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RADIOECOLOGY OF SOME NATURAL ORGANISMS AND SYSTEMS IN COLORADO

ELEVENTH ANNUAL PROGRESS REPORT

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MAY 1, 1972 - APRIL 30, 1973

Department of Radiology
and Radiation Biology
Colorado State University
Fort Collins, Colorado

DISCLAIMER

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ELEVENTH
TECHNICAL PROGRESS REPORT
DEPARTMENT OF RADIOLOGY AND RADIATION BIOLOGY
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

TO: U. S. Atomic Energy Commission
Chicago Operations Office
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FOR THE PERIOD: May 1, 1972 - April 30, 1973

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I. SUMMARY

I. Summary

The broad purpose of this research is to provide information on the behavior of radionuclides in, and radiation sensitivity of, selected organisms and natural ecosystems in Colorado. Components of alpine tundra, montane forests, shortgrass plains and freshwater lakes and streams are currently under investigation with respect to behavior and effects of radionuclides. This research is conducted primarily by graduate students and faculty of the Department of Radiology and Radiation Biology at Colorado State University. Dr. W. C. Nelson, Colorado Division of Wildlife and Dr. W. S. Ferguson, Department of Chemistry, CSU collaborate on portions of the aquatic studies and Dr. K. G. Doxtader, Department of Agronomy at CSU is collaborating on studies of soil microbes in the irradiated grassland plots. Dr. L. Fraley, Jr., presently with the Division of Biomedical and Environmental Research of the U. S. Atomic Energy Commission, is collaborating part-time on continued observations on the irradiated grassland study plots. This report summarizes project activities and major findings during the period May, 1972 - April, 1973.

The study on plutonium in the terrestrial environs at Rocky Flats was initiated in the summer of 1972 as the pilot phase of a rather major and hopefully, long-term effort. Partly because of uncertainties in funding for this program until early 1973, the work did not gain much momentum until early this year. The notoriety in regard to Rocky Flats was another important factor in our decision to proceed rather carefully and thoughtfully. In view of large sampling variations and analytical uncertainties associated with environmental plutonium at Rocky Flats, a "crash" program did not seem warranted from our standpoint. This report summarizes our experiences to date at Rocky Flats with regard to field sampling, sample processing, analytical procedures, biotic inventories, and initial surveys of plutonium-238, 239 in soil, litter, vegetation and animals. Early results indicate that in time, we will be able to assemble a rather detailed and extensive view of the behavior of plutonium in the terrestrial ecosystem at Rocky Flats.

Concerning the mule deer work, a four year study on the kinetics and distribution of strontium and calcium in captive deer is nearing completion, with interpretation and modeling remaining as the major activities in 1973. The goal of this study is a model of strontium-calcium accumulation in deer of various ages under specified circumstances of season, including modifications due to antler growth and lactation. As a part of long-term studies on the persistence of fallout ^{137}Cs in mule deer, tissues from several animals as well as from a set of forage samples collected in mid-winter 1972/73 were assayed for ^{137}Cs. Essentially all of our earlier studies on fallout ^{137}Cs in mule deer and on metabolism of cesium in captive animals culminated in a model capable of providing realistic estimates of forage consumption rates in free-roaming deer. Additional interpretations of inert tracer data were also made to estimate rate of ingesta passage in captive deer for radionuclide modeling purposes.

In regard to nuclide studies of aquatic ecosystems, the in-situ cesium kinetics work at East Twin Lake culminated in a Ph.D. Thesis by T. E. Hakonson. The lake has been periodically sampled since, in order to verify seasonal patterns in concentration factors in trout and certain invertebrates. Some planning of experiments designed to explain some of the seasonal phenomena was also done. The studies on ^{137}Cs levels in mountain lakes throughout Colorado continued on a small scale in 1972, primarily to document long-term fallout cesium behavior in selected lakes. The lead studies, which were quite active in 1972, yielded estimates of lead fallout deposition rates in rain and snow at high elevations in remote mountain areas and preliminary data for a mass balance and systems analysis of a remote alpine lake.

The large ^{137}Cs gamma source at the Pawnee Grassland is still active and chronic irradiation initiated in April, 1969 is continuing. The plant community was inventoried again in 1972 and two major papers were submitted to Radiation Botany. Observations of selected arthropods from the outset of the study were compiled and two manuscripts summarizing these observations were submitted to journals. A detailed study on soil microorganisms and soil chemistry across the chronic irradiation gradient was completed in 1972 and a summary of the findings is included in this report.

Energy flow from the dominant grass of the shortgrass plains, Bouteloua gracilis, through arthropod consumers has been investigated by tagging the grass with ^{32}P and tracing its movement into primary and secondary consumers. Feeding rates of three common grasshopper species are being measured from data on accumulation and retention of ^{32}P from contaminated herbage. A status report on this investigation is given herein.

II. PLUTONIUM IN THE TERRESTRIAL ENVIRONS OF ROCKY FLATS

II. Plutonium in the Terrestrial Environs of Rocky Flats

C. A. Little, T. F. Winsor, J. E. Johnson and F. W. Whicker

A. Introduction

In recent years the element plutonium has been the focus of increasing interest not only due to its tremendous potential for biological damage, but also as a result of several well publicized contamination events at the Rocky Flats plant. A great deal of investigation has been done concerning the effects of plutonium on and interactions with biological systems. Generally, however, these studies have been concerned with intra-organismic plutonium or a single biotic-abiotic interaction. Little work has been directed toward understanding the sum of the interactions of plutonium in a given ecosystem.

This study attempts to understand the physical and biological processes affecting plutonium mobility in the grassland ecosystem at the AEC Rocky Flats plant near Golden, Colorado. The work has two main thrusts; to better define and understand the patterns of contamination which presently exist on the Rocky Flats plant site, and to investigate the kinetics of plutonium movement in a grassland ecosystem which could result in such contamination patterns.

B. Development of Methods

1. Field sampling

The Rocky Flats plant site contains approximately 4 square miles of grassland at an elevation near 6000 ft. Of this 4 square miles, about 2100 acres is being considered in this study. Five separate water-courses are present which generally run west to east across the plant site. These streams have created a series of flat, wind-scoured plateaus divided by stream-channeled ravines in the northwest quarter of the plant site. This characteristic blends into less severe topographic features as one moves south and east.

It was felt that the 2100 acres of the plant site were too large for intensive sampling. Therefore, smaller areas characteristic of large portions of the site were sought. Fig. II. 1 illustrates two areas of the plant site which were chosen for intensive study. Area 1 was chosen for its high level of plutonium contamination in the soil, and because it includes a reasonably undisturbed plant community and affords relatively easy access. Area 2 has many characteristics in common with Area 1 with the exception that its soil plutonium contamination level approaches background levels.[1,2,3] Additionally,

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[1]This conclusion was reached from contours of plutonium contamination in soil supplied us by Rocky Flats personnel.

[2]Krey, P. W. and E. P. Hardy. 1970. Plutonium in Soil Around the Rocky Flats Plant. AEC Document #HASL-235.

[3]Boss, M. R., et al. 1973. Annual Environmental Monitoring Report, Rocky Flats Plant, January through December, 1972. Document #RFP-ENV-72.

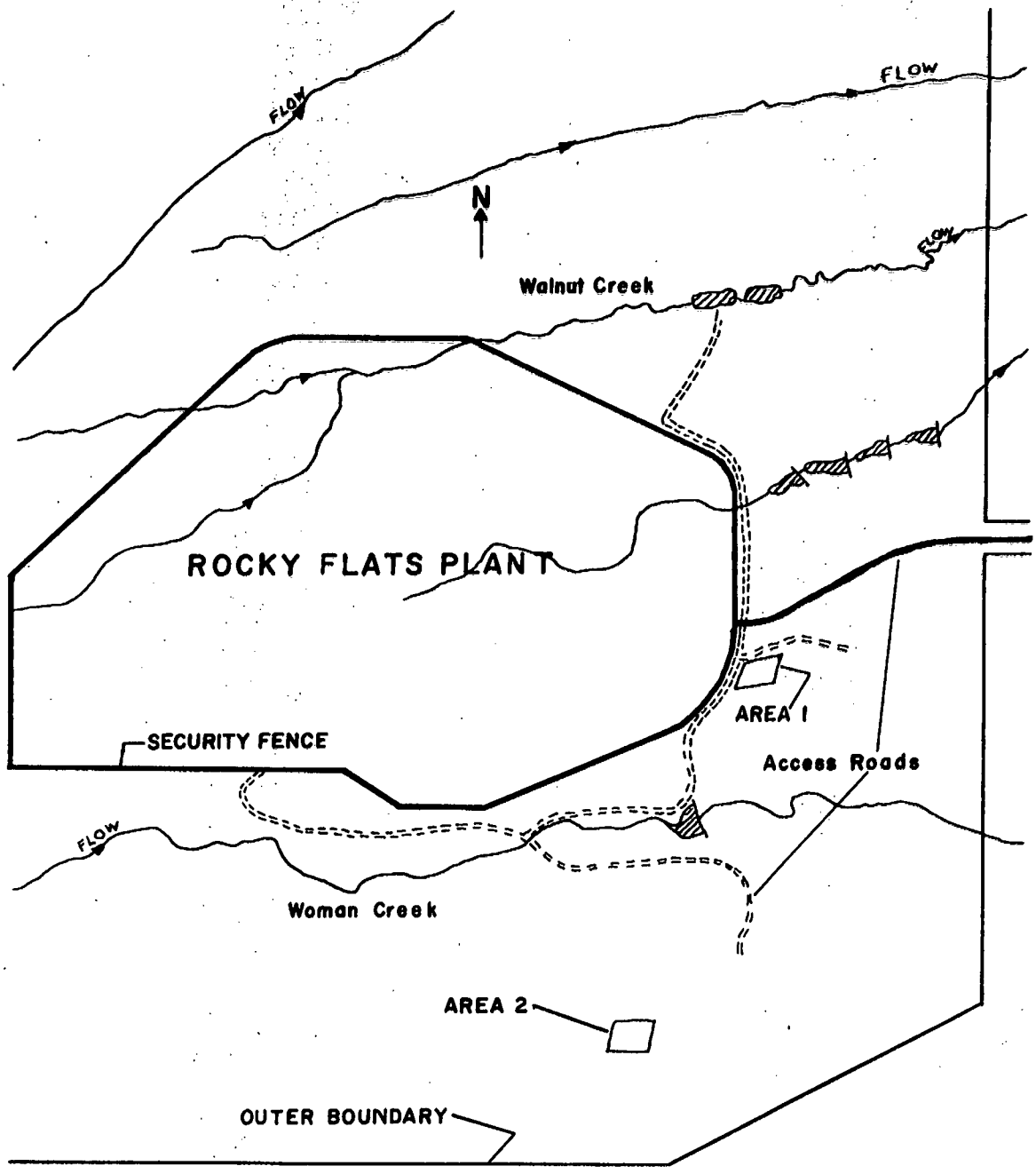

Fig. II. 1. Schematic of the Rocky Flats Installation showing intensive study macroplots. Area 1 is immediately downwind from the former barrel storage pad. Area 2 is ecologically similar to Area 1 but far less contaminated.

Area 2 has similar slope and exposure to the sun (southerly) as Area 1. Both of these areas are about .75 hectares. Area 1 was fenced because much human activity passes near its boundaries, while Area 2 was merely designated by corner posts.

Of the two sampling areas, Area 1 has been sampled much more intensively due to its high plutonium concentration. A 100 intersection (10 x 10) grid, 72 x 81 m, was established for use in sampling vegetation and soil. Ten intersections were chosen at random and designated as sites of vegetation and soil sampling. Soil samples are taken by first marking a 25 x 25 cm plot having its southwest corner 0.5 m north of the appropriate intersection. In several cases, due to extremely rocky soil, the plot has been east rather than north of the intersection. The standing vegetation is then clipped and bagged. The litter is collected by hand and bagged. Next, a 20 x 25 cm area is removed to a depth of 3 cm using a hand trowel. This soil and subsequent 20 x 25 cm areas at other depths is saved to refill the hole following sampling. From the remaining 25 x 5 cm strip at the 0-3 cm depth, four 5 x 5 x 3 cm samples are taken and bagged separately. Following this, loose soil on the floor of the now 3 cm deep 25 x 25 cm hole is removed to prepare for the next 3 cm removal. This process is repeated until all four columns of 5 x 5 cm are sampled 7 times to a depth of 21 cm unless rocks preclude sampling. If a sample is blocked by rocks, the column may be resumed below the blockage.

Vegetation samples were taken by first marking a 1 m^2 square having its northwest corner 1 meter east of the appropriate intersection. Four genera and species representative of the area were chosen for sampling, i.e., Agropyron smithii (Western wheatgrass), Bromus spp. (Brome grass), Tragopogon spp. (Salsify), and Lactuca scariola (Prickly lettuce). All of the individuals of a species were removed by hand from the 1.0 m^2 plot. The roots and foliage were separated and bagged for future ^{239}Pu analysis.

Methods of studying animals resident on the plant site are described elsewhere in the report. Several small mammals were trapped for preliminary purposes using snap traps. These were taken from both Areas 1 and 2 for purposes of analyzing various tissues for plutonium.

2. Sample processing

Soils were transported to the lab and air dried. Large particles (greater than 0.5 cm diameter) were removed from the sample with forceps. Following 24 hrs. of oven drying the samples were weighed. The samples were placed on a set of three-inch diameter brass soil sieves in a mechanical sieve shaker for 20 minutes and the accumulation on each sieve was weighed. Each sieve fraction was placed in a small paper envelope which was then sealed with tape.

Vegetation samples were oven dried in the laboratory and weighed. Large soil particles on root samples were removed by hand. Large vegetation samples were pulverized with a Wiley mill. Following milling, the sample was placed in a 20 or 40 dram vial and sealed with a snap cap and tape.

Small mammals were transported to the laboratory and either dissected immediately or frozen for dissection at a later date. To prevent cross-contamination from one tissue to another, special precautions were taken during dissection. We removed the hide cautiously, in order to prevent contamination of either the peritoneal or pleural cavities. A different set of instruments was used to handle exterior surfaces, such as the hide, the fascia exposed following removal of the hide, and interior surfaces, especially the organs. Approximately 10 cm^2 of hide were used as an aliquot of hide. The lung, liver, and G. I. tract were removed whole. Muscle samples were taken from the forelegs in most cases. Bone samples consisted of the whole skeleton which was cleaned of flesh by a vigorous dermestid beetle larval colony. All samples except bone were placed on ashless filter papers of known weight, oven dried, and weighed. The dried sample and filter paper, or sample alone in the case of bone, were placed in 40 dram vials for mailing to the analysis laboratory.

3. Analytical procedures

All prepared samples were sent to commercial laboratories for analysis of plutonium content. The labs which received samples were LFE Environmental (formerly Trapelo/West), Richmond, California and Eberline Instrument Corp., Santa Fe, N. M. Samples reported later which were processed by LFE Environmental are designated by an asterisk (*).

Both of these laboratories totally dissolved the samples using concentrated hydroflouric acid when necessary. Ion exchange columns were utilized to remove impurities and separate plutonium from the samples prior to alpha spectrometry.

We are in the process of establishing our own plutonium laboratory for the sake of convenience and independence. Within a year we hope to be analyzing our own samples. Analytical equipment purchased under this contract should give this laboratory the capability of accurate analysis of plutonium. The equipment includes a low energy photon spectrometer (LEPS) Ge-Li x-ray detector, a coaxial Ge-Li detector, and four surface barrier alpha detectors. The Ge-Li detectors are housed in a graded shield of lead, copper, aluminum, and masonite hardboard. The LEPS detector should allow direct counting of Pu in many environmental samples, or, at worst, counting after dissolution of the sample matrix. The alpha detectors are contained in vacuum chambers. Outputs are to two Ortec 1024 channel analyzers. Data output is currently by teletype or paper punch tape, but a magnetic tape system compatible with the university CDC computer should be available in the future. Also available for alpha counting of Pu is a Nuclear Chicago Mark II liquid scintillation counter.

C. Biotic Survey

1. Vegetation

The plant site can generally be described as grassland, but the elevation gradient is evidenced in increased incidence of shrubby plants and montane species as one progresses west. A comprehensive plant inventory was not attempted because of a proposal to that effect submitted by Dr. William A. Weber of the University of Colorado. In the course of working in the area, we have collected and identified a number of plants. These are listed in Table II.1. This list incorporates collections and identifications reported by Ms. Sharon Svalberg and Mr. Donald Paine while working on the aquatic plutonium study now progressing at Rocky Flats.[4] The descriptions of the plants are from Weber (1967)[5] or Harrington (1964).[6]

Insight into the vegetative community of Areas 1 and 2 was gained by performing a frequency analysis on the vegetative community of each area. The primary reason for such an exercise was to compare the vegetative communities of the areas to decide whether or not Area 2 was a suitable control for Area 1. To test similarity, Dr. Leslie Fraley and C. A. Little performed frequency analyses on both areas during July, 1972. The method used was comparable to that of Hyder, et al. (1965).[7] A 100 meter line was laid out and divided into ten lengths ten meters long. Ten transects fifty meters long were laid out perpendicular to the original line at a point within each of the ten meter sections as determined by a random number. The frequency values were generated by noting the presence or absence of a species in 250 0.1 m^2 plots (25 plots per 50 meter transect x 10 transects) and dividing the number of occurrences by 250. The results of this investigation are shown in Table II.2.

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[4]Johnson, J. E., S. Svalberg, and D. Paine. 1972. Study of Plutonium in Aquatic Systems of the Rocky Flats Environs. Second Technical Progress Report of the Department of Animal Sciences. Colorado State University, Fort Collins. 60 p.

[5]Weber, W. A. 1967. Rocky Mountain Flora. University of Colorado Press, Boulder, Colorado. 437 p.

[6]Harrington, H. D. 1964. Manual of the Plants of Colorado. The Swallow Press, Inc., Chicago, Illinois. 666 p.

[7]Hyder, D. N., R. E. Bement, E. E. Remmenga, C. Terwilliger, Jr. 1965. Frequency Sampling of Blue Grama Range. Journal of Range Management, 18(2): 90-93.

Table II. 1. Plants identified at Rocky Flats

Family	Genus Species	Common Name
Alismaceae		
	Sagittaria cuneata	Sagittaria
Anacardiaceae		
	Rhus trilobata	Skunkbrush
Asclepiadaceae		
	Asclepias speciosa	Showy milkweed
	Asclepias stenophylla	Narrowleafed milkweed
Boraginaceae		
	Mertensia lanceolata	Chiming bells
Cactaceae		
	Echinocactus simpsonii	Mountain ball cactus
	Opuntia polycantha	Plains prickly-pear
	Opuntia rafinesquei	Prickly-pear
Caprifoliaceae		
	Symphoricarpos occidentalis	Snowberry bush
Caryophyllaceae		
	Cerastium arvense	Mouse ear
Chenopodiaceae		
	Chenopodium leptophyllum	Goose foot
	Kochia iranica	Burning bush
	Salsola kali tenuiflora	Tumbling russian thistle
Commelinaceae		
	Tradescantia occidentalis	Spiderwort
Compositae		
	Achillea lanulosa	Yarrow
	Ambrosia spp.	Ragweed
	Artemisia frigida	Fringed sage
	Artemisia ludoviciana ludoviciana	Sagebrush
	Aster commutatus crassulus	Aster
	Aster ericoides	Aster
	Chrysopsis villosa	Golden aster
	Chrysothamnus nauseosus pinifolius	Rabbitbrush
	Cirsium arvense	Canadian thistle
	Dyssodia papposa	Fetid marigold
	Erigeron speciousus	Fleabane
	Gaillardia aristata	Blanket flower
	Grindelia squarrosa	Gumweed
	Gutierrezia sarothrae	Turpentine weed
	Helianthus annuus	Sunflower
	Helianthus petiolaris	Sunflower
	Lactuca scariola	Wild lettuce
	Liatris punctata	Dotted gay feather
	Ratibida columnifera	Prairie cone flower
	Senecio atratus	Butterweed
	Senecio spartioides	Butterweed
	Solidago ciliosa	Goldenrod
	Stephanomeria pauciflora	Wire lettuce
	Taraxacum officinale	Dandelion

Table II. 1. (Continued)

Family	Genus Species	Common Name
Compositae (cont'd)		
	Thelesperma megapotamicum	Thelesperma
	Tragopogon dubius	Goatsbeard
	Xanthium strumarium	Cockleburr
Convolvulaceae		
	Convolvulus arvensis	Bindweed
Cruciferae		
	Descurainia sophia	Tansy mustard
	Erysimum asperum	Wallflower
	Lepidium campestre	Pepper grass
	Lepidium densiflorum	Pepper grass
	Lesquerella spp.	Bladder pod
	Rorippa islandica	Cress
	Thlaspi alprestre	Pennycress
Cyperaceae		
	Carex filifolia	Sedge
	Cyperus filiculmis	Flatsedge
	Scirpus microcarpus	Bulrush
Euphorbiaceae		
	Euphorbia dictyosprerma	Spurge
	Euphorbia marginata	Snow-on-the-mountain
Geraniaceae		
	Erodium cicutarium	Heron bill
	Geranium fremontii	Cranes bill
Gramineae		
	Agropyron smithii	Western wheatgrass
	Andropogon gerardii	Big bluestem
	Andropogon hallii	Sand bluestem
	Aristida longiseta	Red threeawn
	Bouteloua gracilis	Blue grama grass
	Bromus inermis	Sleepy grass
	Buchloë dactyloides	Buffalograss
	Hordeum jubatum	Foxtail barley
	Setaria viridis	Green bristlegrass
	Sitanion hystrix	Squirrel tail
	Stipa comata	Needle-and-thread
	Stipa neomexicana	New Mexico feather grass
Hypericaceae		
	Hypericum perforatum	St. Johnswort, Klamath weed
Iridaceae		
	Sisyrinchium montanum	Blue-eyed grass
Juncaceae		
	Juncus balticus	Rush
Labiatae		
	Mentha arvensis	Mint
	Monarda fistulosa menthaefolia	Bee balm
	Scutellaria brittonii	Skull cap

Table II. 1. (Concluded)

Family	Genus Species	Common Name
Leguminosae		
	Amorpha nana	False indigo bush
	Astragulus spp.	Milk vetch
	Glycyrrhiza lepidota	Wild licorice
	Lathyrus eucosmus	Peavine
	Melilotus alba	White sweet clover
	Melilotus officinalis	Yellow sweet clover
	Oxytropis spp.	Loco-weed
	Petalostemon purpureus	Prairie clover
	Psoralea tenuiflora	Scurfpea
	Thermopsis divaricarpa	Golden banner
Liliaceae		
	Leucocrinum montanum	Sand lily
	Yucca glauca	Spanish bayonet
Linaceae		
	Linum lewisii	Flax
Malvaceae		
	Sphaeralcea coccinea	Globe mallow
Najadaceae		
	Potamogeton natans	Pondweed
Nyctaginaceae		
	Mirabilis linearis	Four o'clock
Onagraceae		
	Gaura coccinea	Butterfly weed
	Oenothera brachycarpa	Evening primrose
Papaveraceae		
	Argemone polyanthemos	Prickly poppy
Polygonaceae		
	Rumex crispus	Curly dock
Ranunculaceae		
	Ranunculus aquatilis	Water crowfoot
	Ranunculus glaberrimus	Sagebrush buttercup
Rosaceae		
	Cercocarpus montanus	Mountain mahogany
	Prunus virginiana	Choke cherry
	Rosa woodsii	Woods rose
Scrophulariaceae		
	Linaria dalmatica	Toadflax
	Mimulus floribundus	Monkey flower
	Penstemon angustifolius	Penstemon
	Scrophularia lanceolata	Figwort
	Verbascum thapsus	Mullein
	Veronica americana	Speedwell
Solanaceae		
	Solanum eleagnifolium	Silverleaf nightshade
	Solanum rostratum	Buffalo burr
Typhaceae		
	Typha latifolia	Cattail
Violaceae		
	Viola nuttallii	Wild violet

Table II. 2. Frequency of occurrence data for plants in areas 1 and 2 of the Rocky Flats site.

PLANT	AREA 1, a_i	AREA 2, b_i	COMMON, c_i
Agropyron smithii	.810	.888	.810
Ambrosia spp.	.124	.036	.036
Andropogon gerardii	.064	.024	.024
Andropogon hallii	0	.028	0
Aristida longiseta	.032	.008	.008
Artemisia frigida	.020	.004	.004
Artemisia ludoviciana ludoviciana	.028	.028	.028
Aster spp.	.048	.092	.048
Astragalus spp.	.024	.092	.024
Bouteloua gracilis	.196	.212	.196
Bromus spp.	.840	.748	.748
Buchloe dactyloides	.004	0	0
Carex spp.	.164	.104	.104
Chenopodium leptophyllum	.004	0	0
Chrysopsis villosa	.004	0	0
Cirsium spp.	.064	.016	.016
Echinocactus simpsonii	.056	.032	.032
Gaura coccinea	.028	0	0
Grindelia squarrosa	.008	.004	.004
Gutierrezia sarothrae	.008	0	0
Helianthus petiolaris	.036	.016	.016
Hordeum jubatum	.004	0	0
Hypericum perforatum	.004	0	0
Lactuca scariola	.252	.244	.244
Lepidium densiflorum	.008	0	0
Lesquerella spp.	.060	0	0
Leucocrinum montanum	.004	0	0
Linum lewisii	.024	0	0
Mirabilis linearis	.024	.008	.008
Opuntia polycantha	0	.020	0
Opuntia spp.	.056	.172	.056
Oxytropis spp.	0	.004	0
Psoralea tenuiflora	.088	.044	.044
Ratibida columnaris	0	.004	0
Salsola kali	.016	0	0
Senecio spartioides	.004	.004	.004
Sitanion hystrix	.012	0	0
Sphaeralcea coccinea	.156	.020	.020
Stephanomeria pauciflora	.004	0	0
Stipa comata	.084	0	0
Thelesperma megapotamicum	.004	0	0
Tradescantia occidentalis	.020	.040	.020
Tragopogon spp.	.232	.528	.232
	a=3.618	b=3.420	c=2.726

From the data in Table II. 2 a coefficient of community (cc) was calculated. This is merely a method of translating frequency data for many species and two areas into a single number, cc. The following formula was used:

$$cc = 2\,c/(a+b),$$

$$\text{where } a = \sum_{i=1}^{n} a_i, \quad b = \sum_{i=1}^{n} b_i,$$

$$\text{and } c = \sum_{i=1}^{n} c_i, \text{ where } c_i = a_i \text{ if } a_i \leq b_i$$

$$\text{or } c_i = b_i \text{ if } a_i > b_i$$

The data in Table II. 2 yield cc = 77.5%. A qualitative method of calculating cc is to use only the number of species found in each area and in common, rather than the frequencies. Using this method cc = 69.7%. For a discussion of both methods, see Oosting (1956).[8] Although there is no scale against which to assess the cc value, 77.5% seems to indicate a reasonable degree of similarity. A coefficient of community will be computed in the coming summers to identify any changes which might occur in the stands.

2. Animals

Observations of the biota of Rocky Flats have included animals as well as plants. A number of animals have been collected through trapping and many more have been sighted. Table II. 3 lists animals which have been taken or observed. In some cases, species identifications are only tentative. As with the plants, the faunal inventory is by no means complete. Additional information contributing to this end shall be compiled through opportunistic observation and trapping.

An obvious and possibly important component of the fauna which should be mentioned are the mule deer. The Rocky Flats site contains a relatively transitory mule deer population. Without any specific efforts being taken, mule deer have been observed during about 45% of the visits to the site. The number of deer comprising a group ranged from a minimum of one to a maximum of 31 animals. Most often the groups were composed of female and immature animals. Observations of deer will be continued with future visits.

During February and March, 1972, live trapping of rodents was conducted by T. F. Winsor in order to explore late winter capture and recapture success, note catchable species, and to obtain supplemental data appropriate to the study. This trapping was preliminary to anticipated exhaustive sampling. The area in which trapping was conducted is on a southeast facing slope about 200 paces east of Area 2.

[8]Oosting, H. J. 1956. The Study of Plant Communities. W. H. Freeman and Company, San Francisco. 440 p.

Table II. 3. Animals observed at Rocky Flats.

Class	Genus	Common Name
Amphibia		
	Rana pipiens	Leopard frog
Aves		
	Agelaius phoeniceus	Red-winged blackbird
	Anas platyrhynchos	Mallard
	Bubo virginianus	Great-horned owl
	Buteo jamaicensis	Red-tailed hawk
	Charadrius vociferus	Killdeer
	Pica pica	Black-billed magpie
	Sturnella neglecta	Western meadowlark
	Zenaidura macroura	Mourning dove
Mammalia		
	Canis latrans	Coyote
	Lepus townsendii	White-tailed jackrabbit
	Mephitis mephitis	Striped skunk
	Microtus pennsylvanicus modestus	Meadow mouse
	Mus musculus	House mouse
	Odocoileus hemionus	Mule deer
	Ondatra zibethicus cinnamominus	Muskrat
	Peromyscus maniculatus osgoodi	White-footed deer mouse
	Peromyscus difficilis nasustus	Rock mouse
	Procyon lotor	Raccoon
	Spermophilus tridecemlineatus	13-lined ground squirrel
	Sylvilagus audubonii baileyi	Cottontail rabbit
	Taxidea taxus	American badger
	Thomomys talpoides	Northern pocket gopher
Reptilia		
	Chrysemyap bellii	Painted box turtle
	Crotalus viridis viridis	Common prairie rattlesnake
	Pituophis catenifer sayi	Common bull snake
	Thamnophis radix	Plains garter snake

Two parallel line transects of 9 trap sites each were established. Transects were separated 55 meters and trap sites within transects were spaced at 15 meter intervals. One No. 0 Havahart live trap (10 x 3 x 3") was placed at each trap site. Trap shelter was deemed unnecessary and temperatures never fell lower than 28°F during nights the traps were open.

Two trapping efforts were conducted. The first effort, from 23 February to 1 March, included 3 consecutive days of prebaiting followed immediately by active trapping for 4 consecutive days. The second effort, from 6 March to 11 March, included 3 days each of prebaiting and active trapping. All trap entrances were prebaited with a mixture of oat flakes and peanut butter, while peanut butter alone was placed on bait pans.

During active trapping, animals were removed from traps at about 0900 hours each morning and traps were immediately reset and baited. All animals were individually marked by toe clipping; species, sex, age class, reproductive condition, pelage, general condition, presence of ectoparasites, and location of capture were recorded. Animals were immediately released at the site of capture.

Trapping results are depicted in Table II. 4. Success was quite high, ranging from 11/18 low to 15/18 high (number animals caught/number traps open) for any one night. Pooled success for the 2 efforts was 88/126 = 69.8 percent.

Twenty seven individual Peromyscus maniculatus were captured and all were adults. Only 1 of 20 males was scrotal and 1 of 7 females was reproductively active with turgid vulval mucosa. On the last day of the first effort all trapped animals were found to be recaptures. On the last day of the second effort only one new individual was captured. Eleven of the 27 were captured 4 or more times and 17 were trapped at least once during each effort. Movement (based on capture location) was greater than 45 meters in the case of only one male which moved 75 meters, and one male which moved 55 meters from one transect to the other.

All animals appeared in generally good condition and none were evidently molting. Sixteen fleas were counted, but not classified.

No live weights were recorded. However, 2 females found dead in traps placed incidentally about 200 yards north of the transects weighed 15.0 and 19.0 g.

The preliminary data presented above indicate a healthy, moderate to high population of Peromyscus maniculatus exhibiting high recapture potential. Population estimates were not attempted, owing to small number of trap nights accumulated.

The high male:female ratio among captures cannot be adequately explained with limited information. Possible explanations include

Table II. 4. Trapping success for Peromyscus maniculatus at Rocky Flats during February and March, 1973.

Date	No. Captures / No. Open Traps	No. Males / No. Females	No. New* Animals
Feb. 26	14/18	11/3	14
Feb. 27	11/18	8/3	7
Feb. 28	11/18	9/2	2
Mar. 1	13/18	10/3	0
Mar. 9	12/18	8/4	2
Mar. 10	12/18	8/4	1
Mar. 11	15/18	9/6	1
Total	88/126	63/25	27 (20 male, 7 female)

* Previously untrapped

real differences, sex differences in above ground activity, and different nocturnal activity periods or home ranges. Sex ratio differences are known to typically favor the male in Peromyscus spp.[9]

This time of year may precede initial reproductive activity by Peromyscus maniculatus by only a few weeks.[10] Therefore, it is not surprising that no subadults were captured.

Microtus pennsylvanicus, Spermophilus tridecemlineatus, and Thomomys talpoides have previously been captured at Rocky Flats. Exhaustive grid trapping is planned in order to estimate populations and biomass of resident species; and additional data on reproduction, pathology, and ectoparasites will be sought.

D. Survey of Plutonium in the Terrestrial Ecosystem

1. Soil

As stated earlier in this report, our data on plutonium concentrations in soils are limited at this time. The available data are listed in Table II. 5 by particle size, depth, and location in which the sample was taken. As expected, the plutonium concentrations increased as the particle size decreased. An interesting trait of the data is that the 0.104-0.264 mm size group had a plutonium concentration lower than might be expected relative to other size groups. This occurred in the sample groups from both Area 1 and Area 2 and with both ^{238}Pu and $^{239,240}Pu$, thus this observation is not likely an artifact of sample handling or analysis.

2. Vegetation

Table II. 6 lists plutonium concentrations in vegetation samples of four prominent species taken from several microsites in Area 1. The values range from near background concentrations to several orders of magnitude above background. This high degree of variation in the samples is evinced by the standard errors which range from 26% to 80% of the means.

There are, of course, several factors which influence the degree of variance, e.g., spatial inhomogeneity, sample collection technique,

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[9]Terman, C. R. 1968. Population dynamics. p. 412-450. In Biology of Peromyscus (Rodentia), Special Publication No. 2, The American Society of Mammalogists. 593 p.

[10]Lechleitner, R. R. 1969. Wild Mammals of Colorado. Pruett Publishing Company, Boulder. 254 p.

Table II. 5. Plutonium concentration of various soil particle sizes.[A]

Location	Depth, cm	Area sampled, m^2	Size, mm	Sample weight, percent of total	dpm/gm dry[B] $^{239,240}Pu$	dpm/gm dry[B] ^{238}Pu
AREA 1 (see Figure 1)	0-2	0.1	>1.65*	31.5	213± 13	4.17±0.25
			.264-1.65*	40.5	2360± 47	41.3±1.7
			.104-.264*	24.3	2010± 60	37.1±1.9
			<1.04*	3.7	5070±203	99.1±4.0
			<5.0*,C	100	1820± 73	38.5±2.3
			<5.0*,C	100	3670±184	66.6±4.0
AREA 2	0-3	0.1	>1.65*	12.0	.648±.039	.015±.010
			.264-1.65*	53.8	3.23±0.16	.071±.013
			.104-.264*	23.0	1.91±0.10	.034±.010
			<.104*	11.2	12.0±0.24	.248±.012

* analyses for plutonium done by LFE Environmental (formerly Trapelo/West).

A sampled 7-14-72.

B ± 2 s.d. due to counting error.

C these two samples were not sieved, all particles sized less than 0.5 cm diameter are included.

Table II. 6 Vegetation samples from contaminated area[A] (listed by major genera)

Plant	Microsite	^{239,240}Pu dpm/gm dry[B]		^{238}Pu dpm/gm dry[B]	
		Roots	Foliage	Roots	Foliage
Agropyron smithii	13	92.8±7.1	3.99±0.31	1.95±0.15	0.10±.03
	20	305 ±62	2.18±0.27	4.63±0.94	0.10±.04
	29	402 ±22	2.19±0.09	6.95±0.37	0.34±.04
	34	592 ±77	1.34±0.08	10.2±1.4	0.35±.04
	39	239 ± 7	7.99±0.34	7.76±0.30	0.47±.05
	65	410 ±25	206 ±9	0.96±0.11	3.76±.17
	83	8.30±0.40	23.6±2.0	0.89±0.10	0.86±.15
	92	72.5±5.3	13.0±0.4	1.58±0.17	0.44±.04
	94	96.9±9.3	8.37±0.27	2.69±0.38	0.83±.05
Mean ± s.e.		247 ±65	29.9±22.1	4.18±1.13	0.81±0.38
Bromus spp.	01	789 ±50	48.4±3.5	110 ±7	1.47±0.33
	13	120 ±17	3.16±0.25	1.38±.28	0.15±0.03
	20	728 ±53	8.79±0.91	12.8±1.0	0.20±0.04
	29	61.3±3.0	9.06±0.70	1.41±0.10	0.50±0.10
	34	3.53±0.42	14.5±0.6	0.18±0.05	0.58±0.06
	39	713 ±37	828 ±44	40.6±4.7	25.7±3.2
	65	120 ±4	75.5±4.3	3.42±0.23	2.87±0.39
	92	48.4±3.7	6.95±0.24	0.81±0.22	0.47±0.04
	94	65.4±4.4	14.3±0.6	1.55±0.33	0.58±0.07
Mean ± s.e.		294 ±113	112 ±90	19.1±12.2	3.61±2.78
Lactuca scariola	01	439 ±14	7.56±0.67	8.60±0.28	0.66±0.13
	13	23.4±2.7	4.96±0.50	0.84±0.11	0.20±0.04
	20	---	4.33±.59	---	0.44±.18
	29	83.1±3.7	4.78±0.43	6.26±0.69	1.32±0.22
	34	---	4.39±0.16	---	0.41±0.06
	39	191 ±15	38.8±1.3	7.44±1.09	3.27±0.30
	65	48.1±2.4	28.0±1.1	1.11±0.20	1.61±0.17
Mean ± s.e.		157 ±76	13.3±5.3	4.85±1.75	1.13±.41
Tragopogon spp.	13	4.64±.84	5.88±0.81	0.00±0.05	0.25±0.11
	20	---	9.06±1.43	---	0.20±0.10
	29	---	26.8±1.0	---	1.89±0.22
	34	21.02±1.0	8.41±0.30	3.05±0.37	0.47±0.04
	65	---	3.94±0.24	---	1.92±0.20
	83	---	22.5±0.7	---	1.21±0.08
Mean ± s.e.		12.8±8.2	12.8±3.9	1.53±1.53	0.99±.32

[A] samples collected on 10-25-72, 11-6-72, and 11-8-72.

[B] ± 2 s.d. due to counting error.

laboratory sample preparation and counting, and presence of large "hot" particles of plutonium. Of these sources of variation, the "particle problem"[11] may be most important. Large particles of PuO_2 were probably responsible for high concentrations of plutonium in several samples in Table II. 6. In Bromus spp., the ^{239}Pu concentration of the foliage sample from microsite 39 was 828 dpm/g, well over an order of magnitude higher than any other Bromus foliage samples. The particle problem may also be the cause of high plutonium concentrations in Bromus ^{238}Pu root samples from microsite 01 with 110 dpm/g, the Lactuca scariola ^{239}Pu root sample from microsite 01 with 439 dpm/g, and the Agropyron smithii foliage sample of 206 $^{239,240}Pu$ dpm/g from microsite 65.

The effect of the particle problem, if responsible, can be appreciated if the mean and standard error of the four vegetation groups mentioned above are calculated without the three "hot" samples:

Bromus spp. foliage, $\bar{X} = 22.6 \pm 9.1$ dpm $^{239,240}Pu$/gm dry

Bromus spp. roots, $\bar{X} = 7.76 \pm 4.91$ dpm ^{238}Pu/gm dry

Lactuca scariola root, $\bar{X} = 86.4 \pm 37.0$ dpm $^{239,240}Pu$/gm dry

Agropyron smithii foliage, $\bar{X} = 7.83 \pm 2.66$ dpm $^{239,240}Pu$/gm dry.

Accordingly, the only practical method of dealing with the particle problem is to take large numbers of samples, at least initially, to improve the statistical considerations.

Another interesting facet of the data from Table II. 6 is the apparently higher plutonium concentration in roots than in foliage. However, the foliage and root mean values were compared using a t-test and only the Agropyron and Lactuca samples showed a difference which was significant at the 95% confidence level. Large particles of dry soil on roots were mechanically removed. Distilled water and dilute nitric acid rinses were considered but not implemented due to fears that some plutonium activity might be lost from the root itself by leaching. However, more careful removal of soil particles from root surfaces might reduce the variation in the data.

We expected to see different plutonium contamination levels for roots of the various species due to differences in root types. The roots of Agropyron and Bromus are largely adventitious, while Lactuca and Tragopogon have a main taproot and fewer adventitious roots. Soil quality, moisture, nutrient availability, etc., may result in highly variable roots in the same species, however. Adventitious roots have a high surface to volume ratio which may result in more surface for plutonium attachment per gram compared to a taproot. For this reason, plants such as grasses might evince higher plutonium concentrations in their roots. The data from Table II. 6 do not show statistically significant differences between roots of various species, but this again is probably a result of high variation in the data.

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[11] Sill, C. W. 1970. The particle problem as related to sample inhomogeneity. In AEC Document No. LA-4756, pp. 81-83.

Table II. 7 shows plutonium concentrations of several vegetation grab samples from Areas 1 and 2. As in Table II. 6, large variations among samples are evident. In Area 1, the plutonium concentration of standing vegetation was lower than that of both the litter and the roots. This difference, which was significant at the 80% confidence level, may be a result of the litter and roots having a more intimate relationship with the soil, which heretofore generally has been assumed to be the largest plutonium compartment in the terrestrial ecosystem. Using data from the Pawnee National Grassland,[12] a short-grass prairie similar to the Rocky Flats grassland, we estimate that the soil (0-2 cm depth) contains 99.464% of the total ^{239}Pu inventory on a square meter basis. The remainder of the ^{239}Pu inventory is partitioned between the standing vegetation, .058%, the litter, .180%, and the roots (0-2 cm depth), .298%. From Area 2, values for both ^{238}Pu and $^{239\ 240}Pu$ tend to indicate that the area holds values comparable to vegetation samples from approximately one mile distant from Rocky Flats as reported by Boss, et al. (1973).[3] Area 2 values appear to be at least two orders of magnitude lower in plutonium concentration than Area 1.

3. Animals

Table II. 8 lists preliminary data on plutonium concentrations in tissues of two resident small mammal species. In Area 1, pocket gophers 1 and 2 had relatively high concentrations of plutonium in the stomach and G. I. tract and contents. Other tissues of gophers 1 and 2 had much lower, but above background levels of plutonium. Pocket gopher 3 had low plutonium contamination levels in all tissues except hide, which was the highest of the three animals. Liver and spleen values in the gopher from Area 2 were higher than might be expected. Lung values in general were much lower than expected since inhalation is supposedly the primary mode of internal contamination by plutonium.

Deer mouse values in Table II. 8 include several apparent anomalies. Area 2 values are higher than Area 1 for the lungs but not for other organs. The hide of the Area 1 mouse is the highest of its kind reported in Table II. 8, as is the muscle value. The muscle concentration of this mouse is higher than any other tissue concentration except the pocket gopher G. I. and stomach values. This fact is even more curious in the knowledge that this mouse had low lung, liver, and bone values. Such a high muscle concentration does not seem possible and may suggest difficulties in prevention of cross contamination during dissection.

Tissue plutonium data from animals collected in areas removed from Rocky Flats are represented in Table II. 9. These values likely represent plutonium background levels typical to the general mountain region of northcentral Colorado. Only the relatively high plutonium content in bone of one trout was unexpected.

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[12]Sims, P. L., et al. 1971. Herbage Dynamics on the Pawnee Site. U. S. International Biological Program Technical Report No. 99.

Table II. 7. Plutonium concentrations in vegetation grab samples.

Location	Sample description	Sampling date	Estimated biomass, g/m^2	$^{239,240}Pu$ dpm/gm dry**	^{238}Pu dpm/gm dry**
AREA 1	Standing vegetation	10-16-72	265	213± 18	2.94±0.23
	Standing vegetation	10-20-72	180	682± 70	12.7±1.3
	Standing vegetation	10-20-72	225	91.7±11.4	1.65±0.21
	mean ± s.e.			329±180	5.76±3.49
	Litter*	7-14-72	1040	399± 8	7.01±0.35
	Litter*	7-14-72	--	2170± 65	42.5±0.9
	Litter	10-16-72	225	969±138	16.5±2.4
	Litter	10-20-72	125	1070±115	20.0±2.1
	Litter	10-20-72	250	945±157	16.4±2.7
	mean ± s.e.			1110±290	20.5±5.9
	Roots*	7-14-72	200	597± 12	11.7±0.5
	Roots*	7-14-72	--	1240± 50	23.1±1.6
	mean ± s.e.			919±322	17.4±5.7
AREA 2	Standing vegetation*	7-14-72	670	3.07±.12	.084±.013
	Litter*	7-14-72	3870	4.73±.19	.112±.013
	Roots*	7-14-72	70	2.16±.04	.043±.006

* analyzed by LFE Environmental

** ± 2 s.d. due to counting error

Table II. 8. Plutonium in animal tissues from Rocky Flats.

Species	Tissue	Area 1 Animal No.[B]	Area 1 dpm/g dry[A] $^{239,240}Pu$	Area 1 dpm/g dry[A] ^{238}Pu	Area 2 Animal No.[B]	Area 2 dpm/gm dry[A] $^{239,240}Pu$	Area 2 dpm/gm dry[A] ^{238}Pu
Thomomys talpoides (Northern pocket gopher)	Stomach (with contents)	1-1	93.1 ±8.5	2.23±0.37			
		1-2	24.0 ±1.4	0.36±0.07			
	G. I. (with contents)	1-1	53.2 ±3.1	0.88±0.08	2-1	2.59±0.23[C]	0.12±0.04[C]
		1-2	25.0 ±1.3	0.47±0.05			
		1-3	1.32±0.17	0.34±0.09			
	Lung	1-1	4.85±0.36	0.72±0.18	2-1	0.85±0.18	0.00±0.05
		1-2	2.91±0.37	0.71±0.12			
		1-3	0.77±0.22	0.00±0.05			
	Liver	1-1	5.11±0.21	0.17±0.04	2-1	4.98±0.39	0.16±0.07
		1-2	2.39±0.38	0.00±0.05			
		1-3	0.82±0.08	0.05±0.01			
	Spleen	1-3	7.12±0.68	0.32±0.12	2-1	6.84±0.94	1.27±0.47
	Bone[D]	1-1	3.43±0.14	0.12±0.02	2-1	0.21±0.05	0.04±0.02
		1-2	6.86±0.2	0.30±0.03			
		1-3	0.65±0.08	0.04±0.02			

[A] ± 2 s.d. due to counting error

[B] sampling dates as follows: #1-1, 11/8/72; 1-2, 11/8/72; 1-3, 1/17/73; 1-4, 8/5/72; 1-5, 8/5/72; 1-6, 8/5/72; 2-1, 1/18/73; 2-2, 8/9/72; 2-3, 8/9/72; 2-4, 8/9/72; 0-1, 8/73.

[C] includes stomach

[D] whole skeleton minus skull and forelegs

Table II. 8. (Concluded)

Species	Tissue	Area 1 Animal No.[B]	Area 1 dpm/g dry[A] $^{239,240}Pu$	Area 1 dpm/g dry[A] ^{238}Pu	Area 2 Animal No.[B]	Area 2 dpm/g dry[A] $^{239,240}Pu$	Area 2 dpm/g dry[A] ^{238}Pu
Thomomys talpoides (Northern pocket gopher)	Muscle	1-1	2.11±0.28	0.12±0.07	2-1	1.94±0.16	0.22±0.05
		1-2	1.08±0.08	0.38±0.05			
		1-3	0.00±0.05	0.00±0.05			
	Hide	1-1	6.2 ±0.8	0.38±0.10	2-1	2.66±0.36	0.18±0.09
		1-2	8.3 ±0.9	0.13±0.06			
		1-3	1.7 ±0.1	0.09±0.02			
Peromyscus maniculatus[E] (Deer mouse)	Lung	1-4,5,6	0.58±0.28	0.00±0.05	2-2,3,4	59.0±3.5	1.85±0.40
	Liver	1-4,5,6	0.59±0.14	0.00±0.05	2-2,3,4	0.08±0.05	0.00±0.05
	Muscle	1-4,5,6	43.82±2.76	7.99±0.50	2-2,3,4	8.55±0.61	0.47±0.13
	Hide	1-4,5,6	9.85±0.68	0.23±0.05	2-2,3,4	0.47±0.09	0.06±0.03
	Bone[D]	1-4,5,6	0.90±0.04	0.20±0.04	2-2,3,4	0.27±0.08	0.00±0.05
Taxidea taxus[F] (Badger)	Lung	---	---	---	0-1	0.18±0.03	0.00±0.05
	Liver	---	---	---	0-1	0.02±0.01	0.00±0.05
	Muscle	---	---	---	0-1	0.07±0.02	0.00±0.05
	Stomach (with contents)	---	---	---	0-1	0.38±0.04	0.02±0.01
	Hide (∿100cm^2)	---	---	---	0-1	0.12±0.03	0.06±0.02

[E] Pu values include tissues from three individuals

[F] road kill from Indiana Avenue east of Rocky Flats

Table II. 9. Plutonium in animal tissues from the northcentral Colorado mountains.

Animal	Location	Animal No.	Date Sampled	Tissue	^{239,240}Pu dpm/gm dry[A]	^{238}Pu dpm/gm dry[A]
Rainbow Trout	Snow Lake	0-2	7-11-72	Bone	0.00±0.05	0.00±0.05
Rainbow Trout	E. Twin Lake	0-4	1-22-73	Bone	0.00±0.05	0.00±0.05
Brook Trout	Upper Camp Lake	0-3	8-2-72	Bone	4.93±0.21	0.13±0.02
Brook Trout	Upper Camp Lake	0-5	8-2-72	Liver	0.08±0.05	0.00±0.05
Brook Trout	Peltier Lake	0-6	8-12-72	Liver	0.00±0.05	0.00±0.05
Rainbow Trout	E. Twin Lake	0-7	1-22-73	Liver	0.27±0.05	0.03±0.02
Mule Deer	Poudre Canyon (30 mi. west of Ft. Collins)	0-8	12-22-72	Muscle	0.00±0.05	0.00±0.05
		0-9	12-26-72	Muscle	0.03±0.01	0.00±0.05
		0-8	12-22-72	Liver	0.00±0.05	0.00±0.05
		0-9	12-26-72	Liver	0.20±0.01	0.02±0.01

[A] ±2 s.d. due to counting error

[B] concentrations now listed as 0.00 ± 0.05 dpm/g are being recounted for longer times.

E. Experimentation

To predict the nature and extent of plutonium contamination patterns at Rocky Flats in the future, knowledge of both the present levels of contamination and the transfer parameters associated with the principal components of the ecosystem are needed. A number of controlled experiments both in the laboratory and field were planned to gain the necessary information. None of these experiments were carried out during the past year, but several will be attempted during the coming year.

We have made plans to perform studies concerning: uptake of plutonium from soil by plants and by small mammals through inhalation and ingestion of soil, atmospheric movement of plutonium to plants and animals, movement into small mammals via food, and effect of burrowing rodents on rearrangement of plutonium soil profiles.

III. RADIONUCLIDE STUDIES WITH MULE DEER

III. A. Strontium-Calcium Metabolism

R. G. Schreckhise and F. W. Whicker

The purpose of this study is to investigate the kinetics of strontium and calcium in mule deer (Odocoileus hemionus hemionus) as affected by sex, age and season. The study is designed to provide information on bone and antler metabolism in deer, necessary parameters to formulate a deterministic model for predicting strontium-90 in deer and an assessment of the possibility of using deer antlers as a bio-indicator of fallout.

Antlers, because of their relatively rapid formation, might provide valuable information on bone metabolism. As stated by Cowan,[13] fundamental knowledge obtained from studies of antlered animals might provide useful information in the treatment of bone diseases and fractures.

Studies have been reported[14,15] relating ^{90}Sr concentrations in deer and their foodstuffs, but little is known about uptake, retention or other parameters which are possibly affected by age, sex and season. These parameters are required to develop a deterministic model for predicting ^{90}Sr burdens in mule deer from a known intake function.

Schultz[16] demonstrated a correlation between the concentration of Sr-90 in the mandible and antlers of white-tailed deer suggesting the possibility of using deer antlers as his indicators of local fallout. He further noted that because of the unknown extent of the utilization of skeletal and/or dietary ^{90}Sr in new antler formation, more studies are required before antlers can be used as fallout indicators.

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[13] Cowan, R. L. et al. 1969. Deer antler growth ideal for study of bone metabolism. Science in Agriculture. 17(1): 3.

[14] Longhurst, W. M., M. Goldman and J. Della Rosa. 1966. Comparison of the environmental and biological factors affecting the accumulation of Sr^{90} and Ca^{45} in deer and sheep. In Radioecological Concentration Processes. B. Aberg and F. P. Hungate, eds. Pergamon Press, Oxford. 635 p.

[15] Farris, G. C. 1967. Factors influencing the accumulation of strontium-90, stable strontium and calcium in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins. 189 p.

[16] Schultz, V. 1965. Comparison of strontium-90 levels between antler and mandible in white-tailed deer. J. Wildlife Mgmt. 29(1): 33-38.

The experimental design, the deer herd and facilities used for this study have been reported previously.[17] Briefly, to study the effect of season on Sr-Ca kinetics in the male deer in reference to antler development, the year was divided into three segments: Early antler growth - March through June; Late antler growth - July through September; and, Dormancy - October through February. For studies involving female deer, the following dates were selected for spiking: Pre-gestation - first of November; Mid-gestation - March; and, Pre-parturition - first of June.

Deer of various age groups were spiked by giving acute oral doses of approximately 1 mCi ^{85}Sr, 5 μCi ^{90}Sr and 100 μCi ^{45}Ca. They were then confined in a metabolic cage for approximately 2 weeks and their excreta collected. They were also periodically whole body counted and their antlers collected in the fall and analyzed for the administered radioisotopes.

All of the scheduled trials have been completed and at this time the last of the urine, fecal and antler samples are being analyzed for ^{45}Ca and ^{90}Sr.

The past year has been spent primarily on developing procedures for analyzing ^{85}Sr in the urine samples and ^{45}Ca and ^{90}Sr in all of the samples.

Difficulty was encountered in attempting to determine the amount of ^{85}Sr excreted in the urine. The urine samples were collected by removing a 1.0 liter aliquot from the bottle on the collection pan of the metabolic cage as described previously.[18] The urine samples unavoidably contained various foreign materials. This interfered with the analysis of the urine samples (by directly counting the 1.0 liter bottles) because the major ^{85}Sr fraction appeared to associate with the settleable solids. The ^{85}Sr also seemed to adhere to the sides of the polypropylene bottles. These problems were alleviated by first evaporating the bottle contents to dryness and then cutting up the bottle and placing it plus the dried residue into a crucible. The crucible was then heated with a bunsen burner to cause melting and ignition of the polypropylene until only a black residue remained. The crucible was then ashed at 600°C for approximately 20 hours to remove the remaining organic residue. Approximately 2.0 grams of the ash was removed, dissolved in 25 ml 1.0 N HCl in a 4 oz. plastic bottle and counted on a 3 x 3 inch NaI crystal attached to a single channel analyzer.

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[17]Schreckhise, R. G. and F. W. Whicker. 1972. Strontium-calcium metabolism. p. 5-10 In Tenth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins.

[18]Schreckhise, R. G., A. W. Alldredge and F. W. Whicker. 1970. Strontium and calcium metabolism in mule deer. p. 5-8 In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins.

Of interest after analyzing the urine and fecal samples for ^{85}Sr, was the difference obtained in total body retention of ^{85}Sr by excreta analysis versus that obtained by whole body counting. An example of this difference is shown in Fig. III. A. 1. The retention function obtained by excreta analysis when compared with that from whole body counting produces a larger value for the intercept of the long component and changes the parameters of the short component. This discrepancy is probably best explained by the change in whole body counting geometry of the ^{85}Sr which changes with time after ingestion of the ^{85}Sr. As illustrated in Figure III. A. 2 the excretion rate of ^{85}Sr reaches a maximum at approximately 1 day after ingestion. It then decreases very rapidly in the feces to small values (approaching the rate constant of the second component) at 3 to 4 days post-ingestion. During this 3 to 4 day period approximately 80 percent of the ingested dose, primarily that which is not absorbed, is in the G. I. tract in a relatively concentrated area. This produced a higher count rate than that obtained when the same amount of ^{85}Sr is distributed fairly evenly throughout the skeleton. This was the apparent reason for observing abnormally high count rates at the beginning of the trial which produced errors in the total body retention curves. This discrepancy is now being corrected in all of the previously reported retention curves.[17]

The procedure developed for analyzing samples for ^{45}Ca and ^{90}Sr is a modification of one reported by Boni.[19] The ashed samples, which were dissolved in 25 or 100 ml 1.0 N HCl, were spiked with an additional known amount of ^{85}Sr for determining chemical recovery. They were then filtered through a glass fiber filter into chromatography columns which contained 75 grams of Dowex 50W x 2 (50-100 mesh) cation exchange resin. This was followed by 3 separate rinses of 25 ml 0.1 N HCl through the sample bottle, filter and resin followed by an additional elution with 100 ml 0.1 N HCl directly through the resin. The eluent, which contained the phosphates and other anions, was discarded. The column was then charged by eluting with 200 ml 6.0 N HCl which also removed the cations (Sr and Ca). The eluent was adjusted to pH 3.0 with ammonium hydroxide, cooled to approximately 5°C and the Sr and Ca precipitated as the oxalate by adding 50 ml of a 5% solution of ammonium oxalate. The precipitate was then filtered onto a GF/A glass fiber filter, placed on a 2 inch planchet, covered with Saran-Wrap and a leaded weight to keep the precipitate flat. This was then dried at 95°C for approximately 38 hours.

The samples were then counted for ^{85}Sr with a 3 x 3 inch NaI crystal - single channel analyzer to determine the chemical recovery of strontium. Because the chemical recovery of calcium was practically the same as that observed for Sr (95 - 100%), the value obtained for Sr recovery was also used for ^{45}Ca determination.

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[19] Boni, A. L. 1963. Determination of total radiostrontium in biological samples containing large quantities of calcium. Analytical Chemistry. 35: 744-747.

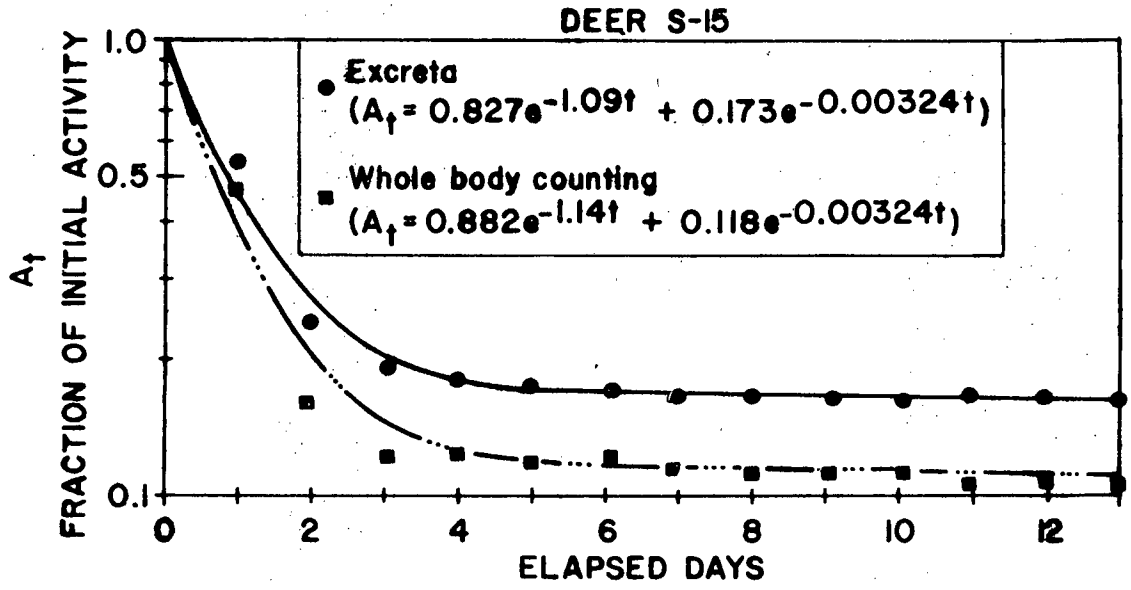

Fig. III. A. 1. Comparison of total body retention of an acute oral dose of ^{85}Sr as determined by accumulative excreta analysis and by whole body counting.

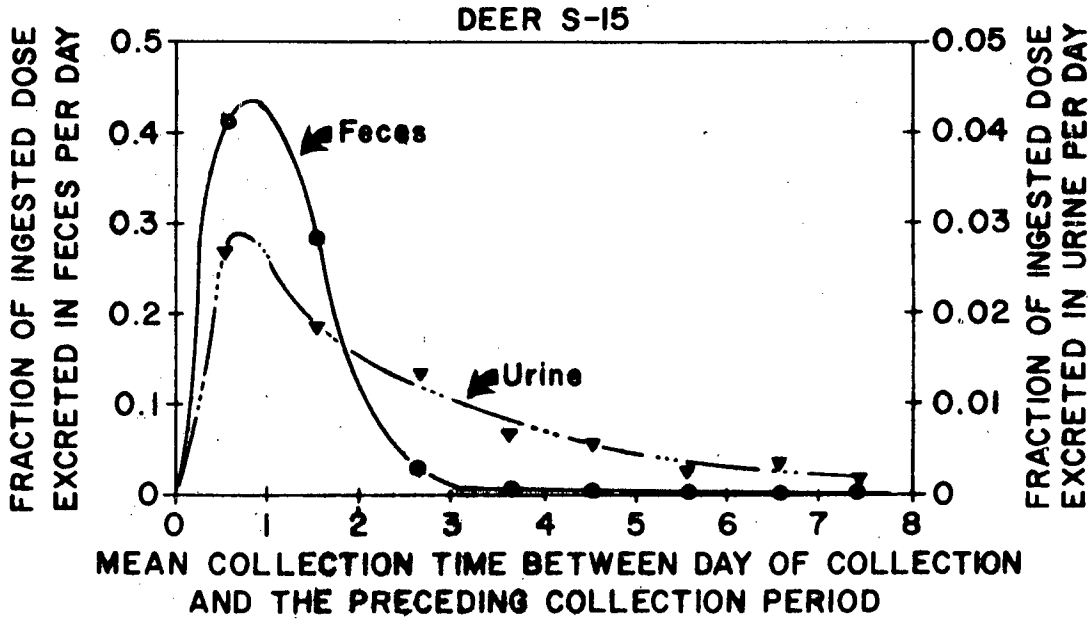

Fig. III. A. 2. Excretion rate of Sr-85 in the feces and urine. All values are corrected for physical decay.

Modifying a method described by Smith[20] the samples were then counted with a 2 x 3/8 inch anthracene crystal attached to a multi-channel analyzer. The mixtures of ^{45}Ca (β_{max} = 0.25 Mev), ^{90}Sr (β_{max} = 0.546 Mev), ^{90}Y (β_{max} = 2.27 Mev) and ^{85}Sr (γ only) in the samples were resolved by first subtracting for the known ^{85}Sr contribution to the composite beta spectrum obtained with the anthracene crystal - multi-channel analyzer. The channels were divided into 2 segments, the first consisting of the channels with energy equivalence of 0.0 to 0.55 Mev and the second set from 0.55 to 2.27 Mev. The sum of the net count rate of the channels in the second set were compared with a standard containing a known amount of ^{90}Sr - ^{90}Y to determine the amount of ^{90}Y in the sample. Because the ^{90}Y in the samples was in radioactive equilibrium with its parent ^{90}Sr, the amount of ^{90}Sr could be determined. The contribution of ^{90}Sr and ^{90}Y to the first set of channels could then be subtracted producing the net count rate due to ^{45}Ca. This was then compared with a ^{45}Ca standard to determine the amount in the samples. Adjustments were made for sample self-absorption and chemical yield.

The last of these samples are being counted at this time. The results of these samples along with those summarized previously will be presented in a Ph.D. dissertation to be completed later this year.

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[20] Smith, L. H. 1966. Resolving mixtures of beta emitters in plants and animals. Nucleonics. 24(4): 60-63.

III. B. Fallout ^{137}Cs and ^{131}I in Mule Deer and Vegetation, Winter 1972-73.
F. W. Whicker

Tissue samples from 5 mule deer killed by rifle within the Cache la Poudre Drainage in north-central Colorado were obtained in late December 1972 and mid February 1973. The animals were taken on winter range shrub communities of the lower montane forest at elevations between 6000 and 7400 feet for the purpose of defining long-range trends in radionuclide burdens. Muscle tissues were assayed for ^{137}Cs, thyroids for ^{131}I, and metacarpals were stored for future ^{90}Sr assay.

Results of the ^{137}Cs and ^{131}I determinations are given in Table III. B. 1. The ^{137}Cs values ranged from 40 to 101 pCi/Kg wet muscle with a mean of 65, which compares to a mean of 64 pCi/Kg in 1971. No ^{131}I was detected in any of the thyroids assayed.

A number of vegetation samples were collected during January, February and March, 1973 from winter and transition range plots established in 1962 by Whicker (1965)[21] and assayed for ^{137}Cs (Table III. B. 2). A number of species such as Ponderosa pine, Douglas fir, Kinnikinik, Rabbitbrush and half-shrub species of sage were collected in addition to species collected in 1962, '63 and '64 by Whicker. The additional species were collected in order to have more complete ^{137}Cs data on the major species found in the rumens of deer by D. E. Medin and A. E. Anderson. Such data were useful in the interpretation of a report on food consumption by free-roaming mule deer prepared by Alldredge, Lipscomb and Whicker.[22] These data will be examined at a later date along with fallout deposition information to estimate effective retention half-times for ^{137}Cs in the species sampled.

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[21] Whicker, F. W. 1965. Factors influencing the accumulation of fallout cesium-137 in mule deer. Ph.D. Thesis. Colorado State Univ., Fort Collins. 220 p.

[22] Alldredge, A. W., J. F. Lipscomb and F. W. Whicker. Forage intake rates of free-ranging mule deer estimated with fallout cesium-137. Submitted to J. Wildlife Mgmt. April 1973.

Table III.B.1. Concentrations of ^{137}Cs and ^{131}I in mule deer collected from the Cache la Poudre Drainage, Colorado, Winter 1972-73.

No.	Date	Sex	Age Class	Location S	T	R	Elevation (feet)	pCi ^{137}Cs/kg Wet Muscle	pCi ^{131}I/g Wet Thyroid
72-1	12/22/72	F	Mature	1	8N	72W	6700	40	N.D.*
72-2	12/22/72	F	Mature	1	8N	72W	6700	63	N.D.
72-3	12/26/72	F	Mature	4	8N	71W	6000	101	N.D.
72-4	12/26/72	M	Immature	4	8N	71W	6000	63	N.D.
73-1	2/16/73	M	Immature	31	9N	72W	7400	59	N.D.

*N.D. - Not detectable

Table III. B. 2. Concentrations of ^{137}Cs in several important mule deer forage species collected from established plots* within the Cache la Poudre Drainage during January-March, 1973.

Species	Location	Elevation (feet)	Date of Collection	pCi ^{137}Cs/g (air dry basis)	Mean for Species (pCi ^{137}Cs/g)
Aspen	L. Beaver Creek	8600	1-5-73	0.13	0.19
	Manhatten	9000	1-19-73	0.25	
Willow	L. Beaver Creek	8600	1-5-73	0.24	0.24
Bog Birch	L. Beaver Creek	8600	1-5-73	1.72	1.72
Bitterbrush	Hewlett Gulch	6000	3-6-73	0.17	0.17
	Kelly Flats	7000	2-24-73	0.16	
	Bennett Creek	7600	1-5-73	0.19	
	Sevenmile Creek	7800	1-9-73	0.16	
	Home Moraine	8000	2-27-73	0.18	
Mtn. Mahogany	Seaman Reservoir	5600	3-6-73	0.14	0.14
	Hewlett Gulch	6000	3-6-73	0.19	
	Young's Gulch	6100	2-27-73	0.14	
	Rist Canyon	6400	3-6-73	0.10	
	Sevenmile Creek	7800	1-9-73	0.11	
Mixed Shrubs	Young's Gulch	6100	2-27-73	0.25	0.25
Rabbitbrush	Home Moraine	8000	2-27-73	0.21	0.21
Big Sagebrush	Sevenmile Creek	7800	1-9-73	0.22	0.24
	Home Moraine	8000	2-27-73	0.24	
	Pingree Hill	8300	1-9-73	0.22	
	Manhatten	9000	1-19-73	0.27	
Mixed Sage (half-shrubs)	Pingree Hill	8300	1-9-73	0.58	0.65
	Manhatten	9000	1-19-73	0.71	
Kinnikinick	L. Beaver Creek	8600	1-5-73	0.68	0.70
	Manhatten	9000	1-19-73	0.73	

* Whicker, F. W. 1965. Factors influencing the accumulation of fallout cesium-137 in mule deer. Ph.D. Thesis. Colorado State Univ., Ft. Collins. 220 p.

Table III. B. 2., concluded

Species	Location	Elevation (feet)	Date of Collection	pCi ^{137}Cs/g (air dry basis)	Mean for Species (pCi ^{137}Cs/g)
Ground Juniper	Manhatten	9000	1-19-73	1.44	1.44
Rocky Mountain Juniper	Hewlett Gulch	6000	3-6-73	0.49	0.43
	Rist Canyon	6400	3-6-73	0.46	
	Kelly Flats	7000	2-24-73	0.27	
	Bennett Creek	7600	1-5-73	0.54	
	Sevenmile Creek	7800	1-9-73	0.44	
	Home Moraine	8000	2-27-73	0.39	
Douglas Fir	Sevenmile Creek	7800	1-9-73	0.45	0.45
Ponderosa Pine	Kelly Flats	7000	2-24-73	0.24	0.19
	Sevenmile Creek	7800	1-9-73	0.12	
	Pingree Hill	8300	1-9-73	0.22	
Mixed Pine & Fir	Bennett Creek	7600	1-5-73	0.26	0.37
	Manhatten	9000	1-19-73	0.48	
Mixed Grasses	Manhatten	9000	1-19-73	0.71	0.71

III. C. Forage Consumption Rates of Free-ranging Deer.
A. W. Alldredge, J. F. Lipscomb and F. W. Whicker

This work is summarized in the following abstract of a manuscript submitted to the J. Wildlife Management on April 13, 1973.[23]

Abstract

Forage intake rates of 87 wild, Rocky Mountain, mule deer (Odocoileus hemionus hemionus) collected over a 2-year period from the Cache la Poudre Drainage, Colorado, were estimated utilizing available data on fallout cesium-137 concentrations in the deer and their inferred diet. The method employed involved the convolution of an intake function and a retention function. Ingestion rates are reported and analyzed by sex, season, and age class. An overall mean forage intake of 21.9 g air dry forage/kg carcass weight/day was calculated. Adult animals consumed significantly ($P<0.10$) more vegetation per unit weight in summer than in winter and subadults significantly ($P<0.01$) more than adults throughout the year.

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[23]Alldredge, A. W., J. F. Lipscomb and F. W. Whicker. Forage intake rates of free-ranging, mule deer estimated with fallout cesium-137. Submitted to J. Wildl. Mgmt. April, 1973.

III. D. Gastrointestinal Retention of Ingesta in Mule Deer and Domestic Sheep.

A. W. Alldredge and D. E. Reeder[24]

This study was initiated in December, 1971, to elucidate some of the problems associated with feeding alfalfa hay to Rocky Mountain mule deer (Odocoileus hemionus hemionus). Six yearling mule deer and six yearling crossbred sheep (Ovis spp.) were used in each of five trials which involved feeding, ad libitum, a pelleted ration containing 0, 15, 35, and 50 percent alfalfa. At the conclusion of the 50 percent alfalfa feeding experiment the 0 percent ration trial was repeated. The chemical analysis of the experimental rations is reported in Table III. D. 1. A discussion of methods has been previously reported[25] and currently a manuscript including this study and other feeding experiments is in preparation for technical publication. Therefore, only a brief synopsis will be given here.

The results of this study are summarized in Table III. D. 2. Apparent dry matter digestion was calculated by,

$$\frac{\text{dry matter intake - dry feces weight}}{\text{dry matter intake}} \times 100.$$

Inert markers for ingesta in this study were chromium-51 ($^{51}CrCl$) and basic fuchshine stain. Mean retention times were calculated using cumulative excretion curves after Castle (1956).[26]

Increasing the percentage of alfalfa hay in the diet resulted in a decrease in mean retention time of ingesta (significant at $P < 0.05$) in sheep. Though mean retention time decreased slightly with increasing percentages of alfalfa, this reduction was not significant in the case of the deer. Mean retention times of ingesta were different ($P < 0.05$) for deer and sheep in this experiment.

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[24]D. E. Reeder is with the Department of Fisheries and Wildlife Biology, Colorado State University. This study was conducted on a cooperative basis between the Department of Radiology and Radiation Biology, the Department of Fisheries and Wildlife Biology, and the Colorado Division of Wildlife, and was funded in part by Colorado Federal Aid Project W-38-R-26.

[25]Alldredge, A. W. and D. E. Reeder. 1972. Gastrointestinal retention of ingesta in mule deer and domestic sheep. Pages 18-24 in Tenth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Dept. of Radiology and Radiation Biology, Colorado State University, Fort Collins.

[26]Castle, Elizabeth J. 1956. The rate of passage of foodstuffs through the alimentary tract of the goat. 1. Studies on adult animals fed on hay and concentrates. British J. Nutrition 10(1):15-23.

Table III. D. 1. Chemical analysis of four diets fed during rate of passage trials.

Diet	% Alfalfa[a]	Chemical analysis			
		Protein	Fat	Fiber	NFE[b]
I	0	13.8	2.4	18.6	52.9
II	15	13.8	2.3	20.1	51.0
III	35	13.4	2.1	22.8	47.7
IV	50	13.5	2.0	24.9	45.3

[a] The remaining portions of the compounded rations consisted of 40 percent barley, 30 percent cottonseed hulls, 20 percent of 32 percent protein supplement and 10 percent corn.

[b] Nitrogen free extract.

Table III. D. 2. Daily feed consumption, dry matter digestion and mean retention time for deer and sheep fed 0, 15, 35, and 50 percent alfalfa diets.

	Trial I 0% Alfalfa		Trial II 15% Alfalfa		Trial III 35% Alfalfa		Trial IV 50% Alfalfa		Trial V 0% Alfalfa	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
DEER (n=6)										
Daily Feed Consumption (g)	698	121	933	135	992	135	944	147	672	72
Apparent Dry Matter Digestion (%)	70.8	0.8	71.7	0.9	67.4	1.0	64.4	1.8	--	--
Mean Retention Time (hrs)	23.6	1.3	23.5	2.0	22.4	2.3	21.8	1.3	23.1	2.1
SHEEP (n=6)										
Daily Feed Consumption (g)	1277	114	1453	84	1493	73	1660	84	1413	83
Apparent Dry Matter Digestion (%)	69.3	1.0	72.0	0.8	68.6	1.3	66.8	1.1	--	--
Mean Retention Time (hrs)	32.5	2.1	29.7	2.2	25.4	1.9	20.6	0.7	30.2	1.4

Accompanying the increase in alfalfa in the diet was a significant increase in feed intake by the sheep while digestibility decreased (though not significantly $P < 0.05$). The decrease in digestibility might lead one to suspect that the increase in food passage was necessitated to supply energy demands.

No significant changes in feed intake were observed for deer as percentages of alfalfa increased, but dry matter digestion decreased significantly ($P < 0.05$) between the 0 percent and the 50 percent alfalfa diets. This would indicate that the deer was obtaining less value from its feed and, while not increasing food passage through the gut, it might be concluded that deer would not be able to maintain themselves on a 50 percent alfalfa diet for any length of time.

We do not imply that deer and sheep are capable of discriminating specifically against alfalfa hay, but instead, against nutritional attributes associated with alfalfa. As evidenced in Table III. D. 1, as percentage alfalfa increases the crude fiber content also increases. Associated with the increase in fiber is also an increase in cell wall constituents and lignin. Possibly these increases influence the digestibility and retention times observed in this experiment.

Ample data do not exist to draw conclusions as to why the deer seem less capable of adapting to increasing percentages of alfalfa hay in their diet. It has been shown, however, that the deer has a smaller rumen, abomassum and omassum than does the sheep.[27] Anatomical and physiological parameters associated with the digestive systems of these animals undoubtedly play a role in observed nutritional responses. It may be concluded, however, that deer in this experiment did not increase the amount of food passing through the digestive tract with increasing percentages of alfalfa and that the dry matter digestion of the diet decreased as alfalfa content increased. It could also be recommended from this study that nutritional problems associated with deer be studied in the deer and not in a similar animal, as different genera of ruminants may respond differently.

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[27] Nagy, J. G., G. G. Schoonveld, and D. S. DeCalesta. 1971. Middle Park Cooperative Deer Study - Physiology and prevention of deer starvation: Job progress report. Colorado Game, Fish and Parks (mimeo). 22 p.

IV. NUCLIDE STUDIES OF AQUATIC SYSTEMS

IV. A. Kinetics of Cesium in a Montane Lake Ecosystem

K. L. Weaver and F. W. Whicker

Studies by Gallegos[28] and Hakonson[29] have examined the in situ kinetics of cesium in East Twin Lake, a natural semi-drainage, 5 hectare, dyseutrophic body located in the montane zone of the Colorado Front Range at an elevation of 2880 meters. East Twin Lake was found to maintain consistently high ^{137}Cs levels in trout muscle while trout in other Colorado mountain lakes have declined in ^{137}Cs content since the atmospheric test ban.[30]

Generally, cesium concentration by freshwater invertebrates depends directly on water concentration. However, Hakonson found disproportionately high midwinter stable cesium levels in invertebrates relative to water and concluded that cesium exchange with water must not be constant with season. Regression of stable cesium concentration in amphipods and zooplankton on water cesium concentration and water conductivity ($r=0.85$, 14df) is contrary to previous studies which have found cesium concentrations in invertebrates to decrease with increased conductivity.[31,32] A more complex relation dependent upon temperature, dissolved oxygen and cations present is suggested.

Seasonal cycling of ^{137}cesium in bluegill has been described using a least squares sine curve,[32] but seasonal variation in invertebrates has not previously been described. Lack of knowledge and data prevented inclusion of a time-variable relation for invertebrates in Hakonson's constant transfer coefficient simulation model of cesium kinetics in East Twin Lake (Figs. IV. A. 1, 2). Winter sampling of East Twin Lake water, sediment, trout and invertebrates has continued

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[28]Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph.D. Thesis, Colorado State University, Fort Collins. 342 p.

[29]Hakonson, T. E. 1971. Cesium kinetics in a montane lake ecosystem. Ph.D. Thesis, Colorado State University, Fort Collins. 152 p.

[30]Whicker, F. W., W. C. Nelson and A. F. Gallegos. 1972. Fallout ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado. Health Physics 23: 519-527.

[31]Kolehmainen, S. E., E. Häsänen and J. K. Miettinen. 1966. ^{137}Cs in fish, plankton and plants in Finnish Lakes during 1964-65. p. 913-919 In Radioecological Concentration Processes, Proc. Symp. April 1966, Stockholm, Sweden, Aberg and Hungate, eds. London: Pergamon Press.

[32]Kolehmainen, S. E. 1972. The balances of ^{137}Cs, stable cesium and potassium in bluegill (Lepomis macrochirus Raf.) and other fish in White Oak Lake. Health Physics 23: 301-315.

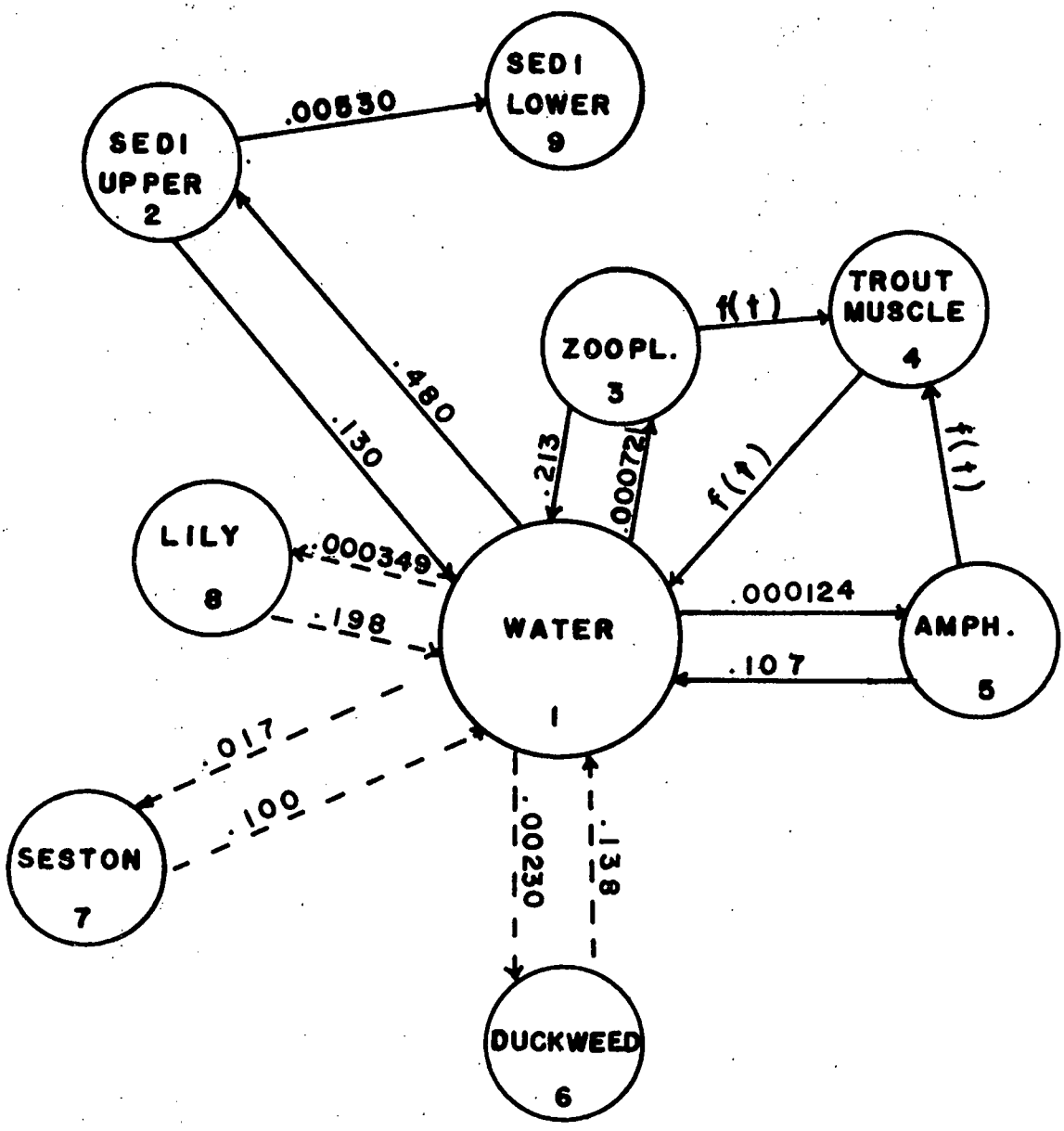

Fig. IV. A. 1. Compartment model used to describe kinetics of ^{133}Cs in East Twin Lake. Courtesy of Dr. T. E. Hakonson.

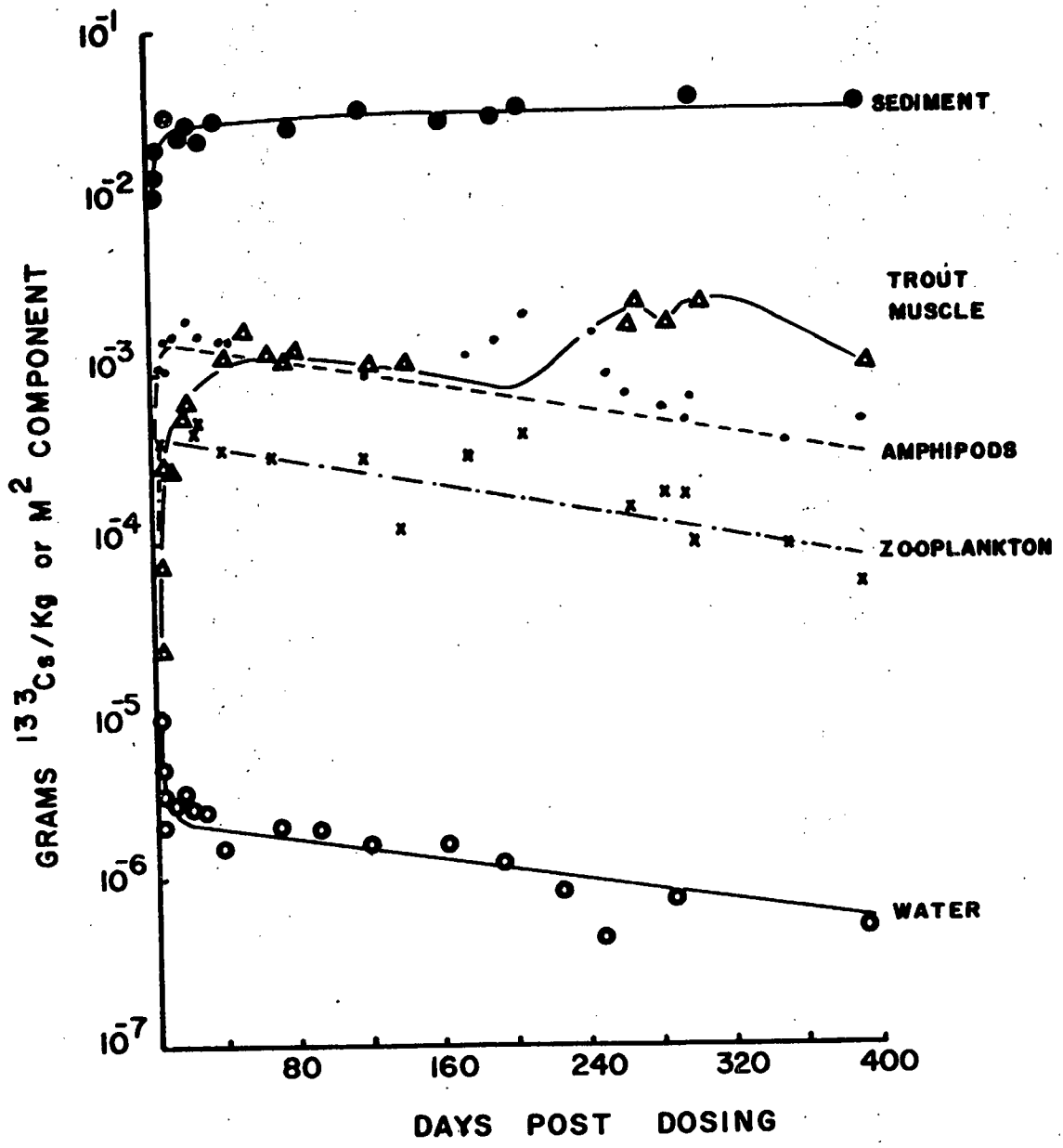

Fig. IV. A. 2. Simulation of the kinetics of ^{133}Cs in East Twin Lake after initial input of 1 kilogram. Points represent observed data. Courtesy of Dr. T. E. Hakonson.

(19 Sep., 19 Oct., 4 Nov., 1972; 4 Jan., 23 Jan., 16 Feb., 21 Feb., 17 Mar., 1 Apr., 18 Apr., 1973) and samples are being prepared for neutron activation analysis for comparison with Hakonson's data. This 1972-73 information, new laboratory data and a 1973-74 sample set will enable extension of Hakonson's model to include seasonal variation in cesium transfer rates.

IV. B. Cesium-137 in Trout from Colorado Mountain Lakes, 1972

F. W. Whicker, W. C. Nelson and A. W. Alldredge

During 1972, trout were collected from 9 montane and alpine lakes and one small stream in the montane zone for ^{137}Cs and lead determinations. The ^{137}Cs results are given in Tables IV. B. 1 and 2; lead results are not yet available. Nunn Creek and Avery, Kroenke and Deadman Lakes were sampled for the first time while the other lakes have been sampled previously.

Results in 1972 generally strengthen our general conclusions which have been published from earlier studies.[33] Referring to Table IV. B. 1, the trout planted during mid summer 1972 in E. Twin Lake show the expected ingrowth of ^{137}Cs into the winter, with levels reaching values which were reported several years previously. This certainly corraborates the idea that the lake is somewhat unique in recycling the cesium which has accumulated in the system over the past decade. Cesium-137 concentrations in trout from Upper Camp Lake also seem to have stabilized since 1966, whereas levels in trout from Snow and Lower Agnes Lakes appear to be undergoing a continual decline. The unusually low ^{137}Cs value for Peltier Lake agrees with data obtained in 1970 and the non-detectable value reported for Avery Lake is expected since Avery is actually an artificial impoundment in the foothills zone and is very high in suspended and dissolved minerals. The relatively low ^{137}Cs value for Deadman Lake is comparable to low values reported previously for lakes in the Sangre de Cristo Range.

Data in Table IV. B. 2 display variations among individual trout in ^{137}Cs concentrations at East Twin Lake. Of particular interest was a comparison between trout which had expired in a gill net prior to removal from the water and those which were still alive. A considerable number of fish samples collected during the past 7 years had expired in gill nets and we were concerned about possible leaching losses of ^{137}Cs. An unpaired t test indicated that those fish which were dead in the nets contained significantly ($P < 0.025$) more ^{137}Cs than those which were alive. This seems counterintuitive and we have no explanation for this observation.

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[33] Whicker, F. W., W. C. Nelson, and A. F. Gallegos. 1972. Fallout ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado. Health Phys. 23: 519-527.

Table IV. B. 1. Cesium-137 in muscle tissues of trout from Colorado waters, 1972 and January, 1973.

Mountain Range	Water	Elevation (meters)	Species	Date of Collection	Mean pCi ^{137}Cs/kg wet muscle
Medicine Bow	E. Twin Lake	2882	Rainbow	9-16-72	794
			Rainbow	10-19-72	2007
			Rainbow	1-22-73	2426
	Upper Camp Lake	3271	Brook	8-2-72	742
	Nunn Creek	2925	Brown	8-23-72	255
Never Summer	Snow Lake	3511	Cutthroat	7-11-72	850
			Cutthroat	8-23-72	960
	Lower Agnes Lake	3251	Brown	8-24-72	349
			Cutthroat	8-24-72	424
			Rainbow	8-24-72	644
Flattops	Adams Lake	3294	Rainbow	8-30-72	170
	Peltier Lake	2713	Brook	8-12-72	89
	Avery Lake	2320	Rainbow	8-11-72	N.D.*
Sawatch	Kroenke Lake	3500	Rainbow	9-13-72	301
			Cutthroat	9-13-72	299
Sangre de Cristo	Deadman Lake	3600	Cutthroat	9-15-72	339

* N. D. - not detectable

Table IV. B. 2. Variability in ^{137}Cs concentrations among individual rainbow trout from East Twin Lake, 1972, January 1973.

Date of Collection	Remarks on samples		pCi ^{137}Cs/kg wet muscle
9-16-72	Planted summer 1972	370	990
		611	611
		1079	612
			1288
		mean	794
10-19-72	43 cm trout, likely planted in 1971		2913
	Partially maimed in gill net by owl (2 trout)		2328
	Expired in gill net, subject to leaching planted summer 1972	2579	2207
		2326	2568
		1656	1933
		2149	2463
		1990	1584
		mean	2146
	Alive in gill net when removed from water, planted summer 1972	1746	1937
		827	1663
		2266	2167
		1476	1641
		1767	1966
		mean	1746
1-22-73	Caught with net under ice, planted summer 1972		3070
			2253
			1892
			2489
		mean	2426

IV. C. Lead Studies in Alpine Lakes

F. W. Whicker, W. S. Ferguson, and F. R. Miera

The annual report for 1971[34] summarized considerable data on lead concentrations in various tissues of trout from 17 montane and alpine lakes in Colorado, as well as preliminary data on the lead content of the snow pack in the Front, Never Summer, and Medicine Bow Ranges. During 1972, the major emphasis was given to the measurement of lead fallout deposition rates, concentrations in water of several mountain lakes, and the distribution of lead in the Snow Lake ecosystem. A brief summary of this effort is given in this report.

Lead fallout deposition rates in the high mountains may be estimated roughly from the quantities measured in polyethylene rainfall collectors (Table IV. C. 1) and the quantities measured in snow samples (Table IV. C. 2). Five precipitation collectors were established in remote locations in the Never Summer and Medicine Bow Ranges at elevations ranging from 10,200 to 12,200 feet in July and removed in October, 1972. Deposition rates, estimated from the areas of the polyethylene collection funnels and the total lead content of the samples, ranged from > 171 to > 395 $\mu g/m^2$-month, with a mean of > 286 $\mu g/m^2$-month (Table IV. C. 1). All of the fallout collectors were full and had obviously overflowed, thus measured deposition rates are minimum estimates. Assuming that rainfall is the predominant form of precipitation 5 months of the year at elevations above 10,000 feet and that the July through October fallout deposition estimate is reasonable, the annual lead deposition associated with rainfall is at least 1.43 mg/m^2. Correction was not made for deposition of resuspended dust particles, however, the fallout sample from Lake of the Clouds contained 0.08 g of dust, and if the average natural lead content of dust of 10-15 ppm[35] is applicable, the dust fraction contributed less than 2% of the total lead in the sample.

The lead values for snow samples in Table IV. C. 2 are variable, ranging from 1 to 20 µg/liter melt water. If it can be assumed that the mean lead content of the snow samples taken, namely 6.85 µg/liter melt water, is applicable to the high mountain regions of northern Colorado, we can estimate mean annual deposition. The 1947-1969 average water content of the May 1 snowpack at 10,285 foot Cameron Pass, which is within a few miles of most of our lead measurements, was 28.2 inches.[36]

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[34]Whicker, F. W. et al. 1972. Tenth technical progress report to the U. S. Atomic Energy Commission on Contract AT(11-1)-1156. COO-1156-54. Colorado State Univ., Fort Collins. 84 p.

[35]Committee on Biological Effects of Atmospheric Pollutants. 1972. Lead: Airborne lead in perspective. National Academy of Sciences, Washington, D. C. 330 p.

[36]Washichek, J. N. and McAndrew. 1967. Summary of snow survey measurements for Colorado and New Mexico. Soil Conservation Service, Colorado State University, Fort Collins, Colorado. 178 p.

Table IV. C. 1. Fallout lead measured in polyethylene precipitation collectors along the Never Summer and Medicine Bow Ranges in late summer - early fall, 1972.

Location	Elevation (feet)	Dates Exposed	Dissolved Phase		Filterable Solids		Pb deposition rate $\mu g/m^2$-month
			Precip. vol. (liters)	µg Pb/l	Mass (grams)	µg Pb/g	
Clarks Peak	12,200	7/8-10/3/72	>4*	8.0	0.73	<5	>171
Montgomery Pass	11,350	7/14-10/12/72	>4	13.5	1.11	16	>333
Diamond Peak	11,500	7/14-10/12/72	>4	11.5	>0.30	10	>283
Lake of Clouds	11,500	7/18-10/7/72	>4	15.0	0.08	<18	>395
Neota Creek	10,200	7/19-10/7/72	>4	8.0	1.03	6	>248
Means	11,350			11.2		<11	>286

*All precipitation collectors were full and overflowing at time of collection.

Table IV. C. 1. Lead determinations of snow samples collected in the Colorado Front (F), Never Summer (N), Medicine Bow (M), and Gore (G) Ranges.

Sample No.	Locale (Range)	Elevation (feet)	Depth Sample Taken (cm)	Date of Collection	Pb in µg/liter Snow-melt	Remarks
Sn-1-a	Snow Lake (N)	11,516	80-100	4-24-71	4	Samples run previously under different conditions of acidification when values of 3,3,3,7, and 2 µg/1, resp. were obtained.
Sn-1-b			60-80		3	
Sn-1-c			40-60		2	
Sn-1-d			20-40		8	
Sn-1-e			0-20		1	
Pb-113	Sawmill Cr. (M)	10,400	0-20	11-5-71	20	Acidified, prolonged contact with solids Re-run, 1.4 µg/1 found previously.
Pb-114	Fall Cr. Ridge (M)	10,200	0-20	12-9-71	12	Re-run, 9µg/1 found previously
Pb-115	Montogmery Pass (M)	10,000	0-20	1-6-72	3	Re-run, 3µg/1 found previously
Pb-116	Dream Lake (F)	9,906	0-20	1-26-72	11	Samples acidified, prolonged contact with solids and re-run. Values of 1.1, 0.8 and 0.4µg/1 found previously.
Pb-117			0-20		8	
Pb-118			0-20		18	
ACF 823	Snow Lake (N)	11,516	0-20	5-9-72	13	Filtered, unfiltered samples gave same results.
ACF 824			60-80		1.5	
ACF 825			120-140		1.5	
ACF 826			50-70		2.0	
ACF 827			110-130		3.0	
ACF 977	Blue Lake (M)	10,720	0-20	3-20-72	5	Samples acidified, prolonged contact with solids.
ACF 978			0-20		5	
ACF 979			0-20		5	
ACF 980	Black Lake (G)	∿10,600	0-20	3-13-72	11	Sample 50 m south of U.S. Highway 6, Vail Pass.

This converts to 716 liters of water accumulated in the winter snowpack per m^2 and this value times 6.85 µg lead/liter yields an annual deposition from snow of 4.91 mg/m^2. Thus, our current estimate of the mean annual lead deposition above 10,000 feet in the northcentral Colorado mountains is of the order of 6 mg/m^2.

Some results on lead determinations of water samples from one stream and several high mountain lakes are summarized in Table IV. C. 3. Variability among samples, which is greater than an order of magnitude in many cases, may result from actual differences and sampling, handling and analytical procedures. It is not clear yet as to the relative magnitudes of these sources of variation but there is strong indication in these and other results that methods of handling the samples and analytical uncertainties influence greatly the results. In general, it appears that the lead content of water in the mountain lakes ranges from 1/2 to 1/20 the lead content of snow or rain and that the lead content of Snow Lake water is within the range found for other lakes.

Lead values for various components of the Snow Lake ecosystem are summarized in Table IV. C. 4. While water samples contain lead in the ppb range, bottom sediments, attached algae and trout bone and liver contain lead in the ppm range. The observed concentration factors, while not firm in view of the limited number of samples, at least are order-of-magnitude approximations. Estimates of total lead inventories in the Snow Lake compartments await total mass estimates of the compartments per se. In 1971 it was estimated that 194 grams of lead entered the lake system from the snowpack and speculated that roughly 400 grams of lead entered the lake annually from fallout. Somewhat more refined estimates in 1972 indicated an annual input of 383 g Pb from the snowpack and 102 g from rainfall for a total of roughly 485 g/year. Lead input from watershed runoff has not yet been estimated.

Table IV. C. 3. Lead determinations of water sampled from six remote mountain lakes and one stream in Colorado during 1972.

AFC Serial No.	Water	Mountain Range	Elevation (feet)	Date	Sample Taken	Pb in µg/l	Field Filtered	Remarks*
809	U. Camp Lake	Medicine Bow	10,730	8/2/72	N. Shore	14	yes	Single, 1 liter sample
810	Peltier Lake	Flattops	8,900	8/12/72	W. Shore	2.5	no	Ditto
811	Nunn Creek	Medicine Bow	9,594	8/22/72	Surface	0.5	no	Ditto
812	Kroenke Lake	Sawatch	11,480	9/13/72	S.E. Shore	2.5	no	Ditto
813	Deadman Lake	Sangre de Cristo	11,800	9/14/72	N.E. Shore	<0.5	no	Ditto
814	L. of Clouds	Never Summer	11,500	10/7/72	W. Shore	<0.5	no	Ditto
815	L. of Clouds	Never Summer	11,500	10/7/72	S.E. Shore	<0.5	no	Ditto
816	L. of Clouds	Never Summer	11,500	10/7/72	N.E. Shore	<0.5	no	Ditto
817	Snow Lake	Never Summer	11,516	10/11/72	E. Shore	5.0	no	Ditto
496	Snow Lake	Never Summer	11,516	7/11/72	Mid. Surface	3	no	Mean of lab and field extractions
497	Snow Lake	Never Summer	11,516	7/11/72	Mid. Surface	1	yes	Ditto
498	Snow Lake	Never Summer	11,516	7/11/72	Outlet	2	no	Ditto
499	Snow Lake	Never Summer	11,516	7/11/72	Outlet	1	yes	Ditto
500	Snow Lake	Never Summer	11,516	7/11/72	N.W. Inlet	2	no	Ditto
501	Snow Lake	Never Summer	11,516	7/11/72	N.W. Inlet	<0.5	yes	Ditto

* All samples acidified in field with lead-free HNO_3.

Table IV. C. 4. Concentrations of lead measured in various components of the Snow Lake ecosystem in 1971 and 1972.

Sample Type	Dates of Collection	Range of Pb Concentrations (ppb-wet)	Mean Pb Concentration (ppb-wet)	Mean Observed Concentration Factor*
Water (filtered)	7/11/72	<0.5-1	0.8	
Water (not filtered)	7/11;10/11/72	2-5	3	
Bottom sediment	7/11;10/11/72	11,000-41,000	27,000	33,750
Attached Algae	10/11/72	5,600	5,600	7,000
Trout bone	9/9/71	670-950	800	1,000
Trout liver	9/9/71	310-570	440	550

* Concentration Factor = $\frac{\text{ppb of Pb in sample}}{\text{ppb of Pb in filtered water}}$

V. RADIATION EFFECTS ON A SHORTGRASS PLAINS ECOSYSTEM

V. A. The Plant Community
L. Fraley, Jr. and F. W. Whicker

This work is summarized in the following abstracts of two manuscripts, entitled "Response of Shortgrass Plains Vegetation to Gamma Radiation: I. Chronic Irradiation and II. Short-term Seasonal Irradiation."

Abstract (I. Chronic Irradiation)

Native shortgrass plains vegetation was exposed to chronic gamma radiation starting in April 1969. Density and frequency were recorded and these data were converted into community indices of coefficient of community (CC) and diversity (D). Fifty percent effects of these two indices resulted from exposures of 15 and 12 R hr^{-1} for CC and D, respectively, by June 1972. Population shifts occurred in the "effects" zone with an annual, Lepidium densiflorum, replacing the perennial, Bouteloua gracilis, as the dominant species by 1972 at exposure rates of 28 to 3.4 R hr^{-1} with the Lepidium producing ample viable seed at an exposure rate of 40 R hr^{-1} in 1972.

Abstract (II. Short-term, Seasonal Irradiation)

Native shortgrass plains vegetation was given a short-term (30 da) exposure in three seasons; Spring, Summer and Late-Fall, to gamma radiation with exposures ranging from 517 kR to 8 R. Data were collected through time to permit an analysis of the effects on community structure as measured by coefficient of community and diversity, and recovery stages for 3 years after the period of irradiation. The greatest sensitivity was shown by vegetation irradiated in late-fall. In general, the short-grass plains vegetation was found to be very resistant. Fifty percent coefficient of community effects resulted from exposures of 164,207 and 95.5 kR for the spring, summer and late-fall exposures respectively. Fifty percent diversity effects resulting from exposures of 57,143 and 46 kR for the spring, summer and late-fall exposures, respectively. Recovery was similar to secondary succession with the major exception that some perennials quickly regenerated from underground perennating organs that survived the radiation insult, apparently due to shielding by the soil and/or differential radioresistance of the above and below ground structures. Recovery communities were new, that is, not the same communities that existed prior to irradiation and evidence to date indicates that a long period of time will be necessary before the original communities become re-established.

V. B. The Arthropod Community
L. L. Cadwell and F. W. Whicker

This work is summarized in the following abstracts of two papers, the first entitled "Colony formation of the western harvester ant in a chronic gamma radiation field" which is in press in American Midland Naturalist and the second, entitled "Responses of naturally occurring arthropods in a gamma radiation field" which was submitted to Ecology in January, 1963:

Abstract

A colony of western harvester ants, Pogonomyrmex occidentalis, became established in a chronically exposed gamma radiation field located on the native short-grass plains of Colorado. The exposure level at the nest site was 18 R/hr. At the end of the colony's first and second seasons the nest mound diameter was 25 and 36 cm respectively. There were no apparent habitat modifications to suggest any avoidance response to the radiation.

Abstract

Pit-fall traps were used to sample arthropods for three seasons subsequent to the initiation of cesium-137 gamma irradiation. Both chronic and seasonal (30-day) irradiation treatments were utilized on the native shortgrass plains community.

No immediate avoidance responses were detected in members of the arthropod community in areas irradiated at rates up to 650 R/hr. Delayed or long-term responses as reflected by changes in arthropod abundances were found during and subsequent to irradiation. These responses were linked to modifications in the plant community via physical habitat change and altered trophic relationships. The attraction of Pogonomyrmex occidentalis (Cress.) to footpaths established for researcher access demonstrated how man, by his presence in natural systems, may alter the parameters that he intends to measure.

V. C. Soil Microorganisms and Soil Chemistry

S. D. Sparrow and K. G. Doxtader

Microorganisms, as the primary decomposers of organic materials and major contributors to mineral cycling, play an important role in ecosystems. Little information is available on the effects of long-term ionizing radiation on soil microorganisms. Data on this aspect is needed to understand the full impact of high, prolonged levels of ionizing radiation on ecosystems. In addition, radiation effects upon the biota can lead to changes in the chemical composition of the soil. Such chemical changes are likely to influence the activity and composition of microbial populations in the soil and will certainly affect plant community succession and overall recovery of the biotic system.

To determine the relationship of grassland soil microorganisms and soil chemistry to chronic gamma radiation, soil samples were collected across the radiation gradient in the chronic sectors during the summer and fall of 1972. Samples were taken with a 2-cm diameter hand core sampler to a depth of 5 cm except when depth relationships were studied; then samples were taken from the 0-2 and 2-5 cm depths. Cores were placed in air-tight, sterile, plastic bags, sealed, and brought into the laboratory for microbial and chemical analyses.

Numbers of bacteria, actinomycetes, and fungi were estimated by the plate-count method. Difco Plate Count Agar was used to culture bacteria and actinomycetes; fungi were cultured on Martin's medium.[37] Numbers of algae and nitrifiers were determined using the most-probable-number method. Algae were cultured in constant light in Bristol's medium.[38] Ammonium-calcium carbonate and nitrite-calcium carbonate media were used to culture nitrifiers.

Concentrations of ammonia and nitrate were determined using the steam distillation method; nitrite was determined colorimetrically. Soil pH, and the concentrations of organic matter, extractable phosphorus, exchangeable potassium, and DTPA-extractable zinc and iron were determined by the Soil Testing Laboratory at Colorado State University.

To determine soil respiration in the field, CO_2 evolution rates were measured. Metal cans, 7.5 cm in diameter and 13.5 cm long, with both ends removed, were placed to a depth of 5 cm into the soil along the radiation gradient. Vials containing 10 ml of 0.5N NaOH were placed inside the cans; the cans were then stoppered. After 24 hours, the vials were collected and brought into the laboratory. CO_2 was analyzed by titrating with standard acid.

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[37]Martin, J. P. 1950. Use of acid, rose bengal, and streptomycin in the plate count method for estimating soil fungi. Soil Sci. 69: 215-232.

[38]Bristol, B. Muriel. 1919. On the retention of vitality by algae. New Phytol. 18: 92-107.

Water extracts of ^{14}C-labeled plant material (primarily Bouteloua gracilis) was added to the soil in the respiration cans and the evoluted $^{14}CO_2$ collected and determined as a sensitive and fairly simple measure of microbial activity under field conditions. Theoretically, over a short period (24 hrs), all of the $^{14}CO_2$ evolved would arise from micro-organisms and not plant roots.

To determine the relative importance of radiation dose rate, soil moisture, and daily air temperature on microbial numbers and activity, plate count data and soil respiration data were analyzed using the 38R Stepwise Regression Analysis computer program at the Colorado State University Computer Center. Because of the small number of samples from the vegetated zone (beyond 8m from the source), only plate count data from the plant-lethal zone (2-8m from the source) were analyzed.

Soil samples were collected on several dates throughout the sampling period, but only data from selected dates are presented in this discussion.

Count data for bacteria, actinomycetes, and fungi in samples from the plant-lethal zone are presented in Tables V. C. 1-3. Bacterial numbers were higher when conditions were moist than when dry. Regression analysis indicated that both moisture and dose rate were significant,[39] but moisture was the more important factor affecting bacterial numbers, with dose rate having little effect.[40]

Dose rate was not a significant factor affecting actinomycete numbers in the plant-lethal zone; the moisture-temperature interaction (soil moisture x average daily temperature) was significant[41] but was negatively correlated. The higher plate counts under dry-cool conditions were likely due to spore production under the more adverse conditions. Sporulation of actinomycetes in soil often results in higher counts.[42]

Dose rate was a significant factor affecting fungi,[43] while moisture and temperature were non-significant.

Results from the plate count data from across the gradient on one sampling date are plotted in Fig. V. C. 1. Bacteria showed the smallest fluctuation in abundance, with counts at 50 m equal to those at 2 m. Except for the high numbers at 4 m, actinomycete abundance was fairly

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[39] Statistical significance in this discussion refer to F value at P = .95 or greater $\left(F = \frac{\text{regression sum of squares}}{\text{residual sum of squares}}\right)$

[40] r^2 for moisture =.58 r^2 for dose rate = .07

[41] r^2 for moisture x temperature = .54

[42] Alexander, M. 1961. Introduction to Soil Microbiology. John Wiley and Sons, Inc. New York.

[43] r^2 for log dose rate = .50

Table V. C. 1. Bacterial numbers in plant-lethal zone (0-5 cm soil depth).

Distance from source (m)	Radiation dose rate (R/hr)	Sampling date: May 25 Cts*	May 25 Soil water (%)	June 12** Cts*	June 12** Soil water (%)	Aug 17 Cts*	Aug 17 Soil water (%)	Sept 27 Cts*	Sept 27 Soil water (%)	Oct 17** Cts*	Oct 17** Soil water (%)	Nov 7 Cts*	Nov 7 Soil water (%)
2	650	6.18	4.1	106.82	16.3	--	--	6.35	2.9	13.53	2.6	--	--
3	315	9.90	4.5	34.76	13.1	--	--	6.26	2.7	4.82	2.5	16.2	7.3
4	185	17.40†	5.9	--	--	12.1	5.4	6.84	2.8	7.32	2.7	16.5	5.7
6	68	8.28	5.3	10.00	12.5	11.4	5.6	4.33	2.6	20.73	2.6	18.0	6.5
Avg. air temperature (°C)		16		20		20		9		15		6	

* 10^5 bacteria/g oven-dry soil

**Samples collected from 0-2 cm and 2-5 cm depths and analyzed separately; bacterial numbers for 0-5 cm depth calculated using weighted means.

† Samples collected at 4.5 m from source; dose rate: 150R/hr.

Table V. C. 2. Actinomycete numbers in the plant-lethal zone (0-5 cm depth).

Distance from source (m)	Radiation dose rate (R/hr)	Sampling Date: Aug 17 Cts*	Aug 17 Soil water (%)	Sept 27 Cts*	Sept 27 Soil water (%)	Oct 17† Cts*	Oct 17† Soil water (%)	Nov 7 Cts*	Nov 7 Soil water (%)
2	650	--	--	17.0	2.9	20.4	2.6	--	--
3	315	--	--	17.5	2.7	33.9	2.5	29.4	7.3
4	185	4.8	5.4	43.2	2.8	45.6	2.7	37.7	5.7
6	68	8.9	4.7	23.7	2.6	66.4	2.6	35.7	6.5
Avg. daily temp. (°C)		20		9		15		6	

† Samples collected in 0-2 cm and 2-5 cm depths and analyzed separately. Actinomycete numbers for 0-5 cm depth calculated using weighted means.

* 10^4 actinomycetes/g oven-dry soil.

Table V. C. 3. Fungal numbers in the plant-lethal zone (0-5 cm soil depth).

Distance from source (m)	Radiation dose rate (R/hr)	Sampling date: May 25 Cts*	May 25 Soil water (%)	June 12** Cts*	June 12** Soil water (%)	Aug 17 Cts*	Aug 17 Soil water (%)	Sept 27 Cts*	Sept 27 Soil water (%)	Oct 17** Cts*	Oct 17** Soil water (%)	Nov 7 Cts*	Nov 7 Soil water (%)
2	650	--	4.1	5.2	16.1	--	--	3.3	2.9	13.7	2.6	--	--
3	315	7.6	4.5	7.3	13.1	20.7	5.4	6.7	2.7	24.6	2.5	13.3	7.3
4	185	24.7†	5.9	--	--	--	--	8.3	2.8	11.7	2.7	17.2	5.7
6	68	63.5	5.3	16.2	12.5	19.8	5.6	19.8	2.6	17.5	2.6	37.3	6.5
Avg. daily air temp. (°C)		16		20		20		9		15		6	

* 10^2 fungi/g oven-dry soil.

** Samples collected from 0-2 cm and 2-5 cm depths and analyzed separately; fungal numbers for 0-5 cm depth calculated using weighted means.

† Samples collected at 4.5 m from source; dose rate: 150R/hr.

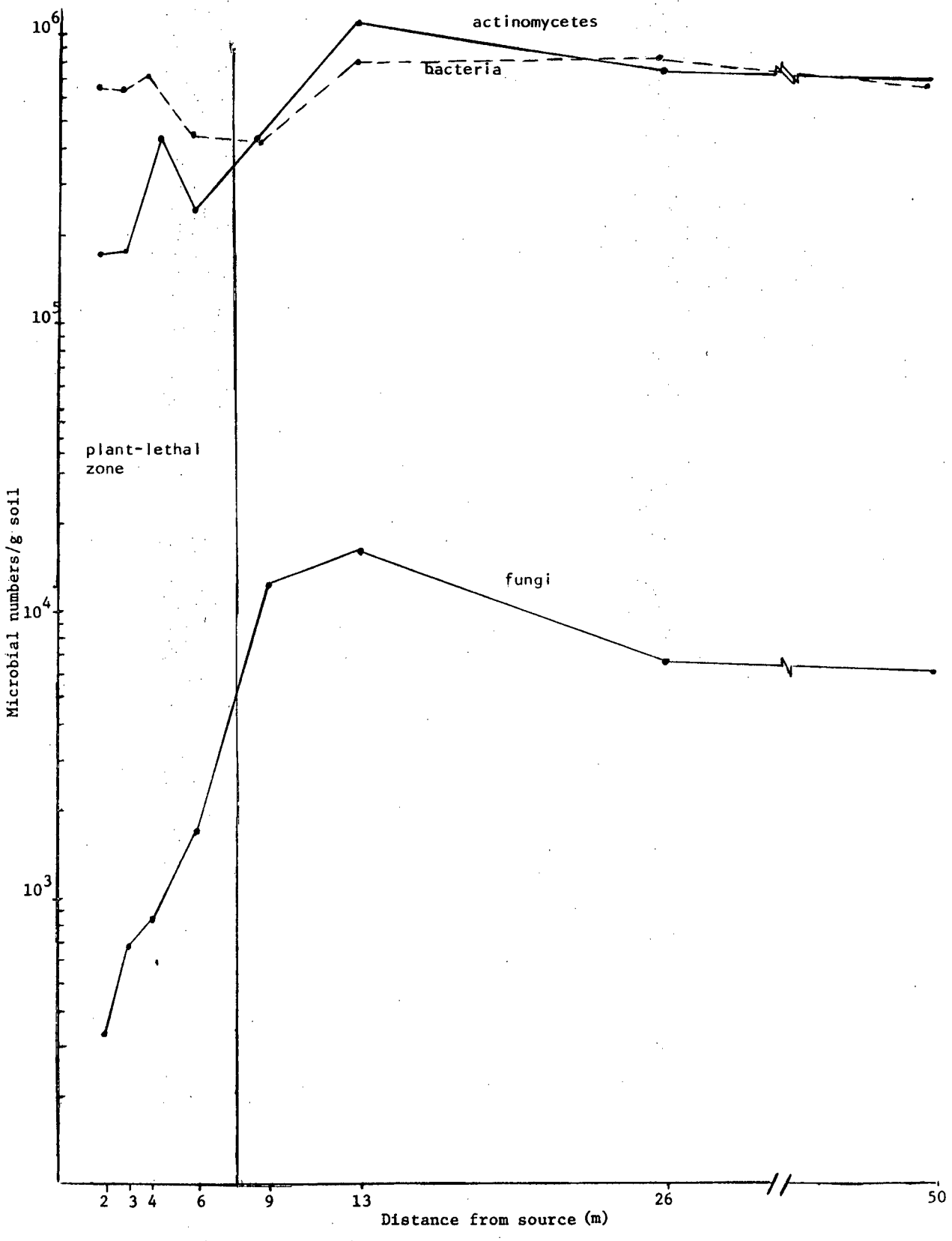

Fig. V. C. 1. Microbial numbers in the 0-5 cm soil depth across the radiation gradient (September 27, 1972).

constant between 2 and 6 m, but increased sharply to 13 m, then decreased with distance. The sharp increase in the vegetative zone may be a higher plant effect rather than a direct radiation effect. Fungal numbers increased with distance to 13 m, then decreased at the 26 and 50 m distances. The soil at 26 and 50 m is sandier and was usually much drier than the soil nearer the source. Over long periods, under dry conditions it is expected that microbial numbers would be low.

The results of one sampling in which samples were collected from the 0-2 and 2-5 cm depths are illustrated in Fig. V. C. 2. Generally, numbers of microorganisms were higher in the 0-2 cm depth than in lower depths. A tendency was noted for numbers in the 0-2 cm depth to be higher at 9 m than near the source. Viable bacteria, actinomycetes, and fungi were found in samples receiving the highest radiation dosage (0-2 cm depth, 2 m from source).

Numbers of algae ranged from 0.31×10^2 propagules/g soil at 6 m from the source to 3.62×10^2 propagules/g soil at 50 m, but no relationship between algal numbers and dose rate was demonstrated statistically. Algae were not eliminated by the radiation as viable algae were found at 2 m from the source.

Ammonia concentrations were higher near the source and decreased rapidly with distance from the source. Nitrate concentrations and numbers of autotrophic ammonia oxidizers (nitrosomonas) increased with distance from the source at 6 to 9 m, then decreased rapidly in the vegetative zone (Fig. V. C. 3). The most-probable-number method did not reveal the presence of autotrophic nitrite oxidizing microorganisms (nitrobacter), perhaps because of inadequate growth media or detection methods. However, these bacteria appear to have been present since appreciable levels of nitrate and no nitrite were measured in the soil.

Near the source, appreciable mineralization of organic nitrogen took place as revealed by the accumulation of NH_4^+-N. At greater distances from the source, nitrification increased as is evidenced by the increase in numbers of nitrosomonas and concentrations of NO_3^--N and decrease in NH_4^+-N. Apparently, nitrifiers were adversely affected in the high radiation environment, but were not completely inactivated even near the source.

In the vegetative zone, low amounts of ammonia and nitrate and small numbers of nitrite producers were found; the uptake of mineral nitrogen by plants and the inhibition of nitrifiers by plants may have contributed to this observation.

Total CO_2 evolution rates varied from as low as $2.03 g/m^2$/day at 2 m from the source on September 27 to as high as $13.7 g/m^2$/day at 50 m on September 7. From Fig. V.C. 4 it is apparent that CO_2 evolution rates were much higher on the September 7 sampling date. At this time the soil was moist and warm whereas on the other dates conditions were cool or dry. An increase in rates with increasing distance from the source is most apparent for the September 7 samples noted. Regression

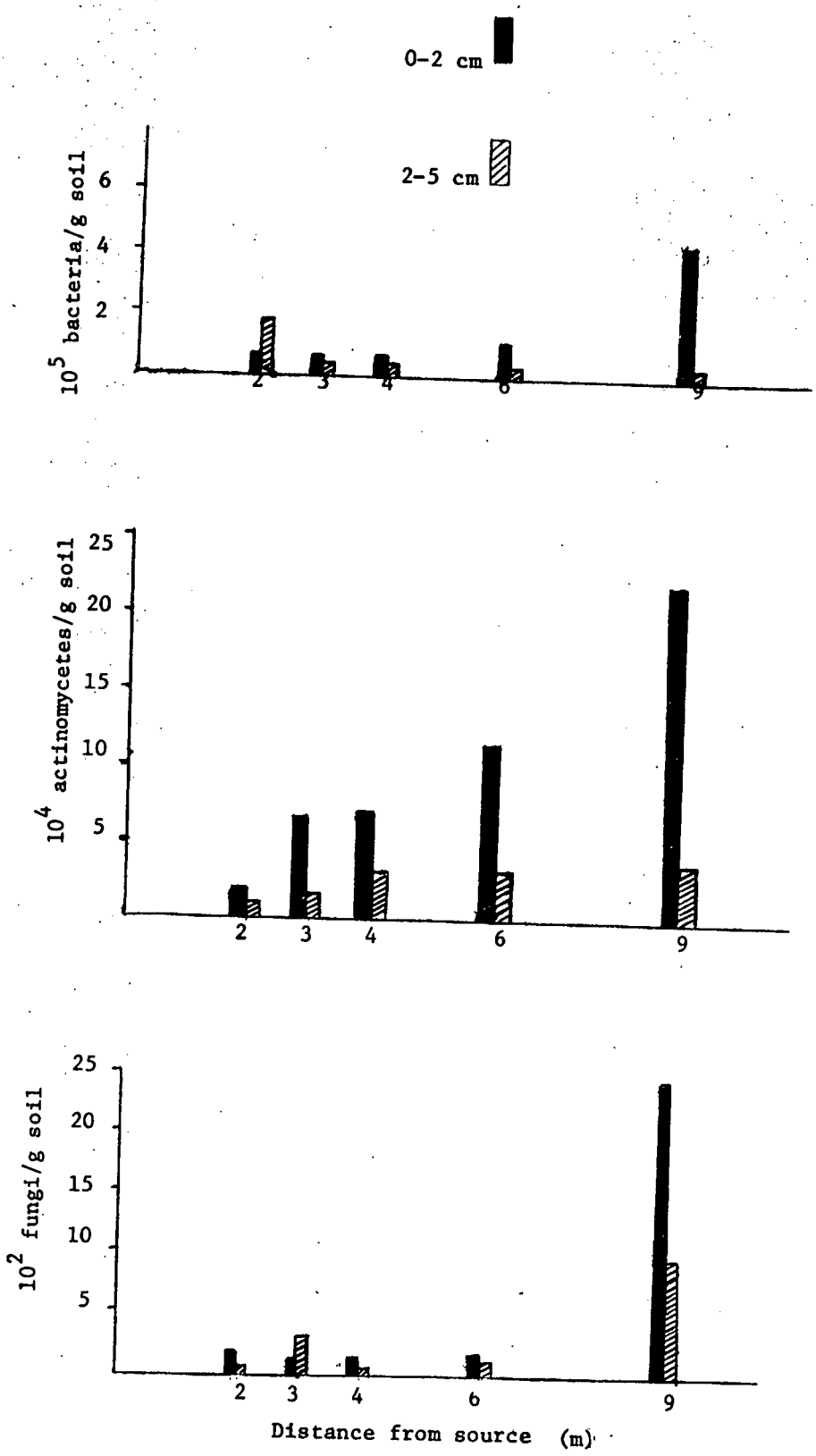

Fig. V. C. 2. Variation in microbial numbers with soil depth across the radiation gradient (October 17, 1972).

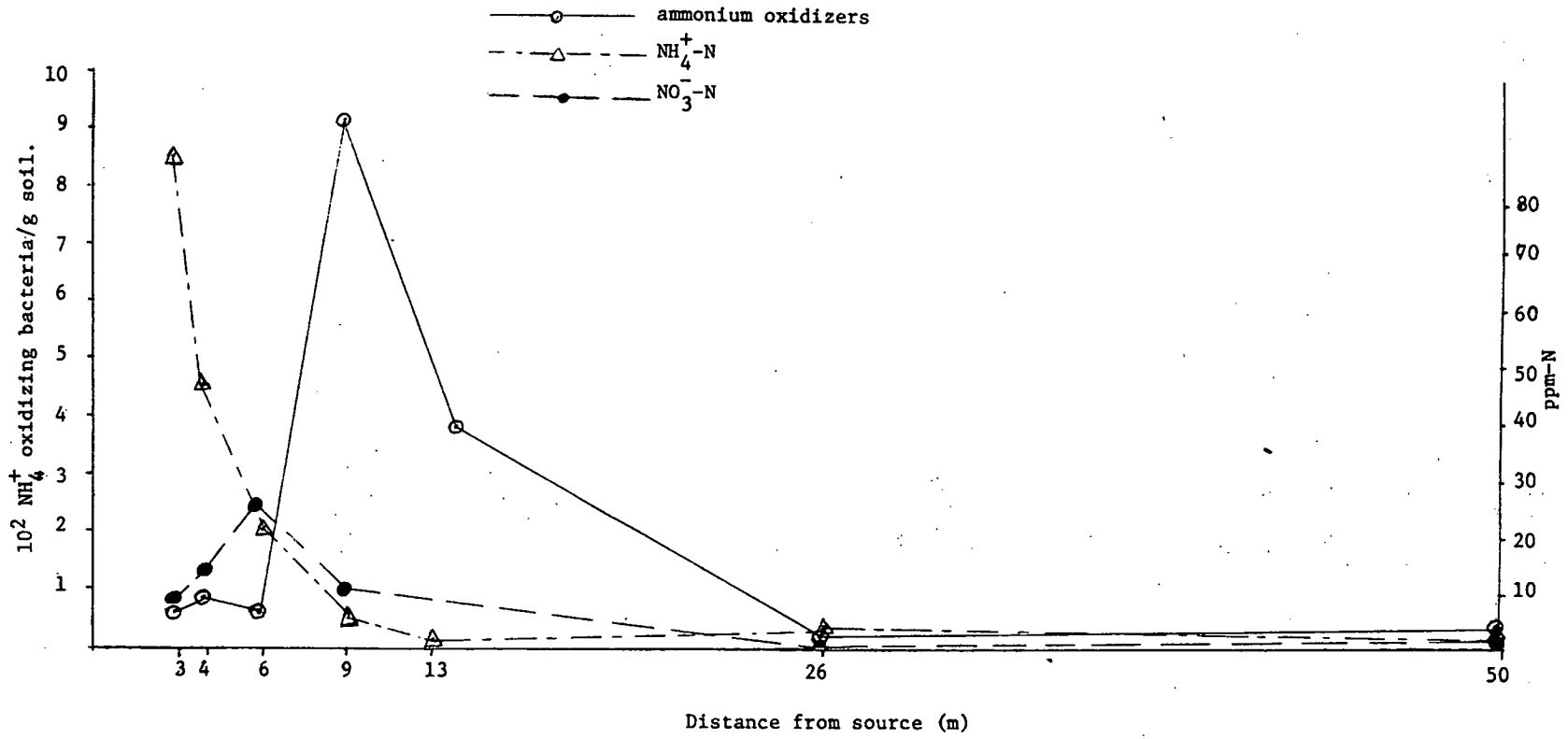

Fig. V. C. 3. Levels of NH_4^+-N and NO_3^--N and of ammonium oxidizing organisms across the radiation gradient in the 0-5 cm soil depth (November 7, 1972).

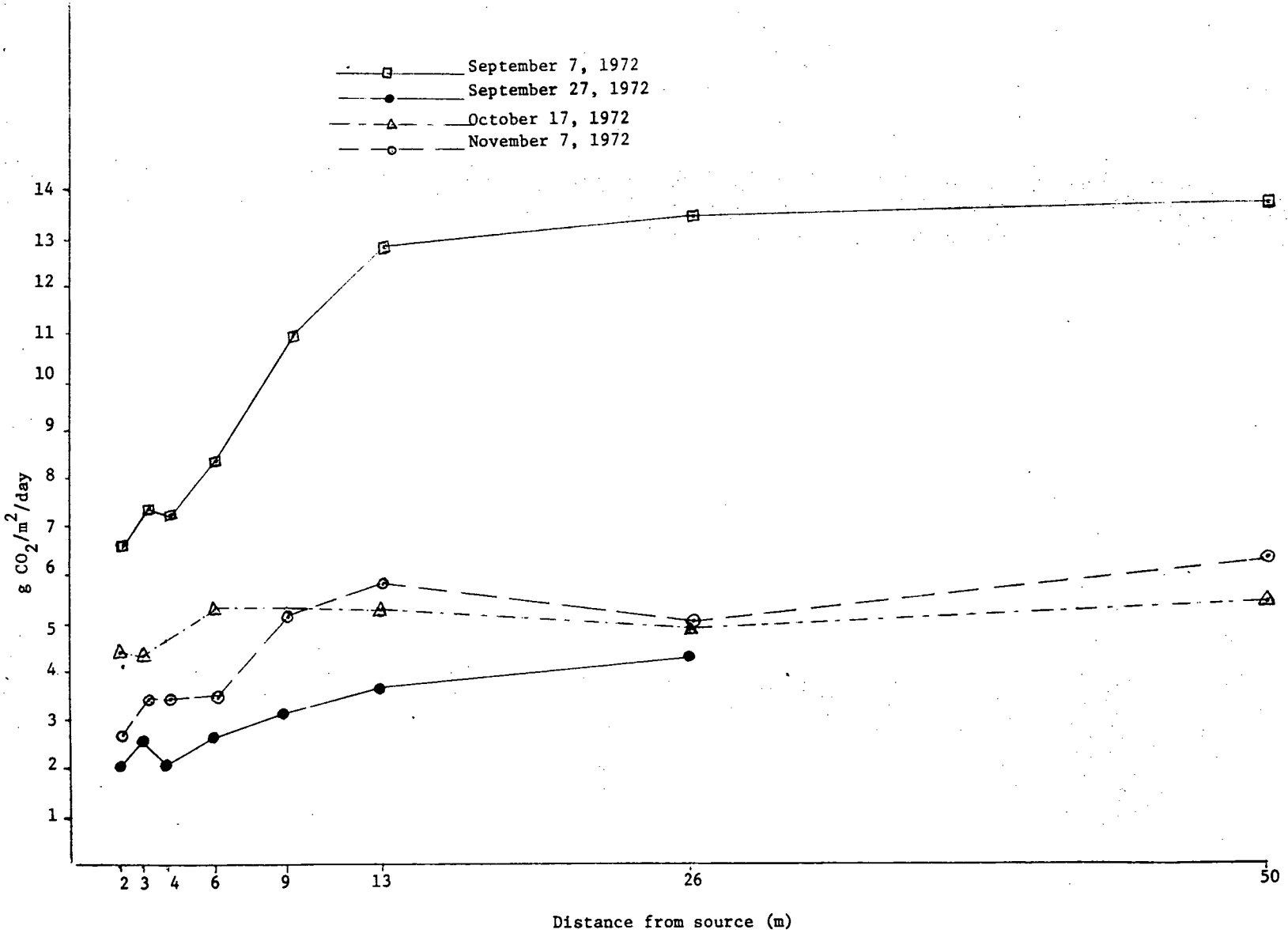

Fig. V. C. 4. CO_2 evolution rate in the field.

analysis of all of the data indicated that dose rate and moisture-temperature interaction were both significant factors affecting soil respiration,[44] but moisture-temperature was a much more important factor than the radiation.

The rates of $^{14}CO_2$ evolution from the labeled plant material increased rapidly with increasing distance from the source to a high at 9 m (Fig. V. C. 5), then decreased at greater distances. Regression analysis on data from across the total radiation gradient failed to indicate a significant effect of dose rate, but dose rate was a significant factor affecting $^{14}CO_2$ evolution rate in the plant-lethal zone.[45] Temperature was also significant, but a significant moisture effect was not observed, possibly because water was added with the plant material, thus masking any moisture effects. The reason for the decrease in $^{14}CO_2$ evolution rates in the vegetative zone is unclear.

Results of chemical analyses for samples taken on one sampling date from across the gradient in the 0-5 cm depth and on one date in which samples were taken at 0-2 cm and 2-5 cm are presented in Tables V.C. 4,5. Soil organic matter levels were about equal in the vegetative zone and the plant-lethal zone, indicating no apparent relationship of total organic matter content to dose rate. It would seem that relatively little decomposition of organic matter occurred in the plant-lethal zone; indeed undecomposed grass crowns were visible at the end of the summer of 1972.

The levels of extractable soil phosphorus were highest near the source and decreased with distance from the source. The high phosphorus concentration near the source may have resulted from phosphorus released from microbial cells or plant tissues which were killed, either directly or indirectly, by the radiation.

Available potassium and DTPA-extractable iron and zinc levels were highly variable with no apparent relationship to dose rate.

General Discussion

Chronic gamma radiation did result in changes in microbial populations and activities in a grassland soil of northeastern Colorado. Many of these changes were probably due to changes in the plant community and chemical composition of the soil brought about by radiation, rather than to direct radiation effects on the microorganisms. Fungi were the only major group of microorganisms to be suppressed significantly within the plant-lethal zone where the radiation dose rate was the highest. Even at the highest dosages, the soil was not sterilized; as viable microorganisms were found in surface soil samples taken near the source. The soil also showed appreciable rates of CO_2 evolution near the source.

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[44] r^2 for moisture x temperature = .69; r^2 for log dose rate = .18

[45] r^2 for dose rate = .35; r^2 for log temperature = .41

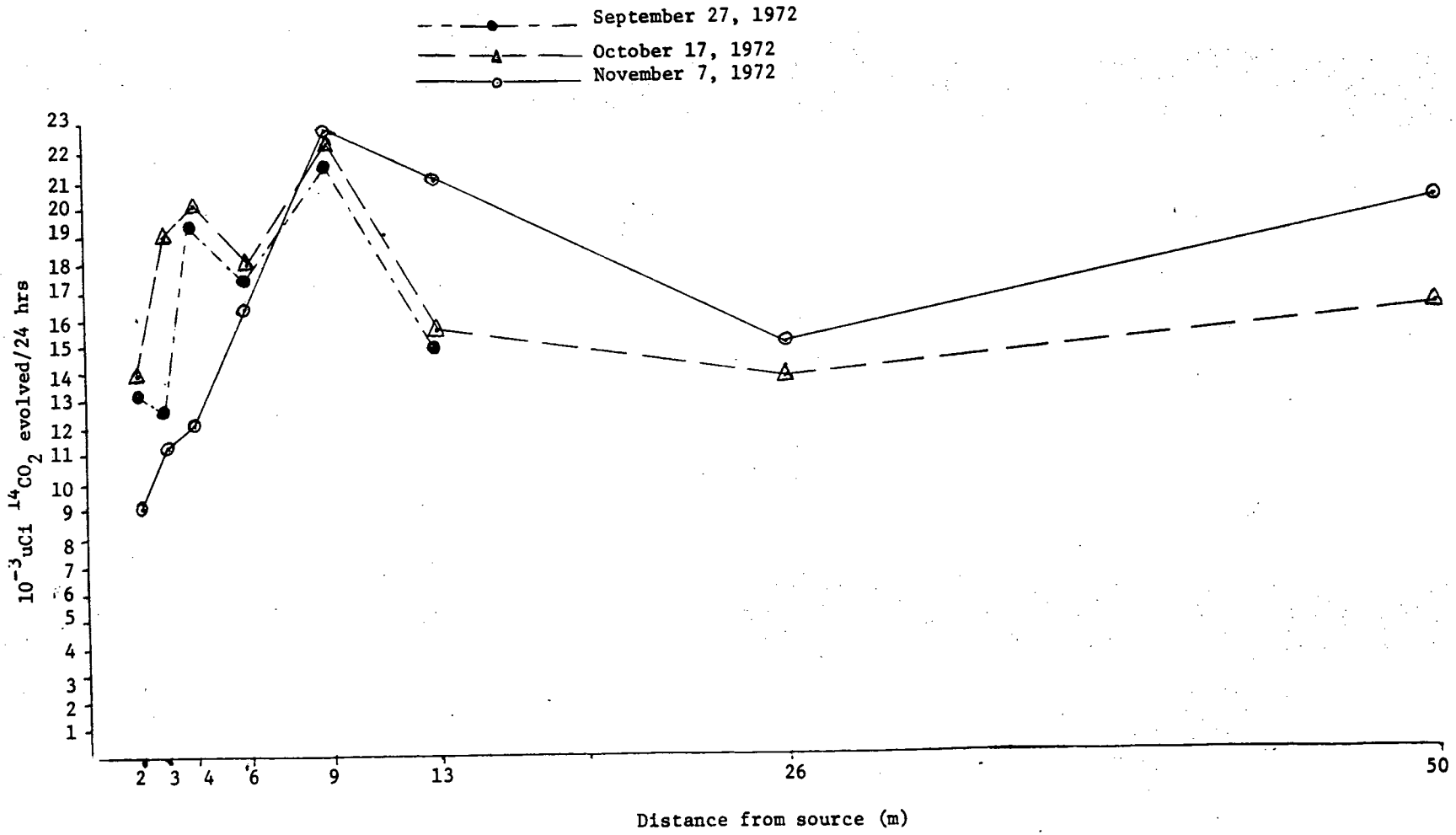

Fig. V. C. 5. $^{14}CO_2$ evolution rate per respiration can under field conditions.

Table V. C. 4. Chemical analyses of soil samples taken across radiation gradient on two sampling dates.

Distance from source (m)	Radiation dose rate (R/hr)	Soil pH		Soil organic matter (%)		Extractable soil phosphorus (ppm)	
		Sept 27	Nov 7	Sept 27	Nov 7	Sept 27	Nov 7
2	650	6.2	6.4[a] 6.3[b]	1.2	1.7[a] 1.3[b]	34.3	46.8[a] 31.6[b]
3	315	6.2	6.4[a] 6.0[b]	1.1	1.3[a] 1.0[b]	28.3	31.3[a] 26.2[b]
4	185	6.1	6.3[a] 5.8[b]	1.2	1.7[a] 1.2[b]	27.3	41.5[a] 40.8[b]
6	68	5.5	6.2[a] 5.4[b]	1.3	1.8[a] 1.2[b]	27.3	37.8[a] 32.6[b]
9	18	5.7	5.8[a] 5.3[b]	1.3	2.0[a] 1.7[b]	24.8	35.8[a] 34.8[b]
13	4.8	6.2		1.5		21.3	
26	0.22	5.7		1.7		22.3	
50	0.01	6.1		1.1		15.8	

[a] 0-2 cm depth

[b] 2-5 cm depth

Table V. C. 5. Chemical analysis of soil samples taken across radiation gradient on two sampling dates.

Distance from source (m)	Radiation dose rate (R/hr)	Exchangeable soil potassium (ppm)		DTPA extractable soil zinc (ppm)		DTPA extractable soil iron (ppm)	
		Sept 27	Nov 7	Sept 27	Nov 7	Sept 27	Nov 7
2	650	345	465[a] 306[b]	3.56	3.60[a] 2.37[b]	31.8	16.1[a] 16.9[b]
3	315	235	475[a] 371[b]	3.32	3.26[a] 1.44[b]	24.5	13.4[a] 14.4[b]
4	185	235	407[a] 381[b]	4.00	3.65[a] 1.18[b]	29.4	14.9[a] 17.4[b]
6	68	245	475[a] 365[b]	2.58	2.84[a] 1.20[b]	31.6	16.0[a] 18.8[b]
9	18	267	650[a] 448[b]	1.85	3.19[a] 1.25[b]	24.2	20.5[a] 25.5[b]
13	4.8	310		1.34		23.0	
26	0.22	220		1.66		31.6	
50	0.01	160		1.48		20.1	

[a] 0-2 cm depth

[b] 2-5 cm depth

An increase in soil respiration rate with distance from the source was noted. Part of the increased CO_2 evolution at greater distances from the source may have been due to plant root respiration, but most of it was likely due to increased microbial activity; it has been shown that plant roots account for a small fraction of the respiration in soil, whereas microorganisms usually are responsible for most of the CO_2 evolved. Depression in $^{14}CO_2$ evolution rates at high dose rates in the plant-lethal zone indicates that the activity of organisms capable of rapidly degrading water-soluble plant material was affected by high radiation.

The constant level of soil organic matter across the gradient and the presence of undecomposed grass crowns near the source is evidence that little decomposition of organic material was occurring in the plant-lethal zone. Some decomposition occurred, however, as revealed by measurable CO_2 evolution in this zone. Much of the organic matter present in normal grassland soils is in the form of humus, which is slowly decomposable, so a longer period than 3 years would be required to cause appreciable changes in total organic matter content. The lower CO_2 evolution rate and smaller numbers of fungi (an important primary decomposer group) in the plant-lethal zone is indicative of decreased decomposition.

Inorganic nitrogen and phosphorus in the soil seem to have been closely associated with the radiation intensity. Increased ammonium and phosphate near the source likely arose from the lysis of dead organisms, although some asymbiotic nitrogen fixation may have occurred. Since phosphate is not easily leached, and very little ammonium or nitrate would be leached under the dry conditions of eastern Colorado, almost all of the phosphorus and nitrogen mineralized would remain in the soil in the zone where the plants were killed.

Nitrification appears to have been affected directly by the radiation as an increase in nitrate production and numbers of nitrite producers with decrease in dose rate was noted.

In summary, changes in the microbial and chemical composition were noted in the areas of high level radiation. The chemical and microbial changes in the plant-lethal zone are closely interrelated and are directly or indirectly related to the irradiation of the plant community. Moisture and temperature appear to be major stress factors affecting microbial populations and activities, and in some cases these factors appear to have exerted greater influence than radiation.

VI. FEEDING RATES OF GRASSLAND ARTHROPODS

VI. Feeding Rates of Grassland Arthropods

L. L. Cadwell and F. W. Whicker

The long-range objective of this study is to evaluate the foraging impact of grasshopper species on the native rangeland vegetation of northcentral Colorado. Forage consumption rates are being estimated by the radiotracer method first suggested by Davis and Foster.[46] In general the technique makes use of the fact that animals feeding upon a radioactively labeled food supply will reach an equilibrium condition. At equilibrium the radiotracer intake rate is equal to its loss rate. The parameters which must be evaluated in order to estimate the forage consumption rates are:

1) the equilibrium body burden of the radioisotope in the organism,

2) the concentration of radioisotope in the food supply,

3) the retention function describing the organism's radioisotopic excretion pattern.

Early laboratory studies indicated that the grasshoppers selected for this study did not consume nearly all of the forage that they cut from the living plants. Thus, if this habit was not an artifact of maintaining these insects in the laboratory, it would suggest that the impact of grasshoppers on the system would be underestimated by simply determining consumption rates. Therefore, another goal of this study is to determine whether or not forage is cut and wasted under natural conditions, and to estimate the importance of this practice if it occurs.

The two grasshopper species selected for this study are Arphia conspersa (Scudder) and Arphia pseudonietana (Scudder). These large grasshoppers are relatively abundant on the grasslands of northcentral Colorado. They also are known to be primarily grass eaters. Thus their impact may be of definite and sizable economic significance since they compete directly with cattle for the available range grasses.

Since blue gramma grass (Bouteloua gracilis) is the dominant plant within the shortgrass community it was selected as the target species for these investigations. This study consists of both laboratory investigations and controlled field experiments.

Selected clumps of blue gramma were labeled in the field by a systematic injection of ^{32}P into the root zone. Enclosures were erected over the labeled grass and grasshoppers were subsequently introduced. A periodic whole body count of the grasshoppers was made in order to evaluate their ingrowth of radiophosphorus and the eventual

[46] Davis, J. J. and R. F. Foster. 1958. Bioaccumulation of radioisotopes through aquatic food chains. Ecology 39(3): 530-535.

equilibrium levels. Also, the labeled grass was sampled and returned to the laboratory for counting to determine the concentration of radiophosphorus. The equilibrium level body burdens in the grasshoppers and the concentration of ^{32}P in the grass have not yet been fully analyzed.

Small open-bottomed cages of approximately 0.2 m^2 were used for the experiments to determine the extent of wasted forage that may have been cut but not eaten by the foraging grasshoppers. Clumps of grass containing nearly pure stands of blue gramma were then groomed by hand to assure that no recently detached grass stems were present. Then the clumps of grass were covered with the cages and grasshoppers were introduced at various concentrations.

Initial trials with A. conspersa were not successful because many of the grasshoppers introduced into the cages died within a short time. Subsequent trials with A. pseudonietana resulted in excellent survival.

After the feeding trials the cut grass was recovered, oven dried and weighed. The results of trial #1 (Table VI. 1) suggest that the males did not cut and destroy detectable quantities of grass whereas the females did. Subsequent calculations assuming no contribution to the cut grass by the males in each cage yield mean dry weights per female-day of 5.1 and 5.4 mg. respectively, for females caged alone and females with males from trial #1. The results of trial #2 give mean dry weights per female-day of 36.6 and 31.2 mg. respectively for cages containing 2 and 3 grasshoppers of each sex.

The importance of this experiment is that it demonstrates that this grasshopper can indeed destroy substantial quantities of native range grass. If we apply the mean value of 36.6 mg. per female grasshopper-day, this impact alone may be of major importance. This value is approximately 15% of the dry weight for females of this species.

A series of laboratory experiments was conducted to determine the retention pattern of ingested radiophosphorus under different temperature combinations. A. pseudonietana were fed blue gramma internally labeled with ^{32}P and then maintained in controlled environment chambers. Whole body counts were periodically conducted and the data were fit by computer to a two component exponential model of the form:

$$A_t = Ae^{-\lambda_1 t} + Be^{-\lambda_2 t}$$

where:

A and B = fractional intercepts of the first and second components respectively, at t = 0 $\quad \lambda = \frac{.693}{T_{eff}}$

A_t = activity at any time t after ingestion (fraction of original activity)

Table VI. 1. Results of feeding trials to determine the amount of forage destroyed but not eaten by Arphia pseudonietana.

Feeding Period (Days)	Group	Number of Grasshoppers: Male	Female	Total	Dry Weight of Grass Destroyed (mg): Total	Per Female-Day	Per Grasshopper-Day
Trial 1 (Begun 8-18-72)							
5	1	1	0	1	0	0	0
5	1	1	0	1	0	0	0
5	1	1	0	1	0	0	0
5	2	0	1	1	0	0	0
5	2	0	1	1	70.3	19.1	14.1
5	2	0	1	1	6.5	1.3	1.3
5	3	1	1	2	21.1	9.2	2.1
5	3	1	1	2	88.2	17.2	8.8
5	3	1	1	2	2.2	0.9	0.2
5	3	1	1	2	22.2	4.4	2.2
5	3	1	1	2	30.1	6.0	3.0
5	3	1	1	2	0	0	0
Trial 2 (Begun 8-25-72)							
5	1	2	2	4	322.8	32.3	16.1
5	1	2	2	4	675.2	67.5	33.8
10	1	2	2	4	485.1	24.3	12.1
10	1	2	2	4	431.4	21.6	10.8
10	1	2	2	4	943.1	47.2	23.6
10	1	2	2	4	534.6	26.7	15.3
11	2	3	3	6	1118.1	33.9	16.9
11	2	3	3	6	1366.4	41.4	24.8
11	2	3	3	6	603.1	18.3	9.1

The resultant effective half times obtained for the two components for both sexes are shown in Fig. VI. 1. These results are consistant with the findings of other investigators who have found shorter half times with decreased body size in poikilotherms. For these grasshoppers the males are considerably smaller than the females.

The pattern for change in the half time at different temperatures is consistant for each component in both sexes. These data do not agree well with a general Q_{10} = relationship used by Reichle[47] and others to describe the change in elimination coefficients at different temperatures for terrestrial arthropods. This experiment differs from many of the previously conducted laboratory experiments in that different illumination intensities and temperatures were used during a simulated day-night cycle.

Attempts to relate these data on laboratory elimination rate response to temperature with actual field trials showed little agreement in half times. Apparently there are factors other than simple ambient temperature which affect elimination rates in the field. An apparent stability in the elimination rate observed in the field with changing temperature suggests that some homeostatic mechanisms may be at work there.

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[47]Reichle, D. E. 1967. Radioisotope turnover and energy flow in terrestrial isopod populations. Ecology 48(3): 351-366.

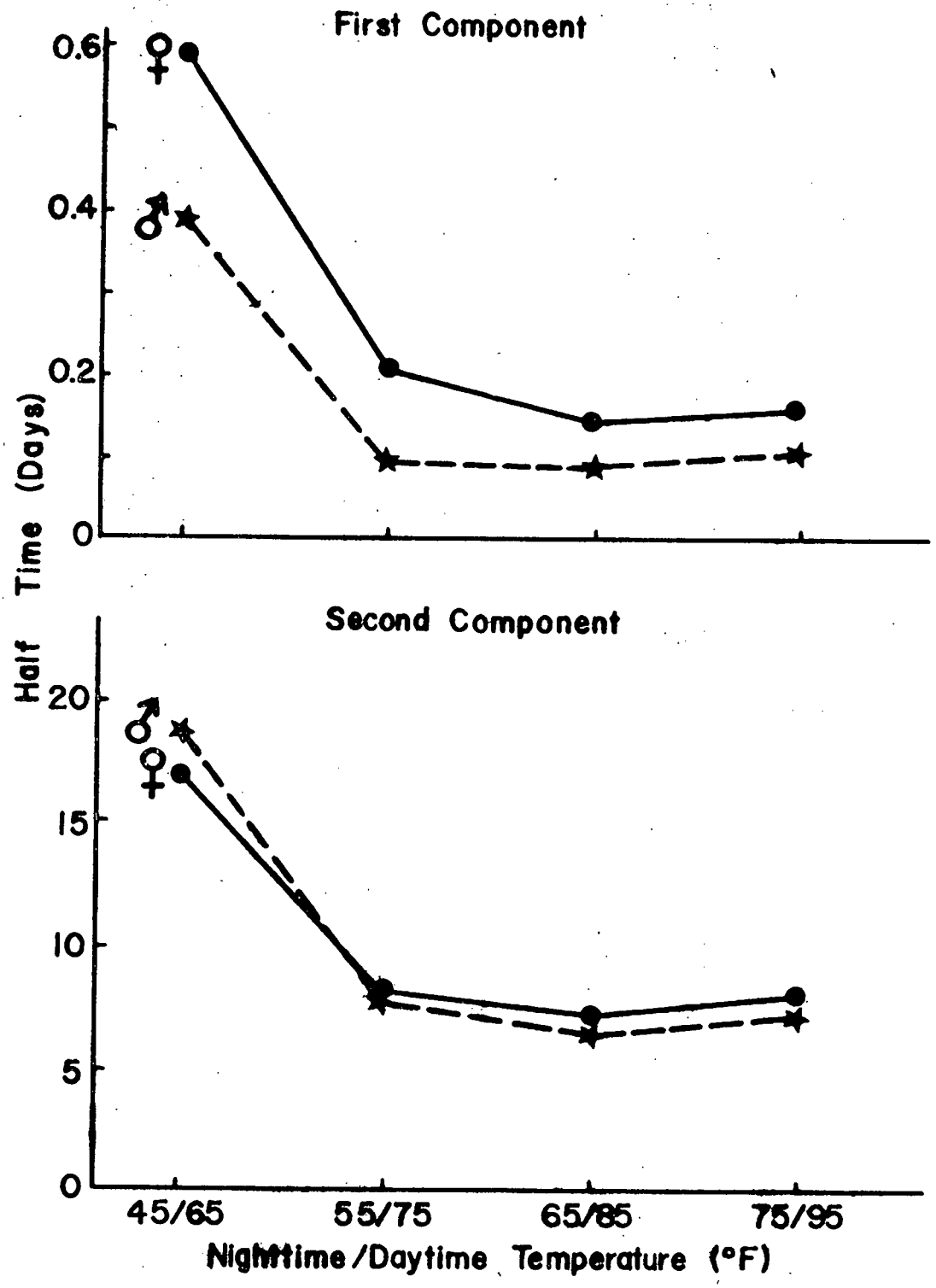

Fig. VI. 1. Effective half time of ^{32}P versus temperature regime for Arphia pseudotenia.

VII. LIST OF PUBLICATIONS

The following reports on work wholly or partially supported under AEC Contract AT(11-1)-1156 have been published or prepared for publication (the recent reprints and pre-prints accompany this report):

Hanson, W. C., F. W. Whicker, and A. H. Dahl. 1963. Iodine-131 in the thyroids of North American deer and caribou: comparison after nuclear tests. Science 140: 801-802. (COO-1156-2)

Hanson, W. C., A. H. Dahl, F. W. Whicker, W. M. Longhurst, V. Flyger, S. P. Davey, and K. R. Greer. 1963. Thyroidal radioiodine concentrations in North American deer following 1961-1963 nuclear weapons tests. Health Physics 9: 1235-1239. (COO-1156-4)

Whicker, F. W., E. E. Remmenga, and A. H. Dahl. 1965. Factors influencing the accumulation of I-131 in Colorado deer thyroids following 1961-1962 nuclear weapons tests. Health Physics 11: 293-296. (COO-1156-8)

Whicker, F. W., G. C. Farris, A. H. Dahl, and E. E. Remmenga. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Health Physics 11: 1407-1414. (COO-1156-10)

Whicker, F. W. 1965. Factors influencing the accumulation of fallout cesium-137 in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins. 230 p. (COO-1156-11)

Farris, G. C. 1965. Strontium-90 in antlers and selected bones of Colorado mule deer. M. S. Thesis. Colorado State University, Fort Collins. 83 p. (COO-1156-12)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1967. Concentration patterns of Sr-90, Cs-137, and I-131 in a wild deer population and environment, p. 621-633. In B. Aberg and F. P. Hungate (Ed.) Radioecological Concentration Processes, Pergamon Press, New York. (COO-1156-13)

Whicker, F. W., R. A. Walters, and A. H. Dahl. 1967. Fallout radionuclides in Colorado deer liver. Nature 214: 511-513. (COO-1156-14)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1966. Radioiodine concentrations in Colorado deer and elk thyroids during 1964-65. J. Wildlife Mgmt. 30(4): 781-785. (COO-1156-16)

Farris, G. C., F. W. Whicker, and A. H. Dahl. 1967. Effect of age on radioactive and stable strontium accumulation in mule deer bone, p. 93-102. In J. M. A. Lenihan, J. F. Loutit, and J. H. Martin (Ed.). Strontium Metabolism, Academic Press, London. (COO-1156-17)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1968. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards, p. 1105-1110. In W. S. Snyder (Ed.) Radiation Protection, Pergamon Press, New York. (COO-1156-18)

Remmenga, E. E. and F. W. Whicker. 1967. Sampling variability in radionuclide concentrations in plants native to the Colorado Front Range. Health Physics 13: 977-983. (COO-1156-19)

Whicker, F. W. and C. M. Loveless. 1968. Relationships of physiography and microclimate to fallout deposition. Ecology 49(2): 363-366. (COO-1156-20)

Nelson, W. C. and F. W. Whicker. 1969. Cesium-137 in some Colorado game fish, 1965-66, p. 258-265. In D. J. Nelson and F. C. Evans (Ed.) Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-21)

Farris, G. C., F. W. Whicker, and A. H. Dahl. 1969. Strontium-90 levels in mule deer and forage plants, p. 602-608. In D. J. Nelson and F. C. Evans (Ed.) Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-23).

Hakonson, T. E. and F. W. Whicker. 1969. Uptake and elimination of cesium-134 by mule deer, p. 616-622. In D. J. Nelson and F. C. Evans (Ed.) Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-24)

Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M. S. Thesis. Colorado State University, Fort Collins. 121 p. (COO-1156-25)

Farris, G. C. 1967. Factors influencing the accumulation of strontium-90, stable strontium, and calcium in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins, 189 p. (COO-1156-26)

Hakonson, T. E. and F. W. Whicker. 1971. Tissue distribution of radiocesium in the mule deer. Health Physics 21(6): 864-866. (COO-1156-27)

Hakonson, T. E. and F. W. Whicker. 1971. The contribution of various tissues and organs to total body mass in the mule deer. J. Mammalogy 52(3): 628-630. (COO-1156-29)

Gist, C. S. 1969. Iodine-131 retention in mule deer. M. S. Thesis. Colorado State University, Fort Collins. 75 p. (COO-1156-31)

Markham, O. D. and F. W. Whicker. 1970. Radiation $LD50_{(30)}$ of pikas (Ochotona princeps) in the natural environment and in captivity. Am. Midland Naturalist. 84(1): 248-252. (COO-1156-32)

Markham, O. D., F. W. Whicker, and R. M. Hansen. 1970. Radiation $LD50_{(30)}$ of Richardson ground squirrels. Health Physics 18(6): 731-732. (COO-1156-33)

Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph.D. Dissertation. Colorado State University, Fort Collins. 342 p. (COO-1156-34)

Nagy, J. G., T. E. Hakonson, and K. L. Knox. 1969. Effects of food quality on food intake in deer. Trans. 34th North Am. Wild. and Natural Resources Conf. 34: 146-154.

Alldredge, A. W. 1971. Those bottle fawns. Colorado Outdoors 20(3): 19-21. (COO-1156-36)

Gallegos, A. F., F. W. Whicker, and T. E. Hakonson. 1971. Accumulation of radiocesium in rainbow trout via a non-food chain pathway. Proceedings, Fifth Ann. Midyear Topical Symposium, Health Phys. Soc., Health Physics Aspects of Nuclear Facility Siting II: 477-498. (COO-1156-37)

Gist, C. S. and F. W. Whicker. 1971. Radioiodine uptake and retention by the mule deer thyroid. J. Wildlife Mgmt. 35(3): 461-468. (COO-1156-38)

Whicker, F. W., W. C. Nelson, and A. F. Gallegos. 1972. Fallout ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado. Health Physics 23(4): 519-528. (COO-1156-39)

Hakonson, T. E., A. F. Gallegos and F. W. Whicker. Use of ^{133}Cs and activation analysis for measurement of cesium kinetics in a montane lake. Proceedings, Third National Symposium on Radioecology, May, 1971, Oak Ridge, Tenn. In Press (COO-1156-41).

Gallegos, A. F. and F. W. Whicker. Radiocesium retention by rainbow trout as affected by temperature and weight. Proceedings, Third National Symposium on Radioecology, May 1971, Oak Ridge, Tenn. In Press (COO-1156-42).

Markham, O. D. and F. W. Whicker. Intraspecific competition and response of pikas (Ochotona princeps) to radiation. Proceedings, Third National Symposium on Radioecology, May 1971, Oak Ridge, Tenn. In Press (COO-1156-43).

Fraley, L., Jr. and F. W. Whicker. Response of a native shortgrass plant stand to ionizing radiation. Proceedings, Third National Symposium on Radioecology, May 1971, Oak Ridge, Tenn. In Press (COO-1156-44).

Fraley, L., Jr. 1971. Response of shortgrass plains vegetation to chronic and seasonally administered gamma radiation. Ph.D. Thesis. Colorado State University, Fort Collins. 170 p. (COO-1156-45).

Schultz, V. and F. Ward Whicker. 1971. A selected bibliography of terrestrial, freshwater and marine radiation ecology. USAEC Report TID-25650. USAEC Division of Technical Information Extension. Oak Ridge, Tenn. 185 p. (COO-1156-46).

Adams, C. E., D. Lund and D. Markham. 1971. A chromosome study of the pika, Ochotona princeps. Mammalian chromosomes Newsletter 12(3): 77-78 (COO-1156-47).

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Markham, O. D. and F. W. Whicker. 1972. Burrowing in the pika. J. Mammalogy 53(2): 387-389 (COO-1156-49).

Markham, O. D. 1971. Observations on an aggressive blue grouse. Colo. Field Ornithologist 10: 6 (COO-1156-50).

Markham, O. D. and F. W. Whicker. Seasonal data on reproduction and body weights of pikas (Ochotona princeps). J. Mammalogy. In Press (COO-1156-51).

Markham, O. D. and F. W. Whicker. 1973. Notes on the ecology of the pika (Ochotona princeps) in captivity. Am. Midl. Naturalist 89(1): 192-199 (COO-1156-52).

Schultz, V. and F. W. Whicker. 1972. Ecological aspects of the nuclear age: Selected readings in radiation ecology. TID-25978. U. S. Atomic Energy Commission, Technical Information Center, Oak Ridge, Tenn. 588 p. (COO-1156-53).

Cadwell, L. L. Colony formation of the western harvester ant in a chronic gamma radiation field. Am. Midl. Naturalist. In Press (COO-1156-55).

Hakonson, T. E. 1972. Cesium kinetics in a montane lake ecosystem. Ph.D. Thesis. Colorado State University, Fort Collins. 154 p. (COO-1156-56).

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Schultz, V. and F. W. Whicker. Radiation ecology. Chapter 12. In Kelley, J. E. T. (Ed.) Irradiated Biological Systems: A Text in Radiation Biology. Univ. Park Press, Baltimore, Md. In Press (COO-1156-58).

Cadwell, L. L. and F. W. Whicker. Responses of naturally occurring arthropods in a gamma radiation field. Submitted to Ecology, Jan. 1973 (COO-1156-59).

Fraley, L. Jr. and F. W. Whicker. Response of shortgrass plains vegetation to gamma radiation: I. Chronic irradiation. Submitted to Radiation Botany, Jan. 1973 (COO-1156-60).

Fraley, L. Jr. and F. W. Whicker. Response of shortgrass plains vegetation to gamma radiation: II. Short-term, seasonal irradiation. Submitted to Radiation Botany, Jan. 1973 (COO-1156-61).

Alldredge, A. W., J. F. Lipscomb and F. W. Whicker. Forage intake rates of free-ranging mule deer estimated with fallout cesium-137. Submitted to J. Wildlife Mgmt., April 1973 (COO-1156-62).

Hakonson, T. E. and F. W. Whicker. Cesium kinetics in a montane lake ecosystem. Submitted to Health Physics, May 1973 (COO-1156-64).

Hakonson, T. E., A. F. Gallegos and F. W. Whicker. The use of cesium kinetics data for estimating food consumption rates of trout. Submitted to Health Physics, May 1973 (COO-1156-65).

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VIII. LIST OF ORAL PRESENTATIONS

The following papers representing work conducted under AEC Contract AT(11-1)-1156 have been presented orally at scientific meetings or formal seminars at other institutions:

Whicker, F. W. and A. H. Dahl. 1963. Accumulation of fallout radionuclides in Colorado mule deer. Presented June 13, 1963 at the annual meeting of the Health Physics Society, New York City. P/90 (COO-1156-3).

Dahl, A. H., F. W. Whicker, and G. C. Farris. 1964. A study of the food chain patterns of Sr-90, Cs-137, and I-131 in a mule deer population. Presented March 10, 1964 at the meeting on Radiation and Wildlife at the North American Wildlife Conference, Las Vegas, Nevada.

Farris, G. C. 1964. Strontium-90 concentrations in bones and forage plants. Presented April 24, 1964 at the AEC-ARMU Technical Conference at the University of New Mexico, Albuquerque. P/1, Session IV (COO-1156-6).

Farris, G. C., A. H. Dahl, and F. W. Whicker. 1964. Accumulation of Sr-90 in selected bones and forage plants of Colorado mule deer. Presented June 18, 1964 at the annual meeting of the Health Physics Society, Cincinnati, Ohio. P/131 (COO-1156-7).

Whicker, F. W., G. C. Farris, A. H. Dahl, and E. E. Remmenga. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Presented May 4, 1965 at the Battelle-Northwest Symposium on Radiation and Terrestrial Ecosystems, Richland, Washington. (COO-1156-10)

Whicker, F. W. 1965. Fallout radionuclides in mule deer. Presented August 9, 1965 at the Central Mountains and Plains Section Conference of the Wildlife Society, Centennial, Wyoming.

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