DISSERTATION

– – – –

FACTORS INFLUENCING THE ACCUMULATION OF FALLOUT CESIUM-137 IN MULE DEER

Submitted by
Floyd Ward Whicker

In Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

DEPARTMENT OF RADIOLOGY AND
RADIATION BIOLOGY

Colorado State University

Fort Collins, Colorado

May, 1965

COLORADO STATE UNIVERSITY

May, 1965

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY Floyd Ward Whicker ENTITLED Factors Influencing the Accumulation of Fallout Cesium-137 in Mule Deer BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

COMMITTEE ON RESEARCH AND DISSERTATION

Edwin H Dahl — Robert A Thompson
Major Professor
Harold W. Steinhoff — E G Rommenga
W W Carlson
Chairman of Department

EXAMINATION SATISFACTORY

COMMITTEE ON FINAL EXAMINATION

Harold W. Steinhoff — E G Rommenga
Fred A. Glover — W W Carlson
W. S. Osburn — Robert A Thompson
Edwin H Dahl
Chairman

Permission to publish this report or any part of it must be obtained from the Dean of the Graduate School

ACKNOWLEDGEMENTS

The investigation leading to this dissertation was part of a long-term project entitled "A study of the food chain pattern of strontium-90, cesium-137, and iodine-131 in a wild deer population", which was supported under contract AT-(11-1)-1156 between Colorado State University and the United States Atomic Energy Commission. The overall project was originally conceived and initiated by Lee E. Yeager, William D. Carlson, and Adrian H. Dahl. The study was coordinated with project W-105-R, Colorado Department of Game, Fish, and Parks, and with a project supported under contract AT-(11-1)-898 between the Colorado Cooperative Wildlife Research Unit and the United States Atomic Energy Commission.

Adrian H. Dahl, who served as chairman of the graduate committee, offered advice, encouragement, training, and critical review throughout the course of the study.

Elmer E. Remmenga, who served as a graduate committee member, was particularly helpful with regard to experimental design, statistical procedures, and data processing.

Robert D. Thompson and Harold W. Steinhoff, who completed the graduate committee, were generous with counsel, guidance, and sincere interest in the investigation.

Dean E. Medin and Allen E. Anderson, Colorado Depart-

ment of Game, Fish and Parks, provided deer samples as well as physiological, climatic, and ecological data. Their interest and suggestions were invaluable to the progress of the study.

George M. Angleton, Department of Mathematics and Statistics, gave major assistance in computer processing of data. Without his help, data reduction would have been a most serious obstacle.

Vincent Schultz, United States Atomic Energy Commission, was instrumental in the initiation and continuance of the work, and provided counsel for a wide variety of technical and administrative problems.

Among the technicians and students who provided assistance were: Richard L. Norman, John L. Oldemeyer, Thomas E. Hakonson, Terry L. Shirey, Darrell A. Bingham, Richard C. Lucas, Jack M. Sugarman, Lavonne Campbell, and Daniel H. Gould.

Photographs appearing on subsequent pages were taken by Allen E. Anderson, Thomas E. Hakonson, and John Bullock.

Finally, I wish to acknowledge the patience of my wife, Sandra, who endured the many sacrifices which were placed upon her during the progress of the investigation. Without her support, this endeavor would likely have never been completed.

TABLE OF CONTENTS

TABLE OF CONTENTS -- Continued

TABLE OF CONTENTS -- Continued

Chapter Page

TABLE OF CONTENTS -- Continued

Chapter | Page

Chapter | Page

LIST OF TABLES

LIST OF TABLES -- Concluded

LIST OF FIGURES

LIST OF FIGURES -- Continued

LIST OF FIGURES -- Continued

LIST OF FIGURES--Concluded

Chapter I

INTRODUCTION

Seldom in the course of history has mankind deliberately and carefully investigated the long-term consequences of his new inventions and products prior to their full-scale exploitation. Wherever man has existed for a significant length of time, his activities and products have brought about changes in his supporting environments. The changes are readily apparent, particularly near the larger population centers. The changes have nearly always been detrimental to the environment (Wolfe 1963). For example, consider the smog of Los Angeles, the dust bowl of the Southwestern United States, and a multitude of polluted streams containing dying fish. Certainly, men who produced the automobile, the plow, and a variety of pesticides and detergents were initially unaware that these goods would bring forth anything but progress and benefit.

Nuclear energy is one of man's recent discoveries. Its proper use offers solutions to many current problems. For example, the depletion of the world's fossil fuels, which are currently man's primary energy source, can be offset by power produced from nuclear reactors (Odum 1959). The capability to destroy wartime enemies was amply provided with the development of nuclear energy (Aronow et al. 1963). Excavation of large quantities of earth for harbors or

canals appears most feasible by the use of nuclear explosions (Wolfe 1963).

The use of nuclear energy however, presents problems, since radioactive by-products, which may become released into the biosphere either by necessity or accident, emit radiation which in sufficient quantities can be harmful to both plant and animal life (Woodwell 1962; Garner 1963). The critical amount of radiation exposure received by a given organism from a particular level of environmental contamination depends upon many factors which may be physical, chemical, biological, or ecological in nature (Davis et al. 1963).

Investigators must not be solely concerned with the direct effects of radiation upon man. They must also consider the possible effects upon the environment which provides sustenance (Kornberg 1958). Commodities such as water, minerals, timber, livestock, crops, fish, and game must all be considered when assessing the effects of man's products.

Atmospheric testing of nuclear weapons has been the primary means by which man-produced radioactive materials have been distributed widely in the biosphere. According to Eisenbud (1963), it is probable that every living cell that has been formed since the early 1950's contain some of the radionuclides produced in weapons testing.

This dissertation is concerned with cesium-137, a major constituent of nuclear weapons fallout, and its time-specific distributions in various trophic levels of the Cache la Poudre drainage in north-central Colorado. The study was designed to evaluate the importance of various sets of conditions and factors in altering Cs-137 contamination of selected environments within the study area. In addition, concentrations of Cs-137 were measured in tissues of wild mule deer, Odocoileus hemionus, which were collected from numerous locations within the area. Variations in tissue burdens of Cs-137 and the associated radiation dose rates were studied in relation to physiological differences among individuals and to behavioral and ecological factors.

Similar studies have been undertaken elsewhere, but primarily with domestic animals under different ecological situations. Only by comparing independently-gathered findings, representing data collected under various kinds of circumstances, can scientific generalizations be formulated. To the best of the author's knowledge, the data presented herein were gathered under ecological conditions different from those of any similar study. Results are compared with those in the literature in Chapter VI.

Because of the complexity and the number of pathways which radionuclides could follow between nuclear devices and deer, the factors studied in this dissertation as having influence on Cs-137

behavior were not necessarily the only factors requiring consideration. Furthermore, the factors considered were likely not entirely independent of other entities. For example, elevation could not be studied under natural conditions as being independent of precipitation, since the two factors were obviously correlated. Nevertheless, certain ecological situations were recognized, studied over a period of time, and compared.

Fundamental to the interpretation of the results presented in Chapter V, were several studies which preceeded or were carried out concurrently with this investigation. Dietz et al. (1962) studied the nutritive composition of several major browse species of the Cache la Poudre drainage, as well as digestibility by mule deer of the same plants. Loveless (1963) quantitatively investigated physical and biological characteristics of a selected portion of the study area. D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks, were engaged in an intensive yet broad ecological investigation of the Cache la Poudre deer herd several years prior to and during the course of the study. Medin's and Anderson's activities included studies on climate, vegetation, and deer over a range of elevations, as well as a study of physiological parameters of deer as influenced by environmental factors.

The Problem

What is the importance of some of the factors or combinations of factors which influence the accumulation of fallout cesium-137 in wild mule deer of the Cache la Poudre drainage?

Problem analysis

1. What are the effects of time and season during the study upon atmospheric levels of cesium-137?

2. How do elevation and associated changes in precipitation rates affect fallout deposition?

3. How do species and local environments influence cesium-137 contamination of several important deer forage plants?

4. How do annual migratory movements and associated changes in foraging habits affect cesium-137 burdens in deer?

5. Do sex or age influence cesium-137 levels in deer?

Delimitations

The study was carried out between January 1, 1962 and April 30, 1965. All sampling was done within that portion of the Cache la Poudre drainage which lies west of Fort Collins, Colorado. The animal species studied was the Rocky Mountain mule deer, Odocoileus hemionus (Rafinesque). Plant species sampled included Artemisia tridentata (Nutt.), Betula glandulosa (Michx.), Cercocarpus montanus (Raf.), Juniperus communis (L.), Juniperus scopulorum (Sarg.), Purshia tridentata (Pursh.) D.C., Deschampsia caespitosa (L.) Beauv., Populus tremuloides (Michx.), Salix sp. (L.), Vaccinium scoparium (Leiberg), mixed forbs and mixed grasses.

Chapter II

BACKGROUND

Introduction

This review was intended to provide a summary of the generation, behavior, and properties of fallout cesium-137, combined with a presentation of studies which were related to the problems of this dissertation. In addition, investigations concerning other factors having possible influence on the results and interpretations of this study, but which have not been accounted for specifically, were brought forth. A limitation of this review was that much of the research in related areas was completed very recently or was in progress. Consequently, a large portion of present knowledge has not been assembled and published.

Fallout

Generation by nuclear explosions

The term "fallout", which was coined in 1945, refers to the radioactive debris that settles to the earth's surface following atmospheric nuclear explosions (Comar 1963). Nuclear explosions are the result of fission processes, or a combination of fission and fusion phenomena. In fission the nuclei of heavy atoms such as uranium-235 or plutonium-239 are split, whereupon fission fragments and energy are liberated.

Depending upon the way in which the heavy nuclei split, some 80 or 90 different primary radioactive fragments may be formed. Many of these decay into radioactive "daughters", resulting in a fission mixture containing about 200 radioactive species (Katcoff 1958).

In a nuclear explosion tremendous quantities of heat are produced within a small fraction of a second, and within a relatively small quantity of matter. The nuclear fuel, fission fragments, structural parts of the devise, and the immediate surroundings are raised to a temperature of several million degrees, vaporized, and form what is called the "fireball". The fireball expands rapidly and ascends into the atmosphere. As it rises, gradual cooling occurs, and causes the vaporized materials to condense and gradually solidify to form particles which will eventually fall back to the earth. The properties and resulting fate of these particles depend upon several factors. A comprehensive review on fallout behavior was prepared by Bjornerstedt and Edvarson (1963).

Properties of fallout particles

The size and solubility of fallout particles depend upon the height of the burst above the ground, the magnitude of the explosion, and the type of support and containment apparatus (Larson 1963). As a rule, the higher the burst above the ground, the less is the amount of earth which becomes sucked up into the fireball, and smaller, more soluble particles result. Also, the

smaller the yield of the burst, the less is the quantity of soil and debris incorporated into the fireball. The radiological properties of the fallout particles are altered by neutron activation of earth, support structure, and other foreign materials. Neutron activation may result in several radionuclides of biological interest such as zinc-65 or manganese-54 which are not formed in the fission process (Klement 1959).

General fallout behavior

Fallout may be either "local" or "world-wide". That which is made up of relatively large and heavy particles normally falls to earth within 24 hours after the explosion and is termed local fallout. That consisting of smaller particles becomes widely dispersed over the earth, and is termed "world-wide" or "delayed" fallout. This study is concerned primarily with the latter type because of the distances involved between the study area and the nearest testing sites. World-wide fallout, which began in 1952 with Operation Ivy, may be further subdivided into "tropospheric" and "stratospheric" fallout.

Tropospheric fallout is primarily the result of low-yield weapons which are detonated at or near the earth's surface. High yield explosions usually propel most of their products into the stratosphere. The residence time of fallout particles in the stratosphere may be a matter of years, but air turbulence at the

gaps in the tropopause allows some stratospheric material to enter the troposphere (Machta 1958). Once in the troposphere, fallout particles are brought to earth within a few weeks with air currents, precipitation, and dust particles acting as the primary agents of deposition. The U. S. Atomic Energy Commission (1958) has estimated that 80-90 per cent of the fallout is deposited during periods of precipitation while only 10-20 per cent descends as "dry fallout". The fraction may differ however, between localities of varying climates.

The majority of world wide fallout remains in the atmosphere for a sufficient length of time to allow most of the radionuclides to decay to insignificant levels. Hunter and Ballou (1951) calculated the relative activities of the important fission products at various times after fission, based upon physical decay properties. Of the few remaining fission products which do reach the biosphere in appreciable quantities, three are of particular biological concern, namely strontium-90, cesium-137, and iodine-131. These isotopes are important because: (1) They have relatively high fission yields; (2) They possess half lives such that they release much of their energy during their likely period of residence in or near organisms; and (3) They are relatively soluble and enter biological systems as analogues to essential nutrient elements.

Properties of Cesium-137

Cesium is one of the rare alkali metals, it forms strong bases, and its salts are mostly water soluble (Finston and Kinsley 1961). Because its chemical characteristics are very similar to those of potassium, cesium behavior in physiological processes is grossly analogous to that of potassium (Davis 1963). However, organism membranes seldom discriminate between the two elements in a constant and predictable manner (Kornberg 1961). Although stable cesium has been found in both plants and animals (Bertrand and Bertrand 1949), it is doubtful that it is an essential nutrient.

Cesium-137 is one of 21 known isotopes of cesium, and with the exceptions of Cs-135 and Cs-133 (which is stable), it has the longest half-life of any in the group. Cesium-137 is produced at the rate of about 0.18 megacuries per megaton of fission energy (Langham and Anderson 1959). It has a fission yield of about 6 per cent, and is produced primarily from gaseous fission produced precursors according to the following scheme (Katcoff 1958):

$$\text{I-137} \xrightarrow{24\text{s}} \text{Xe-137} \xrightarrow{3.9\text{m}} \text{Cs-137} \xrightarrow{30\text{y}}$$

$$\text{Ba-137m} \xrightarrow{2.57\text{m}} \text{Ba-137 (stable)}$$

As indicated, the physical half life of Cs-137 is about 30 years. About 92 per cent of Cs-137 nuclei decay with the release of a 0.514 Mev (maximum energy) beta particle to form Ba-137m, which

in turn decays to stable Ba-137 with the release of a 0.662 Mev gamma ray. The remaining 8 per cent of Cs-137 nuclei decay directly to stable barium with the emission of 1.18 Mev (maximum energy) beta particles.

Solubility of Cesium in Fallout

The association of Cs-137 with relatively small fallout particles, coupled with its chemical properties, render the majority of cesium water soluble. Thus, its entry into organisms is enhanced. Seventy per cent of the Cs-137 in fallout collected in New York City in 1958 was water soluble (Welford and Collins 1960). Neel and Larson (1963) found that the fraction of soluble strontium-90 in fallout increased with the distance from ground zero. The difference in solubility was probably related to particle size, since the smaller, more soluble particles would travel further than large ones.

Behavior of Cesium-137 in Fallout

Factors affecting large scale distribution

Because of its gaseous precursors, Cs-137 is formed relatively late during nuclear explosions and therefore most of it is associated with small particles which constitute world-wide fallout (Holland 1963). Deposition of fallout over the earth's surface appears to be a function of latitude, with maximum levels occurring between 40 and 50 degrees north latitude (Davis 1963).

Minimum levels occur at the equator and poles, while there is a smaller peak at middle latitudes in the southern hemisphere. Only a small amount of atmospheric mixing occurs between hemispheres and weapons testing has occurred primarily in the northern hemisphere. The Cache la Poudre drainage is between the latitudes of 40 and 41 degrees north and thus falls within the belt of maximum fallout deposition. Maximum fallout deposition at the middle latitudes in both hemispheres supports the Brewer-Dobson atmospheric circulation model which states that air enters the stratosphere primarily at the equator and descends at temperate and polar latitudes (Machta and List 1958).

Deposition of fallout follows a seasonal pattern with maximums occurring in spring. Welford and Collins (1960) observed this pattern in precipitation; Gustafson et al. (1961) and Perkins et al. (1964) in air; and Anderson et al. (1957) in people. The spring maximums can be explained on the basis of increased air turbulence at the tropopause gaps at middle latitudes at this time. Precipitation, the primary agent of fallout deposition, is also generally higher during this season (Libby 1956b; Welford and Collins 1960).

Various types of topographic structures modify air currents and thus influence fallout deposition and its ultimate distribution (Davis et al. 1963; Martin 1963).

Influence of precipitation

It has already been mentioned that Cs-137 deposition occurs mainly with rain or snowfall. Hardy and Alexander (1962) found that total deposition of Sr-90 fallout was a linear function of amounts of rainfall during the same period of time. In Sweden, Low and Edvarson (1960) found a strong relationship between annual quantities of precipitation and Cs-137 levels in soils. Average concentrations of Cs-137 in dried milk products from three major phytoclimatic zones in the northwestern U. S. were significantly different and were correlated with the average yearly quantities of precipitation for each zone (Rickard et al. 1963). In the state of Washington, Davis et al. (1963) found that the abundance of Cs-137 in conifer twigs and needles increased with increasing annual rainfall.

Often, however, the relationship between rainfall and cesium deposition on foliage or soils is not linear, for there are several factors which can modify the response. For example, Middleton (1958, 1959) found that significant quantities of Cs-137 which had been sprayed onto crop plants, were removed by rainfall. In addition, light, brief rains tended to have higher concentrations of fallout than heavy, prolonged rains (Hinzpeter 1958; Stewart et al. 1958). Itagaki and Koenuma (1962) studied fallout concentrations in precipitation at various altitudes and found that

the concentrations decreased with altitude. This suggested that collection of fallout particles by rain and snow was a direct process. Greenfield (1957) has offered a theoretical treatment of the phenomena involved in rain scavenging of air particulates.

Radioactive fallout particles are also scrubbed from the atmosphere by snowfall. Osburn (1963) has studied fallout as contained in and distributed by large snowbanks in an alpine tundra region of Colorado. The distribution of large snowdrifts markedly influenced the distribution of fallout in soils and vegetation after meltout. Fallout deposition was dependent on the type of snowfall, temperature, time of year, atmospheric dust load, and perhaps other factors. In addition, snow flurries appeared to have more radioactivity per liter than single large storms.

Cesium-137 in Soils and Surface Waters

Most fallout cesium eventually reaches the soil where it is strongly adsorbed and retained. In general, large-scale distribution of Cs-137 in soils parallels general fallout deposition. Distribution of cesium in soils at the ecosystem level depends upon several environmental factors and considerable variability may occur between sampling sites. From work on some Great Smoky Mountain soils, Ritche (1962) found that the Cs-137 distribution was dependent upon elevation and associated precipitation rates, but that it was not apparently related to the vegetative cover types

or exposures studied.

The absorption qualities and availability of cesium to plants depend upon several factors including soil depth, composition, particle size, chemistry, pH, and moisture (Nishita et al. 1956; Graham 1958). Low and Edvarson (1959) found that most of the cesium-137 from fallout was confined to the top 2.5 cm of Swedish soils. In tests with basic ephrata and acid cinebar soils, Cline (1960) showed that Cs-137 did not move into the second inch, even after 300 inches of water were passed through the soil columns. This behavior of cesium renders very slight its uptake from soils by plants (Romney et al. 1957; Nishita et al. 1958; and Fowler and Christenson 1959). Menzel (1954) reported a distribution factor of 0.04 for Cs/K between plants and soils.

Furthermore, soils prevent surface waters from having the concentrations of Cs-137 that might be expected on the basis of levels in precipitation. Morgan and Stanbury (1961) reported that the concentration of Cs-137 in rainwater ranged from 15 to 130 times greater than river water concentrations. Libby (1956a) has shown that samples from several large rivers had less than 5 per cent of the concentration of Sr-90 that was estimated to be in the rains that supplied the rivers. Osburn (1963) reported that vegetation (particularly sedge mats), litter, and soils served as highly effective filters in reducing the specific radioactivity of snowmelt

runoff waters.

Obviously, other factors including uptake by aquatic organisms remove cesium from surface waters (Davis 1958). Phenomena which increase fallout concentrations in surface waters include direct deposition, flooding, and erosion of top soil and debris (Morris 1958; Setter et al. 1959). According to the latter authors, the radioactivity in surface waters is proportional to the concentration of suspended materials.

Cesium-137 Contamination of Plants

There are three main pathways by which plants may become contaminated with fallout Cs-137 (Menzel 1963). These are: (1) Direct deposition on aerial parts; (2) Uptake from the plant base region; and (3) Uptake from the soil. The primary mechanism of fallout Cs-137 entry into the terrestrial biota however, appears to be the direct deposition on foliage (Biddulph 1960).

In comparing Cs-137 activity on adjacent burned and unburned grass fields, Davis et al. (1963) found more radioactivity in the grass from the unburned field. They attributed the result to a high proportion of old grass in the unburned field sample which had been exposed to foliar deposition for a longer period. Anderson (1958) presented Cs-137 data for humans which indicated that biospheric contamination was indicative of recent deposition, and was not accumulative as would be the case if the soil were the primary

route. Sommermeyer and Godt (1958) found similar relative quantities of several fallout radionuclides on greased paper which had been exposed to the atmosphere to quantities deposited on the aerial parts of grasses. This further supported the importance of direct foliar deposition.

Romney et al. (1963) demonstrated fallout particles, which were mostly less than 44 microns in diameter, on leaf surfaces with photomicrographs. From studies on vegetation radioactivity following the Windscale accident in England, Kimber and Booth (1958) concluded that those species which presented the greatest surface area per unit weight contained the greatest concentrations of radioactivity. Rickard (1963) indicated that the amount of ground area covered by plant canopies is probably the most important factor influencing vegetative interception of fallout.

Should the stratospheric load of Cs-137 become depleted however, then the soil will eventually become the main reservoir. At such a time, soil characteristics and moisture conditions would govern the rate of cesium release to plants (Fredriksson et al. 1958). Increasing moisture conditions generally increase cesium uptake by plants (Pendleton and Uhler 1960), while increasing concentrations of available potassium tend to depress cesium uptake (Cline and Hungate 1960). The latter authors noted however, that large changes in potassium concentrations were required to produce

relatively small changes in cesium uptake.

Part of the cesium which is deposited on foliage surfaces may be absorbed and translocated throughout the plant. Middleton (1958, 1959) demonstrated with autoradiographs that soluble, carrier-free Cs-137 which had been administered as a spray to various crop plants was readily absorbed and translocated. Work by Lindberg et al. (1959) however, indicated that under some conditions much of the fallout contamination on foliage surfaces is insoluble. In their studies, an average of only 22 per cent of the fallout on leaves was soluble in 0.1 normal HCl. Although the distribution varies with species, cesium concentrates primarily in the leaves and flowers (Rediske and Hungate 1956; Auerbach and Crossley 1958).

The degree of Cs-137 contamination of plants is influenced by many factors (Miller 1963). Cesium-137 accumulation by plants under natural conditions varies among species and also among individuals of the same species growing in different environments (Davis 1963). Gorham (1963) found higher concentrations of fallout radioactivity in both leaves and soil litter from angiosperms than from gymnosperms. The difference was attributed to the larger surface area per unit weight of the angiosperm leaves. In addition, lichens and mosses were shown to contain more fallout radioactivity per gram of ash than angiosperms (Gorham 1959). These differences were attributed to variations in morphology.

A large source of variation between species appears to be different mechanical trapping characteristics of the leaf surfaces (Romney et al. 1963). These authors reported that fallout particles are trapped mostly in matted hairs and crevices and on resinous glands of leaf surfaces. Ljunggren (1960) found that spruce twigs, having rugose-asperous surfaces, accumulated about twice as much fallout as the glabrous needles, and that two-year-old twigs and needles were 1.5 to two times as radioactive as one-year-old twigs and needles.

Structural components of plants which have a relatively high surface area per unit weight tend to have comparatively high fallout concentrations (Bormann et al. 1958). Davis (1963) relates differences in levels of Cs-137 between several species of arctic plants with differences in morphology and habitat. The age of aboveground parts also appears to be an important factor (Chandler and Wieder 1963). In cases where the majority of the cesium burden in plants is derived from the soil, the physiological requirements for potassium should be considered (Straub et al. 1961).

As mentioned previously, leaching of cesium from foliage by rainfall has been demonstrated (Middleton 1958, 1959), as well as the loss of significant quantities of radioactivity by the dropping of dead leaves (Witherspoon 1963). With regard to the latter, deciduous species would tend to have less fallout radio-

activity over a period of several years than non-deciduous plants, other factors being equal. Wind is like rainfall in that it can simultaneously deposit and remove fallout from vegetation.

Considerable quantities of Cs-137 are deposited directly on small soil particles which may in turn be impacted on vegetation by wind or other natural disturbances. Wind pickup and transport of radioactive particles depends upon several factors including wind velocity, surface cover such as vegetation and larger stones, particle size, cohesiveness, density, and shape and soil moisture (Healy and Fuquay 1958). Wijk and Braams (1960) reported that cows may ingest several hundred grams of topsoil which is adsorbed to grass each day. On the other hand, Romney et al. (1963) reported a removal of fallout particles from vegetation by wind. Plant pollens may serve as collection nuclei for fallout particles and likewise act as vehicles of transport with winds. Osburn (1963) reported that the pollen fraction of debris samples collected from the surface of alpine snowfields in Colorado were more radioactive per unit weight than the dust fraction.

Cesium-137 in Animals

Since the discovery of Cs-137 in meats, milk products and humans in 1955 by Miller and Marinelli (1956), there has been much interest in the occurrence of this nuclide in animals. Fallout Cs-137 has been reported in many species, especially herbivores.

Van Dilla et al. (1961), Ward and Johnson (1965), and many others have reported fallout Cs-137 in cattle. Among the highest levels reported in ruminants are those given by Liden (1961) for Scandinavian reindeer. Muscle tissue concentrations as high as 28 nc/kg were reported. These comparatively high levels were mostly attributed to the habit of grazing on lichens by the reindeer. During the same period, the author reported Cs-137 concentrations ranging from 10 to 30 nc/kg in lichens, which was much higher than levels found in other forage species. It was found that people living in this particular region who consumed reindeer as a normal part of the diet contained much higher body burdens of Cs-137 than persons on reindeer-free diets. Similar but slightly lower levels have been reported for lichens and caribou from northwestern Alaska (Chandler and Wieder 1963). A seasonal pattern of Cs-137 levels in caribou was apparent, with highs occurring in winter when lichens became a major source of forage. Alaskan eskimos who utilized caribou to a large extent in the diet had much higher body burdens of Cs-137 than residents of the United States (Palmer et al. 1963).

Differences in radionuclide levels between grazing animals are to be expected as a result of varying forage habits. In Norway, Hvinden and Lillegraven (1961b) found that reindeer consistently had higher tissue levels of Cs-137 than sheep, which in turn had greater burdens than cattle or horses. These differences

were apparently not attributable to variations in fallout levels. In the United States, Anderson et al. (1957) found that beef and lamb consistently had higher concentrations than pork, which likewise reflected differences in feeding habits.

General metabolism

As previously mentioned, cesium is taken up by animals largely as an analogue to potassium. Therefore, its absorption and distribution is similar.

Cesium is readily absorbed from the gastro-intestinal tract, but the quantity assimilated varies with species. In the case of some non-ruminants, including mice, rats, dogs, monkeys and man, essentially 100 per cent of orally administered cesium was absorbed (Richmond 1958). According to the review of Davis (1963) however, McClellan et al. (1961) found 50-80 per cent absorption in rams while Ilin and Moskalev (1957) reported about 50 per cent absorption of cesium in cows. Hood and Comar (1953) discussed differences in excretory patterns between ruminants and non-ruminants which may account for this variation.

Orally administered cesium rapidly enters the blood and is soon distributed to other tissues or excreted. Its transfer from blood plasma to cells is an active process working against concentration gradients (Hood and Comar 1953). In goats, maximum plasma levels occurred within 0.5-6 hours and maximum

blood cell levels within 36-72 hours after oral administration (Ekman 1961). Ekman also found that the excretion of cesium was relatively rapid, with measureable quantities being found in the urine, feces, and milk.

Distribution

Distribution studies 14 days after administration of cesium to goats indicated the highest concentrations in skeletal muscles and the lowest in blood plasma and bone (Ekman 1961). Measureable amounts were found in all other organs and tissues. Wasserman et al. (1961) however, reported that cesium was concentrated to the greatest extent in the kidneys of lactating goats. In reviewing the work of others, Langham and Anderson (1959) reported that about 80 per cent of the total body burden of Cs-137 was located in voluntary muscle in cattle, sheep, swine and man.

Biological half-life

The excretion rate of cesium in most animals studied can usually be described in terms of a multi-component exponential equation (Comar et al. 1962). This behavior seems reasonable for cesium since it is distributed in several compartments, each having a characteristic size and elimination coefficient. Thus, the concept of the simple biological half-life is seldom precise. There is some evidence which indicates that biological half-lives for

cesium may be related to body surface area (Richmond 1958). Retention half-times for cesium in ruminants appear to be shorter than in non-ruminants of comparable body size. Ekman (1961) reports biological half-lives of cesium in goats in terms of two components, one of 2.5-4.5 days and the other of 29-33 days. Data for cows presented by Ilin and Moskalev (1957) and Cragle (1961) indicated half-lives of 4.5 and 3 days, respectively.

Influence of age and sex

Cesium retention may also be related to age or physiological status (Comar et al. 1962). In studies with rats, Hood and Comar (1953) found that young animals had higher excretion rates and lower tissue concentrations of Cs-137 than older animals. However, these authors reported little if any effect of age on relative cesium distribution. They found no differences with regard to sex. In addition, they reported no accumulation of cesium in fetal rats. Analyses of wild rabbit tissues for mixed fission products however, indicated that young animals had higher concentrations than adults (Hanson 1960).

Influence of dietary bulk

The presence of relatively non-digestible, bulky materials in the diet appears to increase total excretion of cesium with the fecal route playing an increasingly dominant role. In

studies with rats, Mraz and Patrick (1957) found that addition of materials such as vermiculite, bentonite, alfalfa, beet pulp, and charcoal to the diet resulted in increased fecal excretion of cesium and decreased urinary to fecal ratios as compared to the basal diet. This finding may explain in part why ruminants, which have considerable quantities of bulk along the digestive tract, tend to excrete a larger fraction of the administered dose of cesium than non-ruminants. In addition, one would expect variations among ruminants on the basis of the quantity of crude fibre in the diet (Stewart 1964).

Influence of sodium and potassium

Certain cations of the alkali metals affect the metabolism of cesium. It was found in studies with sheep that dietary potassium significantly increased the excretion of Cs-134 in both the presence and absence of dietary sodium (Mraz 1959). Dietary sodium was also shown to affect the excretory pattern of cesium in the presence of dietary potassium. Similar effects were noted in studies with rats (Mraz et al. 1957). Wasserman and Comar (1961) demonstrated a two-fold reduction in cesium retention with a nine-fold potassium increase in rats. These authors pointed out that due to the lack of proportional dilution of cesium by potassium, the two ions are not always strictly competitive.

Inhalation of fallout

Accumulation of fallout cesium by animals from inhalation contributes to the total intake, but it is uncertain what proportion enters the body by this route. It is apparent that many variables such as particle size, density, shape, and solubility, breathing characteristics of the host, and climatic variables could influence the relative importance of this pathway (Bair 1960).

Insoluble fallout materials have been detected in livestock and human lung tissues (Schonfeld et al. 1960), which is evidence that at least some Cs-137 could be taken in by animals directly from the atmosphere. According to Langham (1960) however, inhalation is much less important than ingestion as a route of entry of fallout Cs-137. Data from Norway in 1959 and 1960 indicated that Cs-137 concentrations in air did not contribute significantly to a total intake by cattle which would have been required to produce the levels which were observed in milk and meat (Hvinden and Lillegraven 1961a). Comparison of human and cattle thyroid iodine-131 levels following the 1955 weapons tests revealed 20 to 250 times more I-131 in cattle thyroids (Comar et al. 1957). Since essentially the same atmosphere was breathed by both the humans and cattle, the difference must have been largely due to the food sources. Furthermore, range-fed cattle had thyroid radioiodine levels 50 to 100 times greater than those of lot-fed animals (White

and Jones 1956). In studies with wildlife species at Hanford, Washington, Hanson (1960) observed that herbivorous animals consistently contained greater amounts of thyroid radioiodine than carnivorous species.

Cesium-137 as a Radiation Hazard

Because of the rather general distribution of cesium throughout the body and the relatively high energy gamma radiation released by its daughter Ba-137m, the irradiation dose from it to the body is quite uniform (Hood and Comar 1953). Because of this, critical tissues such as the gonads and blood forming organs absorb a significant fraction of the dose from internal Cs-137 and thus it is a potential genetic as well as a somatic hazard (Langham and Anderson 1959). Cesium-137 in the environment may also be considered a potential external radiation hazard because of the associated gamma radiation. Some authorities believe that any dose, however small, will cause a proportional increase in gene mutations (Fowler 1960; Blatz 1964). At current levels of fallout contamination, genetic changes seem more likely than observable somatic damage (Langham and Anderson 1959).

Because, in general, cesium is taken up from the soil very slowly and excretion rates from animals are relatively rapid, equilibrium between diet and tissue concentrations is reached rapidly and the internal dose rate is approximately proportional to

current fallout rates (Szepke 1962).

As to critical dose rates in large animals for observable effects, Garner (1963) reported that sheep died after accumulating 2000 roentgens of total body irradiation given at 100 r/day. At 10 r/day, pigs and donkeys showed some deterioration in a few weeks and died after a few months. At a dose rate of 0.1 r/day, no effects have been observed in large animals.

In sufficient quantities, Cs-137 has pronounced deleterious effects upon plants as well as animals. According to the work of Sparrow and Schairer (1962), there is great variability in radiosensitivity among different species. In general, plant radiosensitivity appears to be proportional to the fraction of the cell occupied by nuclear material. Contrary to earlier ideas, these investigators have shown that serious damage will occur to many native or cultivated plants at about the same radiation levels which would produce serious effects on mammals. Woodwell (1962), who has studied the effects of radiation from Cs-137 on terrestrial ecosystems, stated that as little as 1 r/day under long term exposure conditions may visually effect the most sensitive plants.

Further information on biological effects of radiation may be sought through National Academy of Sciences (1960) and Pierce (1963).

Chapter III

DESCRIPTION OF STUDY AREA

Described briefly in the following section are the location, topography, climate, soils, vegetation, and the deer herd of the Cache la Poudre study area. Most of the description is based upon general observations by the author and associates. For more detailed accounts see Bowes (1958), Dietz et al. (1962), and Loveless (1963).

Location and Topography

All sampling was from the Cache la Poudre drainage, which is located in Larimer County, Colorado, on the eastern slope of the Rocky Mountain front range (Fig. 1). The approximate center of the area is 40° 40' north latitude and 105° 30' west longitude. The area is about 41 miles in east-west length and 23 miles between the southern- and northern-most boundaries. The study area boundaries encompass approximately 576 square miles. About 91 per cent of the area is within Roosevelt National Forest. The area is bounded on the south and west by the alpine meadows and peaks of Rocky Mountain National Park and the Medicine Bow Mountains, and on the east and northeast by the Great Plains. Elevations vary from 5,200 to over 13,000 feet.

The topography of the region is relatively complex.

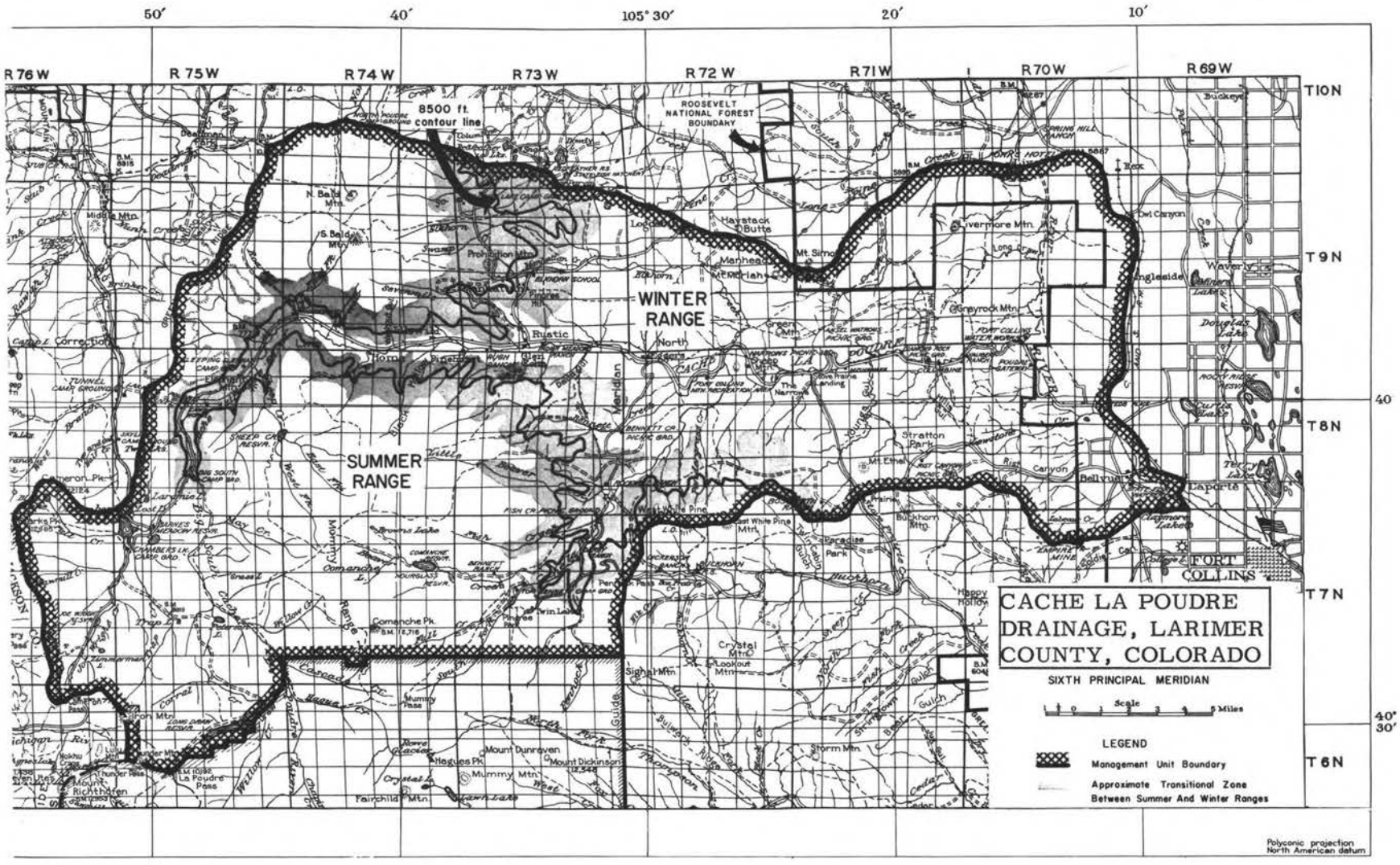

Fig. 1. Boundaries of the Cache la Poudre study area showing the 8,500 foot contour line as a separation between summer and winter ranges.

Beginning at the edge of the plains and moving westward, one first encounters a series of low, exposed sedimentary ridges and escarpments, followed by irregular and steep-sided valleys and ridges of metamorphic geology. This region is followed by irregular, but more gently rolling hills and broad valleys which gradually extend to high basins and smooth ridges. The study area terminates on the west at bare, rocky, steep-sided peaks, alpine ridges and glacial recesses. The entire east-west length of the study area is bisected by the Cache la Poudre river, which consists of alternating steep rapids and quiet, meandering stretches. Numerous tributary streams drain both sides of the canyon and join the main river at rather uniform intervals along its length. Glacial activity has influenced topography down to about 8,000 feet elevation.

Climate

Climatic data from various locations in the study area have not been available until recently. Such data have been collected on a continuous basis since 1961 at five elevations between 6,440 and 10,320 feet by Medin et al. (1962). The following discussion is general, but specific data will be referred to as appropriate in later chapters.

Climatic characteristics vary widely throughout the area, and seem to be highly dependent on various combinations of elevation, topography, and vegetative cover (Loveless 1963).

Generally, temperatures decrease and precipitation increases with elevation. North-facing slopes are higher in relative humidity and soil moisture than south-facing slopes. On the deer winter range, at elevations below 8,500 feet, northern exposures are heavily timbered and temperature variations are smaller in comparison to the southern exposures. Mean wind velocities measured a few feet above the ground likewise vary with topography and vegetative cover.

The study area is characterized by warm, sunny days and cool nights during the summer. Winter temperatures average much lower, but prolonged periods of sub-zero temperatures are infrequent. Most of the deer summer range is covered with deep snows between December and May and is relatively inaccessable during these months. The south-facing slopes at lower elevations however, are snow-free through much of the winter. Annual precipitation may vary between 12 inches at lower elevations to over 30 inches in alpine areas. Westerly winds are usually prevalent.

Soils

No extensive soil surveys have been undertaken in the study area. Such a task would appear formidable because it is apparent that many types of soils from varying parent materials and in varying stages of development exist in the region.

Most of the soils in the area were formed from igneous

and metamorphic rocks and vary in organic content. In wet sites, the soils are often nearly pure humus, while on dry sites, soils may be largely inorganic and undifferentiated. Fertility, profile, texture, and acidity vary widely among sites, and this is reflected by the kinds and quantities of vegetation encountered.

Vegetation

Several distinct vegetative zones are apparent with increasing elevation in the study area. Marr (1961) has devised a zonal classification based upon ecosystem units of the Colorado front range which seems applicable to the Cache la Poudre drainage. An elevational sequence of photographs taken between 6,100 and 11,000 feet in the study area by A. E. Anderson, Colorado Department of Game, Fish, and Parks, is presented in Figs. 2-9.

The prairie grassland ends abruptly at the edge of the front range and woody shrubs and conifers rapidly come into dominance. Shrub communities in the lower foothills consist largely of mountain mahogany, while Ponderosa pine, Rocky Mountain juniper and Douglas fir are the dominant conifers.* Most of the tree cover is restricted to northern exposures and drainages throughout the lower portion of the canyon. Cottonwood and several other deciduous trees occur along stream bottoms.

Proceeding upward in elevation, bitterbrush and other

* Common names of plants taken from Harrington (1954).

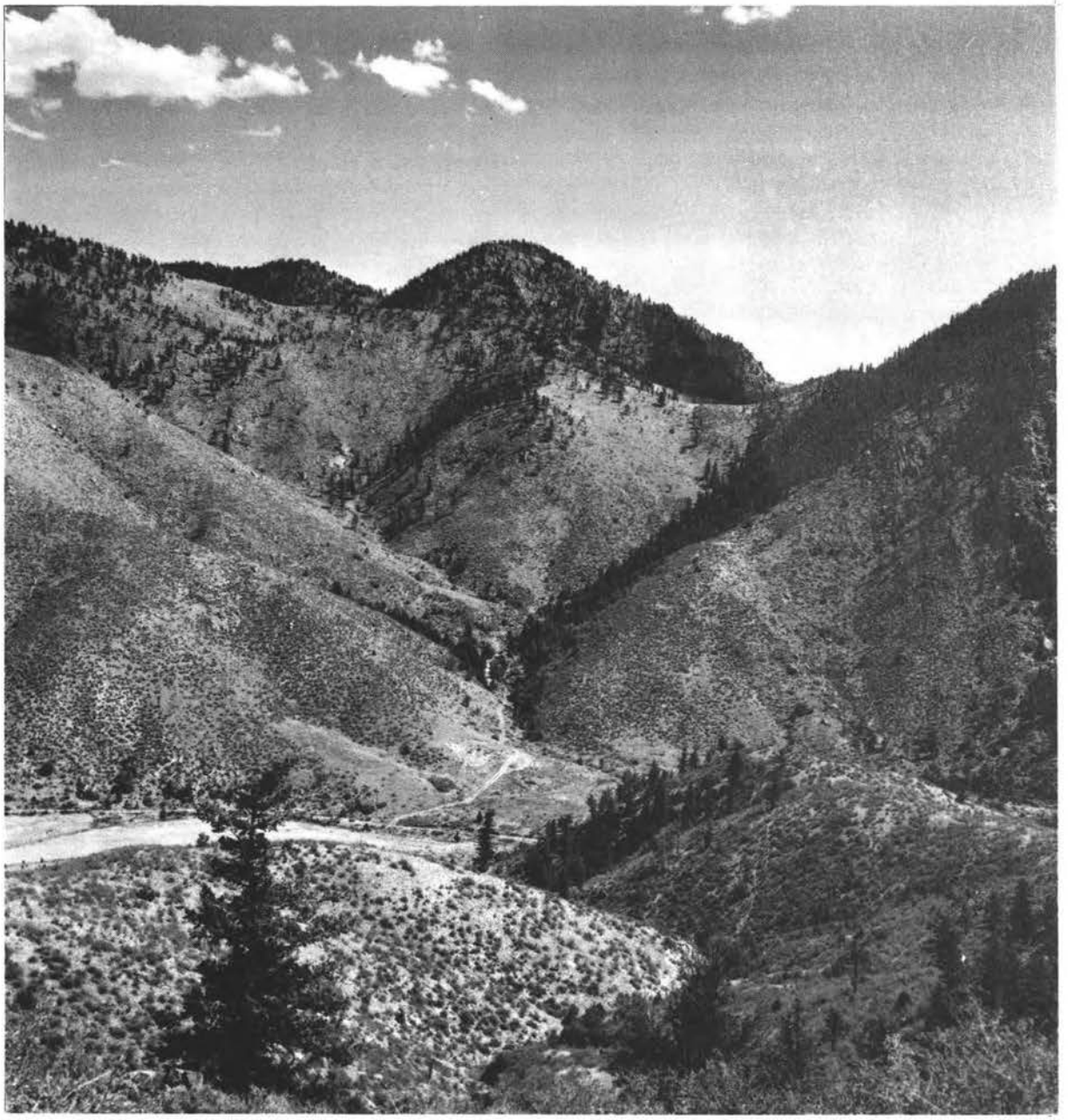

Fig. 2. Lower winter range at 6,100 feet showing mountain mahogany shrub communities with stands of Douglas fir predominating on the northern exposures.

Fig. 3. Mountain mahogany and bitterbrush shrub communities at 6,400 feet with scattered juniper trees.

Fig. 4. A ponderosa pine-bitterbrush community at 7,300 feet with heavily timbered north-facing slopes in the background.

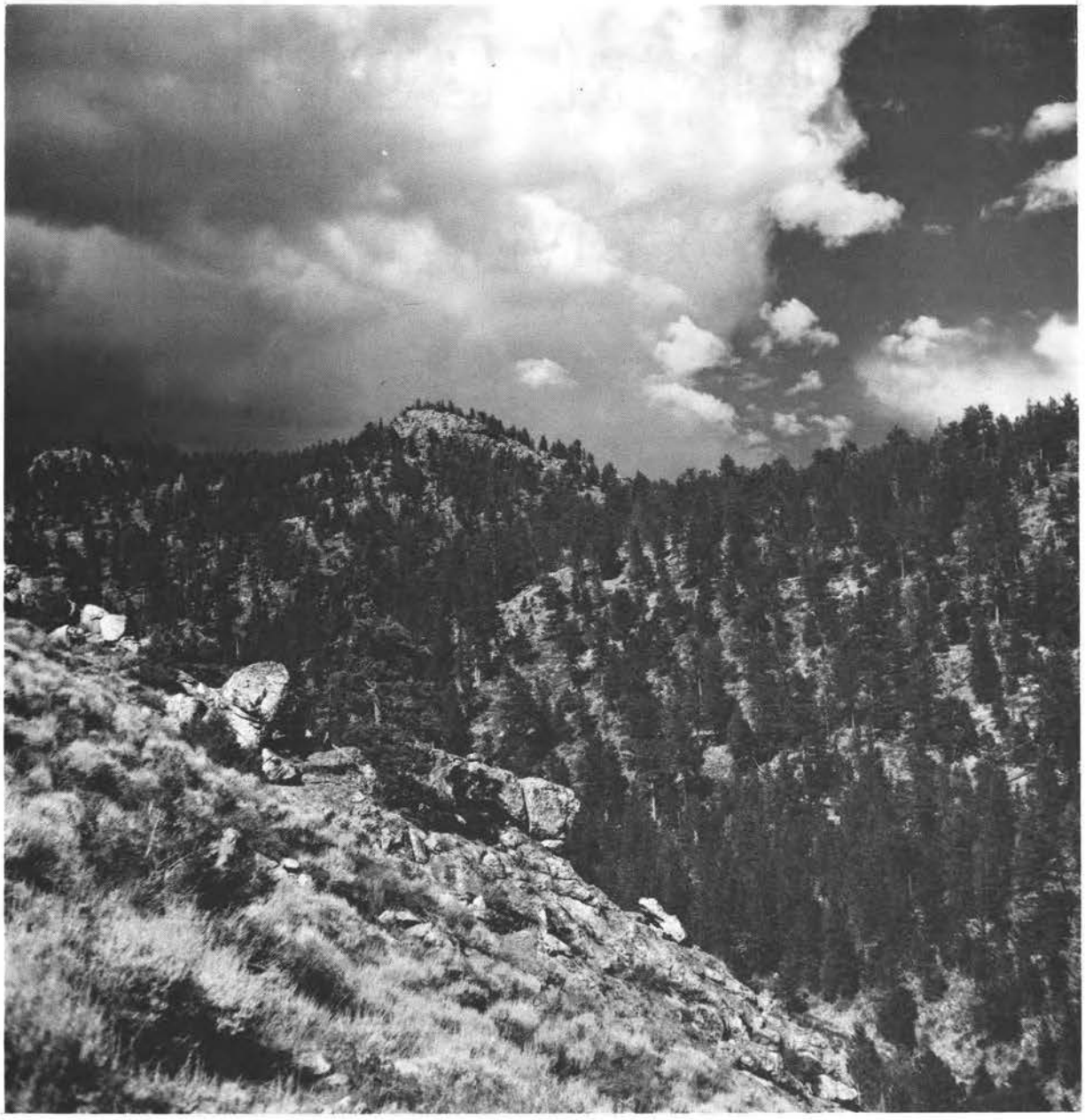

Fig. 5. Upper winter range at 8,100 feet showing a sagebrush-bitterbrush community characteristic of south- and east-facing exposures and a ponderosa pine-Douglas fir community representative of west-facing slopes.

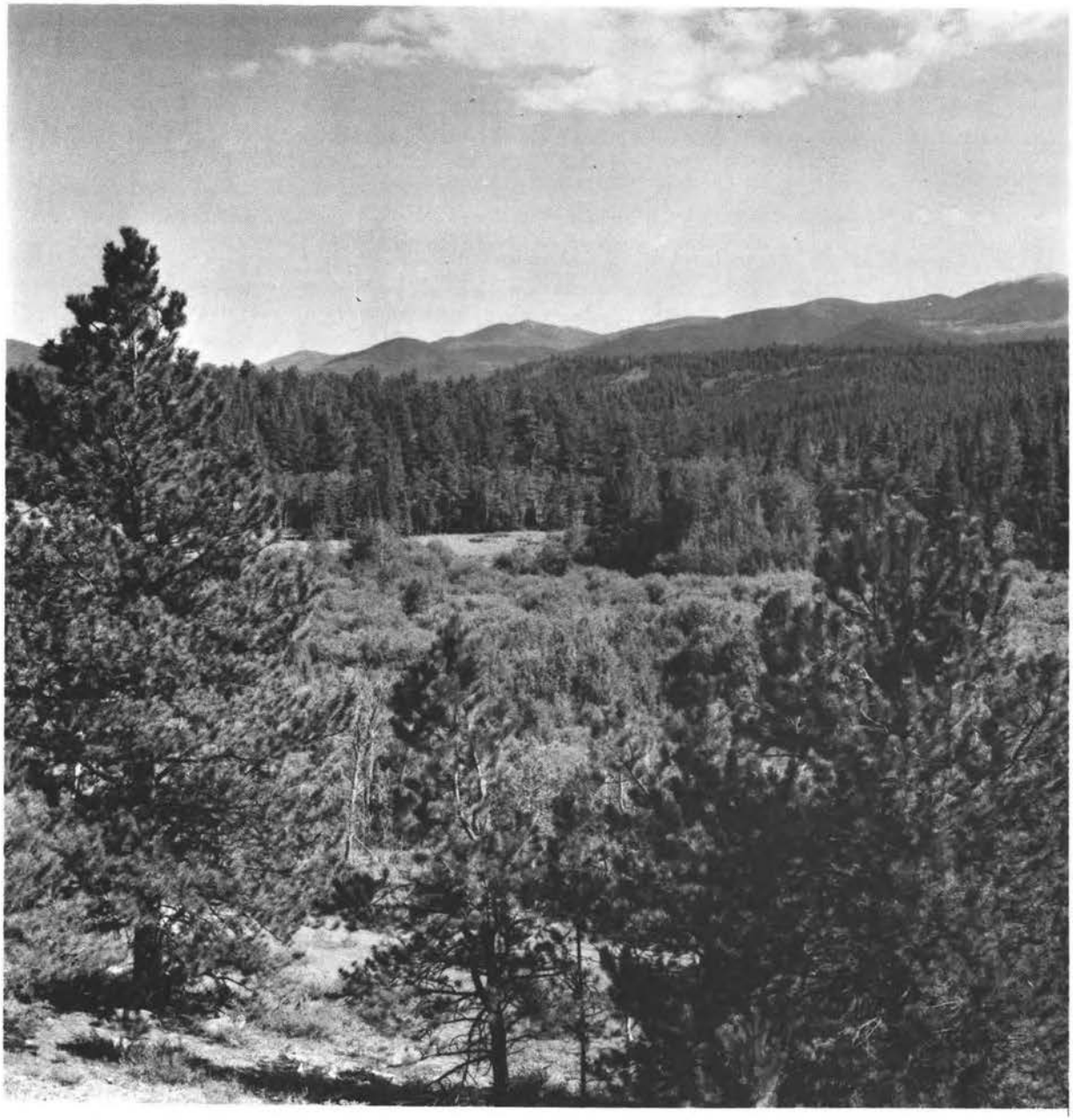

Fig. 6. A lodgepole pine stand at 8,600 feet showing a typical moist meadow with an abundance of willows, various grasses and sedges, and aspen along the edges.

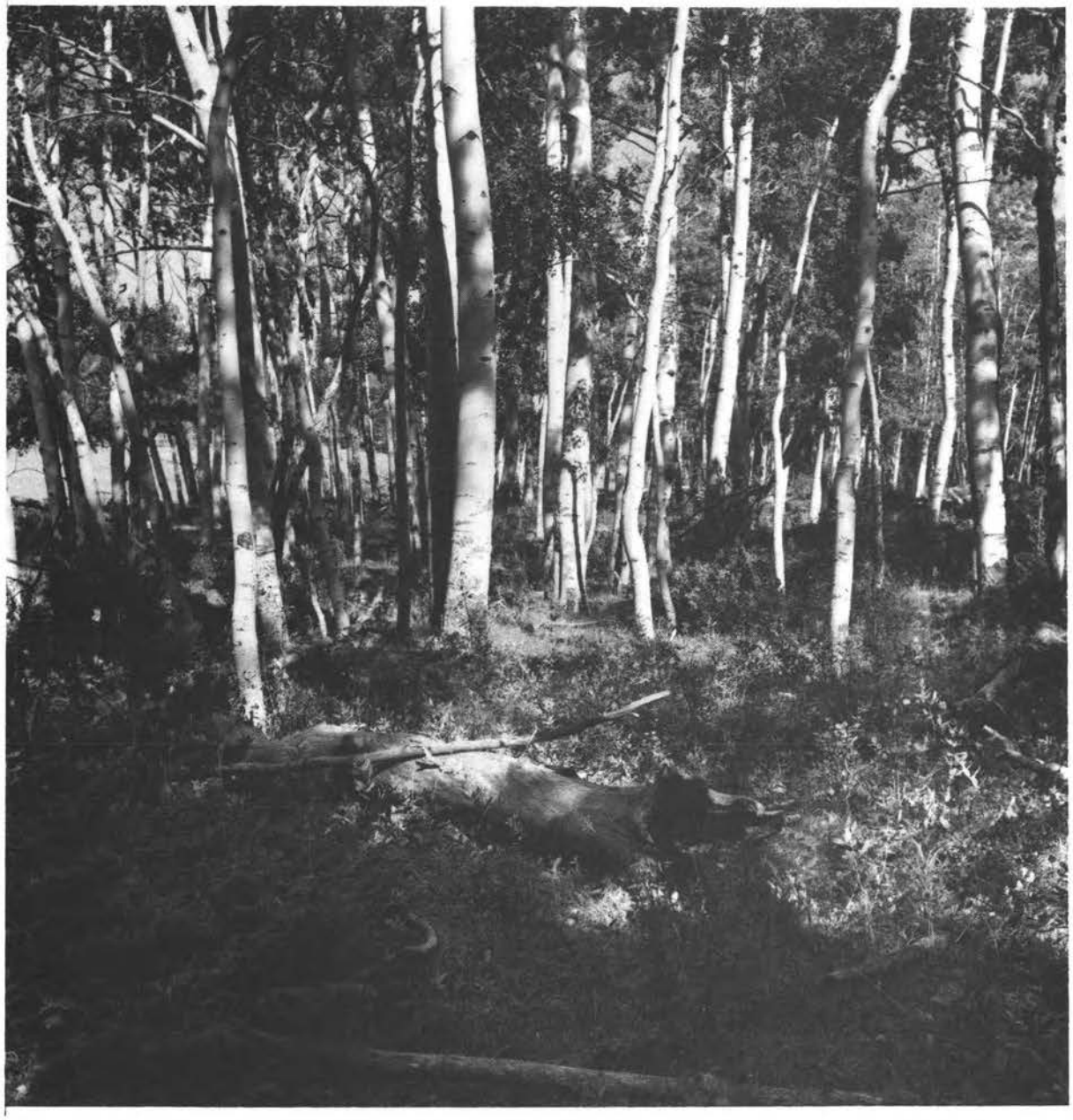

Fig. 7. An aspen grove at 8,800 feet with an understory composed of common juniper and various herbacious plants.

Fig. 8. A stand of Englemann spruce and sub-alpine fir at 10,500 feet showing a point quadrat frame used by the Colorado Department of Game, Fish, and Parks for measuring vegetative composition.

Fig. 9. Transition ecotone at 11,000 feet between the Englemann spruce-sub-alpine fir zone and the alpine tundra.

shrubs become more dominant, particularly on southern exposures. Ponderosa pine and Douglas fir increase in density through this zone until merging with stands of lodgepole pine. A belt of sagebrush occurs along much of the 8,000 foot elevational contour, especially on the canyon's southern exposure.

The lodgepole pine region is characterized by small, grassy meadows having an abundance of willow along the stream beds. Patches of quaking aspen occur within large conifer stands on a variety of moist sites throughout this zone. Understory stands of kinnikinick and common juniper are frequently encountered.

The lodgepole pine region merges into a zone dominated by Englemann spruce and sub-alpine fir. These stands are usually dense and extensive, but occasionally they are interspersed by meadows with birch and willow and by isolated patches of aspen. Blueberry is a dominant understory plant in this region.

The spruce-fir vegetation extends to approximately 11,000 feet where the alpine zone suddenly poses a striking contrast. The transition ecotone is characterized by open meadows dotted with dwarfed clumps of willow and Englemann spruce. The alpine-tundra is characterized by various sedges, grasses, herbs, dwarf shrubs, and a complete absence of trees or tall shrubs.

The Deer Herd

The Rocky Mountain mule deer (Odocoileus hemionus),

is the most abundant wild ruminant presently inhabiting the Cache la Poudre drainage. The herd is currently under ecological study by the Colorado Department of Game, Fish, and Parks and the Colorado Cooperative Wildlife Research Unit. The following description is general and is based largely on scattered observations. Specific quantitative characteristics will be referred to as appropriate in later chapters. A historical review of the herd was prepared by Medin (1960).

The actual size of the deer herd is not known, but there has been no evidence during the past 4 years to indicate that the population was not vigorous and relatively stable during that period. Hunter harvest estimates have ranged between 846 and 2,356 animals per year since 1959 Anderson and Medin (unpublished). A possible reason for the apparent stability of the population is that the Cache la Poudre winter range, unlike several others in Colorado, seems to have the qualities necessary to adequately support the animals through the critical winter months.

Most of the deer are migratory, vacating the wintering areas in April or May to occupy the summer range, whose lower boundary begins at about 8,500 feet elevation. Some animals apparently do not migrate, but spend the entire year at the lower elevations. The fall migration back to the winter range occurs sometime between September and December. The actual time of the movement apparently depends upon weather conditions.

Chapter IV

METHODS AND MATERIALS

Collection and Preparation of Samples

Air

In order to follow trends in air concentrations of cesium-137 throughout the study period, a sampling station was installed near the summit of Buckhorn Mountain at an elevation of about 8,300 feet. A staplex model TF 1A/27 sampler was housed 3.5 feet above the ground in a wooden shelter provided with air access and exhaust ports (Fig. 10). The ports, which were 6 inches in diameter, were covered with 0.25 inch wire mesh and fitted with tin hoods to prevent snow or debris from entering the shelter. The sampler was provided with Staplex TFA-2133 filter pads which allowed flow rates of about 35 cfm. Flow rates were measured by use of variable orifice guages which were calibrated against public utility gas meters.

Sampling was performed automatically with Intermatic model T 101 time switches which could be pre-set for desired sampling periods. The sampler operated 4 hours per day throughout the study. The collection time was arbitrarily chosen from 6:30 a.m. to 10:30 a.m. Filters were changed weekly for analysis.

The filters were placed in polyethylene envelopes for storage and radioassay. Since all of the analyses involved gamma

Fig. 10. Air sampling installation at Buckhorn Mountain.

counting, it was unnecessary to alter the form or geometry of the samples.

Precipitation

Precipitation collectors were established in order to determine the quantities of radioactivity deposited by rain and snowfall through the course of the study. The collectors were established in proximity to the five weather installations which were maintained by the Colorado Department of Game, Fish, and Parks. The location and elevation of these installations are given in Table 1.

The collectors consisted of 12 inch diameter polyethylene funnels which were mounted about 2 feet above the ground (Fig. 11). Five-liter jugs of brown polyethylene were mounted beneath each funnel to contain the precipitation. The jugs were maintained between June 1 and October 31 and changed at monthly intervals.

Table 1. Location and elevation of weather installations and precipitation collectors.

Site locations	Approximate Elevation in feet
Hewlett Gulch	6,440
Kelly Flats	7,000
Sevenmile Creek	8,120
Little Beaver Creek	8,940
Crown Point	10,320

Because the 12-inch funnels were not suitable for the collection of snow, a large, open collector was constructed and installed at the Kelly Flats site for year-around service. It consisted of a 1.3 foot deep box having a collection area of 0.48 square meter (Fig. 12). The box was lined with 4 mil polyethylene sheeting which was held in place by a rectangular frame grooved to fit over the top edge of the collector. The frame was provided with an inside vertical flange which defined the collection area. Approximately one inch of water was maintained in the collector to prevent loss of residues by wind action. At monthly intervals, the polyethylene liner and contents were removed and transported to the laboratory for processing.

Precipitation samples were reduced to dry residues in teflon-lined pans over a steam bath. The polyethylene collection jugs were rinsed with cesium and strontium carrier solutions, dilute nitric acid, and distilled water. The rinsings were added to the main samples in the evaporating pans. In the case of the large, open collector, the polyethylene liner was carefully reduced to ash in porcelain crucibles over a low flame, placed in a 350 C muffle furnace for about 8 hours, and the ash was then added to the residue from the liquid portion of the sample.

By use of a rubber-tipped rod and a minimum amount of distilled water and dilute nitric acid, the residues were

Fig. 11. Portion of weather installation showing polyethylene funnel used for rain sampling in foreground.

Fig. 12. The open collector at Kelly Flats which was used for rain, snow, and dust sampling.

transferred from the teflon evaporating pans to 6 ounce nalgene bottles. The samples were adjusted to a uniform geometry in the bottles with dilute nitric acid for gamma counting. Some of the equipment used in the procedures is shown in Fig. 13.

Soils

To gain information on differences in long-term fallout deposition throughout the study area, soils were sampled each summer from 22 locations. Five of the sampling locations were in proximity to the weather installations (Table 1), while the other 17 sites corresponded with the vegetative sampling plots (Table 2). The approximate locations of the plots listed in Table 2 are indicated in Fig. 14.

Four samples were collected from randomly chosen sites within each location plot. The plots varied in size between 5,000 and 15,000 square feet. Each sample was a composite of six 8.5 cm diameter disks of soil, one inch deep. Each sample thus represented an area of 340 square centimeters.

Once in the laboratory, the soil samples were oven-dried at 110 C for about four hours, then weighed. The samples were then sieved through 1.65 mm wire mesh, and the large rocks and debris were discarded. The material which passed through the sieve was then reweighed so that the relative stoniness and the mass of effective ion-exchangeable material per square meter

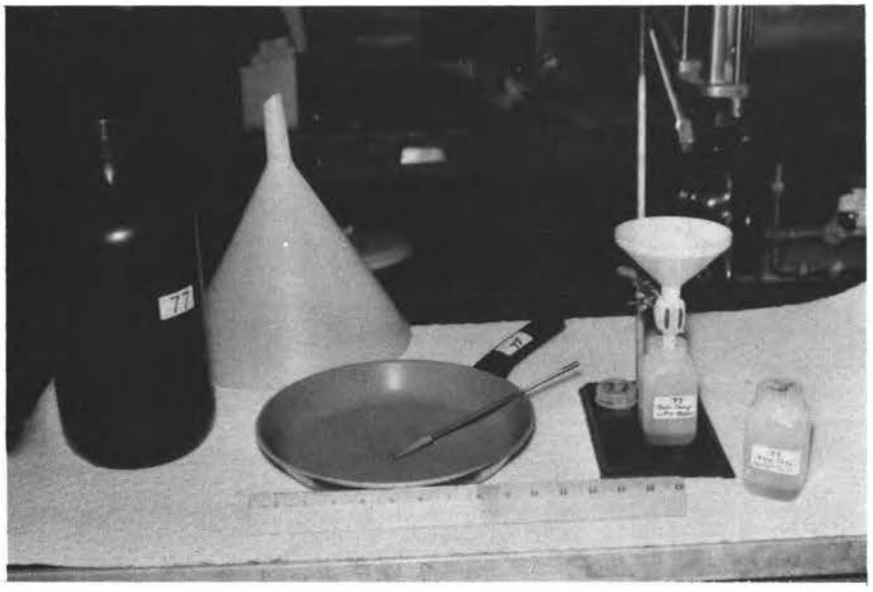

Fig. 13. Apparatus used for reducing precipitation samples to a uniform geometry.

could be calculated. The samples were then mixed thoroughly and weighed into containers of uniform geometry for comparative gamma counting.

Vegetation

Selected species of deer forage were sampled 3 or 4 times during each period of utilization from the locations listed in Table 2. and indicated in Fig. 14. Four species were sampled from

Table 2. Location and elevation of soil and vegetative sampling plots.

Plot no.	Site locations	Approximate Elevation in feet
Summer Range:		
1	Laramie Meadow (upper)	9,400
2	Laramie Meadow (lower)	9,300
3	Zimmerman Bench	10,500
4	Trap Park	10,480
5	Manhattan	9,000
6	Nunn Creek	9,900
7	Little Beaver Creek	8,600
8	Crown Point *	10,320
9	Pennock Creek	9,400
Winter Range:		
10	Young's Gulch	6,100
11	Kelly Flats	7,000
12	Sevenmile Creek	7,800
13	Home Moraine	8,000
14	Rist Canyon	6,400
15	Seaman Reservoir	5,600
16	Bennett Creek	7,600
17	Pingree Hill	8,300
18	Hewlett Gulch	6,000

* This site corresponds with the Crown Point weather installation.

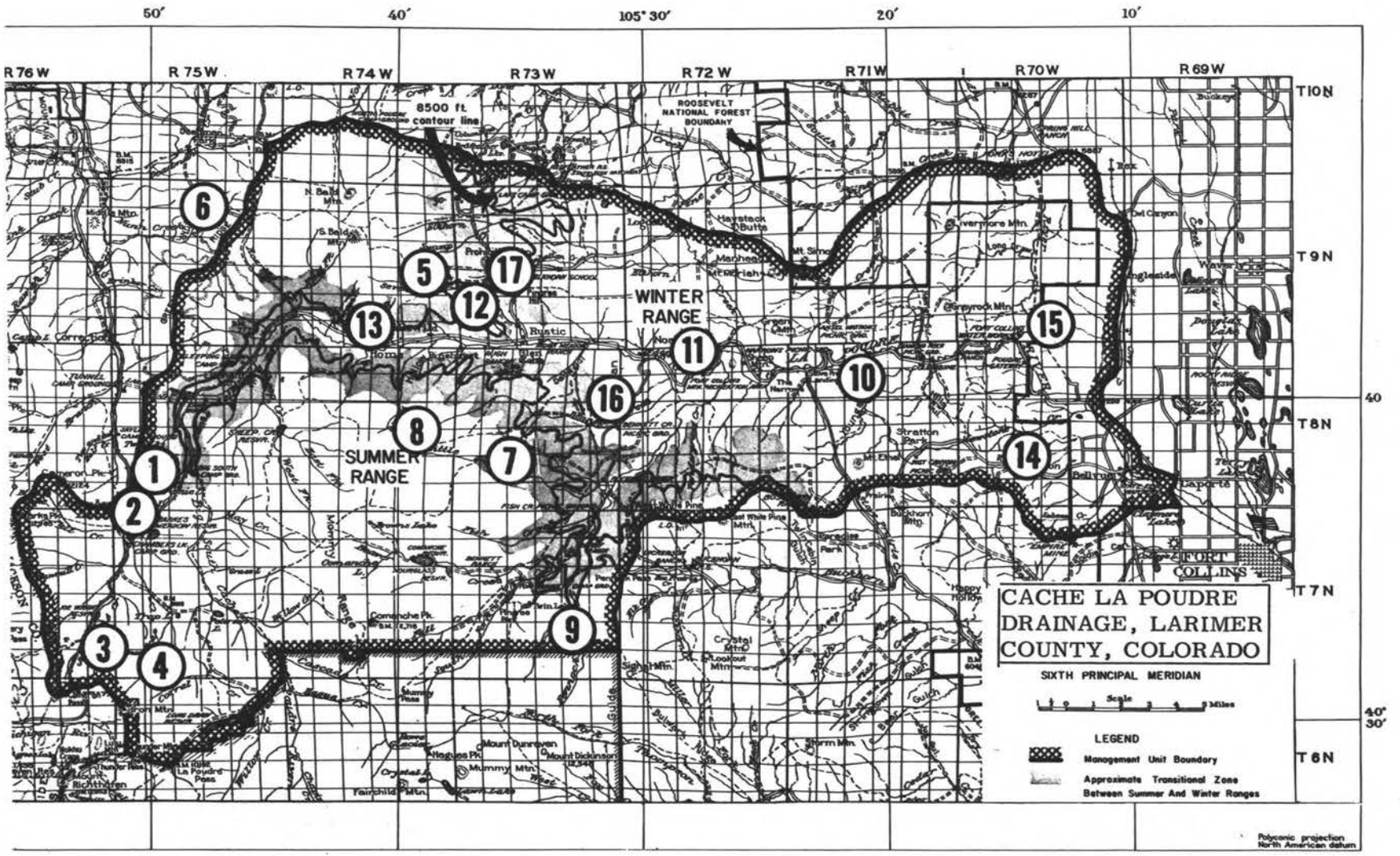

Fig. 14. Approximate locations of soil and forage sampling plots.

the winter range while eight species or categories of vegetation were collected on the summering areas. Species were chosen for sampling on the basis of abundance, field observations of deer utilization, and deer rumen contents. A list of the species sampled is given in Table 3.

After February, 1964, four samples were collected from each plot, in order to estimate variability of cesium-137 levels within plots. Prior to that time, only one replicate was collected per plot. Approximately 400 grams of air-dry material was collected for each sample by selective clipping (Fig. 15). The number of individual plants required to provide an adequate sample

Table 3. Scientific and common names of plants collected for radionuclide analyses.*

Winter Range:	
Artemisia tridentata	sagebrush
Cercocarpus montanus	mountain mahogany
Juniperus scopulorum	juniper
Purshia tridentata	bitterbrush
Summer Range:	
Betula glandulosa	bog birch
Deschampsia caespitosa	hairgrass
Juniperus communis	common juniper
Populus tremuloides	aspen
Salix sp.	willow
Vaccinium scoparium	blueberry
	mixed forbs**
	mixed grasses

* Scientific and common names were taken from Harrington (1954).

** Plants, excluding grasses, with no persistent woody stem above ground.

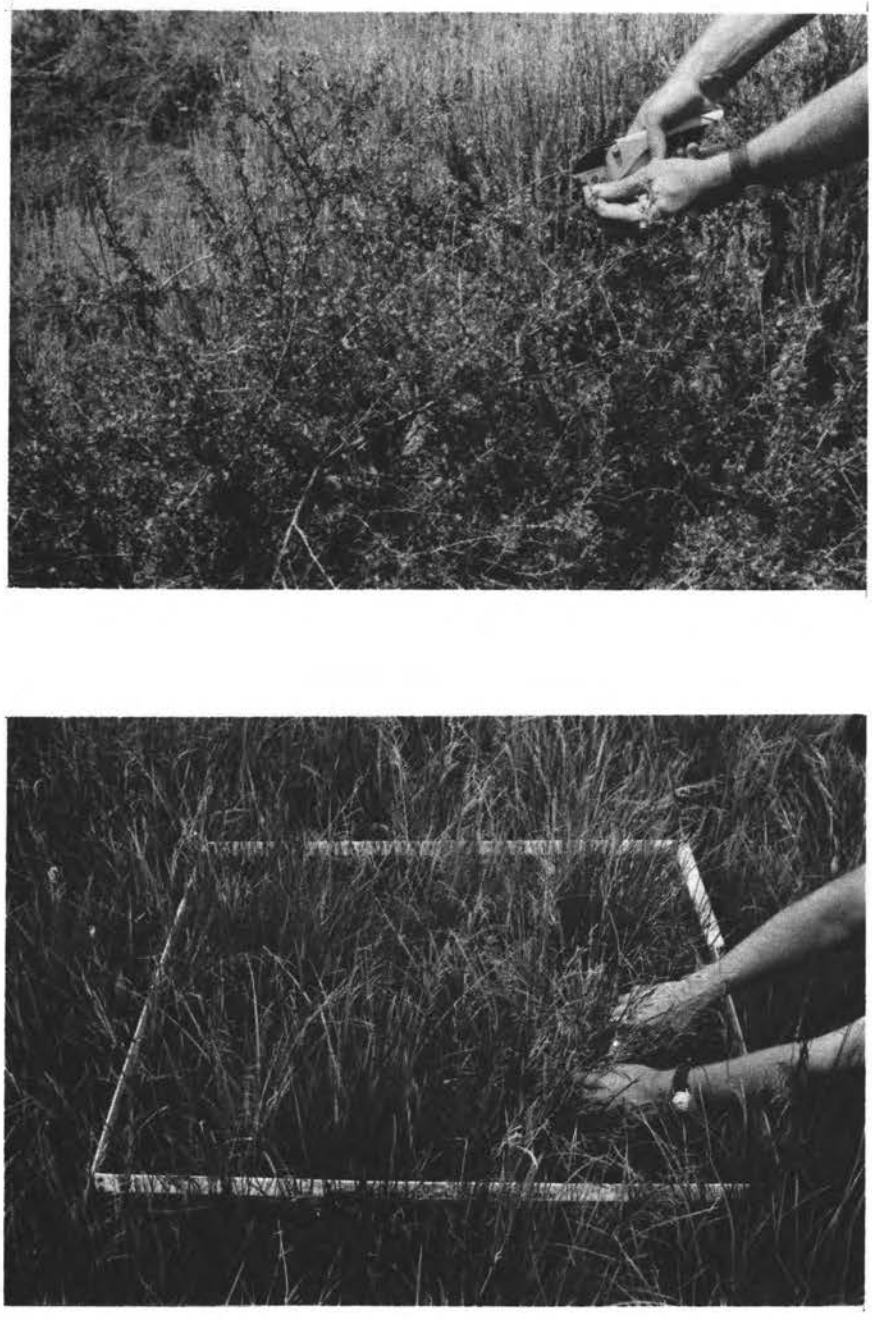

Fig. 15. Collection of current annual growth from bitterbrush (upper photo) and from hairgrass (lower photo).

varied with the species, but attempts were made to sample about the same number of individuals of each species during each collection. As much as possible, only the current annual growth of plants was collected. This procedure was followed for the sake of uniformity and because deer seem to prefer the succulent annual growth over the old, woody plant parts.

Vegetation samples were brought into the laboratory and loosely stored in paper bags for about two weeks to allow desiccation. The samples were then ground in a Wiley mill until the material was sufficiently fine to pass through a metal sieve with 1 mm openings. The material was then thoroughly mixed and weighed into containers of uniform geometry for counting.

Deer

Muscle and rumen content samples were taken from deer which were collected weekly on the study area by the Colorado Department of Game, Fish, and Parks. The animals were hunted and killed in a manner which was considered systematic, in that preference was executed so as to have samples representing a reasonable cross section of ages and sexes from a uniform distribution of locations. However, selectivity among individuals was sometimes secondary to practicality, in that the first animal encountered was often collected without regard to age, sex, or location.

During necropsy, muscle tissues of the thigh posterior

to the femur were removed, separated from fat and connective tissues, diced into one-inch cubes, and immediately weighed into uniform containers for gamma counting. The entire wet contents of the rumen were thoroughly mixed, and a sample was weighed into a container of uniform geometry for counting. Another aliquot of the rumen sample was removed, weighed, oven-dried, and re-weighed so that results could be expressed on an oven-dry basis.

Radioassay

Gross gamma

A gross gamma counting technique was developed in order to make rapid comparisons of radioactivity between various types of bulk samples. The method was used for air, precipitation, soil, and plant samples. Only the activities of those samples which were collected and counted at about the same times under identical geometry conditions were comparable. With the exception of soils, which contained varying amounts of natural radioactivity, the gross gamma levels were correlated with the relative Cs-137 concentrations (Fig. 16).

Bulk samples were counted adjacent to a solid Hawshaw 2 x 2 inch NaI (Tl) crystal which was connected to an RIDL model 10-2 photomultiplier assembly. The entire assembly was mounted in an IDP model E-1 lead shield which was two inches thick.

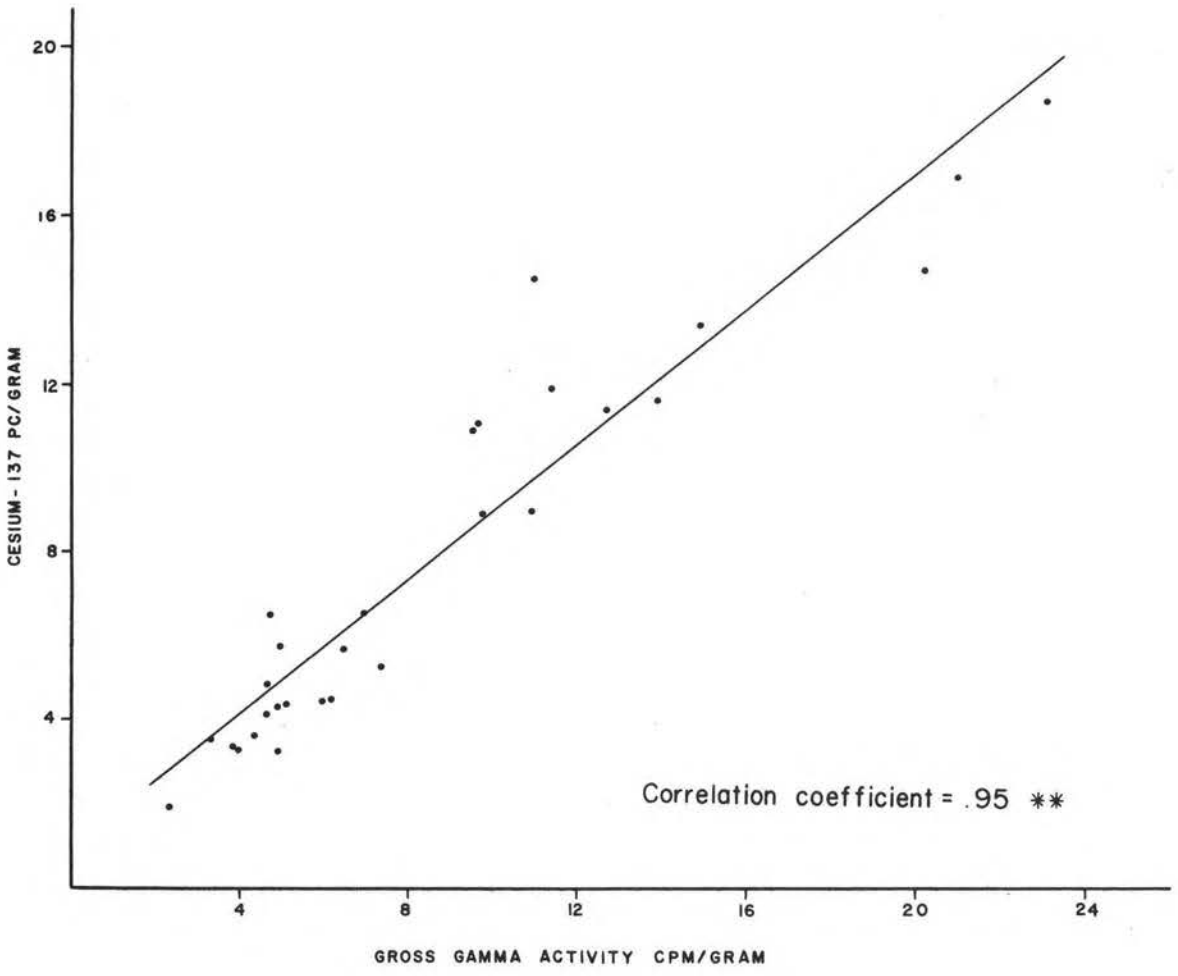

Fig. 16. Relationship between gross gamma and cesium-137 activity for a series of forage samples which were each allowed equal time for radioactive decay.

Pulses from the photomultiplier were fed into an RIDL model 49-50 scaler. The discriminator and operating voltage were adjusted so that all pulses above about 85 Kev were counted. The background counting rate for the system was about 600 counts per minute.

Samples were generally counted for a length of time sufficient to reduce the random counting fluctuations to less than 10 per cent of the expected mean with 95 per cent confidence. Results were expressed in terms of counts per minute per unit of weight, area, or volume, depending on the type of sample. The samples were usually counted four times over a period of 4-5 weeks so that the activities could be normalized to the time of sample collection.

Cesium-137

Quantitative measurements of Cs-137 in bulk samples were made by the technique of gamma ray spectrometry. The counting system (Fig. 17) consisted of a solid Harshaw 4 x 8 inch NaI (Tl) crystal which was mounted over three matched photomultiplier tubes. The assembly was surrounded by a five-inch thick shield constructed of steel laminations. Electrical pulses from the photomultipliers were amplified and fed into an RIDL model 34/12 analyzer with a 400 channel memory capacity. Spectra representing pulses from gamma rays up to two Mev were stored in 200 channels. The amplifier gain was adjusted so that

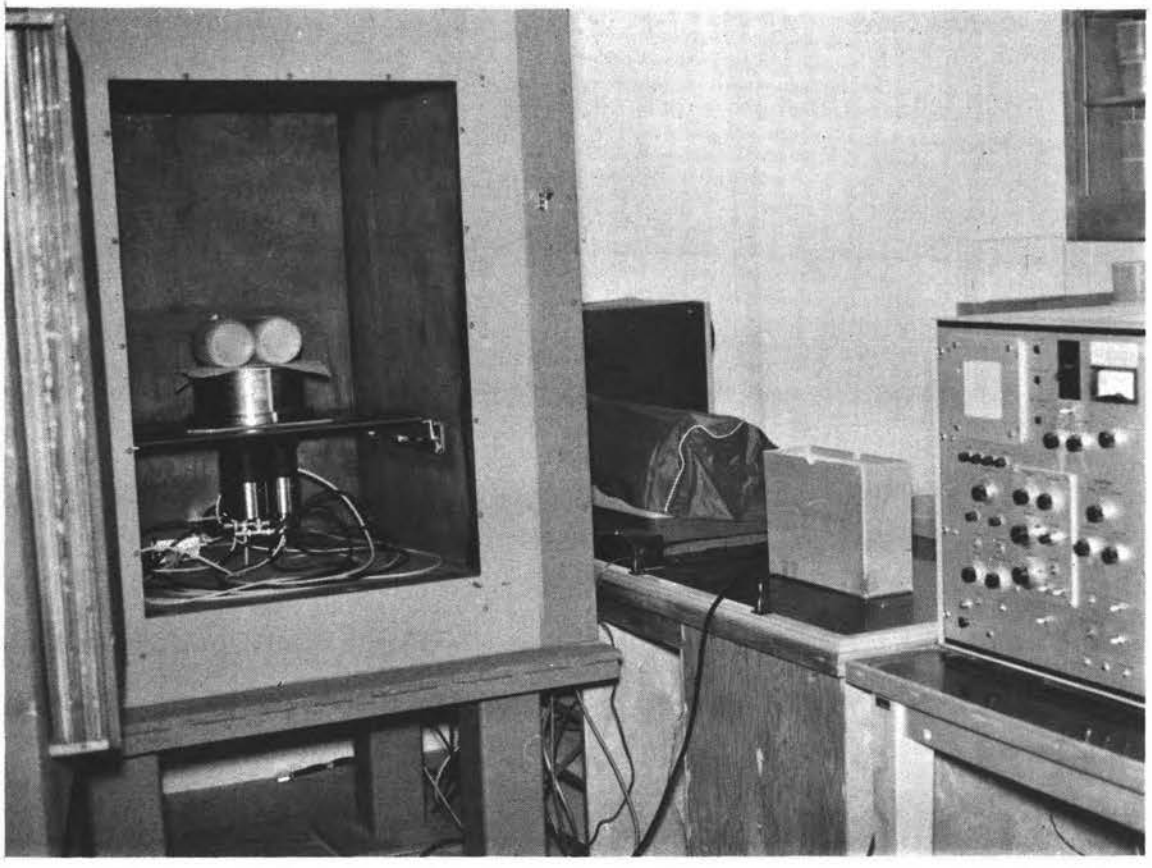

Fig. 17. Gamma spectrometric counting system used for various types of bulk samples.

each channel increment represented a total gamma ray absorption energy in the detector of 10 Kev. The spectral information was read out in digital form with an IBM typewriter.

Gamma spectra from the various types of samples indicated that several radionuclides were ordinarily present. Representative spectra for various types of samples are shown in Fig. 18. This situation made it necessary to account for Compton and secondary gamma pulses from other nuclides, as well as background pulses, which contributed to the total count in the Cs-137 photopeak region.* The problem was solved as follows:

1. Standard geometry sample containers were filled with a medium, such as distilled water or ground straw, which was the same density as the sample material in question.

2. The medium was uniformly contaminated with a known quantity of a radionuclide which required consideration.

3. The standard thus prepared was counted with the gamma-ray spectrometer and the ratio of its counts falling into the photopeak regions of the other nuclides to the counts in its own photopeak region was determined.

---

* Photopeak region refers to the energy interval into which total gamma ray absorption energies are likely to fall. Channel integration limits were chosen for each nuclide such that any shifts in amplifier gain would result in a minimum change in the integrated values. The channel limits chosen for integration were 11-16, 39-46, 48-54, 62-70, 72-79, 79-87, and 141-151 for Ce-144, Sb-125, Ru-106, Cs-137, Zr-95, Mn-54, and K-40, respectively.

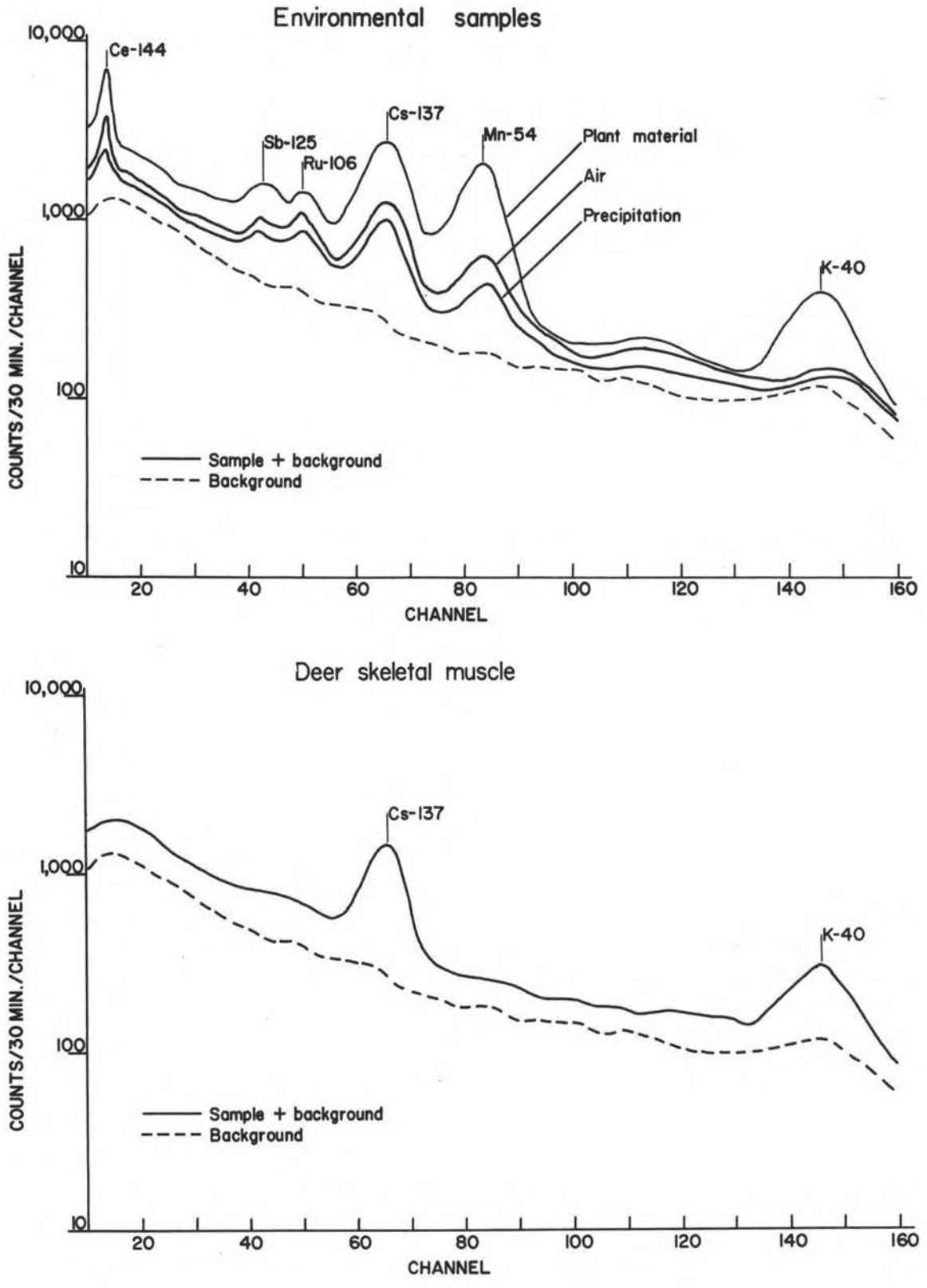

Fig. 18. Representative gamma ray spectra of various types of samples.

4. The above procedure was repeated for each nuclide likely to appear in the samples.

5. From this data, it was possible to construct a matrix of n equations, each with n independent variables, for n radionuclides (Table 4.).

6. A simultaneous solution of the n equations yielded the net counts in each photopeak region which were due only to the nuclide of interest.

Once the net Cs-137 counts were determined in the proper energy region, it was possible to convert the counting rate to picocuries using a conversion factor which was determined from the counting rate of the appropriate standard. Standards were prepared from isotope solutions which were calibrated by three independent methods, namely, comparative beta counting, comparative gamma counting, and the value given by the commercial supplier. The activities were corrected for physical isotope decay to the time of sample collection and expressed in terms of picocuries per unit of weight, area, or volume, depending on the type of sample. The standard deviation of each counting rate was calculated by the following expression:

$$\sigma_{rate} = \left[\frac{2 R_{total} - R_{isotope}}{t}\right]^{1/2}$$

where: σ_{rate} = The standard deviation of the observed counting rate.

Table 4. Example of the general form of the equation matrix for solving the net counting rates of seven radionuclides.

$$A_1 = 1.0\,R_1 + k_1\,R_2 + k_2\,R_3 + k_3\,R_4 + k_4\,R_5 + k_5\,R_6 + k_6\,R_7$$

$$A_2 = k_7\,R_1 + 1.0\,R_2 + k_8\,R_3 + k_9\,R_4 + k_{10}\,R_5 + k_{11}\,R_6 + k_{12}\,R_7$$

$$A_3 = k_{13}\,R_1 + k_{14}\,R_2 + 1.0\,R_3 + k_{15}\,R_4 + k_{16}\,R_5 + k_{17}\,R_6 + k_{18}\,R_7$$

$$A_4 = k_{19}\,R_1 + k_{20}\,R_2 + k_{21}\,R_3 + 1.0\,R_4 + k_{22}\,R_5 + k_{23}\,R_6 + k_{24}\,R_7$$

$$A_5 = k_{25}\,R_1 + k_{26}\,R_2 + k_{27}\,R_3 + k_{28}\,R_4 + 1.0\,R_5 + k_{29}\,R_6 + k_{30}\,R_7$$

$$A_6 = k_{31}\,R_1 + k_{32}\,R_2 + k_{33}\,R_3 + k_{34}\,R_4 + k_{35}\,R_5 + 1.0\,R_6 + k_{36}\,R_7$$

$$A_7 = k_{37}\,R_1 + k_{38}\,R_2 + k_{39}\,R_3 + k_{40}\,R_4 + k_{41}\,R_5 + k_{42}\,R_6 + 1.0\,R_7$$

Where: A_n = Total count rate in photopeak region of nuclide (n) minus the background count rate.

R_n = Net count rate in photopeak region of nuclide (n) due to that nuclide alone.

k_{1-42} = Ratio of counts contributed to photopeak region of measured nuclide to photopeak counts of each contributing nuclide.

R_{total} = The total number of counts per minute observed in the energy region of interest.

$R_{isotope}$ = The number of counts per minute contributed to the energy region by the nuclide of interest.

t = The number of minutes for which the sample was counted.

It was necessary to allow environmental samples which were collected in 1962 and 1963 to decay for a period of time prior to counting so that σ_{rate} would be small with respect to $R_{cesium-137}$. During periods immediately following atmospheric nuclear testing, Zr-95 was so abundant that its photopeak completely obscured the Cs-137 peak and R_{total} was larger than $R_{cesium-137}$ by as much as several orders of magnitude. However, since Zr-95 has a relatively short half-life, the samples were stored until the spring of 1964 prior to radioassay. At that time it became possible to obtain an accurate estimate of the Cs-137 activity.

The calculations involved in solving the gamma spectral components were sufficiently lengthy to warrant computer processing. A program was written for the IBM 1620 computer by Dr. G. M. Angleton, Department of Mathematics and Statistics at Colorado State University. Pertinent data were entered on three IBM cards for each sample (Fig. 19). The cards were then keypunched and run through the computer behind an object program and a set of cards with instructions concerning the number of

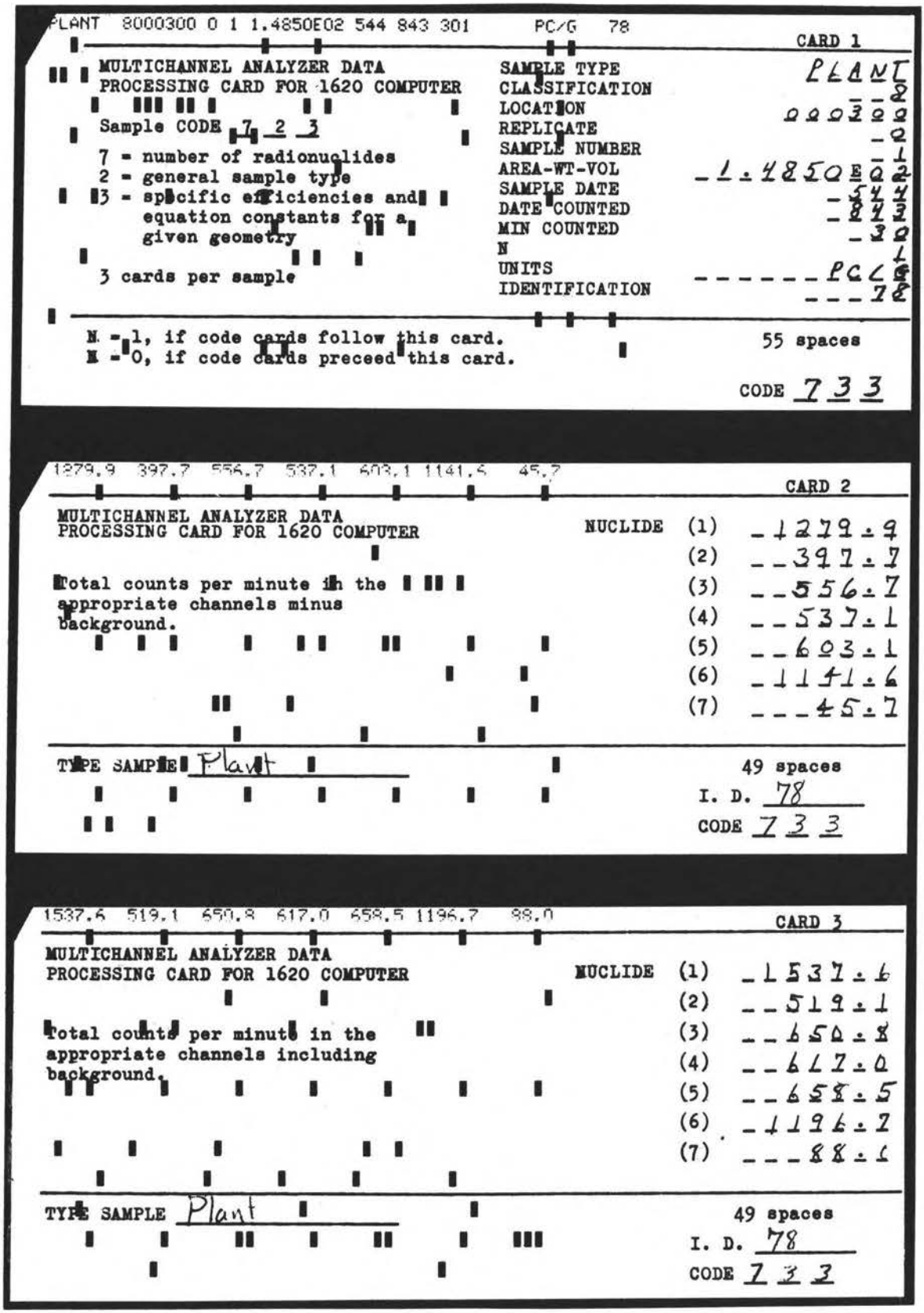

Fig. 19. IBM cards used for computer processing of spectrometer data.

nuclides and equations, the nuclide half-lives and counting efficiencies, and the coefficients of the equation matrix. The output listing containing the desired information was then available within a matter of seconds. (Table 5).

Statistical Procedures

The statistical procedures, taken largely from Snedecor (1956), were utilized as an aid to data interpretation and were compatible with the sampling schemes. The sampling designs were primarily factorial arrangements of variables such as years, seasons, locations, species, age groups, and sexes. Sampling replication within cells or specific categories was executed as much as feasible to gain information on factor interactions as well as sampling variability.

Analysis of variance and covariance techniques were used to test the significance of factors or combinations of factors, and interactions. Individual and group comparisons were made on pre-selected items of interest. Regression and correlation analyses were utilized on certain data in appropriate situations.

All factors were considered as systematic or fixed effects, because a high degree of selectivity was exercised in their choices. Thus, in theory, inferences extending to other years, locations, or species, for example, would be inappropriate.

Computations were performed either with a desk

Table 5. Typical computer listing for a plant sample gamma spectrum.

		I. D.	78
SAMPLE TYPE	PLANT	P. D. TAKEN	544
CLASSIFICATION	8	SAMPLE NO.	1
LOCATION	00.03.00	P. D. COUNTED	843
REPLICATE	1	MINUTES COUNTED	30
AWV	1.4850E+02	UNITS	PC/G

ACT (1) =	194.3398	UL(1) =	197.5642
SDEV(1) =	1.6121	LL(1) =	191.1154
ACT (2) =	6.0508	UL(2) =	6.6522
SDEV(2) =	.3007	LL(2) =	5.4494
ACT (3) =	65.4696	UL(3) =	67.5251
SDEV(3) =	1.0277	LL(3) =	63.4142
ACT (4) =	3.6707	UL(4) =	3.9572
SDEV(4) =	.1432	LL(4) =	3.3842
ACT (5) =	71.1068	UL(5) =	73.9925
SDEV(5) =	1.4428	LL(5) =	68.2211
ACT (6) =	49.4754	UL(6) =	50.1561
SDEV(6) =	.3403	LL(6) =	48.7946
ACT (7) =	.0161	UL(7) =	.0182
SDEV(7) =	.0010	LL(7) =	.0141

ORDER	HALF LIFE	COUNTER EFFICIENCY	ELEMENT
1	28.5000E+01	13.920	CE
2	73.0000E+01	6.050	SB
3	36.5000E+01	15.420	RU
4	97.1100E+02	3.470	CS
5	65.0000E-00	1.510	ZR
6	29.1000E+01	3.630	MN
7	45.6250E+10	.070	K

calculator or the IBM 1620 or 1401 computers. All calculations were double-checked for accuracy.

Chapter V

RESULTS

Air

Concentrations of cesium-137 in air were measured on a weekly basis from October, 1962 through February, 1965 in order to study fluctuations with time. Monthly means and the standard error of each mean are presented in Fig. 20.

Mean air concentrations of Cs-137 were higher in 1963 than in 1964 by a factor of about two. The major series of atmospheric nuclear tests conducted by the Soviet Union and by the United States in 1961 and 1962 were terminated in December, 1962. Because no other major atmospheric test series were conducted during the remainder of the study, one would have expected a yearly decrease in air radioactivity.

In addition to the yearly pattern, a pronounced seasonal variation was revealed, in that peak levels occurred in spring or early summer of each year. This result was expected because much of the radioactive debris from the nuclear tests conducted in 1961 and 1962 was "injected" into the stratosphere. Mixing of air between the stratosphere and troposphere reaches a maximum during the spring months (Machta 1958). Therefore, the lower atmosphere becomes more enriched with radioactive debris in spring.

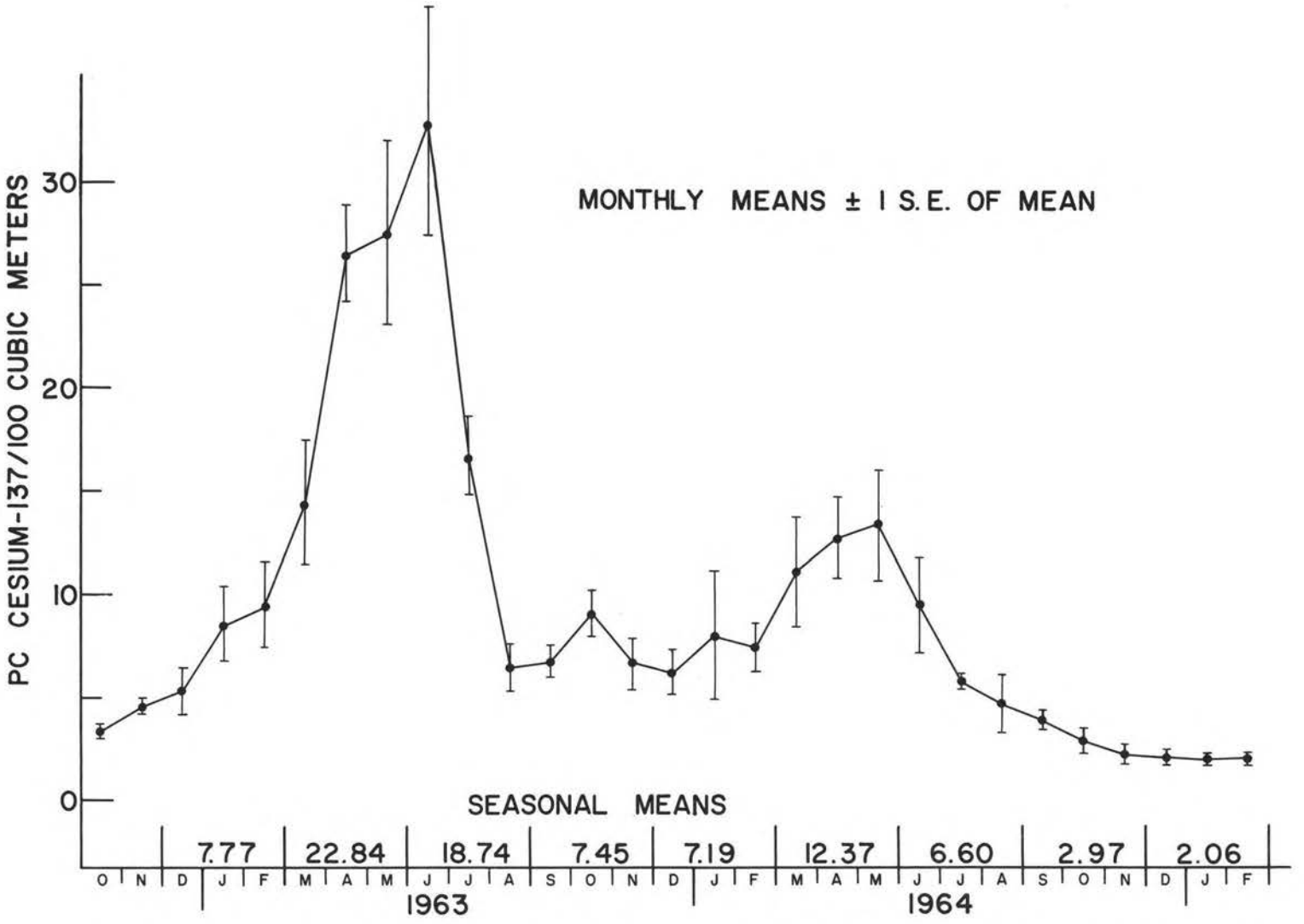

Fig. 20. Cesium-137 concentrations in air collected at Buckhorn Mountain, October 1962 through February 1965.

A two-way analysis of variance was performed on the data to test the hypothesis that the yearly and seasonal means were equal. Approximately 12 weekly observations were considered in the analysis for each season. Prior to performing the analysis, Cochran's test (Dixon and Massey 1957) for heterogeneous variance was performed on the data and the condition was found to exist. The higher variances were associated with the higher means (Fig. 20). This condition seems very common with most fallout data (Eberhardt 1964). It was found that by transforming the data to logarithms, cell variances became statistically homogeneous. Therefore, the analysis was performed on the logarithms of the observed values. The analysis of variance summary, which includes the means, the analysis, and an orthogonal set of individual comparisons, is given in Table 6.

The analysis indicated a highly significant ($P<0.01$) difference between years and between seasons. Therefore, the original hypothesis was rejected. The interaction was also highly significant, but its F value was small in relation to the values for the main effects. Thus, the interpretation of "real" main effects should be valid. With regard to the individual comparisons, the spring mean versus the combined mean of the other three seasons had the largest mean square, indicating that the spring peaks constituted the greatest fluctuations from the overall trends.

Table 6. Variation in air concentrations of cesium-137 between years and seasons.

Means (in terms of picocuries/hundred cubic meters):

	Season				
Year	Winter	Spring	Summer	Fall	Means
1963	7.77	22.84	18.74	7.45	14.20
1964	7.19	12.37	6.60	2.97	7.28
Means	7.48	17.61	12.67	5.21	

Analysis of variance:

Source	DF	MS	F
Years	1	1.928	40.4 **
Seasons	3	1.293	27.1 **
Interaction	3	0.205	4.27 **
Error	90	0.048	

Individual comparisons:

Comparison	DF	MS	F
Spring vs. rest	1	2.500	52.1 **
Summer vs. fall, winter	1	0.897	18.7 **
Winter vs. fall	1	0.492	10.3 **

** Statistically significant at the 1 per cent level.

Precipitation

Deposition of cesium-137 in the open, wet collector

To study variations in total cesium-137 deposition* with time, monthly measurements were made from October, 1963 to November, 1964 at the Kelly Flats sampling station. Cesium-137 deposition rates and monthly precipitation totals are plotted with time in Fig. 21.

The maximum deposition rates of Cs-137 in 1964 occurred during April, May, and June when rainfall was relatively high. Minimum levels were deposited during fall and winter, which were dry in comparison to the other seasons. The comparatively high deposition rates during the spring months were likely the result of: (1) higher air concentrations during the period, and (2) higher rainfall totals. The peak in precipitation during August and September did not produce a proportionately high peak in fallout deposition. This was probably because the air concentrations of Cs-137 were relatively low during August and September.

It was noted during the course of the study that precipitation scavenging was not the only mechanism which could deposit

---

*Total cesium-137 deposition refers to the total quantity deposited per unit area of the collecting device per unit of time by all agents of deposition, including rain, snow, dust, and air currents.

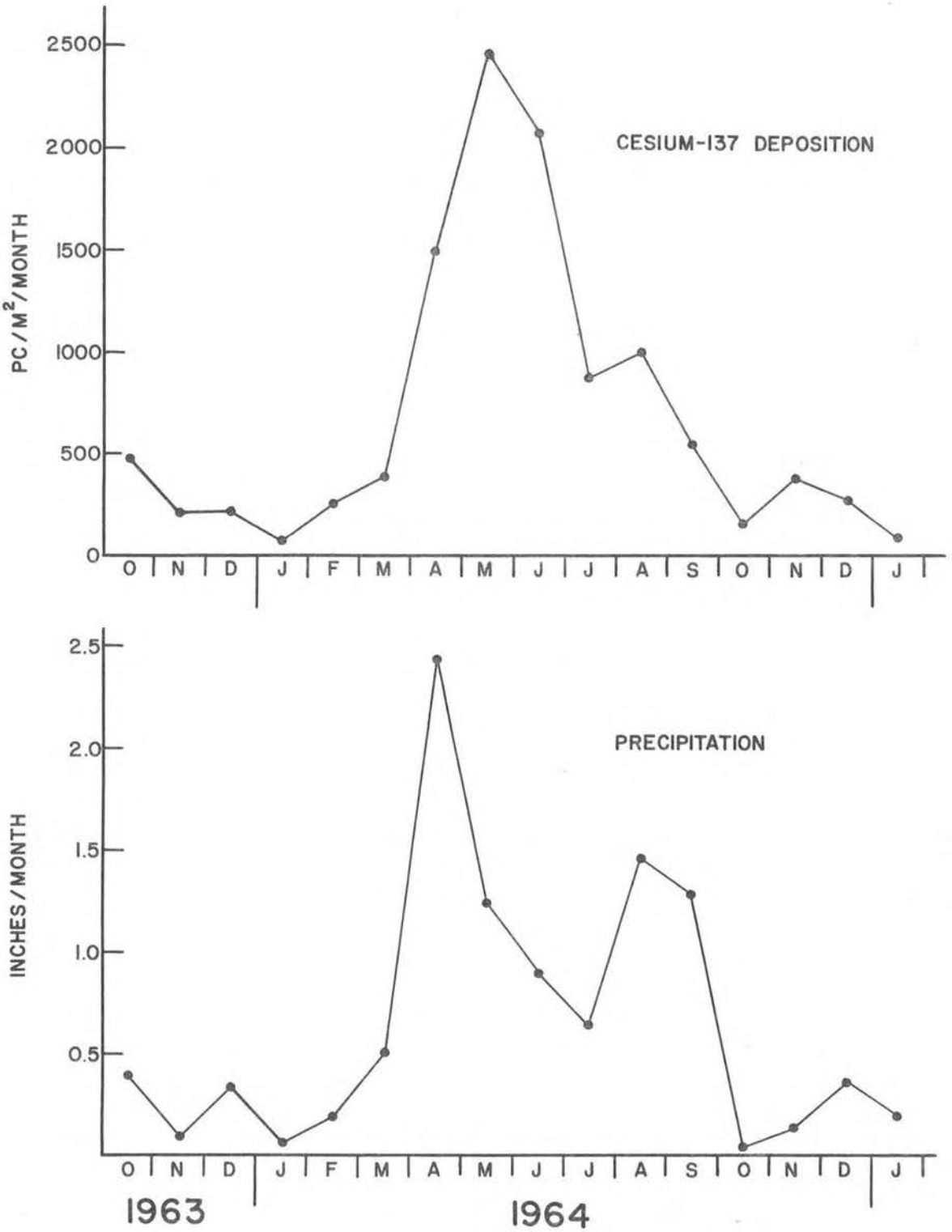

Fig. 21. Total cesium-137 deposition and precipitation by months at Kelly Flats, October 1963 through January 1965.

fallout. For example, considerable quantities of Cs-137 were deposited with dust particles, particularly during dry, windy periods. As much as 50 per cent of the total radioactivity in some samples was in the dust or solid debris fraction. Plant pollens were also found in the fallout samples during the summer months; and although the pollen fractions were not separated, Osburn (1963) has noted that pollens may transport considerable quantities of fallout. Practically no precipitation fell during October, 1964. Yet considerable quantities of the short-lived radionuclides I-131, Zr-95, and Ba-140 were deposited in the collector following the Chinese nuclear test of 16 October 1964. The test apparently did not significantly increase the atmospheric levels of Cs-137.

Furthermore, a comparison of collection efficiencies between the open, wet collector and a funnel-type rain collector indicated that the open collector accumulated an average of 73 per cent more radioactivity per square meter than the funnel collector during the summer of 1964. The funnel collector did not retain dust, debris, pollens, or other air-borne material to any significant extent.

Fallout deposition in the funnel-type rain collectors

Time-specific variations in fallout deposition by rainfall were studied during the summer and fall months at five locations of varying elevations. Data for 1964 are given in Table 7.

Table 7. Gross gamma radioactivity in precipitation collected at various locations, June-October, 1964.

Sample No.	Location	Month	Precip., Inches*	Rel. Act. in cpm/m^2/mo.	Fall. Dep. C. V., %
79	Hewlett Gulch	June	0.78	4026	
75	Kelly Flats	"	0.90	2477	
76	Sevenmile Cr.	"	1.28	4905	27
77	Little Beaver	"	0.96	3052	
78	Crown Point	"	1.34	4720	
80	Hewlett Gulch	July	0.62	1536	
85	Kelly Flats	"	0.65	1440	
88	Sevenmile Cr.	"	0.93	2229	28
86	Little Beaver	"	1.17	1441	
87	Crown Point	"	1.82	2525	
93	Hewlett Gulch	Aug.	0.86	1508	
94	Kelly Flats	"	1.48	827	
95	Sevenmile Cr.	"	1.65	1578	31
96	Little Beaver	"	2.17	814	
97	Crown Point	"	2.04	1073	
102	Hewlett Gulch	Sept.	0.31	256	
103	Kelly Flats	"	1.31	869	
104	Sevenmile Cr.	"	1.81	493	42
105	Little Beaver	"	1.04	474	
106	Crown Point	"	1.23	536	
111	Hewlett Gulch	Oct.	0.07	139	
112	Kelly Flats	"	0.03	108	
113	Sevenmile Cr.	"	0.03	152	38
114	Little Beaver	"	0.11	258	
115	Crown Point	"	0.21	254	

*Data collected by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks.

The monthly totals of precipitation generally increased with elevation (locations are listed in order of increasing elevation). The deposition of fallout varied considerably between locations, but the variations did not show any consistent patterns with locations or with precipitation totals. In other words, the location and/or precipitation effects were dependent upon the month of sampling.

A two-way analysis of variance of the data is given in Table 8. The analysis indicated a highly significant ($P<0.01$) difference between months but no difference between the sampling locations. The plausible reason for the result of no effect due to locations was that the interaction between months and locations was by necessity used as the error term, and it was obvious from the data that considerable interaction existed. The factors which caused the interaction were not apparent, but it seemed possible that variations between locations in dust and pollen loads, air currents, rain intensity, and other phenomena could have easily contributed.

These data point out that a single fallout collector would not necessarily provide an accurate concept of fallout deposition in a surrounding region. It seems that the more complex the topography and other characteristics of a region, the more sampling locations would be required to obtain a representative estimate of fallout deposition.

The question of whether or not Cs-137 deposition was

Table 8. Variation in gross gamma radioactivity in precipitation collected at various locations in 1964.

Means (in terms of cpm/m^2/month):

Location	Month					Means
	June	July	Aug.	Sept.	Oct.	
Hewlett Gulch	4026	1536	1508	256	139	1493
Kelly Flats	2477	1440	827	869	108	1144
Sevenmile Cr.	4905	2229	1578	493	152	1871
Little Beaver	3052	1441	814	474	258	1208
Crown Point	4720	2525	1073	536	254	1822
Means	3836	1834	1160	526	182	

Analysis of variance:

Source	DF	MS	F
Months	4	10,462,436	42.5 **
Locations	4	566,374	2.3 N.S.
Error (interaction)	16	245,999	

** Statistically significant at the 1 per cent level.
N.S. Not significant.

generally higher at the higher elevations, remains unanswered at this point, because the rain sampling network was obviously inadequate to provide a conclusive answer. The data on soil radioactivity, however, provide a more satisfactory answer to the question.

Soils

The chemical nature of soil is grossly similar to that of an ion-exchange resin. Therefore, cesium-137 in ionic form should be bound rapidly to soil particles upon reaching the ground, and would not penetrate the soil to any great extent. Neither should fallout materials already bound to or occluded by insoluble particles penetrate far into the soil. Thus, undisturbed surface layers of soil should provide a means of determining long-range differences in fallout deposition between sampling locations.

To test the hypothesis that most of the fallout radioactivity would be found in the upper soil layers, samples were collected from two depths at ten locations in the study area. Soil characteristics such as organic content and texture differed widely between the collection sites. The results of gross gamma-ray analyses of the samples and the analysis of variance are given in Table 9.

The 0-1 inch layer of soil was more radioactive than the 4-6 inch layer by an average factor of 6.1. The difference was highly significant ($P<0.01$). Gamma ray spectral analyses of the samples revealed that nearly all the radioactivity in the 4-6 inch

Table 9. Gross gamma radioactivity in soils collected at two depths, July 1963.

Collection Location	Relative Activity in cpm/gram 0-1" layer	4-6" layer
Laramie Meadow (upper)	10.0	1.8
" " "	9.4	1.7
Laramie Meadow (lower)	10.6	1.8
Zimmerman Bench	13.5	2.3
Long Draw	10.3	1.2
Manhattan	5.6	1.7
Nunn Creek	12.3	1.5
Little Beaver Creek	9.1	2.1
Crown Point	7.9	0.9
Pennock Creek	14.0	2.3
Means:	10.3	1.7
Ratio of means:	6.1	

Analysis of variance:

Source	DF	MS	F
Layer	1	364.66	132.12 **
Locations	9	3.91	1.42 N.S.
Error (interaction)	9	2.76	

** Statistically significant at the 1 per cent level.
N.S. Not significant.

soil layer was from primordial radionuclides such as K-40, Th-232, Ra-226, and U-238. Most of the radioactivity in the 0-1 inch layer was from fallout nuclides such as Ce-144, Sb-125, Ru-106, Cs-137, and Mn-54. All subsequent soil sampling involved the 0-1 inch layer.

Soil samples were collected from 22 locations throughout the study area and assayed for gross gamma-radioactivity. No clear-cut relationship was found when activity was plotted against elevation, because there were greater differences in activity within locations than between locations.

Gamma-ray spectra analyses indicated that variations in organic content and primordial radioactivity of the samples was sufficient to obscure any fallout patterns. For example, soils at higher elevations generally had more organic material in the surface layers sampled, and most of their activity was due to fallout. Soils sampled at lower elevations, however, were largely inorganic and much of their activity was from naturally-occurring radionuclides. This is illustrated in Fig. 22 by gamma-spectra representative of organic and inorganic soils.

Because a suitable quantitative method for Cs-137 assay in soils was not developed, the gross-gamma activities of a group of highly organic soils from the summer range were compared. The soil activities are plotted against precipitation received the winter previous to sample collection in Fig. 23. The correlation

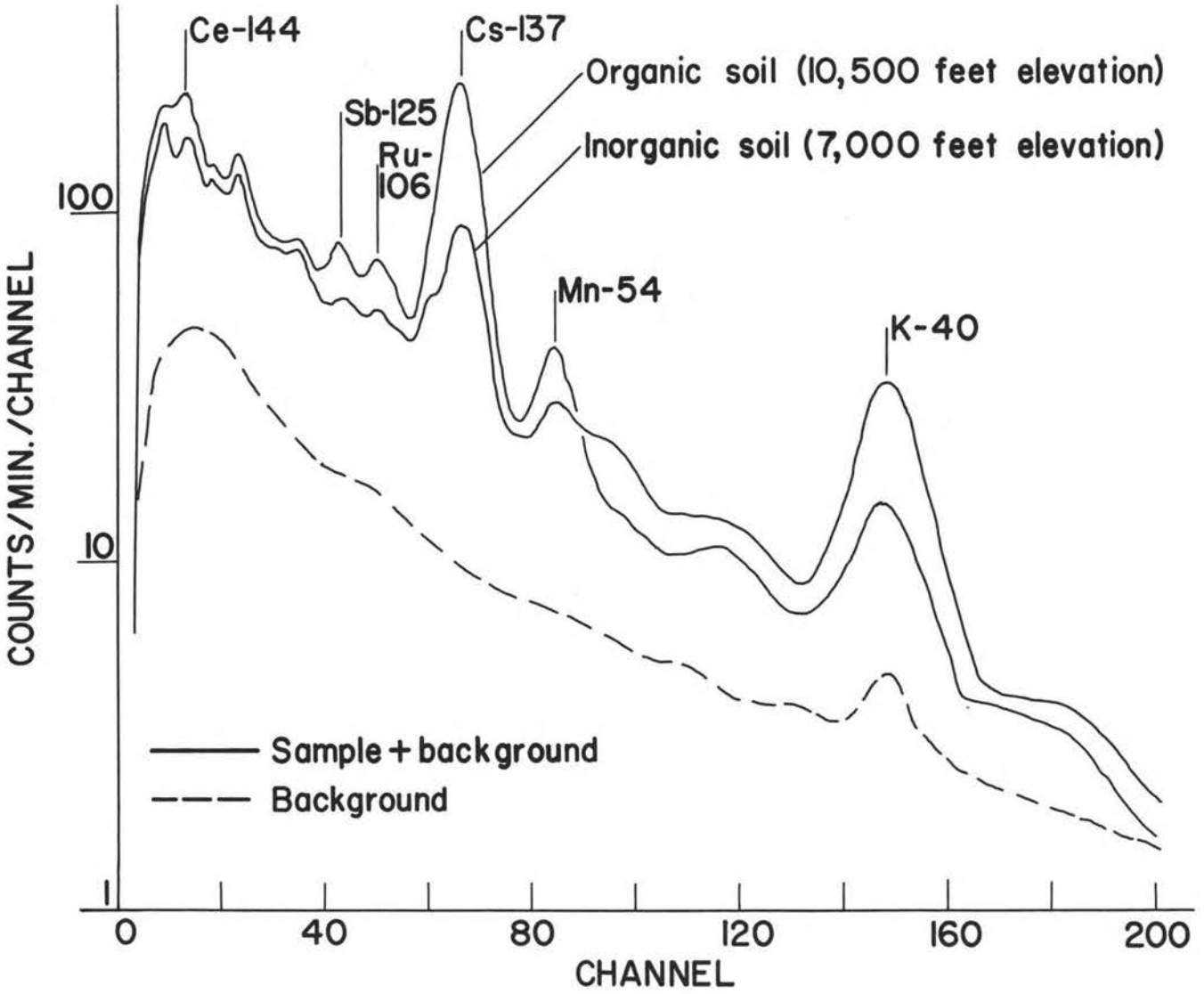

Fig. 22. Comparative gamma ray spectra of organic and inorganic soil samples collected from different elevations.

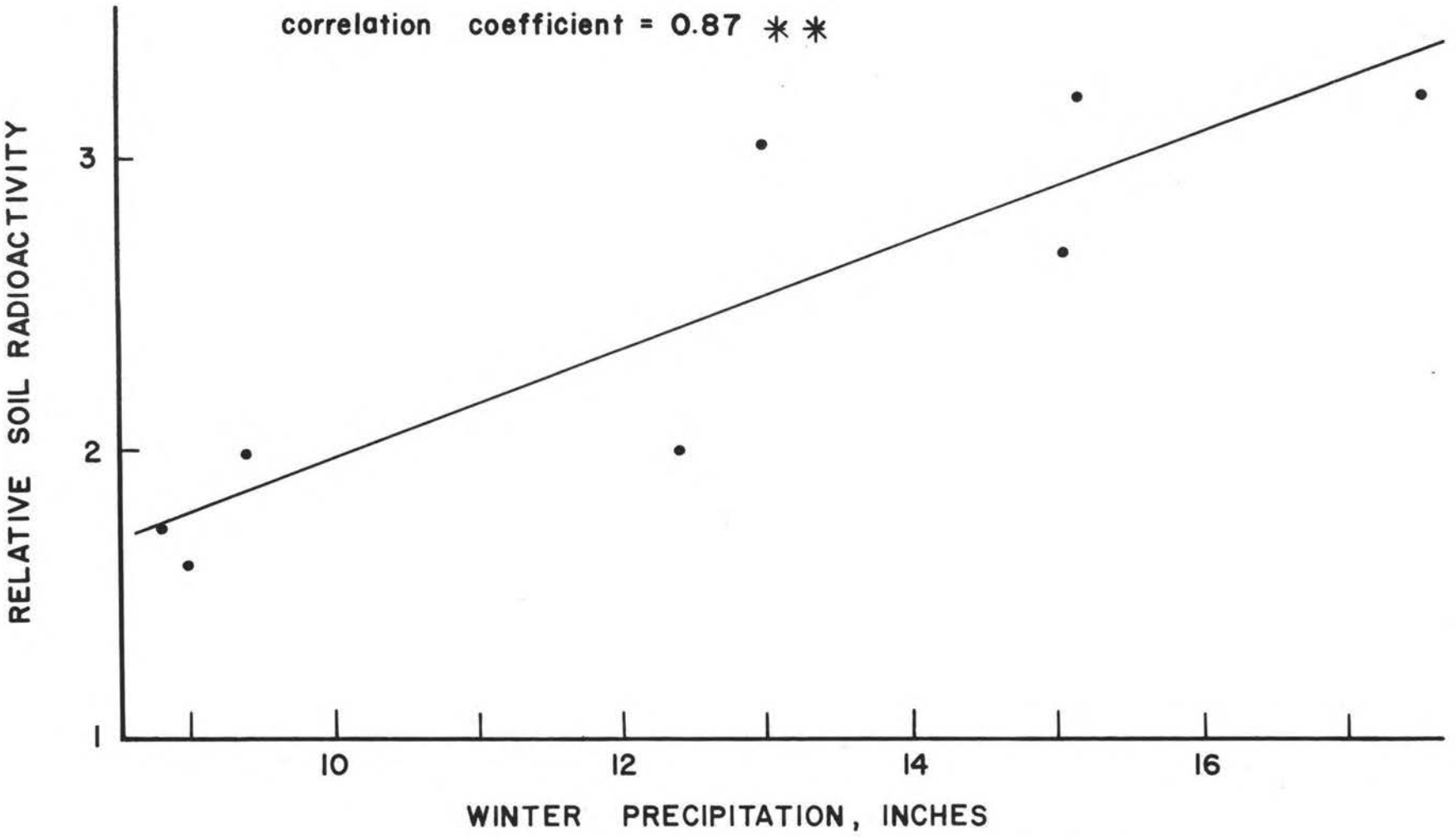

Fig. 23. Mean levels of gross gamma radioactivity in organic-rich summer range soils collected in June, 1964 versus precipitation recieved the previous winter.

coefficient of 0.87 with six degrees of freedom was highly significant ($P<0.01$). The higher soil activities and precipitation levels both occurred at the higher elevations. It was not clear whether precipitation or other phenomena associated with elevation actually caused the higher levels of fallout in soil, because the factors could not be studied individually.

With regard to the original question of Cs-137 deposition as influenced by elevation, it appeared that in general, deposition did actually increase with elevation. However, this statement must only be considered qualitative because the sampling techniques and analytical methods were insufficient to establish a quantitative relationship.

If one could sample soils over a large range of elevations such that organic content, texture, vegetative cover, degree of slope, and degree of disturbance were all similar, then it should be possible to obtain a satisfactory relationship between Cs-137 deposition and elevation.

Vegetation

Periodic sampling and subsequent Cs-137 analysis of 12 species of deer forage plants from 18 locations within the study area indicated complex patterns of variability. Among the categories of stratification which appeared to affect the levels of Cs-137 contamination were: years, seasons, months, species, locations, elevations,

and plant parts. Although the data are presented in terms of these factors, one must exercise caution in the deduction of cause-effect relationships.

Time trends and range comparisons

Trends in vegetational levels of Cs-137 were constructed by computing averages for all species collected from each sampling location for each sampling period. Each species mean was computed by using the values for each location. The species means were then weighed equally and used for computing the vegetational means. Only the winter range species were considered in calculating the means during the winter and spring months. Likewise, only the summer range species were used in deriving means during the periods of herd residence at elevations above 8,500 feet.

The vegetational means thus constructed are plotted versus time in Fig. 31. It was found that the vegetational levels, which would hopefully reflect the pattern of Cs-137 consumption by deer, showed both yearly and seasonal fluctuations. With regard to years, levels in 1963 were higher than in 1964, which in turn were higher than those in 1962. Seasonal trends within years were apparent, with highs occurring during the summer months in the summer range vegetation and with lows occurring in mid-winter in the winter range species. A comparison of ranges (seasons) and years is given in Table 10. Data for 1962 were incomplete and were not included

Table 10. Comparison of mean cesium-137 concentrations* of all species of vegetation sampled over all locations between summer and winter ranges for 1963 and 1964.

	1963	1964
Overall means	5.56	4.49
Winter range means	2.83	3.59
Summer range means	6.93	4.94
Ratio of means, summer/winter	2.45	1.38

*Concentrations given in terms of picocuries per gram air dry material.

in the table.

It is not immediately clear whether the summer highs were caused by time-associated phenomena or by the change in the environment and species sampled. Evaluation of other data, however, indicated that both types of phenomena probably contributed to the pattern.

Species comparisons

Species comparisons indicated some patterns which were consistent through time, but the majority of the comparisons were highly dependent upon time or season. For example, a comparison of Cs-137 concentrations among four winter range species collected at Sevenmile Creek indicated that the ranking of species changed with time and phenological activity (Fig. 24).

Juniper and sagebrush, which both have relatively persistent leaves, apparently retain Cs-137 for considerable lengths of time, and the activity tended to increase during the winter of 1963-1964. Bitterbrush and mountain mahogany, on the other hand, consist only of relatively bare, smooth-surfaced stems during the winter months, which appeared less efficient in picking up fallout material from the atmosphere. This was demonstrated by the lack of an increase in Cs-137 activity of those species during that period. Between April and June, however, bitterbrush and mountain mahogany leafed out and their Cs-137 concentrations approximately

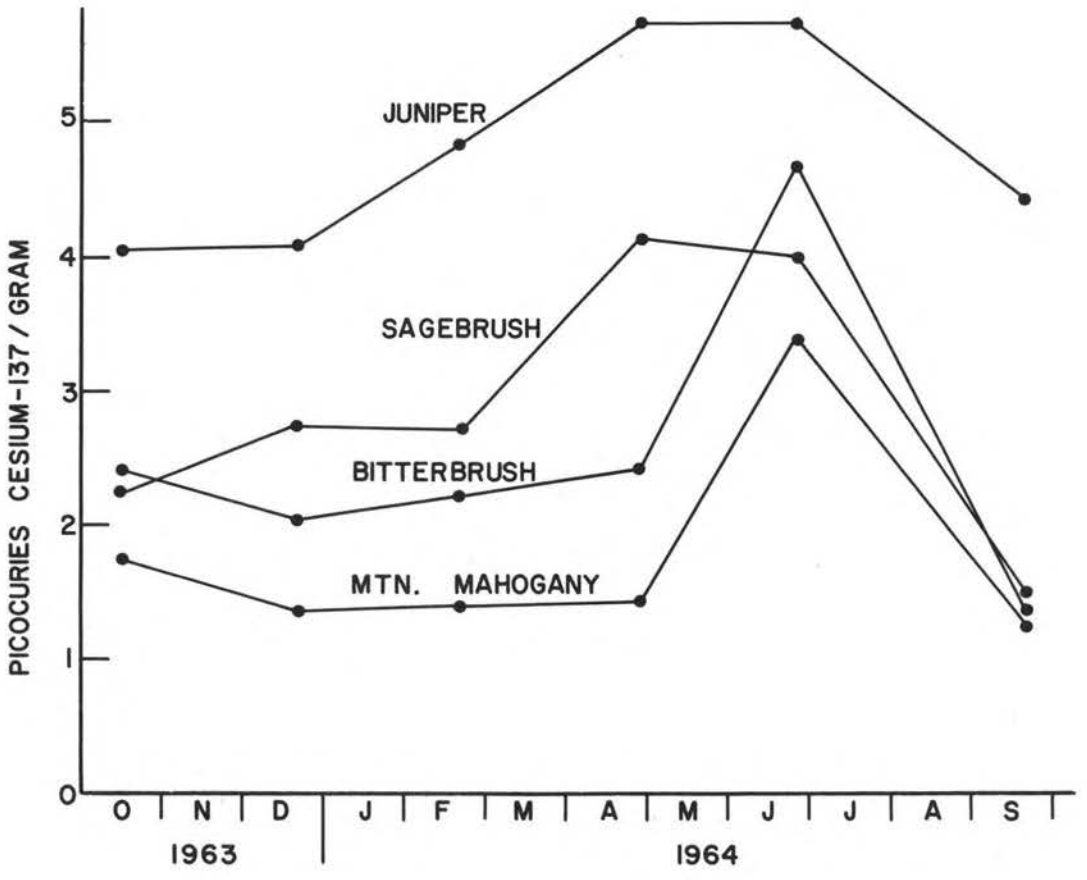

Fig. 24. Mean concentrations of cesium-137 in four winter range plant species collected at Sevenmile Creek, October 1963 through September 1964.

doubled, while levels in juniper and sagebrush remained nearly constant.

It appears that leaf and stem surface characteristics could account at least partly for the phenomena just described. A series of photographs of leaves and stems of the plant species sampled, which were taken at 20 X magnification through a stereomicroscope, are shown in Figs. 25-29. The hairy nature of bitterbrush and mountain mahogany leaves (Fig. 25) would appear to contribute to fallout entrapment during the period of leafing out, especially when air levels of Cs-137 were relatively high (Fig 20). Later in the summer of 1964 when the air concentrations of Cs-137 decreased markedly, the continued vegetative growth apparently tended to "dilute" the contamination, and the forage levels of activity decreased sharply, as noted by the September values.

The winter buildup in sagebrush activity would seem likely since no growth was taking place and the persistent, hairy leaves and stems (Fig. 26) would efficiently collect air particulates. Between April and May, plant growth and possibly other mechanisms caused the activity to decrease. Although juniper has smooth leaf surface characteristics, it still seemed to collect fallout efficiently. The resinous character of juniper leaves possibly compensated for the lack of hairiness or surface area per unit weight.

Rankings of Cs-137 concentrations for all species sampled

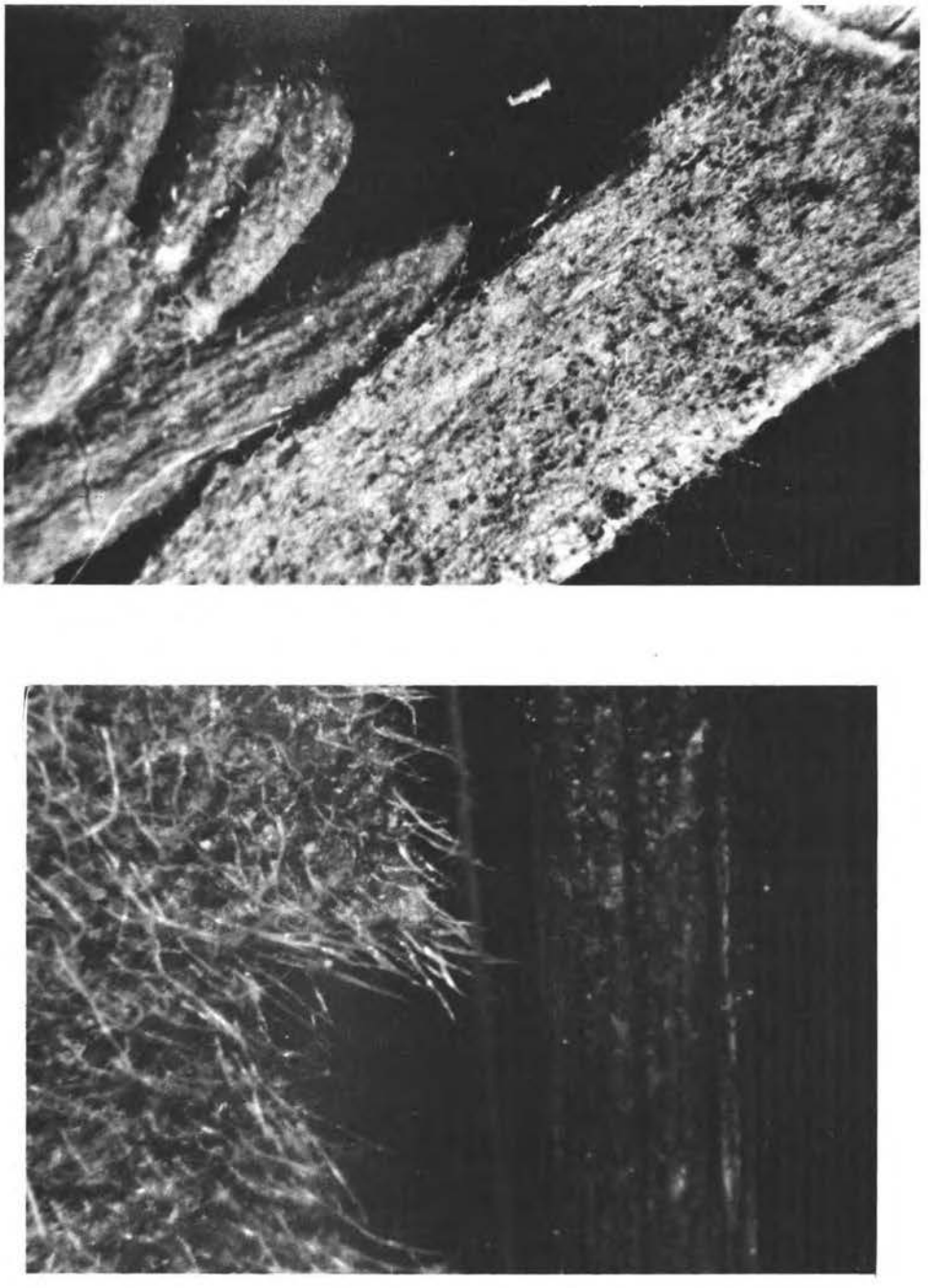

Fig. 25. Leaf and stem surface characteristics of bitterbrush (upper photo) and mountain mahogany (lower photo). 20X magnification.

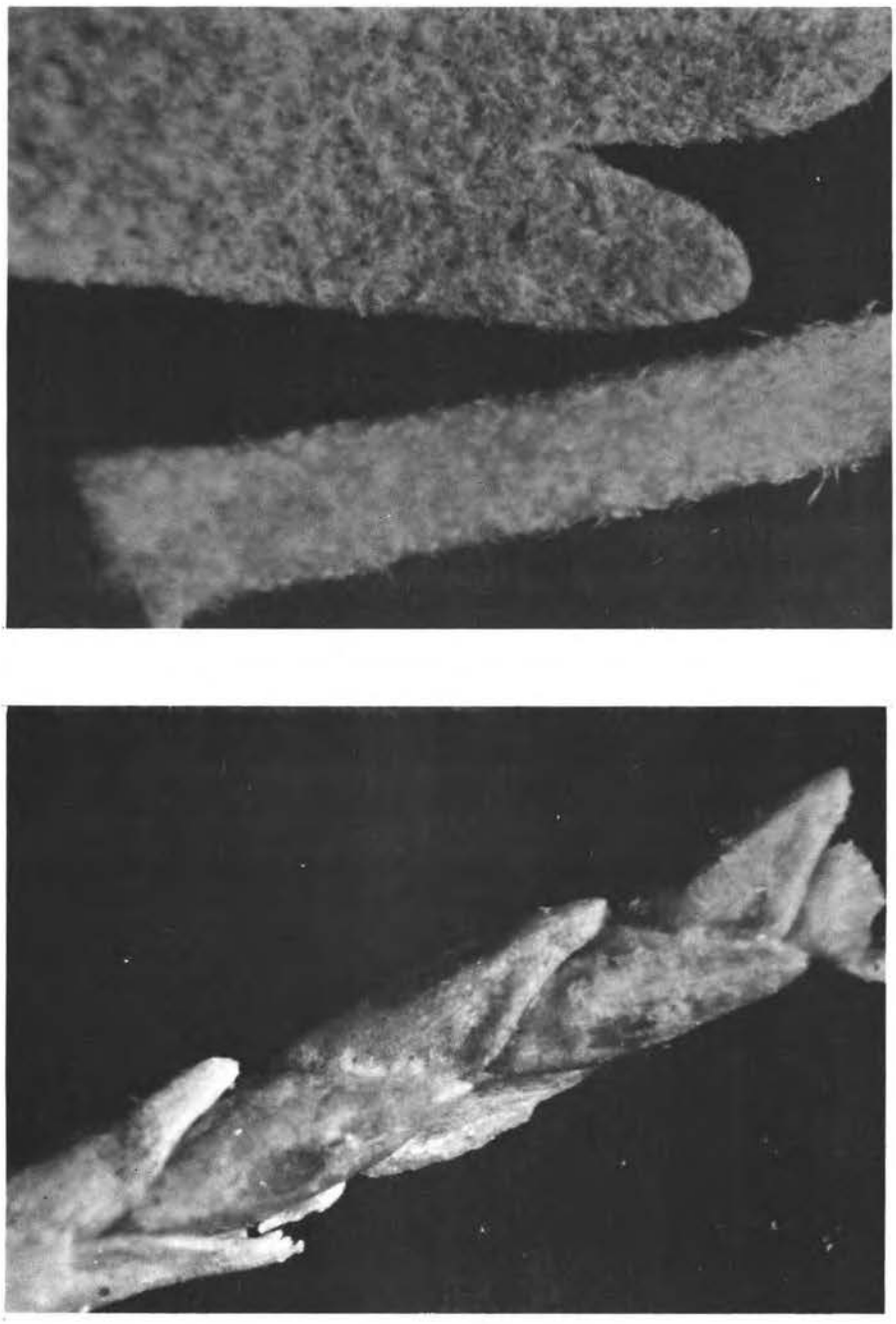

Fig. 26. Leaf and stem surface characteristics of sagebrush (upper photo) and juniper (lower photo). 20X magnification.

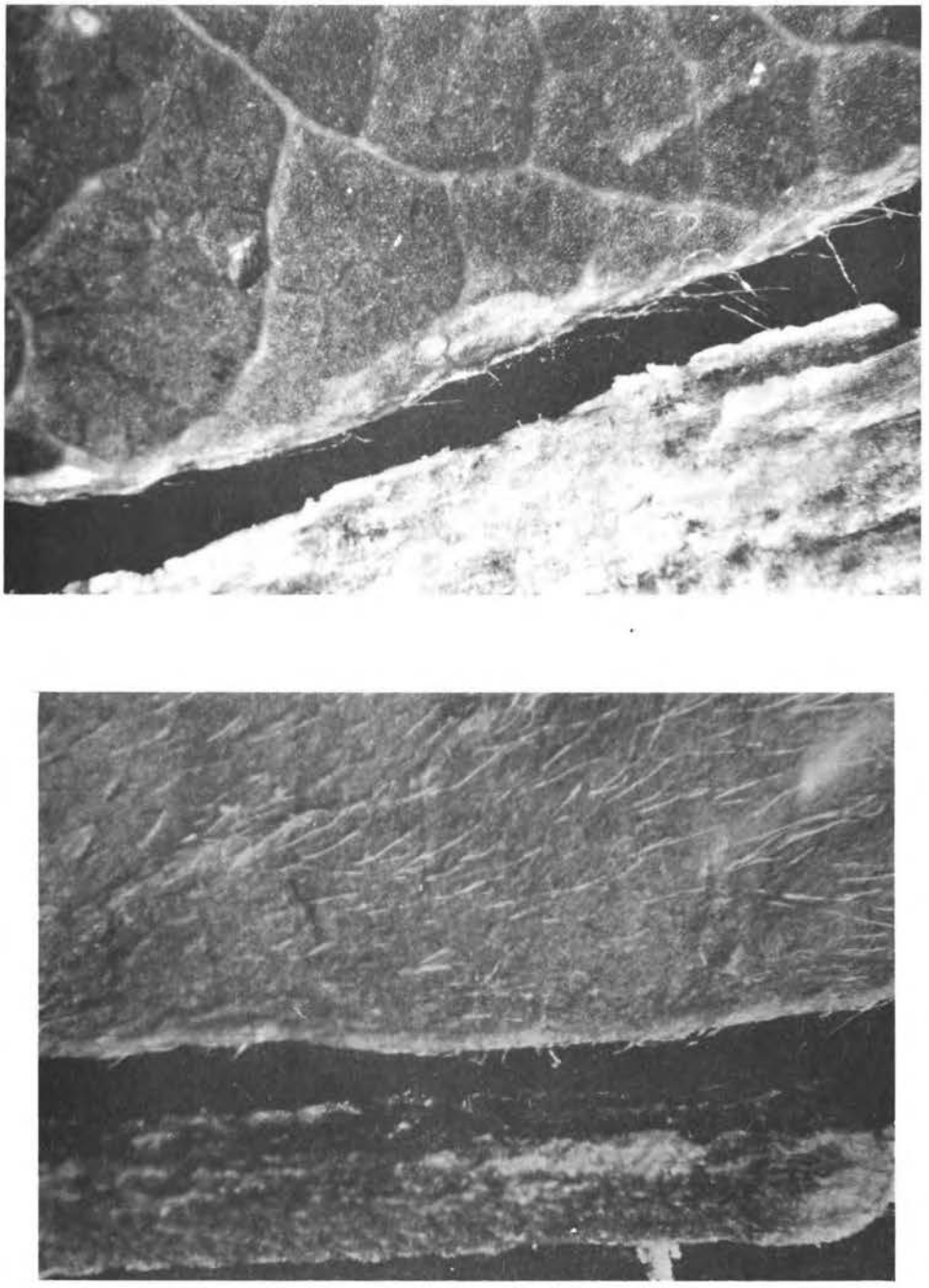

Fig. 27. Leaf and stem surface characteristics of aspen (upper photo) and willow (lower photo). 20X magnification.

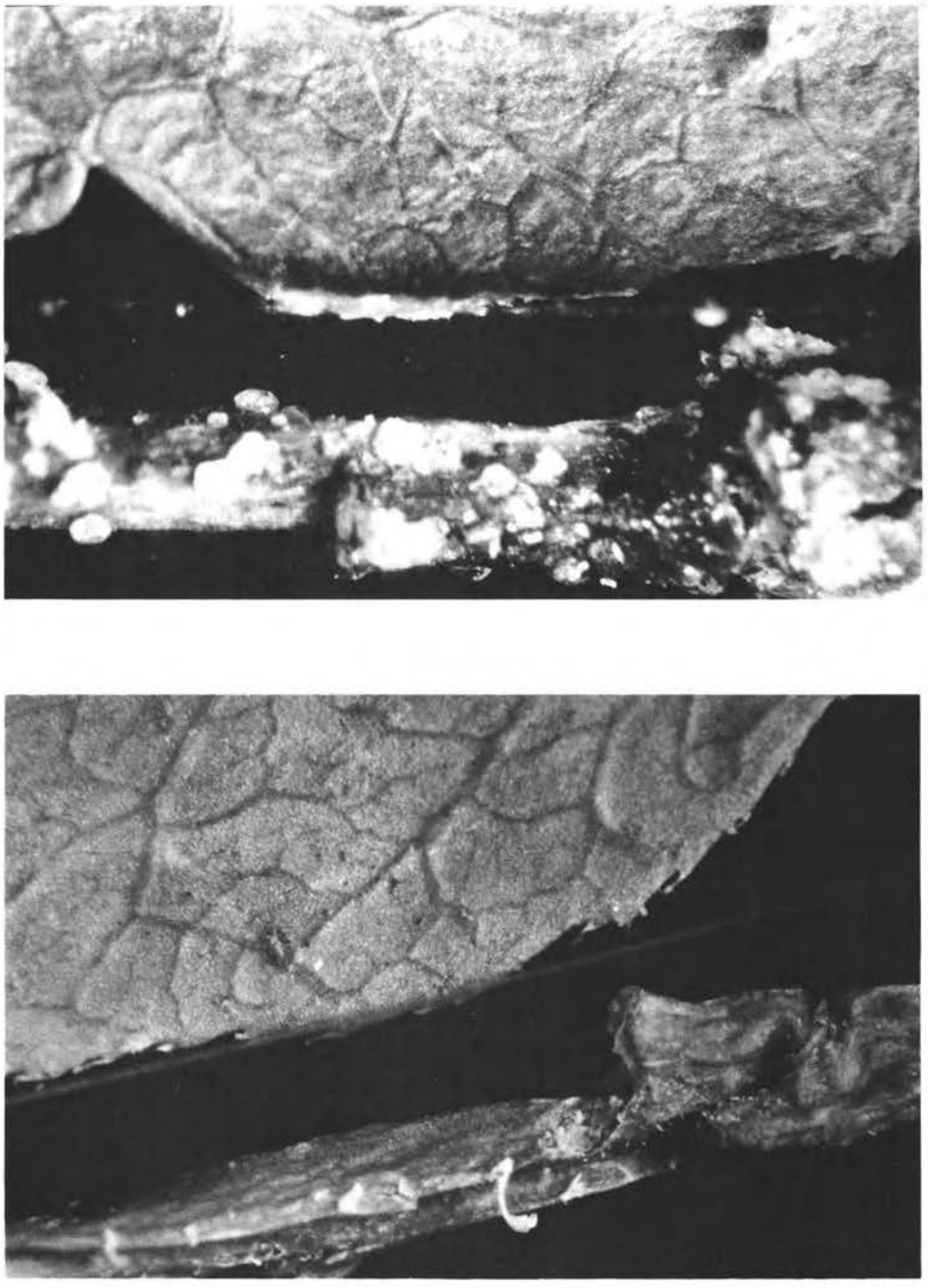

Fig. 28. Leaf and stem surface characteristics of bog birch (upper photo) and blueberry(lower photo). 20X magnification.

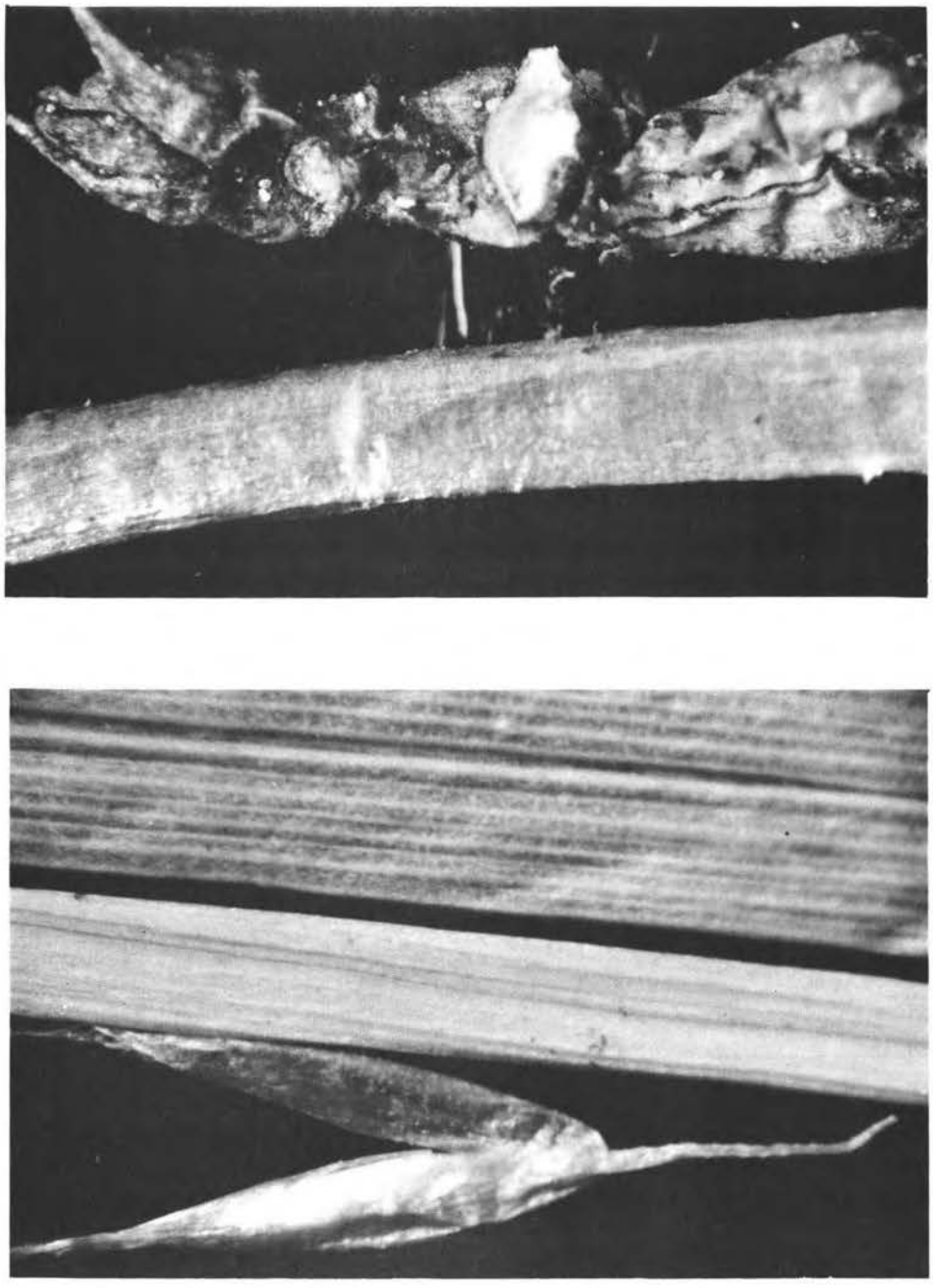

Fig. 29. Leaf and stem surface characteristics of common juniper (upper photo) and hairgrass (lower photo). 20X magnification.

are presented in Table 11 for 1963 and for 1964. Variance analyses indicated in nearly all cases where different species growing on the same plots were compared that the means were significantly different ($P<0.05$). The values given in Table 11 were reflective of only those periods of utilization by deer.

Differences among species seemed most closely related with longevity of the plant parts sampled and with gross morphology. For example, aspen and willow leaves remain exposed to the atmosphere for a maximum of about four months and wind tends to prevent snow or rain from accumulating on the plants. These plants were consistently relatively low in activity. On the other hand, hairgrass and blueberry were consistently high in activity. The low-growing nature of these plants would allow snow and moisture to remain in contact with the vegetation for much longer periods of time, facilitating the adsorption of Cs-137 and other radionuclides. Furthermore, in the case of blueberry, the production of new stems is a very slow process, and consequently, it was necessary to sample parts of older stems. Signs of deer utilization of blueberry indicated that our sampling was not unlike that by the animals.

Note from Table 11 that species ranking was different between the two years. This can partly be explained on the basis that persistent plants, such as sagebrush, juniper, and common juniper increased in activity in 1964, whereas plants with short-

Table 11. Ranking of mean concentrations* of cesium-137 among species of vegetation sampled over all locations in 1963 and 1964.

1963		1964	
Species	Mean conc.	Species	Mean conc.
Mountain mahogany (w)	1.80	Aspen(s)	1.29
Bitterbrush (w)	2.44	Mountain mahogany (w)	2.24
Sagebrush (w)	2.45	Willow (s)	2.72
Aspen (s)	2.49	Bitterbrush (w)	3.11
Willow (s)	4.58	Mixed forbs (s)	3.64
Juniper (w)	4.61	Bog birch (s)	3.80
Common juniper(s)	5.55	Sagebrush (w)	3.90
Bog birch (s)	5.72	Mixed grasses (s)	4.86
Mixed grasses (s)	7.41	Juniper (w)	5.10
Mixed forbs(s)	7.83	Common juniper (s)	6.09
Hairgrass (s)	10.42	Hairgrass (s)	6.59
Blueberry (s)	11.43	Blueberry (s)	10.52

*Concentrations given in terms of picocuries per gram air dry material.

(w) Winter range plants

(s) Summer range plants

lived leaves such as aspen, willow, bog birch, grasses, and mixed forbs decreased in activity, due to the lower fallout levels in 1964.

Influence of location and elevation

It was found that with the exception of mountain mahogany, all species sampled varied significantly in Cs-137 levels between collection locations. Each sampling location for a given species varied in one or more respects, such as elevation, surrounding vegetation, slope exposure, slope gradient, or surrounding topography. These variables would alter climatic variables, which in turn would affect fallout deposition on the sampling plots. Differing soil characteristics between sampling sites could further complicate any comparisons because of the influence of soil type on root absorption of fallout materials.

The only effect which appeared relatively consistent was that of elevation. For most of the species, on both winter and summer ranges, cesium-137 concentrations increased with elevation of the sampling plot. Because elevation affected the time-phase of the phenological sequence, particularly in the deciduous species, juniper was chosen as an example to demonstrate the elevational pattern. The juniper leaves sampled were very persistent and seemed comparable between sampling locations and between seasons. Further, the topography and surrounding vegetation seemed more uniform for the juniper plots than for the

plots of the other species. Mean concentrations of Cs-137 in juniper between February and June 1964 are plotted against elevations of the five sampling locations in Fig. 30. The correlation coefficient of 0.93 with three degrees of freedom was significant at the 5 per cent level.

The increasing vegetational fallout contamination with elevation could concievably have been associated with higher rainfall, higher average wind velocities, or higher air concentrations of radioactivity.

Leaf-stem comparisons

Comparison of leaves and stems with regard to surface characteristics (Figs. 25-29) would lead one to postulate differences in airborne particulate collection and retention between the vegetative parts. Because the relative proportion of leaves to stems which is available to deer, changes with the seasonal progression, it became of interest to analyze the parts separately. This relationship was investigated with a series of deciduous or semi-deciduous plants collected in September, 1964 just prior to the onset of leaf abscission.

The means of interest, expressed in terms of the ratios of the leaf concentrations of Cs-137 to the stem concentrations, are given in Table 12. It was found that the ratios varied from about 1.0 for blueberry and sagebrush, to about 3.3 for aspen and mountain mahogany. The ratio of unity may be explained on the basis of stem

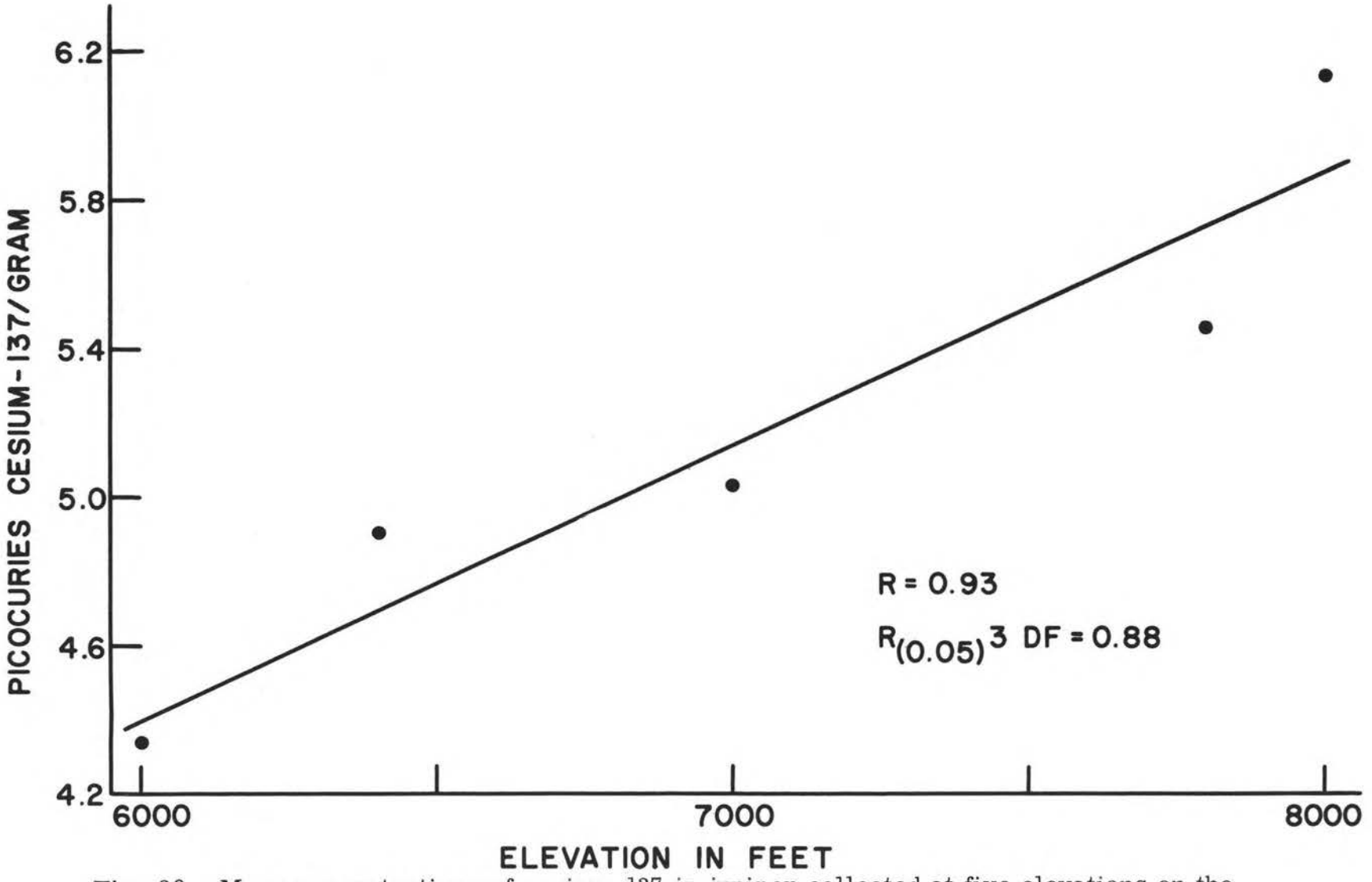

Fig. 30. Mean concentrations of cesium-137 in juniper collected at five elevations on the winter range between February and June, 1964.

Table 12. Mean ratios* of cesium-137 concentrations for leaves and stems of plants collected in September, 1964.

Species	Location	Location means	Species means
Bitterbrush	Sevenmile Creek	1.51	
"	Hewlett Gulch	1.44	1.48
Mountain mahogany	Sevenmile Creek	3.32	
" "	Hewlett Gulch	3.35	3.34
Sagebrush	Sevenmile Creek	1.08	1.08
Aspen	Laramie Meadow	2.39	
"	Little Beaver Creek	3.22	
"	Pennock Creek	4.19	
"	Manhattan	3.41	3.30
Bog birch	Nunn Creek	1.47	
" "	Little Beaver Creek	1.03	1.25
Blueberry	Laramie Meadow	1.18	
"	Zimmerman Bench	1.00	
"	Pennock Creek	0.93	
"	Crown Point	0.99	1.03
Willow	Nunn Creek	1.97	
"	Laramie Meadow	3.21	
"	Trap Park	2.17	
"	Little Beaver Creek	2.70	2.51

*Ratios in terms of $pcCs^{137}$/g leaf/$pcCs^{137}$/g stem.

longevity in the case of blueberry, while sagebrush leaves and stems appeared to have similar surface characteristics (Fig. 26) and thus similar fallout collection efficiencies. The higher ratio for mountain mahogany seemed reasonable because the leaf surface was extremely hairy with respect to that of the stems (Fig. 25). An obvious explanation for aspen is presently lacking.

It did appear that in general, leaves were higher in Cs-137 content than their respective stems. Thus, in certain range types, the degree of leaf abscission could affect the overall intake of Cs-137 by deer.

Deer

Cesium-137 analyses of muscle tissues of deer collected weekly from the study area between February 1962 and March 1965 indicated considerable overall variability. In this section, the probable sources of variation are discussed.

Time trends and range comparisons

The overall trends in muscle Cs-137 with time are represented by the monthly means in Fig. 31. Yearly differences were apparent, as well as seasonal fluctuations within years. Average vegetational levels of Cs-137 are also plotted in Fig. 31. The trends in deer and in vegetation were similar in both magnitude and direction.

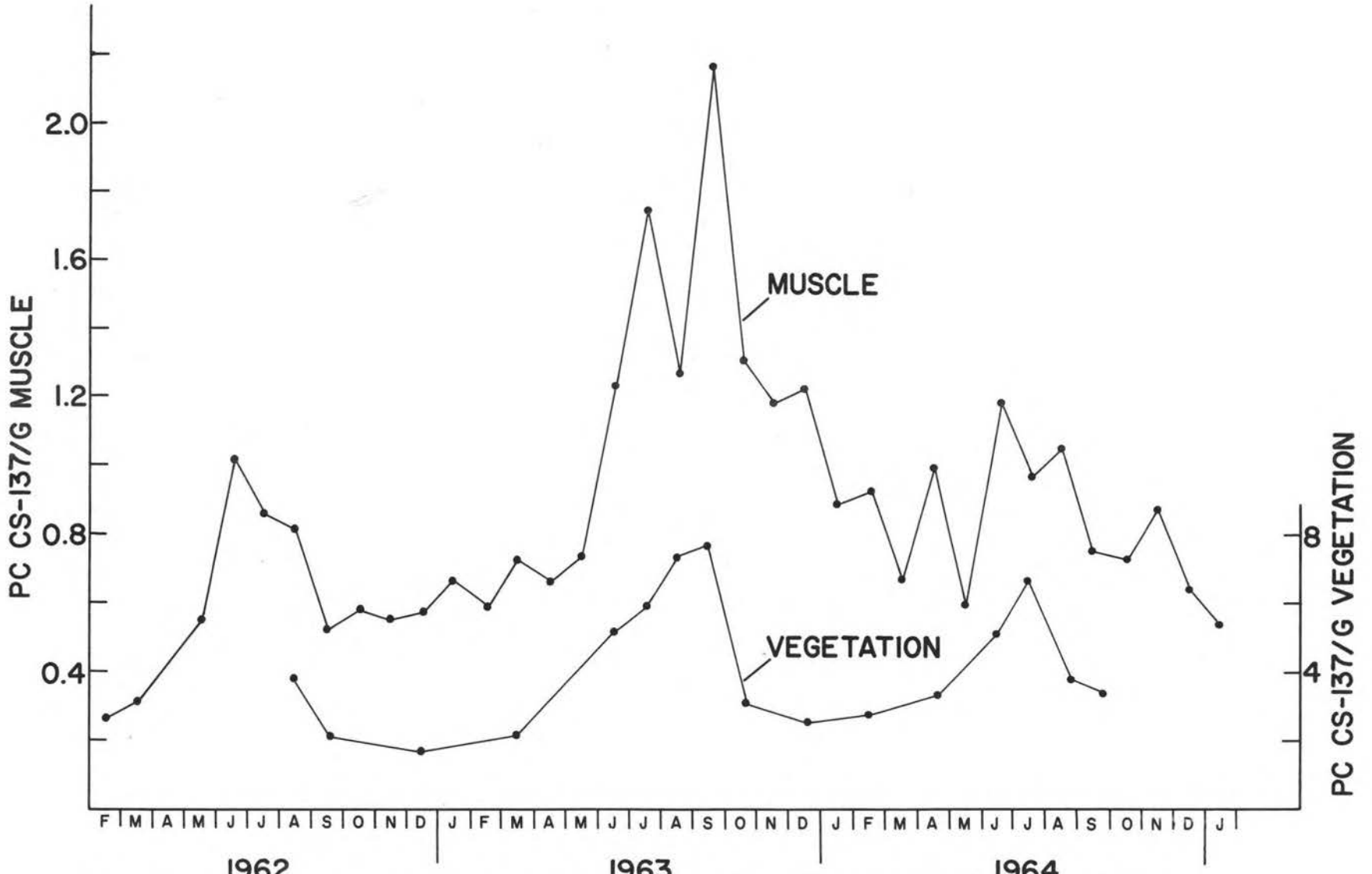

Fig. 31. Mean monthly concentrations of cesium-137 in deer muscle tissue and mean concentrations of cesium-137 in all species of vegetation sampled over all locations, February 1962 through January 1965.

Because the weekly fluctuations in muscle Cs-137 were large, especially during the summer, it was not certain whether the apparent seasonal variations were due to phenomena associated with seasons or to inherent variation in the population. It was obvious that the highest muscle Cs-137 levels usually occurred in deer which were collected on the summer range which was defined as all elevations above 8,500 feet. Therefore, data were stratified according to years and to summer and winter ranges. Means and the variance analysis of the data thus arranged are presented in Table 13.

The analysis indicated significant differences ($P < 0.01$) between years and between ranges. The highest Cs-137 concentrations were found in 1963, which was also the year of highest environmental fallout contamination (Figs. 20, 31). Generally higher levels of Cs-137 in summer range vegetation (Table 10) probably contributed to the higher concentrations in deer collected above 8,500 feet.

The significant interaction indicated in Table 13 between years and ranges was likely caused by the 1964 values. In 1962 and 1963, the summer range values were nearly twice those of the winter range. In 1964, however, the summer range mean only slightly exceeded the winter range mean. This finding was not inconsistent with the vegetative data because the difference in summer and winter range vegetation was also diminished in 1964 (Table 10).

Table 13. Analysis of variance of muscle cesium-137 in deer between years and between ranges[1].

Means (in terms of pc/Kg):

	1962	1963	1964	Means
Winter range	515	808	812	741
Summer range	814	1660	992	1176
Means	652	1127	872	

Analysis of Variance:

Source	DF	MS	F
Years	2	163,359	24.9**
Range	1	295,184	45.0**
Interaction	2	64,253	9.8**
Error	125	6,561	

[1]Ranges separated by the 8,500 foot elevational contour.
**Statistically significant at the 1 per cent level.

Influence of elevation

Another statistical approach considered with regard to muscle Cs-137 as affected by range was that of regression with elevation. This seemed plausible because range type is undoubtedly related to elevational phenomena.

Elevations of deer collections and muscle Cs-137 were compared by years using analysis of covariance methods (Table 14). The analysis indicated significant correlations between elevation and muscle Cs-137 for all years except 1965. The exception in 1965 was probably the result of no summer range data being available for the analysis. The total correlation which considered all years was still highly significant ($P < 0.01$).

The F tests indicated that: (1) the regression lines were different between years and therefore, prediction equations could not be applied outside the year of formulation; (2) the slopes of the regression lines were not zero; and (3) there were differences in the adjusted mean Cs-137 concentrations between years.

Correlation with vegetation

A relationship between Cs-137 in vegetation and in deer is qualitatively indicated in Fig. 31. These data are matched by months and plotted in Fig. 32. Only those data representing vegetation and deer collected from approximately the same

Table 14. Analysis of covariance of elevation (X) and muscle cesium-137 (Y) of deer by years.

Means, adjusted means, and correlations:

	Sample Size	$X^{(1)}$	$Y^{(2)}$	Adj. Y	Correlation Coefficient
1962	35	8329	652	603	0.52 **
1963	48	8002	1127	1129	0.63 **
1964	48	8013	872	872	0.35 *
1965	12	7108	669	809	0.30 N.S.

Correlations between, within, and through all years:

Source	DF	Correlation Coefficient
Between years	3	0.04 N.S.
Within years	138	0.49 **
Total	141	0.43 **

F Tests:

Hypothesis	DF Num.	DF Denom.	F	Conclusion about Hypothesis
Common regression line	3	135	5.15 **	reject
Within slope is zero	1	138	43.10 **	reject
Adjusted means of Y equal	3	138	13.24 **	reject

(1) In terms of feet above sea level.
(2) In terms of picocuries per kilogram.
** Statistically significant at the 1 per cent level.
* Statistically significant at the 5 per cent level.
N.S. Not statistically significant.

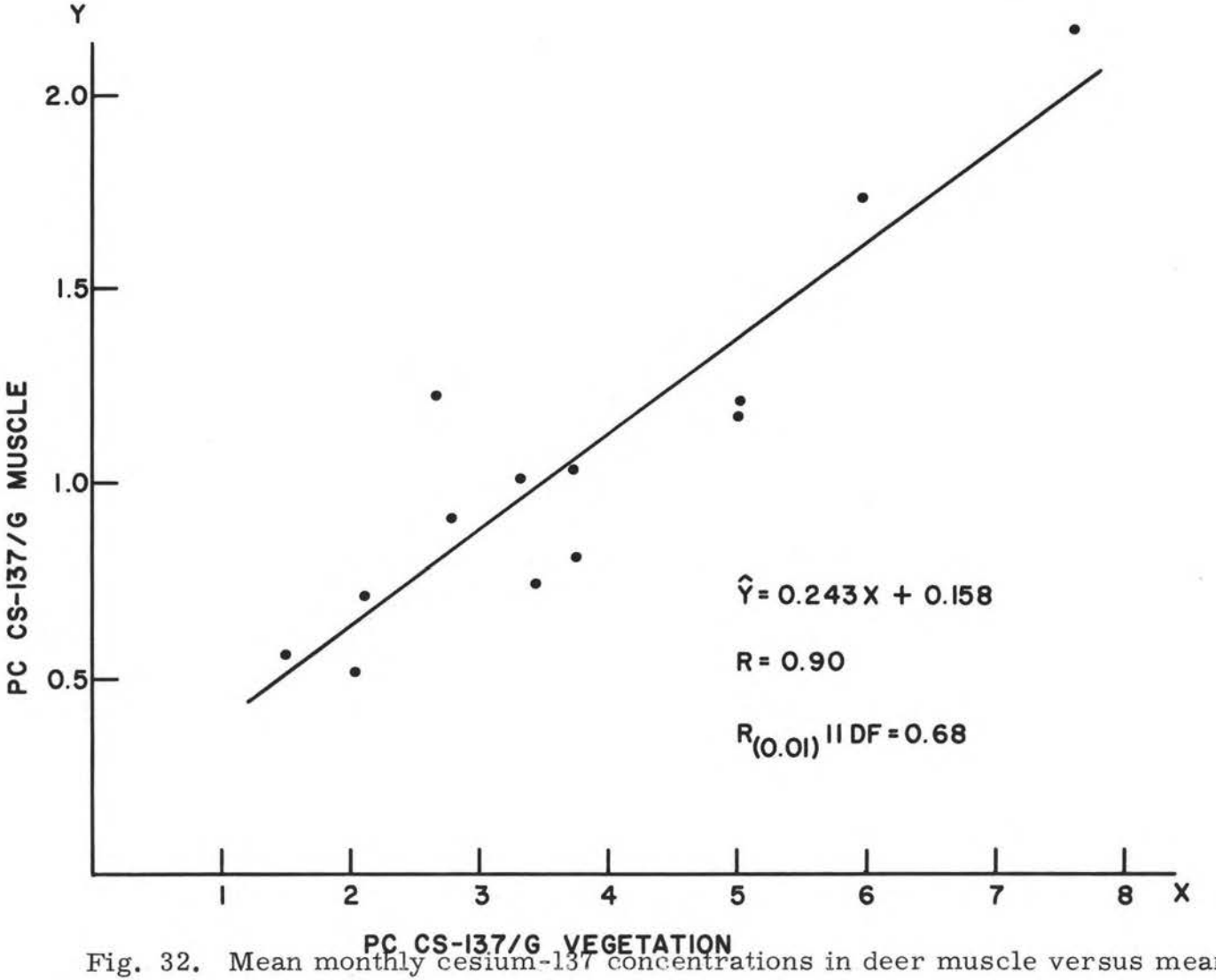

Fig. 32. Mean monthly cesium-137 concentrations in deer muscle versus mean cesium-137 concentrations of all species of vegetation sampled over all locations during 13 comparable months between August 1962 and September 1964.

elevations were used in the regression analysis. The analysis gave a correlation coefficient of 0.90 with 11 degrees of freedom, which is statistically significant at the 1 per cent level. The slope of the regression line indicated a muscle Cs-137 increase of 0.243 units per unit in vegetation. It is doubtful whether anything can be inferred from the Y intercept of 0.158 because many factors not considered could alter the slope or position of the regression line.

A series of 76 rumen samples were collected from deer sampled between May 1963 and March 1965 to compare Cs-137 levels with those of vegetation. The mean concentration in rumen samples during the period was 5.45 pc/g, contrasted to a mean of 4.85 pc/g in vegetation during the same period. This indicated that the species of vegetation chosen for sampling provided a fairly good representation of actual Cs-137 concentrations in the diet.

Rumen concentrations of Cs-137 are plotted against muscle concentrations in Fig. 33. The correlation coefficient of 0.56 with 74 degrees of freedom is significant at the 1 per cent level. The large amount of variation about the regression line was not surprising because muscle Cs-137 would reflect the average cesium consumption over one or two previous weeks. Food habits can easily vary from day to day and considerable variability existed between food species in Cs-137 levels (Table 11).

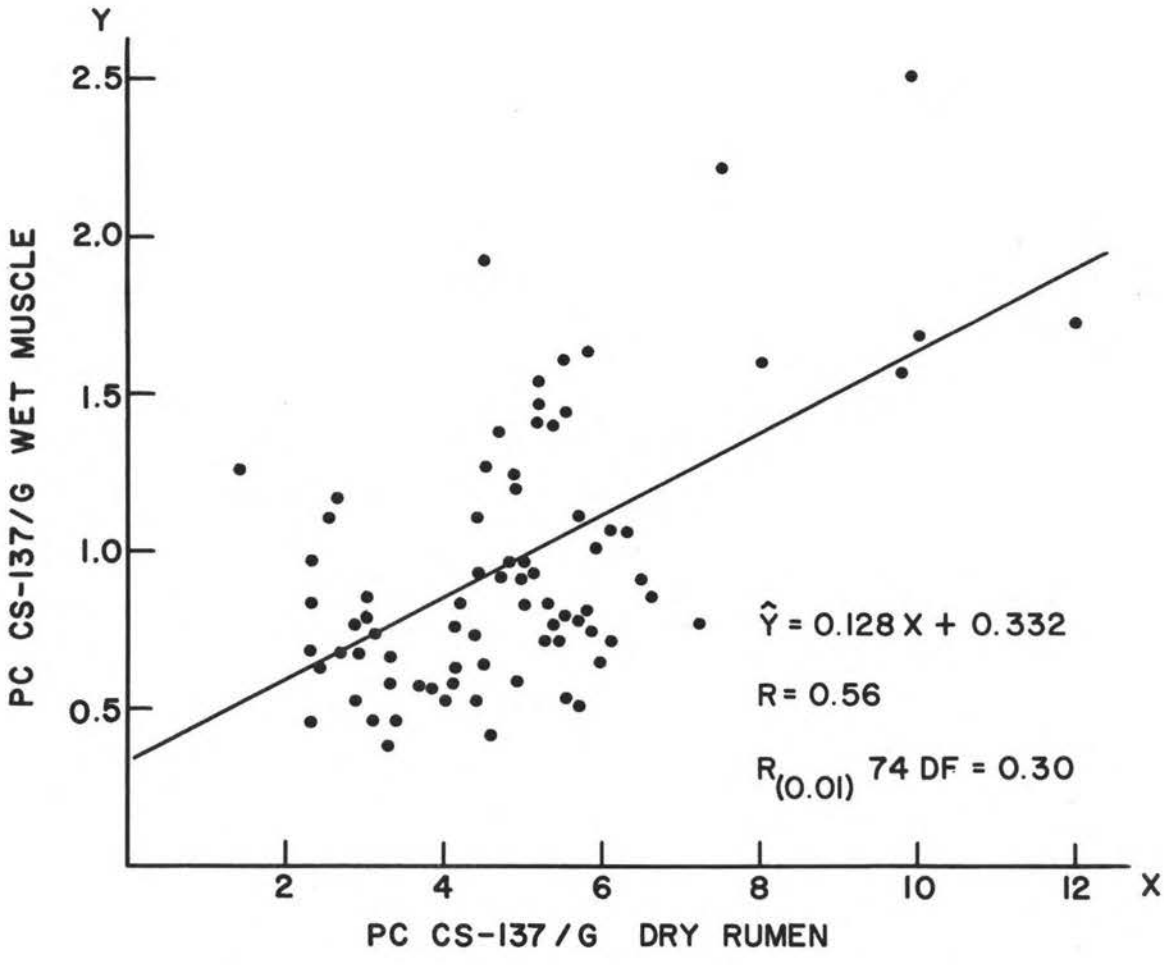

Fig. 33. Muscle tissue concentrations of cesium-137 versus concentrations in oven-dry rumen contents of deer collected between May, 1963 and March, 1965.

Because Cs-137 is absorbed and deposited in the body in relation to potassium (Langham and Anderson 1959), it was of interest to calculate the discrimination factor (D. F.) between diet and animal. The discrimination factor is defined as follows:

$$D.F. = \frac{(Cs\text{-}137/K)\ muscle}{(Cs\text{-}137/K)\ diet}$$

Using the slope of the regression line in Fig. 33, and the average potassium concentrations in muscle and in rumen contents, an estimated discrimination factor was calculated as follows:

$$D.F. = \frac{0.128/0.003}{1/0.021} = 0.9$$

The result of 0.9 is in fair agreement with the value of 2 given by Langham and Anderson (1959) for humans, if one considers the differences between ruminants and non-ruminants in cesium absorption from the gastro-intestinal tract. Ruminants may only absorb 50 per cent of the Cs-137 from the digestive tract (McClellan et al. 1961) while humans are likely to absorb 100 per cent (Richmond 1958).

Influence of age and sex

In order to study effects of age and sex, data were normalized to a comparable time period to remove effects due to years and ranges. This procedure allowed a reasonable number of observations within each category of sex and age. Age classes used for comparison were arbitrarily chosen as fawns (0-11 months),

yearlings (12-23 months), and adults (24 + months). The means of interest, the analysis, and a group of individual comparisons are presented in Table 15.

The analysis indicated that neither sex or age produced significant variation. The same result was indicated in a regression analysis which did not account for time-associated variations. It cannot be said with certainty, however, that sex or age have no affect on Cs-137 accumulation. These data merely indicate that any possible variation associated with age or sex was small in relation to other sources of variation which were manifest in the error term.

Pathways of cesium-137 entry

The existence of Y intercepts in Figs. 32, 33 indicated the possibility that significant quantities of Cs-137 could enter the animals by routes other than the ingestion of contaminated vegetation. Therefore, calculations were made for other possible pathways of entry where sufficient data were available. Results of the computations are summarized in Table 16.

The estimates presented are admittedly crude. Nevertheless, it was apparent that inhalation, the drinking of surface waters, and the ingestion of snow were minor sources of Cs-137 intake in comparison to the ingestion of forage. This conclusion would hold even if some of the estimated parameters were in error by a

Table 15. Analysis of variance of muscle cesium-137 in deer between age and sex[1].

Means (in terms of pc/Kg):

		Age class fawns	yearlings	adults	Sex Means
Males	n	11	20	31	
	mean	540	502	480	498
Females	n	10	12	48	
	mean	529	460	550	531
Age Means		535	487	522	

Analysis of Variance:

Source	DF	MS	F
Between cells	5	28,706	0.84 N.S.
Error	126	34,192	

Individual Comparisons:

Comparison	DF	MS	F
Males vs. females	1	27,558	0.81 N.S.
Fawns, yearlings vs. adults	1	9,015	0.26 N.S.
Fawns vs. yearlings	1	29,416	0.86 N.S.
Yearlings vs. adults	1	29,423	0.86 N.S.

(1) The effects of elevational ranges and years were removed by normalizing all data to a comparable period.

N.S. Not statistically significant.

Table 16. Comparison of mean estimated intake rates of cesium-137 by deer from January, 1963 to December, 1964 by various pathways.

Pathway	Medium	Mean Cs-137 conc. in medium	Exchange or consumption rate	Fraction reaching blood	Mean pc Cs-137 reaching blood per day
Inhalation	Air	0.1 pc/m^3[1]	20 m^3/day[2]	0.75[5]	1.5
Ingestion	Surface water	2 pc/liter[1]	2.5 liters/day[3]	1.0	5.0
Ingestion	Snow	50 pc/liter[1]	1.5 liters/day[3]	1.0	75
Ingestion	Vegetation	5 pc/gram[1]	800 grams/day[4]	0.5[6]	2,000

[1] Estimated from data gathered by author.

[2] The respiratory exchange rate of the "standard man" (U. S. Public Health Service 1960). The respiratory exchange rate for deer should not be greatly different than for man, because lung and body masses are very similar for the two species.

[3] Estimated from observations of captive deer and from the "standard man" (U. S. Public Health Service 1960).

[4] Estimated from data presented by Dietz et al. (1962).

[5] Estimated from U. S. Public Health Service (1960).

[6] Estimated from McClellan et al. (1961).

factor of two.

Other plausible sources of Cs-137 intake might include the ingestion of soil, the ingestion of hair from other deer, or the licking of hair and other objects. The author has observed such behavior in deer, but no quantitative data pertinent to the problem are available.

Chapter VI

DISCUSSION

Cesium-137 in the Environment

Air concentrations of Cs-137 followed nearly the same seasonal trends, including spring maxima and winter minima, as data collected in the state of Washington by Perkins et al. (1964). However, concentrations measured by Perkins and co-workers were only about one-half the concentrations measured in this study. The difference may have been caused by an elevational effect (Washington collection site is less than 1,000 feet above sea level) and/or by a latitude effect. The Cache la Poudre drainage falls near the middle of the latitudinal peak of maximum fallout deposition (Davis 1963).

Air concentrations of Cs-137 appeared very important from the standpoint of vegetative contamination. Many studies have demonstrated that contamination of foliage is primarily the result of direct deposition of air-borne material (Biddulph 1960; Menzel 1963). This should be particularly true in the case of cesium because this nuclide is practically unavailable to plants from the soil (Romney et al. 1957).

Data indicated that fallout deposition was influenced by precipitation as well as by concentrations of air-borne material.

Data gathered in New York City in 1958 by Welford and Collins (1960), indicated maximum Cs-137 deposition during the spring months of high rainfall. A similar pattern was noted in this study, with the exception of August and September, 1964. Cesium-137 deposition did not increase in proportion to rainfall during those months, probably because air concentrations were low during that period.

It is not entirely clear how the deposition of cesium with precipitation affects vegetational contamination. In the case of snow-borne debris, wind would normally prevent the transfer of cesium to upright plant parts. However, with regard to low-growing vegetation such as blueberry and grasses, snow would be in continual contact with the vegetation while melting and considerable transfer of radioactivity would occur.

The effect of rainfall is not known, since it can add as well as remove cesium from foliage (Middleton 1958, 1959). It does seem plausible, however, that light, misty rains would tend to deposit cesium on leaves, while intense rains would tend to wash or leach the contamination from the vegetation. Rainfall could also be quite important with regard to vegetational contamination by affecting soil moisture, which in turn would influence the transport of contaminated soil particles by wind. Because the amounts and characteristics of precipitation were highly variable within the study area, this was undoubtedly a factor which

complicated the general fallout patterns.

Studies on soil radioactivity revealed generally increasing fallout levels at the higher elevations. This was expected because of higher precipitation rates at the higher elevations. The studies also indicated, however, that soil radioactivity could vary greatly within elevations, because of complicating factors associated with local environments. For example, the kind and degree of vegetative cover, topography, soil characteristics, snow-drift patterns, and degree of soil disturbance could all influence the amount of Cs-137 in the surface layers of soil.

With regard to vegetation, it was found that summer range species were generally higher in Cs-137 than the winter range species. This was likely the result of two sets of phenomena. In the first place, soil data indicated that fallout generally increased with elevation. Therefore, summer range species were probably exposed to higher levels of contamination. In the second place, sampling of summer range vegetation was begun soon after the occurrence of peak levels of Cs-137 in air and in precipitation. Winter range species were not sampled during the summer months, but rather during and after leaf-fall, and during winter when cesium levels in air and precipitation were low.

Species of vegetation differed significantly with regard to cesium content. Davis (1963) found a similar range of differences

among plants collected in artic regions of Alaska. The differences could be explained satisfactorily on the basis of morphology, habitat, or longevity. The same groups of characteristics were used in comparing the differences among species in this study. The actual Cs-137 values reported by Davis were very similar to the values reported herein, even though his results were for specimens collected in 1960.

In nearly all species sampled, significant differences were found between collection locations. This was expected because the sampling plots were purposely chosen so as to represent a wide range of environments for each species. Sampling plots varied in elevation, surrounding vegetation, slope exposure and gradient, surrounding topography, or soil type. It was found that cesium activity in most of the species increased with elevation. Environmental features other than elevation were not quantitatively investigated.

It was found that leaves were generally higher in cesium than stems. This supported previous findings of Rediske and Hungate (1956) and Auerbach and Crossley (1958). The exceptions were sagebrush and blueberry. The leaf-stem comparisons seemed, for the most part, resonable when one considered differences in surface characteristics or longevity of the parts sampled. Other investigators, including Ljunggren (1960), Gorham (1963), and

Romney et al. (1963) have discussed differences among plant parts on the basis of surface area per unit weight or other surface characteristics such as hairiness or stickiness.

Factors Affecting Cesium-137 in Deer

The net accumulation of cesium-137 in deer would be a function of the difference between the intake rate and the excretion rate. The greater the intake rate with respect to the excretion rate, the greater would be the accumulation in tissues. This relationship is complicated by the fact that many factors can alter both intake and elimination (Eberhardt 1964).

An obvious factor affecting Cs-137 intake would be the forage consumption rate. This could be influenced by season, weather, physiological status, and other factors. Long et al. (1959) indicated that forage consumption by white-tailed deer followed a season trend with highs occuring in spring and fall, and a definite low in winter. Loveless (1963) found that deer movements and feeding activities were affected by a complex set of climatic and environmental circumstances. Increased forage consumption during the summer months could have contributed to the higher Cs-137 levels observed in animals collected above 8,500 feet. Unfortunately, data on food consumption in the population studied were lacking. This could only be investigated under controlled conditions, but food consumption under controlled conditions would

probably be different than consumption under natural conditions.

The concentration of Cs-137 in the diet would likewise affect the net intake. Comparisons between plant species revealed significant differences in Cs-137 levels. Therefore, food preference by deer would greatly influence Cs-137 intake (Eberhardt 1964). The species utilized by deer would depend upon species abundance, palatability, season, and environmental factors. Brown (1961) showed that the relative proportions of browse, grass, and forbs utilized by black-tailed deer varied with the time of year. Cowan (1947) postulated that as much as six inches of snow would alter the types of food consumed by mule deer in Alberta. The higher levels of Cs-137 in summer range vegetation were convincingly reflected by the proportionately higher levels in deer utilizing the summer range. Further, magnitudes of variation of Cs-137 in deer within ranges were comparable to the variations in contamination among the plant species. Variations were greater in both plants and deer from the summer range.

The type of food consumed would also affect the crude fibre levels in the diet (Dietz et al. 1962), which in turn would affect Cs-137 absorption and retention (Stewart 1964). During the periods of utilization by deer, the summer range species in general seemed more succulent and probably contained less fibre than the bare, woody stems of winter range browse species. Since crude

fibre and bulk tend to decrease cesium absorption and increase excretion, the winter range diet would appear less favorable to the accumulation of Cs-137 in deer. Measurements of total oven-dry weights of deer rumen contents by D. E. Medin and A. E. Anderson, Colorado Dept. of Game, Fish, and Parks, indicated higher average quantities of material in the rumen per body weight in animals collected on the winter range. Thus, the increased bulk in the winter range diet likely contributed to the lower Cs-137 levels in deer in winter.

It was observed that forage species varied considerably in potassium content. Increasing quantities of sodium or potassium in the diet can decrease cesium uptake and retention (Mraz 1959). Thus, potassium intake was probably another source which contributed to the variability of Cs-137 in muscle. However, dietary potassium may not have been a large source of variation because Wasserman and Comar (1961) found only a two-fold reduction in cesium retention with a nine-fold increase in dietary potassium with rats. Potassium analyses of 76 rumen samples indicated a maximum three-fold variation, which should not have caused large differences in cesium uptake.

It was found that the phenological stage of plant growth influenced vegetative contamination and thus Cs-137 intake by deer. For example, in the period of leafing out, bitterbrush and

mountain mahogany contamination increased two-fold. Later in the summer, plant Cs-137 levels usually decreased, due to lower air concentrations and continued vegetative growth. Because the leaves were higher in Cs-137 than stems in most of the species studied, the levels of activity in deciduous species generally declined abruptly during leaf abscission. Leaf abscission, however, may not significantly decrease cesium intake by deer when the ground is snow-free, because deer are known to eat dead leaves from the ground (Hill 1956; A. E. Anderson, personal communication).

Higher levels of Cs-137 in given plant species were generally associated with increasing elevation. Therefore, it would be possible for animals utilizing the same forage species during common time periods, but residing at different elevations, to vary with regard to cesium burdens. It was indeed found that Cs-137 levels in deer were highly correlated with the elevation of collection, even with no other factors being considered. Characteristics other than elevation, such as topography and surrounding vegetation could also cause differences in fallout contamination within species (Davis et al. 1963).

The physical and chemical form of ingested Cs-137 could influence its absorption into the blood. For example, if cesium atoms were incorporated into insoluble fallout particles

during a nuclear explosion, the material would probably pass through the digestive tract without being absorbed. Hydrochloric acid leaching studies on the ash of several plant species indicated that the higher the silicate content of the ash, the smaller was the fraction of cesium removed by the acid. Cesium was particularly resistant to acid leaching in the case of grasses. Nevertheless, the majority of fallout Cs-137 in environments far-removed from nuclear test sites is thought to be water soluble (Welford and Collins 1960; Davis 1963).

Cesium-137 can also enter animals by inhalation (Bair 1960). Thus, fluctuations in air concentrations of this nuclide would affect overall intake. However, calculations indicated that the amounts of Cs-137 which could enter deer by inhalation were insignificant in comparison to the amounts taken in by the ingestion of vegetation. This finding is in agreement with results presented by Langham (1960) and by Hvinden and Lillegraven (1961 a). Air concentrations must be considered in any case, because most vegetational contamination appears to result from direct deposition of air-borne materials (Biddulph 1960).

Calculations also indicated that the concentrations of Cs-137 in surface waters were insufficient to contribute significantly to the total intake by deer. This would be expected because Osburn (1963) and others have demonstrated that soil

and vegetation rapidly remove fallout contamination from surface water.

Because deer are known to eat snow (Cowan 1945; D. E. Medin, personal communication) and since snow generally contained much more Cs-137 per liter of melt-water than surface water, this source of contamination was considered. However, calculations indicated this pathway likewise to be of minor importance in comparison to the ingestion of vegetation.

Cesium retention may also be related to age or physiological status (Comar et al. 1962). The data presented herein, however, were confounded with too many other variables to detect any possible effects due to sex or age. It is now apparent that this could only be investigated properly in controlled experiments. The author is unaware of any well-founded generalities concerning the effect of age or sex. The literature which was found on the subject appeared contradictory and inconclusive. It was concluded in this study, however, that sex and age were insignificant in comparison to the other sources of variability.

If the cesium excretion half-time in deer is approximately 2-4 days as in other ruminants (Cragle 1961; Ekman 1961), then metabolic equilibrium should be established in a matter of a week or so. Under equilibrium conditions, Cs-137 body burdens would be proportional to the intake of the nuclide

(Szepke 1962). Further, since cesium is taken up from the soil by plants very slowly (Romney et al. 1957) and since vegetation loses cesium by several mechanisms, foliage contamination would likely be nearly proportional to fallout levels in air. Thus, one would expect Cs-137 burdens in deer to be proportional to air concentrations. Such was not the case in this study when air concentrations of Cs-137 were compared directly to deer concentrations. For example, mean air concentrations decreased by a factor of 1.9 from 1963 to 1964 while concentrations in deer (and in vegetation) only decreased by a factor of 1.3. It was concluded, therefore, that certain types of vegetation retained Cs-137 for a sufficient length of time to prevent strict equilibrium with air concentrations. Vegetative data indicated that persistent and non-deciduous species retained Cs-137 much longer than short-lived foliage. Thus, it would be difficult to predict Cs-137 levels in deer solely from air concentrations.

Chapter VII

SUMMARY AND CONCLUSIONS

This investigation was concerned with factors influencing the accumulation of fallout cesium-137 in a wild population of mule deer, Odocoileus hemionus, in the Cache la Poudre drainage of north-central Colorado. Deer were collected weekly from a distribution of locations within the study area and muscle tissues were assayed for Cs-137. In addition, air, precipitation, soils, and twelve species of forage plants were periodically sampled in the study area and subsequently assayed for Cs-137 or gross fallout radioactivity. Variations in the Cs-137 burdens in deer were then related to environmental levels of fallout contamination and to physiological, behavioral, and ecological factors.

Air concentrations of Cs-137 during the study were maximal in 1963. Concentrations were significantly higher during the spring and early summer months of each year. Atmospheric levels of Cs-137 were sufficiently high to cause significant contamination of vegetation but not sufficiently high to contribute noticeably to intake by deer from direct inhalation.

Maximum deposition of Cs-137 by precipitation in 1964 occurred during April, May, and June. Quantities of rainfall and air concentrations of cesium were also high during those months.

It was concluded that both precipitation and fallout levels in air must be considered in making predictions of fallout deposition. Measureable quantities of fallout were transported by dust, pollens, and other air-borne debris, particularly during dry, windy periods. Significant quantities of fallout of recent origin were deposited in an open, wet collector during a two week period of no rainfall. Deposition of fallout by rain was variable and inconsistent between the five sampling locations in the study area. Precipitation contained much higher concentrations of Cs-137 than surface waters, but the concentrations were insufficient to contribute significantly to total cesium intake by deer if ingested.

The major portion of Cs-137 in soils was located in the 0-1 inch layer. Levels of fallout radioactivity in soils generally increased with elevation. This observation was attributed primarily to the higher average precipitation rates at the higher elevations.

Maximum vegetational contamination during the study was observed in 1963. Summer range plant species generally contained higher levels of Cs-137 between June and September than the winter range species between October and May. There were a few cases, however, where winter range species were higher than some of the summer range specimens. Statistically significant differences between species growing on the same plots were found. It was concluded that longevity, phenology, gross morphology, and foliage

surface characteristics were primarily responsible for the variations observed. The more persistant the plant part, the greater the proportion of leaves to stems, the more mat-like the structure, and the greater the surface area per unit weight (or hairiness), the higher was the cesium content.

Significant differences in the Cs-137 content of given species between locations were encountered. In general, the location effect seemed most closely associated with elevation because cesium contamination usually increased with elevation. The actual mechanisms causing increased vegetative radioactivity with elevation probably included higher air concentrations, more precipitation, and higher average wind velocities.

With the exceptions of sagebrush and blueberry, leaves were higher than stems in cesium content. This observation was attributed mostly to differences in surface characteristics between leaves and stems. Translocation of absorbed cesium to the rapidly growing leaves probably also contributed to the differences observed.

The levels of cesium-137 in deer were influenced by a complex group of variables, most of which were not independent of other phenomena. Variations in muscle Cs-137 appeared dependent upon time, elevation, food habits, climatic variables, and general fallout levels during the study. Possible variations caused by age, sex, inhalation of Cs-137, or ingestion of the nuclide with water or

snow, appeared insignificant.

As with air and vegetation, maximum levels of Cs-137 in deer were observed in 1963. Maximum levels within years occurred during the summer months in animals collected above 8,500 feet elevation. Increased variability between individuals also occurred in the group sampled from the summer range. This was likely caused by the larger and more complex flora of the summer range, and a wider range of fallout levels. Nearly all regression analyses of muscle Cs-137 versus elevation of collection indicated highly significant correlations. The slopes of the regression lines were different between years, however, indicating that the elevational effect was more pronounced at certain times than at others.

All evidence examined indicated a high degree of correlation between cesium levels in vegetation and the levels in deer. It was concluded that the degree of foliage contamination and food habits were the most important factors contributing to the cesium burdens in deer. Thus, factors affecting forage contamination would likewise be important. Cesium-137 assay of rumen samples indicated concentrations similar to those measured in native plants. A Cs-137/K discrimination factor between the diet and muscle was estimated as 0.9 from the rumen samples.

Variance analyses indicated no significant differences between age groups or sexes in Cs-137 burdens. However, since

many other sources of variability were inherent in the statistical analysis, it can only be concluded that possible differences between sexes or age groups were too small to be detected.

BIBLIOGRAPHY

Anderson, E. C. 1958. Radioactivity of people and milk: 1957 Science 128: 882-886.

Anderson, E. C., R. L. Schuch, W. R. Fisher, and W. Langham. 1957. Radioactivity of people and foods. Science 125: 1273-1278.

Aronow, S., F. R. Ervin, and V. W. Sidel (ed.). 1963. The fallen sky--Medical consequences of thermonuclear war. Hill and Wang, New York. 134 p.

Auerbach, S. I. and D. A. Crossley, Jr. 1958. Strontium-90 and cesium-137 uptake by vegetation under natural conditions. 2nd Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 18: 494-499.

Bair, W. J. 1960. Radioisotope toxicity: From pulmonary absorption, p. 431-448. In R. S. Caldecott and L. A. Snyder (ed.) Radioisotopes in the biosphere. Univ. of Minnesota Printing Dept., Minneapolis.

Bertrand, G. and D. Bertrand. 1949. Existence normale du cesium chez les animaux. Compt. Rend. Acad. Sci. 229: 609-610.

Biddulph, O. 1960. Radioisotopes in plants: Foliar entry and distribution, p. 73-85. In R. S. Caldecott and L. A. Snyder (ed.) Radioisotopes in the biosphere. Univ. of. Minnesota Printing Dept., Minneapolis.

Bjornerstedt, R. and K. Edvarson. 1963. Physics, chemistry, and meteorology of fallout. Ann. Rev. Nucl. Sci. 13: 505-534.

Blatz, H. 1964. Introduction to radiological health. McGraw-Hill Book Co., New York. 315 p.

Bormann, F. H., P. R. Shafer, and D. Mulcahy. 1958. Fallout on the vegetation of New England during the 1957 atom bomb test series. Ecology 39: 376-378.

Bowes, A. L. 1958. Ecological analysis of mule deer winter range, Cache la Poudre Canyon, Colorado. M. S. Thesis. Colorado State Univ., Fort Collins. 189 p.

Brown, E. R. 1961. The black-tailed deer of western Washington. Washington State Game Dept. Biol. Bull. 13. 124 p.

Chandler, R. P. and S. Wieder. 1963. Radionuclides in the northwestern Alaska food chain, 1959-1961--A review. Radiol. Health Data 4:317-324.

Cline, J. F. 1960. Potassium, cesium-137 and rubidium-86 relationships in plant uptake, soil diffusion rates and irrigation practices. Nucl. Sci. Abstr. 14:22714.

Cline, J. F. and F. P. Hungate. 1960. Accumulation of potassium, cesium-137, and rubidium-86 in bean plants grown in nutrient solutions. Plant Physiol. 35:826-829.

Comar, C. L. 1963. Fallout from nuclear tests. U. S. Atomic Energy Commission, Div. Tech. Information Extension, Oak Ridge, Tennessee. 39 p.

Comar, C. L., B. F. Trum, U. S. G. Kuhn, III, R.H. Wasserman, M. M. Nold, and J. C. Schooley. 1957. Thyroid radioactivity after nuclear weapons tests. Science. 126:16-18.

Comar, C. L., R. H. Wasserman, F. W. Lengemann, and J. C. Thompson, Jr. 1962. Fallout and the food chain: A status review, p. 426-456. In Radioactive fallout from nuclear weapons tests. TID-7632. U. S. Atomic Energy Commission, Div. Tech. Information, Washington, D. C.

Cowan, I. M. 1945. The ecological relationships of the food of the Columbian black-tailed deer in the coast forest region of southern Vancouver Island, British Columbia. Ecol. Monographs 15:109-139.

Cowan, I.M. 1947. Range competition between mule deer, bighorn sheep and elk in Jasper Park, Alberta. N. Am. Wildlife Conf., Trans. 12:223-227.

Cragle, R. G. 1961. Uptake and excretion of cesium-134 and potassium-42 in lactating dairy cows. J. Dairy Sci. 44:352-357.

Davis, J. J. 1958. Dispersion of radioactive materials by streams. J. Am. Water Works Assoc. 50: 1505-1515.

Davis, J. J. 1963. Cesium and its relationships to potassium in ecology, p. 539-556. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Davis, J. J., W. C. Hanson, and D. G. Watson. 1963. Some effects of environmental factors upon accumulation of world-wide fallout in natural populations, p. 35-38. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Dietz, D. R., R. H. Udall, and L. E. Yeager. 1962. Chemical composition and digestibility by mule deer of selected forage species, Cache la Poudre Range, Colorado. Colorado Game and Fish Dept. Tech. Publ. 14. 89 p.

Dixon, W. J. and F. J. Massey, Jr. 1957. Introduction to statistical analysis. 2nd ed. McGraw-Hill Book Co., Inc., New York. 488 p.

Eberhardt, L. L. 1964. Variability of the strontium-90 and cesium-137 burden of native plants and animals. Nature 204: 238-240.

Eisenbud, M. 1963. Environmental radioactivity. McGraw-Hill Book Co., Inc., New York. 430 p.

Ekman, L. 1961. Distribution and excretion of radio-cesium in goats, pigs and hens. Acta Vet. Scand. 2: Supp. 4. 83 p.

Finston, H. L. and M. T. Kinsley. 1961. The radiochemistry of cesium. Nat. Acad. Sci., Nucl. Sci. Ser. NAS-NS-3035. U. S. Dept. of Commerce, Office of Tech. Services, Washington, D. C.

Fowler, E. B. and C. W. Christenson. 1959. Factors affecting uptake of radioactive cesium by lettuce, grass, and alfalfa. J. Agr. Food Chem. 7: 847-849.

Fowler, J. M. 1960. Fallout--A study of superbombs, strontium-90 and survival. Basic Books, Inc., New York. 235 p.

Fredriksson, L., B. Eriksson, B. Rasmuson, B. Gahne, K. Edvarson, and K. Low. 1958. Studies on soil-plant-animal interrelationships with respect to fission products. 2nd Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 18: 449-470.

Garner, R. J. 1963. Environmental contamination and grazing animals. Health Phys. 9: 597-605.

Gorham, E. 1959. A comparison of lower and higher plants as accumulators of radioactive fallout. Can. J. Botany 37: 327-329.

Gorham, E. 1963. A comparison of natural and fallout radioactivity in Ontario soils under pine. Can. J. Botany 41: 1309-1318.

Graham, E. R. 1958. Uptake of waste Sr-90 and Cs-137 by soil and vegetation. Soil Sci. 86: 91-97.

Greenfield, S. M. 1957. Rain scavenging of radioactive particulate matter from the atmosphere. J. Meteorol. 14: 115-125.

Gustafson, P. F., S. S. Brar, and M. A. Kerrigan. 1961. Appearance of a spring maximum in nuclear test debris in 1960. Science 133: 460-461.

Hanson, W. C. 1960. Accumulation of radioisotopes from fallout by terrestrial animals at Hanford, Washington. Northwest Sci. 34: 89-98.

Hardy, E. P., Jr. and L. T. Alexander. 1962. The relationship between rainfall and strontium-90 deposition in Clallam County, Washington, p. 287-298. In Radioactive fallout from nuclear weapons tests. TID-7632. U. S. Atomic Energy Commission, Div. Tech. Information, Washington, D. C.

Harrington, H. D. 1954. Manual of the plants of Colorado. Sage Books, Denver. 666 p.

Healy, J. W. and J. J. Fuquay. 1958. Wind pickup of radioactive particles from the ground. 2nd Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 18: 291-295.

Hill, R. R. 1956. Forage, food habits, and range management of the mule deer, p. 393-414. In W. P. Taylor (ed.) The deer of North America. Stackpole Co., Harrisburg, Penn.

Hinzpeter, M. 1958. The influence of meteorological parameters on the propagation of radioactive fission products in the biosphere. 2nd Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 18: 284-290.

Holland, J. Z. 1963. Distribution and phsyical-chemical nature of fallout. Federation Proc. 22: 1390-1397.

Hood, S. L. and C. L. Comar. 1953. Metabolism of cesium-137 in rats and farm animals. Arch. Biochem. Biophys. 45: 423-433.

Hunter, H. F. and N. E. Ballou. 1951. Fission product decay rates. Nucleonics 9: C2-C7.

Hvinden, T. and A. Lillegraven. 1961a. Caesium-137 in air, precipitation, drinking water, milk, and beef in Norway during 1959 and 1960. Nature 190: 402-404.

Hvinden, T. and A. Lillegraven. 1961b. Caesium-137 and strontium-90 in precipitation, soil, and animals in Norway. Nature 192: 1144-1146.

Ilin, D. I. and Yu. I. Moskalev. 1957. On the problem of the metabolic exchange of cesium, strontium, and a mixture of beta-emitters in cows. Soviet J. At. Energy 2: 183-188. Cited by Davis, J. J. 1963. Cesium and its relationships to potassium in ecology, p. 539-556. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Itagaki, K. and S. Koenuma. 1962. Altitude distribution of fallout contained in rain and snow. J. Geophys. Res. 67: 3927-3933.

Katcoff, S. 1958. Fission product yeilds from U, Th, and Pu. Nucleonics 16: 78-85.

Kimber, G. and A. Booth. 1958. Radioactivity of plant material collected after the accident at Windscale No. 1 pile. Nature 181: 1391-1392.

Klement, A. W., Jr. 1959. A review of potential radionuclides produced in weapons detonations. WASH-1024. U. S. Atomic Energy Commission, Div. Biology and Medicine, Washington, D. C. 102 p.

Kornberg, H. A. 1958. Radiation biology as a supporting function for atomic energy installations. 2nd Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 18: 329-335.

Kornberg, H. A. 1961. The use of element-pairs in radiation hazard assessment. Health Phys. 6: 46-62.

Langham, W. H. 1960. Radioisotope absorption and methods of elimination: Relative significance of portals of entry, p. 489-513. In R. S. Caldecott and L. A. Snyder (ed.) Radioisotopes in the biosphere. Univ. of Minnesota Printing Dept., Minneapolis.

Langham, W. H. and E. C. Anderson. 1959. Cs-137 biospheric contamination from nuclear weapons tests. Health Phys. 2: 30-48.

Larson, K. H. 1963. Continental close-in fallout: its history, measurements and characteristics, p. 19-25. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Libby, W. F. 1956a. Radioactive strontium fallout. Nat. Acad. Sci. U. S., Proc. 42: 365-390.

Libby, W. F. 1956b. Current research findings on radioactive fallout. Nat. Acad. Sci. U. S., Proc. 42: 945-962.

Lidén, K. 1961. Cesium-137 burdens in Swedish Laplanders and reindeer. Acta Radiol. 56: 237-240.

Lindberg, R. G., E. M. Romney, J. H. Olafson, and K. H. Larson. 1959. Factors influencing the biological fate and persistence of radioactive fallout. WT-1177. Univ. of Calif. at Los Angeles, Dept. and Lab. of Nuclear Medicine and Radiation Biology, Los Angeles. 78 p.

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

Long, T. A., R. L. Cowan, C. W. Wolfe, T. Rader, and R. W. Swift. 1959. Effect of seasonal feed restriction on antler development of white-tailed deer. Pennsylvania Agr. Exp. Sta. Prog. Rept. 209. 11 p.

Loveless, C. M. 1963. Ecological characteristics of a selected mule deer winter range. Ph. D. Thesis. Colorado State Univ., Fort Collins. 318 p.

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

Low, K. and K. Edvarson. 1960. Content of caesium-137 and (zirconium + niobium)-95 in Swedish soils. Nature 187: 736-738.

Machta, L. 1958. Discussion of meteorological factors and fallout distribution, p. 310-325. In Environmental contamination from weapon tests. HASL-42. U. S. Atomic Energy Commission, Health and Safety Laboratory, New York.

Machta, L. and R. J. List. 1958. Meteorological interpretation of strontium-90 fallout, p. 327-338. In Environmental contamination from weapon tests. HASL-42. U. S. Atomic Energy Commission, Health and Safety Laboratory, New York.

Marr, J. W. 1961. Ecosystems of the east slope of the front range in Colorado. Univ. of Colorado Press, Boulder. 134 p.

Martin, W. E. 1963. Notes on the deposition of fallout in relation to topography and local meteorological conditions. Nucl. Sci. Abstr. 17: 29128

McClellan, R. O., J. R. McKenney, and L. K. Bustad. 1961. Metabolism and dosimetry of cesium-137 in rams. Nucl. Sci. Abstr. 15: 27354.

Medin, D. E. 1960. The Cache la Poudre deer herd--A historical review, p. 65-81. In Federal Aid Division quarterly report, October, 1960. Colorado Game, Fish, and Parks Dept., Denver.

Medin, D. E., A. E. Anderson, and C. M. Loveless. 1962. Climatic environment, p. 169-185. In Federal Aid Division quarterly report, pt. 2, July, 1962. Colorado Game, Fish, and Parks Dept., Denver.

Menzel, R. G. 1954. Competitive uptake by plants of potassium, rubidium, cesium, and calcium, strontium, barium from soils. Soil Sci. 77: 419-425.

Menzel, R. G. 1963. Factors influencing the biological availability of radionuclides for plants. Federation Proc. 22: 1398-1401.

Middleton, L. J. 1958. Absorption and translocation of strontium and caesium by plants from foliar sprays. Nature 181: 1300-1303.

Middleton, L. J. 1959. Radioactive strontium and caesium in the edible parts of crop plants after foliar contamination. Intern. J. Radiation Biol. 1: 387-402.

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

Miller, C. F. 1963. Fallout nuclide solubility, foliage contamination, and plant part uptake contour ratios. SRI Proj. No. IMU-4021. Stanford Research Inst., Menlo Park, Calif. 30 p.

Morgan, A. and D. G. Stanbury. 1961. The contamination of rivers with fission products from fallout. Health Phys. 5: 101-107.

Morris, R. L. 1958. The effect of radioactive rains on surface water supplies. Water Sewage Works 105: 92-94.

Mraz, F. R. 1959. Influence of dietary potassium and sodium on cesium-134 and potassium-42 excretion in sheep. J. Nutr. 68:655-662.

Mraz, F. R., M. Le Noir, J. J. Pinajian, and H. Patrick. 1957. Influence of potassium and sodium on uptake and retention of cesium-134 in rats. Arch. Biochem. Biophys. 66: 177-182.

Mraz, F. R. and H. Patrick. 1957. Some factors influencing the excretory pattern of cesium-134 in rats. Arch. Biochem. Biophys. 71: 121-125.

National Academy of Sciences. 1960. The biological effects of atomic radiation; summary reports. National Academy of Sciences-National Research Council, Washington. 90 p.

Neel, J. W. and K. H. Larson. 1963. Biological availability of strontium-90 to small native animals in fallout patterns from the Nevada test site, p. 45-49. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Nishita, H., B. W. Kowalewsky, A. J. Steen, and K. H. Larson. 1956. Fixation and extractability of fission products contaminating various soils and clays: I. Sr-90, Y-91, Ru-106, Cs-137, and Ce-144. Soil Sci. 81: 317-326.

Nishita, H., A. J. Steen, and K. H. Larson. 1958. Release of Sr-90 and Cs-137 from vina loam upon prolonged cropping. Soil Sci. 86: 195-201.

Odum, E. P. 1959. Fundamentals of ecology. W. B. Saunders Co., Philadelphia. 546 p.

Osburn, W. S., Jr. 1963. The dynamics of fallout distribution in a Colorado alpine tundra snow accumulation ecosystem, p. 51-71. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Palmer, H. E., W. C. Hanson, B. I. Griffin, and W. C. Roesch. 1963. Cesium-137 in Alaskan eskimos. Science 142: 64-66.

Pendleton, R. C. and R. L. Uhler. 1960. Accumulation of caesium-137 by plants grown in simulated pond, wet meadow and irrigated field environments. Nature 185: 707-708.

Perkins, R. W., J. M. Nielsen, and C. W. Thomas. 1964. Air concentrations of twelve radionuclides from 1962 through mid-1964. Science 146: 762-764.

Pierce, C. M. 1963. The effects of radiation and radioisotopes on the life processes: An annotated bibliography. TID-3098. U. S. Atomic Energy Commission, Div. Tech. Information, Washington, D. C. 1, 479 p.

Rediske, J. H. and F. P. Hungate. 1956. The absorption of fission products by plants. Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 13: 354-356.

Richmond, C. R. 1958. Retention and excretion of radionuclides of the alkali metals by five mammalian species. Nucl. Sci. Abstr. 12: 11284.

Rickard, W. H. 1963. Vegetational analyses in a creosote bush community and their radioecologic implications, p. 39-44. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Rickard, W. H., A. D. Wiggins, and J. K. Fremstad. 1963. Caesium-137 in dried milk products in relation to phytoclimatic zones. Nature 197: 197-198.

Ritche, J. C. 1962. Distribution of fallout cesium-137 in litter, humus, and surface soil layers under natural vegetation in the Great Smoky Mountains. M. S. Thesis. Univ. Tennessee, Knoxville. 47 p.

Robinette, W. L., D. A. Jones, G. Rogers, and J. S. Gashwiler. 1957. Notes on tooth development and wear for rocky mountain mule deer. J. Wildlife Management 21: 134-153.

Romney, E. M., R. G. Lindberg, H. A. Hawthorne, B. G. Bystrom, and K. H. Larson. 1963. Contamination of plant foliage with radioactive fallout. Ecology 44: 343-349.

Romney, E. M., J. W. Neel, H. Nishita, J. H. Olafson, and K. H. Larson. 1957. Plant uptake of Sr-90, Y-91, Ru-106, Cs-137, and Ce-144 from soils. Soil Sci. 83: 369-376.

Schonfeld, T., K. Liebscher, F. Karl, and C. Friedmann. 1960. Radioactive fission products in lungs. Nature 185: 192-193.

Setter, L. R., J. E. Regnier, and E. A. Diephaus. 1959. Radioactivity of surface waters in the United States. J. Am. Water Works Assoc. 51: 1377-1392.

Snedecor, G. W. 1956. Statistical methods. Iowa State Univ. Press, Ames. 534 p.

Sommermeyer, K. and K. J. Godt. 1958. The uptake of radioactivity directly through leaves and indirectly via the roots of plants. 2nd Intern. Conf. on the Peaceful Uses of Atomic Energy, Proc. 18: 500-502.

Sparrow, A. H. and L. A. Schairer. 1962. Plant radiosensitivities and potential damage from fallout radiation. Radiation Res. 16: 584.

Stewart, H. F. 1964. Factors influencing the levels of cesium-137 secreted in milk. Ph.D. Thesis. Colorado State Univ., Fort Collins. 124 p.

Stewart, N. G., R. G. D. Osmond, R. N. Crooks, and E. M. Fisher. 1958. The world-wide deposition of long-lived fission products from nuclear test explosions, p. 231-248. In Environmental contamination from weapon tests. HASL-42. U. S. Atomic Energy Commission, Health and Safety Laboratory, New York.

Straub, C. P., G. K. Murthy, and J. E. Campbell. 1961. Radionuclides in foods. J. Am. Dietet. Assoc. 38: 15-21.

Szepke, R. 1962. An estimation of radiation exposure from fallout. Health Phys. 8: 81-89.

U. S. Atomic Energy Commission. 1958. Fallout mechanism, p. 136. In Environmental contamination from weapon tests. HASL-42. U. S. Atomic Energy Commission, Health and Safety Laboratory, New York.

U. S. Public Health Service. Division of Radiological Health. 1960. Radiological health handbook. Washington, D. C. 468 p.

Van Dilla, M. A., G. R. Farmer, and V. R. Bohman. 1961. Fallout radioactivity in cattle and its effects. Science 133: 1075-1077.

Ward, G. M. and J. E. Johnson. 1965. The cesium-137 content of beef from dairy and feed-lot cattle. Health Phys. 11: 95-100.

Wasserman, R. H. and C. L. Comar. 1961. The influence of dietary potassium on the retention of chronically ingested cesium-137 in the rat. Radiation Res. 15: 70-77.

Wasserman, R. H., C. L. Comar, and A. R. Twardock. 1961. Metabolic behaviour of Cs-137-Ba-137m in the lactating goat. Intern. J. Radiation Biol. 4: 299-310.

Welford, G. A. and W. R. Collins, Jr. 1960. Fallout in New York City during 1958. Science 131: 1711-1715.

White, M. R. and H. B. Jones. 1956. Uptake of iodine-131 in human and bovine thyroids following detonation of nuclear weapons, p. 161-164. In The shorter-term biological hazards of a fallout field, symposium. U. S. Atomic Energy Commission, Dept. of Defense, Washington, D. C.

Wijk, H. F. Van and R. Braams. 1960. Incorporation of caesium-137 from nuclear debris into the biosphere. Nature 188: 951-952.

Witherspoon, J. P., Jr. 1963. Cycling of cesium-134 in white oak trees on sites of contrasting soil type and moisture, p. 127-132. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Wolfe, J. N. 1963. Impact of atomic energy on the environment and environmental science, p. 1-2. In V. Schultz and A. W. Klement, Jr. (ed.) Radioecology. Reinhold Publ. Corp., New York.

Woodwell, G. M. 1962. Effects of ionizing radiation on terrestrial ecosystems. Science 138: 572-577.

APPENDIX

Table 1. Cesium-137 concentrations in air collected at Buckhorn Mountain, October 1962 through February 1965.

Sample No.	Mean Date of Collection	Cubic Meters Sampled	Picocuries per Hundred Cubic Meters*
12B	10- 2-62	1532	3.65
13B	10- 9-62	1612	4.13
14B	10-16-62	1710	3.90
15B	10-23-62	1667	2.95
16B	10-30-62	1667	3.05
17B	11- 6-62	1650	5.92
18B	11-14-62	1888	3.70
19B	11-21-62	1112	4.31
20B	11-27-62	1518	4.54
21B	12- 4-62	1650	4.68
22B	12-11-62	1770	3.01
23B	12-18-62	1480	4.94
24B	12-25-62	1871	8.51
25B	1- 1-63	1695	6.87
26B	1- 8-63	1750	7.52
27B	1-15-63	1650	4.92
28B	1-22-63	1602	7.81
29B	1-28-63	1467	15.63
30B	2- 5-63	1710	6.67
31B	2-11-63	1728	15.41
32B	2-18-63	1695	8.87
33B	2-25-63	1818	6.98
34B	3- 4-63	1590	7.77
35B	3-11-63	1682	12.52
36B	3-18-63	1772	15.43
37B	3-26-63	1712	22.01
38B	4- 1-63	1651	34.56
39B	4- 8-63	1742	21.87
40B	4-15-63	1730	22.48
41B	4-22-63	1710	35.25
42B	4-30-62	1766	18.50
44B	5-14-63	1521	36.25
45B	5-20-63	1713	21.48
46B	5-27-63	1617	24.94
47B	6- 3-63	1603	38.22
48B	6-10-63	1640	38.49
49B	6-17-63	1704	16.43
50B	6-25-63	1604	38.51

*Theoretical statistical counting errors less than $\pm$ 10% of the expected mean with 95% confidence.

Table 1, Continued.

Sample No.	Mean Date of Collection	Cubic Meters Sampled	Picocuries per Hundred Cubic Meters*
51B	7- 2-63	1588	19.39
52B	7- 8-63	1628	11.61
53B	7-15-63	1465	21.44
54B	7-22-63	1486	13.23
55B	7-29-63	1774	18.03
56B	8- 5-63	1560	6.49
57B	8-12-63	1713	6.94
58B	8-19-63	1576	6.55
59B	8-26-63	1850	6.35
61B	9-10-63	771	6.64
62B	9-16-63	1901	8.01
63B	9-24-63	1743	5.41
65B	10- 8-63	1428	10.77
66B	10-14-63	1928	11.16
67B	10-22-63	1499	7.07
68B	10-29-63	1916	7.19
69B	11- 5-63	1713	8.60
70B	11-12-63	1509	3.56
71B	11-18-63	1713	8.70
72B	11-25-63	1713	5.58
73B	12- 3-63	1713	5.28
74B	12-10-63	1522	9.00
75B	12-17-63	1542	6.63
76B	12-24-63	1743	3.84
78B	1- 8-64	1914	3.29
79B	1-15-64	1927	7.14
80B	1-22-64	1874	4.52
81B	1-28-64	1770	17.03
82B	2- 4-64	2021	4.79
83B	2-12-64	1999	8.22
84B	2-19-64	1743	6.29
85B	2-25-64	2142	10.24
86B	3- 4-64	292	19.09
87B	3-10-64	1794	8.42
88B	3-18-64	2174	7.77
89B	3-25-64	1892	9.04
90B	4- 1-64	2866	8.48
91B	4- 9-64	1147	10.72
92B	4-13-64	2123	9.73

*Theoretical statistical counting errors less than $\pm$ 10% of the expected mean with 95% confidence.

Table 1, Continued.

Sample No.	Mean Date of Collection	Cubic Meters Sampled	Picocuries per Hundred Cubic Meters*
93B	4-21-64	1937	18.23
94B	4-27-64	1817	16.45
95B	5- 5-64	2047	17.92
96B	5-11-64	2046	13.98
97B	5-18-64	2054	15.64
98B	5-25-64	2076	5.65
99B	6- 2-64	1798	2.87
100B	6- 8-64	2334	11.35
101B	6-15-64	2004	15.62
102B	6-22-64	2016	11.51
103B	6-29-64	2130	5.50
104B	7- 6-64	2107	6.09
105B	7-13-64	1963	6.00
106B	7-20-64	1845	5.64
107B	7-28-64	1679	5.41
108B	8- 4-64	2006	2.31
109B	8-11-64	1734	2.11
110B	8-18-64	1973	6.53
111B	8-24-64	1549	7.65
112B	9- 1-64	2066	4.61
113B	9- 8-64	1950	2.44
114B	9-15-64	1879	5.24
115B	9-22-64	1855	2.97
116B	9-29-64	1713	4.11
117B	10- 6-64	1903	3.48
118B	10-13-64	1903	2.22
121B	11- 2-64	1855	3.69
122B	11-10-64	1832	3.17
123B	11-17-64	1879	0.93
124B	11-24-64	1903	1.82
125B	11-30-64	1639	1.29
126B	12- 7-64	1879	1.88
127B	12-14-64	1809	3.03
128B	12-21-64	1855	1.46
129B	12-28-64	1879	1.87
130B	1- 4-65	1858	2.27
131B	1-11-65	1785	1.69
134B	2- 1-65	1682	2.36
135B	2- 8-65	1816	1.90

*Theoretical statistical counting errors less than $\pm$ 10% of the expected mean with 95% confidence.

Table 2. Monthly and yearly mean cesium-137 concentrations in air collected at Buckhorn Mountain, October, 1962 through February, 1965.*

Month	YEAR 1962	1963	1964	1965
January	----	8.55	8.00	1.98
February	----	9.48	7.39	2.13
March	----	14.43	11.08	----
April	----	26.53	12.72	----
May	----	27.56	13.30	----
June	----	32.91	9.37	----
July	----	16.74	5.79	----
August	----	6.58	4.65	----
September	----	6.69	3.87	----
October	3.54	9.05	2.85	----
November	4.62	6.61	2.18	----
December	5.29	6.19	2.06	----
Yearly Means	----	14.20	7.28	----

*Mean cesium-137 concentrations expressed as picocuries per hundred cubic meters.

Table 3. Total cesium-137 deposition rates at Kelly Flats, October 1963 through January 1965.

Sample No.	Month	Year	Precipitation in Inches*	Cs-137 Deposition in $pc/m^2/month$**
11T	Oct.	1963	0.41	476
13T	Nov.	1963	0.10	208
15T	Dec.	1963	0.35	216
17T	Jan.	1964	0.07	76
19T	Feb.	1964	0.20	254
21T	March	1964	0.52	387
23T	April	1964	2.45	1491
25T	May	1964	1.24	2459
27T	June	1964	0.90	2080
29T	July	1964	0.65	879
31T	Aug.	1964	1.48	1000
33T	Sept.	1964	1.31	543
35T	Oct.	1964	0.03	164
37T	Nov.	1964	0.14	398
39T	Dec.	1964	0.38	290
41T	Jan.	1965	0.21	95

* Data collected by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks.

**Theoretical statistical counting errors less than $\pm$ 10 per cent in the expected mean with 95 per cent confidence.

Table 4. Precipitation data for summer range vegetative plots.

Location	Period	Elevation Feet	Precipitation Inches
Little Beaver	10- 3-63 to 6-16-64	8600	9.04
Manhattan	"	9000	8.78
Laramie (2)	"	9300	15.08
Laramie (1)	"	9400	12.98
Pennock Creek	"	9400	9.37
Nunn Creek	"	9900	12.47
Crown Point	"	10320	12.46*
Trap Park	"	10480	15.13
Zimmerman	"	10500	17.56
Little Beaver	6-16-64 to 10- 2-64	8600	5.21
Manhattan	"	9000	4.04
Laramie (1)	"	9400	6.66
Pennock Creek	"	9400	3.55
Nunn Creek	"	9900	6.63
Crown Point	"	10320	5.64*

*Data collected by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks.

Table 5. Gross gamma radioactivity in surface soil samples in June, 1964.*

Sample No.	Rep.	Location	Date	Percent Stoniness**	grams/cm^2, 1" depth	Relative Activity in cpm/cm^2 determination (a)	(b)
62	1	Hewlett (G, F & P)	6- 1-64	13.7	1.96	2.03	2.25
	2	"	"	13.8	2.06	2.66	2.74
	3	"	"	16.9	1.88	2.54	2.53
	4	"	"	9.2	2.32	2.27	2.08
63	1	Kelly Flats (G, F & P)	6- 1-64	28.8	1.64	2.86	2.96
	2	"	"	20.6	1.94	3.44	3.47
	3	"	"	26.6	1.95	3.61	3.36
	4	"	"	26.5	2.13	3.68	4.01
64	1	Little Beaver (G, F & P)	6- 1-64	15.8	1.75	3.75	4.35
	2	"	"	23.5	1.44	3.96	3.38
	3	"	"	31.9	1.95	5.10	4.94
	4	"	"	34.0	1.64	3.48	3.55
65	1	Crown Point	6- 1-64	22.9	0.79	1.61	1.56
	2	"	"	47.9	0.86	2.30	2.29
	3	"	"	25.9	1.12	2.93	3.26
	4	"	"	32.7	0.30	1.20	1.58
66	1	Little Beaver (meadow)	6-15-64	27.7	2.29	2.38	2.23
	2	"	"	28.0	1.62	2.04	1.38
	3	"	"	11.2	0.34	0.98	1.84
	4	"	"	18.1	1.70	1.28	1.38

* Samples collected from the 0-1 inch layer. Area sampled = 340 cm^2/sample.

**Percent stoniness = $\frac{\text{wt. rocks} > 1.65 \text{ mm diam. in sample}}{\text{Total wt. sample}} \times 100$

Table 5, Continued.

Sample No.	Rep.	Location	Date	Percent Stoniness**	grams/cm^2, 1" depth	Relative Activity in cpm/cm^2 determination (a)	(b)
67	1	Rist Canyon	6- 1-64	24.5	2.04	3.09	3.41
	2	"	"	46.7	1.64	2.94	2.94
	3	"	"	29.2	1.83	2.25	2.53
	4	"	"	31.4	1.36	3.03	2.74
68	1	Seaman Reservoir	6- 1-64	29.7	1.46	3.20	3.10
	2	"	"	41.3	1.63	2.97	3.06
	3	"	"	30.3	2.00	3.51	3.87
	4	"	"	32.0	1.24	2.59	1.93
69	1	Young's Gulch	6- 1-64	25.3	2.14	3.59	3.17
	2	"	"	13.7	2.48	4.12	4.51
	3	"	"	26.4	1.44	2.46	2.56
	4	"	"	15.3	1.88	1.12	2.87
70	1	Kelly Flats	6- 1-64	18.6	2.18	1.01	3.62
	2	"	"	32.2	1.79	1.25	3.38
	3	"	"	31.2	1.81	3.87	3.18
	4	"	"	28.8	1.58	3.27	2.90
71	1	Bennett Creek	6- 1-64	18.7	2.24	3.64	3.95
	2	"	"	20.1	2.20	3.55	3.47
	3	"	"	10.0	1.91	2.75	2.60
	4	"	"	16.6	1.99	2.63	2.54

* Samples collected from the 0-1 inch layer. Area sampled = 340 cm^2/sample.

**Percent stoniness = $\frac{\text{wt. rocks} > 1.65 \text{ mm diam. in sample}}{\text{Total wt. sample}} \times 100$

Table 5, Continued.

Sample No.	Rep.	Location	Date	Percent Stoniness**	grams/cm^2, 1" depth	Relative Activity in cpm/cm^2 determination (a)	(b)
72	1	Home Moraine	6- 1-64	13.2	2.12	3.16	2.51
	2	"	"	17.3	1.66	2.82	2.30
	3	"	"	5.6	2.55	3.14	3.10
	4	"	"	7.5	2.24	3.31	3.09
73	1	Sevenmile Creek (G, F & P)	6- 1-64	25.3	2.09	4.15	3.52
	2	"	"	26.1	1.65	4.50	3.95
	3	"	"	30.5	1.41	4.13	3.74
	4	"	"	25.1	1.83	3.73	3.33
74	1	Sevenmile Creek	6- 1-64	27.5	1.93	4.08	3.70
	2	"	"	29.6	1.53	2.42	2.11
	3	"	"	22.1	2.29	3.41	3.21
	4	"	"	32.0	1.90	3.95	2.78
75	1	Pingree Hill	6- 1-64	14.0	1.42	2.74	1.42
	2	"	"	18.3	2.02	2.84	1.43
	3	"	"	13.2	2.13	3.87	1.90
	4	"	"	28.4	2.17	3.46	3.15
76	1	Hewlett Gulch (1)	6- 5-64	14.4	2.21	3.85	3.62
	2	"	"	14.7	2.50	2.63	2.67
	3	"	"	9.9	2.16	2.72	2.69
	4	"	"	9.3	1.58	2.13	2.10

* Samples collected from the 0-1 inch layer. Area sampled = 340 cm^2/sample.

**Percent stoniness = $\frac{\text{wt. rocks} > 1.65 \text{ mm diam. in sample}}{\text{Total wt. sample}} \times 100$

Table 5, Continued.

Sample No.	Rep.	Location	Date	Percent Stoniness**	grams/cm^2, 1" depth	Relative Activity in cpm/cm^2 determination (a)	(b)
77	1	Hewlett Gulch (2)	6- 5-64	32.5	1.13	1.66	1.59
	2	"	"	40.1	1.52	2.31	2.46
	3	"	"	31.7	0.90	1.60	1.61
	4	"	"	35.0	1.19	1.83	1.61
78	1	Hewlett Gulch (3)	6- 5-64	20.0	1.84	2.92	3.04
	2	"	"	23.7	2.12	2.48	2.35
	3	"	"	26.5	1.98	2.40	2.23
	4	"	"	21.3	2.05	2.63	2.89
79	1	Hewlett Gulch (4)	6- 5-64	21.2	1.69	3.02	2.79
	2	"	"	13.0	1.78	2.36	2.58
	3	"	"	22.7	1.36	1.71	1.73
	4	"	"	23.5	1.67	2.76	2.56
80	1	Pennock Creek	6-15-64	25.5	0.89	1.54	1.21
	2	"	"	20.7	0.50	2.53	2.05
	3	"	"	23.8	0.89	1.65	1.61
	4	"	"	25.9	0.73	2.38	2.86
81	1	Manhattan	6-15-64	17.1	1.64	2.31	2.11
	2	"	"	----	0.74	1.85	1.54
	3	"	"	9.9	1.67	1.90	1.49
	4	"	"	10.0	1.49	1.76	0.92

* Samples collected from the 0-1 inch layer. Area sampled = 340 cm^2/sample.

**Percent stoniness = $\frac{\text{wt. rocks} > 1.65 \text{ mm diam. in sample}}{\text{Total wt. sample}} \times 100$

Table 5. Continued.

Sample No.	Rep.	Location	Date	Percent Stoniness**	grams/cm^2, 1" depth	Relative Activity in cpm/cm^2 determination (a)	(b)
82	1	Nunn Creek	6-15-64	34.4	0.42	1.10	0.97
	2	"	"	10.2	0.73	1.95	1.31
	3	"	"	36.1	1.04	2.26	2.23
	4	"	"	22.7	2.31	3.16	3.00
83	1	Laramie Meadow (1)	6-17-64	9.8	0.93	2.52	1.73
	2	"	"	13.5	1.40	3.23	2.58
	3	"	"	11.7	2.09	3.75	2.95
	4	"	"	8.9	1.66	4.44	3.58
84	1	Laramie Meadow (2)	6-17-64	7.6	0.81	3.13	2.57
	2	"	"	6.4	1.22	3.92	3.40
	3	"	"	31.1	0.44	1.23	1.26
	4	"	"	9.0	1.50	3.18	2.69
85	1	Zimmerman Bench	6-17-64	18.8	1.34	3.30	3.88
	2	"	"	41.0	1.34	3.99	3.45
	3	"	"	15.7	1.27	4.20	3.52
	4	"	"	16.1	1.08	1.84	1.43
86	1	Trap Park	6-18-64	35.4	0.87	3.22	2.94
	2	"	"	20.5	2.00	3.71	3.76
	3	"	"	24.7	1.37	2.52	3.00
	4	"	"	26.4	1.11	3.48	3.03

* Samples collected from the 0-1 inch layer. Area sampled = 340 cm^2/sample.

**Percent stoniness = $\frac{\text{wt. rocks} > 1.65 \text{ mm diam. in sample}}{\text{Total wt. sample}} \times 100$

Table 6. Levels of various gamma emitting radionuclides in several important species of deer forage plants, August 1962 - September 1964. *

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
21	0	4	01-00	229	112	7.71	20.1	8.56	71.5	3.83
22	0	3	12-00	229	57.2	3.16	10.3	3.28	48.3	2.26
23	0	9	02-00	229	12.9	0.71	1.90	0.75	27.7	0.79
24	0	1	12-00	229	61.0	6.00	8.87	4.04	45.7	2.38
25	0	4	02-00	229	74.6	4.40	15.1	4.79	64.0	2.81
26	0	11	02-00	228	40.8	2.30	7.29	2.49	53.6	2.01
28	0	9	16-00	228	17.2	1.11	2.53	0.72	29.4	0.91
29	0	10	16-00	228	72.9	2.78	12.9	4.58	68.0	2.12
30	0	10	11-00	228	63.2	3.24	12.3	4.43	26.2	2.10
31	0	10	11-00	228	106	4.86	15.1	5.09	79.0	2.86
32	0	3	10-00	233	62.2	4.58	7.93	3.63	72.0	3.18
34	0	1	13-02	233	56.4	3.08	10.8	3.85	83.7	2.64
35	0	10	13-02	233	47.6	2.55	6.66	3.19	94.2	2.46
36	0	1	13-01	233	65.2	3.39	11.7	4.22	103	2.56
37	0	10	13-01	233	50.6	2.78	9.81	3.99	30.1	2.29
39	0	9	16-00	270	34.3	2.15	5.14	1.95	56.9	2.18
40	0	11	16-00	270	56.1	3.21	4.59	3.08	83.0	2.86
41	0	9	07-00	270	39.5	2.13	5.32	2.34	82.4	1.91
43	0	11	02-00	272	22.6	1.25	1.11	1.59	33.9	1.27
45	0	4	02-00	272	33.0	2.70	4.82	2.55	45.3	1.86
46	0	4	01-00	272	93.5	6.58	14.3	5.04	71.5	4.48
47	0	12	01-00	272	24.9	2.16	3.31	1.24	42.1	1.54
48	0	12	19-00	272	60.7	3.94	10.6	5.91	20.1	3.21
49	0	1	13-02	355	106	1.40	4.73	1.19	99.9	2.00
50	0	10	13-02	355	31.4	1.14	2.97	1.46	54.2	1.73
51	0	1	13-01	355	53.6	1.46	7.98	2.13	122	2.05
52	0	10	13-01	355	27.6	0.83	2.40	1.26	47.9	1.93
53	0	3	12-00	355	45.0	0.98	3.46	0.90	26.2	0.95
54	0	1	12-00	355	59.5	2.05	N.D.	1.91	107	1.98
55	0	10	12-00	355	78.8	1.50	2.98	1.37	57.7	1.91
56	0	10	11-00	355	43.7	1.40	3.58	1.93	41.5	2.12
57	0	10	11-00	355	56.0	1.37	4.64	2.14	85.7	2.16
58	0	3	10-00	356	26.0	0.85	1.79	1.31	22.9	0.97
60	0	10	13-01	426	42.6	1.71	7.57	2.01	40.6	1.97
61	0	1	13-01	426	84.0	3.20	16.9	3.80	101	4.27

* Code system for classification, location, and date given in Table 7.

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
62	0	1	13-02	426	91.9	3.89	17.4	4.32	103	4.80
63	0	10	13-02	426	47.6	N.D.	7.69	2.42	41.3	2.92
64	0	10	11-00	426	56.4	2.34	7.93	3.10	47.1	2.37
65	0	10	11-00	426	61.2	2.31	8.96	3.04	51.5	2.79
66	0	3	10-00	438	20.8	0.94	2.23	1.14	11.2	0.97
67	0	3	10-00	438	19.2	0.60	2.34	1.17	9.98	0.96
68	0	3	12-00	438	17.5	0.60	3.30	1.01	12.8	0.90
69	0	10	12-00	438	38.9	1.66	0.37	1.69	34.4	2.24
70	0	1	12-00	438	40.2	1.41	6.48	1.74	38.8	2.42
72	0	11	02-00	544	54.5	3.66	9.89	4.16	23.9	6.43
73	0	9	02-00	544	12.3	0.98	3.12	1.12	6.85	2.14
74	0	4	01-00	544	62.3	5.34	11.9	4.62	33.1	8.26
75	0	12	01-00	544	121	8.09	21.4	8.98	43.5	12.9
76	0	4	02-00	544	197	14.0	39.8	12.4	87.3	22.1
77	0	4	02-00	544	78.9	5.68	15.7	5.83	36.8	11.3
78	0	8	03-00	544	194	6.05	65.5	3.67	71.1	49.5
79	0	9	07-00	547	31.8	2.48	6.35	2.14	15.8	4.55
80	0	11	07-00	547	43.8	2.79	8.45	3.13	19.5	5.25
81	0	12	08-00	547	95.5	6.58	15.3	6.45	34.1	10.2
82	0	12	09-00	564	147	10.9	25.7	10.2	54.6	19.9
83	0	9	09-00	564	40.8	3.80	8.91	0.41	8.41	5.38
84	0	7	09-00	564	86.4	6.28	18.3	6.15	38.3	13.6
85	0	9	07-00	565	42.0	2.96	7.82	2.67	20.2	6.32
86	0	11	07-00	565	119	7.09	18.8	7.39	37.2	12.4
87	0	2	07-00	565	74.0	4.55	15.2	4.35	26.3	8.92
88	0	8	07-00	565	80.6	5.40	19.1	4.30	31.2	9.50
89	0	7	07-00	565	48.5	3.60	11.3	3.23	18.1	6.96
90	0	12	08-00	565	114	8.38	18.8	8.78	37.8	11.0
91	0	5	08-00	565	69.7	4.52	9.50	5.77	23.0	5.53
92	0	4	01-00	565	210	12.8	44.9	11.7	73.5	23.9
93	0	12	01-00	565	147	8.17	27.7	11.9	52.2	17.0
94	0	9	02-00	566	22.3	1.85	4.99	1.86	10.1	3.42
95	0	11	02-00	566	51.5	3.73	8.74	4.31	21.0	7.23
96	0	4	02-00	566	98.0	7.04	21.4	6.60	41.5	13.0
97	0	11	06-00	566	55.2	3.92	14.0	4.51	23.2	6.80
98	0	4	06-00	566	197	11.6	43.4	10.6	77.0	21.5
99	0	2	06-00	566	82.9	4.53	13.0	6.48	29.6	10.3
100	0	8	06-00	566	93.2	6.19	20.7	6.15	36.5	11.7
101	0	7	06-00	566	103	6.82	26.8	10.2	43.5	14.6
102	0	4	03-00	568	86.9	6.75	19.4	5.30	32.9	15.5

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
103	0	8	03-00	568	63.4	3.35	16.7	3.28	21.5	14.3
104	0	12	03-00	568	245	15.4	58.2	17.5	81.4	28.6
105	0	11	04-00	569	35.9	2.85	6.19	3.08	14.8	4.87
106	0	4	04-00	569	115	7.47	27.0	10.0	44.1	15.4
107	0	9	05-00	569	46.2	4.31	7.96	2.82	20.0	6.84
108	0	7	05-00	569	48.3	3.82	10.5	3.43	17.6	9.10
109	0	5	05-00	569	66.9	5.79	7.25	5.12	22.1	6.96
110	0	12	09-00	599	134	10.2	32.6	11.6	37.0	20.9
111	0	9	09-00	599	41.1	3.65	8.84	3.13	15.9	6.01
112	0	7	09-00	599	87.7	7.29	20.3	8.44	33.0	19.7
113	0	9	07-00	599	37.7	2.43	8.14	2.77	12.2	5.99
114	0	11	07-00	599	74.4	4.11	11.8	6.23	16.2	9.07
115	0	2	07-00	599	73.1	3.27	10.1	5.85	14.1	9.96
116	0	8	07-00	599	95.2	6.11	20.1	6.68	27.6	11.0
117	0	7	07-00	599	58.5	2.94	12.5	5.13	14.5	9.98
118	0	12	08-00	600	117	9.28	16.2	9.87	30.0	14.9
119	0	5	08-00	600	63.3	4.41	6.84	6.50	14.3	5.65
120	0	9	05-00	600	52.5	4.40	8.38	3.02	18.8	6.52
121	0	7	05-00	600	67.9	5.10	11.2	4.93	16.6	11.6
122	0	5	05-00	600	48.0	4.60	5.49	4.53	11.7	5.42
123	0	4	01-00	601	206	13.1	41.9	14.2	44.7	25.5
124	0	12	01-00	601	158	11.5	25.4	15.6	37.0	20.7
125	0	9	02-00	604	20.7	1.42	3.31	2.01	5.92	2.88
126	0	11	02-00	604	54.3	3.40	9.29	5.07	12.7	6.32
127	0	4	02-00	604	106	7.93	20.5	7.86	27.4	12.8
128	0	4	03-00	603	73.2	5.96	12.3	5.54	21.5	11.3
129	0	8	03-00	603	55.0	3.87	12.2	4.13	15.9	11.0
130	0	12	03-00	603	102	6.09	18.2	8.86	20.5	15.1
133	0	11	06-00	600	86.9	4.85	13.3	6.15	19.5	9.69
134	0	4	06-00	600	252	14.8	46.4	16.6	53.3	27.0
135	0	2	06-00	600	96.1	4.62	14.1	7.72	17.5	11.4
136	0	8	06-00	600	171	9.59	35.5	11.9	35.3	20.3
137	0	7	06-00	600	150	9.05	34.6	12.6	29.5	24.6
138	0	12	09-00	625	117	8.86	30.3	11.4	20.7	20.3
139	0	9	09-00	625	46.2	4.31	8.51	3.23	10.8	7.37
140	0	7	09-00	625	110	8.22	22.0	11.9	21.2	24.0
141	0	9	07-00	625	43.9	3.47	9.30	3.29	9.75	6.13
142	0	11	07-00	625	58.0	3.57	9.10	4.39	9.98	7.43
143	0	2	07-00	625	60.7	2.71	7.80	4.18	9.21	8.31

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
144	0	8	07-00	625	60.2	4.89	12.1	4.41	14.5	9.13
145	0	7	07-00	625	67.4	4.09	12.7	5.69	10.0	11.4
146	0	12	08-00	625	107	7.82	17.0	10.9	15.9	14.1
147	0	5	08-00	625	57.4	4.73	6.72	6.52	9.00	5.64
148	0	9	05-00	630	56.7	4.41	8.98	3.64	9.90	7.89
149	0	5	05-00	630	46.9	4.37	6.19	4.87	9.45	5.66
150	0	7	05-00	630	100	7.61	N.D.	8.87	13.8	18.5
151	0	11	06-00	632	53.3	3.79	9.58	4.32	7.79	6.42
152	0	11	06-00	632	96.8	4.78	15.0	6.56	11.7	11.3
153	0	4	06-00	632	270	15.0	52.7	18.7	40.1	24.6
154	0	7	06-00	632	145	9.14	35.0	13.4	21.8	21.4
155	0	2	06-00	632	59.3	2.52	9.05	5.74	7.02	6.63
156	0	8	06-00	632	223	13.3	46.7	16.9	35.8	23.0
157	0	12	01-00	632	128	8.53	19.0	14.5	17.1	15.0
158	0	4	01-00	632	217	13.0	44.5	14.7	33.4	24.4
159	0	4	02-00	632	144	9.05	26.9	11.6	24.2	17.1
160	0	9	02-00	632	25.3	1.59	4.40	1.90	5.00	3.26
161	0	11	02-00	632	34.0	2.06	5.56	3.59	5.72	4.60
162	0	8	04-00	634	105	6.90	24.0	8.98	17.6	14.3
163	0	11	04-00	634	41.2	3.01	5.19	3.33	6.50	5.10
164	0	12	03-00	634	108	6.04	17.5	11.1	13.2	16.6
165	0	4	03-00	634	73.6	6.09	13.3	5.25	12.3	12.7
166	0	8	03-00	634	57.0	4.52	11.6	4.47	13.8	12.4
167	0	3	12-00	653	26.0	1.57	3.75	1.73	2.56	3.23
168	0	1	12-00	653	47.8	2.58	6.42	2.25	5.87	4.30
169	0	10	12-00	653	37.0	1.64	5.95	2.42	3.22	4.71
170	0	6	12-00	653	45.6	4.62	6.49	4.06	6.93	4.47
171	0	10	16-00	655	36.8	1.64	5.32	2.42	3.08	4.07
172	0	10	11-00	655	30.9	1.53	4.52	2.02	3.72	3.42
173	0	6	11-00	655	46.6	4.81	5.33	4.14	7.85	4.38
174	0	3	10-00	655	36.0	2.36	5.99	2.43	3.52	4.29
175	0	3	14-00	656	33.8	2.16	5.48	2.19	3.55	4.09
176	0	6	14-00	656	50.1	4.27	6.99	5.04	5.93	5.01
177	0	3	15-00	662	39.9	2.48	5.91	2.89	3.89	4.12
178	0	1	17-00	662	33.0	1.75	5.22	2.00	4.76	2.86
179	0	6	13-00	662	51.1	4.88	5.21	5.28	6.87	5.04
180	0	10	13-02	662	41.7	1.40	4.65	2.66	1.81	4.72
181	0	1	13-02	662	49.5	2.56	4.91	2.70	6.25	4.24
182	0	10	13-01	662	129	7.44	18.2	5.86	12.6	10.3

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
183	0	1	13-01	662	54.0	3.10	5.69	0,24	7.32	3.81
184	0	1	13-01	718	47.1	2.77	7.57	3.01	4.17	3.54
185	0	1	13-02	718	44.4	2.92	6.94	2.74	3.33	3.67
186	0	6	13-00	718	50.2	5.37	6.02	5.57	4.72	5.03
187	0	10	13-01	718	69.2	2.73	8.11	3.97	2.61	4.96
188	0	10	13-02	718	45.2	1.50	5.79	2.62	1.83	4.21
189	0	10	12-00	718	38.4	1.03	4.18	2.03	1.29	3.50
190	0	3	12-00	718	15.7	0.80	1.33	1.36	0.68	1.64
191	0	1	12-00	718	46.0	2.36	5.98	2.77	3.75	3.70
192	0	6	12-00	718	37.6	4.56	5.17	4.09	3.66	4.19
193	0	1	17-00	718	27.4	1.88	4.66	1.77	2.49	2.28
194	0	10	16-00	719	30.7	1.30	3.56	2.14	1.21	3.01
195	0	10	11-00	719	25.3	0.86	3.25	1.35	0.49	2.40
196	0	6	11-00	719	39.7	4.01	4.79	4.31	3.52	4.05
197	0	3	10-00	719	19.2	0.88	1.49	1.44	0.64	1.61
198	0	3	14-00	719	17.8	0.89	1.91	1.35	0.69	1.60
199	0	6	14-00	719	39.5	3.83	4.98	4.35	3.34	3.90
200	0	3	15-00	719	26.2	1.38	2.71	1.87	1.51	2.08
201	1	3	14-00	780	14.2	0.72	1.53	1.06	0.47	1.10
	2	3	14-00	780	13.9	0.78	1.71	1.13	0.32	1.19
	3	3	14-00	780	11.1	0.59	1.27	0.91	0.25	0.95
	4	3	14-00	780	13.7	0.43	1.34	1.12	0.33	0.99
202	1	6	14-00	780	37.2	4.42	6.71	4.26	2.05	4.03
	2	6	14-00	780	24.9	3.40	4.78	2.81	1.66	2.37
	3	6	14-00	780	32.6	3.69	5.42	3.68	2.12	3.19
	4	6	14-00	780	32.5	3.65	5.01	3.92	1.17	3.52
203	1	3	15-00	781	16.4	1.09	2.69	1.47	0.74	1.59
	2	3	15-00	781	15.9	0.95	2.64	1.31	0.44	1.48
	3	3	15-00	781	14.3	0.93	2.43	1.46	N.D.	1.49
	4	3	15-00	781	15.9	1.07	2.64	1.35	0.67	1.47
204	1	3	10-00	795	15.1	0.78	2.03	1.66	0.13	1.52
	2	3	10-00	788	15.0	0.79	1.71	1.53	0.30	1.35
	3	3	10-00	789	12.1	0.72	1.61	1.33	0.24	1.29
	4	3	10-00	788	19.5	1.13	2.40	1.78	0.52	1.44

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
205	1	1	13-01	781	41.8	2.92	10.7	3.45	2.12	3.65
	2	1	13-01	781	31.9	2.31	7.24	2.45	1.93	2.85
	3	1	13-02	781	47.3	3.05	8.73	4.11	2.42	3.93
	4	1	13-02	781	43.7	2.91	9.66	3.44	2.17	3.87
206	1	10	13-01	781	73.3	2.80	10.5	4.83	1.35	5.31
	2	10	13-01	781	42.6	1.72	6.70	2.84	1.01	3.86
	3	10	13-00	781	43.4	1.92	7.21	2.95	0.62	4.32
	4	10	13-00	781	60.7	2.48	9.21	4.12	0.09	5.04
207	1	6	13-00	781	36.7	4.85	7.51	4.34	2.33	4.12
	2	6	13-00	781	48.1	5.67	7.79	6.28	2.62	5.04
	3	6	13-00	781	43.8	5.20	6.72	5.93	2.45	4.92
	4	6	13-00	781	32.8	4.24	5.09	4.14	2.16	3.71
208	1	10	18-01	783	27.8	1.27	4.19	1.92	0.30	3.01
	2	10	18-02	789	28.5	1.43	8.14	1.81	0.36	3.12
	3	10	18-03	783	29.7	1.42	4.89	2.18	0.55	3.10
	4	10	18-04	783	31.7	1.35	5.55	2.38	1.32	3.40
209	1	3	18-01	783	13.6	0.57	1.94	1.28	0.13	1.38
	2	3	18-02	789	17.9	0.70	2.40	1.90	0.17	1.79
	3	3	18-03	789	15.8	0.77	2.02	1.57	0.35	1.40
	4	3	18-04	783	14.2	0.94	1.33	1.36	0.52	1.48
210	1	6	18-01	783	30.3	4.01	5.92	3.71	2.17	3.34
	2	6	18-02	789	36.0	3.94	5.17	4.55	1.73	3.64
	3	6	18-03	790	26.4	3.15	5.30	3.07	1.30	2.87
	4	6	18-04	783	32.3	3.57	6.24	3.56	1.76	3.53
211	1	3	12-00	783	14.2	0.73	2.52	1.25	0.26	1.40
	2	3	12-00	783	15.4	0.85	2.72	1.45	0.23	1.57
	3	3	12-00	783	15.1	0.78	2.33	1.49	0.37	1.61
	4	3	12-00	783	13.9	0.72	2.11	1.41	0.18	1.49
212	1	6	12-00	783	37.6	4.79	8.40	4.81	2.20	3.98
	2	6	12-00	783	34.2	4.24	7.47	4.70	2.07	3.54
	3	6	12-00	783	37.2	4.87	6.02	4.77	2.08	3.90
	4	6	12-00	783	44.1	5.46	7.67	5.07	2.74	4.56

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
213	1	10	12-00	783	28.2	1.11	5.31	1.94	0.64	3.12
	2	10	12-00	783	27.9	1.01	4.67	1.89	0.64	3.03
	3	10	12-00	783	34.2	1.11	6.07	2.39	0.95	3.34
	4	10	12-00	783	40.9	1.93	6.84	2.69	0.92	3.95
214	1	1	12-00	783	33.7	2.41	8.86	2.64	1.83	2.97
	2	1	12-00	783	34.0	2.71	8.79	2.71	1.93	3.24
	3	1	12-00	783	40.9	2.68	9.31	2.87	1.97	3.51
	4	1	12-00	783	36.5	2.54	14.2	2.59	1.88	3.36
215	1	1	17-00	783	25.5	2.08	8.96	2.30	1.50	2.67
	2	1	17-00	783	30.9	2.03	8.59	2.61	1.48	2.80
	3	1	17-00	783	29.4	2.15	8.77	2.68	1.40	2.84
	4	1	17-00	783	34.0	2.01	8.72	2.88	1.70	2.85
216	1	10	16-00	795	25.4	1.19	5.70	2.08	0.47	2.53
	2	10	16-00	788	26.9	1.12	4.88	2.02	0.57	2.78
	3	10	16-00	788	31.4	1.14	4.89	2.14	0.70	2.97
	4	10	16-00	788	46.5	1.96	6.94	3.17	0.66	4.02
217	1	10	11-00	788	25.6	1.43	4.30	1.75	0.42	2.52
	2	10	11-00	788	24.6	1.04	3.95	1.65	0.65	2.32
	3	10	11-00	788	25.6	1.16	4.45	1.96	0.63	2.34
	4	10	11-00	788	26.4	1.35	5.37	1.88	0.70	2.83
218	1	6	11-00	788	41.2	4.72	7.43	5.24	2.24	4.24
	2	6	11-00	788	33.1	4.16	5.35	4.12	1.69	3.49
	3	6	11-00	788	41.1	5.09	6.00	5.53	1.99	3.89
	4	6	11-00	788	40.3	5.15	6.17	5.53	2.46	4.29
219	1	10	18-01	848	26.5	1.44	4.40	2.20	0.51	2.61
	2	10	18-02	848	28.7	1.79	5.35	2.34	0.65	2.52
	3	10	18-03	854	27.7	1.66	4.93	2.26	1.03	1.67
	4	10	18-04	854	27.4	1.55	4.37	2.12	N.D.	2.79
220	1	3	18-01	848	12.8	0.61	1.66	1.39	0.18	1.14
	2	3	18-02	848	14.3	0.76	2.13	1.64	0.25	1.35
	3	3	18-03	854	15.7	0.93	2.30	1.73	0.26	1.26
	4	3	18-04	854	14.7	0.85	2.13	1.68	N.D.	1.25

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
221	1	6	18-01	848	28.7	3.75	4.78	3.85	0.93	3.06
	2	6	18-02	848	30.8	4.21	5.77	3.90	1.13	3.17
	3	6	18-03	854	31.1	3.95	4.71	4.51	0.85	3.03
	4	6	18-04	854	30.3	4.13	5.18	4.17	0.81	3.41
222	1	6	13-00	849	39.2	5.44	8.08	5.62	1.54	4.20
	2	6	13-00	849	38.8	5.27	7.41	6.00	1.29	4.34
	3	6	13-00	849	43.7	5.73	9.69	6.91	1.78	4.58
	4	6	13-00	849	42.8	5.90	8.82	6.55	0.85	4.50
223	1	10	13-00	849	35.4	1.39	5.88	2.85	0.37	3.02
	2	10	13-00	849	34.5	1.36	5.76	2.89	0.22	2.96
	3	10	13-00	849	31.1	1.49	5.18	2.59	0.49	2.82
	4	10	13-00	849	33.4	1.19	5.54	2.70	N.D.	3.09
224	1	1	13-00	849	43.5	3.07	11.9	4.42	1.21	3.66
	2	1	13-00	849	49.7	3.43	12.6	5.39	1.35	4.01
	3	1	13-00	849	46.6	3.52	12.0	4.98	1.11	4.16
	4	1	13-00	849	53.0	4.16	13.2	5.80	0.92	4.32
225	1	10	16-00	850	22.3	1.18	4.13	1.70	0.22	1.82
	2	10	16-00	850	23.7	1.29	3.87	1.83	0.18	1.91
	3	10	16-00	850	24.4	1.10	4.42	1.94	0.30	2.05
	4	10	16-00	850	28.3	1.39	3.57	1.87	0.26	2.13
226	1	1	17-00	850	32.1	2.69	7.96	3.74	0.94	2.96
	2	1	17-00	850	28.6	2.63	7.89	2.86	1.11	2.70
	3	1	17-00	850	29.0	2.41	8.13	2.93	0.93	2.69
	4	1	17-00	850	30.0	2.40	9.83	2.68	1.08	2.60
227	1	6	11-00	850	32.4	4.51	6.96	4.66	1.06	3.57
	2	6	11-00	850	32.5	4.86	6.33	4.47	1.12	3.42
	3	6	11-00	850	30.8	4.51	6.47	4.88	1.12	3.20
	4	6	11-00	850	32.7	4.90	5.42	4.68	1.24	3.47
228	1	10	11-00	853	22.8	1.02	4.46	1.89	0.31	1.93
	2	10	11-00	851	23.5	1.25	4.75	1.85	N.D.	1.97
	3	10	11-00	853	23.8	1.58	4.92	2.01	0.40	2.08
	4	10	11-00	853	29.7	1.71	5.75	2.45	0.35	2.51

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
229	1	3	10-00	851	15.8	1.08	2.72	2.20	0.25	1.64
	2	3	10-00	851	16.4	0.94	2.43	2.12	0.31	1.50
	3	3	10-00	851	16.9	1.03	4.07	2.06	0.30	1.55
	4	3	10-00	851	15.2	0.96	2.53	1.69	0.26	1.30
230	1	6	12-00	851	30.3	4.10	8.03	5.26	0.94	3.12
	2	6	12-00	851	38.6	5.56	7.08	5.53	1.48	3.71
	3	6	12-00	851	40.5	5.96	9.08	6.09	1.69	4.27
	4	6	12-00	851	43.7	5.88	8.71	6.10	1.29	4.52
231	1	1	12-00	851	40.8	3.56	8.00	3.73	1.35	3.51
	2	1	12-00	851	49.9	3.80	9.60	4.32	1.62	4.17
	3	1	12-00	851	21.9	2.52	7.46	4.12	1.36	3.42
	4	1	12-00	851	48.6	3.85	9.33	4.43	1.18	3.99
232	1	10	12-00	851	31.6	1.51	4.74	2.38	0.36	2.55
	2	10	12-00	851	29.9	1.31	4.42	2.52	N.D.	2.64
	3	10	12-00	851	34.0	2.09	4.58	2.46	0.60	3.05
	4	10	12-00	851	32.7	1.40	4.54	2.39	0.52	2.72
233	1	3	12-00	851	13.6	0.71	1.63	1.56	0.14	1.10
	2	3	12-00	851	12.1	0.76	1.82	1.30	0.42	1.07
	3	3	12-00	851	15.4	0.75	1.42	1.46	0.05	1.34
	4	3	12-00	851	15.9	0.85	2.10	1.45	0.35	1.31
234	1	3	15-00	853	20.3	1.40	3.39	1.89	0.68	1.47
	2	3	15-00	853	21.1	1.21	3.63	2.28	0.54	1.68
	3	3	15-00	853	20.6	1.55	3.61	2.28	0.51	1.75
	4	3	15-00	853	21.1	1.24	4.07	2.49	0.32	1.79
235	1	6	14-00	855	35.9	4.19	7.40	5.20	1.07	3.46
	2	6	14-00	855	34.8	4.21	6.65	4.53	0.89	3.59
	3	6	14-00	855	34.7	4.11	4.70	4.98	1.02	3.37
	4	6	14-00	855	33.8	4.33	7.82	4.85	1.11	3.10
236	1	3	14-00	855	15.2	1.41	2.80	1.40	0.52	1.13
	2	3	14-00	855	16.1	1.08	2.55	1.64	0.46	1.29
	3	3	14-00	855	17.7	1.03	3.18	1.65	0.45	1.44
	4	3	14-00	855	19.1	1.53	4.02	1.65	0.67	1.55

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
237	1	10	18-01	901	48.5	3.74	11.2	5.85	0.64	4.32
	2	10	18-02	907	49.8	3.89	12.2	6.07	0.83	4.23
	3	10	18-03	907	49.9	3.85	12.1	6.14	0.84	4.24
	4	10	18-04	907	45.7	3.52	11.4	5.72	0.58	3.90
238	1	3	18-01	901	35.7	3.33	9.78	4.84	0.89	3.26
	2	3	18-02	907	32.9	3.05	8.54	4.46	0.77	3.06
	3	3	18-03	907	31.9	3.19	8.27	4.38	0.68	3.10
	4	3	18-04	907	27.8	2.50	7.61	3.45	0.67	2.48
239	1	6	18-01	901	29.0	3.86	6.34	4.40	0.76	2.67
	2	6	18-02	907	34.2	4.25	7.77	5.26	0.67	3.18
	3	6	18-03	907	34.1	3.59	6.86	5.45	0.68	2.85
	4	6	18-04	907	35.9	4.40	7.60	5.61	0.69	3.18
240	1	10	16-00	904	48.4	3.35	10.6	5.19	0.66	3.24
	2	10	16-00	904	37.4	3.04	9.03	4.54	0.81	2.65
	3	10	16-00	904	37.4	2.71	9.42	3.99	0.52	2.95
	4	10	16-00	904	37.1	2.91	9.59	4.31	6.77	2.76
241	1	1	17-00	904	42.7	4.40	14.0	5.14	0.94	3.87
	2	1	17-00	904	39.1	3.28	11.6	4.55	1.04	3.40
	3	1	17-00	904	34.2	3.38	12.1	4.18	0.80	2.76
	4	1	17-00	904	40.0	3.51	11.1	5.19	0.99	3.43
242	1	6	13-00	904	38.3	5.43	7.80	6.67	0.78	3.70
	2	6	13-00	904	41.0	5.16	6.73	6.98	0.96	3.84
	3	6	13-00	904	43.4	5.20	8.01	7.34	0.97	4.09
	4	6	13-00	904	41.2	5.56	6.69	6.94	0.78	3.98
243	1	10	13-00	904	56.8	4.04	10.0	6.56	0.64	4.30
	2	10	13-00	904	69.5	4.39	11.7	8.19	0.84	4.87
	3	10	13-00	905	52.5	4.07	9.39	6.32	0.85	4.02
	4	10	13-00	905	60.8	4.73	10.2	7.00	0.74	5.16
244	1	1	13-00	904	68.3	4.98	16.0	8.04	1.32	5.13
	2	1	13-00	904	70.5	5.52	15.0	9.10	1.31	5.77
	3	1	13-00	905	38.6	4.11	10.0	4.84	0.74	3.35
	4	1	13-00	905	51.4	4.33	10.6	5.71	0.99	4.22

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
245	1	10	11-00	905	37.6	2.85	6.63	3.59	0.52	2.30
	2	10	11-00	905	33.9	3.04	6.98	3.92	0.54	2.48
	3	10	11-00	905	31.3	2.49	5.97	3.54	0.48	2.33
	4	10	11-00	905	36.4	2.95	7.80	4.15	0.55	2.82
246	1	6	11-00	905	34.8	4.77	5.90	5.91	0.79	3.35
	2	6	11-00	905	33.2	4.48	6.57	5.41	0.93	3.12
	3	6	11-00	905	29.2	3.91	5.50	4.83	0.73	2.82
	4	6	11-00	905	27.1	3.65	5.86	4.79	0.58	2.66
247	1	3	12-00	906	26.1	2.48	7.53	3.46	0.59	2.20
	2	3	12-00	906	24.5	2.47	7.74	3.49	0.44	2.34
	3	3	12-00	906	24.5	2.48	7.19	3.33	0.42	2.27
	4	3	12-00	906	26.8	2.47	7.18	3.36	0.36	2.37
248	1	10	12-00	906	35.4	3.20	8.28	4.49	0.42	3.02
	2	10	12-00	906	38.7	3.27	9.49	4.79	0.31	3.17
	3	10	12-00	906	33.6	2.79	8.00	4.35	0.29	2.73
	4	10	12-00	906	41.8	3.43	10.0	5.20	0.43	3.23
249	1	6	12-00	906	27.8	3.70	6.59	4.77	0.73	2.66
	2	6	12-00	906	32.5	4.20	7.26	5.30	0.67	3.21
	3	6	12-00	906	40.9	5.84	7.94	6.67	0.45	4.17
	4	6	12-00	906	37.3	5.16	7.68	6.26	0.78	3.61
250	1	1	12-00	906	28.9	2.64	7.27	3.75	0.85	2.49
	2	1	12-00	906	34.8	2.95	8.87	4.51	0.44	2.87
	3	1	12-00	906	31.3	2.84	9.29	3.95	0.45	3.02
	4	1	12-00	906	32.8	2.70	10.1	3.79	0.51	2.68
251	1	3	15-00	907	35.0	3.17	7.50	4.58	0.40	3.04
	2	3	15-00	907	23.9	2.74	6.93	2.94	0.47	2.42
	3	3	15-00	907	25.4	2.31	6.31	3.43	0.25	2.42
	4	3	15-00	907	25.6	2.83	8.61	3.78	0.27	2.87
252	1	3	10-00	906	28.2	2.86	8.66	3.88	0.23	2.60
	2	3	10-00	906	29.6	2.54	8.56	4.35	0.50	2.83
	3	3	10-00	907	24.7	2.60	7.66	3.66	0.59	2.42
	4	3	10-00	907	22.4	2.48	8.02	3.58	0.55	2.24

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
253	1	3	14-00	908	35.8	2.87	8.73	4.70	0.37	3.51
	2	3	14-00	908	19.5	1.67	5.30	2.50	0.27	1.84
	3	3	14-00	908	33.5	3.21	9.60	4.26	0.47	3.50
	4	3	14-00	908	32.4	2.40	7.86	4.55	0.79	3.08
254	1	6	14-00	908	41.3	4.16	8.49	7.42	0.66	3.72
	2	6	14-00	908	27.9	3.32	6.37	5.03	0.47	2.68
	3	6	14-00	908	34.5	3.98	6.44	5.74	0.51	2.92
	4	6	14-00	908	37.2	3.89	6.98	6.65	0.93	3.43
255	1	9	09-00	911	8.22	1.18	2.65	1.78	0.32	0.99
	2	9	09-00	911	9.54	1.49	4.54	1.95	0.45	0.97
	3	9	09-00	911	8.86	1.43	4.43	1.86	0.53	0.97
	4	9	09-00	911	10.7	1.64	4.34	2.06	0.19	1.12
256	1	12	09-00	911	39.3	4.24	8.14	8.31	0.56	4.85
	2	12	09-00	911	49.9	4.96	12.3	10.2	1.09	5.65
	3	12	09-00	911	49.1	4.99	12.7	9.95	0.95	5.79
	4	12	09-00	911	46.7	4.54	10.4	9.32	0.88	4.81
257	1	7	09-00	911	15.7	2.27	5.06	3.27	0.73	1.73
	2	7	09-00	911	16.4	2.32	4.57	3.54	0.18	1.71
	3	7	09-00	911	17.7	2.49	6.34	4.69	0.61	2.36
	4	7	09-00	911	18.5	1.93	5.06	4.07	0.23	1.58
258	1	7	07-00	911	16.2	1.73	5.59	2.88	0.30	2.43
	2	7	07-00	911	12.4	1.38	4.28	2.61	0.21	1.28
	3	7	07-00	911	10.0	1.26	3.43	1.67	0.52	1.20
	4	7	07-00	911	21.4	1.89	6.86	3.93	0.31	2.77
259	1	2	07-00	911	24.9	1.79	5.07	4.61	0.59	2.13
	2	2	07-00	911	27.8	2.06	5.99	4.75	0.49	2.55
	3	2	07-00	911	27.8	2.47	5.41	4.80	0.78	2.57
	4	2	07-00	911	30.4	2.24	6.32	4.99	0.38	2.51
260	1	8	07-00	911	16.5	2.07	5.65	2.87	0.36	1.78
	2	8	07-00	911	10.4	1.13	2.62	1.68	N.D.	3.87
	3	8	07-00	911	44.0	4.57	12.1	6.70	0.43	3.81
	4	8	07-00	911	23.1	2.32	6.19	3.66	0.54	1.80

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
261	1	11	07-00	911	15.4	1.83	4.52	3.16	0.22	1.51
	2	11	07-00	911	11.4	1.42	3.74	2.95	0.22	1.07
	3	11	07-00	911	13.1	1.44	3.72	3.23	0.30	1.20
	4	11	07-00	911	12.4	1.48	3.16	3.05	0.16	1.31
262	1	9	07-00	911	9.21	0.71	2.29	1.79	0.05	0.95
	2	9	07-00	911	6.25	0.84	2.29	1.54	0.19	0.75
	3	9	07-00	911	8.63	1.44	2.61	1.59	0.46	0.97
	4	9	07-00	911	7.04	1.19	2.39	1.13	0.22	0.61
263	1	5	05-00	912	35.6	4.83	6.26	7.40	0.48	3.79
	2	5	05-00	912	22.8	3.48	3.74	3.82	0.56	2.47
	3	5	05-00	912	34.9	4.29	5.02	6.49	0.13	3.19
	4	5	05-00	912	27.5	3.88	4.43	5.15	0.55	2.93
264	1	9	05-00	912	14.4	1.99	3.67	2.42	0.48	1.48
	2	9	05-00	912	12.6	1.72	2.24	2.23	0.10	1.29
	3	9	05-00	912	23.1	1.48	2.62	1.99	N.D.	1.38
	4	9	05-00	912	14.8	1.92	3.07	2.38	0.31	1.57
265	1	7	05-00	912	14.1	1.79	3.47	2.26	0.27	1.83
	2	7	05-00	912	10.5	0.83	2.26	1.59	N.D.	1.10
	3	7	05-00	912	15.4	1.97	3.32	2.27	0.36	1.69
	4	7	05-00	912	10.6	1.29	2.52	1.78	0.25	1.23
266	1	4	06-00	912	32.3	4.47	9.51	4.99	0.31	4.35
	2	4	06-00	912	26.8	4.16	7.09	4.21	0.99	3.43
	3	4	06-00	912	32.5	4.09	9.53	4.94	0.58	4.22
	4	4	06-00	912	48.6	5.72	13.6	7.72	0.85	5.07
267	1	2	06-00	912	49.7	2.95	10.7	9.44	0.47	4.15
	2	2	06-00	912	45.3	2.61	8.26	7.36	0.14	3.55
	3	2	06-00	912	42.7	2.71	8.68	6.43	0.37	3.29
	4	2	06-00	912	51.4	3.09	11.1	9.04	0.49	3.87
268	1	7	06-00	912	31.0	3.22	5.38	6.43	N.D.	4.20
	2	7	06-00	912	35.7	4.22	8.93	6.29	0.22	4.63
	3	7	06-00	912	20.8	3.05	8.49	4.78	0.39	2.89
	4	7	06-00	912	22.3	2.94	8.13	4.98	0.54	2.92

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
269	1	11	06-00	912	14.6	1.75	3.99	4.15	0.40	1.43
	2	11	06-00	912	26.2	2.65	6.95	5.09	0.66	2.33
	3	11	06-00	912	25.1	2.48	6.03	4.91	0.39	2.25
	4	11	06-00	912	21.7	2.08	5.81	9.87	0.51	2.19
270	1	8	06-00	912	24.7	2.78	8.04	6.94	0.98	3.49
	2	8	06-00	912	52.7	5.26	15.2	12.1	0.86	5.94
	3	8	06-00	912	36.8	4.05	10.6	8.84	1.14	4.44
	4	8	06-00	912	39.4	4.19	14.0	8.00	0.79	7.75
271	1	5	08-00	913	49.9	5.42	8.83	10.5	0.53	4.31
	2	5	08-00	913	57.2	5.77	10.3	11.8	0.63	5.06
	3	5	08-00	913	56.9	5.48	8.46	10.9	N.D.	4.94
	4	5	08-00	913	50.4	5.59	9.47	9.92	0.51	4.41
272	1	12	08-00	913	69.4	6.82	12.6	12.9	0.42	10.3
	2	12	08-00	913	57.5	6.90	10.9	11.3	0.61	7.48
	3	12	08-00	913	57.6	6.93	11.5	11.1	0.50	7.89
	4	12	08-00	913	67.9	6.82	12.8	12.8	0.69	8.90
273	1	12	03-00	914	65.0	6.20	12.9	12.1	0.68	9.00
	2	12	03-00	914	79.8	7.71	21.3	15.5	1.07	11.9
	3	12	03-00	914	67.4	6.88	19.7	13.3	1.01	9.98
	4	12	03-00	914	82.4	8.01	15.4	15.6	1.24	10.1
274	1	8	03-00	914	61.6	5.12	17.7	8.67	1.14	7.68
	2	8	03-00	914	72.8	5.72	20.2	10.3	0.82	9.08
	3	8	03-00	914	64.2	4.16	20.1	9.29	1.01	8.69
	4	8	03-00	914	170	12.8	55.4	22.0	1.74	19.7
275	1	4	03-00	914	148	8.87	40.7	17.3	1.54	16.7
	2	4	03-00	914	152	8.77	39.5	18.0	0.80	17.2
	3	4	03-00	914	161	11.3	46.3	22.4	1.31	15.8
	4	4	03-00	914	217	11.4	59.3	19.3	0.78	27.6
276	1	11	04-00	914	18.2	1.60	3.27	3.28	N.D.	1.60
	2	11	04-00	914	21.0	1.96	3.94	3.40	0.70	1.45
	3	11	04-00	914	17.3	1.31	2.96	3.04	N.D.	1.33
	4	11	04-00	914	16.9	1.48	3.40	3.42	0.44	1.43

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
277	1	8	04-00	914	30.2	2.98	9.48	4.54	0.39	3.77
	2	8	04-00	914	32.2	2.93	8.97	4.82	0.80	3.96
	3	8	04-00	914	27.6	3.16	9.32	4.39	0.66	4.38
	4	8	04-00	914	28.4	3.25	8.78	4.06	0.38	4.14
278	1	4	01-00	920	63.9	6.41	14.3	9.08	1.09	5.86
	2	4	01-00	920	92.8	9.34	20.1	12.7	1.71	8.33
	3	4	01-00	920	71.1	7.44	16.1	9.33	0.81	6.55
	4	4	01-00	920	83.4	8.81	19.0	12.0	1.35	7.84
279	1	12	01-00	920	78.9	9.08	18.0	16.6	0.94	9.74
	2	12	01-00	920	70.9	8.23	15.3	15.3	1.01	8.57
	3	12	01-00	920	67.9	8.06	12.3	14.7	1.06	7.15
	4	12	01-00	920	83.7	9.00	17.0	17.7	0.76	9.89
280	1	4	02-00	920	39.5	4.23	8.55	6.57	0.26	3.88
	2	4	02-00	920	45.3	4.51	10.1	7.93	0.55	4.13
	3	4	02-00	920	58.4	5.48	12.3	11.2	0.56	5.73
	4	4	02-00	920	29.5	3.34	7.18	5.40	0.55	3.54
281	1	9	02-00	920	3.70	0.40	1.00	0.89	0.18	0.28
	2	9	02-00	920	3.22	0.32	0.43	1.13	0.02	0.44
	3	9	02-00	920	3.55	0.37	0.43	1.91	0.06	0.35
	4	9	02-00	920	4.30	0.71	1.24	1.36	0.18	0.34
282	1	11	02-00	920	13.2	1.39	2.69	3.72	0.31	1.28
	2	11	02-00	920	11.6	1.31	2.63	4.06	0.33	1.13
	3	11	02-00	920	7.08	1.09	1.58	2.76	0.11	0.71
	4	11	02-00	920	10.3	1.08	2.92	3.72	0.15	2.89
283	1	9	09-00	953	6.49	0.90	1.14	1.06	0.28	0.52
	2	9	09-00	953	6.89	0.76	1.48	1.29	0.23	0.69
	3	9	09-00	953	5.95	0.86	1.56	1.06	0.00	0.52
	4	9	09-00	953	5.35	0.76	0.70	0.97	N.D.	0.49
284	1	12	09-00	953	24.9	3.45	5.70	5.91	0.46	3.39
	2	12	09-00	953	28.9	3.77	5.89	6.34	0.33	3.49
	3	12	09-00	953	25.0	3.13	7.04	5.39	0.09	3.27
	4	12	09-00	953	29.9	3.59	7.66	6.76	0.10	4.08

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
285	1	7	09-00	953	14.9	1.97	3.22	3.82	0.01	1.70
	2	7	09-00	953	27.9	3.39	5.29	6.71	0.31	3.43
	3	7	09-00	953	22.4	2.13	3.70	4.97	0.13	2.84
	4	7	09-00	953	12.4	1.92	1.92	2.94	N.D.	1.41
286	1	2	07-00	953	10.9	0.86	1.25	2.20	N.D.	1.18
	2	2	07-00	953	11.2	0.92	1.38	2.44	0.15	1.28
	3	2	07-00	953	11.6	0.87	1.57	2.19	0.08	1.11
	4	2	07-00	953	13.0	1.14	2.03	2.69	0.16	1.32
287	1	9	07-00	953	4.91	0.59	0.76	0.95	0.14	0.25
	2	9	07-00	953	4.73	0.63	0.39	0.83	0.19	0.38
	3	9	07-00	953	7.41	0.81	1.03	1.18	N.D.	0.62
	4	9	07-00	953	7.05	0.89	0.90	1.00	0.09	0.55
288	1	11	07-00	953	6.59	0.63	1.28	1.29	0.12	0.50
	2	11	07-00	953	10.8	1.09	1.11	2.27	N.D.	0.89
	3	11	07-00	953	7.16	0.76	0.68	1.86	0.07	0.84
	4	11	07-00	953	8.68	0.82	1.73	1.83	0.35	1.00
289	1	7	07-00	953	16.9	1.19	4.72	3.23	0.34	1.81
	2	7	07-00	953	21.2	2.05	5.86	5.28	0.48	2.33
	3	7	07-00	953	21.3	2.04	5.73	5.24	0.56	2.45
	4	7	07-00	953	13.2	1.36	3.66	3.02	0.15	1.81
290	1	8	07-00	953	10.6	1.15	2.26	1.70	0.13	0.91
	2	8	07-00	953	12.4	1.41	3.23	2.40	0.34	1.19
	3	8	07-00	953	10.2	1.35	2.89	1.80	0.40	0.92
	4	8	07-00	953	11.9	1.51	2.56	1.99	0.18	1.21
291	1	5	08-00	954	24.1	3.53	2.89	6.00	0.53	2.35
	2	5	08-00	954	23.3	3.43	3.22	5.90	0.32	2.25
	3	5	08-00	954	40.0	4.79	6.79	9.61	0.48	3.90
	4	5	08-00	954	45.6	5.13	7.45	10.8	0.55	4.13
292	1	12	08-00	954	31.7	3.96	6.57	6.82	0.20	5.62
	2	12	08-00	954	57.0	5.89	9.49	11.1	0.39	7.86
	3	12	08-00	954	43.0	5.18	6.40	9.00	0.38	7.32
	4	12	08-00	954	50.4	6.00	9.43	10.6	0.23	7.87

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
293	1	4	01-00	954	35.0	3.00	6.65	5.76	0.45	2.79
	2	4	01-00	954	18.4	2.10	3.79	3.35	0.29	1.81
	3	4	01-00	954	37.6	3.80	7.74	6.03	0.47	3.51
	4	4	01-00	954	34.6	3.80	7.35	5.96	0.40	3.42
294	1	12	01-00	954	48.5	6.67	10.6	12.6	0.48	6.42
	2	12	01-00	954	48.3	6.10	10.3	11.9	0.73	6.49
	3	12	01-00	954	40.0	5.74	10.0	10.4	0.62	5.91
	4	12	01-00	954	58.9	7.92	12.8	14.3	0.83	8.01
295	1	4	02-00	954	33.1	3.71	6.50	5.90	N.D.	3.15
	2	4	02-00	954	33.9	3.44	6.13	5.62	0.65	3.05
	3	4	02-00	954	17.1	1.79	3.26	3.22	0.32	1.74
	4	4	02-00	954	25.0	2.48	5.19	4.73	0.40	2.30
296	1	9	02-00	954	3.04	0.46	0.43	1.06	0.10	0.28
	2	9	02-00	954	1.14	0.18	0.33	0.85	0.17	0.18
	3	9	02-00	954	1.36	0.22	0.48	0.91	N.D.	0.23
	4	9	02-00	954	2.23	0.13	0.54	0.89	N.D.	0.20
297	1	11	02-00	954	6.64	0.70	0.19	1.66	0.12	0.64
	2	11	02-00	954	6.82	0.46	1.32	3.62	0.11	0.59
	3	11	02-00	954	7.51	0.63	1.11	2.21	0.07	0.78
	4	11	02-00	954	5.29	0.61	0.54	1.84	N.D.	0.71
298	1	4	06-00	955	13.1	1.18	2.85	1.99	0.25	1.33
	2	4	06-00	955	19.8	2.47	3.88	3.10	N.D.	1.88
	3	4	06-00	955	3.77	0.65	1.24	1.05	N.D.	0.62
	4	4	06-00	955	12.9	1.76	3.09	2.38	N.D.	1.45
299	1	2	06-00	955	11.1	0.67	2.41	2.35	0.08	1.19
	2	2	06-00	955	11.5	0.92	1.56	2.12	N.D.	1.22
	3	2	06-00	955	12.2	0.92	2.22	4.61	N.D.	1.36
	4	2	06-00	955	8.72	0.57	1.59	1.99	N.D.	1.01
300	1	11	06-00	955	6.21	0.50	0.41	3.96	N.D.	0.69
	2	11	06-00	955	8.49	0.92	1.11	5.59	0.26	0.90
	3	11	06-00	955	12.0	0.96	1.81	2.39	0.15	1.00
	4	11	06-00	955	11.8	0.96	1.81	2.68	0.01	1.09

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
301	1	7	06-00	955	17.1	1.73	3.91	4.10	0.02	2.20
	2	7	06-00	955	19.0	2.21	4.36	4.86	0.14	2.56
	3	7	06-00	955	22.0	2.21	4.96	4.81	0.04	2.86
	4	7	06-00	955	22.6	2.29	5.32	5.55	0.34	3.04
302	1	8	06-00	955	25.2	2.78	4.95	3.79	0.10	2.04
	2	8	06-00	955	8.17	0.80	2.36	1.52	0.04	0.91
	3	8	06-00	955	5.38	0.31	1.00	3.25	N.D.	0.78
	4	8	06-00	955	6.34	0.52	1.99	1.80	N.D.	0.92
303	1	5	05-00	957	9.57	1.71	2.02	2.67	N.D.	1.37
	2	5	05-00	957	12.6	2.48	1.95	3.35	0.01	1.67
	3	5	05-00	957	10.8	2.34	1.45	2.71	0.13	1.37
	4	5	05-00	957	13.9	2.44	1.75	3.21	0.13	1.69
304	1	9	05-00	957	9.42	1.28	2.54	1.42	N.D.	0.90
	2	9	05-00	957	6.66	0.82	1.34	1.23	0.06	0.63
	3	9	05-00	957	10.3	1.45	2.51	1.32	0.20	0.88
	4	9	05-00	957	7.20	0.98	1.32	1.19	N.D.	0.65
305	1	7	05-00	957	10.7	1.39	1.69	2.12	0.06	1.14
	2	7	05-00	957	8.19	1.19	1.65	1.60	0.09	1.03
	3	7	05-00	957	9.57	1.32	2.10	1.79	N.D.	1.10
	4	7	05-00	957	8.63	0.78	1.24	1.46	N.D.	1.03
306	1	4	03-00	956	16.2	0.94	3.65	2.01	0.26	4.27
	2	4	03-00	956	14.6	1.30	2.07	2.27	N.D.	2.34
	3	4	03-00	956	15.1	0.86	2.42	1.88	0.18	4.12
	4	4	03-00	956	21.8	1.15	4.41	2.06	0.06	4.36
307	1	12	03-00	956	37.0	4.03	8.52	8.16	0.28	7.54
	2	12	03-00	956	35.7	3.90	7.67	7.54	0.33	6.85
	3	12	03-00	956	41.8	5.08	8.18	9.34	0.54	7.84
	4	12	03-00	956	38.3	3.82	8.41	8.10	0.39	7.36
308	1	8	03-00	956	27.7	2.14	5.22	3.65	0.07	3.69
	2	8	03-00	956	13.9	1.00	2.49	3.16	0.33	4.78
	3	8	03-00	956	27.1	1.70	6.23	5.53	0.33	8.32
	4	8	03-00	956	21.9	1.00	4.62	2.39	0.04	5.30

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
309	1	11	04-00	956	6.90	0.97	0.22	2.05	0.01	0.47
	2	11	04-00	956	5.14	0.12	0.83	1.08	0.20	0.39
	3	11	04-00	956	5.42	0.45	0.46	2.38	0.03	0.56
	4	11	04-00	956	5.51	0.59	0.29	1.38	0.11	0.42
310	1	8	04-00	956	6.53	0.75	0.90	1.10	0.12	0.73
	2	8	04-00	956	10.9	1.26	1.77	1.93	0.09	1.23
	3	8	04-00	956	9.14	1.20	1.34	2.26	0.30	1.13
	4	8	04-00	956	8.91	1.10	1.54	1.71	0.17	1.55
311	1	4	06-00	988	31.7	4.10	7.10	4.65	0.49	2.43
	2	4	06-00	988	19.7	3.06	5.52	3.87	0.18	2.48
	3	4	06-00	988	10.4	2.06	3.06	1.98	0.13	1.39
	4	4	16-00	988	18.9	2.24	3.44	3.33	N.D.	1.86
312	1	2	06-00	988	12.0	0.98	2.42	2.16	0.16	1.16
	2	2	06-00	988	9.92	0.72	1.86	2.46	0.05	1.26
	3	2	06-00	988	10.4	0.89	1.56	2.02	0.11	1.03
	4	2	06-00	988	11.4	0.73	1.98	2.04	0.07	1.07
313	1	11	06-00	988	7.85	0.94	1.30	1.68	0.11	0.85
	2	11	06-00	988	6.55	0.65	1.32	2.02	0.04	0.77
	3	11	06-00	988	9.11	1.05	1.71	2.48	0.12	1.03
	4	11	06-00	988	6.07	0.78	1.06	1.94	0.06	0.77
314	1	7	06-00	988	21.6	2.43	5.10	5.01	0.08	3.15
	2	7	06-00	988	14.7	2.10	3.65	4.14	0.18	2.04
	3	7	06-00	988	22.7	2.67	5.83	5.39	0.15	3.15
	4	7	06-00	988	17.9	2.53	4.11	4.82	0.06	2.63
315	1	8	06-00	988	40.8	4.82	8.85	5.87	0.48	3.56
	2	8	06-00	988	33.8	4.29	6.35	4.88	0.46	2.95
	3	8	06-00	988	29.8	4.05	5.93	4.61	0.24	2.96
	4	8	06-00	988	34.9	3.77	6.63	4.80	0.26	2.68
316	1	4	01-00	989	37.3	4.64	8.12	6.44	0.18	3.44
	2	4	01-00	989	43.9	5.27	8.94	6.73	0.59	3.41
	3	4	01-00	989	49.4	5.35	10.9	7.75	0.27	4.10
	4	4	01-00	989	44.1	5.11	8.17	7.21	0.36	3.35

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
317	1	12	01-00	989	35.3	6.60	9.76	12.4	0.64	6.38
	2	12	01-00	989	31.6	5.60	10.2	13.5	0.38	5.85
	3	12	01-00	989	36.0	6.33	12.1	11.9	0.96	6.79
	4	12	01-00	989	36.5	5.87	10.9	11.3	0.51	6.19
318	1	4	02-00	990	22.8	2.86	6.12	4.27	0.50	2.02
	2	4	02-00	990	22.3	2.44	7.12	4.05	0.48	2.14
	3	4	02-00	990	27.8	3.77	7.07	5.29	0.41	2.96
	4	4	02-00	990	19.9	2.40	5.37	3.54	0.24	2.04
319	1	9	02-00	990	3.72	0.42	0.86	0.85	0.16	0.39
	2	9	02-00	990	4.16	0.61	1.05	0.91	0.04	0.45
	3	9	02-00	990	3.12	0.68	0.99	1.27	0.19	0.46
	4	9	02-00	990	4.12	0.64	0.69	1.05	0.05	0.46
320	1	11	02-00	990	4.52	0.82	1.61	1.92	0.20	1.10
	2	11	02-00	990	5.30	0.68	1.43	1.43	0.19	0.79
	3	11	02-00	990	8.88	0.77	1.05	1.55	N.D.	0.91
	4	11	02-00	990	4.01	0.57	0.77	1.51	0.04	0.85
321	1	4	03-00	989	45.1	3.11	10.9	5.09	N.D.	10.5
	2	4	03-00	989	63.5	4.23	19.6	8.26	0.32	11.6
	3	4	03-00	989	62.7	3.97	16.5	8.08	0.16	10.4
	4	4	03-00	989	42.6	2.67	9.87	6.14	0.29	8.28
322	1	12	03-00	989	44.5	5.26	10.8	11.3	0.54	7.46
	2	12	03-00	989	39.9	5.24	12.2	9.78	0.76	8.67
	3	12	03-00	989	45.7	4.86	10.0	9.98	0.34	8.58
	4	12	03-00	989	40.5	3.91	10.7	8.37	0.27	8.45
323	1	8	03-00	989	29.0	2.51	6.97	5.66	0.86	9.50
	2	8	03-00	989	20.5	2.08	6.13	3.95	0.72	6.44
	3	8	03-00	989	21.3	2.09	4.79	4.74	0.33	8.13
	4	8	03-00	989	32.3	3.11	7.48	4.88	3.79	1.55
324	1	8	04-00	989	22.7	2.22	6.03	4.43	0.37	2.66
	2	8	04-00	989	24.7	2.58	6.14	5.42	0.24	2.66
	3	8	04-00	989	39.7	3.60	10.7	8.13	0.38	4.53
	4	8	04-00	989	25.0	2.81	6.59	4.86	0.17	3.58

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
325	1	11	04-00	989	9.67	1.17	1.12	2.17	N.D.	1.16
	2	11	04-00	989	2.44	1.29	2.07	2.08	0.39	0.92
	3	11	04-00	989	7.04	1.44	1.63	2.14	0.28	1.01
	4	11	04-00	989	6.84	1.12	1.50	1.94	0.17	1.04
326	1	11	07-00	991	7.32	1.17	1.67	1.59	0.24	1.18
	2	11	07-00	991	6.44	0.79	1.87	1.27	0.10	0.60
	3	11	07-00	991	6.06	0.86	1.64	1.52	0.18	0.71
	4	11	07-00	991	6.11	0.88	0.96	1.25	0.15	0.62
327	1	9	07-00	991	4.56	0.47	1.06	0.94	0.18	0.47
	2	9	07-00	991	3.78	0.64	1.22	0.86	0.16	0.39
	3	9	07-00	991	4.49	0.66	0.83	0.90	0.16	0.43
	4	9	07-00	991	4.47	0.66	0.94	0.93	0.04	0.48
328	1	2	07-00	991	16.0	1.43	3.75	2.68	0.34	1.77
	2	2	07-00	991	16.0	1.45	2.71	2.49	0.41	1.59
	3	2	07-00	991	15.7	1.58	2.93	2.54	0.24	1.66
	4	2	07-00	991	13.2	1.32	3.02	2.59	0.14	1.47
329	1	8	07-00	991	15.8	2.13	4.93	3.03	0.41	1.84
	2	8	07-00	991	9.11	1.57	2.51	1.71	0.26	1.17
	3	8	07-00	991	16.1	1.91	4.76	3.03	0.00	2.07
	4	8	07-00	991	22.7	2.75	7.57	3.94	0.58	2.41
330	1	7	07-00	991	13.8	1.28	3.92	3.29	0.58	1.38
	2	7	07-00	991	10.6	1.77	3.62	2.68	0.23	1.32
	3	7	07-00	991	11.5	1.69	3.36	2.81	0.26	1.49
	4	7	07-00	991	5.27	0.75	1.79	1.20	0.11	0.81
331	1	12	09-00	991	21.7	3.67	6.25	6.43	0.10	4.00
	2	12	09-00	991	35.2	4.02	10.3	9.26	0.51	5.56
	3	12	09-00	991	22.0	3.25	5.43	5.81	0.22	3.80
	4	12	09-00	991	21.7	3.26	5.17	5.44	0.35	3.68
332	1	7	09-00	991	14.8	2.17	4.75	3.93	0.35	2.34
	2	7	09-00	991	15.4	2.36	5.03	4.67	0.29	2.99
	3	7	09-00	991	8.12	2.53	4.57	3.52	0.69	2.00
	4	7	09-00	991	4.51	2.40	3.52	2.02	0.60	1.69

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
333	1	9	09-00	991	2.12	1.25	2.69	1.18	0.77	0.66
	2	9	09-00	991	1.30	0.93	2.07	1.08	0.52	0.53
	3	9	09-00	991	5.79	0.80	1.45	1.01	0.26	0.55
	4	9	09-00	991	4.30	0.82	1.34	1.13	0.20	0.58
334	1	5	08-00	992	19.8	3.33	3.42	6.44	0.23	2.22
	2	5	08-00	992	20.7	3.52	4.21	6.94	0.24	2.47
	3	5	08-00	992	18.9	3.42	3.40	5.68	0.24	2.33
	4	5	08-00	992	23.4	4.03	3.12	7.31	0.28	2.78
335	1	12	08-00	992	29.3	4.62	6.72	8.66	0.39	6.06
	2	12	08-00	992	40.5	5.27	9.53	9.98	0.67	7.41
	3	12	08-00	992	42.4	5.70	9.59	10.8	0.52	8.03
	4	12	08-00	992	35.8	5.00	8.44	8.86	0.30	6.51
336	1	5	05-00	995	10.2	1.87	1.98	3.12	0.20	1.43
	2	5	05-00	995	8.02	1.79	1.12	2.03	0.19	1.07
	3	5	05-00	995	6.90	1.76	1.52	1.85	0.16	1.06
	4	5	05-00	995	7.90	2.02	0.93	2.41	0.29	1.25
337	1	9	05-00	995	5.10	0.71	0.93	1.16	0.04	0.59
	2	9	05-00	995	3.79	0.60	0.98	1.11	0.09	0.49
	3	9	05-00	995	4.92	0.80	1.29	1.10	0.28	0.59
	4	9	05-00	995	5.55	0.61	1.34	0.99	0.06	0.51
338	1	7	05-00	995	13.4	1.43	2.69	2.47	0.31	1.47
	2	7	05-00	995	20.9	2.19	5.95	3.62	0.24	2.65
	3	7	05-00	995	15.3	2.27	3.78	3.20	0.27	2.34
	4	7	05-00	995	16.4	2.18	3.25	3.16	0.25	2.32
339	1	1	12-00	997	8.81	0.65	1.19	1.19	0.29	0.61
	2	1	12-00	997	15.7	1.15	2.58	2.09	0.03	1.14
	3	1	12-00	997	8.96	0.86	1.41	1.25	0.10	0.70
	4	1	12-00	997	6.91	0.68	0.81	1.11	0.22	0.54
340	1	3	12-00	997	8.39	0.81	0.99	1.36	0.13	0.86
	2	3	12-00	997	7.42	0.80	0.79	1.31	0.08	0.76
	3	3	12-00	997	6.75	0.86	0.95	1.18	0.14	0.69
	4	3	12-00	997	7.73	0.87	0.48	1.23	0.17	0.81

Table 6, continued

Sample ID	Rep	Cl	Loc.	Date	Nuclide Levels in pc/g air dry					
					Ce-144	Sb-125	Ru-106	Cs-137	Zr-95	Mn-54
341	1	6	12-00	997	20.3	4.34	1.89	4.65	0.33	2.05
	2	6	12-00	997	20.4	3.95	3.34	4.70	0.03	2.25
	3	6	12-00	997	18.4	3.57	2.42	4.47	0.30	1.96
	4	6	12-00	997	16.7	3.14	2.21	3.87	0.00	1.64
342	1	10	12-00	997	6.39	0.49	1.11	1.07	0.02	0.71
	2	10	12-00	997	7.57	0.63	0.79	1.36	0.09	0.85
	3	10	12-00	997	7.01	0.45	0.40	1.07	2.87	0.16
	4	10	12-00	997	7.87	0.46	0.84	1.40	0.12	0.78
343	1	6	18-01	996	14.9	2.47	1.86	3.28	0.62	1.26
	2	6	18-02	996	24.2	4.21	2.80	5.77	0.23	2.31
	3	6	18-03	996	20.4	3.13	3.48	4.08	0.17	1.72
	4	6	18-04	996	23.8	3.46	2.81	4.78	0.09	2.18
344	1	10	18-01	996	8.05	0.82	1.04	1.40	0.22	0.89
	2	10	18-02	996	9.04	1.01	1.27	1.85	0.20	1.03
	3	10	18-03	996	8.39	0.93	1.37	1.35	0.02	0.97
	4	10	18-04	996	14.2	1.37	2.34	2.06	N.D.	1.43
345	1	3	18-01	996	7.76	0.92	1.21	1.50	0.02	0.80
	2	3	18-02	996	6.79	1.00	0.90	1.27	0.01	0.91
	3	3	18-03	996	6.79	0.84	1.34	1.20	0.15	0.72
	4	3	18-04	996	5.54	1.03	1.51	1.27	0.21	0.88

Table 7. Code numbers for plant species classification, collection location, and dates.

CLASSIFICATION

Artemesia tridentata (sagebrush)	1
Betula glandulosa (bog birch)	2
Cercocarpus montanus (mountain mahogany)	3
Deschampsia caespitosa (hairgrass)	4
Juniperus communis (common juniper)	5
Juniperus scopulorum (juniper)	6
Mixed forbs	7
Mixed grasses	8
Populus tremuloides (aspen)	9
Purshia tridentata (bitterbrush)	10
Salix sp. (willow)	11
Vaccinium scoparium (blueberry)	12

LOCATION

Laramie Meadow (upper)	01-00
Laramie Meadow (lower)	02-00
Zimmerman Bench	03-00
Trap Park	04-00
Manhattan	05-00
Nunn Creek	06-00
Little Beaver	07-00
Crown Point	08-00
Pennock Creek	09-00
Young's Gulch	10-00
Kelly Flats	11-00
Sevenmile Creek	12-00
Home Moraine (general)	13-00
Home Moraine (saddle)	13-01
Home Moraine (south slope)	13-02
Rist Canyon	14-00
Seaman Reservoir	15-00
Bennett Creek	16-00
Pingree Hill	17-00
Hewlett Gulch (Metcalf Basin - general)	18-00
Hewlett Gulch (Metcalf Basin - draw)	18-01
Hewlett Gulch (Metcalf Basin - N. slope)	18-02
Hewlett Gulch (Metcalf Basin - S. slope)	18-03
Hewlett Gulch (Metcalf Basin - W. slope)	18-04

DATE

Days are numbered consecutively with day 1 as 1-1-62

Table 8. Mean concentrations of cesium-137 in winter range plant specimens collected at Young's Gulch, Seaman Reservoir, Bennett Creek, and Pingree Hill.*

Year	Location	Young's Gulch	Seaman Reservoir	Bennett Creek	Pingree Hill
	Species	Mountain Mahogany	Mountain Mahogany	Bitterbrush	Sagebrush
1962	August	3.63	----	4.58	----
	December	1.31	----	----	----
	Means	2.47	----	4.58	----
1963	March	1.16	----	----	----
	October	2.43	2.89	2.42	2.00
	December	1.44	1.87	2.14	1.77
	Means	1.68	2.38	2.28	1.89
1964	February	1.58	1.40	2.35	2.62
	April	2.02	2.24	1.84	3.05
	June	3.87	3.68	4.51	4.77
	Means	2.49	2.44	2.90	3.48

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 9. Mean concentrations of cesium-137 in winter range plant specimens collected at Kelly Flats and Rist Canyon.*

Year	Location	Kelly Flats		Rist Canyon	
	Species	Juniper	Bitterbrush	Mountain Mahogany	Juniper
1962	August	----	4.76	----	----
	December	----	2.04	----	----
	Means	----	3.40	----	----
1963	March	----	3.07	----	----
	October	4.14	2.02	2.19	5.04
	December	4.31	1.35	1.35	4.35
	Means	4.23	2.15	1.77	4.70
1964	February	5.11	1.81	1.06	3.67
	April	4.67	2.05	1.59	4.89
	June	5.24	3.80	4.00	6.21
	Means	5.01	2.55	2.22	4.92

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 10. Mean concentrations of cesium-137 in winter range plant specimens collected at Sevenmile Creek.*

Year	Month	Species			
		Mountain Mahogany	Bitterbrush	Sagebrush	Juniper
1962	August	3.28	----	4.04	----
	December	0.90	1.37	1.91	----
	Means	2.09	1.37	2.98	----
1963	March	1.01	1.69	1.74	----
	October	1.73	2.42	2.25	4.06
	December	1.36	2.03	2.77	4.09
	Means	1.37	2.05	2.25	4.08
1964	February	1.40	2.23	2.70	4.84
	April	1.44	2.44	4.15	5.75
	June	3.41	4.71	4.00	5.75
	September	1.27	1.22	1.41	4.42
	Means	1.88	2.65	3.07	5.19

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 11. Mean concentrations of cesium-137 in winter range plant specimens collected at Home Moraine.*

Year	Month	Species		
		Sagebrush	Juniper	Bitterbrush
1962	August	4.04	----	3.59
	December	1.66	----	1.36
	Means	2.85	----	2.48
1963	March	4.06	----	2.22
	October	2.70	5.28	4.26
	December	2.88	5.57	3.30
	Means	3.21	5.43	3.26
1964	February	3.36	5.17	3.69
	April	5.15	6.27	2.76
	June	6.92	6.98	7.02
	Means	5.14	6.14	4.49

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 12. Mean concentrations of cesium-137 in winter range plant specimens collected at Hewlett Gulch during 1964.*

Month	Site	Species		
		Bitterbrush	Mountain Mahogany	Juniper
February	Draw	1.92	1.28	3.71
	North	1.81	1.90	4.55
	South	2.18	1.57	3.07
	West	2.38	1.36	3.56
	Means	2.07	1.53	3.72
April	Draw	2.20	1.39	3.85
	North	2.34	1.64	3.90
	South	2.26	1.73	4.51
	West	2.12	1.68	4.17
	Means	2.23	1.61	4.11
June	Draw	5.85	4.84	4.40
	North	6.07	4.46	5.26
	South	6.14	4.38	5.45
	West	5.72	3.45	5.61
	Means	5.95	4.28	5.18
September	Draw	1.40	1.50	3.28
	North	1.85	1.27	5.77
	South	1.35	1.20	4.08
	West	2.06	1.27	4.78
	Means	1.67	1.31	4.48

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 13. Mean concentrations of cesium-137 in summer range plant specimens collected at Laramie Meadow (upper and lower combined).*

Year	Month	Species			
		Aspen	Willow	Hairgrass	Blueberry
1962	August	0.75	2.49	6.68	5.17
	September	0.61	1.59	3.80	1.24
	Means	0.68	2.04	5.24	3.21
1963	June	1.12	4.16	8.51	8.98
	July	1.86	4.31	9.15	11.88
	August	2.01	5.07	11.03	15.57
	September	1.90	3.59	13.15	14.45
	Means	1.72	4.28	10.46	12.72
1964	July	1.32	3.57	9.28	16.08
	August	0.93	2.33	5.07	12.31
	September	1.02	1.60	5.66	12.26
	Means	1.09	2.50	6.67	13.55

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 14. Mean concentrations of cesium-137 in summer range plant specimens collected at Zimmerman Bench.*

Year	Month	Species		
		Hairgrass	Blueberry	Mixed Grasses
1963	June	5.83	-----	3.67
	July	5.30	17.47	3.28
	August	5.54	8.86	4.13
	September	5.25	11.06	4.47
	Means	5.48	12.46	3.89
1964	July	19.27	14.12	12.60
	August	2.06	8.29	3.68
	September	6.89	9.86	4.81
	Means	9.41	10.76	7.03

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 15. Mean concentrations of cesium-137 in summer range plant specimens collected at Trap Park and Crown Point.*

Year	Location	Trap Park		Crown Point	
	Species	Willow	Mixed Grasses	Blueberry	Common Juniper
1963	July	----	----	7.62	5.77
	August	----	----	9.87	6.50
	September	3.33	8.98	10.89	6.52
	Means	3.33	8.98	9.46	6.26
1964	July	3.29	4.45	12.02	10.77
	August	1.72	1.75	9.38	8.09
	September	2.08	5.71	9.58	6.59
	Means	2.36	3.97	10.33	8.48

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 16. Mean concentrations of cesium-137 in summer range plant specimens collected at Manhattan.*

Year	Month	Species		
		Common Juniper	Aspen	Mixed Forbs
1963	July	5.12	2.82	3.43
	August	4.53	3.02	4.93
	September	4.87	3.64	8.87
	Means	4.84	3.16	5.74
1964	July	5.77	2.26	1.98
	August	2.99	1.29	1.74
	September	2.35	1.09	3.11
	Means	3.70	1.55	2.28

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 17. Mean concentrations of cesium-137 in summer range plant specimens collected at Nunn Creek.*

Year	Month	Species				
		Hairgrass	Bog Birch	Willow	Mixed Forbs	Mixed Grasses
1963	July	10.59	6.48	4.51	10.19	6.15
	August	16.63	7.72	6.15	12.65	11.87
	September	18.70	5.74	5.44	13.40	16.89
	Means	15.31	6.65	5.37	12.08	11.64
1964	July	5.47	8.07	6.01	5.62	8.98
	August	2.13	2.77	3.66	4.83	2.59
	September	3.46	2.17	2.03	4.84	5.04
	Means	3.69	4.34	3.90	5.10	5.54

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 18. Mean concentrations of cesium-137 in summer range plant specimens collected at Little Beaver Creek.*

Year	Month	Species				
		Bog Birch	Aspen	Willow	Mixed Forbs	Mixed Grasses
1962	September	----	2.34	----	----	----
	Means	----	2.34	----	----	----
1963	July	4.35	2.41	5.26	3.23	4.30
	August	5.85	2.77	6.23	5.13	6.68
	September	4.18	3.29	4.39	5.69	4.41
	Means	4.79	2.82	5.29	4.68	5.13
1964	July	4.79	1.51	3.10	2.77	3.73
	August	2.38	0.99	1.81	4.19	1.97
	September	2.58	0.91	1.41	2.50	2.93
	Means	3.25	1.14	2.11	3.15	2.88

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 19. Mean concentrations of cesium-137 in summer range plant specimens collected at Pennock Creek.*

Year	Month	Species		
		Aspen	Blueberry	Mixed Forbs
1963	July	0.41	10.22	6.15
	August	3.13	11.57	8.44
	September	3.23	11.42	11.86
	Means	2.26	11.07	8.82
1964	July	1.91	9.44	3.89
	August	1.10	6.10	4.61
	September	1.10	6.75	3.54
	Means	1.37	7.43	4.01

*Cesium-137 concentrations given in terms of picocuries per gram air dry material.

Table 20. Comparison of mean Cesium-137 concentrations in various plant species collected from Laramie (1) during Summer, 1964.

Means (pc/g air dry material):

	Plant Species		
	Hairgrass	Blueberry	Means
July	10.78	16.08	13.43
August	5.27	12.31	8.79
September	7.03	12.26	9.64
Means	7.70	13.55	

Analysis of Variance:

Source	DF	MS	F
Species	1	205.218	115.8**
Date	2	48.820	27.6 **
Interaction	2	2.097	1.2 N.S.
Error	18	1.772	

** Statistically significant at the 1 per cent level.
N.S. - Not significant.

Table 21. Comparison of mean Cesium-137 concentrations in various plant species collected from Laramie (2) during Summer, 1964.

Means (pc/g air dry material):

	Plant Species			
	Hairgrass	Aspen	Willow	Means
July	7.77	1.32	3.57	4.22
August	4.87	0.93	2.33	2.71
September	4.29	1.02	1.60	2.30
Means	5.64	1.09	2.50	

Analysis of Variance:

Source	DF	MS	F
Species	2	65.126	61.1 **
Date	2	12.219	11.5 **
Interaction	4	2.896	2.7 N.S.
Error	27	1.066	

** Statistically significant at the 1 per cent level.
N.S. - Not significant.

Table 22. Comparison of mean Cesium-137 concentrations in various plant species collected from Zimmerman Bench during Summer, 1964.

Means (pc/g air dry material):

	Plant Species			
	Hairgrass	Blueberry	Mixed Grasses	Means
July	19.27	14.12	12.60	15.33
August	2.06	8.29	3.68	4.67
September	6.89	9.86	4.81	7.19
Means	9.41	10.76	7.03	

Analysis of Variance:

Source	DF	MS	F
Species	2	42.868	7.0 **
Date	2	371.658	61.1 **
Interaction	4	36.925	6.1 **
Error	27	6.085	

** Statistically significant at the 1 per cent level.

Table 23. Comparison of mean Cesium-137 concentrations in various plant species collected from Trap Park during Summer, 1964.

Means (pc/g air dry material):

	Plant Species		
	Willow	Mixed Grasses	Means
July	3.29	4.45	3.87
August	1.72	1.75	1.74
September	2.08	5.71	3.90
Means	2.36	3.97	

Analysis of Variance:

Source	DF	MS	F
Species	1	15.504	26.6 **
Date	2	12.285	21.0 **
Interaction	2	6.770	11.6 **
Error	18	0.584	

** Statistically significant at the 1 per cent level.

Table 24. Comparison of mean cesium-137 concentrations in various plant species collected from Manhattan during summer, 1964.

Means (pc/g air dry material):

	Plant Species			
	Aspen	Common Juniper	Mixed Forbs	Means
July	2.26	5.77	1.98	3.34
Aug.	1.29	2.99	1.74	2.01
Sept.	1.09	2.35	3.11	2.19
Means	1.55	3.70	2.28	

Analysis of variance:

Source	DF	MS	F
Species	2	14.185	37.9 **
Dates	2	6.046	16.2 **
Interaction	4	5.215	13.9 **
Error	27	0.374	

**Statistically significant at the 1 per cent level.

Table 25. Comparison of mean cesium-137 concentrations in various plant species collected from Nunn Creek during summer, 1964.

Means (pc/g air dry material):

	Plant Species					
	Hairgrass	Willow	Mixed Grasses	Bog Birch	Mixed Forbs	Means
July	5.47	6.01	8.98	8.07	5.62	6.83
Aug.	2.13	3.66	2.59	2.77	4.83	3.19
Sept.	3.46	2.03	5.04	2.17	4.84	3.51
Means	3.68	3.90	5.54	4.34	5.10	

Analysis of variance:

Source	DF	MS	F
Species	4	7.466	4.5 **
Dates	2	81.087	48.7 **
Interaction	8	7.686	4.6 **
Error	45	1.664	

**Statistically significant at the 1 per cent level.

Table 26 Comparison of mean cesium-137 concentrations in various plant species collected from Little Beaver during summer, 1964.

Means (pc/g air dry material):

	Plant Species					
	Aspen	Willow	Mixed Grasses	Bog Birch	Mixed Forbs	Means
July	1.51	3.10	3.73	4.79	2.77	3.18
Aug.	0.99	1.81	1.97	2.38	4.19	2.27
Sept.	0.91	1.41	2.93	2.58	2.50	2.06
Means	1.14	2.11	2.88	3.25	3.15	

Analysis of variance:

Source	DF	MS	F
Species	4	9.422	15.5 **
Dates	2	7.062	11.6 **
Interaction	8	2.510	4.1 **
Error	45	0.608	

**Statistically significant at the 1 per cent level.

Table 27. Comparison of mean Cesium-137 concentrations in various plant species collected from Crown Point during Summer, 1964.

Means (pc/g air dry material):

	Plant Species		
	Blueberry	Common Juniper	Means
July	12.02	10.77	11.40
August	9.38	8.09	8.74
September	9.58	6.59	8.08
Means	10.33	8.48	

Analysis of Variance:

Source	DF	MS	F
Species	1	20.295	9.3 **
Date	2	24.646	11.3 **
Interaction	2	1.961	0.9 N.S.
Error	18	2.178	

** Statistically significant at the 1 per cent level.
N.S. -Not significant

Table 28. Comparison of mean Cesium-137 concentrations in various plant species collected from Pennock Creek during Summer, 1964.

Means (pc/g air dry material):

	Plant Species			
	Blueberry	Aspen	Mixed Forbs	Means
July	9.44	1.91	3.89	5.08
August	6.10	1.10	4.61	3.94
September	6.75	1.10	3.54	3.80
Means	7.43	1.37	4.01	

Analysis of Variance:

Source	DF	MS	F
Species	2	110.643	118.8 **
Date	2	6.017	6.5 **
Interaction	4	4.336	4.7 **
Error	27	0.931	

** Statistically significant at the 1 per cent level.

Table 29. Comparison of mean Cesium-137 concentrations in sagebrush collected from various locations during 1964.

Means (pc/g air dry material):

	Locations			
	Sevenmile Creek	Home Moraine	Pingree Hill	Means
February	2.70	4.15	4.00	3.62
April	3.36	5.15	6.92	5.14
June	2.62	3.05	4.77	3.48
Means	2.89	4.12	5.23	

Analysis of Variance:

Source	DF	MS	F
Locations	2	2.563	16.8 **
Dates	2	4.092	26.8 **
Interaction	4	0.499	3.3 *
Error	27	0.153	

* Statistically significant at the 5 per cent level.
** Statistically significant at the 1 per cent level.

Table 30. Comparison of mean Cesium-137 concentrations in mountain mahogany collected from various locations during 1964.

Means (pc/g air dry material):

	Locations					
	Young's Gulch	Sevenmile Creek	Rist Canyon	Seaman Reservoir	Hewlett Gulch	Means
February	1.58	1.40	1.06	1.40	1.53	1.39
April	2.02	1.44	1.59	2.24	1.61	1.78
June	3.87	3.41	4.01	3.68	4.28	3.85
Means	2.49	2.08	2.22	2.44	2.47	

Analysis of Variance:

Source	DF	MS	F
Locations	4	0.097	2.5 N.S.
Dates	2	8.734	229.3 **
Interaction	8	0.082	2.2 *
Error	45	0.038	

* Statistically significant at the 5 per cent level.
** Statistically significant at the 1 per cent level.
N.S. Not significant.

Table 31. Comparison of mean Cesium-137 concentrations in juniper collected from various locations during 1964.

Means (pc/g air dry material):

	Locations					
	Hewlett Gulch	Rist Canyon	Kelly Flats	Sevenmile Creek	Home Moraine	Means
February	3.72	3.10	5.11	4.84	5.17	4.39
April	4.11	4.89	4.67	5.75	6.27	5.14
June	5.18	6.21	5.24	5.75	6.98	5.87
Means	4.34	4.73	5.00	5.44	6.14	

Analysis of Variance:

Source	DF	MS	F
Location	4	1.444	10.5 **
Date	2	2.755	20.1 **
Interaction	8	0.363	2.6 *
Error	45	0.137	

* Statistically significant at the 5 per cent level.
** Statistically significant at the 1 per cent level.

Table 32. Comparison of mean Cesium-137 concentrations in bitterbrush collected from various locations during 1964.

Means (pc/g air dry material):

	Locations					
	Kelly Flats	Sevenmile Creek	Home Moraine	Bennett Creek	Hewlett Gulch	Means
February	1.81	2.23	3.69	2.35	2.07	2.43
April	2.05	2.44	2.76	1.83	2.23	2.26
June	3.80	4.71	7.02	4.51	5.95	5.20
Means	2.55	3.12	4.49	2.90	3.42	

Analysis of Variance:

Source	DF	MS	F
Locations	4	1.628	35.2 **
Dates	2	13.570	293.3**
Interaction	8	0.333	7.2 **
Error	45	0.046	

** Statistically significant at the 1 per cent level.

Table 33. Comparison of mean cesium-137 concentrations in bog birch collected at various locations during summer, 1964.

Means (pc/g air dry material):

	Locations		
	Nunn Creek	Little Beaver	Means
July	8.07	4.79	6.43
Aug.	2.77	2.38	2.57
Sept.	2.17	2.58	2.37
Means	4.34	3.25	

Analysis of variance:

Source	DF	MS	F
Locations	1	7.096	11.6 **
Dates	2	41.780	68.4 **
Interaction	2	7.525	12.3 **
Error	18	0.611	

**Statistically significant at the 1 per cent level.

Table 34. Comparison of mean cesium-137 concentrations in hair-grass collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations				
	Laramie Meadow(1)	Laramie Meadow(2)	Zimmerman Bench	Nunn Creek	Means
July	10.79	7.77	19.27	5.47	10.82
Aug.	5.28	4.87	2.06	2.13	3.58
Sept.	7.03	4.29	6.89	3.46	5.42
Means	7.70	5.64	9.41	3.68	

Analysis of variance:

Source	DF	MS	F
Locations	3	73.996	34.7 **
Dates	2	226.652	106.3 **
Interaction	6	48.508	22.7 **
Error	36	2.133	

**Statistically significant at the 1 per cent level.

Table 35. Comparison of mean cesium-137 concentrations in common juniper collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations		
	Manhattan	Crown Point	Means
July	5.77	10.77	8.27
August	2.99	8.09	5.54
September	2.35	6.59	4.47
Means	3.70	8.48	

Analysis of variance:

Source	DF	MS	F
Locations	1	138.192	80.252 **
Dates	2	30.224	17.552 **
Interaction	2	0.470	0.273 N.S.
Error	18	1.722	

** Statistically significant at the 1 per cent level.
N.S. Not significant.

Table 36. Comparison of mean cesium-137 concentrations in aspen collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations				
	Laramie(2)	Manhattan	Little Beaver	Pennock Creek	Means
July	1.32	2.26	1.51	1.91	1.75
Aug.	0.93	1.29	0.99	1.10	1.08
Sept.	1.02	1.09	0.91	1.10	1.03
Means	1.09	1.55	1.14	1.37	

Analysis of variance:

Source	DF	MS	F
Locations	3	0.539	15.2 **
Dates	2	2.608	73.7 **
Interaction	6	0.144	4.1 **
Error	36	0.035	

**Statistically significant at the 1 per cent level.

Table 37. Comparison of mean cesium-137 concentrations in willow collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations				
	Laramie(2)	Trap Park	Nunn Creek	Little Beaver	Means
July	3.57	3.29	6.01	3.10	3.99
Aug.	2.33	1.72	3.66	1.81	2.38
Sept.	1.60	2.08	2.03	1.41	1.78
Means	2.50	2.36	3.90	2.11	

Analysis of variance:

Source	DF	MS	F
Locations	3	7.749	8.6 **
Dates	2	20.846	23.2 **
Interaction	6	1.619	1.8 N.S.
Error	36	0.900	

** Statistically significant at the 1 per cent level.
N.S. Not significant.

Table 38. Comparison of mean cesium-137 concentrations in blueberry collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations				
	Laramie(1)	Zimmerman	Crown Point	Pennock Creek	Means
July	16.08	14.12	12.02	9.44	12.91
Aug.	12.31	8.29	9.38	6.10	9.02
Sept.	12.26	9.86	9.58	6.75	9.61
Means	13.55	10.75	10.33	7.43	

Analysis of variance:

Source	DF	MS	F
Locations	3	75.292	45.6 **
Dates	2	70.647	42.8 **
Interaction	6	2.096	1.3 N.S.
Error	36	1.652	

** Statistically significant at the 1 per cent level.
N.S. Not significant.

Table 39. Comparison of mean cesium-137 concentrations in mixed forbs collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations				
	Manhattan	Nunn Creek	Little Beaver	Pennock Creek	Means
July	1.98	5.62	2.77	3.89	3.57
Aug.	1.74	4.83	4.19	4.61	3.84
Sept.	3.11	4.84	2.50	3.54	3.50
Means	2.28	5.10	3.15	4.01	

Analysis of variance:

Source	DF	MS	F
Locations	3	17.424	22.5 **
Dates	2	0.543	0.7 N.S.
Interaction	6	2.315	3.0 *
Error	36	0.774	

* Statistically significant at the 5 per cent level.
** Statistically significant at the 1 per cent level.
N.S. Not significant.

Table 40. Comparison of mean cesium-137 concentrations in mixed grasses collected from various locations during summer, 1964.

Means (pc/g air dry material):

	Locations				
	Zimmerman	Trap Park	Nunn Creek	Little Beaver	Means
July	12.60	4.45	8.98	3.73	7.44
Aug.	3.68	1.75	2.59	1.97	2.50
Sept.	4.81	5.71	5.04	2.93	4.62
Means	7.03	3.97	5.54	2.88	

Analysis of variance:

Source	DF	MS	F
Locations	3	39.436	8.2 **
Dates	2	98.078	20.5 **
Interaction	6	18.926	4.0 **
Error	36	4.789	

**Statistically significant at the 1 per cent level.

Table 41. Ratios of cesium-137 concentrations for leaves and stems of plants collected in September, 1964.

Sample No.	Rep.	Species	Location	Leaf Cs-137/stem Cs-137 Ratio	Location mean	Species mean
319	1	aspen	Laramie Meadow	2.89		
	2	"	"	2.31		
	3	"	"	1.74		
	4	"	"	2.63	2.39	
327	1	aspen	Little Beaver	2.39		
	2	"	"	2.41		
	3	"	"	3.80		
	4	"	"	4.26	3.22	
333	1	aspen	Pennock Creek	4.47		
	2	"	"	4.99		
	3	"	"	2.46		
	4	"	"	4.83	4.19	
337	1	aspen	Manhatten	2.67		
	2	"	"	2.77		
	3	"	"	5.15		
	4	"	"	3.03	3.41	3.30
312	1	bog birch	Nunn Creek	1.73		
	2	"	"	1.43		
	3	"	"	1.37		
	4	"	"	1.34	1.47	
328	1	bog birch	Little Beaver	0.85		
	2	"	"	0.94		
	3	"	"	1.08		
	4	"	"	1.24	1.03	1.25
317	1	blueberry	Laramie Meadow	1.15		
	2	"	"	1.13		
	3	"	"	1.24		
	4	"	"	1.20	1.18	
322	1	blueberry	Zimmerman	0.89		
	2	"	"	1.12		
	3	"	"	0.85		
	4	"	"	1.13	1.00	

Table 41, Continued.

Sample No.	Rep.	Species	Location	Leaf Cs-137/stem Cs-137 Ratio	Location mean	Species mean
331	1	blueberry	Pennock Creek	0.90		
	2	"	"	0.86		
	3	"	"	1.04		
	4	"	"	0.93	0.93	
335	1	blueberry	Crown Point	0.85		
	2	"	"	0.97		
	3	"	"	1.11		
	4	"	"	1.02	0.99	1.03
313	1	willow	Nunn Creek	2.13		
	2	"	"	2.25		
	3	"	"	1.67		
	4	"	"	1.84	1.97	
320	1	willow	Laramie Meadow	2.71		
	2	"	"	3.65		
	3	"	"	2.85		
	4	"	"	3.64	3.21	
325	1	willow	Trap Park	1.39		
	2	"	"	2.50		
	3	"	"	2.10		
	4	"	"	2.70	2.17	
326	1	willow	Little Beaver	2.84		
	2	"	"	2.56		
	3	"	"	3.40		
	4	"	"	2.00	2.70	2.51
342	1	bitterbrush	Sevenmile	1.37		
	2	"	"	1.31		
	3	"	"	1.40		
	4	"	"	1.96	1.51	
344	1	bitterbrush	Hewlett Gulch	1.47		
	2	"	"	1.14		
	3	"	"	1.36		
	4	"	"	1.80	1.44	1.48

Table 41, Continued.

Sample No.	Rep.	Species	Location	Leaf Cs-137/stem Cs-137 Ratio	Location mean	Species mean
340	1	mahogany	Sevenmile	3.26		
	2	"	"	3.45		
	3	"	"	3.03		
	4	"	"	3.53	3.32	
345	1	mahogany	Hewlett Gulch	3.45		
	2	"	"	3.01		
	3	"	"	3.59		
	4	"	"	3.36	3.35	3.34
339	1	sagebrush	Sevenmile	1.36		
	2	"	"	0.67		
	3	"	"	1.23		
	4	"	"	1.06	1.08	1.08

Table 42. Concentrations of cesium-137 in deer muscle tissues and supplementary information.

No.	Sex	Age*	Date	Location S	T	R	Elevation	pc Cs-137 per Kg
A- 38	F	56	2-20-62	27	9	71	6,900	227
A- 39	M	44	2-27-62	2	8	72	7,100	304
A- 40	M	21	3- 8-62	36	9	74	8,000	305
A- 48	F	144	5- 2-62	28	9	72	7,800	417
A- 49	M	23	5- 9-62	34	9	74	7,800	490
A- 50	F	23	5-16-62	26	9	73	8,400	503
A- 51	F	11	5-23-62	6	8	72	7,400	497
A- 52	M	11	5-30-62	33	9	73	7,500	868
A- 53	M	12	6- 6-62	5	7	75	9,100	960
A- 54	M	24	6-13-62	30	8	72	8,500	859
A- 55	M	24	6-20-62	14	9	74	9,200	1274
A- 56	F	60	6-27-62	3	6	75	10,200	982
A- 57	F	25	7- 9-62	33	10	75	10,100	1060
A- 58	F	13	7-16-62	29	7	75	10,500	1115
A- 59	F	37	7-23-62	25	10	75	10,000	604
A- 60	M	61	7-30-62	9	7	72	8,500	636
A- 61	F	26	8- 6-62	25	7	76	10,700	1280
A- 62	F	13	8-13-62	33	8	75	8,700	508
A- 63	M	14	8-20-62	2	9	75	10,000	588
A- 64	F	25	8-27-62	27	7	75	10,100	905
A- 65	M	84	9- 5-62	14	9	74	9,400	413
A- 66	F	38	9-11-62	18	7	75	9,600	637
A- 67	M	15	9-18-62	15	9	75	9,700	566
A- 68	M	15	9-27-62	21	9	73	8,400	492
A- 69	F	28	10- 4-62	29	9	73	7,700	658
A- 70	M	16	10-10-62	19	9	73	9,000	643
A- 71	F	4	10-18-62	4	8	71	5,900	584
A- 72	F	40	10-23-62	3	8	72	6,700	476
A- 73	F	112	11-15-62	19	9	71	6,900	466
A- 74	M	30	11-21-62	28	9	70	5,600	714
A- 75	F	113	11-28-62	27	9	72	7,700	497
A- 76	M	6	12- 5-62	18	9	70	6,400	538
A- 77	F	54	12-12-62	22	9	73	8,400	574
A- 78	M	54	12-19-62	15	8	70	5,700	686
A- 79	F	114	12-26-62	33	9	74	7,800	492
A- 80	M	55	1- 2-63	17	9	71	7,100	648
A- 81	M	55	1- 9-63	28	9	70	5,700	533
A- 82	F	67	1-16-63	33	9	74	7,700	779
A- 83	F	115	1-23-63	2	8	72	7,000	715

*Ages estimated in terms of months by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks, by the tooth replacement and wear method (Robinette et al. 1957).

Table 42, Continued.

No.	Sex	Age*	Date	Location S	T	R	Elevation	pc Cs-137 per Kg
A- 84	F	55	1-30-63	28	8	70	6,300	724
A- 85	M	32	2- 6-63	32	9	74	8,000	602
A- 86	M	8	2-13-63	27	9	72	7,600	678
A- 87	M	20	2-20-63	2	8	71	6,000	601
A- 88	F	44	2-27-63	35	9	74	7,700	509
A- 89	M	69	3- 6-63	7	8	72	7,500	643
A- 90	F	117	3-13-63	2	8	73	7,600	735
A- 91	F	105	3-20-63	17	9	71	6,800	1006
A- 92	M	21	3-27-63	15	8	70	5,500	495
A- 93	F	106	4- 8-63	5	8	72	6,900	558
A- 94	M	10	4-15-63	34	9	73	7,200	640
A- 95	F	58	4-22-63	18	9	70	5,900	590
A- 96	M	10	4-29-63	4	8	71	6,300	884
A- 97	F	11	5- 6-63	24	9	73	8,000	716
A- 98	F	107	5-13-63	17	9	72	7,900	582
A- 99	M	35	5-20-63	3	8	73	8,200	718
A-100	M	83	5-27-63	22	9	73	8,400	905
A-101	F	48	6- 5-63	14	8	73	8,000	1053
A-102	M	60	6-12-63	13	9	74	9,100	872
A-103	F	12	6-19-63	21	7	75	9,900	1725
A-104	F	0.5	6-26-63	8	8	73	8,600	1235
A-105	M	109	7- 2-63	34	10	75	10,100	1252
A-106	F	12	7- 9-63	31	8	75	9,400	1603
A-107	F	25	7-16-63	25	7	76	10,500	2515
A-108	M	13	7-23-63	26	7	75	10,000	2071
A-109	F	37	7-30-63	27	7	73	9,500	1262
A-110	F	50	8- 6-63	3	9	75	10,000	1009
A-111	M	14	8-13-63	22	7	75	9,400	1577
A-112	F	50	8-20-63	2	6	76	10,200	1208
A-113	M	15	9- 6-63	5	7	75	9,000	3310
A-114	M	3	9-10-63	3	9	75	9,900	2601
A-115	F	39	9-18-63	8	9	72	8,100	1404
A-116	F	27	9-25-63	20	7	73	9,000	1393
A-117	F	4	10- 1-63	26	10	74	8,900	1409
A-118	F	16	10- 8-63	9	8	73	8,500	1206
A-119	M	4	10-16-63	7	8	73	8,900	1682
A-120	F	112	10-22-63	2	8	71	5,900	944
A-121	F	5	11-12-63	20	8	71	7,400	1002
A-122	M	65	11-20-63	13	9	71	6,700	913
A-123	M	17	11-26-63	7	9	70	6,400	1648

*Ages estimated in terms of months by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks, by the tooth replacement and wear method (Robinette et al. 1957).

Table 42, Continued

No.	Sex	Age*	Date	Location S	T	R	Elevation	pc Cs-137 per Kg
A-124	M	18	12- 4-63	27	9	72	7,500	937
A-125	F	54	12-10-63	5	8	72	6,900	963
A-126	F	114	12-17-63	1	8	74	8,000	1112
A-127	M	18	12-26-63	24	9	73	9,000	1944
A-128	F	19	1- 7-64	29	9	73	7,600	760
A-129	M	7	1-14-64	23	9	73	6,500	466
A-130	F	139	1-21-64	29	9	73	8,000	1541
A-131	M	55	1-28-64	27	9	73	8,400	791
A-132	M	20	2- 4-64	8	9	70	6,500	403
A-133	M	56	2-11-64	5	8	72	7,000	783
A-134	F	116	2-18-64	36	9	74	7,400	1620
A-135	M	8	2-25-64	32	9	72	7,100	905
A-136	F	33	3- 3-64	28	8	70	5,900	471
A-137	F	21	3-10-64	33	9	71	6,900	935
A-138	M	105	3-17-64	35	9	74	8,000	904
A-139	F	9	3-24-64	27	8	70	6,000	393
A-140	F	10	4- 2-64	33	9	72	7,500	1069
A-141	F	130	4- 7-64	36	9	74	7,600	1454
A-142	M	94	4- 8-64	32	9	74	7,900	1113
A-143	F	46	4-21-64	31	9	70	5,600	787
A-144	M	118	4-28-64	19	9	72	7,600	713
A-145	M	47	5- 5-64	32	9	70	5,600	505
A-146	F	47	5-12-64	12	8	72	6,400	708
A-147	M	59	5-19-64	26	9	73	8,400	526
A-148	F	23	5-26-64	33	9	74	8,000	597
A-149	M	36	6- 2-64	21	9	72	7,900	770
A-150	M	72	6- 9-64	13	9	74	9,100	841
A-151	F	108	6-16-64	7	8	72	7,400	638
A-152	F	24	6-23-64	24	7	73	9,700	1442
A-153	F	60	6-30-64	27	7	75	10,200	2224
A-154	M	121	7- 7-64	3	9	75	10,000	1404
A-155	F	37	7-13-64	24	7	76	9,800	1076
A-156	F	25	7-20-64	35	7	76	10,200	752
A-157	F	25	7-28-64	18	8	73	9,300	763
A-158	F	14	8- 4-64	27	7	75	10,200	847
A-159	F	62	8-11-64	2	6	75	10,100	1484
A-160	M	14	8-17-64	24	7	76	9,900	1111
A-161	M	2	8-25-64	33	8	75	9,400	757
031	F	3	9- 9-64	25	9	70	5,500	984
A-162	M	15	9- 9-64	34	7	75	10,200	795

*Ages estimated in terms of months by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks, by the tooth replacement and wear method (Robinette et al. 1957).

Table 42, Continued.

No.	Sex	Age*	Date	Location S	T	R	Elevation	pc Cs-137 per Kg
A-163	F	15	9-15-64	28	8	74	10,900	693
A-164	F	15	9-21-64	24	9	74	9,000	639
A-165	M	15	9-29-64	18	8	73	9,500	664
A-166	F	4	10- 5-64	13	9	73	7,700	1168
A-167	M	28	10-12-64	14	9	74	9,400	564
A-168	M	40	10-20-64	18	9	72	7,700	472
A-169	F	41	11- 4-64	18	9	70	6,300	675
A-170	M	29	11-10-64	1	8	72	6,900	1265
A-171	M	77	11-17-64	32	9	73	7,600	782
A-172	M	5	11-23-64	4	8	71	6,500	857
A-173	F	78	12- 8-64	19	9	70	6,400	742
A-174	M	18	12-15-64	17	9	71	6,900	508
A-175	M	30	12-23-64	33	10	71	6,400	676
A-176	M	19	1- 5-65	29	9	73	7,500	566
A-177	F	7	1-12-65	5	8	72	7,100	583
A-178	M	103	1-19-65	3	9	71	6,100	511
A-180	F	20	2- 3-65	35	9	72	6,900	728
A-181	F	80	2-10-65	33	9	73	7,500	840
A-182	M	8	2-17-65	5	8	72	6,900	835
A-183	F	104	2-24-65	5	8	72	6,900	625
A-184	F	21	3- 3-65	35	9	74	7,600	533
A-185	M	81	3-11-65	35	9	72	6,900	750
A-186	F	93	3-17-65	33	9	73	7,400	652
A-187	M	57	3-24-65	29	9	73	7,900	794
A-188	M	9	3-31-65	34	9	72	6,600	613

*Ages estimated in terms of months by D. E. Medin and A. E. Anderson, Colorado Department of Game, Fish, and Parks, by the tooth replacement and wear method (Robinette et al. 1957).

Table 43. Mean cesium-137 concentrations in muscle, mean ages, and mean collection elevations of all deer collected between February, 1962 and March, 1965.

Variable	Group	Sample Size	Means	Standard Deviation	Coefficient of Variation
Muscle Cs-137(1)	Males	68	870	516	0.59
	Females	75	903	425	0.47
	All Data	143	887	469	0.53
Age(2)	Males	68	37	32	0.85
	Females	75	50	40	0.80
	All Data	143	44	37	0.83
Elevation(3)	Males	68	7879	1328	0.17
	Females	75	8129	1424	0.18
	All Data	143	8010	1380	0.17

(1) In terms of picocuries per kilogram.
(2) In terms of months.
(3) In terms of feet above sea level.

Table 44. Correlations between age, elevation, and muscle concentrations of cesium-137 for all deer collected between February, 1962 and March, 1965.

Variables X	Variables Y	Group	Sample Size	Correlation Coefficient
Elevation	Age	Males	68	0.016 N.S.
		Females	75	-0.298 **
		All Data	143	-0.152 N.S.
Elevation	Muscle Cs-137	Males	68	0.387 **
		Females	75	0.477 **
		All Data	143	0.429 **
Age	Muscle Cs-137	Males	68	-0.119 N.S.
		Females	75	-0.078 N.S.
		All Data	143	-0.087 N.S.

N.S. Not statistically significant.
** Statistically significant at the 1 per cent level.

Abstract of Dissertation

FACTORS INFLUENCING THE ACCUMULATION
OF FALLOUT CESIUM-137 IN MULE DEER

This investigation was concerned with factors influencing the accumulation of fallout cesium-137 in a wild population of mule deer, Odocoileus hemionus, in the Cache la Poudre drainage of north-central Colorado.

Air, precipitation, soils, twelve deer forage species, and deer were sampled periodically from various elevations within the study area over a three year period. Experimental sampling designs were primarily factorial with sufficient replication to allow statistical treatment of data. Materials were assayed for Cs-137 using the technique of gamma-ray spectrometry.

Air concentrations of Cs-137 were maximal in 1963. Concentrations were significantly higher during spring and early summer months of each year.

Maximum deposition of Cs-137 by precipitation in 1964 occurred during April, May, and June. Measureable quantities of fallout were transported by dust, pollens, and other air-borne debris during dry, windy periods.

The majority of Cs-137 in soils was located in the 0-1 inch layer. Soil radioactivity generally increased with elevation and associated higher average precipitation rates.

Maximum vegetational levels of Cs-137 were observed in 1963.

Species collected during the summer and fall above 8,500 feet were generally higher in cesium than species collected during the winter and spring from lower elevations. Significant differences between species growing on the same plots were found. Significant differences in Cs-137 concentrations of given species between locations were also encountered. The location effect was attributed mostly to phenomena associated with elevation. Leaves were generally higher in Cs-137 than stems.

Maximum levels of Cs-137 in deer were observed in 1963. Maximum levels within years occurred during the summer months in animals collected above 8,500 feet elevation. Regression analyses of muscle Cs-137 versus elevation indicated significant correlations. Evidence indicated a high degree of correlation between Cs-137 levels in vegetation and deer. It was concluded that the degree of foliage contamination and food habits were the most important factors contributing to Cs-137 burdens in deer. A Cs-137/K discrimination factor between the diet and muscle of 0.9 was estimated from the rumen samples. Neither sex or age produced statistically significant variations in muscle Cs-137.

Inhalation, the drinking of surface waters, and the ingestion of snow were minor sources of Cs-137 intake by deer in comparison to the ingestion of forage.

Floyd Ward Whicker
Department of Radiology and
Radiation Biology
Colorado State University
May 7, 1965