8-1962

Distribution of Fallout Cesium-137 in Litter, Humus, and Surface Soil Layers Under Natural Vegetation in the Great Smoky Mountains

Jerry Carlyle Ritchie
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Jerry Carlyle Ritchie entitled "Distribution of Fallout Cesium-137 in Litter, Humus, and Surface Soil Layers Under Natural Vegetation in the Great Smoky Mountains." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.

R. E. Shanks, Major Professor

We have read this thesis and recommend its acceptance:

J. S. Olsen, G. E. Hunt, L. F. Seatz

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

June 15, 1962

To the Graduate Council:

I am submitting herewith a thesis written by Jerry Carlyle Ritchie entitled "Distribution of Fallout Cesium-137 in Litter, Humus, and Surface Soil Layers under Natural Vegetation in the Great Smoky Mountains." I recommend that it be accepted for twelve quarter hours credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.

Royal E. Shanks
Major Professor

We have read this thesis and recommend its acceptance:

Jerry S. Olson

Andrew Edmunt

Lloyd L. Lentz

Accepted for the Council:

Hilton A. Smith
Dean of the Graduate School

DISTRIBUTION OF FALLOUT CESIUM-137 IN LITTER, HUMUS, AND SURFACE SOIL LAYERS UNDER NATURAL VEGETATION IN 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

---

by

Jerry Carlyle Ritchie

August 1962

ACKNOWLEDGEMENTS

The author wishes to thank the members of his committee who helped prepare the manuscript. Special thanks go to Dr. R. E. Shanks and Dr. J. S. Olson whose suggestions were both timely and helpful. Thanks are to be given to the Health Physics Whole Body Counting Laboratory at Oak Ridge, Tennessee for the use of their gamma spectrometer and to P. E. Brown for his assistance with the use of the spectrometer. Thanks also go to the Great Smoky Mountains National Park Service for stimulation toward research in the Park. The work was done through a University contractual project supported by the United States Atomic Energy Commission.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Since the explosion of the first nuclear weapon in July of 1945 and with subsequent tests, especially of hydrogen devices which contribute most of the world-wide fallout, and with the development of nuclear power plants, the world has become more and more interested in radioactive fallout and the problems related to it. During the detonation of a nuclear device some 170 radioactive isotopes are produced. Of these 170 isotopes there are seven principal gamma-ray-emitting fission products which have sufficiently long half-lives to be important in world-wide fallout (Table I, adapted from Mortensen 1961). The purpose of this study was to measure the amount of cesium-137 in the organic layers and top four and one-half inches of mineral soil in representative evergreen and deciduous forest stands of the Great Smoky Mountains of North Carolina and Tennessee with emphasis on its distribution and movement downward through the soil.

TABLE I

PRINCIPAL GAMMA-EMITTERS OF WORLD-WIDE FALLOUT IMPORTANCE

Isotope	Half-life[a]
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

[a]Half-life is the time it takes the radioactivity to decrease to one-half of its initial value.

II. LITERATURE SURVEY

At Alamogordo, New Mexico on July 16, 1945 the United States of America tested the first atomic bomb (Hearings before the Special Subcommittee on Radiation 1957). Since this first explosion radioactive fallout has been identified and measured extensively. The United States Atomic Energy Commission (USAEC) initiated its fallout studies in 1947 through a group at the University of California at Los Angeles, formed to study effects of radiation on living organisms at the detonation site at Alamogordo. This program developed further, with more nuclear detonations to study patterns of local fallout. The United States Naval Research Laboratory began measurement of air-borne fission products in 1950. In 1951 the USAEC began to analyze rain water from the northeastern United States for fission-produced radioactivity. From this developed a nation-wide rainfall collection system under the USAEC Health and Safety Laboratory in New York. The United States Weather Bureau in 1952 began a gummed filter and air sample collection system at 121 fixed monitoring stations in the United States. Then in 1954 the USAEC through various organizations began to study world-wide fallout. In these studies soil, air, water, milk, and foodstuffs were collected and analyzed for radioactivity with particular emphasis on strontium-90. In 1955 the United States Agriculture Department entered the above program and has since done extensive work on strontium-90 in soil (United States Atomic Energy Commission 1960).

Many of the early published reports (Eisenbud and Harley 1953, 1955, and Libby 1956, 1958) were on studies of radioactive fallout patterns. They were based on studies of strontium-90 and used this information to predict future levels of radioactivity.

Late in the fall of 1955 Miller and Marinelli (1956), working in Argonne National Laboratory at Lemont, Illinois, found cesium-137 in humans. This was the first reported cesium-137 in man. In the spring of 1956 Rundo (1958) found the first cesium-137 in British subjects. Using the above information the United States in 1956 began a program at Los Alamos Scientific Laboratory to measure cesium-137 in man (United States Atomic Energy Commission 1960).

In April 1957 Argonne National Laboratory began a program to measure the amount of fission gamma-ray emitters in the soil at Lemont, Illinois (Gustafson, Marinelli, and Brar 1957). They found no measurable amount of cesium-137 but calculated the amount of cesium-137 to be 0.02 micro-microcuries per gram. The program continued and for October 1957 the amount of cesium-137 was found to have increased to 37 millecuries (mc.) per square mile (Gustafson, Marinelli, and Brar 1958a). They also found that the total amount of gamma-ray emitters was increasing. By March 1959 the amount of cesium-137 had risen to 128 mc. per square mile at Lemont (Gustafson 1959b). At the same time Low and Edvarson (1959) working in Sweden found 39.4 mc. of cesium-137 per square kilometer (equivalent to 102 mc. per square mile). In June of 1960 Gustafson, Brar, and Kerringan (1960) concluded that the amount of cesium-137 and other fission-produced gamma-ray emitters had reached

a maximum and was now declining at a rate closely related to their half-lives. The highest amount reported in 1960 was 198 mc. per square mile, although 201 mc. per square mile had been reported in October 1959 (Gustafson, Marinelli and Brar 1959).

Other workers such as Welford and Collins (1960) have reported the amount of individual gamma-ray emitters in rainwater. Lundblom (1962), Gustafson, Kerringan, and Brar (1961), and others have reported on the amount of cesium-137 in the air at ground level. Ljunggren (1960), working in Norway, and Olson (1961), working in Tennessee, have reported on the gamma-ray emitters in living plant material (especially tree leaves).

III. THE PROBLEM AREA

The study area was the Great Smoky Mountains National Park (GSMNP). Located in the Blue Ridge Province and part of the Unaka Chain (King and Stupka 1950), the Great Smoky Mountains have a relief of over a mile. Shanks (1954) reported temperature and precipitation data collected for the five year period 1946 to 1950. He found the mean annual temperature varied from 56.6° F. at 1460 feet to 45.8° F. at 6300 feet and the mean annual precipitation ranged from 57.8 inches at 1460 feet to 90.9 inches at 6300 feet. The data suggest a humid climate at the lower elevations and a perhumid climate at the higher elevations with the boundary between the humid and perhumid climates falling a short distance above the 1400 foot station (Shanks 1954). With such varying physiographic and climatic conditions, the area presents good conditions for studying distribution patterns of radioactive fallout material as related to environmental patterns.

Collections were made at ten sites, one at 6600 feet, four at 5200 feet, four at 3400 feet, and one at 1400 feet. The approximate locations and site descriptions which follow are summarized in Table II. Citation of species follows the nomenclature of Fernald (1950) and Little (1953). Sampling was done between August 29, 1961 and September 13, 1961.

1. Clingmans Dome Evergreen (66E). Located on a southeast-facing slope on the north side of the trail 0.2 miles from Forney Ridge Parking Area toward Clingmans Dome, GSMNP, at an elevation of

approximately 6600 feet. The closed canopy was made up of Picea rubens and Abies fraseri. The trees were mostly below ten inches in diameter at breast height. The ground cover consisted mostly of the feather-moss Hylocomium splendens.

2. Beech Gap North-facing Evergreen (HNE). Located on a north-facing slope on the south side of the Appalachian Trail 0.6 miles from Newfound Gap toward Clingmans Dome, GSMNP, at an elevation of approximately 5200 feet. The closed canopy consisted of Picea rubens and Abies fraseri. The understory was made up of scattered Viburnum alnifolium. The ground cover was made up of dense mats of the feather-moss Hylocomium spendens.

3. Beech Gap North-facing Deciduous (HND). Located on a north-facing slope on the north side of the Appalachian Trail 0.8 miles from Newfound Gap toward Clingmans Dome, GSMNP, at an elevation of approximately 5200 feet. The moderately well closed canopy was made up of Betula alleghaniensis and Fagus grandifolia. The ground cover consisted of mixed ferns and broad-leaved herbs.

4. Beech Gap South-facing Evergeen (HSE). Located on a south-facing slope on the south side of the Appalachian Trail 0.8 miles from Newfound Gap toward Clingmans Dome, GSMNP, at an elevation of approximately 5200 feet. The closed canopy was made up of Picea rubens and Abies fraseri. The understory consisted of scattered Viburnum alnifolium. The ground cover was made up of the feather-moss Hylocomium splendens.

5. Beech Gap South-facing Deciduous (HSD). Located on a south-facing slope on the south side of the Appalachian Trail 0.8 miles from Newfound Gap toward Clingmans Dome, GSMNP, at an elevation of approximately 5200 feet. The moderately well closed canopy consisted mainly of Fagus grandifolia with a few Betula alleghaniensis. The ground cover was made up of ferns and broad-leaved herbs.

6. Chimneys North-facing Evergreen (LNE). Located on a north-facing slope on the north side of the trail 0.2 miles from the Chimneys Parking Area toward the Chimneys Camping Ground, GSMNP, at an elevation of approximately 3400 feet. The closed canopy was made up of Tsuga canadensis with a few Betula alleghaniensis. The understory consisted of dense stands of Rhododendron maximum. The ground cover was sparse, consisting of ferns and mosses.

7. Chimneys North-facing Deciduous (LND). Located on a north-facing slope on the south side of the trail 0.5 miles from the Chimneys Parking Area toward the Chimneys Camping Ground, GSMNP, at an elevation of approximately 3400 feet. The moderately well closed canopy consisted of Tilia heterophylla, Acer saccharum, Aesculus octandra, and Helesia carolina. The dense ground cover was made up of ferns and broad-leaved herbs.

8. Chimneys South-facing Evergreen (LSE). Located on a south-facing slope on the south side of highway US 441 at the west end of the Chimneys Parking Area, GSMNP, at an elevation of approximately 3400 feet. The moderately well closed canopy consisted of Tsuga canadensis

with some Betula alleghaniensis. The understory was made up of Rhododendron maximum. The ground cover was very sparse.

9. Chimneys South-facing Deciduous (LSD). Located on a south-facing slope on the north side of highway US 441 100 yards west of the Chimneys Parking Area, GSMNP, at an elevation of approximately 3400 feet. The closed canopy consisted of Tilia heterophylla, Acer saccharum, Aesculus octandra, and Betula alleghaniensis. The ground cover was made up of dense stands of broad-leaved herbs and ferns.

10. Metcalf Bottoms Evergreen (14E). Located on a level area on the west side of highway US 411 at Metcalf Bottoms Picnic Area, GSMNP, at an elevation of approximately 1400 feet. The moderately well closed canopy consisted of Pinus virginiana and Pinus echinata with a few Liriodendron tulipfera. The ground cover was made up of broad-leaved herbs, grasses, and ferns.

TABLE II

SUMMARY OF STAND DESCRIPTIONS

Site	Elevation	Aspect	Vegetation
66E	6600	Southeast	Spruce-Fir
HNE	5200	North	Spruce-Fir
HND	5200	North	Birch-Beech
HSE	5200	South	Spruce-Fir
HSD	5200	South	Beech-Birch
LNE	3400	North	Hemlock
LND	3400	North	Cove Hardwood
LSE	3400	South	Hemlock
LSD	3400	South	Cove Hardwood
14E	1400	Level	Pine

IV. METHODS

Field Methods

Forest floor and soil collection. At each of the ten sites five samples of the forest floor and mineral soil were collected. Representative collection sites were selected, care being taken to stay well within the type described and to stay away from any fallen trees.

Collection of the forest floor samples were made by placing a one-foot-square piece of cardboard on the litter, then taking a knife and cutting around the edge of the cardboard, through the forest floor and into the mineral soil. The surrounding forest floor was then carefully raked away and the material under the cardboard was collected by layers (Litter or L layer, F layer, and H layer, Lutz and Chandler 1946). The samples were placed in labeled containers and brought to the laboratory.

Samples of the mineral soil at all sites were collected by placing a six-inch-square piece of cardboard in the middle of the mineral soil exposed by the collection of the forest floor samples. One of two methods was used in the collection of the mineral soil samples. In the first method a trenching shovel and a heavy knife were used to expose the soil profile beneath the piece of cardboard. Then, using the heavy knife, three one-and-one-half-inch layers of the mineral soil were collected. By the second method, which was used

only when it was impossible to use the first method, the soil was carefully dug out with a knife and a small hand shovel. All roots and rocks in the profile were included in the sample. The soil samples were placed in labeled containers and brought to the laboratory.

Laboratory Methods

Counting. After the material was brought to the laboratory it was placed in a 105° C. forced-draft oven for forty-eight hours. It was removed and weighed, then transferred to quart-size plastic bags and taken to the Health Physics Whole Body Counting Laboratory of the Oak Ridge National Laboratory at Oak Ridge, Tennessee, where gamma-ray analysis was carried out.

The five samples of similar material from each site were made into a composite sample for the purpose of gamma-ray analysis. Thus the five litter samples from HND were combined and counted as one sample, the five F layers were counted as one, etc. The composite samples were placed in plastic containers designed by the Health Physics Laboratory for analysis of bulk samples. The containers were then placed over thallium-activated sodium iodide crystals. One crystal was 3 x 3 inches and the other was 2 x 4 inches. The 3 x 3 inch crystal gave better resolution than the 2 x 4 inch crystal but was not as efficient. Pulses of different energies from the 2 x 4 inch crystal were sorted into channels 0 to 99 of a 200 channel RIDL (Radiation Instrument Development Laboratory) pulse height analyzer and the pulses from the 3 x 3 inch crystal were sorted into channels 100 to 199 of the

same 200 channel pulse height analyzer. A background count was made with each crystal and subtracted from the gross count before the data were printed out by the analyzer. Beta radiation contribution to the values recorded was minimized by using a beryllium absorber with a mass of 1.23 grams per square centimeter.

Standards with similar counting geometry for the L, F, and H material were made by pipetting standard solutions of isotopes into seven cellulose sponges in plastic bags (Olson 1961).

Standards for the mineral soil were made by pipetting standard solutions of isotopes into 100 gram samples of mineral soil. After drying each 100 gram sample was thoroughly mixed with enough soil to give a standard with counting geometry similar to that of the soil samples. Activity in counts per minute due to the introduced isotope was determined by subtracting the counts of a blank sample of mineral soil of the same type as that of the "spiked" soil from the counts of the "spiked" soil. A soil sample from four and one-half inches to six inches deep was stripped of its potassium-40 activity and used as a standard for thorium-uranium. Monozite sand was also used as a standard for thorium. Potassium chloride was used as the standard for potassium-40.

Computations of net counts per minute (CPM) and disintegrations per minute (DPM). Estimates of CPM due to the individual isotope were made by graphically stripping the spectra of standards from the spectrum of the sample (Figure 1 in Results and Discussion). This is done to

correct for scatter radiation in the photopeak of the isotope measured (Gustafson, Marinelli, and Brar 1958). The spectra had been plotted on semi-log graph paper. After making a number of estimates as described above, a simple mathematical formula was derived which could be used to make estimates of CPM in the samples being studied (Appendix). A comparison of the two methods is presented in Table VIII and discussed in the Results and Discussion.

After CPM for an isotope were determined, DPM for the isotope were determined by comparison with CPM of a standard of the same isotope (Appendix).

Soil analysis. The Sevier County soil survey (Hubbard, et al. 1956), the Swain County soil survey (Perkins and Gettys 1947), and a geologic map of East Tennessee (Rodgers 1953) made possible general identification of probable soil type and geologic material. These classifications were checked by field observations at each site.

After the samples had been dried and weighed as described earlier, bulk densities were calculated. The pH was determined electrometrically for the mineral soil and humus (H) layers, using a 1 to 1 water and material suspension and a Beckman Model G pH meter.

Mechanical analysis was made by the hydrometer method as described by Bouyoucos (1936) and modified by Day (1956).

V. RESULTS AND DISCUSSION

Soil and forest floor. The soil type as given in the Swain County soil survey (Perkins and Gettys 1947) for sites one through three was Rough mountainous land (Ramsey soil material). Sites four through nine was also Rough mountainous land (Ramsey soil material) and site ten was Staser fine sandy loam (Hubbard, et al. 1956). The geologic material for sites one through nine was Great Smoky conglomerate while the parent material at site ten was alluvium from the Little Pigeon River, surrounded by and principally derived from the Lowest part of the Ocoee series (Rodgers 1953).

Mechanical analysis of the mineral soil (Table III) showed that the soil was moderately coarse textured (sandy loam). The soil was low in clay (2-8%) with more sand than silt in all cases except at the 66E station. The 54% sand, 40% silt, and 6% clay for the HSE stand is in agreement with the 57.2% sand, 36.9% silt, and 5.9% clay reported by McCracken, Shanks, and Clebsch (1962) for the same stand.

The thickness of the organic layers differed with forest type (Table IV). As expected the evergreen types had a thicker organic layer than the deciduous types. The data are in general agreement with data taken in the same area by McGinnis (1958), although the H layer was much thicker in sites LNE and LSE than reported for the hemlock-hardwood site McGinnis studied.

Table V presents the weight of the unincorporated organic matter on the forest floor in tons per acre. The HSE stand showed

TABLE III

PARTICLE SIZE DISTRIBUTION IN THE 1.5- TO 3-INCH SOIL LAYERS FROM THE DIFFERENT SITES

Site	Sand %	Silt %	Clay %	Textural Class[a]
66E	38	55	7	Silt loam
HNE	63	51	6	Sandy loam
HND	62	35	3	Sandy loam
HSE	54	40	6	Sandy loam
HSD	58	36	6	Sandy loam
LNE	50	42	8	Loam
LND	62	30	8	Sandy loam
LSE	75	23	2	Loamy sand
LSD	80	15	5	Loamy sand
14E	68	29	3	Sandy loam

[a]Determined from the textural triangle, Soil Survey Manual (Soil Survey Staff 1951), page 209.

TABLE IV

THICKNESS OF THE ORGANIC LAYERS (L, F, AND H)
AT THE DIFFERENT SITES IN INCHES

Site	Organic Layers		
	L	F	H
66E	0.5	1.5	0.5
HNE	0.5	2.0	3.0
HND	0.5	1.0	--
HSE	0.5	2.0	3.5
HSD	0.5	0.75	--
LNE	0.5	1.5	3.0
LND	0.5	1.0	--
LSE	0.5	1.5	2.5
LSD	0.5	1.5	--
14E	0.5	2.0	0.5

TABLE V

WEIGHT OF THE UNINCORPORATED ORGANIC MATTER IN THE L, F, AND H LAYERS IN TONS PER ACRE AT EACH SITE

Site	Layer			Total
	L	F	H	
66E	3.12	14.18[a]		17.30
HNE	2.34	13.78	19.52	35.64
HND	1.41	4.94	--	6.35
HSE	2.01	11.31	26.30	39.62
HSD	1.59	2.86	--	4.45
LNE	1.84	6.46	27.29	35.59
LND	1.48	5.27	--	6.75
LSE	1.92	6.23	29.14	37.29
LSD	2.07	4.77	--	6.84
14E	1.24	6.57[a]		7.81

[a]F and H layers.

the greatest accumulation of organic matter, with the HNE, LNE, and LSE stands in the same range. The accumulation under the spruce-fir stands (HNE and HSE) falls between the 87,400 pounds reported by McGinnis (1958) and the 66,941 pounds reported by Morgan and Lunt (1931) for similar types. The accumulation under the hemlock stands (LNE and LSE) was about twice the amount reported by McGinnis (1958) for a hemlock-hardwood stand, but this is believed to be due to a difference in type of stands. There was no H layer under the stand McGinnis sampled while there was a thick H layer under the stand here reported. The organic matter accumulation under the evergreen stands with a prominent H layer was approximately six times as much as that under the deciduous stands. The H layer was the horizon of maximum organic matter accumulation in the HNE, HSE, LNE, and LSE stands, the amount being approximately two times the amount in the L and F layers in the HNE and HSE stands and approximately four times the amount in the L and F layers in the LNE and LSE stands. The deciduous stands showed two to three times as much accumulation in the F layer as in the L layer.

Bulk density (Table VI) showed a general increase with depth. The bulk densities of the L and H layers did not vary greatly between stands. On the other hand the bulk density of the F layer was greater under evergreen cover than it was under the deciduous cover in every case. The bulk densities of the mineral soil ranged from 0.28 grams per cubic centimeter to 1.46 grams per cubic centimeter. This is similar to the range of 0.50 to 1.41 grams per cubic centimeter

TABLE VI

BULK DENSITIES OF THE VARIOUS LAYERS IN GRAMS PER CUBIC CENTIMETER AT EACH SITE

Site	Organic Layers			Mineral Soil		
	L	F	H	0-1.5 Inches	1.5-3 Inches	3-4.5 Inches
66E	0.06	0.13[a]		0.70	0.89	1.02
HNE	0.04	0.12	0.17	0.45	0.49	0.64
HND	0.03	0.09	--	0.40	0.56	0.62
HSE	0.04	0.12	0.18	0.69	0.78	0.83
HSD	0.03	0.08	--	0.45	0.56	0.78
LNE	0.03	0.11	0.16	0.64	0.66	N.D.
LND	0.03	0.09	--	0.38	0.56	0.71
LSE	0.04	0.11	0.17	0.36	0.66	1.00
LSD	0.04	0.08	--	0.28	0.37	0.40
14E	0.02	0.12[a]		1.01	1.41	1.49

[a]F and H layers.

reported by McGinnis (1958) in his study of forest humus types of East Tennessee.

The pH of the H layer of the spruce-fir stands (Table VII) was in the same range reported by McGinnis (1958). The pH of the mineral soil was similar to the 3.4 reported by McGinnis (1958) and also by McCracken, Shanks, and Clebsch (1962) for spruce-fir. The pH under the deciduous stands at the higher elevation (3.4 to 3.7) was in agreement with the 3.7 reported by McCracken, Shanks, and Clebsch (1962) for the upper three inches of soil in a high elevation deciduous stand, but lower than the 4.1 to 4.3 reported by McGinnis (1958) and 4.5 found by Cain (1931) in the same area. The pH of the hemlock stands was similar to the pH of the spruce-fir stands while the hydrogen ion concentration of the low elevation deciduous stands was an order of magnitude lower than the high elevation deciduous stands but in the same range as the pine stand at 1400 feet. The low elevation deciduous stands had a pH similar to the 4.7 reported by McGinnis (1958) for a similar stand.

Comparison of methods used in determining CPM. Figure 1 shows the graphical method to determine CPM and the mathematical method is given in the Appendix. Table VIII provides a comparison of data obtained by the two methods on a series of samples.

The graphical method gave the higher count two times and the mathematical method gave the higher count three times. The per cent difference ranged from 6.9% favoring the graphical method to 7.4% favoring the mathematical method. The per cent difference increased

TABLE VII

pH OF THE H LAYER AND THE THREE ARBITRARY LAYERS OF MINERAL SOIL

Site	H	Layers		
		0-1.5 Inches	1.5-3 Inches	3-4.5 Inches
66E	--	3.42	3.30	3.48
HNE	3.11	3.05	3.45	3.45
HND	--	3.40	3.65	3.65
HSE	3.22	3.20	3.80	3.70
HSD	--	3.70	3.55	3.44
LNE	3.15	3.20	3.52	N.D.
LND	--	4.85	4.85	4.90
LSE	3.25	3.01	3.32	3.22
LSD	--	4.32	5.08	4.56
14E	--	4.72	4.62	4.60

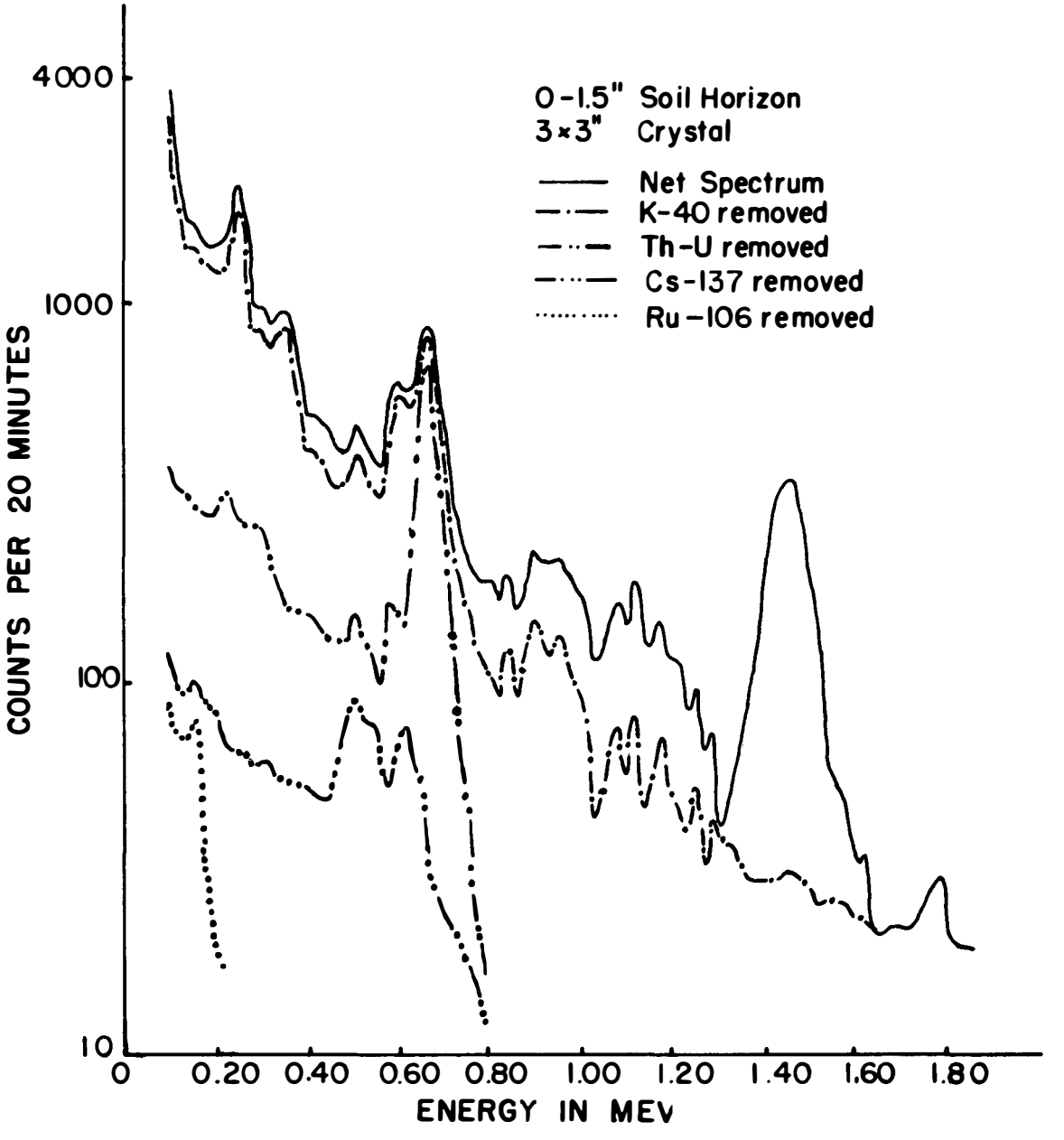

FIGURE 1

GRAPHICAL METHOD OF STRIPPING A SAMPLE SPECTRUM INTO ITS COMPONENT PARTS

TABLE VIII

COMPARISON OF TWO METHODS USED TO OBTAIN COUNTS PER 20 MINUTES DUE TO CESIUM-137 IN THE CESIUM-137 PHOTOPEAK

Sample	Graphical Method	Mathematical Method	Difference[a] %
6600 L	3140	3194	+1.7
6600 F	9570	9678	+1.1
6600 0-1.5	2130	1992	-6.9
6600 1.5-3	910	983	+7.4
6600 3-4.5	395	374	-5.6

[a]Per cent difference was obtained by dividing the difference between the two figures by the figure of the mathematical method and multiplying by 100.

in the mineral soil. This was due to an increase in the amount of thorium-uranium present in the sample which greatly increased the back-scatter in the cesium-137 photopeak. Figures 2, 3, 4, 5, and 6 show typical spectra of the various layers with the dominance of the cesium-137 and the low amount of other fission-produced gamma-emitters in the material. The low amount of other fission-produced gamma-emitters was due to the fact that there had been no major nuclear test for approximately three years (fall of 1958) before the collection of material was made and therefore most of the activity of the short-lived gamma-emitters was gone (Lundblom 1962). Ruthenium-106 and cerium-144 were the only other fission-produced gamma-ray emitters present that were identifiable in the samples.

Cesium-137. The range of cesium-137 in millicuries per square mile (Table IX) in the study area was 246.2 to 386.0. This is approximately 20 to 100 per cent higher than the 191 mc. per square mile reported in the Lemont, Illinois area in June 1960 (Gustafson, Brar, and Kerringan 1960).

A comparison of the two exposures and cover types at 3400 feet with the two exposures and cover types at 5200 feet by means of a factoral analysis of variance (Table X) indicated no significant difference at the 95% confidence level with exposure or cover type, but there was a significant difference with elevation. Figure 7 shows graphically the distribution of total cesium-137 with elevation. The coefficient of determination (R^2) of the regression of cesium-137 on elevation was 0.84.

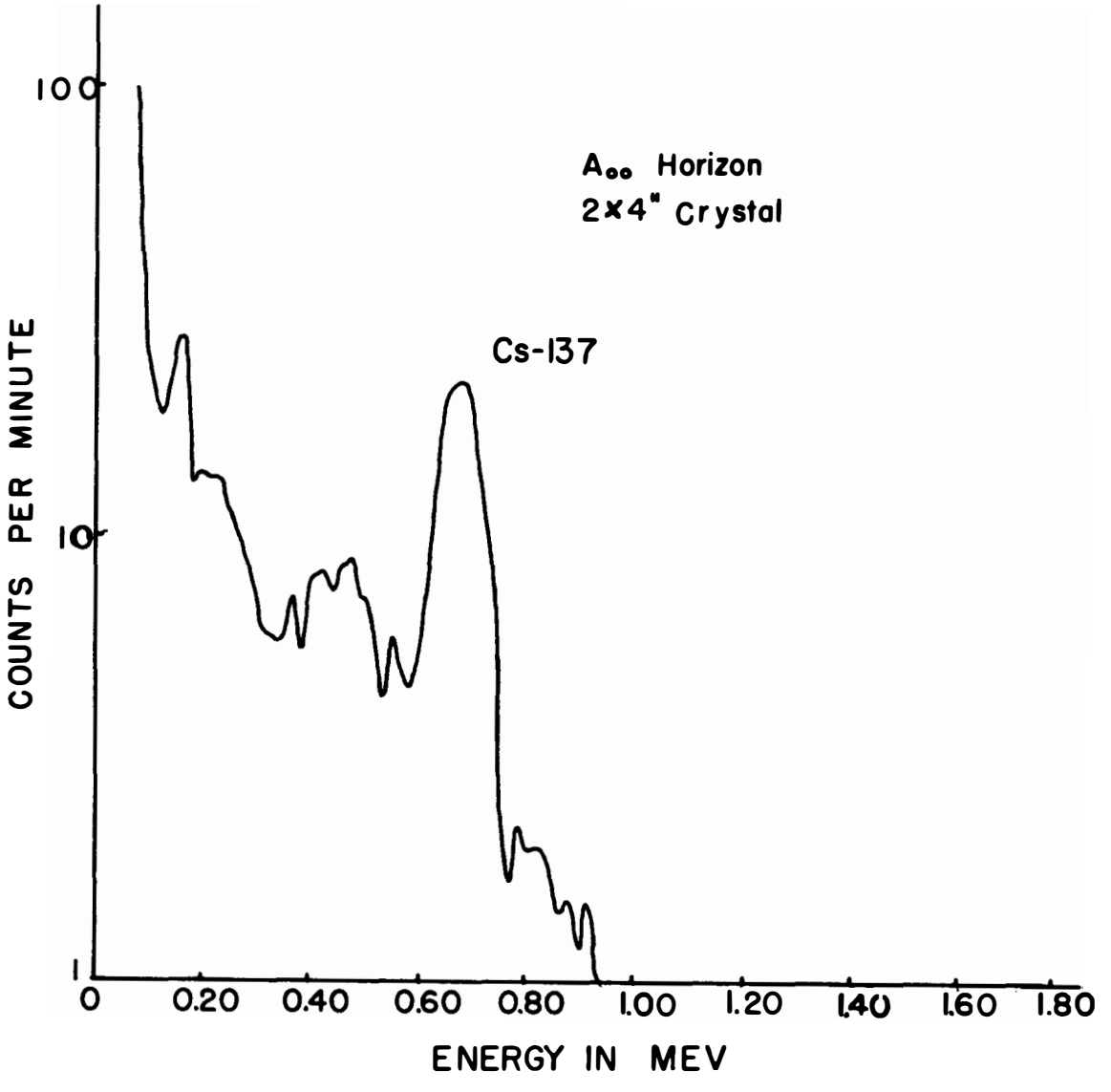

FIGURE 2

TYPICAL SPECTRUM OF THE LITTER (L) LAYER, TAKEN FROM THE HND STAND

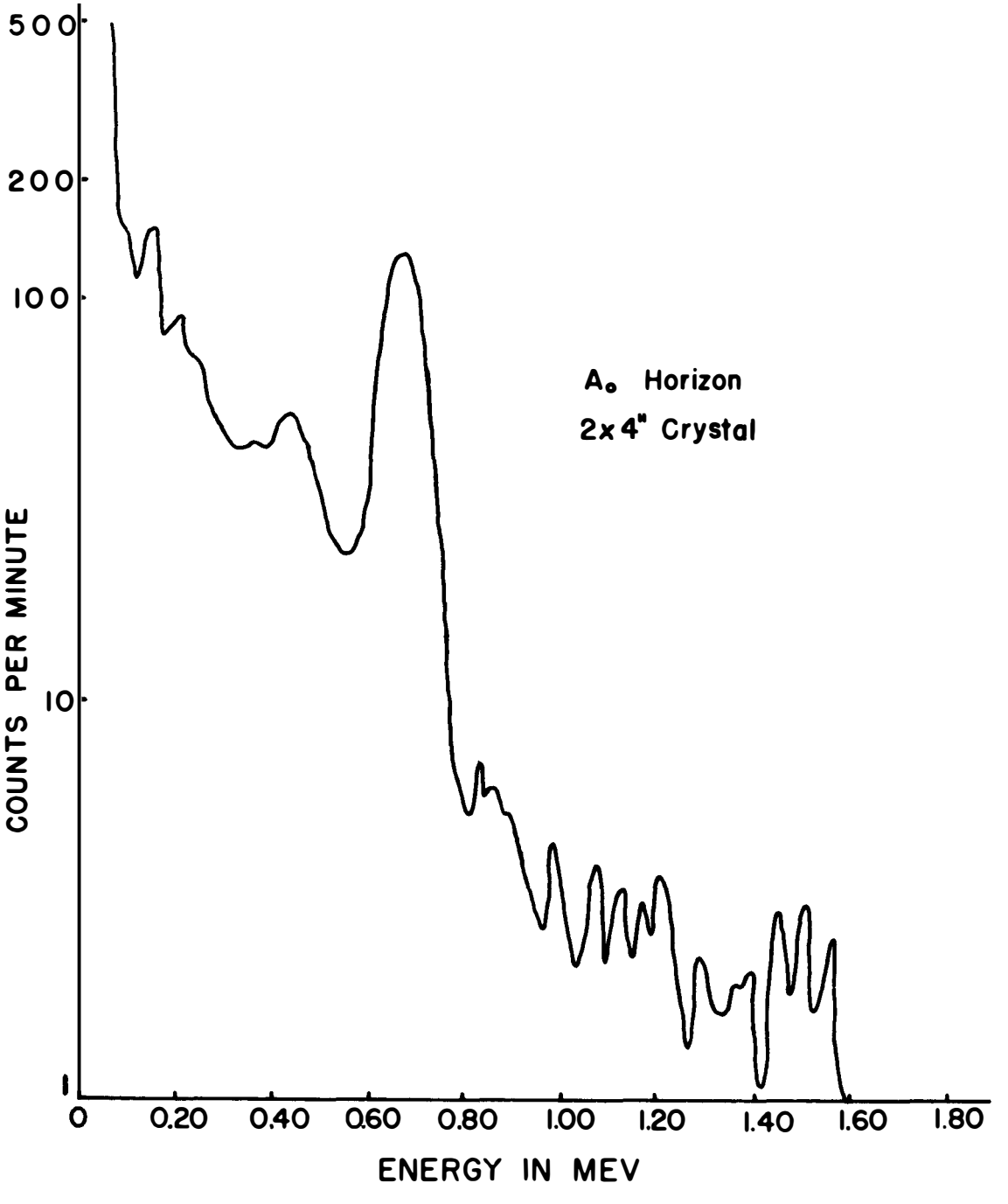

FIGURE 3

TYPICAL SPECTRUM OF THE FERMENTATION (F) LAYER, TAKEN FROM THE HND STAND

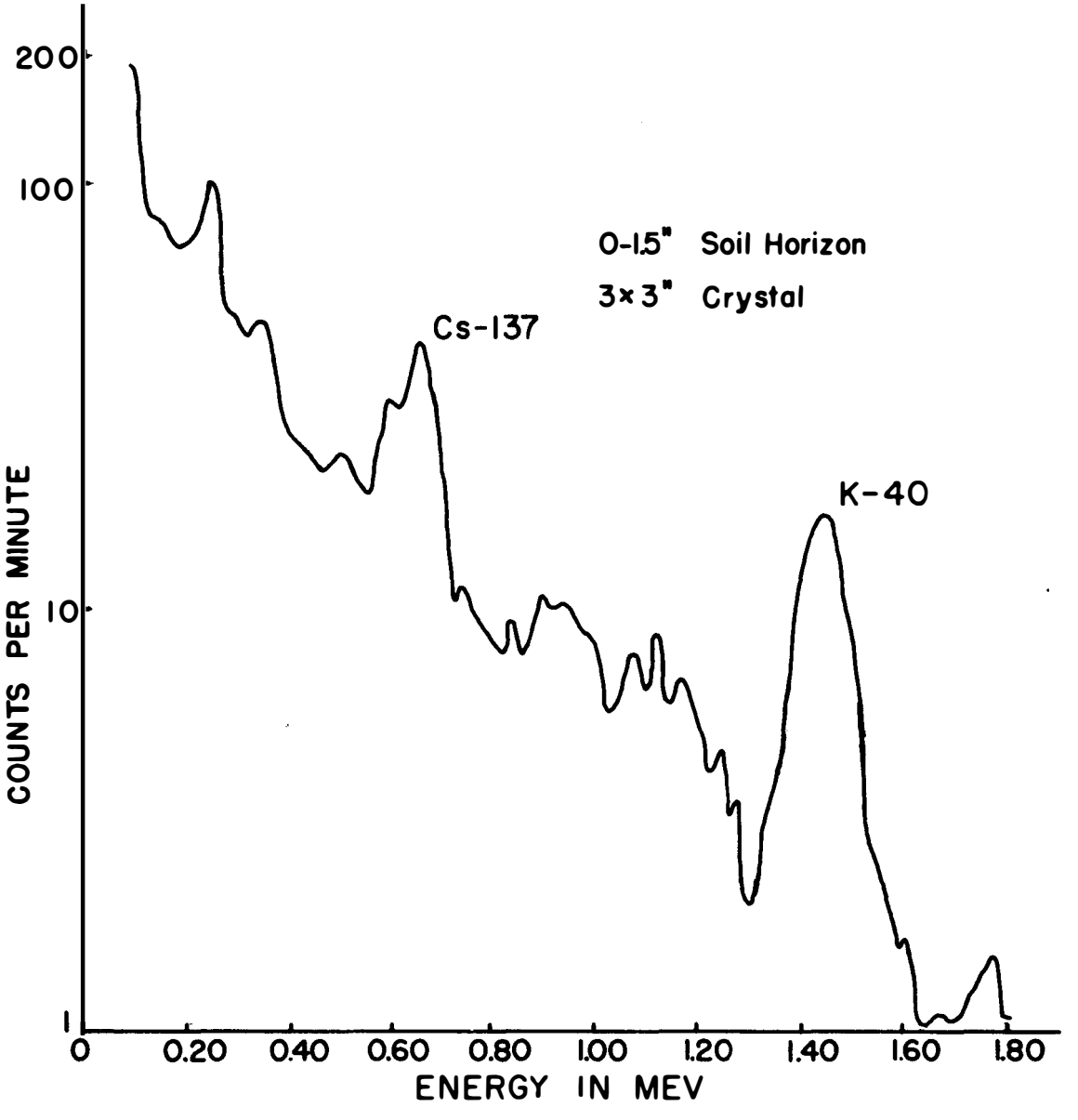

FIGURE 4

TYPICAL SPECTRUM OF THE 0-1.5 INCH SOIL LAYER, TAKEN FROM THE HND STAND

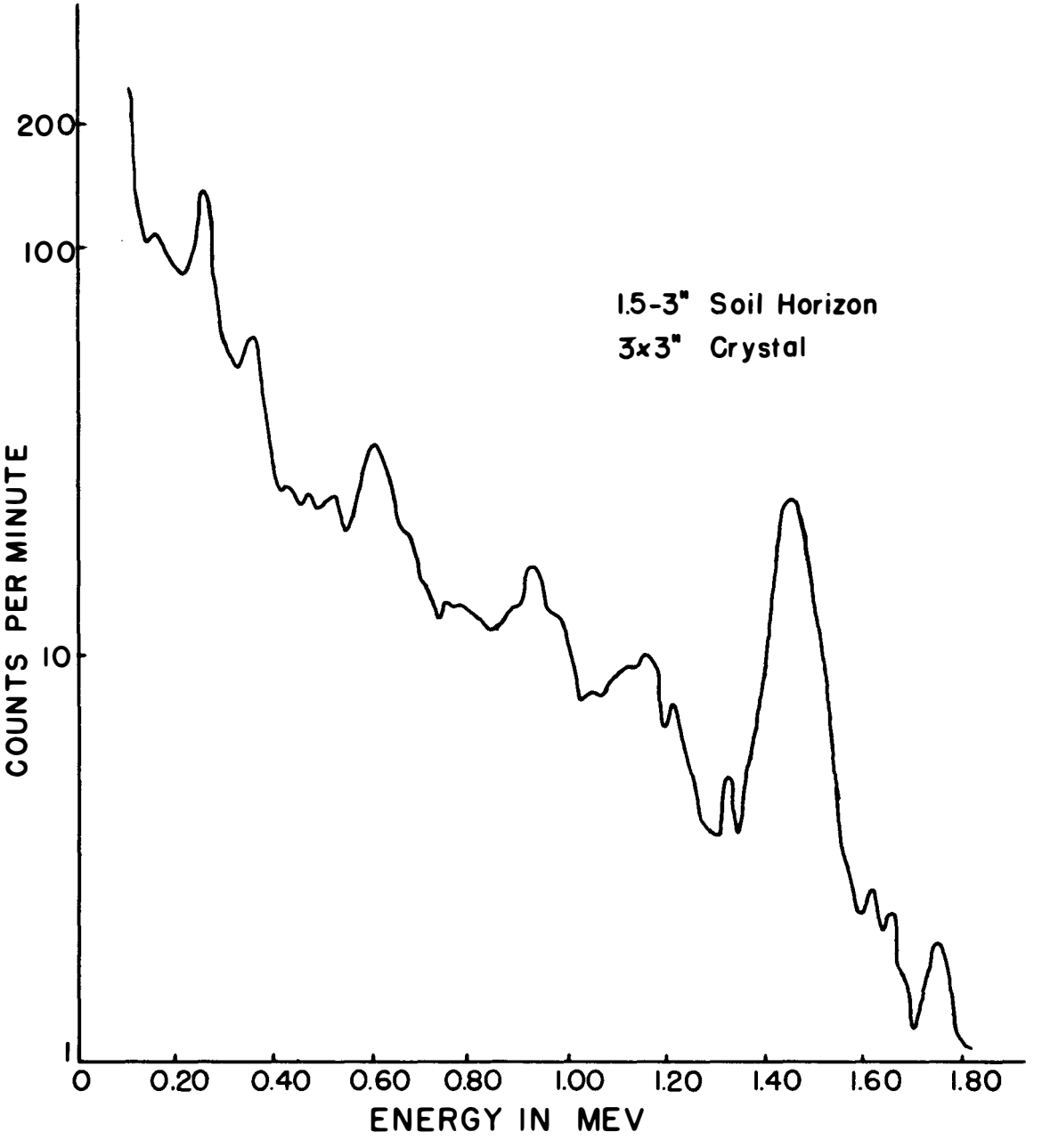

FIGURE 5

TYPICAL SPECTRUM OF THE 1.5-3 INCH SOIL LAYER, TAKEN FROM THE HND STAND

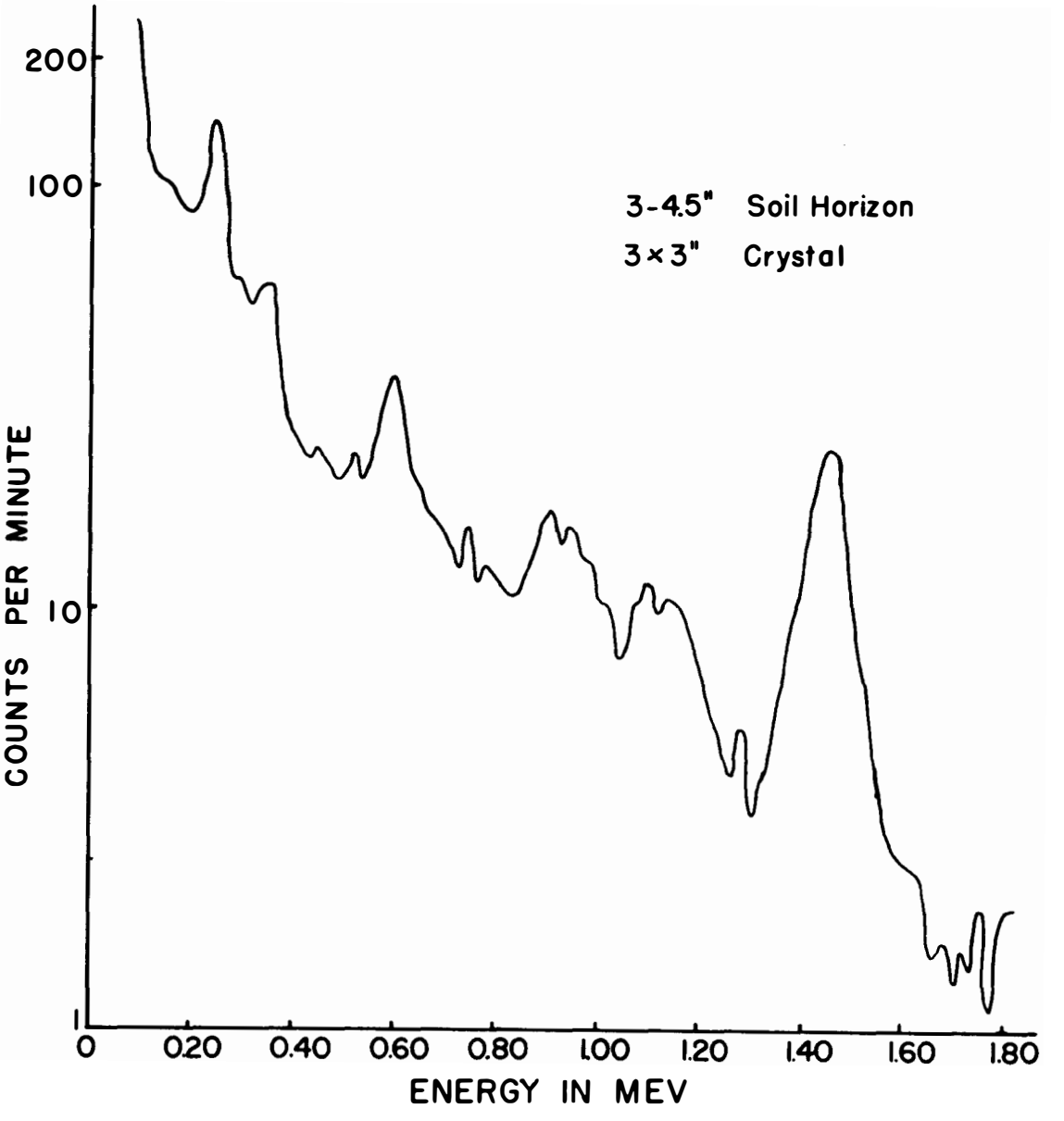

FIGURE 6

TYPICAL SPECTRUM OF THE 3-4.5 INCH SOIL LAYER, TAKEN FROM THE HND STAND

TABLE IX

DISTRIBUTION OF CESIUM-137 IN THE VARIOUS LAYERS EXPRESSED IN MILLICURIES PER SQUARE MILE, SEPTEMBER 1, 1961

Elevation Feet	Exposure	Cover	Precipitation Inches Per Year	Cesium-137 Content by Layers						
				L	F	H	0-1.5 Inches	1.5-3 Inches	3-4.5 Inches	Total
6600	Southeast	Evergreen	90.9	43.8	121.3[a]		135.9	66.1	19.0	386.0
5200	North	Evergreen	90.0	37.5	235.9	33.1	19.8	0.3	4.5	331.1
5200	North	Deciduous	90.0	19.0	186.4	--	104.2	17.7	6.9	334.2
5200	South	Evergreen	90.0	30.3	213.6	70.9	25.5	N.D.	N.D.	340.3
5200	South	Deciduous	90.0	17.8	75.2	--	193.6	44.8	17.4	348.8
3400	North	Evergreen	76.3	10.4	86.1	108.3	33.3	8.2	N.D.	246.2
3400	North	Deciduous	76.3	6.1	91.6	--	155.1	32.7	10.5	296.0
3400	South	Evergreen	76.3	9.8	75.5	94.6	66.9	11.1	12.4	270.3
3400	South	Deciduous	76.3	5.4	73.2	--	84.5	89.6	32.6	285.3
1400	Level	Evergreen	57.8	9.1	77.1[a]		138.5	26.8	5.2	256.9

[a]F and H layers.

TABLE X

ANALYSIS OF VARIANCE OF TOTAL CESIUM-137 WITH ELEVATION, COVER TYPE, AND EXPOSURE: FACTORIAL DESIGN

Source	d.f.	SS	MS	F
Elevation	1	8230.4	8230.4	608.76[a]
Exposure	1	173.0	173.0	12.79
Error I	1	13.5	13.5	--
Cover	1	729.6	729.6	3.61
Cov. x Elev.	1	353.8	353.8	1.75
Cov. x Exp.	1	108.0	108.0	0.54
Error II	1	202.0	202.0	--
Total	1	9810.4		

[a]Significant at the 95% confidence level.

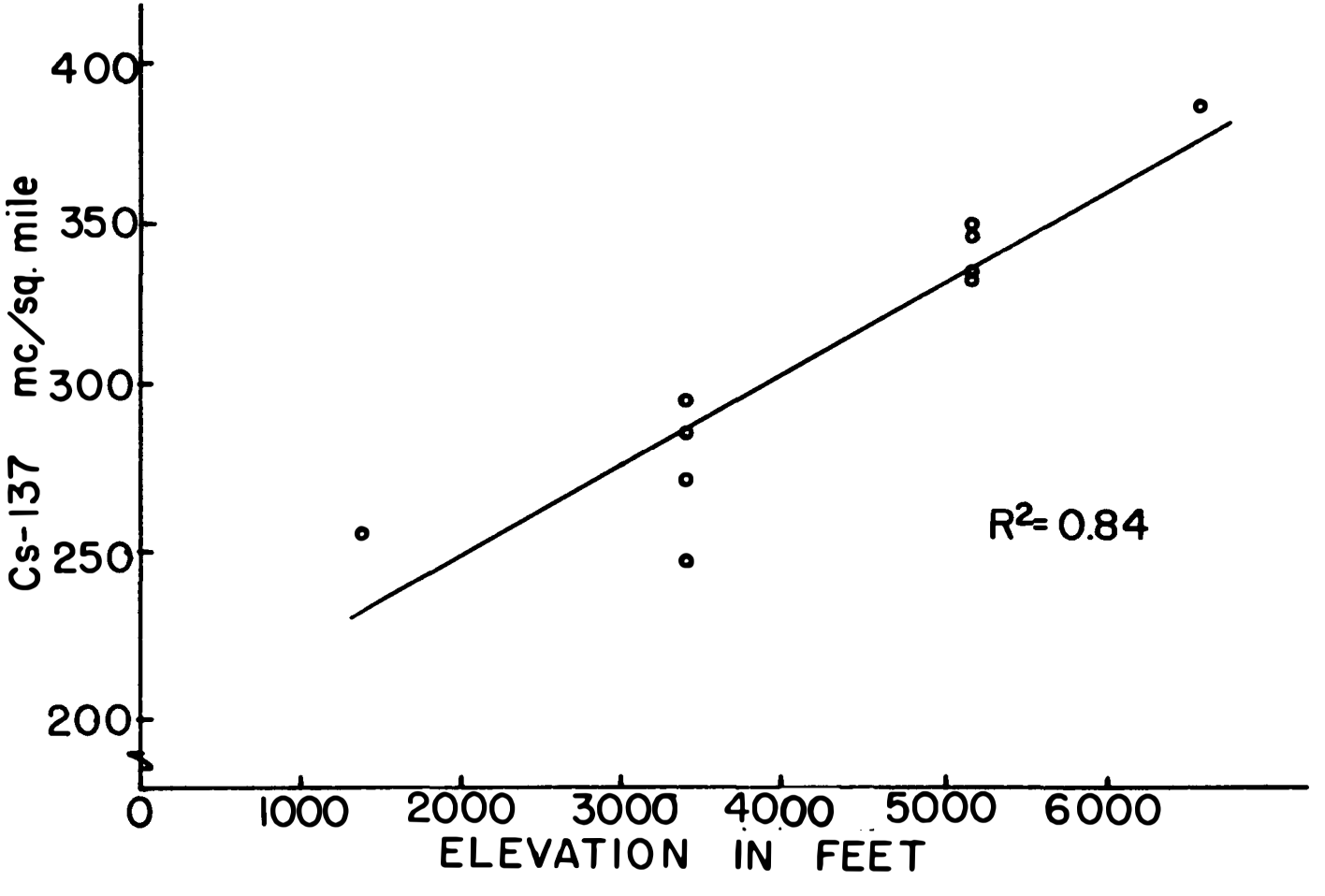

FIGURE 7

REGRESSION OF TOTAL CESIUM-137 ON ELEVATION

The difference in the distribution of cesium-137 with elevation seems most closely related to the amount of precipitation an area received. The ratio of precipitation between 5200 feet and 3400 feet was 1.18 and the ratio of cesium-137 between these same elevations was 1.23. Taking the whole range from 6600 feet to 1400 feet, the precipitation ratio was 1.57 and the cesium-137 ratio was 1.51. Other workers have also found a relationship between precipitation and the distribution of radioactive fallout. Welford and Collins (1960) reported that rainfall is clearly a controlling factor in the fallout deposition patterns of strontium-90 and cesium-137. Booker (1959), working in Great Britain, found that dried milk from a region of low rainfall contained a lower concentration of cesium-137 than dried milk from a region of higher rainfall. Libby (1958) reported that "there is essentially no world-wide fallout in the absence of rainfall." Gustafson (1959) reported that there was a close relationship between the ratio of cesium-137 to strontium-90 in rainwater.

Table XI is a comparison of the distribution of cesium-137 in the different layers in the evergreen stands at 5200 feet and 3400 feet and the deciduous stands in the same locations. The data show that 80% of the cesium-137 activity was in the organic matter and upper inch and one-half of mineral soil in the deciduous stands and 96% was in the same layers in the evergreen stands. These figures approximate the 89% Gustafson reported in grass, organic matter, and the upper inch and one-half of the soil. He found 3% of the total activity in the 3-4.5 inch soil layer while here the range was from 2% in the

TABLE XI

DISTRIBUTION OF CESIUM-137 IN THE DIFFERENT LAYERS IN PER CENT OF THE TOTAL CESIUM-137

Material	Cover		
	Deciduous %	Evergreen %	Grass[a] %
Organic Layers			
L	4	7	67[b]
F	36	49	
H	--	27	
Mineral Soil			
0-1.5 inches	40	13	27
1.5-3 inches	15	2	8
3-4.5 inches	5	2	3

[a]Adapted from Gustafson, Marinelli, and Brar (1957).

[b]Per cent of the total activity in grass and organic material.

evergreen to 5% in the deciduous. Maximum retention in the upper part of the soil is inferred from the work done by Cline (1960) on the movement of cesium-137 through a nine-inch soil column in the laboratory. He found that 10% of the cesium-137 moved beyond the surface inch in an acid soil when 300 column inches of well water, containing 261 micrograms of total solids per milliliter of water, was passed over the column. He found more movement when 0.1 N KCl was substituted for the water.

The per cent of cesium-137 in the organic matter under the evergreen was approximately 2.1 times that of the deciduous stands. This is assumed to be due to the thicker organic layer (Table IV) present under the evergreen stands, which served as an ion-exchange area on which the cesium-137 could become adsorbed and thereby reduce its further movement through the profile. Cline's (1960) work showed that "cesium, after becoming adsorbed to a soil colloid, becomes difficult to replace and was relatively unavailable to plants."

Other gamma-emitting fission products. The only other identifiable fission-produced gamma-emitters present in the material were ruthenium-106 and cerium-144, which together contributed approximately 28% of the total activity produced by fission-produced gamma-emitters.

Natural gamma-emitters. Potassium-40, thorium, and uranium comprised the natural gamma-emitters present. Table XII gives the activity of potassium-40 in micro-microcuries per gram of material. The counting statistics are very poor on the estimates of potassium-40

TABLE XII

DISTRIBUTION OF POTASSIUM-40 IN THE VARIOUS LAYERS
IN MICRO-MICROCURIES PER GRAM

Site	Organic Layers			Mineral Soil		
	L	F	H	0-1.5 Inches	1.5-3 Inches	3-4.5 Inches
66E	0.69	1.15[a]		2.11	2.24	2.19
HNE	0.60	0.30	1.26	1.88	2.93	2.08
HND	0.61	1.30	--	2.88	2.78	3.04
HSE	0.52	0.34	0.62	1.42	1.37	1.68
HSD	0.63	1.93	--	2.64	2.57	2.42
LNE	0.24	0.16	0.81	1.76	2.65	N.D.
LND	0.31	0.92	--	2.74	2.81	3.11
LSE	0.28	0.35	0.34	1.27	2.32	2.81
LSD	0.45	1.04	--	1.35	2.15	3.33
14E	0.16	1.13[a]		1.58	1.47	1.33

[a]F and H layers.

in the L, F, and H layers, a fact which should be kept in mind when studying these data. Potassium-40 increased with depth in eight of the sites, HSD and 14E showing a decrease with depth. Thorium and uranium showed no consistent pattern of change with depth. The activity of thorium-uranium was slightly more than the activity of potassium-40. The natural radioactivity contributed 80% or more of the total activity in the soil layers.

VI. SUMMARY

The organic layers and three one-and-one-half-inch soil layers were collected at four different elevations and under two contrasting cover types in the Great Smoky Mountains. Gamma-ray analysis was carried out on them with a 200 channel RIDL pulse height analyzer.

Total cesium-137 varied from 246.2 to 386.0 millicuries per square mile. There was no significant difference in the distribution of cesium-137 with cover type or exposure but there was a significant difference at the 95% confidence level in the distribution of cesium-137 with elevation. This difference with elevation seemed most closely related to the amount of precipitation received. The ratio of precipitation from 6600 feet to 1400 feet was 1.57 and the ratio of cesium-137 over the same range was 1.51.

Most of the cesium-137 was in the organic layers and upper one and one-half inches of the mineral soil. Eighty per cent of the total cesium-137 under the deciduous stands and 96% under the evergreen stands were in this organic material and upper part of the mineral soil.

The other identifiable fission-produced gamma-emitters present were ruthenium-106 and cerium-144 which contributed approximately 28% of the fission product activity. Potassium-40, thorium, and uranium made up the naturally occurring gamma-ray emitters present. They produced 80% or more of the total activity in the soil layers.

BIBLIOGRAPHY

BIBLIOGRAPHY

Baver, L. D. 1956. Soil Physics. John Wiley and Sons, Inc., New York.

Booker, D. V. 1959. Caesium-137 in dried milk. Nature, 183: 921-924.

Bouyoucos, G. J. 1936. Directions for making mechanical analysis of soil by the hydrometer method. Soil Science, 42: 225-229.

_____. 1951. A recalibration of the hydrometer method for making mechanical analysis of soil. Agronomy Journal, 43: 434-438.

Cain, S. A. 1931. Ecological studies of the vegetation of the Great Smoky Mountains of North Carolina and Tennessee. I. Soil reaction and plant distribution. Botanical Gazette, 41: 22-41.

Cline, J. F. 1960. Potassium, cesium-137, and rubidium-86 relationship in plant uptake, soil diffusion rates and irrigation practices. HW-62037.

Crouthamel, C. E. (ed.). 1960. Applied Gamma-ray Spectrometry. Pergamon Press, New York.

Day, P. R. 1950. Physical basis of practical size analysis by the hydrometer method. Soil Science, 70: 363-374.

_____. 1956. Report to the committee on physical analysis (1954-1955). Soil Science Society of America Proceedings, 20: 167-169.

Eisenbud, M. and J. H. Harley. 1953. Radioactive dust from nuclear detonations. Science, 117: 141-147.

_____. 1955. Radioactive fallout in the United States. Science, 121: 677-680.

Fernald, M. L. 1950. Gray's Manual of Botany. American Book Co., New York.

Freese, Frank. 1956. A Guidebook for Statistical Transient. Reprinted by permission of the U. S. Forest Service by and for use of the U. S. Army Engineer Waterway Experiment Station Corp of Engineers, Vicksburg, Mississippi.

Gustafson, P. F. 1959a. Measurement of soil radioactivity and calculation of dose therefrom. pp. 156-163. In Radiological Physics Division Semiannual Report, July through December, 1958, Argonne National Laboratory. Processed Report 5967.

_____. 1959b. Radioactivity measurement and dose calculation on soil collected at Argonne. pp. 53-54. In Radiological Physics Division Semiannual Report, January through June, 1959. Argonne National Laboratory. Processed Report 6049.

_____. 1959c. Ratio of cesium-137 and strontium-90 in the soil. Science, 130: 1404-1405.

Gustafson, P. F., S. S. Brar, and M. A. Kerringan. 1960. Gamma-ray studies on radioactive fallout in soil. pp. 66-67. In Radiological Physics Division Semiannual Report, January through June, 1960. Argonne National Laboratory. Processed Report 6199.

Gustafson, P. F., M. A. Kerringan, and S. S. Brar. 1961. Fission and natural radioactivity in ground level air. pp. 81-85. In Radiological Physics Division Semiannual Report, January through June, 1961. Argonne National Laboratory. Processed Report 6398.

Gustafson, P. F., L. D. Marinelli, and S. S. Brar. 1957. Gamma-ray emitting elements present in the soil. pp. 18-21. In Radiological Physics Division Semiannual Report, January through June, 1957. Argonne National Laboratory. Processed Report 5755.

_____. 1958a. Measurement of gamma-ray emitting elements in the soil. pp. 136-143. In Radiological Physics Division Semiannual Report, July through December, 1957. Argonne National Laboratory. Processed Report 5829.

_____. 1958b. Natural and fission-produced gamma-ray emitting radioactivity in the soil. Science, 127: 1240-1242.

_____. 1959. Gamma-ray studies on radioactive fallout. pp. 69-77. In Radiological Physics Division Semiannual Report, July through December, 1959. Argonne National Laboratory. Processed Report 6104.

Hearings Before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States, Eighty-sixth Congress, First Session on Fallout from Nuclear Weapons Tests, May 5, 6, 7, and 8, 1959. 4 volumes.

Hubbard, E. H., M. E. Austin, C. B. Beadles, W. E. Cartwright, J. A. Elder, and E. P. Whiteside. 1956. Soil Survey of Sevier County, Tennessee. United States Department of Agriculture.

King, P. B. and B. Stupka. 1950. The Great Smoky Mountains, their geology and natural history. Scientific Monthly, 71: 31-43.

Kinsman, Simon (ed.). 1957. Radiological Health Handbook. United States Department of Health, Education, and Welfare; Public Health Service, Bureau of State Services, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

Libby, W. F. 1956. Radioactive fallout and radioactive strontium-90. Science, 123: 657.

_____. 1958. Remarks prepared by Dr. Libby. pp. 253-267. In Environmental Contamination from Weapons Tests. Health and Safety Laboratory. Processed Report 42.

Little, E. L., Jr. 1953. Check List of Native and Naturalized Trees of the United States (Including Alaska). Forest Service. Agriculture Handbook No. 41.

Ljunggren, P. 1960. Fallout of radioactivity in southern Sweden. Nature, 186: 655-656.

Low, K. and K. Edvarson. 1959. Caesium-137 in Swedish milk and soil. Nature, 183: 1104-1106.

Lundblom, G. 1962. Determination of concentration of caesium-137 in precipitation and ground level air in Sweden. Nature, 193: 866-867.

Lutz, H. J. and Robert F. Chandler. 1946. Forest Soils. John Wiley and Sons, Inc., New York.

McCracken, R. J., R. E. Shanks, and E. E. C. Clebsch. 1962. Podsols and Sol Bruns Acides at higher elevations of the Great Smoky Mountains. To be published in Soil Science Society of America Proceedings.

McGinnis, J. T. 1958. Forest litter and humus types of east Tennessee. Unpublished M. S. thesis. The University of Tennessee.

McIlhenny, R. C. and Jane McCarthy. 1959. Analytical gamma spectrometry: semiempirical estimates of response-curve slopes. pp. 40-48. In Fifth Annual Meeting, Bio-assay and Analytical Chemistry Group. Gatlinburg. TID 7591.

Miller, C. E. and L. D. Marinelli. 1956. Gamma-ray activity of contemporary man. Science, 124: 122-123.

Morgan, M. F. and H. A. Lunt. 1931. The role of organic matter in the classification of forest soils. Journal of the American Society of Agronomy, 23: 1059-1060.

Mortenson, J. L. 1961. Radioactive fallout. Agronomy Journal, 53: 343-348.

Olson, J. S. 1961. Ecological sampling and meterological calculation of fallout on forest near Oak Ridge, Oak Ridge National Laboratory. Processed Report 3181.

Perkins, S. O. and W. Gettys. 1947. Soil Survey of Swain County, North Carolina. United States Department of Agriculture.

Rodgers, John. 1953. Geologic Map of East Tennessee with Explanatory Text. Tennessee Division of Geology. Bulletin 58.

Snedecor, G. W. 1957. Statistical Methods. The Iowa State College Press. Ames, Iowa.

Rundo, J. 1958. Measurement of caesium-137 in human beings in the United Kingdom. pp. 249-252. In Environmental Contamination from Weapons Tests. Health and Safety Laboratory. Processed Report 42.

Shanks, R. E. 1954. Climates of the Great Smoky Mountains. Ecology, 35: 354-361.

Soil Survey Staff. 1951. Soil Survey Manual. United States Department of Agriculture.

United States Atomic Energy Commission. 1960. Fallout Studies. Reprinted from the Annual Report to Congress for 1959 of the U. S. Atomic Energy Commission.

Welford, G. A. and W. R. Collins, Jr. 1959. Fallout deposition of seven nuclides in New York City during 1959. pp. 55-63. In Fifth Annual Meeting, Bio-assay and Analytical Chemistry Group. Gatlinburg. TID 7591.

_____. 1960. Fallout in New York City in 1960. Science, 131: 1711-1715.

APPENDIX

I. MATHEMATICAL FORMULA DERIVATION

To account for the backscatter effect of potassium-40 in the cesium-137 photopeak, the average ratio of CPM of a potassium-40 standard in the cesium-137 photopeak to the CPM in the potassium-40 photopeak was determined. This is the backscatter correction for potassium-40 (Z_1).

The thorium-uranium backscatter correction (Z_2) was determined by getting the average ratio of CPM of a thorium-uranium standard in the cesium-137 photopeak to the CPM in the thorium-uranium photopeak. Since the thorium-uranium photopeak used had potassium-40 backscatter in it, a backscatter correction (Z_3) had to be determined for potassium-40 in the thorium-uranium photopeak. This was done by getting the average ratio of CPM of a potassium-40 standard in the thorium-uranium photopeak to the CPM in the potassium-40 photopeak.

Then combining the above:

$$CPM_a = CPM_b - \left[CPM_c \cdot Z_1 + (CPM_d - (CPM_c \cdot Z_3))Z_2\right]$$

where

CPM_a is CPM in the cesium-137 photopeak due to cesium-137

CPM_b is the total CPM in the cesium-137 photopeak

CPM_c is the CPM in the potassium-40 photopeak

CPM_d is the CPM in the thorium-uranium photopeak

Z_1 is the backscatter correction for potassium-40 in the cesium-137 photopeak

Z_2 is the backscatter correction for thorium-uranium in the cesium-137 photopeak

Z_3 is the backscatter correction for potassium-40 in the thorium-uranium photopeak.

II. DETERMINATION OF DPM

$$\frac{CPM_1}{DPM_1} = \frac{CPM_2}{DPM_2}$$

CPM_1 is the counts per minute for an for an isotope in the sample

CPM_2 is the counts per minute for a standard of the isotope in CMP_1

therefore

$$DPM_1 = \frac{CPM_1 \cdot DPM_2}{CPM_2}$$

DPM_1 is the disintegrations per minute for isotope in CPM_1

DPM_2 is the disintegrations per minute for the standard isotope in CPM_2.