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To the Graduate Council:

I am submitting herewith a thesis written by William Kenneth Rudolph entitled "Concentrations of Gamma-Emitting Fallout Radionuclides from Picea rubens and Rhododendron maximum of the Great Smoky Mountains." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.

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CONCENTRATIONS OF GAMMA-EMITTING FALLOUT RADIONUCLIDES FROM *PICEA RUBENS* AND *RHODODENDRON MAXIMUM* OF THE GREAT SMOKY MOUNTAINS

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science

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by

William Kenneth Rudolph

June 1963

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I. INTRODUCTION

The testing of nuclear bombs and the subsequent release of radioactive fallout over the past 18 years has brought many problems related to the distribution of radioactive fallout and the affect of fallout on man and on his environment. The detonation of a nuclear devise produces some 170 radioactive isotopes. From these 170 isotopes there are seven gamma-ray-emitting fission products that have a half-life of such significant length that they are important in world-wide radioactive fallout problems (Table I, adapted from Mortensen, 1961).

It was the purpose of this study to measure the amount of fission produced gamma-emitting radionuclides in certain broad leafed and needle leafed evergreen woody plants of different cover types at sites receiving different amounts of rainfall in the Great Smoky Mountains of North Carolina and Tennessee.

TABLE I

PRINCIPAL GAMMA-EMITTERS OF WORLD-WIDE FALLOUT IMPORTANCE

Isotope	Half-Life
Cs-137 -- Ba-137	27 years -- 2.6 minutes
Ru-106 -- Rh-106	1.0 years -- 30 seconds
Ce-144 -- Pr-144	290 days -- 17 minutes
Zr-95 -- Nb-95	65 days -- 35 days
Ru-103 -- Rh-103	39.8 days -- 57 minutes
Ba-140 -- La-140	12.8 days -- 40 minutes
I-131	8.0 days

II. LITERATURE SURVEY

The study of radioactive fallout from nuclear testing has increased both in intensity and scope since the studies initiated in 1947 by the United States Atomic Energy Commission (USAEC). This study began with a radiological survey of soil, animals, and vegetation at the 1945 detonation site near Alamogardo, New Mexico. Air sampling for natural radioactive particles was begun in 1948 and measurement of fission produced radionuclides in 1950 (USAEC, 1961).

As the importance of radioactive fallout became apparent, many stations throughout the United States and the world were set up by agencies of both the federal and state governments as well as private organizations for sampling purposes. From this beginning of sampling radioactive fallout and studies of fallout patterns, research began on the effect of fission produced radionuclides in man and his enviroment. The United States Department of Agriculture began extensive work on strontium-90 in soils; this was soon followed by other programs in detection and analysis of radionuclides in food and man (USAEC, 1961).

The Los Alamos Scientific Laboratory began a program to measure radionuclides (cesium-137 and potassium-40) in milk and man in 1956. This study has included the measurement of activities in individuals from all over the world by means of a large scintillation whole-body counter (USAEC, 1961). Other studies which began on the relation of radionuclides to the environment have grown to encompass many fields of the biological and physical sciences.

The amount of fission produced radionuclides in soils has been studied extensively at Argonne National Laboratory (Gustafson, 1959a, 1959b, 1959c, and Gustafson et. al., 1957, 1958a, 1958b, 1959, 1960, 1961) and also in Sweden (Low and Edvason, 1959) and in the Great Smoky Mountains of North Carolina and Tennessee (Ritchie, 1962a).

Studies of radioisotopes in plants were first initiated for those plants occuring within the food chains of man (USAEC, 1961). Most of these studies were concerned with strontium-90, iodine-131, and cesium-137 and with respect to soil-plant relationships, root entry and distribution, foliar entry and distribution, and other similar areas (Fried and Heald, 1960; Hope, 1960; and Biddulph, 1960).

A pertinent fallout study in forest vegetation was reported from Sweden by Ljuggren (1960). Gamma-ray analysis was done on trees of Picea sp. (spruce) at an elevation of 120 meters (393.7 feet). This study showed a relative increase in gamma concentrations with age of both stems and needles. Dead twigs showed relatively high amounts of gamma emitters, comparable with the amounts detected in live twigs. Extremely small amounts of gamma emitters were detected within the wood though detectable amounts were found in the bark.

Olson (1961), in a study of pine and deciduous foliage in the area of the Oak Ridge National Laboratory, found that amounts of fission produced radionuclides decreased between 1958 and 1959. This decrease seemed to be accounted for by the nuclear test moratorium beginning October 1958.

Davis, Hanson, and Watson (1961) reported on the effects of rainfall on accumulation of fission produced cesium-137. In this study concentrations of cesium-137 in Pseudotsuga menziesii (Mirb.) Franco (Douglas fir) and Pinus ponderosa Laws. (Ponderosa pine) foliage were related to annual precipitation in areas of varying rainfall. They reported a general increase in the ratio of radiocesium to rainfall, but in areas having the greatest rainfall there was a decrease in the ratio. They presume that this decrease in ratio is caused by the washing of the radioactive material from the surface of the vegetation by heavy rains.

III. PROBLEM AREA

The Great Smoky Mountains National Park (GSMNP) is an area of lofty mountains of the Unaka chain in the Blue Ridge Province near the southern end of the Appalachian Highlands (Rodgers, 1953). The Park includes portions of Haywood and Swain counties of western North Carolina and Cocke, Sevier, and Blount counties of eastern Tennessee. Relief of these mountains of over a mile results in climatic and vegetational characteristics which are uniquely combined for the study of the distribution of radioactive fallout.

The bedrock of the area is mostly Great Smoky conglomerates of the Ocoee series of Precambrian age (Rodgers, 1953 and King et. al., 1958). These materials have weathered to soils described in the Swain county, North Carolina Soil Survey (Perkins and Getty, 1947) and the Sevier county, Tennessee Soil Survey (Hubbard et. al., 1956) as Rough Mountainous soils of the Ramsey Soil Group. These descriptions are not detailed and are inadequate with respect to many important points. Profiles recently analyzed by McCracken, Shanks, and Clebsch (1962) indicate that the great soil groups, Sol Brun Acide and Podzol, are present above 4500 feet. They are reported to be present in spruce-fir forests and heath balds. The Sol Brun Acide soil group lacks A_2 horizons with thin A_1 and "color B" horizons. They have very low base status and high exchangeable aluminum, low carbon-nitrogen ratio in the B horizon, and do not accumulate free iron. The Podzol soil group is distinquished from

the Sol Brun Acide group by the presence of A_2 horizons, its levels of differential iron accumulation, and high carbon-nitrogen ratio in B horizons. However not enough samples to justify generalization about the sampling areas of this study has been done.

The vegetation of the Great Smoky Mountains range from low elevation oak-pine forests, also characteristic of other areas of the Deciduous Forest, to representation of the Boreal Forest at elevations above 5000 feet. These forests are dominated by Picea rubens* (red spruce) and Abies fraseri (Fraser's fir) and are similar in composition and structure to the Boreal forests of Canada. The spruce-fir forest type is sometimes broken by communities of evergreen ericaceous shrubs which occur on sharp exposed ridges throughout its ranges (Whittaker, 1956). These ericaceous communities are locally known as heath balds and are referred to as such throughout this work.

The mean annual temperature ranges from 56.6 degrees F. at 1460 feet to 45.6 degrees F. at 6300 feet and the mean annual precipitation ranges from 57.8 inches at 1460 feet to 90.9 inches at 6300 feet. Total precipitation increases steadily from 1460 to 5000 feet where it reaches 89.0 inches per year. From 5000 feet to 6300 feet annual precipitation increases only 1.9 inches. In his climatic summary Shanks (1954) found that stations above 1460 feet could be characterized as perhumid and those below as humid in the 1948 Thornthwaite system. Precipitation data cited below comes from the above paper.

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*Nomenclature is that of Fernald (1950).

Collection sites for this study were at three elevations: one each at 3200 feet, 4000 feet, and 5200 feet in the Great Smoky Mountains National Park. Specific locations and site descriptions follow:

1. Chimneys Parking Area Heath Bald. This heath bald is located on a northwest facing lead 440 yards from the Chimneys parking area on U. S. Highway 441 at the junction of Road Prong Creek and West Prong little Pigeon River at approximately 3200 feet elevation. This is an open heath held bald (the lowest known in the Park) dominated by Rhododendron catawbiense, Rhododendron maximum, and Kalmia latifolia. The surrounding forest has a closed canopy of which the major tree species are Teuga canadensis with some Betula alleghaniensis and Picea rubens. The understory is primarily Rhododendron maximum.

The parent rock material is Great Smoky Conglomerate of graywacke and graywacke conglomerate of the Ocoee series (Rodgers, 1953). The soil type is reported as Rough Mountainous soil of the Ramsey Soil group (Hubbard et. al., 1956).

The mean annual precipitation is approximately 75 inches.

2. Alum Cave Parking Area Heath Bald. This bald is located on a northwest facing lead 440 yards from the Alum Cave parking area on U. S. Highway 441 at the junction of Alum Cave Creek and Walker Prong Creek at approximately 4000 feet elevation. The bald, surrounding vegetation, geology, and soils are similar to that at the Chimneys Parking Area Heath Bald. The mean annual precipitation is approximately 80 inches.

3. Thomas Divide Heath Bald. This heath bald is located on a northwest-southwest trending ridge 0.5 mile south of the Newfound Gap-Clingman's Dome road, 0.8 mile west of Newfound Gap at approximately 5200 feet elevation. It is a moderately open heath bald of Rhododendron catawbiense, Kalmia latifolia, and Rhododendron maximum with a few individuals of Picea rubens and Abies fraseri. The surrounding forest is characterized by a closed canopy of Picea rubens and Abies fraseri with some Betula allegheniensis. The understory is predominately Rhododendron maximum. The parent rock material is the same as sites one and two. The soil is classified as Burton stony loam, shallow phase (Perkins and Getty, 1947). The mean annual precipitation is approximately 90 inches.

IV. METHODS

Field Collection Methods

At each site three samples were collected by clipping branches of Rhododendron maximum and Picea rubens. Rhododendron branches were collected from the open heath bald with no canopy (overstory Rhododendron) and from the forest understory adjacent to the open heath bald with a canopy of Picea rubens (understory Rhododendron). Picea rubens branches were collected from the selected tree well within the tree canopy.

All samples were labeled, bagged, and removed to the laboratory for processing.

Preparation of Material

The clipped branches were separated into 1962 growth and 1961 and older growth and dried in a forced draft oven at 105 degrees centigrade for 48 hours. The dried samples were subdivided into stems and leaves. All samples were ground in a Wiley mill to pass a 20 mesh screen, weighed, and placed in cylindrical plastic containers (1½ inches deep and 3-3/8 inches in diameter) for gamma-ray analysis.

Gamma-ray Analysis

Gamma-ray analysis of the material was made using a 200 channel RIDL (Radiation Instrument Development Laboratory) pulse height analyzer*.

Since the plastic sample boxes were standard in size and shape they were used during counting to maintain constant geometry and placed,

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*Courtesy of the Health Physics Technology Section, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

with the sample, directly on the sodium iodide, thallium activated crystal. Two crystals were available, one three inches in diameter by three inches and the other two inches in diameter by four inches. The former gave better resolution while the latter had better efficiency. Both crystals could be used simultaneously by connecting one to the first 100 channels and the other to the second 100 channels, with each energy scan ranging from 0 to 1.86 MEV. The count values were recorded on a printed tape for each sample. Figure 1 shows a gamma spectrum typical of all samples counted.

Beta radiation contributions to the values recorded were minimized by using a beryllium absorber with a surface-weight of 1.23 grams per square centimeter. Background counts were made and printed out at irregular intervals during the counting period.

Standards with similar counting geometry were made by pipetting standard solutions of isotopes into cellulose sponges in the same size plastic containers (Ritchie, 1962a).

Activity of the individual isotopes was computed by grouping channels around the photopeak of the characteristic energy of the isotope. Table II shows the channel grouping and characteristic energies used. The counts in these channel groups were then totaled and data processed with an IBM computer program developed by J. S. Olson. All activities are corrected for decay to the date of collection (September 15, 1962).

TABLE II

CHANNEL GROUPING AND CHARACTERISTIC ENERGY
OF CERTAIN RADIOISOTOPES

Isotope	Characteristic[a] Energy	Channel group	Energy[a] band
Cerium-144	0.134	7-9	0.130-0.168
Ruthenium-106	0.51	26-30	0.484-0.559
Cesium-137	0.661	34-37	0.633-0.688
Zirconium-95-Niobium-95	0.754	39-43	0.726-0.801

[a]All energies are in million electron volts.

All of the samples have been stored in their original counting vessels at the Botany Department of the University of Tennessee for possible re-analysis after the decay of short-lived isotopes.

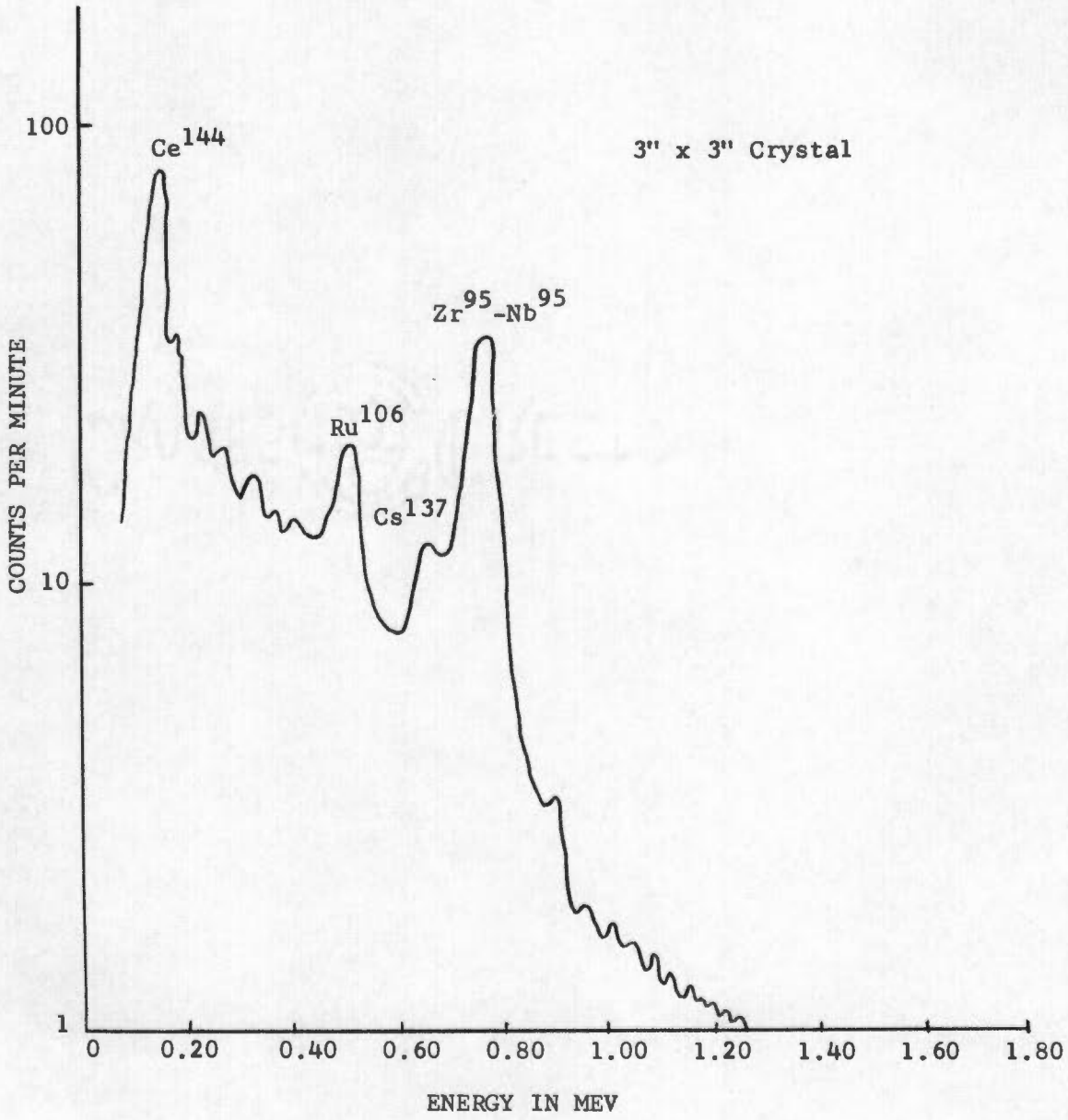


FIGURE 1

GAMMA-RAY SPECTRUM OF OLD LEAVES OF UNDERSTORY RHODODENDRON FROM AN ALTITUDE OF 3200 FEET

V. RESULTS

Tables III through VI show the concentrations of gamma-ray emitters in the samples of Rhododendron and spruce. These values range from a high of 218.3 μμc/gm of cerium-144 in old spruce stems to a low of 2.3 μμc/gm of cesium-137 in old leaves of understory Rhododendron. The concentrations of the four isotopes are considerably higher than those reported by Olson (1961) in his work with fallout in pine and deciduous vegetation. The usefulness of this and other works (Ljuggren, 1960 and Davis et. al., 1962) for comparison is not as great as they were done during the bomb testing moratorium which lasted from October 1958 until September 1961. Ritchie (1962b), working at Oak Ridge on pine vegetation in the summer of 1962, found values that were more comparable to the values found in this study. He found cerium-144 varying from 27 μμc/gm to 169 μμc/gm, ruthenium-106 varying from 17 μμc/gm to 89 μμc/gm, cesium-137 varying from less than 1 μμc/gm to 11 μμc/gm, and zirconium-niobium-95 varying from 10 μμc/gm to 54 μμc/gm. These data seems to be in the same general range though slightly lower than those reported here. This difference may be due to the variation in amounts of precipitation at the two collecting sites.

Examination of relative concentrations between nuclides shows cerium-144 highest with zirconium-niobium-95, ruthenium-106, and cesium-137 following in order of decreasing concentrations. Other workers in this field have found the order of concentrations to be generally the

TABLE III

CONCENTRATIONS OF CERIUM-144
IN VEGETATION

	Elevation					
	3200		4000		5200	
	Stem	Leaf	Stem	Leaf	Stem	Leaf
New Spruce	28.3[a]	15.2	50.4	18.3	87.8	63.3
Old Spruce	33.9	37.6	77.6	44.6	218.3	85.7
New Overstory Rhododendron	97.9	81.4	42.0	54.8	138.4	153.4
Old Overstory Rhododendron	48.6	111.3	24.3	72.4	39.8	36.8
New Understory Rhododendron	20.9	25.0	73.7	46.9	25.1	45.3
Old Understory Rhododendron	56.3	19.4	25.5	38.2	21.7	52.9

[a]Data are in micro-micro curies per gram of dry tissue.

TABLE IV

CONCENTRATIONS OF RUTHENIUM-106
IN VEGETATION

	Elevation					
	3200		4000		5200	
	Stem	Leaf	Stem	Leaf	Stem	Leaf
New Spruce	9.4[a]	4.8	14.0	4.3	56.9	18.0
Old Spruce	12.3	10.0	24.6	11.2	70.8	28.3
New Overstory Rhododendron	29.2	21.7	16.2	18.1	36.3	27.8
Old Overstory Rhododendron	25.7	23.8	8.3	20.5	15.9	15.9
New Understory Rhododendron	6.3	5.5	21.4	15.2	14.5	10.5
Old Understory Rhododendron	ND[b]	11.3	9.6	11.0	9.1	15.5

[a]Data are in micro-micro curies per gram of dry tissue.

[b]No determination.

TABLE V

CONCENTRATIONS OF CESIUM-137
IN VEGETATION

	Elevation					
	3200		4000		5200	
	Stem	Leaf	Stem	Leaf	Stem	Leaf
New Spruce	2.8[a]	4.7	10.2	3.2	8.9	11.1
Old Spruce	5.8	3.9	11.2	4.1	17.2	14.1
New Overstory Rhododendron	19.2	9.9	12.8	15.7	5.0	7.9
Old Overstory Rhododendron	7.5	11.6	4.9	5.9	3.5	2.3
New Understory Rhododendron	6.0	5.9	8.7	8.5	7.1	9.1
Old Understory Rhododendron	5.7	3.4	4.1	3.9	3.8	8.7

[a]Data are in micro-micro curies per gram of dry tissue.

TABLE VI

CONCENTRATIONS OF ZIRCONIUM-95-NIOBIUM-95
IN VEGETATION

	Elevation					
	3200		4000		5200	
	Stem	Leaf	Stem	Leaf	Stem	Leaf
New Spruce	23.2[a]	16.9	33.9	13.8	50.7	49.7
Old Spruce	21.0	43.5	36.8	38.2	78.5	50.4
New Overstory Rhododendron	98.5	77.9	18.6	28.6	176.2	100.3
Old Overstory Rhododendron	20.4	87.4	7.5	27.6	13.5	12.1
New Understory Rhododendron	16.8	19.6	33.1	28.8	14.6	52.2
Old Understory Rhododendron	94.5	9.7	8.4	27.6	15.0	83.9

[a]Data are in micro-micro curies per gram of dry tissue.

same with ruthenium-106 and zirconium-nobium-95 varying with each other in levels of concentrations between cerium-144 and cesium-137 (Alexander et. al., 1960; Olson, 1961; Ritchie, 1962b).

VI. ANALYSIS AND DISCUSSION

General

Samples for this study were collected in the late summer of 1962, one year after the 1958 moratorium on nuclear testing had ended. Within that year over 50 nuclear devices were exploded in the atmosphere in the northern hemisphere. Most studies of radioactive fallout in natural vegetation were done during the moratorium (October 1958 to September 1961) and there is little comparative data available from studies done after September 1961. A study is in progress at the Oak Ridge National Laboratory in Tennessee on fallout and uptake of radioactive nuclides in pine trees, initiated in the summer of 1962 by Jerry C. Ritchie. Some of these unpublished data have been available to the writer and from time to time were used for comparison (see Results).

There is little known about the amount of root uptake and foliar absorption of radionuclides in natural vegetation. Tracer techniques have been used to study the amount of uptake, and these studies have shown cesium-137 to be absorbed by foliage (Biddulph, 1960). DeSelm and Shanks (1962) reported on cesium-137 in natural vegetation from a radioactive disposal area and found the ratio of cesium concentrations in vegetation to soil concentrations to be very low. Ruthenium-106 shows varying degrees of root uptake in different types of farm crops (Myers, 1960). Cerium was found to be taken up by roots in a nutrient solution with very little being transported to aerial parts, and very little taken up by roots in soil (Myers, 1960).

Ritchie (1962a) found, in the organic and top four inches of mineral soil under evergreen forest, only 4% of the total cesium-137 between 1.5 and 4 inches in the mineral soil. The organic layers (L, F, and H) contained 82% and the first 1.5 inches of mineral soil contained 13%. The soil cesium concentrations seem to be so low that it would be an unlikely source of the plant cesium found. The only other source of the vegetational cesium would therefore be fallout. Whether the plant cesium was actually surface contamination or had been absorbed inside the epidermis or cork layers was not determined.

Cover

Table VII gives average values of nuclides of concentrations in spruce, overstory Rhododendron, and understory Rhododendron. These averages show overstory Rhododendron with the most activity and spruce and understory Rhododendron following respectively. Overstory Rhododendron samples were taken from open heath balds and had no canopy (overstory). The spruce samples, from within the canopy of the tree, were an overstory themselves to the understory Rhododendron. Data in Table VII suggest that concentrations of fallout on vegetation are related to canopy position.

Age

Stem and leaf materials were divided into 1962 growth and 1961 and older growth to see if there were differences in concentration. Table VIII gives these average concentrations by cover types. Spruce shows a higher concentration of each isotope in old material than in

TABLE VII

AVERAGE VALUES OF SPRUCE AND
RHODODENDRON SAMPLES

	Isotope			
	Ce-144	Ru-106	Cs-137	Zr-Nb-95
Spruce	63.4[a]	22.0	8.1	38.1
Overstory Rhododendron	83.4	21.6	8.8	55.7
Understory Rhododendron	37.6	11.8	7.5	33.7

[a]Data are in micro-micro curies per gram dry tissue. These are means of old and new stem and leaf material from the three collecting sites.

TABLE VIII

AVERAGE VALUES OF OLD GROWTH AND NEW GROWTH OF SPRUCE AND RHODODENDRON

	Isotope			
	Ce-144	Ru-106	Cs-137	Zr-Nb-95
New Spruce	43.8[a]	17.9	6.8	31.3
Old Spruce	82.9	26.2	9.4	44.7
New Overstory Rhododendron	94.6	24.9	11.6	83.3
Old Overstory Rhododendron	55.5	18.3	6.0	28.0
New Understory Rhododendron	39.4	12.2	7.6	27.5
Old Understory Rhododendron	35.6	11.3	4.9	39.8

[a]Data are in micro-micro curies per gram of dry tissue. Values are means of concentrations of stem and leaf material from the three collection sites.

new. This same relation was found by Ljuggren (1960) working in Sweden with gamma emitters in spruce. Table IX* shows significance at the 90% level of probability between ages in spruce.

The roughness of bark and the "keeled" shape of the needles in spruce is probably the best explanation for a build-up of concentrations of radionuclides with age. These organs would be less likely to have fallout material washed off by rain and it would therefore accumulate with age.

Both cover types of Rhododendron showed differences due to age, the 1962 growth being higher than the 1961 and older growth. There is significance at the 90% level of probability between ages in overstory Rhododendron, but there is no significance between ages in understory Rhododendron (Tables X and XI). The fact that new growth has a higher concentration than older growth suggests that no build-up of concentrations of radionuclides within organs has occured. The smoothness of stems and leaves in Rhododendron may account for fallout material being washed off the surface by rain more readily than in spruce.

Organs

Table XII shows average concentrations of gamma emitters on stem and leaf material by cover type. The spruce stems have higher concentrations than leaves. Ljuggren (1960) working with spruce also found higher concentrations in the twigs than in the needles. The averages for

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*Analysis of variance follows the design of Freese (1956).

TABLE IX

ANALYSIS OF VARIANCE FOR SPRUCE
FACTORIAL DESIGN[a]

Source	DF	SS[b]	MS[b]	"F"
Altitude	2	55.721	27.860	10.5[c]
Age	1	12.662	12.662	4.8[d]
Organ	1	12.008	12.008	4.5[d]
Residual	7	18.623	2.661	
Total	11	99.014		

[a]Data used were the means of the four isotopes.

[b]Sum of square and mean square figures are times 10^3.

[c]Significant at the 95% level of probability.

[d]Significant at the 90% level of probability.

TABLE X

ANALYSIS OF VARIANCE FOR OVERSTORY RHODODENDRON
FACTORIAL DESIGN[a]

Source	DF	SS[b]	MS[b]	"F"
Altitude	2	26.928	13.464	1.99[c]
Age	1	34.165	34.165	5.06[d]
Organ	1	1.100	1.100	0.16[c]
Residual	7	47.289	6.754	
Total	11	109.473		

[a]Data used were the means of the four isotopes.

[b]Sum of square and mean square figures are times 10^3.

[c]Not significant.

[d]Significant at the 90% level of probability.

TABLE XI

ANALYSIS OF VARIANCE FOR UNDERSTORY RHODODENDRON FACTORIAL DESIGN[a]

Source	DF	SS[b]	MS[2]	"F"
Altitude	2	0.903	0.451	0.15[c]
Age	1	0.029	0.029	0.001[c]
Organ	1	0.262	0.262	0.09[c]
Residual	7	20.489	2.927	
Total	11	21.683		

[a]Data used were the means of the four isotopes.

[b]Sum of square and mean square figures are times 10^3.

[c]Not significant.

TABLE XII

AVERAGE VALUES OF STEM AND LEAF SAMPLES
OF SPRUCE AND RHODODENDRON

	Isotope			
	Ce-144	Ru-106	Cs-137	Zr-Nb-95
Spruce Stems	83.7[a]	31.3	9.4	40.7
Spruce Leaves	44.1	12.8	6.9	35.4
Overstory Rhododendron Stems	65.1	21.9	8.8	55.8
Overstory Rhododendron Leaves	62.6	17.9	8.9	55.7
Understory Rhododendron Stems	37.2	12.4	5.9	30.4
Understory Rhododendron Leaves	38.1	11.1	6.6	37.0

[a]Data are in micro-micro curies per gram dry weight. Values are means of concentrations of old and new material from the three collection sites.

Rhododendron showed similar concentrations in stems and leaves. Table IX shows significance at the 90% level of probability between organs in spruce. There is no significance between stem and leaf material in Rhododendron (Tables XI and XII).

Altitude

Three studies in radioactive fallout have shown that cesium-137 concentrations in soil and vegetation increase with an increase in rainfall (Libby, 1958; Davis et. al., 1962; and Ritchie 1962a). In this study samples were collected at three sites each having a different total annual precipitation. Between the 3200 foot altitude in the Smoky Mountains and the 5200 foot altitude there is an increase of about 15 inches of precipitation per year.

Table XIII gives average concentrations of gamma emitters by cover type and altitude. Concentrations on spruce increase with altitude, but are erratic in Rhododendron. The analysis of variance for each cover type (Tables IX, X, and XI) shows significance only in spruce with no significance in overstory or understory Rhododendron.

The lack of significance between altitudes in Rhododendron may be due to the "wash-off" of radionuclides by rain. Davis, Hanson, and Watson (1962), working in Washington State, compared concentrations of cesium-137 in Ponderosa pine and Douglas fir with annual precipitation and found and increase in concentration with an increase in precipitation, but found that the ratio between the two variables decreased in areas of highest rainfall. Removal of cesium-137 from the surface of the vegeta-

TABLE XIII

AVERAGE VALUES OF SPRUCE AND RHODODENDRON SAMPLES AT THREE ALTITUDES[a]

	Cerium-144		
	3200	4000	5200
Spruce	28.7	47.7	113.7
Overstory Rhododendron	84.8	73.3	92.1
Understory Rhododendron	30.4	46.0	36.2
	Ruthenium-106		
	3200	4000	5200
Spruce	9.1	13.5	43.5
Overstory Rhododendron	25.1	15.8	24.0
Understory Rhododendron	7.7	14.3	12.4
	Cesium-137		
	3200	4000	5200
Spruce	4.3	7.2	12.8
Overstory Rhododendron	12.0	9.8	4.7
Understory Rhododendron	5.2	6.3	7.2
	Zirconium-Niobium-95		
	3200	4000	5200
Spruce	26.2	30.6	67.3
Overstory Rhododendron	71.0	20.6	75.5
Understory Rhododendron	35.1	24.5	41.4

[a]Data are in micro-micro curies per gram dry tissue. Values are means of concentrations of old and new stems and leaves.

tion by heavy rain is thought to be the explanation for this decreased ratio.

VII. CONCLUSIONS

The concentrations of fission produced gamma-ray emitters in sampled spruce and Rhododendron stems and leaves of the Great Smoky Mountains are controlled by many environmental factors. The amount of precipitation is one of the more important of these. Fallout concentrations increase with an increase in rainfall in spruce, but where large amounts of rainfall occur there are indications that a considerable amount of fallout material is washed from the surface of vegetation. The latter is most readily seen in plants with smooth textured leaf and stem surfaces such as Rhododendron. Spruce, with a rough bark, seems to hold fallout material, and such accumulations increase the concentrations on exposed organs. This mechanical adherence would also explain the increase, with age, of concentrations in spruce while in Rhododendron the increased precipitation washes the fallout from the smooth stems and leaves. There are indications that concentrations of radioactive fallout are higher in vegetation that has no canopy than in that under a canopy.

VIII. SUMMARY

Branches of Picea rubens from within its canopy and branches of overstory and understory Rhododendron maximum were collected from three different stations of different altitudes and with different total annual precipitation in the Great Smoky Mountains National Park. Gamma-ray analysis of radioisotopes in these branches were done on one year old, and older than one year, stem and leaf material with a 200 channel RIDL pulse height analyser.

Concentrations of isotopes varied from 218.3 μμc/gm of cerium-144 in old spruce stems to 2.3 μμc/gm of cesium-137 in old leaves of understory Rhododendron.

Significance at the 90% level of probability was shown in spruce between altitude, age, and plant part. An increase in concentration was shown in samples from areas of lowest yearly rainfall to areas of highest rainfall. Old material in spruce showed higher concentrations than new material and stems were higher in concentration than leaves.

Rhododendron samples showed no significance between altitude or plant part, but there was significance at the 90% level of probability between ages in overstory Rhododendron, with the new growth having higher concentration than old growth. There was no significance between ages in understory Rhododendron.

It was concluded that annual rainfall is important in bringing down radioactive fallout and also in washing radioactive material from the surface of vegetation.

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