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Chapter H-13

Fallout Radioactivity and Epiphytes

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After relatively high levels of fallout retention were discovered in the epiphytic mossy forest of the Luquillo Mountains during 1962, a survey of the distribution of radioactivity in the rain forest system was made with beta counting of 1500 samples supplemented with gamma spectra. High levels, up to 4138 counts per minute per gram, were found mainly in or on green plant tissue and the derived litter, with as much variability among leaves of the same tree as between trees. The degree of uptake was correlated with epiphytic mode of growth, with algae–moss–liverwort encrustations highest, massive mosses second, bromeliads third, and rooted plants last. The radioactivity in leaves was found to be in proportion to the epiphytic growth on the leaves and thus was related to their age. Gamma spectra were similar in most materials including leaves of many tree species, litter, termite nest, and the roof algae near San Juan.

In September 1962 a sample of epiphytic moss from the cloud-shrouded elfin forest (see Fig. 17, Chap. B-1) was examined for radioactivity and was found to have a very high specific activity, especially for a tropical location (18°N latitude). With primitive plants in a rainfall regime growing between 140 and 200 in./year and with no apparent earthly source of minerals except the rain and airborne materials, it was recognized that the mechanisms for binding fallout might have some of the properties of encrusting vegetation of the Arctic in which high levels had been established earlier (Gorham, 1959; Watson, Hanson, and Davis, 1964; Hanson, Watson, and Perkins, 1967). Independently, the general surveys with survey meters by the Soil Conservation Service of radioactivity of the island of Puerto Rico had indicated a higher than normal reading in the vegetation of the upper Luquillo Experimental Forest, apparently resulting from fallout retention. Menzel et al. (1963) documented the uptake of 20 to 400 picocuries/m^2 of ^{90}Sr on plant foliage in single rains in the spring of 1962 in south Florida, about 7° latitude north of Puerto Rico. Shleien, Glavin, and Friend (1965) found 88% of the fallout radioactivity filtered from air in particles of 1.75 μ or less.

It was clear that the forest as a whole had been tagged with enough activity for the study of mineral cycling. Several elements were studied later as reported in other chapters of Sec. H which follow. The high radioactivity was instrumental in gaining authorization for the AEC Rain Forest Project of the Puerto Rico Nuclear Center. When equipment became available in 1963, a survey of fallout distribution in the forest was started to determine the concentrations, distribution, elevation, and biological meaning of the fallout retention. The properties affecting retention of a tracer in a compartment are rates of growth, age, and amounts of mineral dilution from nonradioactive sources. Some selection of samples was made to include comparisons related to these factors.

In the marine environment, considerable specificity had been shown in the patterns of radioactive retention, and different genera, families, and orders showed different properties of retention (Polikarpov,

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1966). Since the wide biochemical diversity of the rain forest is well known, a natural hypothesis was that there might also be considerable differential retention quantitatively and qualitatively in the rain forest. Chemical analyses of leaves varied between species (Chap. H-2). A comparison of species was made for beta activity also.

When the high fallout retention was first discovered in 1962, testing in the free atmosphere was near its height (Kuroda et al., 1965). By the time the main collecting began in late 1963, fallout was already declining, and short-lived components were dropping out. Long-lived ^{90}Sr showed a maximum in rain in Arkansas in the spring of 1963 and of 1964 of about 50 picocuries/liter of water (Kuroda et al., 1965). Most of the counts were done during 1964 on materials collected at the beginning of that year. Gamma spectra were made on some of these same samples in late 1964 and early 1965.

METHODS

Tree-leaf and bromeliad samples were dried 24 hr at 105°C, then ground in a Wiley or a Weber mill with a 0.040 screen. Individual planchets filled with ground-up sample were dried at the same temperature for an additional 24 hr.

Moss and leaf scrapings, principally algae, were treated in the same way, except the grinding was by mortar and pestle. Ground shrimp was dried at the same temperature; snail shells ground to powder were counted.

All beta counts were made with a Nuclear-Chicago Corp. low beta counter (Model 115) using Q gas (a counting gas mixture containing helium), with a scaler, an automatic sample changer, and a printing timer. An empty planchet was included with each group of samples to monitor background, and a ^{90}Sr standard was included to ensure constant machine response.

Since much of the counting of fallout in a gas-flow counter involves the emissions of beta particles, the counts are received from the upper layer only; deeper counts are self-absorbed depending on their energies. Sample size was made uniform by using standard low-rim planchets, 3 cm^2 in area, the bottom covered and level, full of dried and ground material. All counts were expressed on a unit-weight basis.

Gamma spectra were obtained with a 400-channel pulse-height analyzer using a 2-in. crystal with 400-min counts from which background was subtracted.

Statistical Study

A statistical study of radioactive counting and of the confidence limits to be found for counting periods of different lengths and radioactivity was conducted by C. B. Briscoe using leaf material from *Euterpe* and *Cecropia*, and shrimp (*Atyia scabra*) from the Sonadora River, and counts to 40,000. The results were presented in detail in the 1964 project progress report (Briscoe, 1963) and confirmed that the previously well-known patterns of statistical variation in radioactive counting were operating normally in these procedures. Included in the report was a graph of error percentage and total counts, which coincided with graphs in texts on radioactive methods. For convenience in any further work, a table of significant differences between means was given as a function of the number of repeat runs of 160 counts each. A series of 10 replications of 160 counts each was adopted as the standard procedure, yielding slightly more than the 1500 counts necessary for a reliable error estimate, yet providing sufficient degrees of freedom to allow a narrow confidence band within the range of beta-emission rates encountered. For 10 runs (1600 counts) differences of 10, 16, and 13 cpm were significant at the 5% level and of 15, 23, 18, and 17 counts per minute at the 1% level.

RESULTS

Results of the beta survey are given in Tables 1 to 5, and the gamma components in some of the samples are indicated by the spectra in Figs. 1 to 4. Counts on rain forest leaves are given by species in Table 1, where the range is from 10 to 158 counts per minute per gram dry weight. Almost as much range is found within single species. In Table 2 counts for those species in Table 1 which have three or more trees were averaged and arranged in order of magnitude from *Psychotria berteriana* with the largest count to *Tabebuia heterophylla* with the smallest. There was so much variation among individual trees that only *Psychotria berteriana* was significantly different from the median count, *Miconia prasina*, and only *Psychotria* and *Cordia borinquensis* were significantly different from the lowest ranked species, *Tabebuia*, which is deciduous. A spectrum was made for 480 g of fruit of *Dacryodes* collected from a major crown Tabonuco in late 1963. There was a definite manganese peak but no cesium peak, suggesting the incorporation at that date of manganese in the cycle back up to the crown but not much cesium.

The results of the study of beta radioactivity in relation to epiphytic habit are given in Table 3. The scrapings from *Manilkara* leaves were counted separately from the scraped leaves, and the radioactivity appeared with the scrapings. In Table 4 are additional data showing the high counts of scrapings and the low counts of scraped leaves. These data are from a

Table 1

BETA COUNTS OF RAIN FOREST LEAVES COLLECTED AT EL VERDE IN NOVEMBER 1963 AND COUNTED IN APRIL–MAY 1964 WITHOUT SCRAPING OFF EPIPHYTIC ENCRUSTATIONS

Species	Counts per minute per gram dry weight	
	First replication	Second replication
Buchenavia capitata	16	14
	34	32
	61	60
Banisteria laurifolia	62	63
Casearia bicolor	21	23
	30	30
Casearia arborea	72	71
	82	87
	59	60
Casearia guianensis	49	50
Casearia sylvestris	45	52
	102	111
	81	83
	67	66
Calycogonium squamulosum	138	136
	86	79
	138	136
	86	79
Cordia borinquensis	161	153
	69	63
	59	58
Cordia sulcata	151	158
Cecropia peltata	39	40
	15	16
	45	49
Cyrilla racemiflora	23	20
Dacryodes excelsa	36	36
	23	23
	19	18
	27	26
	18	18
Didymopanax morototoni	20	22
Drypetes glauca	43	43
	83	91
Eugenia stahlii	56	51
	68	66
	39	36
	64	65
	42	40
	49	48
Hirtella rugosa	102	96
	36	35
	27	28
Inga vera	31	30
Inga laurina	14	15
Ixora ferrea	30	30
	22	18
	23	25
Magnolia splendens	23	28
Matayba domingensis	50	46
	23	22
	27	26
Manilkara nitida	102	100
	68	61
	32	32
	36	30
Marcgravia rectiflora	84	81
Meliosma herbertii	66	54
	72	60
Micropholis garciniaefolia	35	35
	13	10
Miconia prasina	64	69
	34	34
	55	59
Miconia tetrandra	48	47
	68	65
Myrcia berberis	144	148
Myrcia splendens	82	77
	82	74
Ocotea leucoxylon	72	68
	68	63
	73	71
Ocotea portoricensis	31	35
Ocotea spathulata	35	32
Ormosia krugii	49	48
Palicourea riparia	119	114
	72	73
	86	83
	69	61
	63	61
	98	100
Philodendron krebsii	36	37
Psychotria berteriana	114	120
	158	157
	143	142
Rourea glabra	20	20
	54	49
	16	16
Sloanea berteriana	39	38
	30	28
	32	29
	29	28
	30	29
Tetragastris balsamifera	40	40
Tabebuia heterophylla	22	25
	11	11
	13	11

Table 2

TREE SPECIES IN ORDER OF BETA ACTIVITY OF LEAVES IN 1963–1964

Species*	Number of trees	Counts/min/g	Canopy position*
Psychotria berteriana	3	139	U
Cordia borinquensis	3	94	U
Species that do not	6	83	U
differ significantly	4	75	O
in activity	5	73	O
	3	72	O
	5	69	O
	6	59	O
	3	54	U
	3	53	O
	6	52	O
	3	52	U
	3	36	O
	3	32	O
	4	31	O
	3	29	V
Tabebuia heterophylla	3	16	O

*U, understory; O, overstory canopy; V, vine (Smith, Chap. D-3).

single limb, the terminal leaves being youngest. Differences were not significant.

In Table 5 are counts for litter composed mainly of old leaves and for ground vegetation in deep shade. Counts are within the range found in leaves growing higher in the forest although means were higher in these older materials.

Table 1 in Chap. E-1 gives counts on calcium carbonate shells of two species of giant snail which are significantly different.

Figure 1 shows the decline in radioactivity in one sample of *Dacroydes* shade leaves between the first run Oct. 9, 1963, and seven months later, a period when the beta counting was done. The geometries were similar but not the same. At the later time the two peaks ^{137}Cs and ^{54}Mn were prominent.

Figure 2 is a comparison of moss from the elfin forest with leaf litter from El Verde after levels had declined.

In Fig. 3 gamma spectra are given for leaves of four trees at El Verde, each of a different species. The general patterns are similar and, like 36 others, were done at about the same time. The leaf-litter

Table 3

BETA COUNTS IN RAIN FOREST EPIPHYTES AND TREE LEAVES

	Counts/min/g (dry weight)	Mean
Scrapings from *Manilkara nitida* leaves (algae, etc.) February 1964		
Tree 1	1429, 1037, 1463, 1682	
Tree 2	1778, 1687, 1243	
Tree 3	2326	
Tree 4	4138, 2714, 3340, 3358	
Tree 5	3154, 2438, 1969, 1524	2205
Moss	325, 352, 316, 346, 435	354
Bromeliads from seven trees, November 1963	77, 80, 110, 121, 59, 54, 67, 65, 194, 183, 211, 196, 248, 253	147
Tree leaves, unscraped, with some epiphytic algae		
Dacryodes excelsa	57, 43, 37, 37, 106	
Manilkara nitida	57, 101, 65, 32	
Cecropia peltata	59, 39, 15, 48	
Ocotea leucoxylon	72, 115, 67, 70, 65, 72	
Cordia borinquensis	157	65
Manilkara nitida leaves, scraped, few epiphytes, February 1964 (see above)		
Tree 1	13, 20, 21, 18	
Tree 2	25, 24, 26, 21	
Tree 3	22, 18, 27, 40	
Tree 4	41, 30, 35, 37	
Tree 5	20, 24, 30, 25	25

Table 4

BETA EMISSION BY LEAF POSITION ON THE BRANCH*

Leaf position	Counts/min/g	
	Leaves	Epiphyte scrapings
Terminal	23	2907
Second	23	1992
Third	27	2112
Fourth	29	2027
Av.	26	2205

*One leaf from each of three branches of five different trees was counted Nov. 15, 1965.

Table 5

BETA EMISSION IN QUADRAT LEAVES AND LEAF LITTER

Quadrat	Counts/min/g	
	Leaf*	Litter*
1	119	104
	127	96
2		70
		73
4	108	
	114	
5	63	119
	69	121
Av.	100	97

*Two planchets of each sample counted.

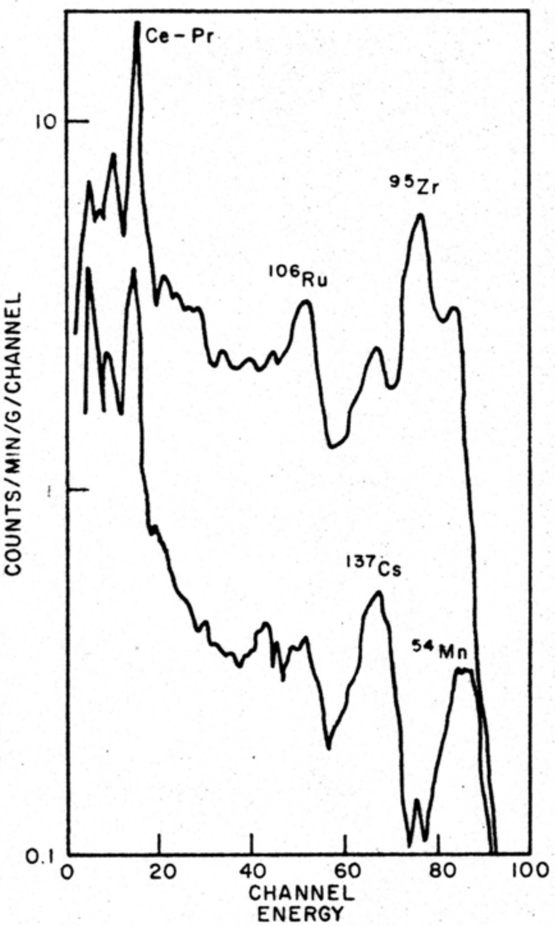


Fig. 1—Gamma spectrum of ash of shade leaves of *Dacryodes excelsa* collected Sept. 25, 1963. Upper spectrum was run for 40 min Oct. 9, 1963. Lower spectrum was from the same sample run June 25, 1964, for 400 min.

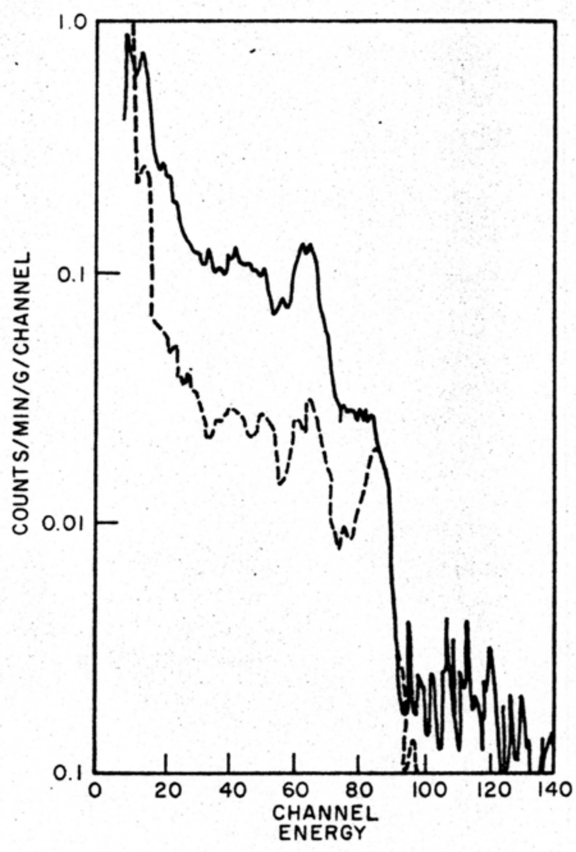


Fig. 2—Comparison of gamma spectra of 61 g of dry moss from the elfin forest at 3000 ft on Mt. Britton collected and run 100 min in July 1964 with 112 g of dry leaf litter collected November 1963 at El Verde and run 100 min July 9, 1964.

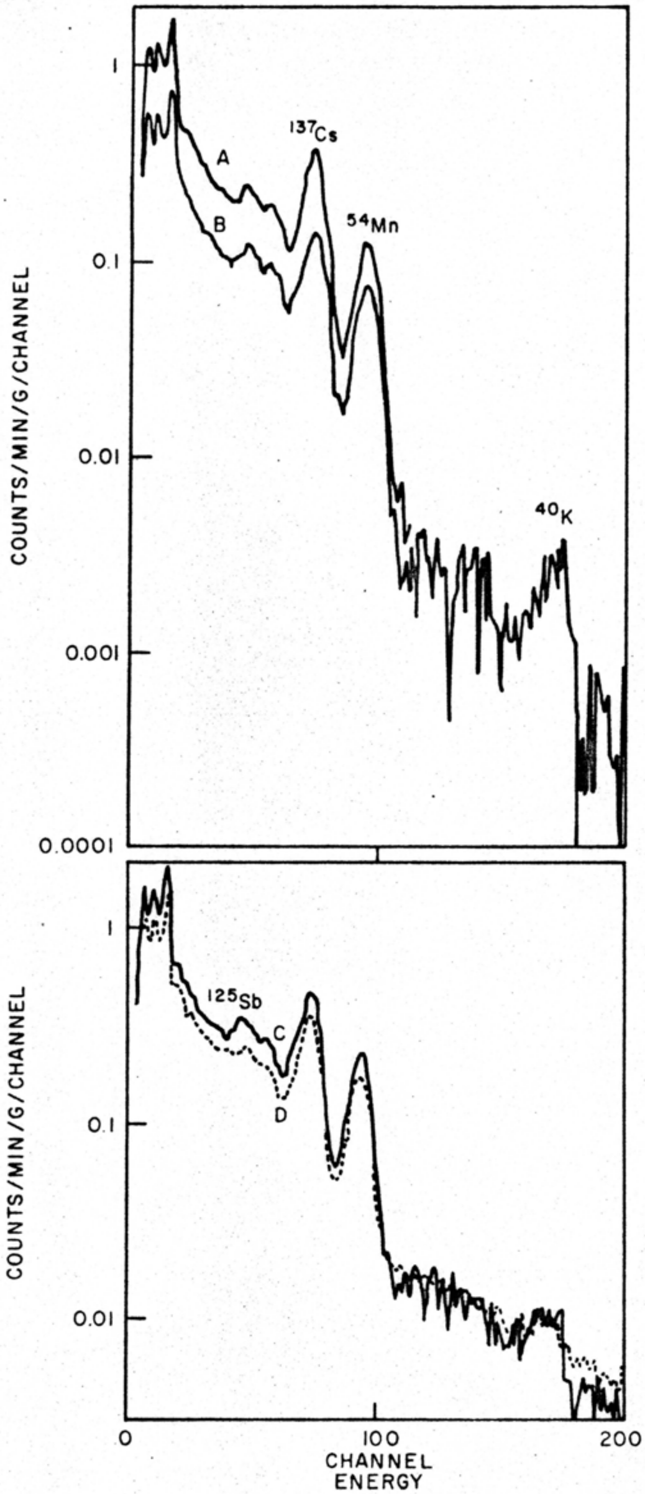


Fig. 3—Gamma spectra of leaves of four species of trees. A, 32 g of ash of shade leaves of *Manilkara bidentata* collected in November 1964 and run 400 min Jan. 21, 1965. B, 42 g of ash from shade leaves of *Dacryodes excelsa* collected in November 1964 and run 400 min Feb. 7, 1965. C, 22.7 g of ash from old leaves of *Sloanea berteriana* collected in November 1964 and run 400 min Feb. 9, 1965. D, 40 g of ash from old leaves of *Croton poecilanthus* collected in November 1964 and run 400 min Feb. 7, 1965.

spectrum in Fig. 2 is also similar and representative of others run. Although there are quantitative differences as reported in later chapters of Sec. 4, there are not the very marked differences that one sometimes observes in different biological components in marine communities. Even the termite nest had the same pattern (Fig. 4). An old sample of Tabonuco leaves from some studies in 1960 was run in 1965. The peak for cesium was there, but the manganese was missing; either it had decayed or was initially absent.

Activities in other components of the forest (mineral soils, wood, limbs, roots, fruits) were much lower.

High values were found in the accumulations of algae on top of the typical concrete residences being

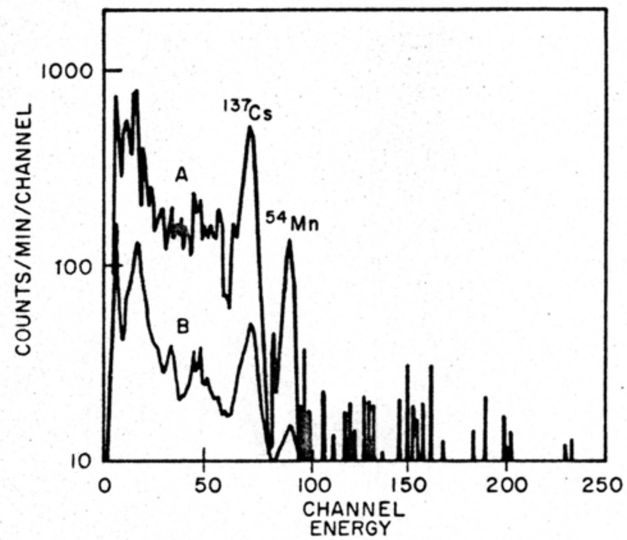


Fig. 4—Gamma spectra. A, 16.3 g of ashed termite nest, June 29, 1965. B, termite bodies, Sept. 9, 1965.

constructed in lowlands by the tens of thousands (Fig. 5). The spectrum is given in Fig. 6. The pattern of principal peaks is similar to those of the forest leaves, litter, and termite nest, suggesting that all these efficient fallout retainers are nonselective or similarly selective and are controlled by similar epiphytic agents. The retention on the flat-topped tropical houses suggests a potential problem for human safety in the event of large concentrations of fallout from atomic catastrophe in the urban tropics.

DISCUSSION

When the forest was first measured, the radioactivity in some components was as high as that in any vegetation and was in a class with the arctic moss—

Fig. 5—Algal mats growing in San Juan on concrete rooftops alternately flooded and dried.

lichen complex. Even in 1964 and 1965, the radioactivity was substantial and rather uniformly distributed over the leaves and litter. The high counts in the scrapings show its superficial aspect, which suggests either mineral uptake by epiphytic algae and mosses, etc., mechanical uptake of particles, or both. Since the main distribution was associated with the epiphytic community, the biochemical specificities of the larger plants were not really involved, and their relative handling of radioactivity remained an open question. Although the small differences in age represented on the branches studied (Table 4) did not show differences, increasing radioactivity may be inferred as due to increasing epiphyte accumulations over longer periods. The studies of epiphytic growth on palm fronds by Watson (Chap. D-13) showed accumulations of two to three years. The great variation that was at first perplexing turned out to be due to the various ages and degrees of accumulation of epiphytic crusts. Additional evidence for greater radioactivity of old shade leaves is given in the chapters that follow. Figure 7 shows the pattern on two old leaves.

The graphs given by Lockhart et al. (1965) of gross beta activity in air for the years 1959–1962 indicate for 18°N that Puerto Rico apparently receives the same levels of radioactivity from fallout as most of the temperate latitudes. Using values from Tables 3 and 4 without any correction for self-absorption and a conservative value of counter efficiency of 27.7% (provided for ^{90}Sr by J. Kline), one may estimate the radioactive contents of the epiphytic growths on leaves as greater than 5000 picocuries per gram—quite high values. Ovington and Lawrence (1964), for example, found the ^{90}Sr on oak, corn, and cattails to be less than 1 picocurie/g. Watson, Hanson, and Davis

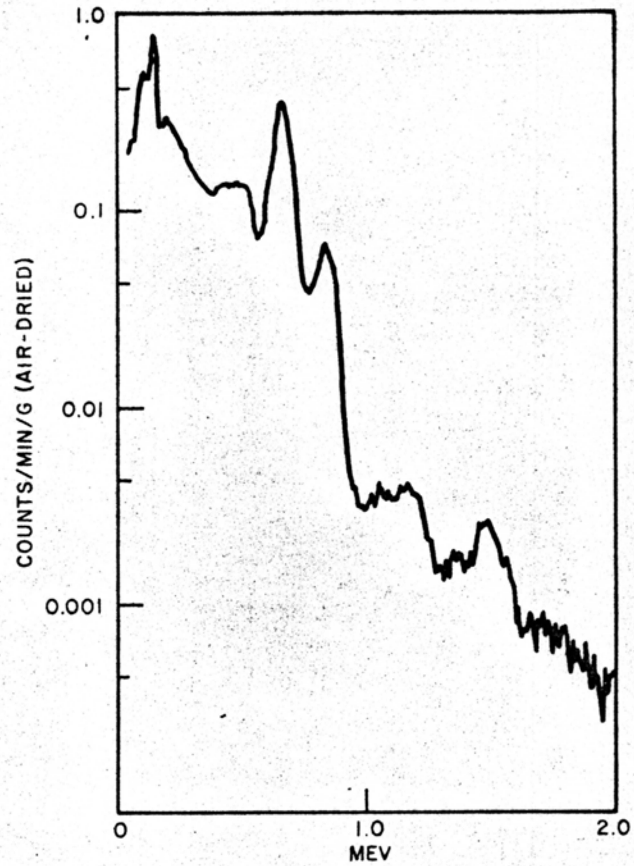


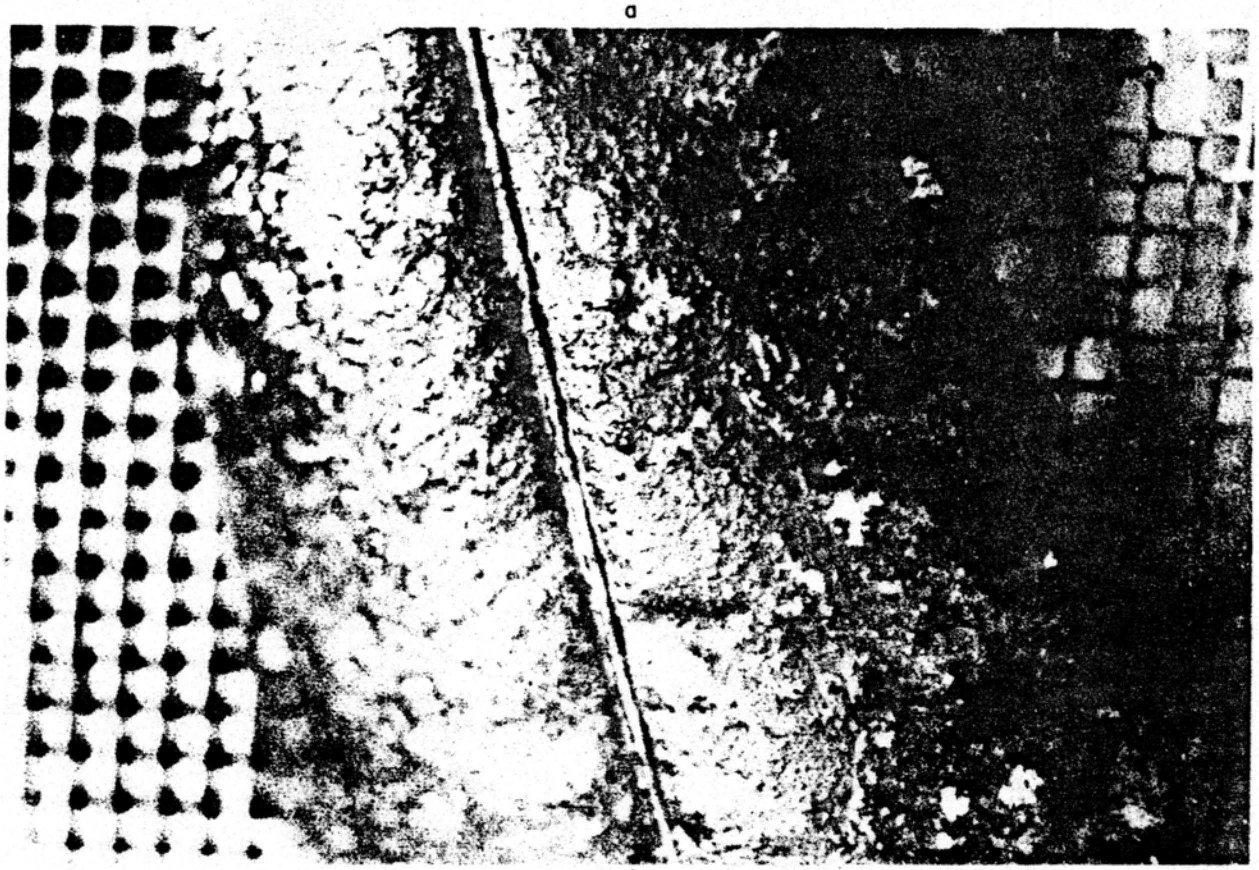
Fig. 6—Gamma spectrum of 1169 g of air-dried roof algae collected and run 100 min Dec. 6, 1965. J. R. Kline determined picocuries per gram for cerium, 7.6; cesium, 4.5; zirconium, 0.1; manganese, 0.8.

(1964) found 2 to 5 picocuries ^{90}Sr/g dry weight in Alaskan plants about 1960. The radioactivity of the nonepiphytic tissues at El Verde (Table 3) was not much larger than that reported in temperate areas of the world. Plummer and Helseth (1965) found up to 1800 picocuries/g dry weight in some plants on granite outcrops in Georgia in 1963. McCormick and Cotter (1964) found up to 0.38 mr/hr in vegetation islands on these outcrops compared to 0.23 from the rock.

Slow Growth Rate of Epiphytes

The slow rate of accumulation of epiphytic growths on leaves is documented by R. Watson in Chap. D-12. The white-painted cinder blocks used for intersections of the polar coordinate lines of the study area provided evidence of very slow growth on ceramic surfaces. Blocks placed in the Radiation and South Control Centers in August 1963 remained white with almost no growth through 1964, as shown by photographs in Chap. D-1 and Fig. 2, Chap. C-1. Michael

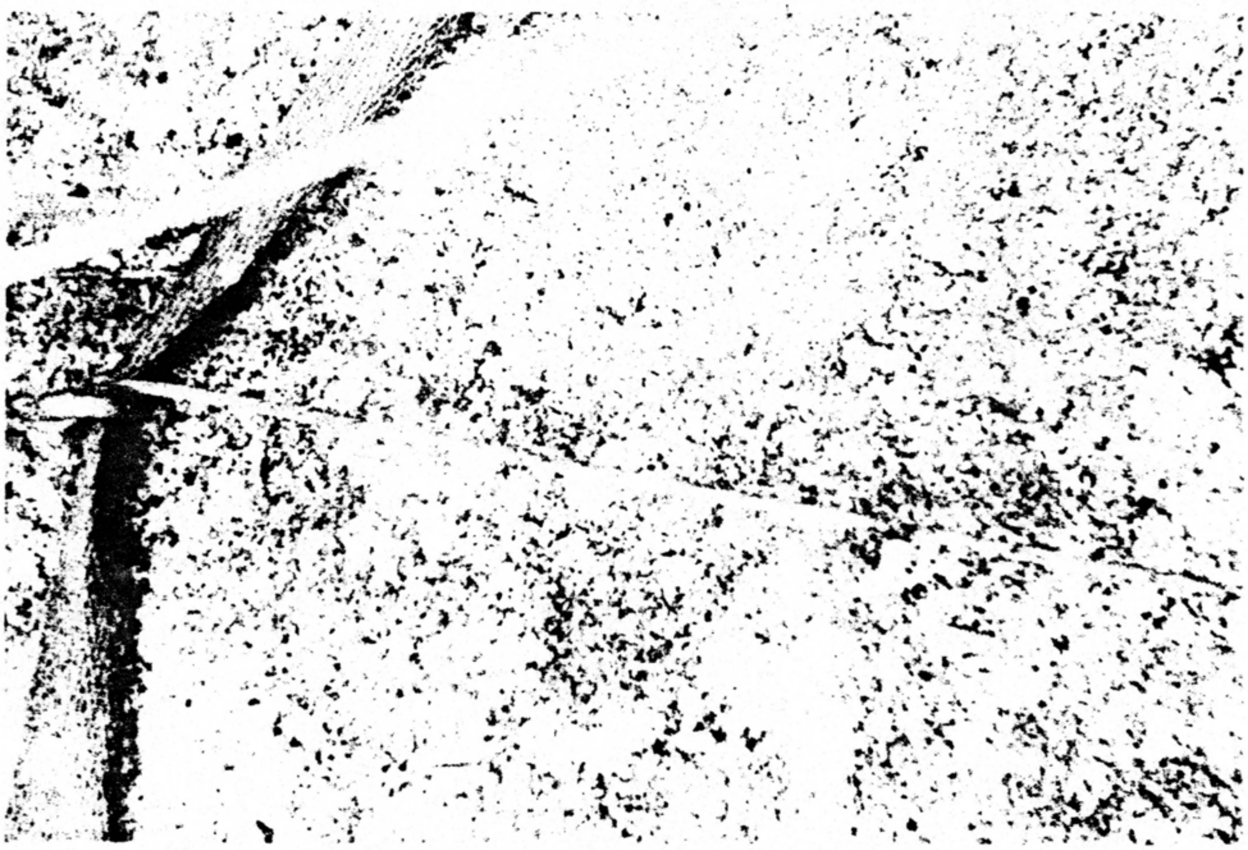
a



b

Fig. 7—Epiphytes of the phyllosphere of old shade leaves, Mar. 3, 1968 (Canoy).

a



b

Fig. 8—Epiphytic growths on white cinder blocks March 1968, After five years in the forest. (a) South Control Center. (b) Radiation Center, 10 m (Canoy).

Canoy provided photographs in 1968, five years later (Fig. 8). Blocks in the South Control Center were beginning to become covered. The slow growth and slow structural turnover are consistent with the extreme binding and holding capacity for fallout. In Fig. 8 contrast the dark epiphyte-covered block in the South Control Center with the block still nearly bare three years after irradiation 10 m from the Radiation Center and exposed to the sunny postirradiation microclimate. Much faster epiphytic growths were reported from the elfin forest by Howard (see citation in Chap. B-20) where leaves were covered in five months.

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