	#6	?	#20	#6	?	#20	#6	?	#20	#6	?	#20	#6	?	#20
5/6&7/54		97			66			101									13.5	
5/19/54	140000		99000	58900		107000										76000		38000
6/9/54	6300		13000	8400		6800	10100		4230				6860			9600		2430
6/16/54											5820							
7/6/54	7700		8000				125		495	574		863	1200		1080	1420		1660
7/27/54		2400						95			330			2240			1770	
7/27/54		2100						147			1070			4000			1060	
9/1/54	1830		1550				797		217	524		745	1100		623	434		78
10/1&2/54	530		1120				67		861	167		210	1840		630	320		223
11/6/54	1400		900				2540		3560	3110		3500	354		215	437		332
11/26/54				1170		1310				200		144						
11/26/54				732		1200												
11/27/54				2120		3410				2170		986						
11/27/54				5260		1250				2000		1270						
12/3/54	810		1360							444		264	49		111	640		325
12/17/54	760		840				604		542	1320		779	506		77	151		149
2/12/55	112						182			146			13.9			20		
3/16/55														12.5			14.4	
3/21/55	260						112			462								
3/21/55	190						439			307								
10/29/55		41						29			21.5						5.0	
10/29/55		163						11.5			10.4						10.4	
10/29/55											2.76							
10/29/55											8.38							
4/27/56										.76	1.60							

Additional "? mesh": on 5/6-8/54, Janet 58, Yvonne 59, Bruce 76, Elmer 72, and Henry 26; on 4/27/56, Bruce 1.36.

permitted comparison, the data are shown separately, and other data appear in columns headed with question marks for mesh, usually either No. 6 of 74/inch or No. 20 of 173/inch.

Table 9 shows for the paired tows the ratio of the activity per unit weight in coarse mesh to that in fine (No.6/No.20, on both a wet and ash weight basis.

Table 9. Ratio of radioactivity in tows with coarse mesh to fine mesh (#6/#20) on wet and ash weight bases. Data from Tables 7 and 8.

Date	Belle		Mike Crater		Vera		Deep Entrance		Wide Passage		Leroy	
1954	Wet	Ash	Wet	Ash	Wet	Ash	Wet	Ash	Wet	Ash	Wet	Ash
5/19	.84	1.41	.33	.55							.77	2.00
6/9	.27	.48	.49	1.23	2.25	2.39					1.78	3.95
7/6	.95	.96			.21	.25	.49	.67	.98	1.11	1.14	.86
9/1	1.39	1.18			3.62	3.67	.59	.70	1.61	1.77	12.0	6.21
10/1&2	.36	.47			.034	.78	.55	.80	6.41	2.92	6.8	1.43
11/6	.31	1.56			.41	.71	1.09	.89	1.38	1.65	1.38	1.32
11/26			.74	.89			.95	1.39				
11/26			.33	.61								
11/27			.85	.62			1.26	2.20				
11/27			1.82	4.21			.95	1.57				
12/3	.42	.60					1.13	1.68	.83	.44	1.85	1.97
12/17	.18	.90			.36	1.11	1.32	1.69	7.50	6.56	.21	1.01

Between the northern localities of Belle Island and the Mike crater and the southern localities of Wide Passage and Leroy Island, there was a difference using the t test, significant at the 2% level on the ash basis. The reason is not apparent for this association of high counts with fine mesh nets at northern, and with coarse at the southern and western localities.

Whereas, in 1952 (WT-616) significantly higher radioactivity occurred in fine mesh net hauls than in coarse, the present data show wide variation. On the wet basis the coarse mesh was higher in 18 pairs and the fine mesh in 25 pairs, while on the ash basis the figures were reversed, the coarse mesh was higher in 25 pairs and the fine mesh in 18 pairs. Thus, neither wet nor ash basis showed a significant difference due to mesh size.

Assuming, as these results indicate, that activities in coarse and fine meshes do not differ, the ratio of coarse to fine should be unity. The ratios in Table 9 were used to determine variability on the wet as opposed to the ash basis. On the ash basis, variance was only half as great as on the wet basis, thus, ash is considered the better basis. Conversion to logarithms was necessary to normalize the skewed (with peak toward the left) frequency distribution of the two arrays of ratios.

Figure 12 shows the decline for plankton samples at 6 localities on a wet weight basis using the data of Table 7, with the two values for paired tows averaged.

Except at the Mike crater and Vera the declines were steep, ranging from -1.8 to -2.61 as seen from Table 1, with an average for all localities combined of -1.96, wet basis, and -1.74 on the ash basis. The gradual decline (-1.0) at the Mike crater could be the result of continuous leaching of radioisotopes, from the crater into the water, thereby maintaining the activity of the plankton. At Vera the trend is too poorly defined (P > 10%) to permit comparisons.

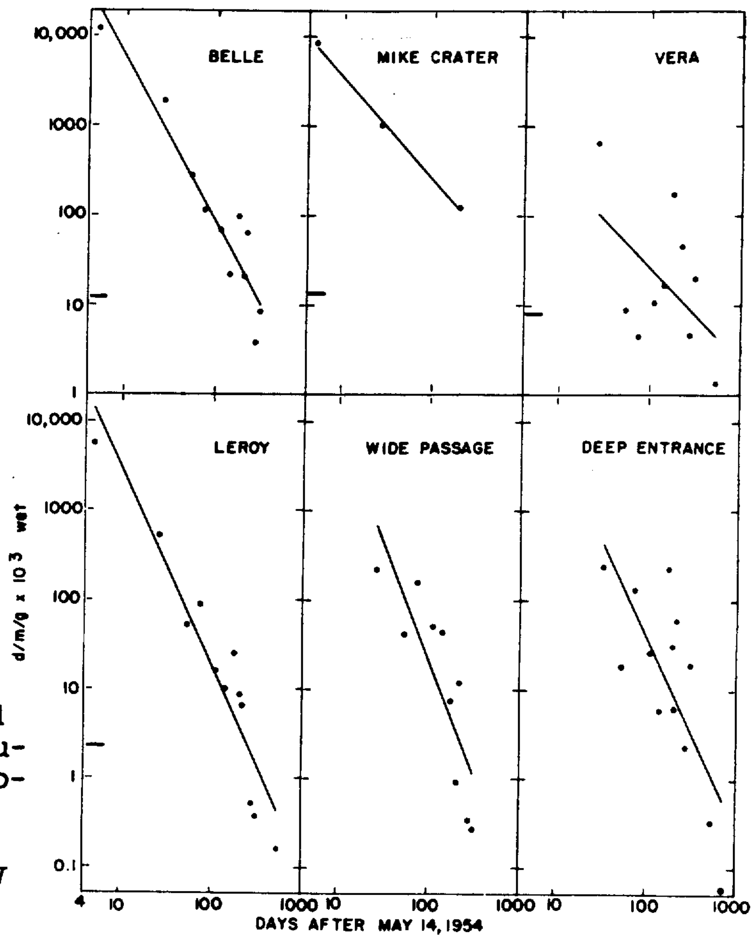

Fig. 12