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FALLOUT STRONTIUM-90 AND CESIUM-137 IN NORTHERN ALASKAN ECOSYSTEMS DURING 1959-1970

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DISCLAIMER

Frontispiece. Anaktuvuk Pass village site under new snow and returning sun. February 8, 1970.

DISSERTATION

FALLOUT STRONTIUM-90 AND CESIUM-137 IN NORTHERN ALASKAN ECOSYSTEMS DURING 1959-1970

Submitted by

Wayne Carlyle Hanson

In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

Colorado State University

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May, 1973

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY Wayne Carlyle Hanson ENTITLED FALLOUT STRONTIUM-90 AND CESIUM-137 IN NORTHERN ALASKAN ECOSYSTEMS DURING 1959-1970 BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Committee on Graduate Work

Adviser

Head of Department

"And then Danny he say: 'But if we got that way, what we use for making fire, Robert?'"

"And I say: We burn coal, Danny."

"Coal? What's coal, Robert?"

"It's a kind of rock that burns, Danny."

"Rock? A rock that burns, Robert?"

"That right, Danny. This is Brooks Range -- wild country!"

--From a story of adventure
told by a _nunamiut_ hunter

ABSTRACT OF DISSERTATION

FALLOUT STRONTIUM-90 AND CESIUM-137 IN NORTHERN ALASKAN ECOSYSTEMS DURING 1959-1970

Cycling routes, rates of transport, and resultant concentrations of the fallout radionuclides strontium-90 and cesium-137 in northern Alaskan ecosystems were defined during the period 1959-1970. Radiochemical analysis of extensive samples of biota and whole-body counting of ^{137}Cs in Eskimo and Indian ethnic groups were related to ecological principles, especially the concept of trophic niche, which elucidated the observed patterns of radionuclide concentrations. Experiments involving strontium and cesium radioisotopes applied to natural *Cladonia-Cetraria* lichen carpets yielded effective half-times of 1.0 to 1.6 years for strontium and more than 10 years for cesium. Direct and indirect estimates of ^{137}Cs half-times in Eskimos on a caribou meat diet were made by dietary manipulation and by relating dietary ^{137}Cs intake and resultant change between periodic whole body counts. Effective half-times of 70 days for adults (more than 21 years old) and minors (14-20 years old) and of 45 days for children (less than 14 years old) were found. Cesium-137 concentrations measured in 9 lichen species collected at 20 sampling sites across the 389,000 km^2 study area showed significant differences between physiogeographic provinces, with highest amounts in those samples from areas of highest annual precipitation. Similar geographic differences were found in comparison of caribou flesh from Alaskan herds; greatest amounts occurred in southern herds and least amounts in Arctic herd animals. Cesium-137 body burdens of native ethnic groups were correlated with their dependence upon caribou meat for the food base; highest amounts were consistently measured in Anaktuvuk Pass Eskimos, median amounts in river village Eskimos and interior Athapascan Indians, and lowest amounts occurred in coastal Eskimos who utilized marine mammals and other food sources. Suitable mathematical models were used to compute lichen forage ingestion rates of free-ranging adult caribou (4.5 to 5.0 kg dry weight per day), caribou meat ingestion rates of Anaktuvuk Pass residents (up to 2 kg wet weight per day for men), and ^{90}Sr body burdens of Anaktuvuk Pass residents during the period 1952-1968 (maximum value of 8 nCi in adult males during late 1966-early 1967). Special emphasis was made of cultural influences upon the food-gathering patterns of the native peoples studied. Culture change, especially in the form of food stamps, welfare payments, acquisition of snowmobiles, and "improved" housing was documented throughout the study and noticeably reduced the radionuclide accumulations. Total radiation dose rates to the Anaktuvuk Pass adult population were estimated to be about 100 mrad/year from natural sources, 60 to 140 mrad/year from ^{137}Cs body burdens, and 20 to 130 mrad/year from ^{90}Sr body burdens.

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CHAPTER I

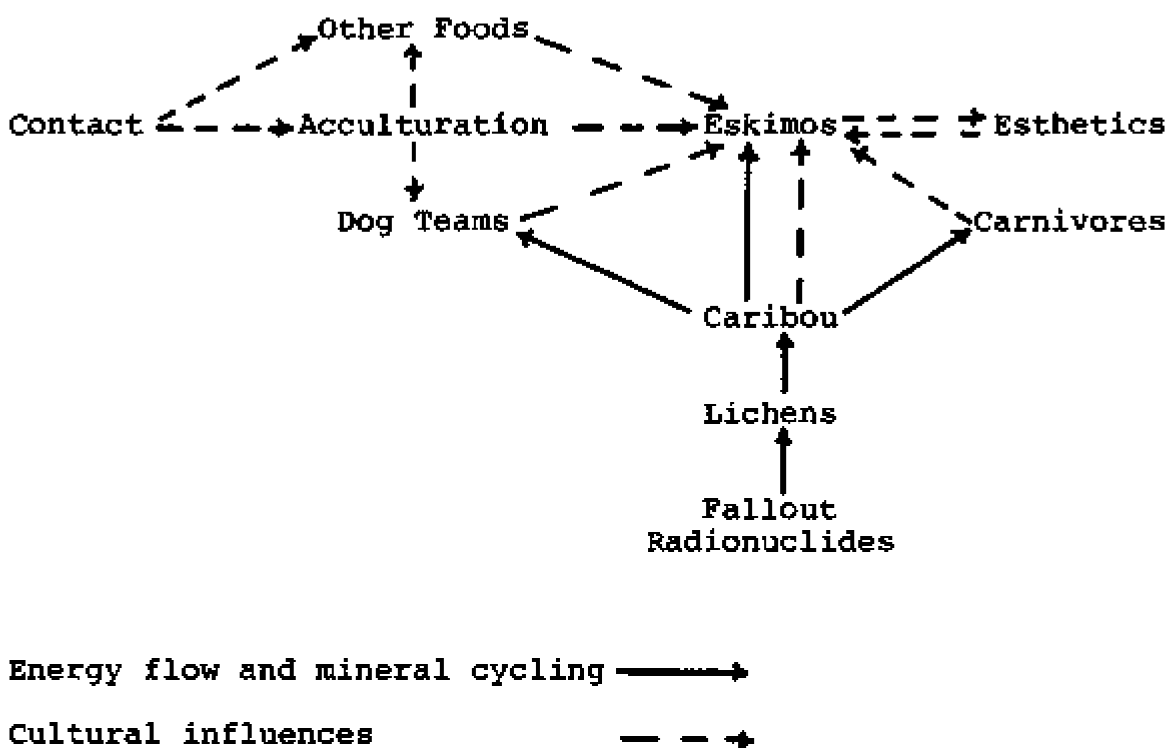
INTRODUCTION

Arctic ecosystems have been noted for their relative simplicity of structure since the early definitive work of Elton (1927, 1933) in the understanding of basic relationships such as food webs, food chains, and trophic levels. Temperature is the predominant limiting factor, enhanced by a long period of winter darkness which accentuates heat loss without compensatory incoming radiation. Conversely, the 24-hour daylight of midsummer imposes an appreciable annual temperature range upon the environment and requires many special adaptations of the arctic inhabitants. The biota of the circumpolar regions are, therefore, relatively few in species and adaptive; these properties recommend them for studies which may lead to better understanding of more complex systems elsewhere.

The concentration of radioactive fallout within various components of arctic ecosystems has been extensively studied during recent years as a consequence of the transmission of significant amounts of radionuclides to human populations. This has resulted from the simple, short food webs of the arctic regions, the dependence of northern peoples upon subsistence hunting and fishing for much of their food; and the retention by lichens of measurable amounts of fallout radionuclides, especially ^{90}Sr and ^{137}Cs, deposited upon northern landscapes, especially following the 1961-1963 series of atmospheric nuclear weapons tests conducted by Britain, France, Russia, and the United States. Several artificial radionuclides are of only transitory interest for one or more of the following reasons: (1) their short physical half-life rapidly removes them from the environment, as in the case of iodine-131; (2) they exist in trace amounts often measurable only by intricate radiochemical methods, such as sodium-22, iron-55, cobalt-60, yttrium-88, silver-110^{m}, and antimony-125; or (3) they are "biologically inactive", such as zirconium-95, ruthenium-106, and cerium-144, and their associated daughters. Studies of these radionuclides in Alaskan arctic ecosystems have previously been reported (Hanson et al., 1963; Palmer and Beasley, 1965; Hanson, Watson, and Perkins, 1966). In addition, samples of Alaskan biota have been furnished to other investigators for analyses of the natural fallout radionuclides lead-210, polonium-210, and their progenitor radium-226; their reports are also available (Beasley and Palmer, 1966; Holtzman, 1966 and 1968).

This Dissertation will discuss routes, rates of transport, and resultant concentrations of the artificial fallout radionuclides ^{90}Sr and ^{137}Cs in northern Alaskan biota during the period 1959-1970, with the implication that the results may apply widely to trace materials in arctic environments. Major emphasis will be made to relate ecological and cultural data to a lucid understanding and explanation of cycling phenomena, food web transfer, and distribution of these radionuclides throughout circumpolar regions. From that standpoint, the following discourse may draw many parallels with radiation ecology studies conducted in several other areas of the world. However, this Dissertation is principally oriented toward the northern Alaskan peoples; and specifically emphasizes the interrelationships of the people and their associated ecosystems as related to radionuclide accumulation. It was, after all, the definition of the consequences of radioactive fallout to northern populations that prevailed as the primary objective of the studies to be described and justified the ancillary areas of investigation. As the studies progressed, it became apparent that cultural considerations were vital to determining which of several pathways might be most important to radionuclide concentration. The intensive study of the Brooks Range ecosystems, of which the nunamiut Eskimos of Anaktuvuk Pass are an integral part, brought the relationship of basic ecological and cultural features into sharp focus.

To set the cultural background against which the radiation ecology data are to be presented, I have first chosen to describe the history of the Anaktuvuk Pass people within recent times so that an appreciation of their heritage may be considered. In this way the reader may discern the rationale for many of the studies of radionuclides that were undertaken and follow the relationships that were established between the people and other ecosystem components. The response of the nunamiut culture to initial contact with the white man and the ensuing acculturation can then be viewed from the standpoint of its impact upon radionuclide accumulation. The application of radiation ecology data and techniques to the definition of food web transfer of energy and mineral cycling provides new and revealing insight into functional aspects of a biome more dynamic than commonly supposed. Finally, the radiological health aspects of fallout within the arctic ecosystems are considered as a facet of the future into which the nunamiut move with equanimity. As a guide to the presentation of the material, a diagram relates the various elements to the central theme; as follows:



CHAPTER II

HISTORICAL PERSPECTIVE

Radiation ecology studies in northern Alaska began in July 1959 as a part of the Hanford Laboratories participation in the comprehensive environmental program designed to establish baseline data for the evaluation of environment consequences of Project Chariot. Project Chariot was a proposal to excavate a harbor on the northwestern coast of Alaska using buried nuclear devices, as part of the United States Atomic Energy Commission's Plowshare Program. The objectives of the radiation ecology studies were to provide background radioactivity measurements and predictions of radionuclide routes of concentration through ecosystems typical of northern Alaska.

Early results showed appreciable concentrations of the worldwide fallout radionuclides, especially strontium-90 and cesium-137, in lichens and caribou of the region and suggested that the nearby subsistence hunting societies of Eskimos were an important next step in the food web for investigation.

Attempts to obtain biopsy samples of human flesh and bone through United States Public Health Service hospitals during 1960 and 1961 were mostly unsuccessful; however, a semi-portable shadow shield whole body counter had been developed at the Hanford Laboratories during 1961 which provided the capability of measuring whole body burdens of gamma-emitters in Alaskan villagers. Accordingly, a major portion of the Alaskan studies effort in 1962 was devoted to a modified research program which had as its objectives the definition of ^{137}Cs body burdens in several native Eskimo and Indian populations of various food-gathering cultures and identifying routes by which these body burdens were obtained. All persons were interviewed about their food habits and samples of various natural and processed foods were analyzed for radionuclides. The survey was repeated during the summer of 1963, expanded to include an additional interior Indian village of greater subsistence hunting base, and a State-wide sampling of moose, reindeer, and caribou herds was undertaken to investigate spatial and species differences in radionuclide concentrations. Information obtained from the native peoples concerning their food habits, seasonal availability of various animals, migration patterns of caribou, and the background of ecological knowledge gained in five summers of field experience suggested that another major revision of the Alaskan radiation ecology studies was in order.

In January 1964, a shadow shield whole body counter was permanently installed in a rented sod house (ivrulik) at Anaktuvuk Pass for the purpose of conducting periodic measurements of ^{137}Cs body burdens of the inland Eskimo population with the objective of defining the seasonal pattern of ^{137}Cs in the people, suggested by previous observations. Whole-body counts were made at five crucial times per year, associated with caribou migrations and dietary changes by the people. A sampling program was also initiated to obtain routine samples of caribou, carnivores, and lichens at Anaktuvuk Pass in order to study in detail the radionuclide transport mechanisms in that unique ecosystem.

The importance of lichens as a reservoir of fallout radionuclides suggested a field experiment involving retention of strontium and cesium radioisotopes to determine loss rate constants and possible cycling phenomena. Such experiments using ^{85}Sr, ^{90}Sr, ^{134}Cs, and ^{137}Cs applied as droplets to individual lichen podetia and as a ^{85}Sr-^{134}Cs water solution sprinkled upon a representative Cladonia-Cetraria lichen carpet were begun in July 1964 and July 1965. These experiments continued until sampling was completed, varying from one year for ^{85}Sr to four years for ^{137}Cs. An unfortunate interruption in the studies occurred during the period August 1965-May 1966, due to administrative difficulties, and considerable effort was required to re-establish the momentum of the studies. During that period a simplified method of measuring ^{137}Cs human body burdens was developed at the Hanford Laboratories (now known as Battelle-Northwest) which allowed greater mobility by reducing the equipment to a total weight of about 20 kg. Several radiological health agencies immediately built such equipment from published schematics and results of broad surveys of ^{137}Cs in native populations of the United States and foreign countries created some confusion in interpretation. Accordingly, a special study was made of seasonal ^{137}Cs body burdens in native residents of three northern Alaskan villages of contrasting food-gathering cultures. Objectives of the study were to correlate ^{137}Cs body burdens with shifts in caribou migrations, environmental and cultural factors, and availability of other foods. The study began in October 1966 and continued through October 1968, at which time sufficient information was available to warrant reduction of whole-body counting to semi-annual measurements and at Anaktuvuk Pass only.

Studies of radionuclides in lichens were expanded in 1967 to define spatial, temporal, and species differences in order to explain so-called "hot spots" in radiological health agency data. Ten lichen species were collected at 21 sampling locations throughout northern Alaska and near the mouth of the Mackenzie River in northwest Canada during July-August 1967 and annual samples were obtained from three major caribou wintering ranges south of the Brooks Range through 1970. Continued sampling of all trophic levels of the Anaktuvuk Pass lichen-caribou-carnivore/man food web provided a standard for comparison with other areas and for input data for a theoretical simulation model of ^{137}Cs in the arctic food chain. This model was periodically updated by special studies mentioned above and by a human ^{137}Cs half-time study of four Eskimo families supplied beef and fowl in place of caribou for the month of August 1965.

At the time we began studies of native peoples of northern Alaska, cultural change was proceeding at a modest pace, particularly at Anaktuvuk Pass. An anthropologist had completed a 15-month study of the nunamiut Eskimo less than a year prior to our first contact with those people and provided a firm basis for comparative observations. Subsistence hunting and trapping was the accepted life-style, dogteams were at their maximal development, permanent sod houses (ivrulit) had recently replaced the caribou skin tents (itchellit) as winter quarters, canvas tents were still used for summer living, and the village had been stabilized for two years prior to our arrival in the summer of 1962. These conditions prevailed for two more years, and then there began a series of event that dramatically changed the nunamiut culture. The snowmobile appeared initially in January 1964 and within three years almost completely replaced dogteams for traction. It also created dissention within the village, and otherwise changed the Eskimo culture pattern. In 1967, the willows used for fuel by the Eskimos were exhausted and a major crisis ensued; a proposal to move the village to an abandoned oil exploration camp some 75 miles north of Anaktuvuk Pass divided the villagers into two fractions, one proposing the move and the other opposing. The situation was resolved at a meeting of village representatives with officials of 23 State and Federal agencies. Out of this came the decision to retain the village at its historic site with an agreement by Federal agencies to furnish fuel, stoves, and limited frame-house building supplies. New houses were begun during the next two years, and by 1970 the last of the original families settling Anaktuvuk Pass in 1951-1952 had achieved a "white man house". Fortunately, I kept a rather complete field journal during the conduct of northern studies and recorded the events of this vital period of adjustment of the <u>nunamiut</u> Eskimos. The documentation of changing traits was of direct relevance to the radionuclide studies and explains many of the important shifts in ^{137}Cs body burdens of the people; however the continuous record of events that materially changed the course of one of the few remaining subsistence hunting cultures of the arctic regions is of comparable value. The consideration of Eskimo cultural change as it related to the radiation ecology studies is somewhat superficial, with the prospect of discussing it fully in another publication.

CHAPTER III

DESCRIPTION OF THE STUDY AREA

Radiation ecology studies were conducted over the general area of northern Alaska between 66° North Latitude and the Arctic Ocean. Most of this 150,000 square miles (389,000 km^2) lies within the Arctic life zone, as defined by the 10°C July isotherm of Koppen and Geiger (1934). This boundary roughly approximates the northern limits of tree growth and seems ecologically more reasonable than the usual definition of the area north of the Arctic Circle (66° 33' N latitude).

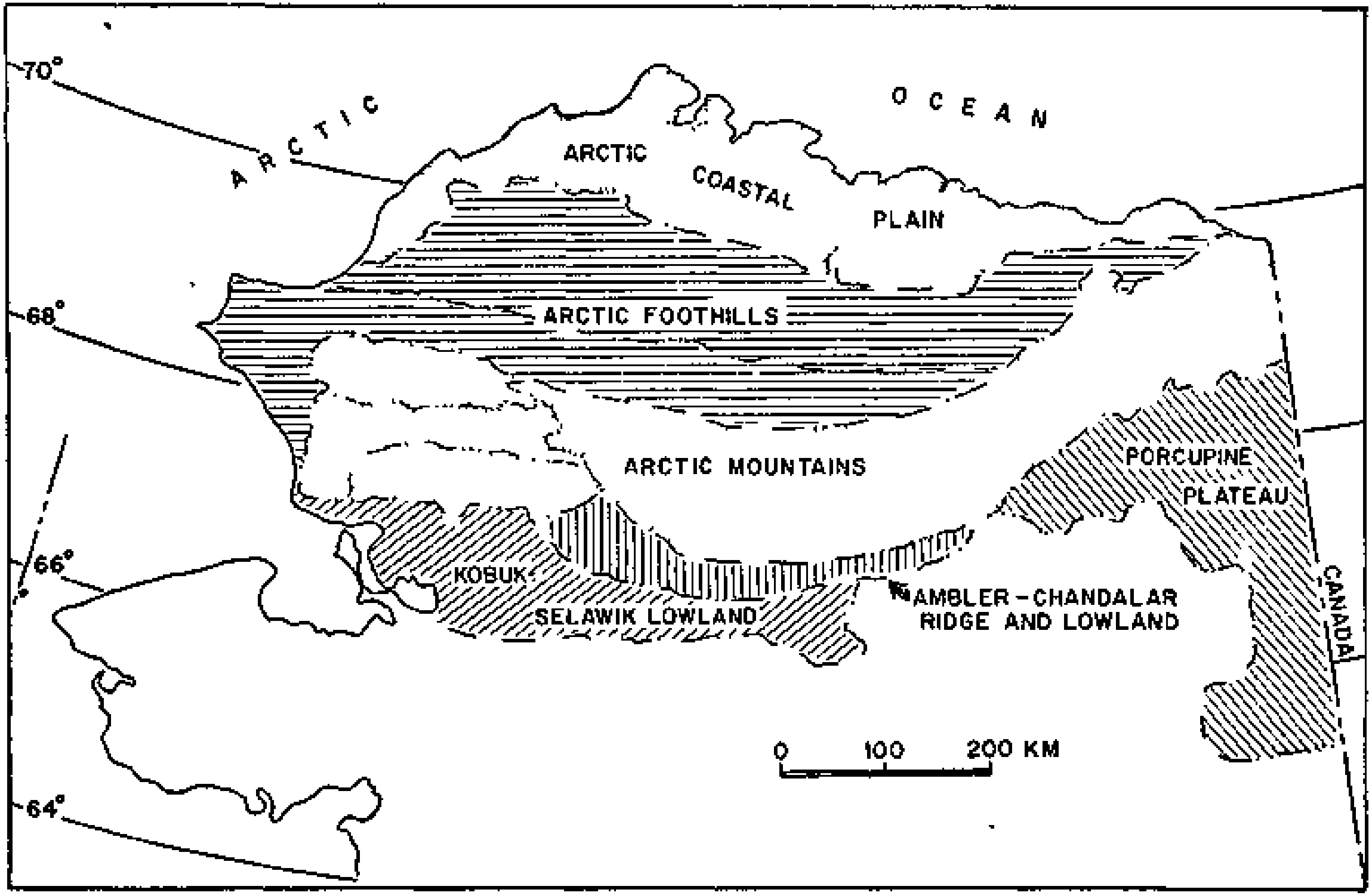
Within this area are five major physiogeographic provinces, the northwestern terminus of the North American continental divide, two major caribou herds which constitute the largest aggregation of big game animals in North America, and several Eskimo and Indian villages representing four major ethnic groups. A spectrum of ecosystems of varying complexity are utilized by the migratory caribou herds and by the native groups inhabiting the regions.

Physiogeographic Provinces of the Study Area

The most recent description of landforms of northern Alaska is that of Wahrhaftig (1965), upon which the following discussion and Figure 1 are based.

The Arctic Coastal Plain, a northern extension of the Great Plains of interior North America, consists of a smooth plain rising imperceptibly from the Arctic Ocean to a

Figure 1. Physiogeographic provinces of northern Alaska (after Wahrhaftig, 1965).


70°
68°
66°
64°
ARCTIC
OCEAN
ARCTIC
COASTAL
PLAIN
ARCTIC FOOTHILLS
ARCTIC MOUNTAINS
PORCUPINE
PLATEAU
KOBUK-
SELAWIK LOWLAND
AMBLER-CHANDALAR
RIDGE AND LOWLAND
CANADA
0
100
200 KM

maximum altitude of 180 m at its southern margin. It is poorly drained, marshy in summer, and the Teshekpuk Lake Section (Fig. 2) (western three-fourths of the Province) is covered by elongated thaw lakes oriented WNW-ESE at right angles to the prevailing wind direction, which are in a constant state of formation and obliteration (Carson and Hussey, 1962). There are no glaciers, although the entire land area is underlain by more than 300 m of permafrost (substrate in which a temperature of 0 C or below has continuously existed for more than two years). A network of ice-wedge polygons covers the Coastal Plain, mostly oriented parallel and perpendicular to receding shorelines because of the stress differences set up by horizontal temperature gradients; random polygons are formed in areas of more uniform stress. An active layer (depth of summer thaw) varies from about one to ten decimeters and allows limited percolation of moisture. A characteristic feature of this arctic tundra is the pingo, a rounded or conical ice-cored turf mound varying in height from one to a hundred meters elevation. These were formed when water trapped under great pressure within layers of permafrost or beneath the permafrost broke through the confining frozen ground and immediately froze, forming a great blister of ice just beneath the turf.

The Arctic Foothills Province consists of rolling plateaus and low linear mountains extending southward from the Arctic Coastal Plain (Fig. 3). Two sections are recognized: The Northern, which rises from 180 m on the north

Figure 2. Photograph of typical Arctic Coastal Plain Province landscape. Shallow lakes, braided streams, and sedge (*Carex*) meadows typify this Province.

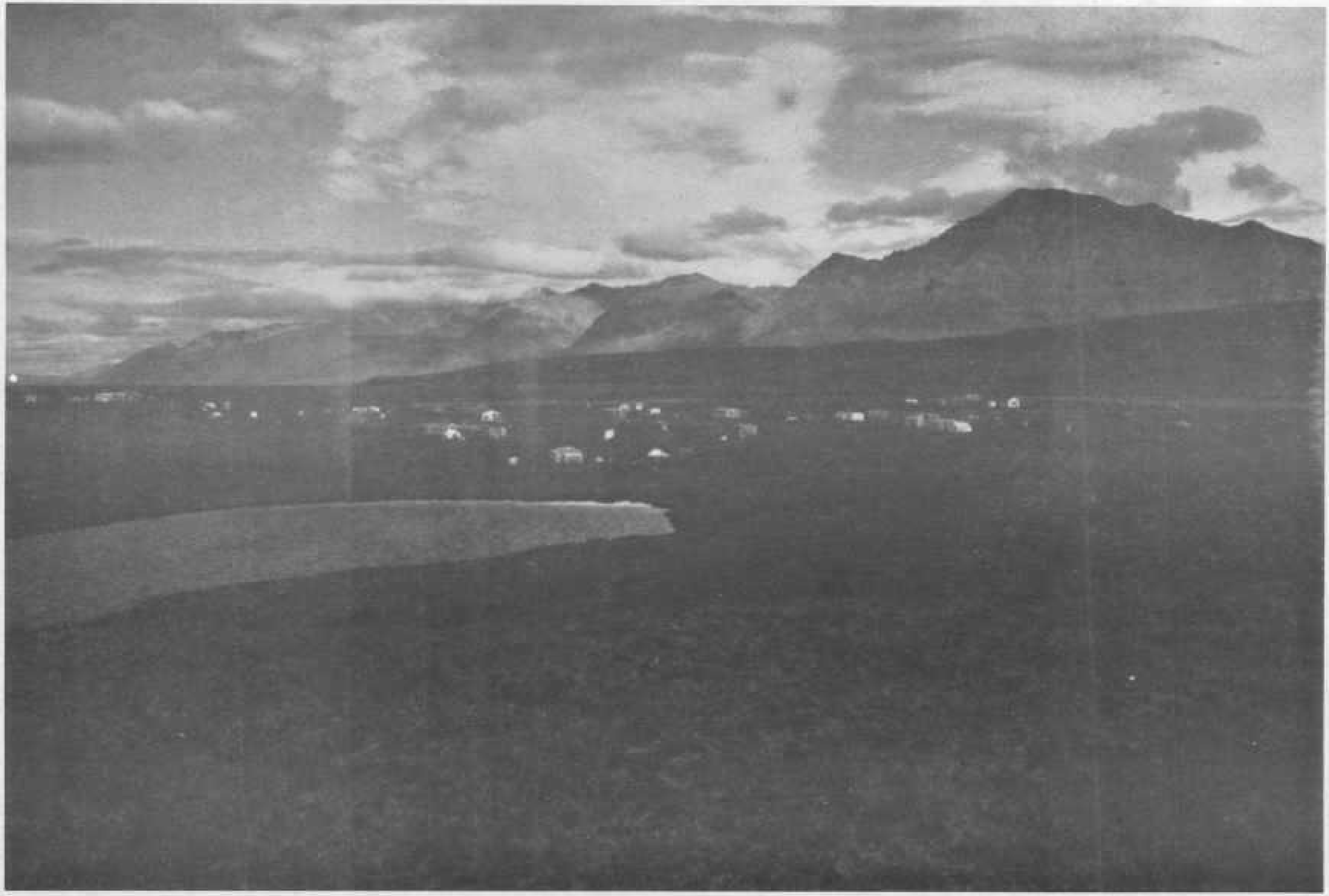
Figure 3. Photograph of typical Arctic Foothills Province landscape. Rolling hills in foreground are mostly covered by *Eriophorum* tussocks, with *Salix* on braided river bars and along small stream courses. Brooks Range mountains in the background.

to 350 m elevation on the south, with broad east-trending ridges dominated by mesa-like mountains; and the Southern, mostly elevations of 350-450 m, with local relief up to 750 m, characterized by irregular buttes, knobs, mesas, east-trending ridges, and intervening gently undulating tundra plains. In common with the Coastal Plain, there are no glaciers and the entire province is underlain by permafrost. The substrate contains ice wedges, stone stripes, polygonal ground, and other features of a frost climate.

The Arctic Mountains Province consists of features carved chiefly from folded and overthrust Paleozoic and Mesozoic sedimentary rocks during Pleistocene glaciation. It is subdivided into four sections: (1) Delong Mountains, with their western terminus near Cape Thompson on the northwest coastline, a central part of rugged glaciated ridges of 1,200-1,500 m elevation with local relief of 450-900 m; many mountain passes of about 1,070 m altitude; an irregular and indistinct northern boundary with the Arctic Foothills Province, and an abrupt southern front; no lakes or glaciers; and completely underlain by permafrost; (2) Noatak Lowlands, consisting of two broad lowlands surrounded by hills and separated by a rolling upland that lays along the Noatak River, no glaciers, entirely underlain by permafrost, and containing many pingos; (3) Baird Mountains, a section of moderately rugged mountains with rounded to sharp 750-900 m summits rising abruptly from lowlands on the south and west; a sub-summit upland along the crest of the mountains slopes gently northward and contains groups of higher (1,100-1,300 m) mountains which were centers of glaciation in Pleistocene time; and there are no lakes or glaciers; and (4) the Central and Eastern Brooks Range (Fig. 4), a wilderness of rugged glaciated east-trending ridges of 2,100-2,400 m elevation in the northern part and 1,200-1,800 m in the southern part. It is characterized by a paucity of lakes for a glaciated area, but large rock-basin lakes lie at the mouths of several glaciated valleys on the north and south sides of the Range. Small cirque glaciers are common in higher parts of the Range, such as the 2,700 m Schwatka and Romanzof Mountains in the northeast section. Along the southern margin of the Brooks Range is the Ambler-Chandalar Ridge and Lowland, which consists of one or two east-trending lines of lowlands and low passes 5-15 km wide and 60-600 m above sea level, bordered on the north by the abrupt front of the Brooks Range. Along the south side is a discontinuous line of rolling to rugged ridges which are 40-120 km long and 10-20 km wide, rising to 2,100-1,700 m; some of these ridges were intensely glaciated. Several large lakes fill ice-carved rock basins in deep narrow canyons across the southern ridge. Flood plains of major streams have thaw lakes and oxbow lakes. There are no glaciers in this Section, but it is underlain by continuous permafrost.

Bordering the southeastern section of the Brooks Range is the Porcupine Plateau, which is physiogeographically similar to the Ambler-Chandalar Ridge and Lowland and

Figure 4. Photograph of typical Brooks Range, Arctic Mountains Province landscape, with Anaktuvuk Pass village site in middle background. Elevations are 600 m at village and 2,100-2,400 m on surrounding mountains.



Kobuk-Selawik Lowland to the west. These areas mainly occupy major river valleys and serve as major wintering ranges for caribou.

Soils of the Study Area

Detailed descriptions of soils of the study area have been made by Tedrow et al. (1958) and Holowaychuk et al. (1966). In general, the Arctic Coastal Plain and Foothills Provinces are mostly covered by Intrazonal Tundra and Bog soils, usually strongly acid and saturated by water. These soils are of least importance in the mountains, where they are confined to the valleys. Arctic Brown is the zonal soil (a well-developed profile in which the dominating influences of climate and vegetation are expressed) of the north slope of the Brooks Range, but occurs on only about one percent of the area; it is most common in dry, well-drained environments of the Foothills Province. Regosols (soils underlain with soft rock) occur in youthful areas of well-drained alluvial, aeolian, talus, and outwash deposits. Lithosols (soils in which the A, or mineral, horizon rests on hard rock) are characteristic of the mountain areas, where erosion prevents cumulative effects of soil-forming processes.

Climate of the Study Area

Northern Alaska's climate is extremely variable due to the dominance of anticyclonic circulation over the polar cap and the existence of a high pressure dome throughout most of the year. Lower layer circulation is conditioned by interaction of the arctic anticyclone with intense cyclones of Icelandic and Aleutian low pressure areas (Allen and Weedfall, 1966). The Brooks Range channels cold air flow around the western end and through mountain passes, such as Anaktuvuk Pass. These winds are of greatest importance, both in average velocity and in total number reaching sustained gale force, during the coldest months of the year. This produces windchill, a parameter more important to survival of biota than the actual temperature reading and an important ecological factor. Mean annual temperatures for the various provinces (Johnson and Hartman, 1959) are as follows:

Arctic Coastal Plain:	-12 C
Arctic Foothills:	-11 C
Brooks Range:	- 9.5 C
Ambler-Chandalar Ridge and Lowland:	- 6.5 to -5.0 C

A more meaningful concept of temperature may be had by consideration of the seasonal temperature variation, which is one-half the difference between the mean July temperature and the mean January temperature:

Arctic Coastal Plain:	18 C
Arctic Foothills:	18 C
Brooks Range:	19 C
Ambler-Chandalar Ridge and Lowland:	20 C

Taken together, these temperature regimes illustrate the maritime climate that prevails along the coast and slightly inland due to moderation by the cool waters of the Arctic Ocean. Following the ice break-up on the Arctic Ocean, varying from late May near Kotzebue to late June near Barrow, the temperature of the surface layer of water rises from freezing to about 10 C by late July and then gradually cools to about -1.5 C prior to freezing in late October.

The greater temperature range in the interior portion of Alaska reflects the continental climate, where summer maxima above 28 C are not uncommon and winter lows often range to -40 C to -45 C.

Precipitation in the various sectors of the study area is difficult to measure because of the sparsity of weather stations and the appreciable wind that affects the readings. Annual averages range from 10-20 cm on the Arctic Coastal Plain and Foothills, 20-30 cm in the Brooks Range, and about 45-50 cm in the Lowland provinces. This classifies the Arctic Coastal Plain and Foothills provinces as "cold deserts" (less than 39 cm annual precipitation) (Odum, 1971: 392); however, the conservation of moisture by permafrost preventing percolation maintains a moist environment. Mean annual snowfall has been estimated (Johnson and Hartman, 1959) at 50-75 cm on the Arctic Coastal Plain, 75-125 cm in the Foothills, 125-200 cm in the Brooks Range, and about 200 cm in the Lowland provinces. In all but the eastern (interior) sectors of the Lowland provinces wind makes snowfall measurements highly variable, and the various ecological considerations of snow cover (Formozov, 1946) usually outweigh mere depth as a criterion of environmental importance.

Vegetation of the Study Area

The following discussion of plant communities of northern Alaska synthesizes the vascular plant studies of Spetzman (1951) for the North Slope in general; Britton (1967) for the Arctic Coastal Plain; Churchill (1955) and Johnson *et al.* (1966) for the Arctic Foothills; and Hanson (1953) and Sigafoos (1958) for the Lowland physiogeographic provinces. Lichens associated with these communities and provinces are described from my own experience.

The Arctic Coastal Plain is typified by relatively simple plant communities composed of few species distributed over a few habitats, usually characterized by extreme wetness. Most plant species are rather ubiquitous and the communities are highly dependent upon microrelief. Dominant plants are the grass or grass-like species such as *Arctophila fulva*, *Carex aquatilis*, *Eriophorum scheuchzeri*, *E. angustifolium*, *Dupontia fischeri*, and *Alopercurus alpina* which may individually occur in essentially pure stands or in various mixtures between certain of the species over thousands of acres. Peat ridges, resulting from deposits of several moss species, surround the polygons and accent microrelief. These ridges are often grassy in aspect, with *Poa arctica*, *Luzula confusa*, and *L. nivalis* the principal cover. A considerable ground cover of mosses and such lichens as *Thamnolia vermicularis* and *Dactylina arctica* are typical, and the early-flowering *Saxifraga oppositifolia* occurs in scattered stands. Cracks around the polygon margins provide bare silt areas which are occupied by *Salix pulchra*, *Petasites frigidus*, and *Potentilla hyparctica*; polygon centers support *Saxifraga hirculis*, *Eutrema* spp. and *Melandrium* sp. Thaw ponds often support *Arctophila fulva* in the deepest parts (usually about 1 m), with *Hippuris vulgaris* and *Ranunculus pallasii* in shallow areas, and successively grading into *Carex aquatilis* and *Eriophorum scheuchzeri* in margins.

The Arctic Foothills generally present an appearance of

> ". . . gently rolling hills with dense vegetation 6-12 inches high consisting of dwarf heath shrubs, dwarf birches and willow, intermingled herbaceous species and, in places, alders and willows occasionally form thickets, especially on slopes and on the flood-plain" (Churchill, *op. cit.*).

This area is predominantly covered by tussocks of *Eriophorum vaginatum* and the associated Dwarf Shrub Heath Type (Churchill, *op. cit.*): *Carex* spp., *Arctogrostis latifolia*, *Empetrum nigrum*, *Ledum decumbens*, *Vaccinium vitis-idaea*, *Betula nana*, *Arctostaphylos alpina*, *Alnus crispa*; and *Salix* spp. Mosses are abundant, usually associated with lichens such as *Cetraria cucullata*, *Dactylina arctica*, *Stereocaulon paschale*, *Cladonia* spp., and *Peltigera* spp. which colonize the interspaces between tussocks. Poorly drained polygonally patterned ground of lowlands and river terraces is usually occupied by the Carex aquatilis-marsh type of vegetation typical of the Coastal Plain. Lakes contain rooted emergent species distributed in zones correlated with water depth; common members are Potamogeton spp., Sparaganium hyperboreum, and Hippuris vulgaris. Vegetation of the river flood-plains and terraces is dominated by Salix alaxensis, grading into increasing cover of Alnus crispa with increasing elevation and better drainage, with an understory of heath and marsh types of vegetation. Dry meadows on upper terraces grade into the lower mountain slopes, with the characteristic shared plant species. At the western end of the Foothills Province near Cape Thompson, the proportion of dominant habitat types was 39% Eriophorum tussock, 30% Dryas fell-field, and 12% Eriophorum-Carex wet meadow (Johnson et al., 1966).

In the Brooks Range, dry meadows of the lower slopes are mostly covered with Dryas spp., with several grasses such as Arctogrostis latifolia, Calamagrostis purpurea, and Hierchloe alpina; dryland sedges and rushes, such as Carex spp., Kobresia myocuroides, and Luzula confusa; low shrubs, such as Empetrum nigrum, Vaccinium vitis-idaea, and Salix spp., and many forbs. Wetter slopes, glacial moraines, and alluvial fans are covered by tussock communities of Eriophorum vaginatum, with associated species characteristic of the type found in the Foothills Province, with which it frequently intergrades. Talus slopes are clothed in vegetation often specific to limestone, sandstone, basalt, or shale; Oxytropis mertensiana is common to most of these, with Crepis nana, Descurainia sophioides, Epilobium angustifolium, and Ermania borealis found characteristically on shale. Crevice populations at elevations of 1,000-1,300 m are often dominated by Saxifraga spp., heaths, grasses, and ferns. Cassiope tetragona frequently flourishes in areas of late snow patches. Upper slopes of the mountains are nearly devoid of vascular plants, while crustose lichens of several genera are abundant. In the more extreme habitats, such as that represented by the northwest side of 2,800 m Mt. Chamberlain in the northeast corner of Alaska, Luzula confusa, Potentilla elegans, and Selaginella siberica are common dominants near the upper limits of vascular vegetation at 1,700-1,800 m above sea level. Lichen communities of major importance to caribou frequenting the Brooks Range tend to occupy terraces, alluvial fans, and moraines along valley floors where moisture gradients are accented by the microrelief. Cladonia alpestris, C. rangiferina, Cetraria cucullata, and Alectoria ochroleuca form extensive mats in association with mosses, Betula nana, Cassiope tetragona, Salix alaxensis and Carex spp. These communities are most extensive in rolling topography, where snow accumulates during winter storms. Small rills in the mats tend to support nearly continuous dendritic outlines of Cetraria richardsonii. Cornicularia divergens colonizes ridgetops, where a centimeter or less of snow provides only limited protection to that species.

Cetraria delisei and *Stereocaulon paschale* are most frequently found in deeper snow accumulation areas in sheltered depressions.

The Ambler-Chandalar Ridge and Lowland, the Kobuk-Selawik Lowland and the Porcupine Plateau are outwardly similar, with the Spruce-Birch Association (Sigafoos, *op. cit.*) predominating in those major river valleys. Major tree species are the white spruce (*Picea glauca*), black spruce (*Picea marianna*) and several birches (*Betula* spp.). Balsam popular (*Populus balsamifera*) occurs on river flood plains, and often pioneers beyond the northern limit of white spruce. The "tree line" approximates the 10 C July isotherm and extends to the middle of the Brooks Range in river valleys, progressing from spruce and poplar to alder and birch to willow and birch at mountain passes of about 600 m. Beneath the tree canopy is a carpet of dwarf shrub types and the *Eriophorum*-*Carex*-Swarf Heath Shrub complex (Hanson, 1953) containing several lichens. This type of habitat is primary winter range for a majority of the Arctic and Porcupine caribou herds. Pure and mixed stands of *Cladonia alpestris*, *C. rangiferina*, *Cetraria cucullata* and *Stereocaulon paschale* cover vast acreages, particularly in the more open spruce forests.

Biotic Communities of the Study Area

Many plants and animals occur in natural associations, as noted by several authors who have termed them "biotic communities" (Phillips, 1931) or "biocoenoses" to delimit them from the abiotic components. The most complete study of such communities in northern Alaska was that of Bee and Hall (1956), who discussed the terrestrial biotic communities of the North Slope. These proceeded from the wettest environments of the Arctic Coastal Plain to the driest habitats in the Foothills and Brooks Range Provinces as follows:

A. Carex aquatilis-Microtus oeconomus; the early stage of the hydrosere, occurring in the wettest places. Reaches optimum development on the Coastal Plain and areas of low elevation along major drainage systems, such as canyon floors in the Brooks Range and Foothills.

B. Meadow grass (damp)-Lemmus trimucronatus; an intermediate stage of the hydrosere associated with damp soils. Optimum development occurs on the Coastal Plain, especially near Barrow.

C. Forb-Marmota monax; a late converging sere of the xerosere and hydrosere. Best developed on damp soils on canyon slopes in protected microrelief.

D. Eriophorum vaginatum-Dicrostonyx groenlandicus; sereclimax of the hydrosere. Best developed on elevated well-drained areas, such as undulating uplands of the Foothills Province and higher ridges of the Coastal Plain Province.

E. Betula nana-Clethrionomys rutilus; a late stage of the xerosere and edaphic subclimax on the Arctic

Slope. Optimum development occurs on the southern part of the Arctic Slope, becoming progressively less dominant from south to north. In the Brooks Range it occupies lower dry slopes, less stabilized moraines, and boulder fields -- habitats of well-drained soils and exposure to sun and wind.

F. *Salix* (riparian)-*Microtus miurus*; an early xerosere of dry, well-drained sandy soils along overflowing streams, lake edges, and on alluvial fans.

G. Meadow grass (dry)-*Ovis dalli* and *Rangifer tarandus*; considered to be pre- or post-climax on the Arctic Slope and as climax of Brooks Range xeroseres, where it occurs on stabilized slopes and ridges above glaciated canyons. Lichens tend to dominate grasses on north slopes.

As with most extensive generalizations of ecosystems, exceptions or modifications to these associations can be found. Their purpose of inclusion here is to further outline the general picture of ecosystems of northern Alaska.

Caribou Herds in the Study Area

Perhaps the most important biotic components of the study area for the purposes of this Dissertation are the caribou populations, which perform impressive seasonal migrations across all of the physiogeographic zones and which have been a basic consideration in the radiation ecology studies herein described. Two major herds of barren-ground

(*Rangifer tarandus*) caribou traverse northern Alaska and maintain their respective identities as the Arctic Herd in the central and western sectors and the Porcupine Herd to the east. Considerable change, mostly due to unknown factors, has occurred in these populations throughout recorded history. Recent evidence (Irving and Harington, 1973) extends the period of human dependence upon the caribou for basic subsistence to about 27,000 years before present; however, a reasonably accurate accounting of relative abundance of the caribou in northern Alaska during modern times dates only from about 1833, according to Skoog (1968: 242), who quoted Ray (1885) as reporting that in 1883, with regard to the lower and middle portions of the Meade River:

> ". . . the natives say that three generations ago all this region was inhabited by a people that lived by fishing and hunting reindeer, and did not come to the coast, but that the deer and fish grew scarce . . . now this whole region is not inhabited . . ."

Skoog further states:

> "This implied that the caribou had abandoned that portion of the Arctic Slope region sometime after the explorations of Dease and Simpson (circa 1837). If the animal had remained numerous from 1837 until 1883 (when they were abundant once again), then one

might suppose the area would have remained populated by 'inland' Eskimos as well. Such movements of Eskimos, to and from the coast, are known to have occurred periodically, depending upon the supply of food available in the inland areas (Larsen and Rainey, 1948)."

From several sources then, the following historical abundance of the Arctic Herd of caribou in northern Alaska emerges:

Period	Relative abundance of caribou
Prior to 1833	- numerous, at least north of the Brooks Range
1833-1875	- locally abundant but generally declined
1880	- scarce along northwest coast from Seward Peninsula to Cape Lisburne; numerous from Barrow eastward
1895	- population low point
1880-1900	- shifted north and east; scarce in northwestern Alaska
1900-1920	- shifted southward to Colville River drainages, Delong Mountains, Chandler Lake. Porcupine Herd shared the Central Brooks Range in winter. Possible population low

Period	Relative abundance of caribou
1920's	- Arctic Herd began a substantial increase, due partly to immigrations from caribou herds to the east and south
1925	- approached maximum population, with high concentration in Central and Eastern Brooks Range
1930's	- again present along the Bering Sea coast
1925-1945	- a general decline in numbers to a low population in mid-1940's; population center shifted to the Western Brooks Range
1950's-1960's	- abundant once more

At the present time, the Arctic Herd is estimated to number about 242,000 and the Porcupine Herd 144,000 animals (Hemming, 1972). Skoog (1968: 310) forecasted a decrease:

> "To the northwest [Region III], the subpopulation is at peak numbers and its seasonal movements extend in all directions. A change seems imminent there in the near future."

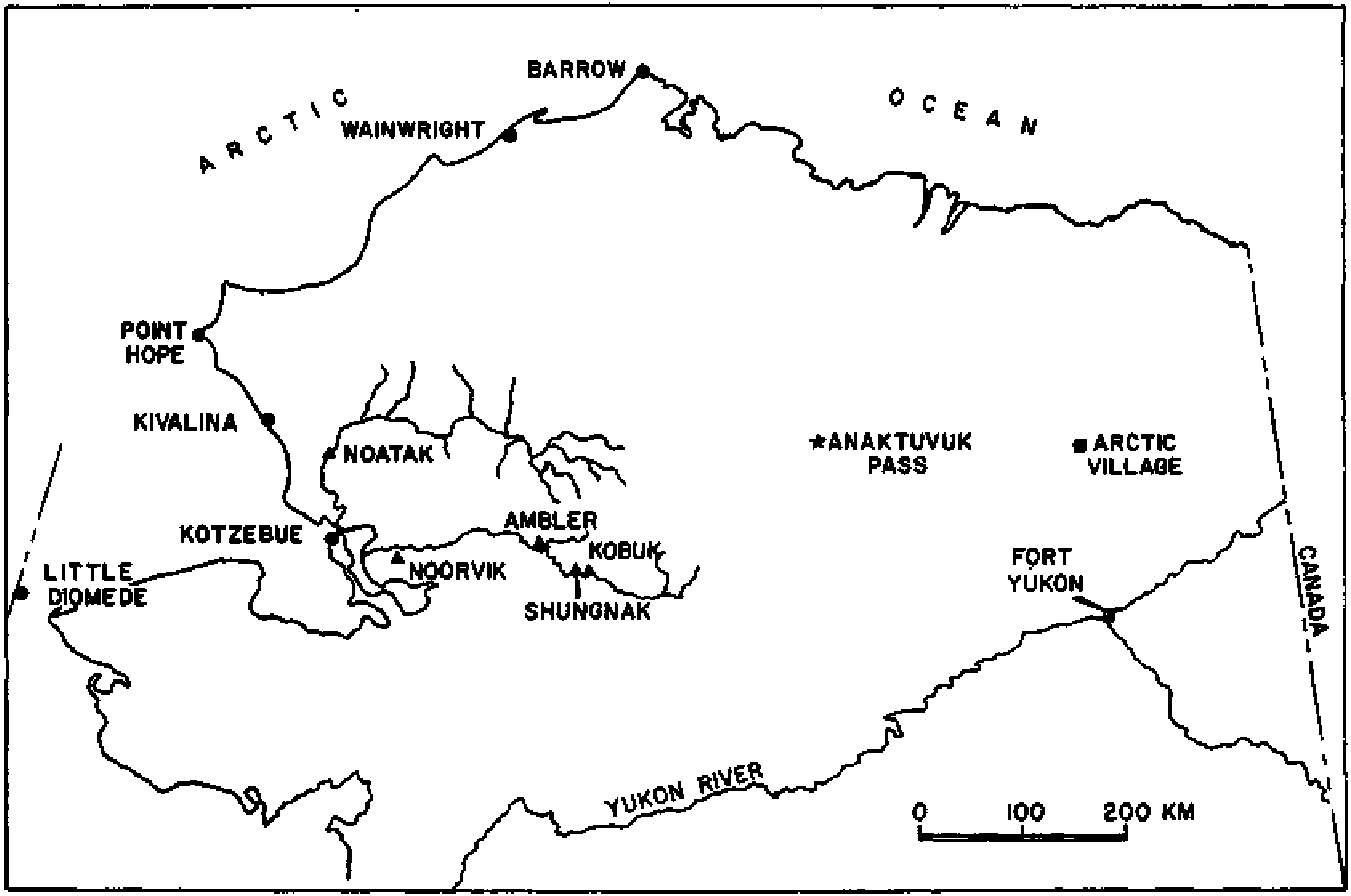
It appears that the Arctic Herd reaches a minimal population about every 25 years, and that another decrease would, therefore, occur in the early 1970's. Leeds (1965) cited Bogoras'

(1904-1909) observation that in Siberia great epidemics and climatic excesses seemed to occur every 20-30 years, and that these factors reduced human and reindeer populations. Larger herds were affected most severely. Epidemic and climatic factors thus served as a control on herds which otherwise would have increased beyond the carrying capacity of the range. Such a decline in the major food supply of the inland Eskimos probably would not have a major influence upon the people. They no longer depend upon the caribou for feeding their sizeable dog populations, which have been replaced by snowmobiles; there is now greater dependence upon processed food by the people than ever before; and the most recent movement of nunamiut from the coast to the interior occurred in 1938-39, at a time when the Arctic Herd was approaching a population low.

Human Ethnic Groups of the Study Area

Three distinct cultural groups of Eskimos dwell within the study area (Fig. 5). The coastal Eskimos inhabit villages along the Bering Strait and the shores of the Arctic Ocean, where marine mammals are the major food base and serve as the focus of cultural orientation. The cosmopolitan Eskimo village of Kotzebue has served as the indigenous trading center for northwestern Alaska for several centuries, and it still attracts considerable numbers of summer visitors from other native villages. For the purposes of this study, the people of Little Diomede Island represented the southern

Figure 5. Map of northern Alaska showing locations of cultural and ethnic groups studies for radionuclide body burdens. Circles are coastal Eskimo villages, triangles are river village Eskimos, the star is the inland Eskimo village of Anaktuvuk Pass, and the squares are Athapascan (Kutchin) Indian villages.


ARCTIC
OCEAN
BARROW
WAINWRIGHT
POINT HOPE
KIVALINA
NOATAK
KOTZEBUE
LITTLE DIOMEDE
NOORVIK
AMBLER
KOBUK
SHUNGNAK
ANAKTUVUK PASS
ARCTIC VILLAGE
FORT YUKON
CANADA
YUKON RIVER
0 100 200 KM

contingent of the coastal population and the population segment most dependent upon walrus (Odobenus rosmarus) for a food base. Point Hope, Point Lay (now abandoned), Wainwright, and Barrow were major whaling centers and we concentrated on the first and last of these as representative of that group. Barrow is considered to be another cosmopolitan Eskimo village, having had contact with the white man since about 1830. Coastal villages have greater flexibility in food-gathering than most other groups, having access to marine mammals, river fishing, waterfowl hunting, and berry picking in addition to caribou hunting. Coastal Eskimos, especially those from the area north of Kotzebue, are believed to represent a later cultural branch of the inland Eskimo (Larsen and Rainey, 1956) who moved to the coast and remained there several centuries ago.

Eskimos living along the Noatak and Kobuk Rivers at the western and southern edges of the Brooks Range have been termed "river village Eskimos" to differentiate their food-gathering patterns from other groups. Residents of Noatak, Kobuk, Shungnak, Ambler, Kiana, Selawik, and Noorvik constitute this group of people who perform seasonal hunting of coastal marine mammals, much river fishing, and depend upon inland moose and caribou for much of their food during fall, winter, and spring months.

The 140 inland Eskimos of Anaktuvuk Pass represent the only remnant of the nunamiut ("people of the land") that have roamed the Brooks Range for centuries. Formerly nomadic in keeping with their tradiation of following the caribou for their major source of subsistence, they have been sedentary since about 1951 at the village site that was a seasonal hunting camp for 5,000-6,000 years (Campbell, 1962; Porter, 1964). Theirs was a history of periodically leaving the Brooks Range during periods of caribou shortage to inhabit coastal locations, returning when sufficient animals were again available, according to Larsen and Rainey (1948). Rausch (1951), however, felt the nunamiut merely turned to other animals (marmots, sheep, ground squirrels, or fish) during periods of caribou shortage; or moved to timbered regions where moose were available. A maximum population of about 1,500 nunamiut was estimated to have occurred in 1890 (Oswalt, 1967). These people are still greatly respected by other native groups and by the white man for their hunting and arctic survival abilities. Their present village occupies a major pass through the Brooks Range which is routinely used by a major portion of the Arctic Herd of caribou migrating to and from winter ranges. Until recently this provided the Anaktuvuk Pass people with their major food supply in fall and spring, and preserved their cultural integrity of the past without the nomadic aspect. Their residence at the village site was prompted by the prospect of a school, post office, and air service in a time when these were wondrous cultural additions.

The Athapascan (Kutchin) Indians of Arctic Village and Fort Yukon were included in the study area because they are culturally and geographically very remote from the Eskimos to the west of their villages. Ancestrally, they apparently arrived during the second wave of immigrants across the Bering Land Bridge in Pleistocene times (Jenness, 1940). The early people continued south to the interior of North America and then returned to the northern plains, where they reduced the interior distribution of Eskimos. At least a small population of Indians shared a considerable area of the Central and Eastern Brooks Range with the inland Eskimos until fairly recent times, but retired southwestward following a series of skirmishes climaxed by a major defeat by the Eskimos (Hall, 1969). Fort Yukon has served as a major trading center for human populations of the interior provinces and several families moved to and from Fort Yukon during the study. Most of the immigrants came in response to the attraction of more employment and family services, and most of the emigrants represented those people who found the larger village life unsatisfactory compared to "the bush". Similar reactions have been noted among most of the native peoples of Alaska; however, the trend during 1950-1967 was toward abandonment of small villages of less than 100 people, particularly in western Alaska, temporary consolidation in the medium-sized villages (more than 200 people), and emigration to the cities by the young people (Federal Field Committee, 1968). This gradual centralization of the native people has been encouraged by the Bureau of Indian Affairs in order to facilitate the administration of various services; however, there are

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serious adjustment in life-style involved in such change and many of the people are unprepared for the consequences. These points will be discussed further in this Dissertation.

CHAPTER IV

ECOLOGICAL-CULTURAL ASPECTS OF NUNAMIUT ESKIMOS AT ANAKTUVUK PASS, 1962-1972

The subsistence hunting economy that prevailed at Anaktuvuk Pass during the first few years of this study was mainly centered on the caribou migrations and the seasonal use of caribou meat that contained definite patterns of fallout radionuclide concentrations. It was necessary to understand the cultural practices of the inland people in order to explain the substantial variations in their ^{137}Cs body burdens and to relate them to environmental and cultural factors, not only within the immediate area of Anaktuvuk Pass but to those of other areas and other peoples. This aspect of the data became more important as the forces of cultural change became increasingly apparent in the post-1964 period.

The trend of changing cultural pattern was most noticeable at Anaktuvuk Pass because our studies centered around the lichen-caribou-Eskimo food web. Also, the inland Eskimos apparently changed to a greater degree than did that of other groups because of their greater isolation from white man influences prior to 1950. Changes then came slowly and gradually until 1964, and then rapidly increased in number and portent. These changes from a subsistence hunting economy to one of trade and barter were accompanied by important shifts in the food habits of the people, and therefore upon their radionuclide concentrations.

Greater availability of processed food made possible through increased food stamps and welfare payments, beginning in 1967, is but one example of these cultural changes.

My association with the Anaktuvuk Pass people began during 1962, some ten months after Gubser (1965) had completed his 15-months residence and anthropological study of the people. This provided a firm basis for comparison and reference for the 700-odd typewritten pages of field notes accumulated during the period 1962-1972. Although not trained in ethnography-anthropology at the beginning of the study, I believe my general acceptance by the people, the cooperation which they displayed throughout the studies, and my subsequent training in anthropology provide a basis for discussing this aspect of the data.

Professional anthropologists have within the past two years suddenly "rediscovered" the <u>nunamiut</u> in an attempt to document the inland Eskimo culture before it further changes in the wake of acculturation processes. Events that led to major changes at Anaktuvuk Pass during the period between Gubser (ca. 1961) and the renewed interest of the anthropologists (ca. 1970) are being reconstructed by interviewing two older men of the village; both of these men have a reputation for being highly entertaining and informative, and one of them provided most of the information for both Ingstad (1954) and Gubser (<u>op</u>. <u>cit</u>.).

The cultural interpretations and observations that follow are primarily related to the ecological relationships of the Eskimos within their ecosystem, and the implications to the radiation ecology studies that were the principal objective. However, they also portray the subsistence of the people prior to, during, and after a critical period of village history.

Historical Background of the Nunamiut People

The nunamiut have been associated with the Brooks Range and its several river systems for some 8,000 to 10,000 years (Campbell, 1962; Porter, 1964). Considerable confusion about the true names of the residents of the Brooks Range exists, so that accurate population estimates cannot be made; however, it is believed that the nunamiut numbered about 1,500-1,800 during the latter part of the 1800's (Oswalt, 1967). The population was widely dispersed and bands designated themselves according to the region in which they lived and hunted by the suffix miut added to the locale. Although there were representatives of several bands in the backgrounds of many of the modern nunamiut (Larsen and Rainey, 1948; Larsen, 1958), there were three main groups: the tulugakmiut ("raven people") lived at Tulugak Lake, some 25 km north of Anaktuvuk Pass; the narivakvukmiut ("big lake people") lived at Chanler Lake, about 40 km west of Anaktuvuk Pass; and the kitlikmiut ("Killik River people") who lived on the Killik River about 100 km west of Anaktuvuk Pass. Each group was led by a knowledgeable and successful hunter or umealik, although there was great fluidity in the combinations of families composing the groups.

The nunamiut made definite seasonal migrations, connected with their hunting and trading with the coastal Eskimos. In late spring the people travelled by dogsled to ancestral camps where they had stored their skin boats the previous autumn. There they cached their sleds and, after "break-up" of the rivers, travelled by boat down to the mouths of the major rivers. There they met their trading partners from Barrow, who came for the purpose of trading seal oil, seal skins, and (later) articles obtained in trade with whalers. In return, the nunamiut traded caribou skins and other animal hides, sinew, and wooden poles that were unavailable to the coastal people. In late summer the nunamiut returned inland, exchanged boats for dogsleds at the ancestral camps, hunted and fished until freeze-up and then returned to their mountain homes for a lengthy period of hunting and trapping.

With the arrival of commercial whaling in the Arctic Ocean, the necessity of coastal Eskimos to trade with the nunamiut declined. Several nunamiut families became engaged in caribou hunting to supply meat for whaling ships during the late 1800's and obtained trade goods in that way rather than maintaining strong ties with coastal tribes. This kind of arrangement continued into the early 1900's and increasingly exposed the nunamiut to aspects of other cultures not always in their best interests. Brower (1942) cited one instance near the turn of the century in which an estimated 200 nunamiut died of influenza contracted at a whaling feast in Barrow.

During the 1920's and 1930's the fur trade encouraged movement to the coast east of Barrow, where arctic fox (Alopex lagopus) skins could be easily obtained. Many families deserted the Brooks Range and moved from a subsistence economy to a trading economy, only to suffer disappointment when the fox population and the demand for pelts declined. The impact of the acculturation process in which the Eskimos had become engaged is strikingly similar to that of Northeastern Algonkians (Murphy and Steward, 1956). Most importantly, both became involved in a mercantile, barter economy in which the natives became tied by bonds of debt and credit to particular merchants; the growing ties of dependency upon the traders weakened the collective bonds within their native societies; and the subsequent decline of the foxes and decreased demand for pelts required a major adaptation of the people who had been cut adrift from many of the cultural aspects that were ideally suited to a rigorous environment. Many nunamiut moved to population centers such as Barrow or (in a few cases) Fairbanks. By 1937, trapping was so poor and life in the larger population centers so unsatisfactory that most of the nunamiut were prepared to move back to the Brooks Range. In 1938, three families spent the winter along the Colville River tributaries; and when they returned to the coast for supplies and prepared to permanently move inland, they were joined by the remainder of the nunamiut in returning to their Brooks Range homeland.

A semi-nomadic way of life was followed during the 1940's with the three groups previously noted living at Tulugak Lake, Chandler Lake, and the Killik River. Special, lengthy hunting and trapping trips were undertaken for certain animals, such as for the hoary marmot (Marmota caligata), when pelts were in demand (Paneak, 1960). These trips required great endurance, knowledge of the country and animals, ingenuity for devising traps and deadfalls, and remarkable means of transportation of supplies involving people, dogs, and handcrafted boats. A general modification of the seasonal activities was required during the 1940's, because trading with the north coast people had ended and the nunamiut resorted to sporadic trading with small villages to the south, along the Kobuk River. Occasional contact between the two groups was the rule until 1949, when the Chandler Lake narivakvukmiut moved to join the tulugakmiut at Tulugak Lake, and were shortly followed by the kitlikmiut. It was at that time that many of the nunamiut met their first white man and saw close up their first airplane, although many of the older people had seen early explorers such as Howard, Stefansson, and others. Conversations with the Eskimos emphasize the great cultural impact of this initial contact.

In 1950, the promise of an elementary school, postal service, and air service contact with Fairbanks prompted a move to Anaktuvuk Pass by all but two families of the *tulugakmiut*, who moved to Savioyuk Valley (some 25 km east of Anaktuvuk Pass) when caribou were in short supply and later moved to several temporary locations prior to finally settling in Anaktuvuk Pass. Presbyterian ministers established contact and began missionizing the people (Chambers, 1970) and a white trader established a trading post. A log cabin served as school and church until 1960, when formal school buildings and teachers' quarters were constructed. At that time the last two *tulugakmiut* families moved to Anaktuvuk Pass, and the *nunamiut* centralized their activities; however, the factionalism of the various bands transcended most decisions, with the combined *narivakvukmiut* allied and led by the *kitlikmiut* under Morry vis-a-vis the *tulugakmiut* under Paneak. It was apparent that these two factions tended to maintain greater kinship activities within their lineages than between the two groups. Similarly, political activities were conducted on a lineage basis and this resulted in periodic dissension within the village. Governmental agencies have not recognized the underlying reasons for the dissension and have made impetuous judgements of the people on the basis of apparent, rather than real, reasons.

Social Groupings

Nunamiut society is basically composed of the family and the community, as discussed by Gubser (_op_. _cit_.). Family membership is highly valued, whether by nature or adoption. Once in the family, the proper performance of role is important to the smooth functioning of the family and its proper place in the village, which constitutes the _band_ of previous times. The formation of bands in the past was rather fluid, being mostly practised in the fall and spring of the year for the purpose of hunting caribou. One of the most popular hunting methods, up until about one hundred years ago, was the corral of snares (Rausch, _op_. _cit_.) that culminated the efforts of several families. Remains of these can be still seen 25 km below Anaktuvuk Pass and at other suitable locations near Tulugak Lake, Chandler Lake, and on the Killik River. Because the _nunamiut_ band now consists of the congregation of several households at the permanent village site, the spirit of cooperation from the past is usually represented by general agreement or a Village Council resolution that enjoins the residents to allow the first small herd of caribou to pass the village unmolested and hunting the followers at an agreed signal.

During their semi-nomadic times the bands were formed primarily for economic or defensive reasons. The defensive needs were modest, and the last major battle with Kutchin Indians was fought near Tulugak Lake about 150 years ago.

However, the exploitation of migrant caribou and organization of trading expeditions provided economic reasons for band formation until modern times. Within the last twenty years a considerable modification of roles of the individual in his performance as an individual, as a family member, and within a band has occurred among the nunamiut; and the consequences of cultural contact with the white man continues to upset societal structure.

In the past, the nuclear family was the basic structural unit in the nunamiut social organization. Single families were often isolated by necessity to exploit sparse and widely scattered hunting and trapping resources. A strict division of labor was necessary to insure survival; fathers and sons tended traplines and hunted, while mothers and daughters maintained the home, gathered firewood, carried water, mended and made clothing, and raised the dogs that were vital to the mobility of the family. Spouse exchange was practised and socially approved because of its recognized service to survival.

Marriage usually was recognized as an extension of a basic attraction between two people over a period of time. It was often optional for both parties, subject to approval by their parents or siblings. Initial residence following marriage was usually in the brides's home; the new husband hunted for the household and in return received weapons and advice from his father-in-law and new clothes from his mother-in-law. He engaged in a close relationship with his in-laws and attempted to perform his role such that the household functioned smoothly and happily. This situation was subject to some variation according to the needs of the husband's parents, the number of brothers and sisters married and single, and other factors.

One of the most important determinants of post-marital residence was personality. Lack of cooperation or head-strong behavior by one member of the extended family was the most frequent cause of suicide, which was undertaken to spite the offender as well as terminating one's misery. I know of only one instance of suicide among the Anaktuvuk Pass families, but recall the shock and chagrin of the relatives and the animosity directed at the person who apparently contributed to the victim's misery. Clashes of personalities, particularly between the bride and her mother or the groom and his father-in-law, were a common reason for establishing independent residence, even though it was recognized as being anticultural and uneconomic.

Incest was viewed by the nunamiut as having two aspects. There was the psychological repugnance of sexual intercourse within the nuclear family or a comparable feeling concerning such relations with collateral relatives; a person should not be so shy as to restrict sexual relations to an intimate relative. Secondly, the incest taboo encouraged the extending of linkages of friendship to in-laws "of a different country", which is important in economic exchange, hospitality in time of emergency or travel, and - most important -

someone new to visit. Second- and third-cousin marriages were avoided if possible, but have occurred due to the limited population available for mate selection. It was recognized, however, that these were in conflict with _nuna-miut_ ideals and such marriages were closely watched for anomalous results.

Polygyny was formerly quite common among the Eskimos, but was generally considered to be an expression of lust and an attempt to gain economic or political advantage by broadening kinship ties. Much jealousy and conflict was the rule in polygynous households, and sororal polygyny (one man marrying sisters) was judged to be nearly as bad as incest. The youngest bride of a polygynous household received the brunt of abuse and work, while the elder wife was caught up in mixed feelings of jealousy and relief from menial tasks. Levirate marriage (obligation of a man to marry his brother's widow) was not generally practiced, but one instance has occurred at Anaktuvuk Pass with at least tacit social approval.

These cultural constraints have been seriously challenged within recent times as the children have outstripped parents in education, job opportunities, and participation in governmental affairs. Parental control has become relaxed in the area of marriage arrangements because of the restricted population and incest taboo. Several girls have "married out" within recent years, mostly to Barrow Eskimos and to white men in two instances. The only male to "marry out" wed a Mexican-American girl while attending a trade school in California. Considerable cross-cultural conflict has arisen from these marriages, principally due to the close familial ties of the nunamiut to their homeland and relatives. Very recently three marriages within two families prevented further disintegration of the nunamiut kinship systems and also crossed band lines.

Adultery among the nunamiut was probably more imagined than real, due to the jealous nature of the Eskimo women and the enjoyment of teasing among the men. It was controlled by threat of reciprocal adultery on the part of the injured spouses, if such an arrangement was possible, much as a case of inadvertant and temporary spouse exchange. Two acknowledged cases have occurred at Anaktuvuk Pass during my study, both involving married women and young single men; these cases were resolved by the Village Council and the women forgiven. Sexual promiscuity has never been socially accepted by the nunamiut, and considerable scorn was heaped upon the mother of four illegitimate children. The father of one of her children expressed a genuine desire to marry the woman but was dissuaded by the outspoken opposition of his brothers, one of whom was proposed as the father of one of her other children. The proposed marriage would have crossed band lines but may not have been a major consideration of the parties involved.

Present Roles in the Family and Community

The nuclear family is still the basic structural unit of nunamiut society, but it is increasingly independent in modern society as modern institutions emphasizing the individual replace those that required cooperation. Distant relatives are becoming less recognized by offspring of second-generation Anaktuvuk Pass residents. This reflects the decreasing need for distant contacts in strange villages, which was vital to survival in former days of shamanistic power; strangers unable to identify relatives were driven out or put to death for fear of their being agents of destruction sent by a powerful angokok or "medicine man". The present situation indicates the gradual withdrawal of the younger people from older nunamiut ideas and cultural attachments.

Obligations were formerly strongly ranked: strongest to parents, shared with children; second, to siblings; and third, to spouse. Thus, when game or other resources were brought in, the choicest cuts or largest share went to the wife's parents, then to her own children, followed by sibling's families, and finally to the husband's family. This demand upon one's resources has been an overriding consideration in seeking and maintaining employment; it does little good to accumulate wealth beyond your immediate needs if relatives knew of your good fortune and made demands for their share.

The nunamiut kinship system does not provide a sufficient or total reference for the formation of the household and community, nor for most activities. Social relationships and economic considerations are closely interrelated, with the individual functioning first as a member of a kinship grouping in relation to which he develops his economic skills and interests. This circle is then broadened by a series of voluntary associations, which were more important in the past than the present cultural situation demands. In former times, as recent as two decades ago, this patterning strongly resembled kinship situations in which the themes of cooperation were paramount. In this context of kinship and the extension of kinship patterns to non-kin in specific ways lies the basis of the nunamiut social system. And it was through such a system that the inland people achieved signal success in mastering a rigorous environment, and which was a source of pride to the people.

Two major physiogeographic provinces, the Arctic Foothills, and the Brooks Range, were mainly utilized by the nunamiut. Throughout these zones the people were scattered in small groups to exploit the basic cultural needs for most of the year. During fall, winter, and spring months the caribou and its associated biotic components were the central theme. During summer the people travelled to the Arctic coast where they exploited the productive marine ecosystems and traded with coastal Eskimos. A subsistence economy was maintained by a system of friendships, trading partnerships, joking partnerships, and other contractual agreements with other groups of people near and far away. But the center of the nunamiut universe was the nuclear family, and because of the dispersed nature of the food resources it was often propitious for households to be isolated from one another for much of the year. Meetings with other families occurred at times of seasonal caribou harvest or trading, but such communities both resulted from and contributed to the Eskimo delight in "visiting 'round" with different people and places. The obligations of a household to the community as such rarely impinged on the nunamiut household desire for autonomy. Although each family was expected to contribute its fair share of caribou skins and labor to the construction of the communal house and to cooperate in the caribou harvest, it generally remained free and unfettered to roam at will.

Inhabitants of nunamiut and other Eskimo settlements were typically connected by blood or marriage (nuatkattait); as such, they owed special duties to one another. They provided for each other in sickness, cared for the aged and infirm, the widows and orphans, and supported each other in important matters. This gave the community its solidarity. It had corporate unity and was called by its specific term of location with the suffix miut as a distinguishing mark. Although often termed "tribes", such designation must be used in a broad interpretation because the groups into which the inland Eskimos divided themselves had none of the permanence and stability associated with tribes in other parts of the world. The people were constantly changing from one location to another for purposes of hunting, trading, or trapping, and formation of _nunamiut_ settlements were less common than those reported among the Copper Eskimos of north central Canada (Jenness, 1922). A household that was poorly prepared for the winter had two choices; it could separate itself from the settlement and attempt to find game on its own, or it could remain in the settlement near more affluent families and hope to find enough to eat through kinship ties and the desire of wealthier households to be known as generous and hospitable. This aspect of _nunamiut_ culture is no longer practiced, due to the influence of governmental policies which have supplied food stamps, welfare payments, housing, and fuel. These same policies required the institution of a Village Council of elected representatives to govern village affairs shortly after the people moved to the present site. Previously, there was no centralized authority within a settlement composed of a few families often connected by kinship. Leadership was provided by an older man or clever hunter (_umealik_) who enjoyed the respect of the others and who decided when to move to another hunting center, when a hunt was to be started, how the spoils were to be divided, and made other decisions. Such leadership was not inherited, but was earned through experience, a reputation for being a successful hunter, and accumulating wealth. One of the surest ways to affluence in former times was for a household to isolate itself from the other households for one to several years, trapping and trading without the interference or demands of other related families. This had its disadvantages in depriving the family of the communal atmosphere that all Eskimos enjoy and it often earned the family head the unenviable reputation of being stingy and unsociable - two of the worst charges that could be made against a man in a region when philanthropy was extolled.

Acculturation processes enhanced the autonomy of the modern Eskimo family and made it increasingly independent of cooperative endeavors. Foremost of these processes is the elementary school education, which places the children above their parents in scholastic ability and has a demeaning effect when the children reach their teens. The children become less responsive to parental authority and challenge the old cultural ideals. Further alienation follows their attending high schools outside Alaska or in distant cities, which transplants them from their ancestral homes for the school year and exposes them to contemporary "white man culture" at an impressionable age. Upon their return to the home during summer, the isolation and boredom of the village compared to the cities soon causes dissatisfaction; the boys spend a few weeks earning several hundred dollars as members of Bureau of Land Management fire-fighting crews and enjoying a brief binge in Fairbanks. They return to Anaktuvuk Pass for another several weeks of endless gambling or playing pool in the village "pool hall" prior to their departure for school.

Their roles, particularly as dutiful sons, are generally forgotton; on the other hand, the girls seem content visiting their parents and helping in the home.

The influence of the Presbyterian mission seems to be declining after enjoying an initial novelty. Services are now attended by the elderly and very young, with few young people of high school age and upwards from the third generation of Anaktuvuk Pass residents. Recruiting of church elders from the population is becoming more difficult. Collections of money from local members has decreased as the families purchase more outside goods, and periodic visits by a missionary are needed to temporarily boost participation in church activities.

<u>The Snowmobile in Anaktuvuk Pass Culture</u>

One of the main expenditures of the modern <u>nunamiut</u> is for purchase and maintenance of a snowmobile, which has now almost entirely replaced the dogteam as a source of traction. The first snowmobile appeared in Anaktuvuk Pass during January 1964, when the white school teacher imported and sold his used machine to two brothers. This innovation of traction appeared at about the same time in other Alaskan Eskimo villages (Hall, 1971) and in Lapland areas of Norway, Sweden and Finland (Pelto, Kinkola and Sammallahti, 1968). In all cultures the snowmobile has had wide-ranging and interrelated consequences, and those in the <u>nunamiut</u> society have been especially noticeable. The number of snowmobiles in the village has increased from the single used machine in January 1964 to a total of 46 machines in August 1972, of which 24 were operable, 19 were inoperable, and three burned chassis that were visible. In addition, there was one larger tracked vehicle and one wheeled all-terrain vehicle. The impressive attrition among the snowmobiles has been due to a combination of extreme cold, sparse snow cover on a rough topography, poor adaptability of construction materials for the hard use the machines receive, and the quality of home repair work of frequent breakdowns. The natural mechanical ability for which the Eskimos have been noted by casual observers seems inadequate to the task of major repairs and several machines have suffered from inquisitive tinkering. When one considers that the base price for a snowmobile ranged from $700 to $1,000 plus $200 air freight from Fairbanks; that gasoline sold for $2.60 per gallon until 1971, when it was reduced to $1.60 per gallon; that active hunters consumed about 200 gallons per season (October-May); and that the average family income during the period of initial snowmobile acquisition at Anaktuvuk Pass was in the range of $2,000 to $4,000 per year, it is readily apparent that the snowmobile had great economic consequences. However, the cultural consequences went far beyond the financial aspects.

During the decade following the settlement of Anaktuvuk Pass in 1950-1951, the people underwent gradual acculturation. Varied amounts of subsistence hunting and trapping were carried out by the families for both dogsledding during periods of snow cover and dogpacking during summer months. My observations during 1962-1964 suggested a relatively stable period of village life-style resembling that described by Gubser (op. cit.) in 1960-1961. Dogs were prestigious and received generally good care, although they were occasionally beaten as a function of a "psychological escape valve" for the venting of feelings of frustration. Five years was the effective life of dogs, in the Eskimos' opinion, and most were shot shortly after reaching that age unless it was a valuable lead dog or "good puller". Gubser (op. cit.) summarized the importance of the dog as being the only means of transportation of caribou carcasses and hunting by which the continued existence of nunamiut society was possible in 1961.

The maintenance of good dog teams required considerable effort to provide hot food and water throughout the winter, particularly after an arduous trip; however, of even greater importance was the preparation of the dogs for a winter of hard work. The better hunters of the village took their teams some distance from the village for periods of one or two weeks, usually during late August, for the express purpose of fattening the dogs on Dall sheep meat. The dogs were then in good condition and strong, worked well, and could survive the winter period that featured daily meals of frozen caribou meat while on the trail, followed by cooked food after long hunts and trapping journeys. Caribou haunches contained little fat and, when served frozen or partially thawed, required nearly as much energy for digestion as was contained in the meal. It was common for a good team to finish the sledding season in May as lean and hard as the frozen meat that typified their rations.

The nunamiut used a heavy sledge better suited to the rough tundra trails than the classic "basket sled" used in many areas of greater snowfall. Two types of runners were used: steel was used during the early winter and late spring when the snow tended to be soft or sticky, and hand-hewn spruce runners were suited to mid-winter conditions when the extreme cold and wind of the region had hard-packed the snow. The runners were coated with ice, built up by applying several layers of melted snow water with a piece of caribou hide each morning before a trip and whenever sledging over rocks or when rough ice broke the smooth running surface. Women and small boys helped with the hitching of dogs in matched pairs to the center tugline. The dogs were mostly ecstatic at the first cue that a trip was in the making, probably because of their training and also because most of their lives otherwise were spent chained to a stake in their owner's dog-yard. Those left behind when a team departed howled mournfully and periodically until their owner returned. Women usually used teams of three or four dogs to haul fuel and ice to the houses from sources about two kilometers from the village; several women were accomplished dog handlers, but only one or two routinely "dog-teamed". Raising of pups was principally the province of the wife.

Prior to the coming of the snowmobile, trapping camps located one or two days journey from the village were usually occupied for varying periods during the winter. Trapping activities required greater effort and tended to scatter the nunamiut men over a considerable area. These semi-permanent camps were the bases of operation for one to four men, who entered into friendly competition in trapping and gambling. Many of the young bachelors spoke glowingly of the good times had in trapping camps and were eager to return after a short visit to the village for holidays. This practice maintained the technology of trapping, hunting, dogteaming, and subsisting in a harsh environment that was the hallmark of the inland people and which earned the respect of most other cultures. The people were fully occupied by the requirements of their culture, which was ideally suited to their environment. Three of four stores were usually operated by older men, several people made modest amounts of money from caribou skin masks (Atamian, 1966), trapping and bounties provided seasonal income, and village life in the early 1960's was relatively calm. Having survived the winter, the people enjoyed the summer as a time of relative ease. The permafrost cellars were usually filled with caribou meat stored from the spring kill, families moved from sod houses into canvas tents, and short hunting trips were occasionally taken with dogs fitted with packs. Women spent several days chopping and drying willows for the coming winter fuel supply, the circadian rhythms were purposely turned topsy-turvy by all night card games, and the usual novelty of visiting scientists provided diversions. The specter of a dwindling fuel supply was in the background of peoples thoughts, however, as noted by Gubser (op. cit.). One had only to survey the diminished willow growth in the valley to appreciate the problem; however, there were persistent stories of a nearby supply of oil shale and coal that would be used when the willows were exhausted.

It was during this relatively calm period that the first snowmobile appeared, during January 1964. It appealed to the curiosity of the Eskimos, and its performance and prestige were magnified by the initial success of the machine in hunting caribou, running traplines, and its apparent ease of maintenance. The first two winters proved to be a period of observation and trial of the snowmobile for a majority of Anaktuvuk Pass people, for most of them could not afford the machines.

During the summer of 1966, the first opportunities occurred for the nunamiut men to serve on the Bureau of Land Management forest fire control crews, and several men served 10 days at $68/day. Many men used these funds for down payments on snowmobiles, and from then on the machines became the central theme in Anaktuvuk Pass culture. All efforts were made by the people to possess an "iron dog" at any cost, and autonomy of the families became more pronounced. That same summer the village was given a crawler-type tractor by a governmental agency for the purpose of hauling oil shale or other fuel. The machine became a center of controversy over its uses, and this was heightened when the coal and oil shale resource was evaluated by a geologist and found to be in negligible supply and of extremely poor quality. A proposal by governmental agencies to have Anaktuvuk Pass hunters supply caribou meat at a fair price to Operation Headstart (education of pre-school children) programs at several other villages in northern Alaska failed; the arrangements for proper inspection, handling, and transportation of the meat required unity of action by the Anaktuvuk Pass Village Council that was unattainable. Similarly, a proposal was made for the village to market 1,000-2,000 caribou skin masks to be sold at the Alaska '67 Centennial Celebration to be held in Fairbanks the next summer, the proceeds to be used to purchase fuel for the village. Mask-making was at a fever pitch in the village, but the objective was to finance individual snowmobiles rather than participation in a community effort to solve the fuel problem.

During the winter of 1966-1967, five snowmobiles were in operation; and the first friction developed between the "haves" and the "have-nots" over whether or not the noisy machines were driving the caribou higher up into the mountains where they were inaccessible to dogteamers. Several people reported that the snowmobiles could more closely approach caribou than could dogteams, probably because the caribou had not yet learned to associate the snowmobiles with danger. Furthermore, snowmobile operators could more quickly ready their machines for pursuit of caribou bands than the dogteamers could harness their dogs, and snowmobiles were faster and more sustained than dogteams in pursuit of caribou.

The friction within the village was undoubtedly abetted by the critical fuel situation that was by then unavoidable; the last of the willow supply was in sight and scattered sources up to 35 km away were being sought out. Alternatives were being discussed, among which was a suggestion from a Barrow minister that the nunamiut move to an abandoned oil exploration camp some 125 km north of Anaktuvuk Pass. This was seized upon by several people as the logical solution and in the following months of confusion over what the village and various governmental agencies could do, the village became polarized into "movers" and "non-movers". The division of the people was generally along band and kinship boundaries, but in a few cases pitted siblings against each other. The crisis was resolved by several government agencies that imported stoves, fuel oil, and building materials for small frame houses poorly adapted to the rigorous arctic climate. The role of women as fuel gathers was abolished; and as the snowmobiles increased, so was the role of custodian of the dogs. The need for the hunter role for men was reduced by the decreased requirement for caribou meat for dog food, and extended hunting and trapping expeditions to distant valleys were curtailed by the increased mobility provided by the snowmobile, and the introduction of weekly movies by the school teachers. Men were reluctant to spend more time outside the village than absolutely necessary, and welfare and food stamp programs encouraged increasing dependence upon governmental programs that eroded the status and roles of both males and females. There has been an accelerating loss of situations for "achieving" and for validating roles in the nunamiut culture where age, sex, kinship, and performance formerly weighed heavily.

Historically, Eskimo bands were led by a competent hunter or umealik, such as Morry of the kitlikmiut and Paneak of the tulugakmiut. Settlement at Anaktuvuk Pass committed the people to greater acculturation and replaced that prestigious position with the Village Council, where the weak as well as the strong had a voice. As democratic as this may be and as well as it may serve the white man, it has not served the nunamiut cause as well as it might be presumed by the casual observer. In their greatest test, during the bitter debate over moving the village, the time-honored concepts of band, kinship, matrilineal loyalty, and partriarchal dominance reappeared; however, their effectiveness had been diminished and compromised by amalgamation with the white man's institutions. Self-determination was lost in a welter of bureaucratic tangles, demeaning assistance in impractical areas, and the urgency of the situation. Since that time the village has changed more rapidly, with commensurate loss of the older nunamiut cultural ideals. As Lantis (1967) expressed it:

> "Eskimos are trying just as hard today to adapt as they did 500 to 900 years ago; the difficulty is that they are adapting not to the Arctic but to a Temperate Zone way of living."

It is not only the mere act of adapting to another culture but the rapidity with which it has been necessary that has culturally devastated the northern native populations. In the case of the nunamiut, they have experienced in approximately 20 years the degree of cultural change that most Americans achieve in many more years. Contact agents of the white man culture had appreciable influence upon a people whose decision-making was based upon informal consultation with persons who led by popular acclaim based upon capability as a hunter and knowledge of the land. Like the natural arctic ecosystems of which they were so integrally a part, the nunamiut society has been sensitive to callous exploitation. The immediate and impressive impact of white man culture upon their carefully balanced societal systems presaged destruction in environmental areas and precipitated problems in several contexts. It is ironic that the nunamiut society, so admirably adapted to its surroundings, should succumb to the culture of the white man, whom the Eskimo considered to be a child in the Arctic.

CHAPTER V

METHODS

Various kinds of plants and animals representative of the major taxa and environments of northern Alaska were collected throughout the study for radiochemical analyses and for limited stable element analyses. Following the general survey of an area, sampling was reduced to a few comparable samples from areas of continuing interest. The greatest variety of samples was obtained at Cape Thompson for the first three years of study and at Anaktuvuk Pass thereafter, reflecting the different focus of studies. Systematic collections were made, usually on a square meter (or portion thereof), basis for plants and replicate samples of animals, wherever possible. Muscle, bone and rumen samples were collected from most caribou and other herbivores. The upper hind quarter provided sufficient muscle mass and the cleaned femur within was the standard bone sample. In the case of most carnivores, both hind quarters with the femurs were required to provide sufficient material for analysis. Leg bones of fifty wolves (Canis lupus) bountied by Brooks Range residents during the years 1960-1964 were contributed by the Alaska Department of Fish and Game.

Gravimetric determinations were made on wet, standard dry and standard ash bases (AOAC, 1960) so that a standard basis for reporting radionuclide concentrations was achieved.

Gamma ray spectrometric analyses of all samples were made for ^{54}Mn, ^{65}Zn, ^{95}Zr, ^{106}Ru, ^{137}Cs, and ^{144}Ce by conventional counting methods using a single 23 x 11 cm well-type sodium iodide crystal and 256-channel analyzer. Spectra were reduced to individual radionuclide amounts by an electronic data processing procedure that also computed radionuclide concentrations in the samples, given input data of gravimetric determinations and biomass measurements. Strontium-90 analyses were made by a chemical separation-extraction method (Silker, 1958) followed by a low-beta counting technique. Selected samples were analyzed for the above gamma-emitting radionuclides and ^{22}Na, ^{60}Co, ^{88}Y, ^{110m}Ag, ^{125}Sb, ^{134}Cs fallout radionuclides and the naturally radioactive elements ^{40}K, ^{226}Ra, and ^{228}Th by means of multidimensional gamma-ray spectrometry by the method of Perkins (1965). Samples were furnished to other investigators who reported concentrations of ^{55}Fe (Palmer and Beasley, 1966), ^{210}Pb, ^{210}Po, and ^{226}Ra (Holtzman, 1966; Beasley and Palmer, 1966).

Of these 14 worldwide fallout radionuclides and five naturally radioactive elements, ^{90}Sr and ^{137}Cs were most extensively studied because of their major contribution to radiation exposures of biota, their long physical half-lives (28 and 30 years, respectively), their localization in bone (^{90}Sr) and soft tissues (^{137}Cs), and their similarity of cycling properties to their chemical analogs (Ca and K, respectively). These analyses form the basis for the following discussion of two important radionuclides in arctic ecosystems. A large number of biotic samples were also analyzed for stable Ca and K by flame spectrophotometry.

Whole-body measurements of ^{137}Cs and other gamma-emitters in human subjects were made with a shadow-shield counter (Palmer and Roesch, 1965) during the period July 1962-July 1966 and by a simplified "lap counter" (Palmer, 1966) subsequent to October 1966. It had previously been calibrated with the shadow-shield counter and results from these two methods favorably compared with a third counter at Anaktuvuk Pass during July 1966. Further calibration was made during November 1968; results were within one percent on the average of seven other whole body counters at various U. S. sites. An Eskimo field assistant accompanied the 1962 summer studies to explain the program and results to those subjects who did not understand English or preferred to converse in their own language of Inupiat.

Information about food habits of the various peoples was obtained by personal interview, the questions so structured to identify contradictory data. Sampling of foods was based upon this information so far as possible; data from those subjects interviewed far from their home villages, such as the Little Diomede residents examined in Kotzebue, were necessarily incomplete.

The remote nature of the study area and its diverse topography made estimates of radioactive fallout deposition difficult to obtain. A determined effort was unsuccessfully made for several years to interest Anaktuvuk Pass village residents in making weather observations, particularly precipitation regimes. Modest wages were offered by the U. S.

Weather Bureau for a few minutes effort each day, but invariably soon paled in the Eskimo interest. The nearest Alaskan fallout measurement station was located at Fairbanks, and fallout collections there began in March 1960 (Hardy, 1973). Monthly ^{90}Sr deposition (mCi/km^2 = nCi/m^2) values are shown in Figure 7 in relation to the periods of atmospheric nuclear weapons tests conducted by Britain, China, France, Russia, and the United States. It is apparent that the period of maximum ^{90}Sr (and therefore ^{137}Cs, also) deposition measured at Fairbanks during the period 1962-1964 resulted from radionuclides that originated from the substantial 1961-1962 tests by Russia and the United States. However, it should be remembered that lichens are very long-lived (50-100 years) and essentially provide an integrated history of atmospheric contamination for many years; therefore, the much larger nuclear test series during 1956-1958 obviously contributed substantial amounts of fallout to the Alaskan atmosphere prior to the beginning of fallout measurements at Fairbanks. The best estimate of fallout deposition at Anaktuvuk Pass is based upon assuming two-thirds the Fairbanks values, on the basis of precipitation differences (30 cm at Fairbanks, 20 cm at Anaktuvuk Pass) (Watson, 1959).

During August 1965 four Anaktuvuk Pass families cooperated in a ^{137}Cs half-time study by agreeing to substitute imported domestic meat for caribou and sheep in their diet for one month. In addition, their needs for flour, sugar, cooking oils, canned milk, butter, rice, noodles, and macaroni were supplied. The timing of the study for the month of August was based upon the desirability of starting the study with maximum ^{137}Cs concentrations in the people, which they obtained from the spring-killed caribou meat, and the declining quality and quantity of caribou meat in the permafrost cellars, which added inducement to cooperation. Care was taken to explain the study to most participants and emphasized its voluntary nature. Total 24-hour urine samples of each individual were collected and measured on two days of each week, one feces sample was obtained from most participants at the beginning of the experiment to compare urinary and fecal ^{137}Cs excretion. Whole body burdens were measured weekly by two consecutive one-minute counts made with a 53 x 76 mm NaI (Tl) crystal connected to the compact single-channel analyzer-scaler calibrated with the shadow-shield counter and previously described. A 500 ml aliquot of each person's urine and entire feces samples were counted for ten minutes each on top of the same instrument surrounded by a 10 cm thick lead housing. Calibrations made with suitable ^{137}Cs sources indicated a counting efficiency of about 2%. An additional study of ^{137}Cs in humans was made with two 20-year old males, one on the normal summer diet of caribou meat and the other on the domestic meat diet. Daily measurements were made of their ^{137}Cs body burdens and excretions via urine and feces over a 12-day period.

CHAPTER VI

RESULTS

Cape Thompson Studies

The general studies of fallout radionuclides in Cape Thompson terrestrial ecosystems were conducted in three general plant communities (Watson *et al.*, 1966): (1) *Eriophorum* tussocks, dominated by *Eriophorum vaginatum*, *Salix pulchra*, and *Sphagnum* spp.; (2) *Carex* wet meadows, dominated by *Carex aquatilis*, *Sphagnum* spp., and *Stellaria ciliatosepala*; and (3) *Cornicularia* lichen mats, principally composed of *Cornicularia divergens*, *Alectoria nigricans*, *A. ochroleuca*, and several other species.

Radionuclide concentrations in plants with persistent aerial parts were two to six times those of plants with new annual above-ground growth, which coincided with the observations of Gorham (1959). An extensive series of collections was made from a typical sedge meadow approximately 13 km inland from the Cape Thompson sea coast, part of them from pristine stands, and part from 1 m^2 plots that had been clipped to plant crowns the previous year. Cesium-137 concentration within one square meter of biomass was judged to be a better measure of fallout deposition rates because of the importance of plant growth in diluting the concentrations and the significant contribution of retained (adsorbed and absorbed) radionuclides in plant litter to recycling through stembase absorption.

During the period 1959-1960, the inventory of ^{137}Cs in the sedge community remained rather constant at about 1.0-1.5 nCi/m^2 and then in 1961 began an increase by about one nanocurie per m^2 per year to the maximum during 1964 (Table 1). Slightly different from the sedge data were the patterns of accumulation that occurred in two lichen communities continuously studied during the period 1961-1970 (Tables 2 and 3). _Cornicularia divergens_ formed appressed tangled mats of comparatively low biomass on top of limestone gravel ridges where it was subjected to the abrasion of gale-force winds and driving snow throughout the winter periods, a severe environmental niche colonized by few other plants. _Cetraria delisei_, the "snow patch lichen", grew in dense mats in sheltered depressions where deep snowdrifts formed during the winter. It thus inhabited a niche at the other extreme of exposure from _Cornicularia_, and it further had the opportunity to filter the melt water from drifts as summer progressed. The two species generally contained comparable concentrations of many fallout radionuclides and promptly reflected fallout deposition. Maximum values in lichens and sedges occurred at various times for different radionuclides (Table 4), with sedges usually achieving maxima before the lichen species and a suggestion that _Cornicularia divergens_ was more efficient than _Cetraria_ in sorbing most fallout radionuclides. All three communities contained maximum ^{137}Cs concentrations during 1965.

Table 1. Cesium-137 in Cape Thompson sedge (<u>Carex aquatilis</u>) 1959-1969.

	Unclipped Plots				New Growth - Clipped Plots			
Date	N	pCi/g	nCi/m^2	kg/m^2	N	pCi/g	nCi/m^2	kg/m^2
15 Aug 59	9	5.0 ± 1.0	1.1 ± 0.2	0.219				
15 Jul 60	3	8.4 ± 0.3	1.5 ± 0.05	0.184				
15 Aug 60	3	4.3 ± 0.3	1.0 ± 0.07	0.232	3	3.2 ± 0.07	0.2 ± 0.004	0.066
1 Aug 61	10	8.7 ± 0.7	2.4 ± 0.4	0.282	4	5.0 ± 0.2	0.7 ± 0.03	0.148
1 Aug 62	9	9.6 ± 1.7	4.6 ± 1.1	0.478	3*	9.3 ± 0.7	0.8 ± 0.02	0.086
28 Jul 63	9	15 ± 2.6	3.2 ± 0.3	0.210				
23 Jul 64	9	34 ± 0.9	5.1 ± 0.7	0.150				
7 Sep 65					3*	60 ± 3.3	3.1 ± 0.1	0.052
11 Aug 66					3*	7.9 ± 0.4	0.6 ± 0.03	0.072
25 Aug 67	3*	2.4 ± 0.2	1.3 ± 0.2	0.556				
6 Jul 68					3*	4.0 ± 0.9	0.3 ± 0.1	0.068
20 Aug 69					3*	0.9 ± 0.2	0.06± 0.01	0.065
Mean biomass				0.289				0.076
				±0.052				±0.0003

* Nine 1 m^2 samples composited into 3 samples of 3 m^2 each.

Table 2. Fallout radionuclides in Cape Thompson lichens - Cornicularia divergens.

Date	Units	N	^{54}Mn	^{65}Zn	$^{95}Zr-Nb$	^{106}Ru	^{137}Cs	^{144}Ce	Biomass kg/m^2
5 Aug 61	pCi/g	4	ND	1.0 ± 0.3	13 ± 3.8	5.8 ± 0.5	20 ± 1.1	36 ± 2.1	0.242
	nCi/m^2	4		0.17 ± 0.05	2.2 ± 0.5	1.6 ± 0.4	4.8 ± 0.9	8.7 ± 1.8	
29 Aug 61	pCi/g	5	1.4 ± 0.7	1.4 ± 0.5	3.3 ± 1.8	7.4 ± 1.9	26 ± 3.7	93 ± 13	
22 Sep 61	pCi/g	4	ND	ND	145 ± 2.9	17 ± 2.3	21 ± 0.8	93 ± 1.9	0.348
	nCi/m^2	4			50 ± 1.5	5.9 ± 0.7	7.2 ± 0.5	32 ± 1.2	
19 Jul 62	pCi/g	12	17 ± 1.0	2.8 ± 0.6	280 ± 15	6.9 ± 2.3	28 ± 1.9	410 ± 17	
27 Jul 63	pCi/g	4	17 ± 2.0	ND	155 ± 5.3	57 ± 3.7	39 ± 2.8	460 ± 29	
23 Jul 64	pCi/g	3	17 ± 1.7	1.7 ± 0.4	7.3 ± 0.2	82 ± 8.8	69 ± 7.0	460 ± 56	
	nCi/m^2								
7 Sep 65	pCi/g	3	8.8 ± 0.7	ND	ND	80 ± 12	87 ±2.8	300 ± 27	
	nCi/m^2								
11 Aug 66	pCi/g	2	2.3 ± 0.4	ND	ND	79 ± 8.4	58 ±3.4	120 ± 6.5	0.334
	nCi/m^2		0.8 ± 0.1			26 ± 3.3	19 ±1.5	41 ± 3.0	
23 Aug 67	pCi/g	2	0.6 ± 0.6	2.0 ± 2.0	11 ± 8.1	12 ± 12	52 ±1.0	82 ± 7.0	
	nCi/m^2								
6 Jul 68	pCi/g	2	ND	7.2 ± 0.2	21 ± 2.6	ND	62 ±2.6	85 ± 1.6	0.326
	nCi/m^2			2.4 ± 0.6	6.7 ± 0.7		20 ±5.2	28 ± 6.6	

Table 2., concluded.

Date	Units	N	^{54}Mn	^{65}Zn	^{95}Zr-Nb	^{106}Ru	^{137}Cs	^{144}Ce	Biomass kg/m^2
20 Aug 69	pCi/g	2	3.1 ± 0.8	ND	ND	32 ± 5.5	52 ± 2.5	68 ± 1.0	
	nCi/m^2								
10 Aug 70	pCi/g	2	4.5 ± 2.5	1.2 ± 1.2	ND	ND	50 ± 9.2	64 ± 0.2	

Table 3. Fallout radionuclides in Cape Thompson lichens - Cetraria delisei

Date	Units	N	^{54}Mn	^{65}Zn	$^{95}Zr-Nb$	^{106}Ru	^{137}Cs	^{144}Ce	Biomass kg/m^2
27 Jun 61	pCi/g	10	0.3 ± 0.08	2.6 ± 0.3	13 ± 3.0	1.9 ± 1.0	37 ± 1.4	80 ± 4.5	
18 Jul 62	pCi/g	12	3.9 ± 0.4	ND	75 ± 1.7	30 ± 0.75	21 ± 0.7	150 ± 3.2	
27 Jul 63	pCi/g	4	13 ± 0.6	ND	86 ± 5.1	97 ± 3.9	33 ± 1.4	315 ±13	
23 Jul 64	pCi/g	3	11 ± 0.56	0.91 ± 0.46	8.5 ± 0.72	58 ± 3.9	69 ± 3.3	350 ±25	
	nCi/m^2								
7 Sep 65	pCi/g	3	6.0 ± 1.1	ND	2.1 ± 1.2	5.7 ± 8.2	98 ± 1.7	200 ±31	
	nCi/m^2								
11 Aug 66	pCi/g	2	2.0 ± 0.4	ND	ND	74 ± 18	57 ± 8.9	39 ± 5.4	0.947
	nCi/m^2		1.9 ± 0.2			71 ± 15	54 ± 6.3	37 ± 3.6	
23 Aug 67	pCi/g	2	ND	3.3 ± 1.8	16 ± 10	ND	35 ± 8.5	9.0 ± 2.4	1.345
	nCi/m^2			4.4 ± 2.7	20 ± 17		48 ± 19	12.8 ± 5.2	
6 Jul 68	pCi/g	2		8.0 ± 1.0	28 ± 6.7	ND	63 ± 3.1	32 ± 2.4	0.651
	nCi/m^2			5.3 ± 1.2	19 ± 6.3		41 ± 2.2	21 ± 0.6	
20 Aug 69	pCi/g	3	2.4 ± 0.4	0.7 ± 0.2	ND	ND	34 ± 2.6	14 ± 1.3	0.594
	nCi/m^2		1.4 ± 0.2	0.4 ± 0.09			19 ± 0.5	8.3 ± 0.8	
10 Aug 70	pCi/g	2	6.7 ± 0.8	2.1 ± 2.1	ND	ND	67 ± 7.1	34 ±13	

Table 4. Years of maximum radionuclide concentrations (in units of pCi/g standard dry weight) in lichens and sedges at Cape Thompson, Alaska during 1961-1970.

	Taxa		
Radionuclide	*Cornicularia divergens*	*Cetraria delisei*	*Carex aquatilis*
^{54}Mn	1963	1962-1964	1963
^{65}Zn	1968	1968	1962
^{95}Zr	1963	1962	1962-1963
^{106}Ru	1963	1964-1966	1964
^{137}Cs	1965	1965	1965
^{144}Ce	1964	1963-1964	1963

Sphagnum moss that grew in water-saturated depressions in Eriophorum tussock communities often contained twice as much fallout as the same vegetation that grew on the tops of small hummocks. Such low areas received runoff from surrounding landscapes, the permafrost prevented percolation, and retention of adsorbed minerals may have created an attractive nutrient base for the several lichens that were often found associated with the moss.

Samples of most of the birds and mammals of the Cape Thompson region during the period 1959-1962 contained ^{137}Cs concentrations that reflected their food habits and environments (Table 5). Highest amounts were in terrestrial carnivores, median values in terrestrial herbivores, and the lowest amounts were in marine feeders. Seasonal concentrations of ^{137}Cs in caribou flesh and ^{90}Sr in bone during 1960-1962 are shown in Figure 6; ^{137}Cs values varied over a hundred-fold range with maximums in winter months and minimums during summer, while ^{90}Sr increased from about 10 pCi/g in 1960 to 20 pCi/g at the end of 1961.

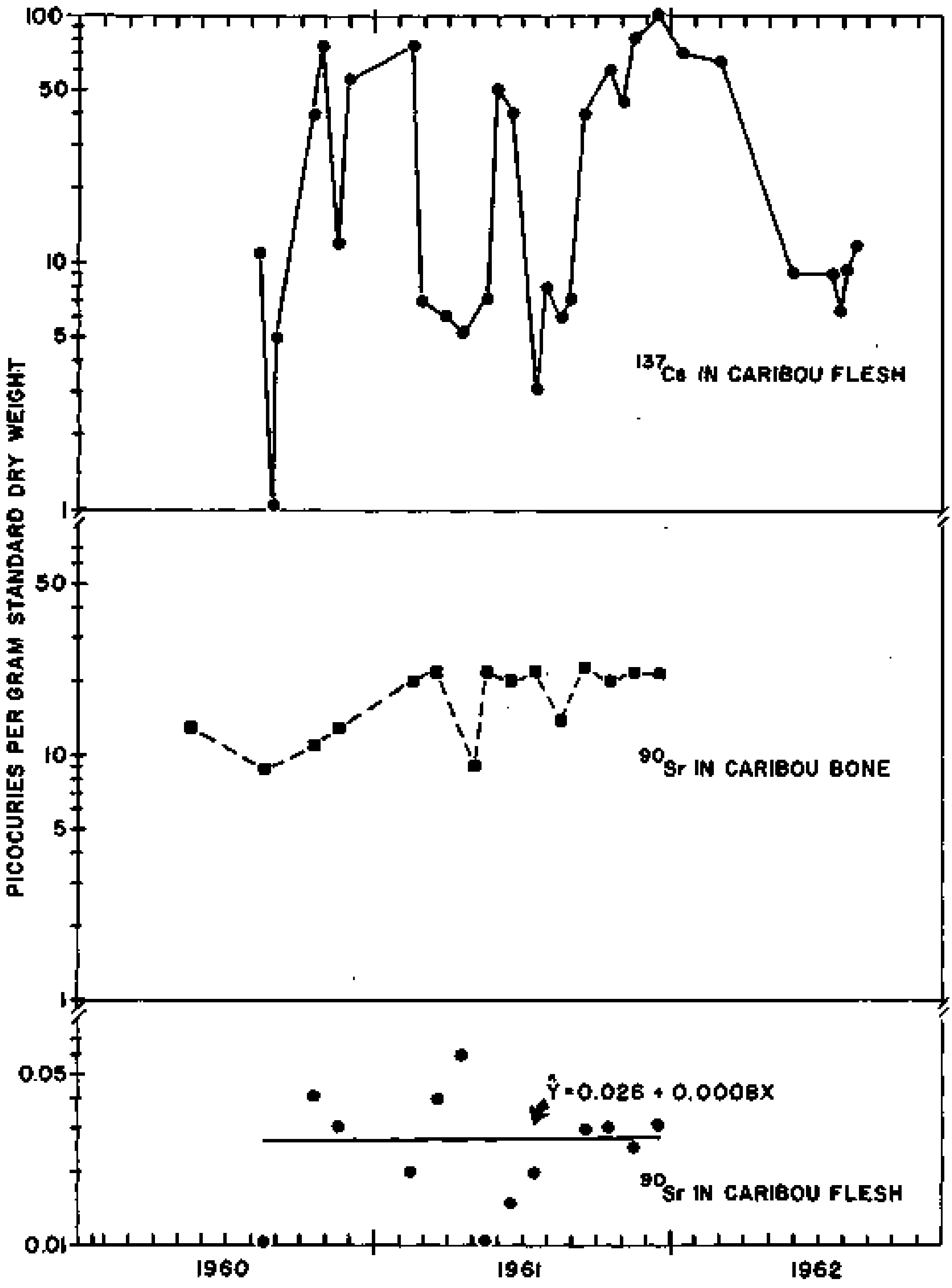
Anaktuvuk Pass Studies

With the beginning of radiation ecology studies at Anaktuvuk Pass in 1962, amounts of fallout radionuclides in each of the trophic levels of the lichen-caribou-Eskimo food web were determined. The early studies were elaborated by more intensive sampling of all components and controlled experiments beginning in 1964. Because of the realistic

Table 5. Representative ^{137}Cs concentrations (units of pCi/g standard dry weight) in birds and mammals of the Cape Thompson region 1959-1962.

Birds		Mammals	
Longspur	20	Wolf	135
Crane	4.3	Red fox	60
Sandpiper	3.0	Caribou	50
Raven	1.2	Grizzly bear	5
Ptarmigan	0.9	Ground squirrel	0.5
Jaeger	0.6	Tundra vole	0.5
Brant	0.4	Seal	0.06
Gull	0.1	Walrus	0.02
Loon	0.1	Whale	0.02
Murre	0.1		

Figure 6. Strontium-90 and cesium-137 in caribou bone and flesh of the Cape Thompson region during 1960-1962. Units of X in the regression equation are in months.


100
50
10
5
1
50
10
5
1
0.05
0.01
PICOCURIES PER GRAM STANDARD DRY WEIGHT
137Cs IN CARIBOU FLESH
90Sr IN CARIBOU BONE
Ŷ=0.026 + 0.0008X
90Sr IN CARIBOU FLESH
1960
1961
1962

complexity of the environmental mechanisms that regulate radionuclide concentrations in the apparently simple ecosystem at Anaktuvuk Pass, the results of our studies are discussed at each trophic level, beginning with the lichens and proceeding up the food web.

Permanent lichen sampling sites were established in 1962 in lichen carpets on rolling topography of ancient river terraces to the east and south of the village. Species composition and biomass of these sampling locations (Table 6) show many similarities between plots within a few hundred meters that were assumed to represent climax or aged stands.

The amount of worldwide fallout deposited upon the Anaktuvuk Pass landscapes, or upon most of the study area for that matter, can only be approximated by extrapolating the deposition values for Fairbanks (some 400 km southeast of Anaktuvuk Pass) to the study area. Cesium deposition was calculated from the ratio $^{137}Cs : ^{90}Sr = 1.9 \pm 0.2$ (Hardy and Chu, 1967). A comparison of the measured amounts of ^{90}Sr and ^{137}Cs in the Cladonia-Cetraria lichen carpet at Anaktuvuk Pass and the deposition at Fairbanks is presented in Table 7 and Figures 7 and 8. Fallout collections at Fairbanks were begun in March 1960, and through December 1964 totalled about 17.0 nCi/m^2 for ^{90}Sr and 32.2 nCi/m^2 for ^{137}Cs. Comparison of these data, corrected by multiplying by 0.67 for extrapolation to Anaktuvuk Pass, with ^{137}Cs deposition in northern Sweden (Svensson and Lidén, 1965) shows the two locations to be nearly identical. However, the Swedish landscape had

Table 6. Lichen species composition and biomass in Cladonia-Cetraria carpet in permanent study plots at Anaktuvuk Pass.

	Percent Composition by Weight	
Species (Populations)	Control Plot	Alternate-E
Cladonia rangiferina	48.0	48.0
Cladonia alpestris	46.0	39.4
Cladonia mitis	0.1	5.5
Alectoria ochroleuca	2.1	3.5
Cetraria cucullata	2.4	2.1
Cetraria islandica	0.6	0.6
Cetraria richardsonii	0.2	0.2
Thamnolia vermicularis	0.6	0.5
Dactylina arctica	0.2	0.1
Totals	100.0	100.0
Lichen Community Biomass:		
Standard dry kg/m^2 ± S.E.	1.41 ± 0.03	1.87 ± 0.08
N	61	34

Table 7. Strontium-90 and cesium-137 inventories in <u>Cladonia</u>-<u>Cetraria</u> carpet at Anaktuvuk Pass, 1962-1972, compared to estimated deposition rates. Units are expressed in standard dry weight.

		Lichens						Deposition nCi/m²*	
	Biomass	^{137}Cs			^{90}Sr				
Date	kg/m²	pCi/g	N	nCi/m²	pCi/g	N	nCi/m²	^{137}Cs	^{90}Sr
3 Jul 62	0.52	12 ± 4.8	6	6.2 ± 2.5	3.5 ± 0.4	2	1.8 ± 0.2	6.21	3.21
7 Jul 63	0.61	24 ± 2.4	3	14 ± 1.4	6.7 ± 3.0	3	4.1 ± 1.8	11.66	6.14
15 Jan 64	--	33 ± 0.4	5	--	12 ± 0.7	5	--	8.70	4.61
15 Apr	--	24 ± 2.4	2	--	8.0 ± 0.2	2	--	0.66	0.35
12 Jul	1.53	27 ± 1.4	4	41 ± 2.6	9.8 ± 1.2	4	16 ± 0.6	3.64	1.92
2 Aug	1.75	20 ± 0.6	10	35 ± 1.1	7.4 ± 0.2	5	12 ± 0.8	0.08	0.04
11 Sep	1.53	30 ± 0.9	10	46 ± 1.5	9.3 ± 0.6	5	15 ± 1.7	1.18	0.62
14 Nov	--	25 ± 1.1	2	--	9.3 ± 0.2	2	--	2.94	1.55
19 Jan 65	--	28 ± 4.1	4	--	9.6 ± 0.9	3	--	2.94	1.55
1 Apr		29 ± 1.6	2	--	5.9	1	--	2.94	1.55
26 Jul	1.45	33 ± 3.6	10	48 ± 4.3	6.4 ± 0.8	5	8.9 ± 1.4	2.94	1.55
28 May 66	0.94	33 ± 1.0	4	31 ± 2.8	9.1 ± 0.9	4	10 ± 2.3	2.014	1.06
2 Aug	1.26	27 ± 1.1	7	34 ± 1.2	8.3 ± 0.2	3	12 ± 0.5	0.513	0.27
5 Oct	0.93	27 ± 0.5	2	25 ± 7.9	7.9 ± 1.3	2	7.5 ± 3.3	0.019	0.01
5 Dec	1.30	23 ± 0.5	3	30 ± 6.9	7.4 ± 0.1	3	9.5 ± 0.5	0.114	0.06

Table 7., continued

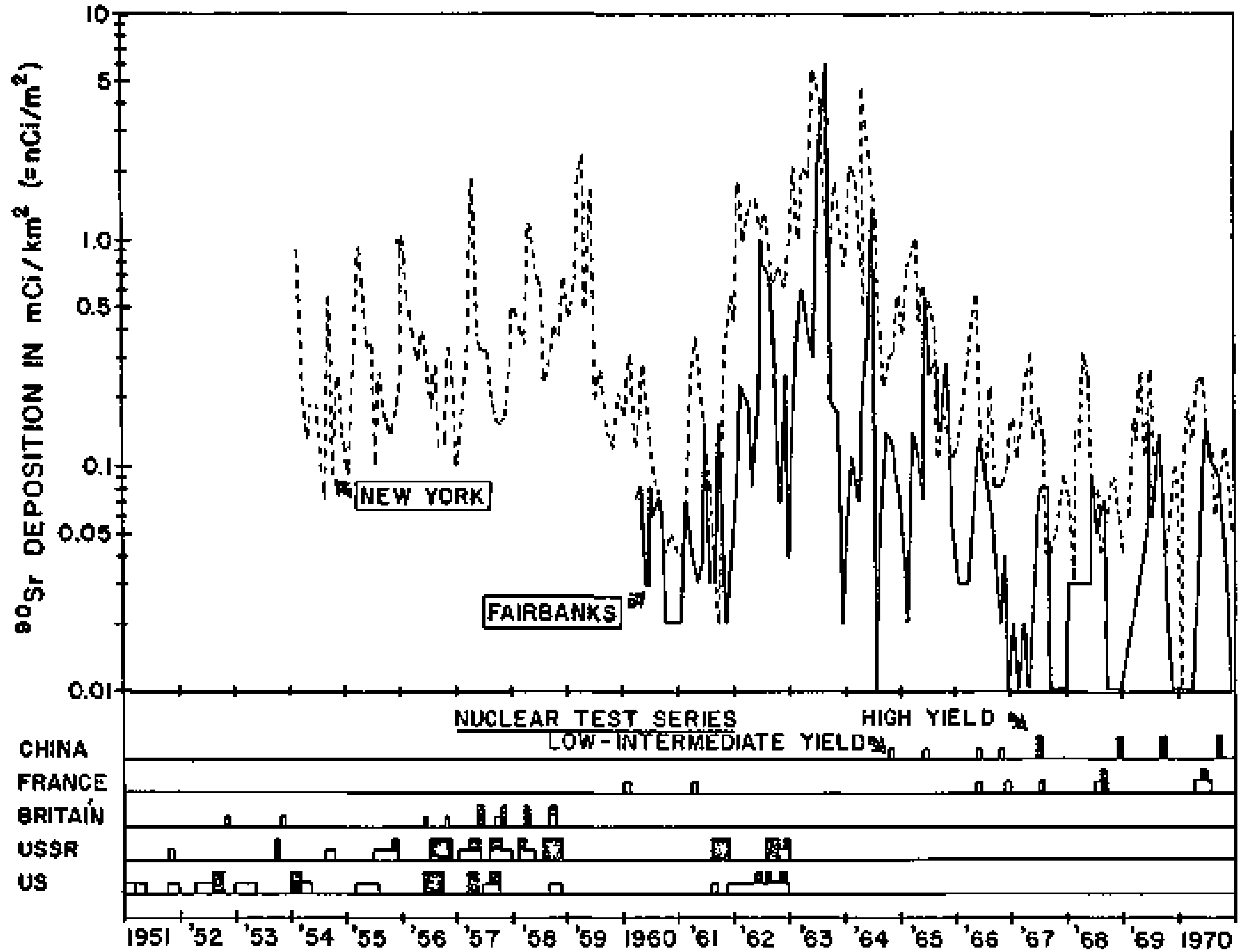
		Lichens						Deposition nCi/m²*	
		^{137}Cs			^{90}Sr				
Date	Biomass kg/m²	pCi/g	N	nCi/m²	pCi/g	N	nCi/m²	^{137}Cs	^{90}Sr
4 Feb 67	2.19	16 ± 0.3	3	35 ± 2.5	5.1 ± 0.06	3	11 ± 0.8	0.057	0.03
4 May	1.71	24 ± 1.2	2	41 ± 2.6	6.8 ± 1.3	2	11 ± 2.1	0.171	0.09
2 Aug	1.20	25 ± 0.67	10	30 ± 1.2	8.3 ± 0.6	3	11 ± 0.8	0.380	0.20
1 Oct	1.14	28 ± 1.4	2	32 ± 2.3	8.8 ± 0.4	2	10 ± 0.5	0.171	0.09
4 Dec	2.41	16 ± 2.2	2	38 ± 5.5	11.7 ± 5.7	2	28 ±13.4	0.019	0.01
17 Feb 68	2.07	15 ± 1.4	2	31 ± 5.0	5.7 ± 0.8	2	12 ± 1.7	0.076	0.04
6 May	--	18 ± 0.4	2	--	6.2 ± 0.5	2	--	0.228	0.12
30 Jun	1.16	26 ± 1.6	10	30 ± 1.3	7.9 ± 0.4	8	9.4 ± 0.4	0.228	0.12
25 Sep									
East	1.50	21 ± 0	2	31 ± 1.6	2.7 ± 0.7	2	3.9 ± 0.8	0.247	0.13
South	1.75	23 ± 0.3	2	40 ± 1.3	4.7 ± 0.7	2	8.3 ± 1.5	0.247	0.13
4 Feb 69	1.27	24 ± 1.1	4	29 ± 7.3	5.0 ± 0.2	4	6.4 ± 1.8	0.038	0.02
29 Jul									
South	1.49	34 ± 0.6	2	50 ± 2.0	7.9 ± 0.2	2	12 ± 0.5	0.494	0.26
East	2.95	15 ± 0.3	5	44 ± 1.6	3.3 ± 0.3	5	9.8 ± 0.9	0.494	0.26
7 Feb 70	3.10	13 ± 0.8	3	39 ± 2.5	4.1 ± 0.5	3	12 ± 1.0	0.361	0.19

Table 7., concluded

		Lichens						Deposition nCi/m²*	
	Biomass	^{137}Cs			^{90}Sr				
Date	kg/m²	pCi/g	N	nCi/m²	pCi/g	N	nCi/m²	^{137}Cs	^{90}Sr
2 Aug	1.66	14 ±3.9	6	24 ± 5.3				0.722	0.38
9 Aug 71	3.96	30	1	24				0.798	0.42
25 Jul 72									
East	2.82	15.6±0.8	2	44.0 ± 1.0					
South	1.84	12.7±0.6	2	23.1 ± 1.6					

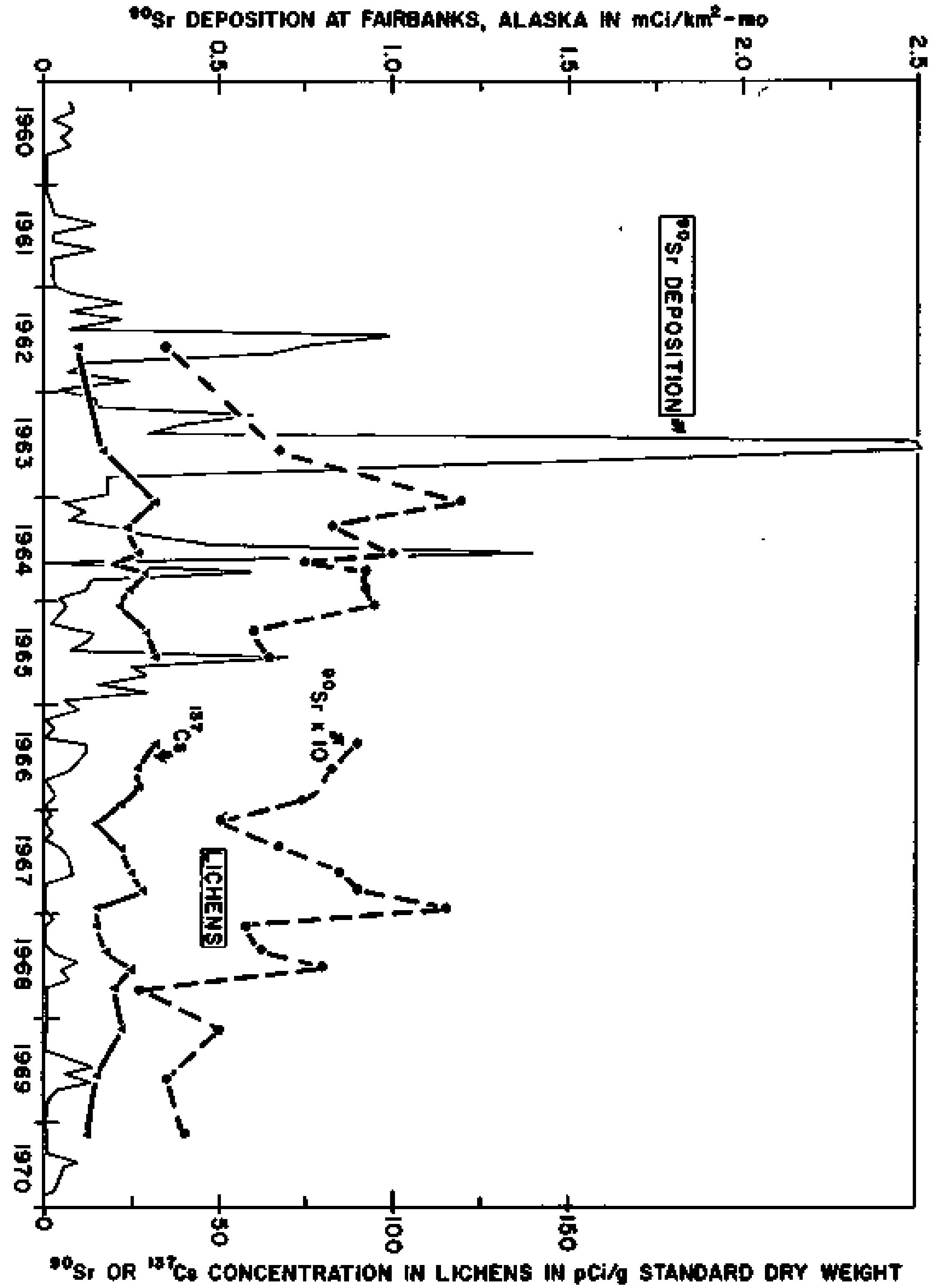
* Cumulative fallout deposition at Anaktuvuk Pass between successive sampling periods based on 0.67 of monthly measurements at Fairbanks (Hardy, 1973).

Figure 7. Fallout deposition at Fairbanks in relation to atmospheric nuclear weapons tests, 1957-1970. Deposition at New York is included to indicate the major period of fallout prior to measurement at Fairbanks. Height and color of bars indicate low-intermediate yield or high yield (>1 megaton) nuclear tests. Width of bars indicate approximate duration of test series.



^{90}Sr DEPOSITION IN mCi/km^2 (=nCi/m^2)
10
5
1.0
0.5
0.1
0.05
0.01
NEW YORK
FAIRBANKS
NUCLEAR TEST SERIES
HIGH YIELD
LOW-INTERMEDIATE YIELD
CHINA
FRANCE
BRITAIN
USSR
US
1951
'52
'53
'54
'55
'56
'57
'58
'59
1960
'61
'62
'63
'64
'65
'66
'67
'68
'69
1970

Figure 8. Strontium-90 and cesium-137 concentrations in lichens at Anaktuvuk Pass in relation to fallout deposition rates measured at Fairbanks, Alaska during the period 1960-1970.



⁹⁰Sr DEPOSITION AT FAIRBANKS, ALASKA IN mCi/km²-mo
0
0.5
1.0
1.5
2.0
2.5
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
⁹⁰Sr DEPOSITION
⁹⁰Sr x 10
¹³⁷Cs
LICHENS
0
50
100
150
⁹⁰Sr OR ¹³⁷Cs CONCENTRATION IN LICHENS IN pCi/g STANDARD DRY WEIGHT

apparently received an additional 16.8 nCi/m^2 of ^{137}Cs up to September 1961-December 1964. During the latter period, Anaktuvuk Pass received about 21.6 nCi/m^2 ^{137}Cs. However, comparison of ^{137}Cs fallout measured at a Swedish station at 64.6°N latitude with that at Fairbanks (64.8°N latitude) during those years showed the following relationship of ^{137}Cs deposition (nCi/m^2):

Station	^{137}Cs deposited during time period: 1 Oct 1962 to 1 Oct 1963	1 Oct 1963 to 1 Oct 1964
Lycksels, Sweden	8.7 nCi/m^2	7.0 nCi/m^2
Fairbanks, Alaska	13.6 nCi/m^2	6.3 nCi/m^2

This illustrates the possible differences between stations during periods of high fallout rates and cautions the extrapolation backward to pre-measurement times of fallout collection. The Swedish investigators cited above also reported 91-100% retention of ^{137}Cs in the lichen carpets, and suggested that lichen carpets were an efficient fallout meter. The results in Table 7 indicate that deposition at Anaktuvuk Pass up to July 1964 was substantially greater than the Fairbanks data indicated, as shown below:

	Radionuclide concentration July 1964	
	Strontium-90	Cesium-137
Cumulative deposition, Fairbanks:	17.0 nCi/m^2	32.3 nCi/m^2
Estimated deposition, Anaktuvuk Pass:	11.4 nCi/m^2	21.6 nCi/m^2
Cladonia-Cetraria carpet:	16.0 nCi/m^2	41.4 nCi/m^2

On the basis that nearly all of these two radionuclides were retained by the lichens, it appears that about 5 nCi ^{90}Sr and 20 nCi ^{137}Cs per m^2 were deposited upon Anaktuvuk Pass lichen carpets by fallout prior to the beginning of fallout measurements at Fairbanks. Restrictions to the acceptance of these values were apparent: (1) the observed ^{137}Cs : ^{90}Sr ratio in the lichen carpet of 2.6 : 1 was substantially greater than the 1.9 : 1 reported in fallout (Hardy and Chu, 1957), suggesting differential loss and/or cycling of the two radionuclides; (2) the excess amount of ^{137}Cs in the lichen carpet was four times the excess amount of ^{90}Sr, and (3) there appeared to be independent seasonal cycles of the radionuclides in the lichens. These descrepancies led to a series of controlled experiments with natural lichen communities to better define loss rates and mechanisms of radionuclide transport and concentration.

One of the first experiments was experimental washing of a representative sample of the _Cladonia-Cetraria_ mat. The lichens were placed in a three-liter beaker with two liters of distilled water and gently agitated for two minutes. The lichens were then removed and excess water gently expressed by hand; the lichens were dried, milled, and analyzed for gamma-emitters, as was another unwashed sample from the same location. The wash water was filtered to remove the undissolved solids and the filtrate was concentrated to a suitable volume for analysis. Results of this simple experiment (Table 8) showed that the concentrations of ^{54}Mn, ^{95}Zr, ^{106}Ru, ^{137}Cs, and ^{144}Ce decreased by washing but only ^{144}Ce decreased significantly; and that 60 to 80% of the removed radioactivity was in the dissolved fraction.

A second set of experiments involved the application of measured amounts of ^{85}Sr, ^{90}Sr, ^{134}Cs and ^{137}Cs in single drops to individual podetia and sprinkled in simulated rain over 25 m^2 plots, at levels calculated to be 10^3 times background. Part of the results of these experiments was lost in a laboratory fire and the ^{85}Sr data are, therefore unavailable. Although fallout could not be precisely simulated by the experiment, ^{137}Cs droplets applied to single podetia and sampled annually for four years yielded an effective half-time of 6.7 years. However, the results from the ^{134}Cs sprinkled on lichens and wetted by a heavy rain immediately following application showed no decrease after four years (Table 9). The apparent immobility (T_{eff} = 51.3 years) during the first year of observation in the ^{137}Cs droplet experiment may be due to several factors, such as adsorption to external mycellia, adjustment of the

Table 8. Removal of fallout radionuclides from Cladonia-Cetraria lichens by washing in distilled water.

Component	N	Radionuclide Concentration in pCi/g (Mean ± S.E.)				
		^{54}Mn	^{95}Zr-Nb	^{106}Ru	^{137}Cs	^{144}Ce
Unwashed lichens	4	8.9 ± 0.6	3.3 ± 0.2	33 ± 1.6	27 ± 1.4	182 ± 13
Washed lichens	3	6.0 ± 1.8	3.0 ± 0.4	30 ± 1.7	22 ± 2.9	125 ± 15

Table 9. Retention of ^{134}Cs and ^{137}Cs by natural lichen communities at Anaktuvuk Pass. Single drops of ^{137}Cs were applied to individual podetia and ^{134}Cs was sprinkled on 25 m^2 lichen carpets.

Sprinkled Treatment		Single Droplet Treatment		
Days After Application	nCi ^{134}Cs per m^2*	Days After Application	nCi ^{137}Cs per podetium*	T_{eff} (years)
	$\bar{X}$ ± S.E.		$\bar{X}$ ± S.E.	
1	971 ± 47	1	22.1 ± 0.56	
23	990 ± 89			
63	967 ± 45			
380	823 ± 34	370	21.8 ± 0.75	51.3
752	905 ± 53	736	19.1 ± 1.08	9.0
1173	890 ± 44	1068	16.9 ± 0.81	7.6
1505	1020 ± 142	1465	14.6 ± 0.82	6.7

* Upper 12 cm of lichens, including most of gray slime layer.

$^{137}CsNO_3$ (pH 4.0) by the podetia, or the rather strict containment of the innoculate within the ten podetia randomly sampled. Sampling error was considered minimal in light of coefficients of variation that ranged from 0.08 to 0.18, which was less than the mean of 0.35 observed in several natural lichen samples obtained from northern Alaska (Eberhardt, 1964). Similar studies of ^{90}Sr droplets on lichen podetia yielded effective half-times of 1.0 to 1.6 years, with the longer period again observed during the first year after application, and the coefficients of variation of 0.20 to 0.87. These results seem compatible with recent translocation experiments using Cladonia alpestris thalli and stable strontium and cesium (Tuominen, 1967 and 1968), in which the movement was described as diffusive in character but complicated by cation exchange, especially with respect to Sr ions. Attraction of Sr to the thallus strongly retarded its movement and Cs was, therefore, the more mobile of the two ions. This contrasted with previous reports of tenacious binding of radionuclides, particularly ^{137}Cs, in the mycellia of lichens (Nevstrueva et al., 1967) and observations of effective half-times of ^{137}Cs in lichens which ranged from 4-5 years (Miettinen and Häsänen, 1967) to greater than 10 years (Lidén and Gustafsson, 1967; Hanson, Watson, and Perkins, 1967; Hanson and Eberhardt, 1969). Consistent observations of higher ^{137}Cs concentrations in the top portions of lichens that exceeded those of ^{90}Sr by factors greater than the 1.9 ratio of Cs : Sr in radioactive fallout were the basis for assuming that this represented tenacious binding and subsequent immobility of ^{137}Cs deposited on lichens.

Part of the explanation for the changed ^{137}Cs : ^{90}Sr ratio in the natural situation was indicated by seasonal sampling of vertical strata of lichens, humus, and soil within the Cladonia-Cetraria carpet (Hanson and Eberhardt, in press). That study provided evidence of mobilization of ^{137}Cs from lower strata during the late winter initiation of photosynthesis by lichens, and the concentration of that radionuclide in the top 6 cm. Exchange of ^{90}Sr between humus and the lower portion of lichens was indicated by seasonal shifts of concentrations. Soil beneath the lichens contained barely detectable amounts of ^{90}Sr. Negligible higher concentrations in the A_2 (organic-mineral soil) horizon compared to the B (mineral soil) horizon may have been due to the presence of small amounts of vascular roots contained in the A_2 samples, although care was taken to remove all roots. Comparison of ^{90}Sr and ^{137}Cs concentrations in lichen community strata sampled in February and July 1969 and February 1970 (Table 10) also indicated radionuclide cycling between various strata, with ^{137}Cs more mobile than ^{90}Sr. The ^{90}Sr in the top 6 cm tended to be more stable than the ^{137}Cs, tended to concentrate in the lower 6 cm to a greater extent, and once in the A_0 (organic humus) horizon tended to be tightly bound and unavailable. Strontium movement was, therefore, apparently much slower than ^{137}Cs and

Table 10. Compartment analysis of ^{90}Sr and ^{137}Cs in vertical strata of a *Cladonia* lichen community during summer and winter periods.

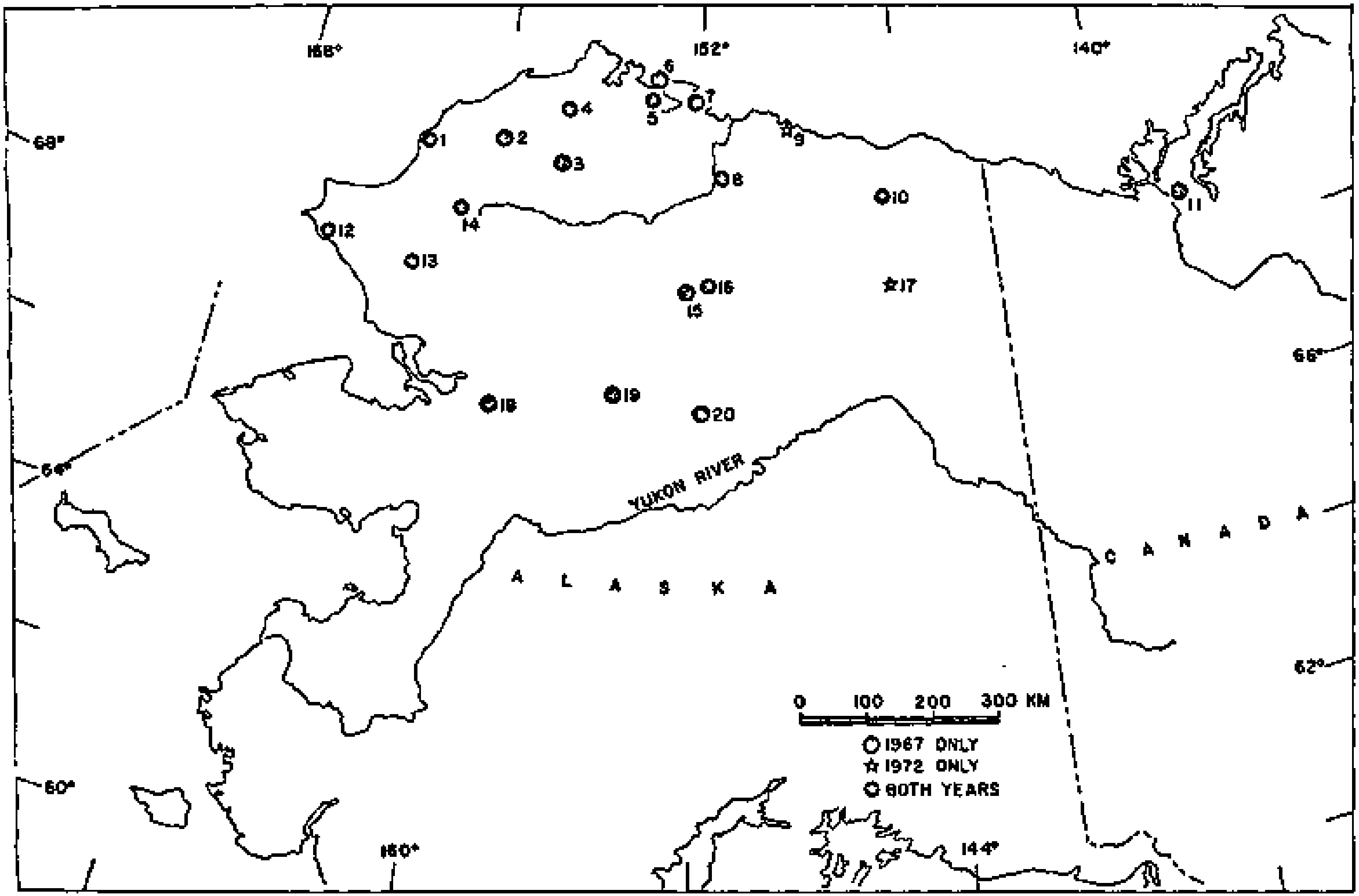
Stratum	Biomass (kg per m^2)			Percent of Total Radionuclide Inventory					
				Strontium-90			Cesium-137		
	Feb. 1969	Jul. 1969	Feb. 1970	Feb. 1969	Jul. 1969	Feb. 1970	Feb. 1969	Jul. 1969	Feb. 1970
Upper 6 cm	1.27	1.31	0.80	42	46	38	60	70	50
Lower 6 cm	0.58	1.64	1.80	25	27	51	21	21	44
A_0	0.48	2.48	2.40	30	22	8	15	6	4
A_2	--	6.83	6.80	--	5	3	--	3	3

more complicated by ion exchange and other processes. Tuominen (op. cit.) suggested that ^{90}Sr transport, at least, was essentially a process of physical chemistry without any indications of metabolic activity; and that ionic movement might be depicted as a pumping action subject to the influences of wind, humidity, and water content of the lichens. It was concluded that radionuclide cycling within natural arctic lichen communities is more of a dynamic process than previously noted, that it is compatible with several circumpolar studies of lichen communities, and that it has important implications to the maintenance of a spring pulse of ^{137}Cs body burdens of northern Alaskan caribou. The general trend of ^{137}Cs concentrations during the period 1962-1970 at Anaktuvuk Pass was that of a gradual increase to a maximum during 1965-1966 and a gradual decrease thereafter. Superimposed upon this general picture is the dynamic process of compartmental exchange and seasonal fluctuation described above.

Cesium-137 in Lichen Communities of Northern Alaska

Concurrent with the comparison of ^{137}Cs whole body burdens in residents of the three villages of differing food-gathering patterns, lichen samples were collected at 20 locations across the study area (Fig. 9). Initial collections at most of the sites were made during July-August 1967 and again during the same period of 1972. Annual sampling was conducted at three locations on the Tagagawik, Pah, and

Figure 9. Lichen collection sites across northern Alaska and Canada.



168°
152°
140°
68°
66°
64°
62°
60°
160°
144°
YUKON RIVER
ALASKA
CANADA
0 100 200 300 KM
1967 ONLY
1972 ONLY
BOTH YEARS

Kanuti River drainages (Locations 18, 19, and 20 in Figure 9) that were representative of the major wintering areas of the Arctic Herd.

The objective of the study was to describe geographical and ecological differences in ^{137}Cs concentrations of lichen communities that are utilized by caribou for food, so that variation in caribou ^{137}Cs concentrations might be better understood. Of prime interest were the annual spring pulses noted in ^{137}Cs concentrations of caribou flesh sampled during each spring migration at Anaktuvuk Pass. There was a possibility that the animals taken during spring represented caribou that had been feeding in areas of higher fallout deposition than the animals taken during the winter months in the vicinity of Anaktuvuk Pass.

As previously described, the study area encompassed a substantial array of complex ecosystems in five physiogeographic provinces across most of Alaska north of 66^{o}N latitude. Twelve major lichen communities were sampled during the two seasons, of which nine were of fairly broad distribution and comparable. The term "community" included all lichen species ("populations") within a sample, which was then designated by the dominant lichen species at that location. All components of a community (sample) were meticulously separated for biomass and ^{137}Cs determinations. This entailed sorting out the dominant lichen species, subordinate lichen species, and litter from 50-750 g samples and required nearly three months to process 75 samples.

The vast area covered in the sampling required several hours of flying in both float plane and wheeled aircraft, and the selection of suitable landing areas more or less limited the amount of time and lichen communities available for sampling. Several locations within each of the major physiogeographic provinces were combined for statistical analysis as follows:

Province	Locations (See Figure 9)
Arctic Coastal Plain	1, 4, 5, 6, 7, 9, 11
Arctic Foothills	2, 3, 8, 12, 14
Arctic Mountains	10, 13, 15, 16
Kobuk-Selawik Lowland	18, 19, 20
Porcupine Plateau	17

Results of ^{137}Cs measurements of nine ubiquitous species are summarized in Table 11, which compares years and major physiogeographic provinces. Data from collections made in the Kobuk-Selawik Lowland during 1967 and the Porcupine Plateau during 1967 have been included for information. These data were statistically analyzed in several ways to discern relationships between species, locations, and years of collection. Two-way analysis of variance with replications (also termed three-way AOV) of Cetraria cucullata and Cetraria richardsonii, and then with Dactylina included showed that there was no significant difference between those species, provinces, or years. This test was upon

Table 11. Cesium-137 concentrations in major lichen communities of northern Alaska during 1967 and 1972.

Year	^{137}Cs Concentration ($\bar{X}$ ± S.E.) in pCi/g Standard Dry Weight in Communities*									
	Cecu	Ceri	Cede	Clal	Clra	Thve	Codi	Stpa	Daar	Combined $\bar{X}$ S.E.(N)
Arctic Coastal Plain										
1967	24±3.5	28 ±2.3		23±1.1	18±2.4	23 ±1.2			24 ±2.0	28±0.4(21)
1972	11±1.1	7.2±0.6			10±0.7	8.5±2.8	20±7.5		9.4±1.1	10±0.6(22)**
Arctic Foothills										
1967	27±2.7	27	35±8.5			15	52±1.0	24±2.5	32	25±0.9(7)
1972	14±0.9	12	16±2.3				11	10±1.7	11	12±0.6(9)**
Arctic Mountains										
1967	42	44 ±2.3	36	36±1.4	30±4.7			28±1.5	39	32±0.4(32)
1972	19±0.6	17 ±1.2	38±4.4	15±2.3	17	15 ±1.6	36	18±3.1	19 ±2.0	19±0.6(29)**
Kobuk-Selawik Lowland										
1967	46±5.0			24±1.7	18±0.7					29±3.4(18)
Porcupine Plateau										
1972	19±0.6	16 ±0.8		16						17±0.8(5)

* Abbreviations for lichen species as follows: *Cetraria cucullata*, *Cetraria richardsonii*, *Cetraria delisei*, *Cladonia alpestris*, *Cladonia rangiferina*, *Thamnolia vermicularis*, *Cornicularia divergens*, *Stereocaulon paschale*, and *Dactylina arctica*.

** Combined means significantly different ($P < 0.01$)

only about one-third of the data, however. "Student's t" test of combined means of all species tested between years were consistent in yielding highly significant ($P < 0.01$) differences between 1967 and 1972 values in all three provinces. Similar tests between locations in each of the sample years were as follows:

<u>1967</u>

Arctic Coastal Plain ($N = 21$, $\bar{x} = 28$)

versus $P = 0.3$ (N.S.)

Arctic Foothills ($N = 7$, $\bar{x} = 25$)

versus $P < 0.05$

Brooks Range ($N = 32$, $\bar{x} = 32$)

versus $P < 0.2$ (N.S.)

Arctic Coastal Plain ($N = 21$, $\bar{x} = 28$)

<u>1972</u>

Arctic Coastal Plain ($N = 22$, $\bar{x} = 10$)

versus $P = 0.3$ (N.S.)

Arctic Foothills ($N = 9$, $\bar{x} = 12$)

versus $P < 0.01$

Brooks Range ($N = 29$, $\bar{x} = 19$)

versus $P < 0.001$

Arctic Coastal Plain ($N = 22$, $\bar{x} = 10$)

These results indicate that there is usually a highly significant difference between the average ^{137}Cs concentrations of the nine species in provinces, and that the values in the Arctic Coastal Plain and Arctic Foothills are more similar than those of either province compared to the Brooks Range. The general ranking of the provinces so far as ^{137}Cs concentrations in lichens is concerned is perhaps correlated with several ecological parameters, such as precipitation, elevation, diversity of microclimate, latitude, and diversity of lichen communities. However, comparison of ^{137}Cs concentrations in the species Cetraria cucullata, Cladonia alpestris, and Cladonia rangiferina collected in the Brooks Range and Kobuk-Selawik Lowland during 1967 showed the Brooks Range values generally highest, and the Lowland values comparable to the Arctic Coastal Plain. The 1972 samples of common lichen species from the Brooks Range and Porcupine Plateau provinces were nearly identical; this was possibly because the Plateau sampling location (#17, northeast of Arctic Village) is very near the southern edge of the Brooks Range and was probably subject to many of the same environmental factors associated with some of the Brooks Range sampling locations situated near the front of the mountains, such as Lake Peters (#10).

Another comparison of interest was that of relative loss rates, or effective half-times, of ^{137}Cs in the lichen communities in the three provinces. In addition to the 11% loss of ^{137}Cs by physical decay during the five year sampling interval, there were differing rates of decline in ^{137}Cs concentrations between the provinces. Greatest loss (60%)

occurred in the combined species of the Arctic Coastal Plain, intermediate loss (48%) occurred in those of the Arctic Foothills, and lowest loss (40%) was measured in the Brooks Range samples. These yielded average T_{eff} values of 3.7, 5.3, and 8.2 years, respectively. The ranking was probably associated with several environmental parameters.

Coefficients of variation for ^{137}Cs concentrations in all species averaged 21%, with a range of 3-75%. Both extreme values occurred in samples of Cornicularia divergens, a species with finely divided structure that usually grows on ridges and other exposed niches. Most of the species had coefficients of variation of about 10-20%, which was similar to those reported for other Alaska lichens (Eberhardt, 1964) and for Colorado mountain vegetation (Remmenga and Whicker, 1967). The modest variations in the samples were probably due in part to the laborious separation of vascular plant debris from the lichen community samples. These litter samples often contained appreciable ^{137}Cs concentrations and coefficients of variation that averaged 15-80%, thus making their contribution to the community samples an important source of variability.

Annual sampling of lichens on the Arctic Herd caribou winter ranges of the Kanuti, Pah, and Tagagawik River drainages on the Kobuk-Selawik Lowland was emphasized during the period 1967-1970. Two important species, Cladonia alpestris and Cetraria cucullata, were usually collected each summer collecting period; the results of ^{137}Cs analyses are

3

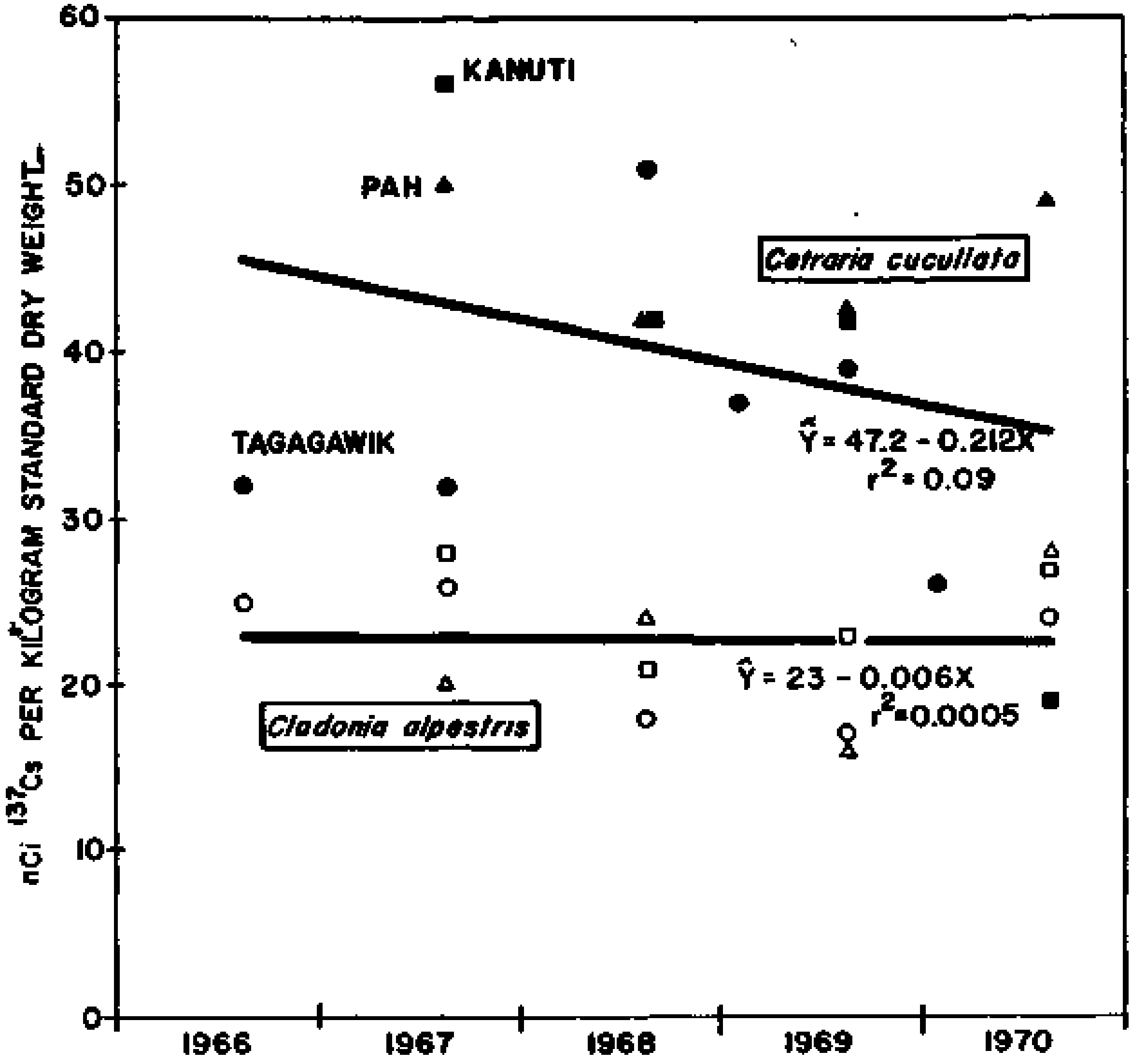
compared in Figure 10. Statistical tests indicated a significant ($P < 0.01$) difference between ^{137}Cs concentrations in the two species, but no demonstrable differences between the three locations or between sampling times. Analysis of variance of the combined data showed no significant difference between the slopes of regression of ^{137}Cs concentrations on sampling periods lines fitted to the data because of too much variability in ^{137}Cs concentrations among samples.

On the basis of these extensive studies of several lichen species sampled from a variety of habitats over the 5,000 km^2 geographic area, it seems appropriate to suggest that the primary winter range of the Arctic Herd of caribou contained rather homogeneous ^{137}Cs concentrations in the principal winter forage of the animals. In their migrations, the animals crossed several provinces of statistically different ^{137}Cs concentrations in lichens. These were integrated by the animals and were exemplified by a gradual increase in the body burdens of the caribou following a rather abrupt initial change in dietary ^{137}Cs associated with the change from sedges to lichens during early fall migration.

Radionuclides in Caribou and Other Ungulates

The caribou of northern Alaska are divided into two populations, the Arctic Herd to the west and the Porcupine Herd to the east. They behave as separate entities, having discrete calving areas, summer ranges, and winter ranges. Two recent reports (Skoog, 1968; Hemming, 1971) have

Figure 10. Comparison of ^{137}Cs concentrations in lichen species Cladonia alpestris (open symbols) and Cetraria cucullata (solid symbols) on Kobuk-Selawik Lowland winter range. Tagagawik site values are circles, Pah site values are triangles, and Kanuti site values are squares. Units of X in regression equations are in months.

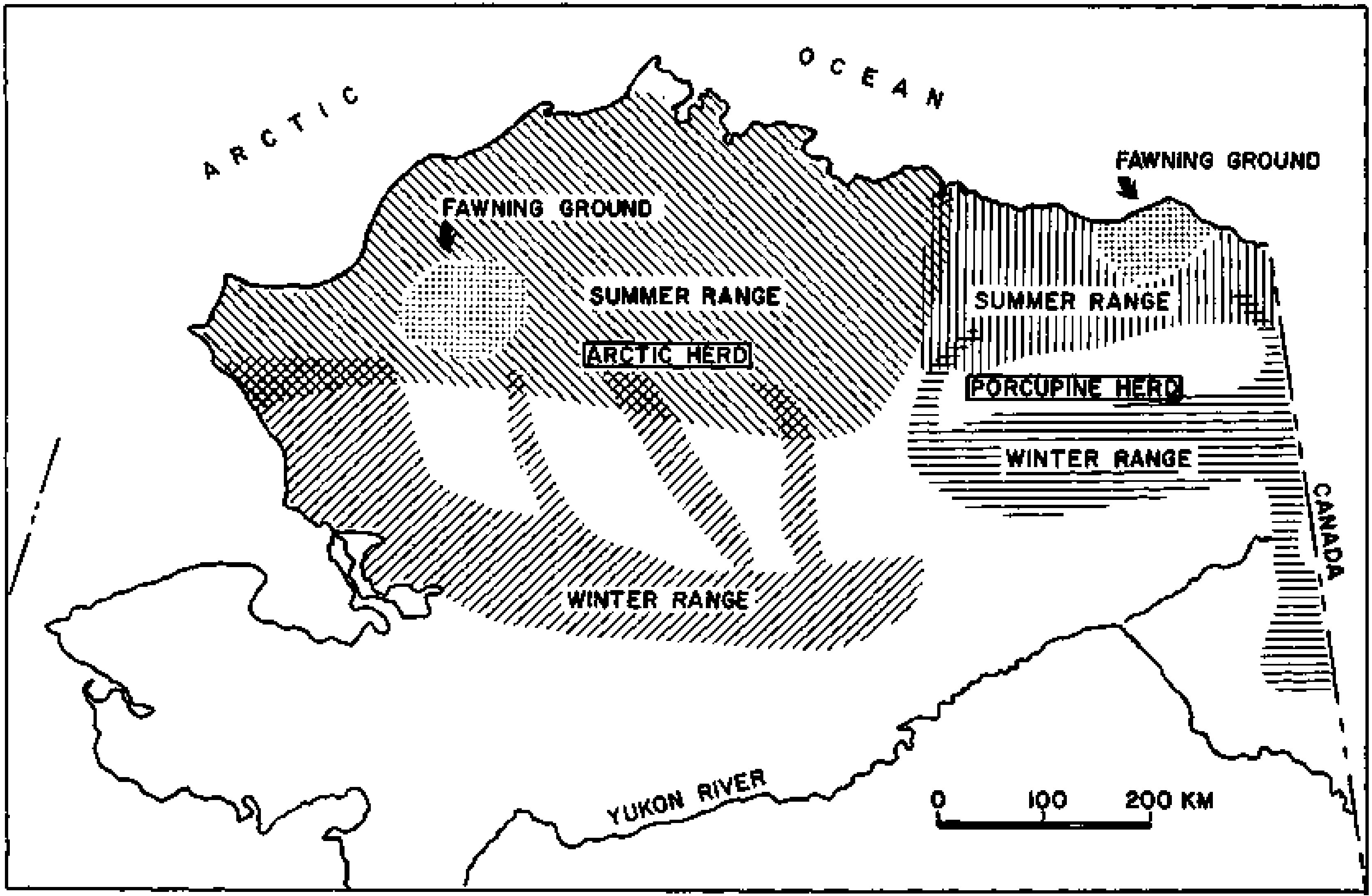

nCi 137Cs PER KILOGRAM STANDARD DRY WEIGHT
60
50
40
30
20
10
0
1966
1967
1968
1969
1970
KANUTI
PAH
TAGAGAWIK
Cetraria cucullata
Ŷ = 47.2 - 0.212X
r2 = 0.09
Ŷ = 23 - 0.006X
r2 = 0.0005
Cladonia alpestris

summarized long-term studies of the caribou herds in Alaska and provided the first realistic estimates of the population size. A historical perspective of the northern caribou herds was previously presented.

The Arctic caribou herd has increased to a present population of about 242,000 animals occupying a range of approximately 140,000 square miles (360,000 km^2) (Fig. 11). The primary winter range of this herd is on the Ambler-Chandalar Ridge and Lowland and the Kobuk-Selawik Lowland physiogeographic provinces, where winds sweep the landscape relatively free of snow and the principal winter forage of lichens is abundant. The animals arrive on their winter range about the month of November and remain rather sedentary until the spring migration begins, usually in March. They then move northward, following many of the same river valleys and mountain passes used on the southern migration, and arrive at their major calving area at the headwaters of the Colville and Utukok Rivers about June first. The caribou leave the calving ground about mid-June and the herd is widely scattered during the summer months. In late August a leisurely drift toward the south begins and by September few animals remain on the Coastal Plain. Major movements are directed toward Anaktuvuk Pass, headwaters of the Noatak River, and along the Chukchi Sea coast.

The Porcupine caribou herd was estimated to contain 140,000 animals in 1964 (Lentfer, 1965) and appears to be increasing at the present time. It occupies an area of

Figure 11. Ranges of the Arctic and Porcupine caribou herds in northern Alaska (after Hemming, 1971).


ARCTIC OCEAN
FAWNING GROUND
FAWNING GROUND
SUMMER RANGE
ARCTIC HERD
SUMMER RANGE
PORCUPINE HERD
WINTER RANGE
WINTER RANGE
CANADA
YUKON RIVER
0 100 200 KM

200,000 km^2 in northeastern Alaska and adjacent Canada. In normal winters most of the herd moves well into the boreal forest, dispersing south and west after a leisurely drift around the east end of the Brooks Range. The animals usually reach their winter range in November, although informants at Arctic Village noted movements into nearby ranges into December. Considerable westward movement occurs on the winter range, the animals in March reversing their early winter route and again passing Arctic Village in April or May on their way north during the spring migration. Most of the herd again passes around the east end of the Brooks Range, avoiding the precipitous Schwatka and Romanzof Mountains, and continues on to the calving area located just south of Barter Island. There is occasional mixing of both Arctic Herd and Porcupine Herd animals where their summer ranges overlap in the vicinity of the Sagavanirktok River. The fall migration is most importantly in Canada, although smaller groups use many of the river valleys on the eastern Brooks Range and pass near Arctic Village. The portion of the Porcupine Herd which summers in the Canning River area is one example.

There are exceptions to these general movements, and within any one area the caribou are liable to be moving in constantly changing patterns. In the Anaktuvuk Pass region, Rausch (1951) described the "erratic nature of caribou movements" within the Anaktuvuk and Killik River valleys. Small bands of caribou occasionally summer in the Brooks Range and in times of deep snow in the southern forests may remain on the Arctic Foothills throughout the winter. A herd of 4,000 animals wintered at Anaktuvuk Pass village site during January-April 1968 for the first time in the memory of the Eskimos; and about 2,000-3,000 caribou wintered on two adjoining creek drainages some 40 km south of the village during January-April 1965. These were considered unusual periods of caribou abundance by the Eskimos.

The general pattern of caribou utilization by the Eskimos consisted of a major kill at the time of autumn migration (late September or early October), occasional harvest of a few animals from small bands that often inhabited the normal winter hunting and trapping range of the people, and another major kill when the spring migration again passed near the village in late April or early May. An average of about 400 animals was estimated by the hunters to have been killed during the major fall and spring periods up until 1968; since then, a gradual reduction in harvest reflected a decreasing dog population due to greater snowmobile use. Typical harvests by families are shown in Table 12. Such harvests illustrate the conservative approach to caribou utilization by the Anaktuvuk people. A hunter tended to underestimate his needs rather than overharvesting. Personal interviews during November 1967 disclosed that the number taken, at least at that time, was substantially greater than 400 (Table 12); that number of animals was required for family meat, and about the same amount was needed

Table 12. Estimated caribou harvest by heads of Anaktuvuk Pass families during fall migration, October 1967.

Family	Number Adults*	Number Children	Number Caribou Killed
A_1	2	4	28
A_2	2	5	30
A_3	2	6	25
A_4	2	5	44
H_1	2	5	40
H_2	2	1	40
H_3	2	6	30-40
K_1	2	0	60
M_1	1	0	25
M_2	3	4	40-50
M_3	3	4	40
M_4	2	1	30
M_5	2	5	26
M_6	2	0	26
P_1	2	1	25-30
P_2	2	3	25
P_3	3	3	40
R_1	1	0	70
R_2	1	0	60
R_3	2	3	45
R_4	2	3	40
Total			790-815
Average per family			38

* Adults plus children > 14 years

to feed dog teams. This may account for the discrepancy between estimated and actual numbers of caribou harvested (Table 13), or it may reflect a deliberate underestimate to avoid the scrutiny of governmental wildlife agencies that constantly survey the hunting population to prevent over-harvesting and waste. Conservation of northern caribou has not, however, been an ancient practice among northern native peoples, particularly in Canada (Parker, 1972).

<u>Cesium-137 Concentrations in Caribou</u>

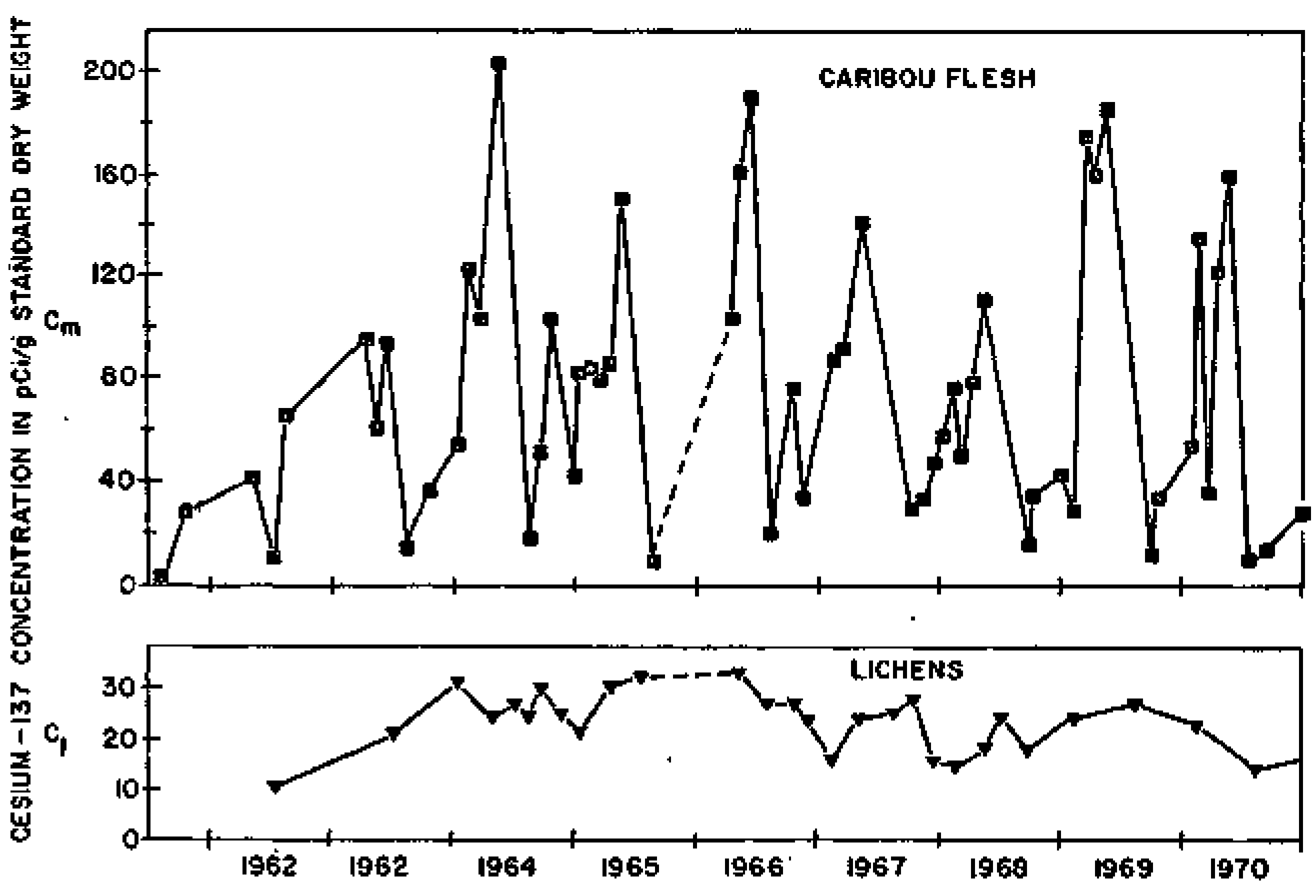
Sampling of northern Alaska caribou for radionuclide analyses was sporadic until the Anaktuvuk Pass intensive phase of the studies began in 1964. Emphasis was placed on obtaining a representative sample from each of the major harvest periods, usually five caribou muscle and bone samples from each of four or five families. In addition, an Eskimo agent was authorized to collect three animals every other week from local herds or to obtain such samples from other hunters. Emphasis was placed upon sampling the fall and spring caribou harvests because they represented the substantial food base for several months.

Cesium-137 concentrations in caribou flesh samples from Anaktuvuk Pass during the study period are shown in Figure 12. An annual cycle is immediately apparent, with low values in fall and highest values in spring. The low values in fall are associated with the caribou returning from summer range on the Arctic Slope, where their diet mainly

Table 13. Comparison of caribou consumption rates by four Anaktuvuk Pass families during 1964 as estimated by family heads and as calculated from ^{137}Cs kinetics equation (see Table 22).

Family	Number and Age of Family Members				Caribou Meat (kg/wk)	
	Men	Women	Minors	Children	Calculated	Estimated
SP	5	1	1	2	84	100
JM	1	1	1	4	38	50
HM	2	1	1	2	46	50
ZH	1	1	0	4	29	34

Figure 12. Cesium-137 in lichens and caribou flesh at Anaktuvuk Pass during the period 1961-1970.


CESIUM-137 CONCENTRATION IN pCi/g STANDARD DRY WEIGHT
C_m
CARIBOU FLESH
200
160
120
80
40
0
C_l
LICHENS
30
20
10
0
1962
1962
1964
1965
1966
1967
1968
1969
1970

consisted of sedges and other vegetation containing relatively small amounts of fallout radionuclides and substantial amounts of potassium, which reduces the net accumulation of ^{137}Cs in the animal tissues (Wasserman and Comar, 1961). The combination of the pronounced change in potassium intake that accompanies a shift from a lichen diet (about 0.37 mg K/g standard dry weight) to predominantly sedges (about 10 mg K/g standard dry weight), the substantially lower ^{137}Cs concentration in the diet and possibly increased summer body water turnover rate (Holleman, Luick, and Whicker, 1971) produce the abrupt decline. An effective half-time of 28 days was observed between sampling times of 25 May-28 August, for example. The caribou then gradually shifted to their usual winter diet consisting mostly of lichens (Ahti, 1967; Skoog, 1968; Hemming, 1971) and the ^{137}Cs concentrations began an abrupt increase through the winter months, usually plateauing during the period January-April of each year. This was especially apparent during the years 1965 and 1968, when caribou herds wintered in the vicinity of Anaktuvuk Pass and provided ideal sampling of both animals and their principal food.

Estimation of Lichen Forage Ingestion Rates of Caribou With Cesium-137

These conditions afforded an opportunity to apply results of several investigations of caribou and reindeer on lichen diets during the winter season for the purpose of estimating ingestion rates of lichen by free-ranging caribou. Several biological parameters needed to establish a model for calculation of these feeding rates were provided in studies of reindeer maintained on natural mountain tundra pastures near Cantwell, Alaska during 1969-1970 (Holleman, Luick, and Whicker, op. cit.). In addition, several hundred stable element analyses of lichen were obtained during 1964-1967 and used in combination with metabolic rate constants to provide more accurate estimates of kinetic parameters on the low potassium intake that characterized caribou diets consisting principally of lichens. The data thus generated (Hanson, Whicker, and Lipscomb, 1972) provide the first information relative to a natural population of caribou under normal stresses of arctic winter survival.

Our general model was

$$Q = R\ C_1\ a\ (C_0 + C_3\ e^{-m_1 t} + C_4\ e^{-m_2 t}) \qquad (1)$$

from Holleman, Luick, and Whicker (op. cit.), which represents a chronic feeding situation, as opposed to an acute injection of the ^{137}Cs tracer. The whole body burden Q was partitioned into several terms such that Equation (1) could be expressed in terms of C_m, the measured ^{137}Cs concentration in caribou muscle (pCi/g standard dry weight):

$$C_m = \frac{f_t\ R\ C_1\ a}{d\ W\ f_m} \left[C_0 + C_3\ e^{-m_1 t} + C_4\ e^{-m_2 t} \right] \qquad (2)$$

where

f_t	=	fraction of total body ^{137}Cs in muscle
R	=	forage intake rate in dry g/day
C_1	=	^{137}Cs concentration in lichens in pCi/g standard dry weight
a	=	fraction of ingested ^{137}Cs that enters the body pool (Holleman, Luick, and Whicker op. cit.)
d	=	standard dry weight to wet weight conversion factor for caribou muscle
W	=	mean adult caribou weight in g (Skoog, 1968)
f_m	=	fraction of body weight that is muscle
C_0	=	a kinetic factor, having the units of days, that is related to the rate constants describing loss of Cs from caribou. Given by $(k_1 + k_2)/(m_1 m_2)$ in (ibid)
C_3 and C_4	=	kinetic parameters, having the units of days, which are related to the rate constants describing loss of Cs from caribou (ibid). C_3 is given by $(m_1 - k_1 - k_2)/(m_1(m_2 - m_1))$ and C_4 by $(k_1 + k_2 - m_2)/(m_2(m_2 - m_1))$.

m_1 and m_2	=	constants describing the two exponential component whole body Cs loss from a caribou following acute intravenous injection of tracer Cs (<u>ibid</u>), in units of days^{-1}
k_1, k_2, and k_3	=	inter-compartmental, first-order rate constants which describe the kinetics of Cs transfer and loss in caribou and which are functions of m_1 and m_2 (<u>ibid</u>), in units of days^{-1}
t	=	time in days for a given chronic intake value for R C_1 a

If reasonable estimates of m_1 and m_2 are available, as well as the fractional time zero (t_0) intercept value for either m_1 or m_2, one can calculate values of k_1, k_2, and k_3, and then values for C_0, C_3, and C_4. It is generally accepted that the rate of cesium loss is dependent upon the potassium intake rate (Wasserman and Comar, <u>op</u>. <u>cit</u>.). In experiments with reindeer, Holleman, Luick, and Whicker (op. cit.) found that the slow component biological half-time was about 17 days with a dietary K concentration of about 1 mg/g dry weight and about 6.7 days with a dietary K concentration of about 5 mg/g dry. Extrapolation of a log-log plot gives a corresponding half-time value of about 30 days for a K concentration of 0.37 mg/g, which is the mean measured value for 17 lichen samples collected at Anaktuvuk Pass

(Table 14). Using this approach, it was estimated that

m_1 = 0.252 day^{-1}

m_2 = 0.0231 day^{-1}

A (fractional intercept of m_1) = 0.39 for an adult female (75 kg) caribou feeding on lichens near Anaktuvuk Pass

Using these values and estimates of their standard errors based upon 7 or more separate animal trials, it was calculated that

k_1	=	0.111 ± 0.018 day^{-1}	C_0	=	27.9 ± 4.3 days
k_2	=	0.052 ± 0.013 day^{-1}	C_3	=	1.54 ± 0.23 days
k_3	=	0.112 ± 0.006 day^{-1}	C_4	=	26.4 ± 4.0 days

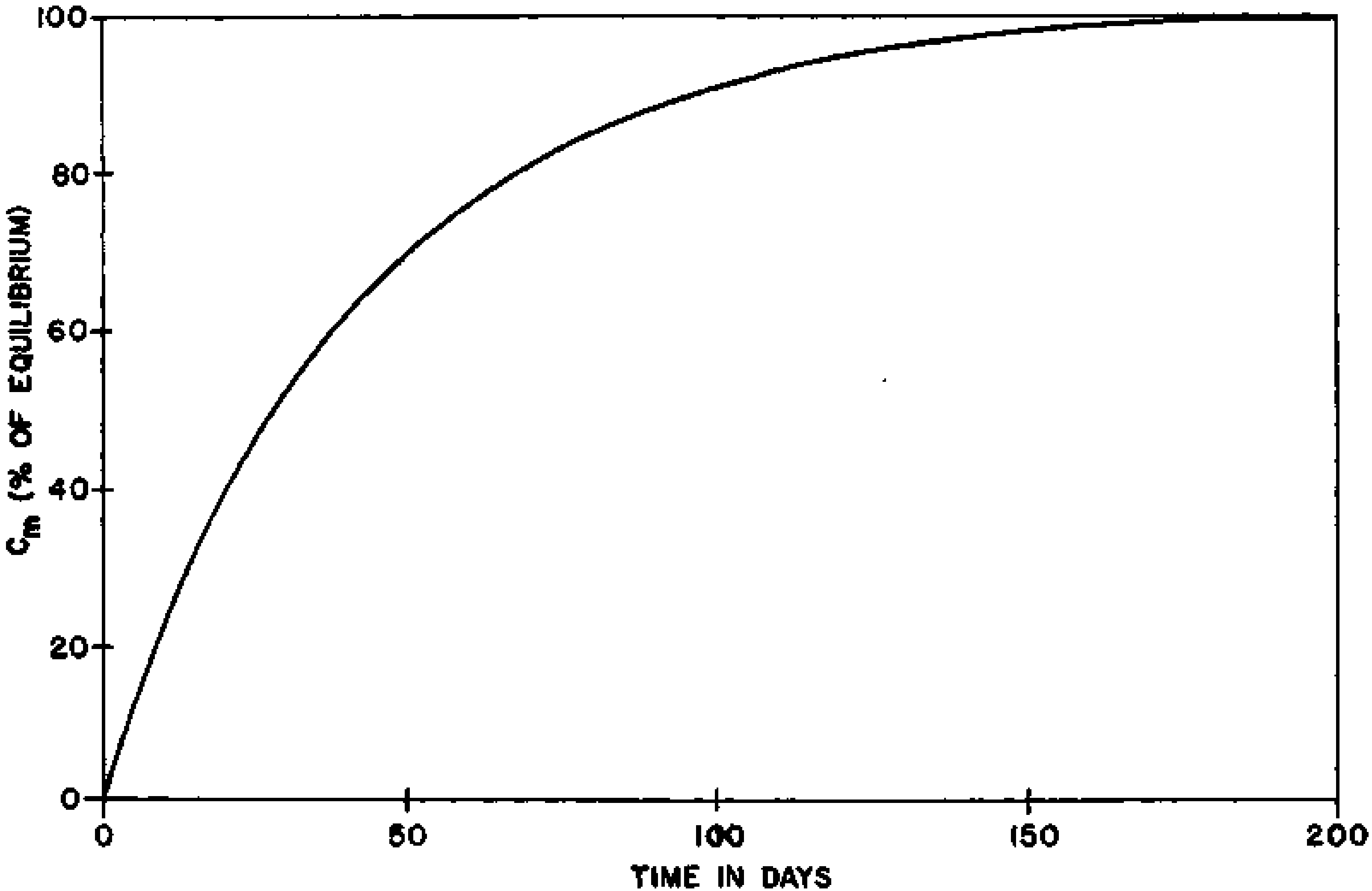
Using these values for C_0, C_3, and C_4 in Equation (2), a build-up curve was generated for caribou coming onto ^{137}Cs contaminated forage (Fig. 13). This predicted that animals reach 50% of equilibrium in about 28 days, 75% at 60 days, and 90% at 96 days if the model and parameter estimates are accurate. Caribou that were sampled at Anaktuvuk Pass in late winter months (January-April) were considered to be at more than 90% of equilibrium because they usually start feeding heavily on lichens during the fall months.

By rearranging terms in Equation (2), it was possible to calculate the mean daily intake rate of dry lichen forage ($\overline{R}$) at equilibrium conditions between ^{137}Cs intake and

Table 14. Potassium concentrations in *Cladonia*-*Cetraria* carpet lichens at Anaktuvuk Pass during the period 1964-1967.

Date of Collection	N	Potassium Concentration (mg/g standard dry wt) Mean	±	S. E.
April 1964	3	0.41		0.12
January 1965	4	0.47		0.08
April 1965	1	0.34		
May 1966	4	0.35		0.01
February 1967	3	0.27		0.02
May 1967	2	0.34		0.003
Overall Mean	17	0.374		0.016

Figure 13. Cesium-137 build-up curve for caribou chronically ingesting contaminated lichen forage, utilizing parameter values described in text (Equation 2).



100
80
60
40
20
0
0
50
100
150
200
TIME IN DAYS
C_m (% OF EQUILIBRIUM)

excretion based on samples and reported values ($\overline{X} \pm$ S.E.) indicated below for the equation

$$\overline{R} = \frac{C_m \, d \, W \, f_m}{C_1 \, f_t \, a \, C_0} \qquad (3)$$

where

d = dry to wet weight conversion factor for caribou muscle, 0.235 ± 0.0027, n = 111

W = average adult female caribou weight, Arctic Herd, during spring, 75 ± 0.636 kg, n = 102 (from Skoog, 1968)

f_m = fraction of body weight that is muscle, 0.41 ± 0.0081, n = 5 (Holleman, Luick, and Whicker, op. cit.)

f_t = fraction of total body ^{137}Cs in muscle, 0.789 ± 0.0121, n = 4 (ibid)

a = fraction of ingested ^{137}Cs that enters the body pool, 0.26 ± 0.02, n = 4 (ibid)

C_0 = kinetic parameter, 27.9 ± 4.3 days, n = 10 (ibid)

These parameters defined a normal frequency distribution for each of the random variables. A value for $\overline{R}$ in each year was calculated by inserting mean values for the variable in Equation (3) (Table 15). The values obtained in this way represent the medial values for daily intake rate. Dispersion about any calculated $\overline{R}$ value is a composite of the

Table 15. Calculated average daily lichen intake rate ($\bar{R}$) for each winter equilibrium period (January-April) during the years 1963-1970.

Year	Mean ^{137}Cs Concentration (pCi/g dry) Caribou flesh (C_m)	Lichens (C_l)	K* (kg/day)	$\bar{R}$** (kg/day)
1963	77.2	24.2	1.26	4.02
1964	116.7	32.7	1.26	4.50
1965	82.6	28.3	1.26	3.68
1966	103.0	33.0	1.26	3.93
1967	87.8	19.2	1.26	5.76
1968	75.6	16.5	1.26	5.77
1969	131.0	23.9	1.26	6.90
1970	98.9	23.6	1.26	5.28
Means			1.26	4.98
S.E. (among years)				0.40

$$^{*}\ K = \frac{d\ W\ f_m}{f_t\ a\ C_0}$$

$$^{**}\ \bar{R} = \frac{K\ C_m}{C_l}$$

variance in each of the parameters in Equation (3) and in turn, the parameter variances result from true population variations as well as variances associated with sampling and measurement. In order to obtain an estimate of this dispersion, it was necessary to assume some distribution function for the variables entering into the calculation of $\bar{\bar{R}}$. For each variable, the normal distribution was judged to be the most reasonable approximation. The distribution function of each variable was described by the mean and standard error. Use of the standard error implies that the resulting distribution of $\bar{\bar{R}}$ is characteristic of the mean of that portion of the population which was sampled.

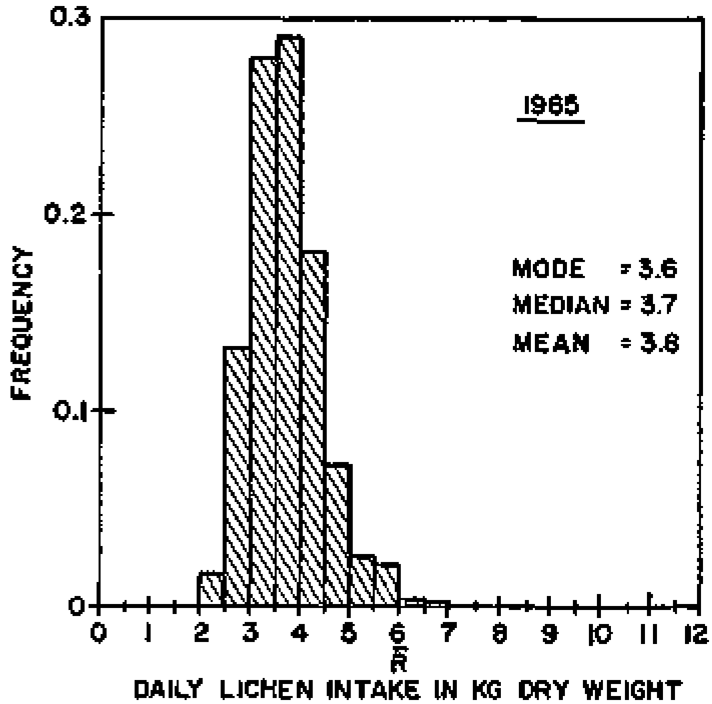
An analytical determination of the probability distribution for $\bar{\bar{R}}$ would be quite difficult; therefore, a Monte Carlo approach was used in which the frequency distributions for 1965 and 1968 (years in which the best sampling data were available) were assumed to approximate the probability distribution for $\bar{\bar{R}}$ in all years. For 1965 and again for 1968, 1000 $\bar{\bar{R}}$ values were calculated using Equation (3). The eight factors entering the calculation of $\bar{\bar{R}}$ were chosen independently and at random from the appropriate distributions for each of the $\bar{\bar{R}}$ calculations.

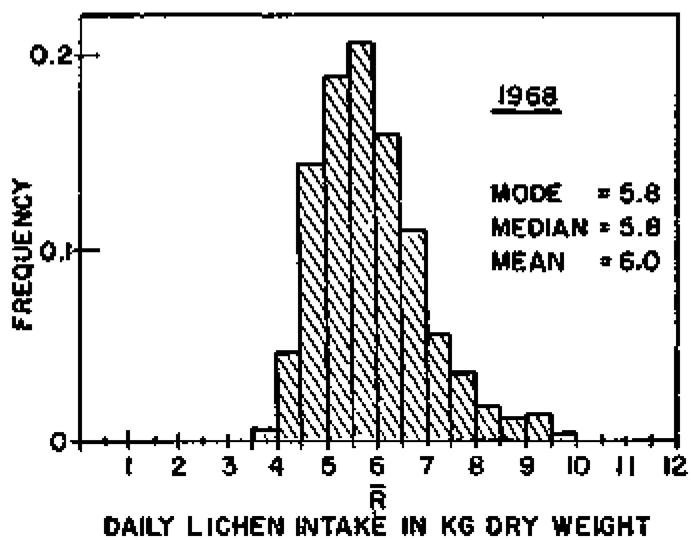
The computer procedure for generating numbers at random from normal distributions was that described by Naylor et al. (1966). The procedure is based on the Central Limit Theorem and truncates the distribution at $\mu \pm 6\ \sigma$. This limitation is of no practical importance in this case and the histograms compiled from the computer output (Fig. 14) provide an accurate approximation of the true distribution of $\bar{R}$. An assumption of independence is implicit in the above procedure. If non-zero correlations exist between factors in Equation (3), the spread of the distribution would be reduced; however, the skewed shape of the curves and the values of $\bar{R}$ would be essentially unaffected.

Values of $\bar{R}$ during the January-April period of the years 1963-1970 (Table 15) varied from 3.7 to 6.9 kg dry weight lichens per day, with an overall mean of 5.0 kg/day. The values for 1965 and 1968 were examined in detail by stochastic methods because they represent values near the extremes of the full range of $\bar{R}$ during the study period and because the wintering caribou herds were located near the Anaktuvuk Pass village and lichen sampling sites during those years. The frequency histograms in Figure 14 are similar although there was a difference in the calculated model values of $\bar{R}$. This difference may be the result of changes in the ^{137}Cs content of lichens during the 90 days immediately preceeding sampling in both years. The frequency data for 1965 and 1968, as well as the deterministic data for all years suggested that the true value for $\bar{R}$ lies in or near the interval 4.5-5.0 kg dry weight lichens per day.

Previous estimates of lichen forage intake rates of about 3 dry kg/day have been based upon extrapolation of domestic ruminant studies or upon direct consumption measurements for penned caribou/reindeer. A rule of thumb for dry

Figure 14. Frequency distributions of $\overline{R}$ (daily lichen forage ingestion rates) values for adult caribou at Anaktuvuk Pass during winters of 1965 and 1968.


1965
MODE = 3.6
MEDIAN = 3.7
MEAN = 3.8
FREQUENCY
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12
$\bar{R}$
DAILY LICHEN INTAKE IN KG DRY WEIGHT


1968
MODE = 5.8
MEDIAN = 5.8
MEAN = 6.0
FREQUENCY
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12
$\bar{R}$
DAILY LICHEN INTAKE IN KG DRY WEIGHT

matter intake for ruminants is I (kg per day) = $0.11\ W^{0.75}$, where W is the live body weight (kg) of the animal. This is based upon the standard equation for basal metabolism rate for ruminants of 70 kcal/day $W^{0.75}$ (Brody, 1945). For a 75 kg caribou, this yields 2.8 kg dry matter intake per day for basal metabolism; this intake rate hardly seems adequate for an animal as mobile and as cold- and wind-stressed as the caribou during winter months. Nor would it seem applicable to forage of such low nutrient value as lichens, which have one-half to one-third the nourishment of poor hay (Scotter, 1965a, 1972). Kelsall (1968) reported that 3.5-4.5 kg dry weight lichens were required to nourish the average caribou, and that animals on feeding trials of 8-20 days durations on feeding regimens of 2.1 to 2.5 kg lichens per day lost weight. It seems apparent, therefore, that the commonly used estimate of 3 kg/day is much lower than would be expected for the free-roaming caribou herds of Holarctic regions, where the stresses of cold, food hunting in snow cover, subsistence hunters, and predators would require greater energy expenditures than normal penned enclosures impose. Lidén and Gustafsson (op. cit.) previously reported an estimate of about 7 kg/day wet weight (about 3.5 to 4.0 kg/day dry weight) lichen consumption by reindeer in northern Sweden, based on 0.65 uptake of ^{137}Cs from lichens. Assuming that 0.26 assimilation of ^{137}Cs more nearly approximates the true situation (Holleman, Luick and Whicker, op.

cit.), this yields an intake of about 7 kg/day dry weight for reindeer in northern Sweden. Furthermore, Herre (1955) summarized several Alaskan and Russian studies that estimated caribou/reindeer lichen intake rates of 4.5 to 7 kg/day dry weight.

Extensive measurements of lichen biomass in *Cladonia-Cetraria* carpets at Anaktuvuk Pass (Table 7 and 10) yielded values of about 1.5 kg standard dry weight per square meter. Assuming that caribou graze the top 6 cm, they would remove about one-half of the standing crop from 6.35 m^2 per animal per day. Various allowances must also be made for selectivity of lichen species, trampling, and other factors that would increase the areal use of lichen stands (Pegau, 1968). It seems more realistic to estimate the average daily winter grazing requirement of Arctic Herd caribou to be at least 10 m^2 per animal for a vigorous lichen stand. This has important implications because of the limited carrying capacity for caribou/reindeer on northern ranges (Scotter, 1965b) and represents the first quantitative measurement of lichen consumption by natural caribou herds.

Unusually High ^{137}Cs Values in 1964 Caribou

Cesium-137 levels in caribou flesh during 1964 were about twice greater than expected from a predictive model (Eberhardt and Hanson, 1969) or our general knowledge of the system. These anomolies occurred two years prior to the maximum ^{137}Cs concentrations in lichens and are thus quite difficult to explain. Inspection of the extensive data presented at the International Symposium of Radioecological Concentration Processes (held in Stockholm in 1966) showed little evidence of a similar anomaly in Scandinavia or in Russia; however, the limited and uninterpreted data on Canadian caribou and reindeer (Canadian Department of National Health and Welfare, 1967) exhibited a strikingly similar pattern to that observed in Alaska. It is thus tempting to propose that weather conditions, on a continental scale, are implicated as a controlling factor in the deposition of fallout in the Nearctic region. Limited samples of caribou tissues and rumen contents from the Arctic, Nelchina, and Alaskan Peninsula Herds and reindeer herds located on or near the Seward Peninsula and on two islands off the western coast of Alaska (USPHS, 1964 and 1965) suggested that the sudden increase in northern Alaskan caribou occurred some six months after a similar increase in the central and southern parts of Alaska. This delay may have been due to short-term deposition during a period when snow cover shielded the lichens in northern Alaska from the fallout until late spring, whereas the Nelchina and Alaskan Peninsula caribou herds had prompt access to the new contamination. At any one time the ^{137}Cs concentrations in caribou samples from the three herds were generally correlated with amounts of annual precipitation in their areas, with highest values in Alaska Peninsula (120 cm ppt.), median values in Nelchina animals (57 cm ppt.) and lowest in Arctic animals (30 cm ppt.) (Table 16). The lower ^{137}Cs values in Arctic Herd caribou can be considered fortuitous from the standpoint of human utilization and resultant radiation exposure.

Cesium-137 Concentrations in Other Ungulates

In addition to caribou, the Dall sheep (*Ovis dalli*) and moose (*Alces alces*) were taken occasionally by Anaktuvuk Pass Eskimos and several samples were obtained during the period 1964-1969. Comparison of ^{137}Cs in flesh of these primary consumers showed the importance of food habits in determining body burdens of fallout radionuclides. Concentrations in sheep and moose were fairly constant throughout the year, but the sheep values were usually about four times those of moose, and about one-fourth to one-tenth of the ^{137}Cs concentrations in caribou muscle at the same time (Table 17). The sheep fed mostly on sedges, forbs, and modest amounts of lichens; moose were observed to feed mostly on willows and other shrubby species, with some minor amounts of grasses. One of the important points in the comparison is the substantial increase of ^{137}Cs in caribou muscle during winter as the lichen diet influence was exerted, compared to the rather steady decrease in sheep muscle ^{137}Cs concentrations through the winter.

Table 16. Comparison of ^{137}Cs concentrations in muscle of caribou from Arctic, Nelchina, and Alaska Peninsula Herds during spring and autumn periods of 1967 and 1968. Nelchina and Alaska Peninsula samples courtesy of Alaska Department of Fish and Game.

	Cesium-137 Concentration in pCi/g					
	Arctic		Nelchina		Alaska Peninsula	
Date	N	$\bar{X}$ ± S. E.	N	$\bar{X}$ ± S. E.	N	$\bar{X}$ ± S. E.
1964						
December	8	43 ± 3.7	5	100 ± 7.8	5	200 ± 17
1965						
March	6	81 ± 7.3	5	130 ± 14	-	--
1966						
November	6	33 ± 3.4	5	66 ± 3.6	5	99 ± 7.8
1967						
Mar-May	3	90 ± 6.4	5	56 ± 5.1	5	79 ± 5.5
Sep-Oct	22	28 ± 1.4	5	33 ± 4.6	4	50 ± 3.1
1968						
Mar-May	15	73 ± 5.2	5	59 ± 6.5	5	92 ± 12
Sep	35	17 ± 1.1	5	16 ± 0.8	6	31 ± 9.2

Table 17. Comparison of ^{137}Cs concentrations in muscle samples of ungulates collected at Anaktuvuk Pass during 1964-1968.

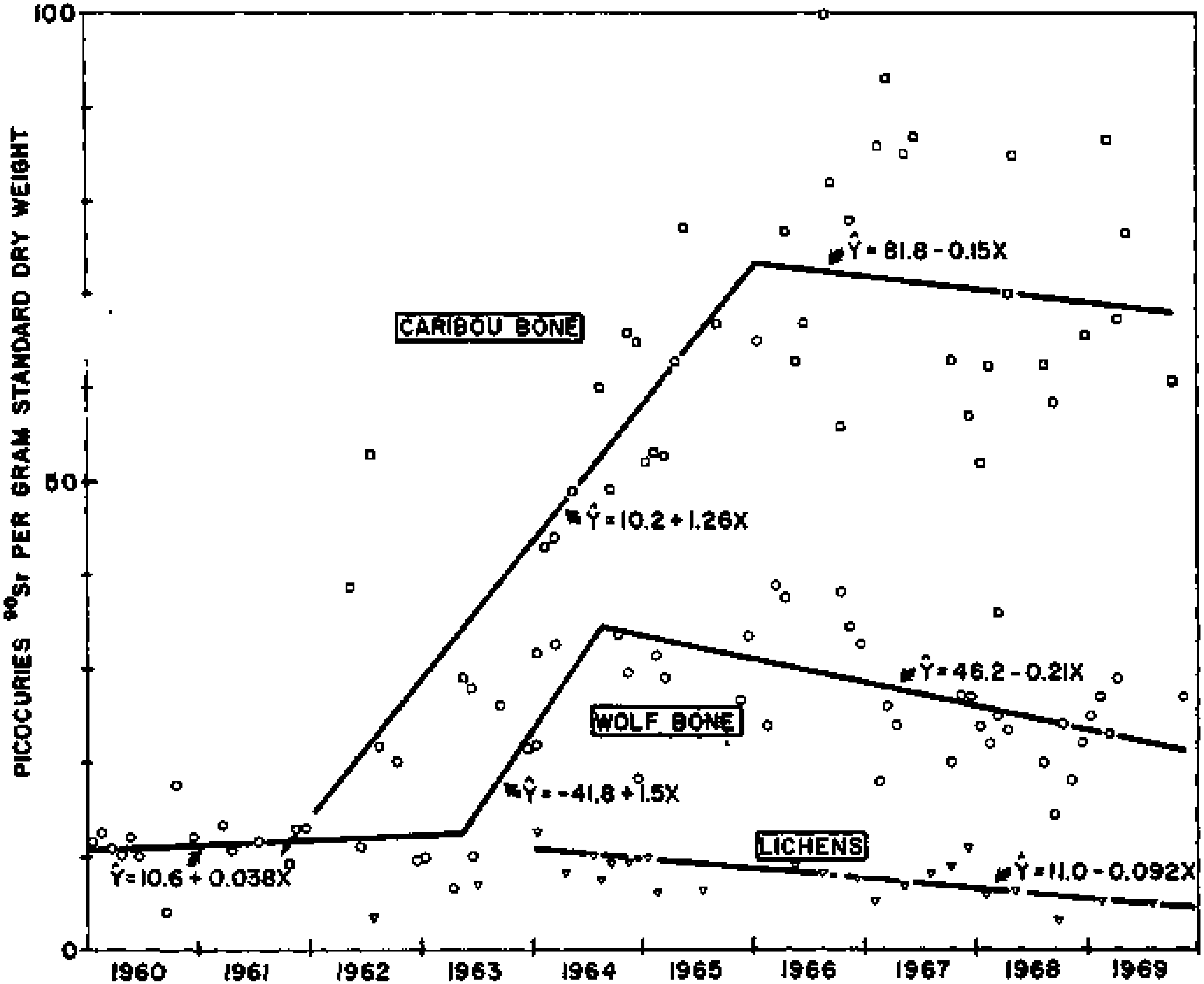
	Dall Sheep (*Ovis dalli*)		Caribou (*Rangifer tarandus*)		Moose (*Alces alces*)	
Date	N	$\bar{X}$ ± S. E.	N	$\bar{X}$ ± S. E.	N	$\bar{X}$ ± S. E.
1964						
March	3	16 ± 1.7	6	110 ± 9.4		
December	3	5.9 ± 1.1	8	43 ± 3.7		
1965						
January	2	12 ± 1.7	6	79 ± 4.6	3	3.6 ± 0.2
February	3	8.4 ± 1.5	6	83 ± 6.6		
May	1	6.3	15	150 ± 21		
1966						
November	3	8.5 ± 1.5	6	33 ± 3.4		
1967						
January					2	0.6 ± 0.01
February			3	86 ± 7.2	2	0.9 ± 0.04
November	2	6.6 ± 1.9	4	32 ± 2.2		
1968						
January	4	5.2 ± 0.7	3	57 ± 11	1	1.4
February	1	4.1	9	77 ± 3.7		
May	4	3.3 ± 0.9	7	111 ± 11		

Strontium-90 Concentrations in Caribou Samples

Strontium-90 concentrations in caribou flesh were highly variable at a level about 0.001 those in caribou bone (Hanson, 1968), the major site of deposition. Concentrations in caribou bone (Fig. 15) were about 20 pCi/g until 1962 and then began a sharp increase until 1966, where they more or less plateaued through 1969. Regression lines were objectively fitted to the data by logical sampling periods and best illustrate the periods of increase and subsequent stability. Most of the animals sampled at Anaktuvuk Pass were between the ages of 4 and 9 years, and the ^{90}Sr concentrations in bone were, perhaps, influenced to some degree by amounts of ^{90}Sr deposited during periods of high fallout deposition (Farris, Whicker, and Dahl, 1969). Comparing the ^{90}Sr levels in lichens and caribou bone, one notes that the amounts in lichens increased until 1964 and have since then declined slowly, while caribou bone levels continued to increase until 1966.

On the basis of the Cape Thompson region samples during the initial part of the study period, it is obvious that the period of major increase of ^{90}Sr in caribou bone began shortly after the major nuclear weapons test series of 1961-1962, attained maximum values 4-5 years later, and have declined only slightly since 1966. Comparison of ^{90}Sr levels between age classes of a relatively few caribou bone samples of known-age animals disclosed no clear relationships;

Figure 15. Strontium-90 concentrations in lichens, caribou bone, and wolf bone at Anaktuvuk Pass during 1960-1969. Units of X in the regression equations are in months.



PICOCURIES ^{90}Sr PER GRAM STANDARD DRY WEIGHT
100
50
0
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
CARIBOU BONE
WOLF BONE
LICHENS
$\hat{Y}$ = 81.8 - 0.15X
$\hat{Y}$ = 10.2 + 1.26X
$\hat{Y}$ = 46.2 - 0.21X
$\hat{Y}$ = -41.8 + 1.5X
$\hat{Y}$ = 10.6 + 0.038X
$\hat{Y}$ = 11.0 - 0.092X

however, it may have been due to the small sample size from a variable population. One of the difficulties in obtaining such information was the inconsistent nature of the Eskimos in accurately determining the age of several caribou at a time when haste was important to securing a food supply for several months. Schultz and Flyger (1965) reported a statistically significant difference between ^{90}Sr concentrations in various age classes of Maryland deer mandibles and an increasing trend with age during a period of increasing fallout deposition.

Regression analyses of the 1966-1969 data on ^{90}Sr in caribou bone (Fig. 15) indicated the slopes of lines for the periods 1966-1967 and 1968-1969 were not significantly different from zero, nor was that of the pooled data. The substantial variance encountered in the samples is one of the facts of life in field studies of large ecosystems; however, the group of low ^{90}Sr values during the period December 1967-April 1968 were from caribou that wintered at the Anaktuvuk Pass village site. These were mostly samples obtained from adult cows 4-9 years old, and they had probably deposited most of their bone ^{90}Sr some years prior to their collection at that locality (Farris, Whicker, and Dahl, 1967 and 1969). Low values are also noted in the samples of January-March 1965, when a herd of caribou wintered about 40 km south of the village. Although substantive data is lacking, it appeared that animals that wintered near Anaktuvuk Pass on these two occasions had uniquely low amounts of ^{90}Sr

in bone and may have represented a discrete population that is otherwise unidentified. Concentrations of ^{137}Cs in these animals were not unusually low, however, nor were Ca levels in their diet unusual. Bone-diet "observed ratios" (OR = bone pCi ^{90}Sr/g Ca + diet pCi ^{90}Sr/g Ca) for caribou vary appreciably through a year, depending upon what the caribou are feeding upon. When feeding mainly upon lichens on the winter range, an average OR was 0.035; when browsing willow leaves in early spring and summer months, the OR was near 0.81; and when grazing sedges in summer, the OR was about 0.20. Thus the integrated value through the year (0.19) is variable over a substantial range, rather than remaining relatively constant as in Colorado mule deer (Farris, Whicker, and Dahl, op. cit.). Furthermore, laboratory studies of rats on a normal diet with Ca/P of unity, the OR was found to decrease sharply with age (Thompson, 1963). It was suggested that OR's must be interpreted with care, as those measured at any time are representative, not of what is going on at that particular time, but reflects everything that has gone before.

Comparison of the trend of ^{90}Sr concentrations in caribou bone suggests that they came into equilibrium with those in lichens about two years after the lichens had reached a maximum, although the considerable variance of the data makes the interpretation somewhat conjectural. The increasing slope of 1968-1969 data, although not satistically significant (F value 1.23; F (α 0.01)= 3.92, 1 and

107 d.f.), is believed to be real because of increased fallout and increased ^{90}Sr and ^{137}Cs in lichens due to the 1967-1969 thermonuclear tests conducted by China and France.

Strontium-90 Concentrations in Other Ungulates

Strontium-90 concentrations in sheep and moose samples are compared to those in caribou in Table 18. Caribou values were highest of the three ungulates, but only twice those of sheep. This relationship may be due to the taking of older sheep by the Eskimos (most were 8+ years old) that contained higher concentrations of fallout in bone laid down in previous times of high fallout rates.

During 1964, moose were collected from four major localities in northern interior Alaska for comparison of ^{137}Cs and ^{90}Sr concentrations in that important game and subsistence species with caribou. Collection sites were at Fort Yukon, in the east-central part of Alaska; Fairbanks, in the south-central; on the Kobuk River, in the west-central; and on the Noatak River, in the northwest portion. Results (Table 19) showed that both ^{90}Sr and ^{137}Cs values over this substantial area were remarkably uniform. Highest values for ^{137}Cs in muscle samples occurred in summer months, but were not statistically greater than values in other seasons. The higher values in summer were likely due to greater accumulation of the normal spring pulse in fallout deposition noted in many other studies and indicated in values at Fairbanks, and perhaps some minor translocation by

Table 18. Comparison of ^{90}Sr concentrations in bone samples of ungulates collected at Anaktuvuk Pass during 1964-1968.

	Dall Sheep (*Ovis dalli*)		Caribou (*Rangifer tarandus*)		Moose (*Alces alces*)	
Date	N	$\bar{X}$ ± S. E.	N	$\bar{X}$ ± S. E.	N	$\bar{X}$ ± S. E.
1964						
March	3	16 ± 2.9	3	44 ± 5.8		
December		NA		65 ± 7.0		
1965						
January		NA	3	52 ± 5.6	3	3.3 ± 3.3
February	3	34 ± 18	6	53 ± 7.3		
May	1	42	3	77 ± 10		
1966						
November	3	36 ± 16	6	78 ± 11		
1967						
January					2	0.6 ± 0.01
February			3	86 ± 2.7	2	0.9 ± 0.04
November	2	16 ± 2.0	20	63 ± 5.4		
1968						
January	4	36 ± 9.8	3	57 ± 6.3	1	4.0
February	1	31	9	63 ± 10		
May		NA	7	85 ± 8.0		

Table 19. Strontium-90 and cesium-137 concentrations in bone and muscle samples of moose (*Alces alces*) collected at various Alaskan locations during 1964.

	Location							
	Fairbanks		Fort Yukon		Kobuk River		Noatak River	
Date	N	$\bar{X}$ ± S.E.	N	$\bar{X}$ ± S.E.	N	$\bar{X}$ ± S.E.	N	$\bar{X}$ ± S.E.
			^{90}Sr Concentration in Bone (pCi/g std dry wt)					
Jan 1964	2	3.2 ± 0.1						
Feb	7	5.7 ± 0.8						
Mar	2	7.0 ± 4.0			1	4.2	2	9.6 ± 4.4
Apr	3	4.8 ± 0.6						
May			2	4.1 ± 1.8				
			^{137}Cs Concentration in Muscle (pCi/g std dry wt)					
Jan 1964	3	3.6 ± 0.4						
Feb	7	3.5 ± 0.3						
Mar	3	4.4 ± 0.2			1	5.4	2	5.7 ± 0.6
Apr	2	4.0 ± 1.1						
May			2	3.9 ± 0.2				
Jul	1	6.3	1	3.9				
Sep	1	2.3						
Oct	2	2.1 ± 0.2						

plant growth. The uniformity of values across Alaska reflect the rather uniform precipitation zones from which the animals were collected.

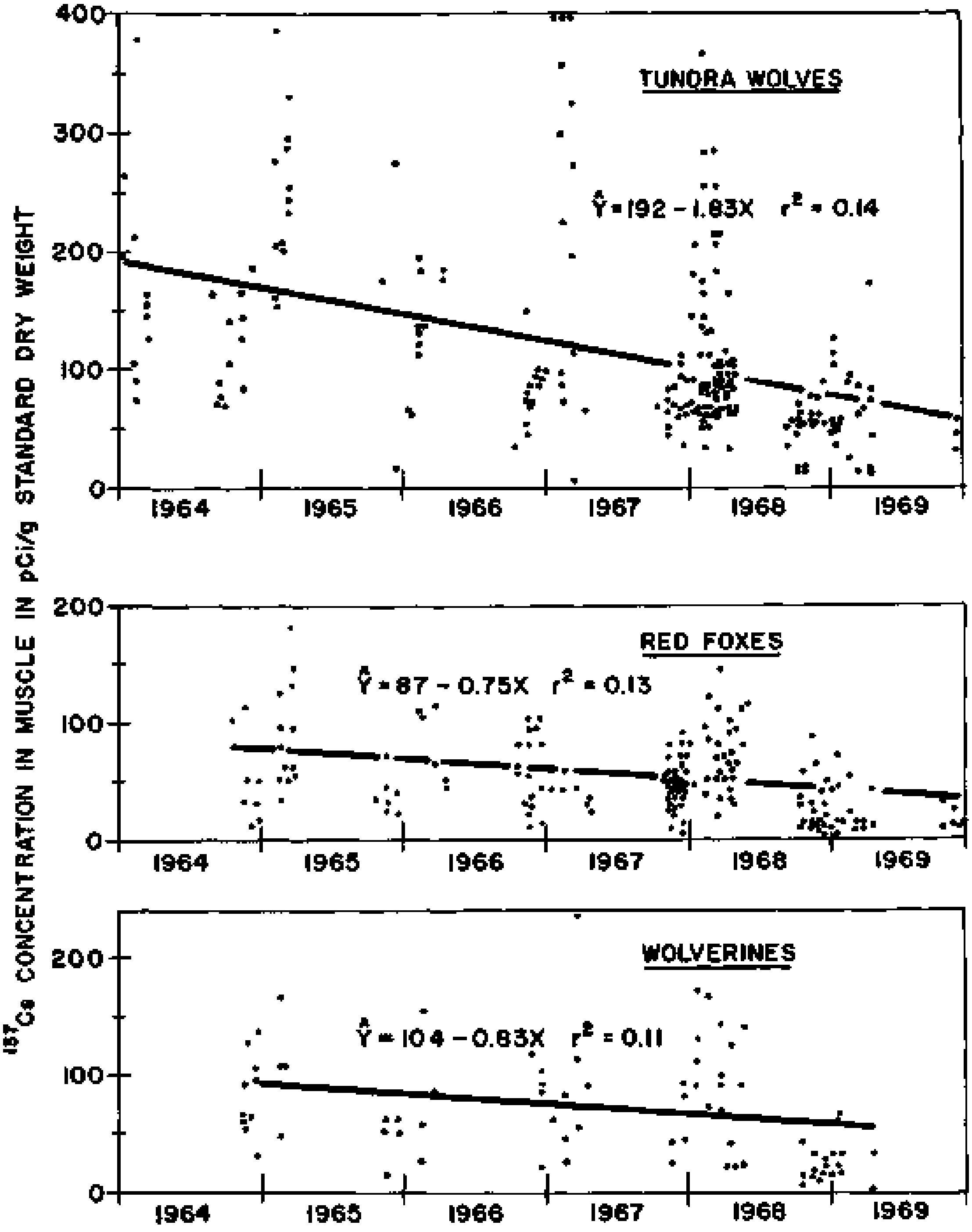
Comparison of the Alaskan data with ^{90}Sr values in Scandinavian and Russian reindeer (Persson, 1970) suggests slightly lower values in our caribou, although only annual averages were used and no seasonal measurements were reported. A later period of maximum values also occurred, as previously noted in the ^{137}Cs measurements, and Alaskan ecosystems responded more noticeably to the ^{90}Sr deposited from recent (1967-1969) high-yield atmospheric nuclear weapons tests by China and France.

Strontium-90 and Cesium-137 in Carnivores

The appreciable harvest of caribou by the Anaktuvuk Pass Eskimos during the fall of each year was usually stockpiled on the tundra, where it remained frozen until needed by the individual hunters. These piles of meat also attracted tundra wolves (*Canis lupus*), wolverines (*Gulo luscus*), and red foxes (*Vulpes fulva*) and provided trapping opportunities for the Eskimos. These carnivores were abundant in the Anaktuvuk Pass area especially at the time of the caribou migration, although they were often seen during the summer as scattered small family grupps. A system of purchases of samples of all carnivores taken by the Eskimos was conducted through the resident agent at the village; and a good series of carnivore flesh and bone samples from

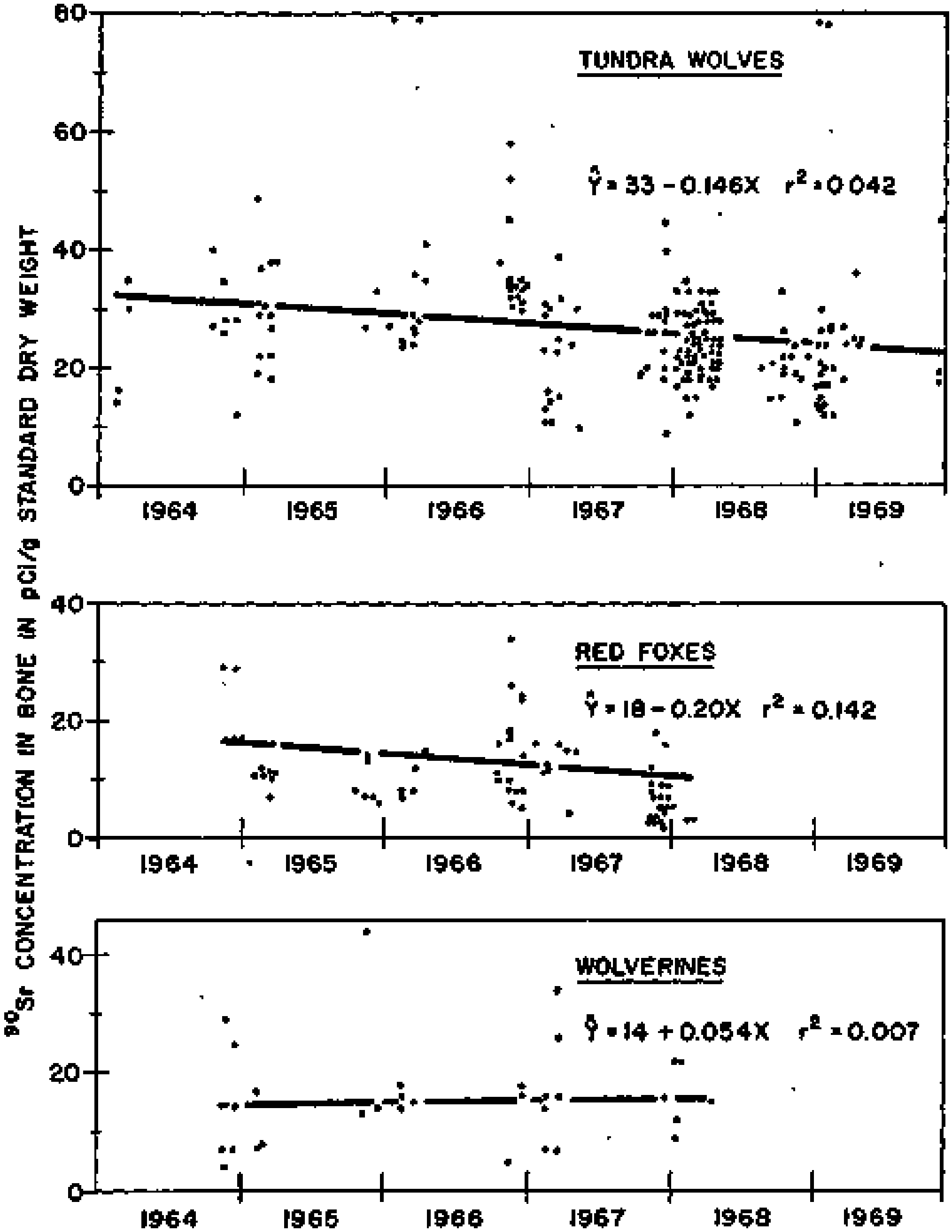
213 wolves, 166 foxes, and 73 wolverines was obtained for the years 1964-1969. Trapping was dependent upon weather conditions, but usually was conducted during the months of October or November through April. Highly variable seasonal patterns were found for ^{137}Cs in muscle (Fig. 16) and for ^{90}Sr in bone (Fig. 17) of each of the species. A slight but continuous downward trend is apparent in the ^{137}Cs values and a relatively long-term plateau was noted in the ^{90}Sr values. A long-term picture of ^{90}Sr in bones of tundra wolves was obtained by analysis of an additional 50 samples from the period 1960-1964 provided by the Alaska Department of Fish and Game. These are presented in Figure 15 for ease of relating the ^{90}Sr in three trophic levels. As with the caribou bone values, regression lines determined by the least squares method have been fitted to three groups of points; these show that a relatively stable value of about 12 pCi ^{90}Sr/g standard dry weight prevailed during 1960-1962, followed by a period of rapid increase during 1963 and early months of 1964 to about 34 pCi/g, and a subsequent decrease at an effective half-time rate of about 7.3 years. A result of the regression analyses was the interpretation that the ^{90}Sr in wolves reached a maximum sooner than did caribou. This suggested that the primary food supply of the wolves was a source which had achieved equilibrium with ^{90}Sr fallout sooner than the caribou. This may reflect the importance of animals other than caribou as prey; such as small rodents that feed upon <u>Carex</u> and other sources of

Figure 16. Cesium-137 in carnivore muscle samples at Anaktuvuk Pass during 1964-1969. Units of X in regression equations are in months.



137Cs CONCENTRATION IN MUSCLE IN pCi/g STANDARD DRY WEIGHT
TUNDRA WOLVES
Ŷ=192 - 1.83X r² = 0.14
400
300
200
100
0
1964
1965
1966
1967
1968
1969
RED FOXES
Ŷ = 87 - 0.75X r² = 0.13
200
100
0
1964
1965
1966
1967
1968
1969
WOLVERINES
Ŷ = 104 - 0.83X r² = 0.11
200
100
0
1964
1965
1966
1967
1968
1969

Figure 17. Strontium-90 in carnivore bone samples at Anaktuvuk Pass during 1964-1969. Units of X in regression equations are in months.



TUNDRA WOLVES
Ŷ = 33 − 0.146X r² = 0.042
RED FOXES
Ŷ = 18 − 0.20X r² = 0.142
WOLVERINES
Ŷ = 14 + 0.054X r² = 0.007
⁹⁰Sr CONCENTRATION IN BONE IN pCi/g STANDARD DRY WEIGHT
0
20
40
60
80
1964
1965
1966
1967
1968
1969

prompt fallout, and that also may have a more rapid turnover rate of radionuclides; and sheep that feed upon fresh forbs and grasses that likewise provide a prompt source of radionuclides rather than accumulating them over a long period, as do lichens. Such food sources are especially utilized in summer and winter by wolves (Stephenson and Johnson, 1972, Kuyt, 1972).

Concentration factors for ^{90}Sr and ^{137}Cs in the trophic levels of the natural food web at Anaktuvuk Pass sampled at many comparable times when animals were near equilibrium levels of radionuclides in their food were as follows:

	^{90}Sr	^{137}Cs
caribou bone pCi/g std dry wt / lichen thalli pCi/g std dry wt	7.6 (0.99 equilibrium)	
caribou flesh pCi/g std dry wt / lichen thalli pCi/g std dry wt	(0.9 equilibrium)	2.5
wolf bone pCi/g std dry wt / caribou flesh pCi/g std dry wt	0.4 (0.5 equilibrium)	
wolf flesh pCi/g std dry wt / caribou flesh pCi/g std dry wt	(0.8 equilibrium)	2.7

These ratios illustrate the transmission of ^{137}Cs up the food web and the effective blocking of ^{90}Sr transfer by its localization in bone.

The ratios of carnivore/herbivore noted in wolves did not strictly apply to other carnivores, such as the foxes and wolverines. Wolves tended to contain higher concentrations of both ^{90}Sr and ^{137}Cs than did foxes and wolverines, both of which are more disposed to scavenging after the wolves and feeding upon small animals to a greater extent. An important age effect upon ^{90}Sr concentration in wolf bone was observed in the fifty wolf leg bone samples obtained from the Alaska Department of Fish and Game. Sub-adult animals of each year of the period 1960-1964 increased with time their "observed ratio" (pCi ^{90}Sr/g Ca bone ÷ pCi ^{90}Sr/g Ca caribou flesh) appreciably faster than did adults (Table 20). Caribou flesh must be considered the major diet for only about 6 months and small mammals for the remainder of the year.

Foxes and wolverines contained similar concentrations of both radionuclides, as shown in Figures 16 and 17. A total of seven lynx (Lynx canadensis) were trapped by the Eskimos during the period March 1966-December 1968 during an incursion of those animals which are usually more closely associated with the taiga (boreal forest) biome than the tundra biome. These animals were taken in creek bottoms with willow and alder growth slightly beyond the "tree line" to the south and east of Anaktuvuk Pass, where an abundance of their prey species usually was found. Cesium-137 concentrations in these animals are compared with other carnivores in Table 21, which included values from three grizzly bears (Ursus arctos) taken by the Eskimos during this period. The values for lynx and wolverine muscle were nearly equal; this contrasts with the relationship between these two species reported in Norway during 1966 (Mohn and Teige,

Table 20. "Observed ratios" (OR = wolf bone pCi ^{90}Sr/g Ca divided by caribou flesh pCi ^{90}Sr/g Ca) in wolves, wolverines, and foxes at Anaktuvuk Pass during 1960-1968.

		1960	1961	1962	1963	1964	1965	1966	1967	1968
Wolves	N									
Subadult*	24	0.31	0.32	0.17	0.20	0.11				
Adult	23	0.31	0.24	0.11	0.09	0.05				
All** $\bar{X}$		0.31	0.28	0.13	0.13	0.09	0.25	0.20	0.21	0.25
All** N		16	11	5	9	24	14	26	32	78
Wolverines						0.04	0.11	0.05	0.12	0.14
Foxes						0.09	0.15	0.07	0.07	0.03

* Less than one year old, aged by epiphyses of long bones (Rausch, R. A., 1961).

** Includes 47 aged and 168 unaged wolves.

Table 21. Cesium-137 concentrations in carnivores of the Anaktuvuk Pass region during 1966-1968.

Carnivore	^{137}Cs Concentration (pCi/g std dry wt) in Muscle								
	Mar. 1966	Jan. 1967	Feb. 1967	Mar. 1967	Dec. 1967	Jan. 1968	May 1968	Nov. 1968	Dec. 1968
Tundra wolf (*Canis lupus*)	150	90	290	180	170	115	90	65	70
Wolverine (*Gulo luscus*)	85	60	55	55	75	170	55	20	20
Red fox (*Vulpes fulva*)	50	45	55	45	55	80	105	30	30
Lynx (*Lynx canadensis*)	--	10	60	45	45	115	--	15	5
Grizzly bear (*Ursus arctos*)	5	--	--	--	90	--	60	--	--

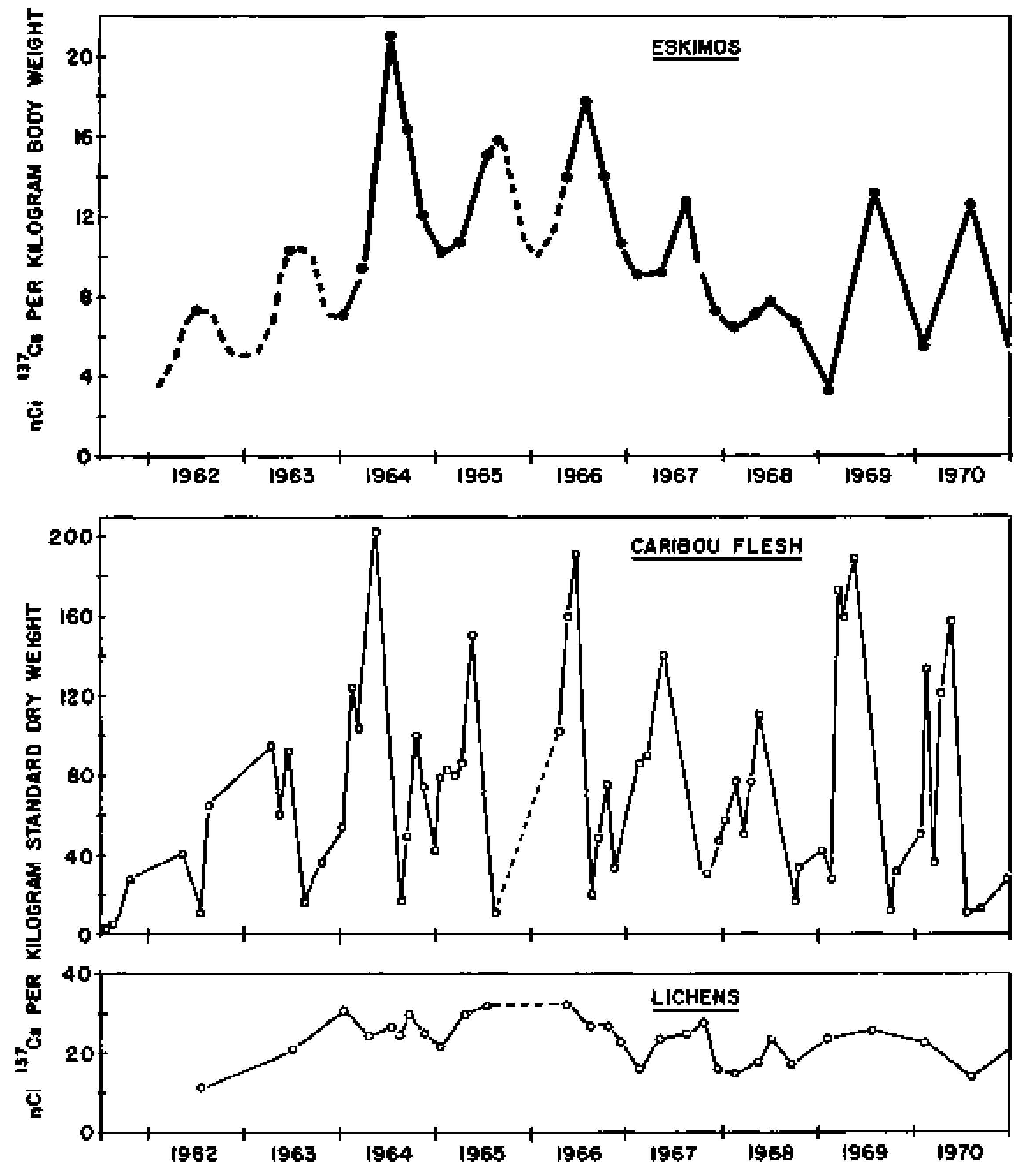
1968), in which lynx contained consistently greater ^{137}Cs concentrations in muscle than did wolverines. This may have resulted from a variety of conditions, not the least of which is the short time period over which collections were made (3 months in Norway) and the small number of samples compared (15 lynx and 9 wolverines in Norway, 7 lynx and 26 wolverines in Alaska). Statistically, the probability of observing the size of the observed difference or larger between the means of Norwegian lynx and wolverines of the same sex was 0.2-0.3, which is usually insufficient for conclusive results.

Cesium-137 Body Burdens in Anaktuvuk Pass Eskimos

A total of 28 measurements of ^{137}Cs body burdens were periodically made of nearly all of the Anaktuvuk Pass villagers during the study period from July 1962 to August 1970. Annual measurements were performed in summers of 1962 and 1963, five measurements were made in 1964, four in 1965, four in 1966, five in 1967, four in 1968, and two each year during 1969 and 1970. Those made during 1964-1968 were for the purpose of defining seasonal cycles correlated with ^{137}Cs levels in the diet. Eskimo body burdens were determined by the levels in the caribou, which in turn were governed by the time of year and diet of the caribou (Fig. 18).

The ^{137}Cs body burdens in Anaktuvuk Pass residents were usually about 100-200 times those of people in the

Figure 18. Cesium-137 in lichens, caribou, and Eskimos at Anaktuvuk Pass during the period 1962-1970.



ESKIMOS
nCi ^{137}Cs PER KILOGRAM BODY WEIGHT
0
4
8
12
16
20
1962
1963
1964
1965
1966
1967
1968
1969
1970
CARIBOU FLESH
nCi ^{137}Cs PER KILOGRAM STANDARD DRY WEIGHT
0
40
80
120
160
200
LICHENS
0
20
40
1962
1963
1964
1965
1966
1967
1968
1969
1970

conterminous United States, which were often in the range of 3-21 nanocuries (Scott, 1972). Canadian native groups which consumed large amounts of caribou were similar to Anaktuvuk Pass levels (Mohindra, 1967).

A usual caribou utilization year among the "inland people" began with the autumn migration of caribou from the summer range on the Arctic Coastal Plain and Foothills toward their winter range some 400 km to the south. The Eskimos allowed the first band of animals to pass their village unmolested and then expeditiously secured their initial winter meat supply of some 400-800 animals, based upon individual family needs for basic human food, hides for clothing and sleeping robes, and dog food. As previously noted, Anaktuvuk hunters usually were conservative in their harvest of caribou. On at least one occasion, a group of hunters admonished the white school teacher that he had killed more caribou than he needed to feed his family and dogs through the winter, and that he must not kill any more animals. He did so, but felt superior to the Eskimos later in the winter when the caribou were unavailable and the meat supply of most families was exhausted. He had failed to grasp the deep concern of the Eskimo over the consequences of overharvesting the herds and the recurrent famine that had been a frequent fact of native history when caribou were in short supply.

The autumn-killed caribou contained low ^{137}Cs concentrations in their flesh and this allowed the ^{137}Cs body burdens of the Eskimos to continue a decline from their summer maxima. The autumn caribou were utilized until about February or March, when fresh animals were obtained from the small bands of caribou that are usually to be found scattered throughout the Brooks Range during winter. These animals had grazed principally upon lichens and thereby increased their ^{137}Cs concentrations, and the consumption of their meat increased the body burdens of the Eskimos. When the caribou migrated northward from the winter ranges and passed the village in late April-early June, the people again killed about 400 animals and stored most of the haunches in underground permafrost cellars for continuous use throughout spring and summer months. Several families also made "dry meat" by hanging thin strips and lighter cuts, such as ribs and loins, on willow racks for use on pack trips or when hunting was poor (Rausch, op. cit.). This meat supply invariably contained the annual maximum ^{137}Cs concentrations and its consumption resulted in a sharp increase in human ^{137}Cs levels during the April-August period. Maximum ^{137}Cs body burdens in the people occurred about three months after the spring harvest of caribou, by which time the stored meat was exhausted or unpalatable. Assuming effective half-times for ^{137}Cs in the body of 70 days for adults and minors and 45 days for children, the measured body burdens were about 70% and 80%, respectively, of equilibrium values.

Fewer caribou were stored during May and June 1967 than for the previous several years because of a late caribou migration and early spring season, which melted much of the snow before the caribou arrived. This condition restricted the use of dogsleds and made transport of caribou carcasses from the main hunting areas to the cellars (a distance of about 12 km) too arduous, in the opinion of the Eskimos. The limited caribou supply was thus sparingly consumed during the summer; and because it normally decreases in both quantity and quality as the summer progresses, it was temporarily replaced by uncommonly large amounts of "white man's grub", fish, sheep and other foods. The late arrival of the 1967 fall caribou migration aggravated the unusual food utilization patterns even further. Upon the arrival of the caribou herds in late October a plentiful supply of animals, containing low ^{137}Cs concentrations, was secured for the winter food supply. However, a herd of about 4,000 caribou returned to the village site in late November and wintered there for the first time in the peoples' memory. This provided a unique supply of fresh animals throughout the winter; accordingly, the ^{137}Cs levels in people increased at a slightly greater rate than expected during the January-May 1968 period. The fall-killed caribou not utilized were stored in the permafrost cellars instead of spring migrant animals, which were sparingly utilized. This significantly lowered the level of ^{137}Cs in the villagers' diet during the summer of 1968 and produced a maximum concentration in the people only 10% greater than the annual minimum, compared to a 35-50% increase annually observed during the preceding four years. The ensuing decrease from the 1968 summer maximum was also less abrupt than in previous years. This anomalous pattern emphasized the influence of seasonal food habits of caribou and of the food-gathering practices of the people upon their ^{137}Cs concentrations, and the importance of relating natural phenomena to the interpretation of results.

During the summers of 1962-1965 the average ^{137}Cs body burden (nCi/kg body weight) of adult Eskimos at Anaktuvuk Pass equalled or surpassed the average ^{137}Cs concentration (nCi/kg dry weight) in caribou flesh stored in permafrost cellars and being consumed; however, since 1966 there has been a widening discrepancy between the values, believed due to the decreased consumption of caribou meat by the people as processed foods are increasingly made available by governmental assistance programs. This was confirmed by a reduction of ^{137}Cs ingestion rates calculated from ^{137}Cs body burdens of the people and the ^{137}Cs concentration in their food base (Table 22).

At any one time of measurement adult males between the ages of 21 and 50 usually contained the highest ^{137}Cs body burdens, apparently due to their greater proportion of muscle tissue and greater consumption of caribou. Children (3-14 years old) usually contained about half as much ^{137}Cs per kg body weight as adults (more than 21 years old), and

Table 22. Caribou meat ingestion rates of various age groups of Anaktuvuk Pass Eskimos during winter periods of 1964-1970 estimated by Equation (5).

Date	Average Ingestion Rate (R) (kg wet wt/day)			
	Men	Women	Minors	Children
13 Jan 1964	1.81	1.03	1.28	0.31
21 Jan 1965	1.98	1.09	1.12	0.31
1 Feb 1967	1.46	0.89	0.93	0.27
1 Feb 1969	0.62	0.36	0.16	0.13
4 Feb 1970	0.80	0.49	--	0.09

No measurements of ^{137}Cs body burdens were made in January 1966, and the February 1968 measurement was omitted because of the peoples' utilization of wintering caribou in the vicinity of the village.

minors (15-20 years old) contained about 70% as much as adults. Comparison of males and females during 1964 and 1965 seasonal maxima indicated no important differences in ^{137}Cs body burdens until about the age of 20; males then consistently contained more ^{137}Cs than did females, with maximum differences occurring at the age of 40 years; and the difference then decreasing during advanced age (Hanson, 1966).

In the ^{137}Cs half-time study, the four families participating were composed of 31 individuals, 28 of whom agreed to a dietary change, consisting of replacement of caribou meat with domestic foods. These people normally eat large amounts of meat compared to average American diets, as witnessed by their estimated consumption of 5-6 kg/person of caribou meat per week. During the month-long study, they consumed about 3 kg of beef and 1 kg of domestic fowl per person per week. The disparity between their estimated and actual consumption may have been due to an overestimate of caribou consumption, to greater intake of domestic food, or to the greater fat content of the domestic beef, to which the adults felt there was some difficulty in adjusting. Several of them suffered diarrhea during the first few days on the new diet but soon adjusted, and after the first week most were entirely satisfied with the beef diet. Turkey was furnished weekly, and was a favorite of most people. Toward the end of the month, most of the people exhibited "withdrawal symptoms" and eagerly looked forward to the end of the study and the arrival of the fall caribou herd migration.

Cesium-137 concentrations in the domestic beef and fowl averaged 0.80 and 0.07 pCi/g standard dry weight, respectively. The total ^{137}Cs intake of adults during the study, based on analysis of average meals, was 0.2 nCi; this was negligible compared to the ^{137}Cs body burdens (200-1,300 nCi) in the people at the start of the new diet.

No attempt was made to determine the shorter-lived ^{137}Cs components, reported to be eliminated at half-times of a few hours (T_1) and about one day (T_2) (Rundo et al., 1963; Naversten and Lidén, 1964); these components are extremely difficult to measure in subjects with ^{137}Cs body burdens maintained for considerable time, such as Eskimos on a caribou meat diet.

Results of the dietary study showed many sources of variance in the data due to human factors, emphasized by the problems of subjects' abstinence from the traditional caribou diet and the difficulties of adapting a routine to an active and independent people unaccustomed to such regimentation. Evidence suggested that urinary collections were incomplete primarily because of the subjects' variable estimations as to what constitutes a "day" during the 24-hour daylight of summer. Using the estimated excretion coefficient for each individual, calculating the daily total ^{137}Cs loss, and comparing it with the measured body burden led to the conclusion that there was a general failure to collect all urine and that there was some surreptitious ingestion of caribou meat. Because of variances in the data from the dietary study and resultant uncertainties, estimates of ^{137}Cs effective half-times were estimated indirectly by computing excretion rates of 21 Eskimos on normal diets of caribou meat during consecutive measurement periods between January 1964 and January 1965 (Hanson and Eberhardt, 1964). Two successive body burdens (neglecting short-term components) were related by the equation:

$$Q = \frac{I}{\lambda} (1 - e^{-\lambda t}) + Q_0 e^{-\lambda t} \qquad (4)$$

where

Q = terminal body burden

Q_0 = initial body burden

λ = excretion rate constant (fraction per day)

I = intake rate (assumed constant over time interval of interest)

t = elapsed time between counts

Equation (4) can be expressed in the form

$$Q = a + b\ Q_0$$

where

Q = terminal body burden

Q_0 = initial body burden

a = $\frac{I}{\lambda}$ $(1 - e^{-\lambda t})$

b = slope, which is an estimate of $e^{-\lambda t}$, depending upon the circumstance that the time interval between counts of individuals was roughly constant

Time periods used were: January to March 1964; September to November 1964; and November 1964 to January 1965 (76-, 66-, and 67-day intervals).

Results of regression calculations for 21 adults indicated that an average half-time very nearly that of the interval between counts, or about 70 days; that is, the slopes (b) of regression lines averaged about 0.5. These results agree with those reported in other arctic peoples (Miettinen et al., 1963; Bengtsson, Naversten and Svensson, 1964; Lidén, 1964; Naversten and Lidén, op. cit.). Our intensive studies at Anaktuvuk Pass have not indicated an appreciable seasonal change in the T_{eff} of ^{137}Cs such as that reported by Nevstrueva et al. (op. cit.) in 60 reindeer breeders (97 days in summer and 57 days in winter with considerable variation of values).

The same general formula used for calculating ingestion rates of lichens by caribou was applied to estimation of caribou meat intake rate of the Anaktuvuk Pass Eskimos during winter periods when ^{137}Cs body burdens of the people were at a seasonal low that resulted from consuming fall-killed caribou. The formula used was the same form as Equation (3):

$$R = \frac{0.693\ (Q_w - Q_0\ e^{-\lambda t})}{T_{eff}\ C\ a\ (1 - e^{-\lambda t})} \qquad (5)$$

where

R	=	intake rate of caribou meat (kg/day)
Q_w	=	^{137}Cs body burden at winter minimum (nCi)
Q_0	=	^{137}Cs body burden at summer maximum (nCi)
C	=	^{137}Cs concentration in caribou meat (nCi/kg)
a	=	assimilation factor (1.0) (ICRP, 1960)
T_{eff}	=	effective half-time (70 days in adults and minors, 45 days in children) (Eberhardt, 1971)

Five periods were suitable for application of the calculations, namely the whole-body measurements made in midwinter (January-February) of the years 1964, 1965, 1967, 1969, and 1970. No measurement was made during 1966; and during the winter of 1967-1968 fresh caribou were constantly available and utilized by the people. The combined use of both fresh and fall-killed caribou meat in the diets invalidated such calculations.

The five periods extended for 91 to 145 days, during which ^{137}Cs body burdens of adults and minors reached 0.59 to 0.76 of equilibrium with the mean ^{137}Cs concentration of their diets. Children reached 0.75 to 0.89 of equilibrium during these same periods, because of their more rapid turnover rate.

Because of the substantial differences in ^{137}Cs body burdens of men, women, minors, and children previously discussed, the mean values for these groups of Anaktuvuk Pass people at each time interval were used in the calculations. Results (Table 22) showed that adult men ate from 0.6-2.0 kg of caribou meat per day, which are large amounts of caribou meat in comparison to average meat and meat products in American diets, or compared to male Russian reindeer herders (about 1 kg per day in winter, less during other seasons) (Nizhnikov et al., op. cit.). Finnish male reindeer-breeder Lapps in 1961 estimated they consumed 0.41 kg reindeer meat per day year round and 0.72 kg/day during November-April (Miettinen et al., 1963).

Interestingly, the amounts of caribou in the Anaktuvuk Pass diet have apparently decreased as the peoples' acculturation has increased.

Cesium-137 Body Burdens in Other Alaskan Native Populations

In the summers of the period 1962-1964 we measured ^{137}Cs and other gamma-emitting radionuclide burdens in about 2,500 natives from the major ethnic groups of northern Alaska (Fig. 5), and in extensive samplings of their foods (Hanson and Palmer, 1964; Hanson, Palmer, and Griffin, 1964). Cesium-137 was the most important and often the only gamma-emitting fallout radionuclide found in the people, although several others were measured in their foods.

The degree to which the native populations of northern Alaska utilized caribou and reindeer for food varied considerably, depending on the location and ethnological grouping. Average ^{137}Cs body burdens of adult natives of the various groups maintained the same general ranking during the three years of study (Table 23); the values were directly proportional to the quantity of caribou or reindeer consumed, as estimated by the people interviewed at the time of measurement. Maximum ^{137}Cs levels occurred in the Anaktuvuk Pass residents, who were more dependent upon caribou for basic food than were the residents of other Alaskan villages; median values occurred in river village Eskimos and Arctic Village Indians, who utilized caribou, moose, and fish; and lowest values were found in coastal Eskimos, who utilized marine mammals and fish, and Fort Yukon Indians, who depended upon moose and fish for major meat supplies (Table 24). These relationships between the various ethnic groups and their food base reflect cultural ties and geographic location to a high degree; however, unusual abundance of a given food source was observed to significantly affect ^{137}Cs body burdens in certain villages. As previously noted, the unusual winter abundance of caribou at Anaktuvuk Pass during 1968 altered the annual pattern of ^{137}Cs body burdens in the people. Similarly, the body burdens of residents of the river village of Selawik were reported to exceed those of Anaktuvuk Pass during April-May 1966 (Fitzpatrick *et al.*, 1966) following their utilization of an unusually close wintering herd of caribou.

Table 23. Cesium-137 body burdens of adult members of various ethnic groups of northern Alaska during summers of 1962-1964.

Ethnic Group and Location	Summer 1962		Summer 1963		Summer 1964	
	N	Mean	N	Mean	N	Mean
Inland Eskimo						
Anaktuvuk Pass	39	450	44	640	40	1330
River Village Eskimo						
River villages*	35	150	16	150	26	360
Coastal Eskimo						
Kotzebue	112	150	102	120	114	340
Barrow	248	55	119	65	--	--
Little Diomede	15	29	--	--	--	--
Other Coastal villages**	8	100	--	--	2	130
Athapascan Indian						
Fort Yukon	--	--	56	37	--	--
Arctic Village	--	--	--	--	25	640

* Ambler, Kiana, Kobuk, Noatak, Noorvik, Selawik, and Shungnak

** Deering, Elim, and Kivalina

Table 24. Native animals as percent of total diets of Alaskan Eskimos and Indians during various seasons as estimated through interviews 1962-1964.

Location and Season	Caribou-Reindeer	Marine Mammals	Fish	Fowl	Moose	Bear	Other Mammals	Total
Anaktuvuk Pass								
Spring	59			1	1	tr		61
Summer	54		1	1	tr	tr	tr	56
Fall	57		1	1	tr	tr	2	61
Winter	55		1	4	1		1	62
River Villages								
Spring	28	11	20	4	2	tr		65
Summer	25	6	23	1	1	tr		56
Fall	31	tr	28	5	3	tr		67
Winter	34	1	25	4	3	tr		67
Barrow								
Spring	17	13	8	12		tr		50
Summer	22	18	9	1				50
Fall	23	17	8	1				49
Winter	26	8	15	1		tr		50

Table 24., continued

Location and Season	Caribou-Reindeer	Marine Mammals	Fish	Fowl	Moose	Bear	Other Mammals	Total
Kotzebue								
Spring	18	15	6	2	2	tr		41
Summer	17	4	15	tr	4	tr		40
Fall	21	5	14	2	5	tr		47
Winter	25	4	11	1	1	tr		42
Point Hope								
Spring	7	27	tr	4	tr			38
Summer	16	5	16	1	tr			38
Fall	21	5	16	2				44
Winter	17	11	8		tr	10*		46
Fort Yukon								
Spring	3			8	10	tr	22	43
Summer	1		35	1	3	tr	tr	40
Fall	11		3	6	18	tr	1	39
Winter	9		6	1	20		6	42

Table 24., concluded

Location and Season	Caribou-Reindeer	Marine Mammals	Fish	Fowl	Moose	Bear	Other Mammals	Total
Arctic Village								
Spring	41		4	2			3	50
Summer	34		7	2	6		1	50
Fall	45		3	2			1	51
Winter	45		1	2	3			51

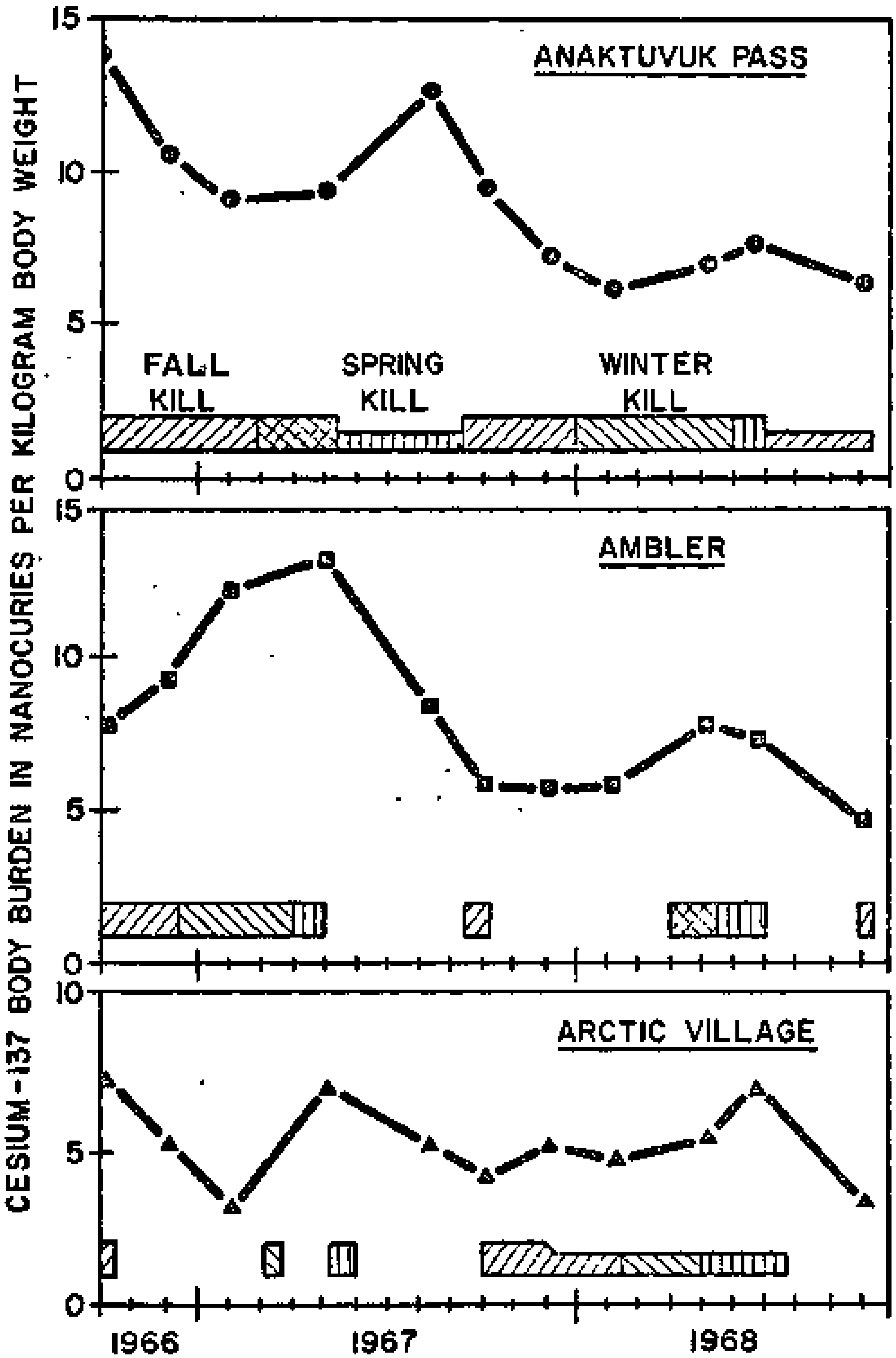
tr = trace

* Polar bear (*Thalarctos maritimus*)

In order to demonstrate the dramatic effect upon human ^{137}Cs body burdens by such a shift in food base, a special whole-body counting schedule of three inland villages was begun in October 1966 (Hanson, 1971). The Eskimo villages of Anaktuvuk Pass and Ambler (on the Kobuk River, to the west of Anaktuvuk Pass) and the Indian village of Arctic Village (on the East Fork of the Chandalar River, to the east of Anaktuvuk Pass) were selected for study on the basis of geographical location and knowledge of their dependence upon caribou gained during the 1962-1964 surveys.

Results of the study showed a marked response of ^{137}Cs in the people to caribou consumption in both expected and unusual patterns. The normal year of caribou utilization and anomalous situations at Anaktuvuk Pass have previously been discussed, and can be graphically seen in Figure 19. Ambler "river village Eskimos" usually returned from summering in the vicinity of Kotzebue in time to secure seasonal food supplies for the approaching winter. Such was the case during the October 1966-October 1967 period. Caribou were intercepted during their annual migration to wintering ranges on the Kobuk and Selawik River drainages, and a dietary shift to caribou as the principal meat source during fall, winter, and spring months resulted in a steady increase in the peoples' ^{137}Cs content. This was reinforced by the use of animals that steadily increased their ^{137}Cs content through lichen consumption. There then followed a summer period of decrease that reflected the

Figure 19. Cesium-137 seasonal patterns in residents of three contrasting Alaskan villages during the period October 1966-October 1968.



CESIUM-137 BODY BURDEN IN NANOCURIES PER KILOGRAM BODY WEIGHT
ANAKTUVUK PASS
FALL KILL
SPRING KILL
WINTER KILL
AMBLER
ARCTIC VILLAGE
15
10
5
0
1966
1967
1968

dietary shift to fish, fowl, marine mammals, and other low ^{137}Cs food sources.

This normal pattern of food habits by Ambler residents produced a seasonal variation of ^{137}Cs body burdens almost opposite that of Anaktuvuk Pass, due almost exclusively to the amount and kind of caribou they consumed.

The 1967-1968 pattern at Ambler was much altered from that of 1966-1967. Cesium-137 concentrations in the people were much lower and attained only about one-half of the expected maximum. Fall-killed caribou were eaten only for a short time, and fresh caribou were not taken at all during much of the winter because of local abundance of moose and fish, and unusually deep snow complicated travel. Conditions improved during April 1968, and the fall-killed caribou were then utilized, causing a modest increase in ^{137}Cs body burdens. Fish became plentiful during June and July, and the body burdens decreased accordingly.

The Athapascan Indian residents of Arctic Village depended upon the fall caribou migration to furnish their main meat supply for fall and winter months. Moose and fish were also taken in limited numbers during this time but the amounts of ^{137}Cs obtained from these sources was insignificant compared to that ingested with caribou meat. Cesium-137 body burdens usually increased through the winter and reached a maximum shortly after the passage of the spring caribou migration of animals that contained their seasonal maximum ^{137}Cs concentrations. The Arctic Village people did not practice food storage in underground permafrost cellars, and body burdens decreased in late spring months as other wildlife food sources containing very low ^{137}Cs concentrations were utilized. The food-gathering practices and the expected seasonal pattern of the ^{137}Cs body burdens at Arctic Village were thus very similar to those of Ambler residents 550 km to the west.

An unusual pattern of ^{137}Cs body burdens occurred in Arctic Village residents at the beginning of the study, caused by the loss to spoilage of nearly all of the fall-killed caribou during unseasonably warm weather in September and October 1966. This required the continued use of fish and other low ^{137}Cs foods instead of the normal caribou meat. The caribou herds continued on beyond the hunting range of the village and remained unavailable throughout the winter. Extremely cold (-50 C) and calm weather prevailed and hampered moose hunting; this caused a severe food shortage in the village. On 1 March 1967, 28 caribou were imported from a special hunt conducted on a wintering herd some 350 km southwest of the village to relieve the shortage. This meat, which lasted about 3 weeks, and a modest spring kill of migrant caribou restored the ^{137}Cs concentrations to near the October 1966 level. Moose, fish and ducks then contributed about 15% and processed food the balance of the total human diet through the summer, accounting for the steady decrease in ^{137}Cs burdens.

During the second year of study (October 1967-October 1968), Arctic Village residents displayed a typical pattern of ^{137}Cs concentrations, although somewhat reduced from normal in amplitude by less caribou consumption. An upward trend began with the fall-kill of caribou during October, and then stabilized near 5 nCi ^{137}Cs per kg body weight in adults for most of the winter; this reflected heavy dependence upon a supply of fall-killed animals rather than nearby wintering animals. The spring 1968 harvest resulted in a 50% increase in the peoples' ^{137}Cs burdens during spring and early summer, followed by a corresponding decrease after a dietary change to fish in summer and fall months.

The unusual dietary phenomena that occurred during this study emphasized the role of the caribou as the major determinant of fallout radionuclide intake by northern natives. Caribou migration and feeding patterns, and the native utilization thereof, often responded to environmental factors in unpredictable ways. The shortage of game animals at Arctic Village during 1966 and the bountiful caribou supply at Anaktuvuk Pass during 1967-1968 illustrated the extremes that beset subsistence economies of the study area and substantially varied the ^{137}Cs patterns in the people. It also explains the changing rank of ^{137}Cs levels of northern Alaskan villages surveyed annually (Fitzpatrick _et al_., 1966; Rechen _et al_., 1968), and the need to understand the ecological background to which the measurements were related. Similarly, the lack of sufficient snow to permit dogsledding the spring-killed caribou to cellars at Anaktuvuk Pass during the spring of 1967 and the presence of too much snow at Ambler during the winter period of 1967-1968 had important implications for the diets of the residents concerned. Snow cover has long been recognized as a complex and extremely important ecological factor in the winter movement and behavioral characteristics of reindeer and caribou, particularly as it affects their food supply (Formozov, op. cit.; Kelsall, op. cit., Pruitt, 1959).

Considerable insight into behavioral ecology of man and his associated animals of the northern ecosystems was provided during this study of the three villages. Snow cover and temperatures had a marked effect upon the behavior of both the caribou herds and the animals dependent upon them as a prime energy source. At the time the caribou herd wintered at Anaktuvuk Pass and severely overgrazed the range, I made several hundred measurements of snow depth above lichen carpets that were not grazed. A depth of 0.7-0.8 m appeared to be the depth at which caribou ceased to dig through hard-packed snow to obtain lichens. Similarly, too much snow at Ambler and too little snow at Anaktuvuk Pass at times determined which food supply the people utilized. The Arctic Village people responded, perhaps unconsciously, to the food shortage of 1966-1967 by securing and utilizing more fall-killed animals than usual the following autumn.

Such responses of native peoples to environmental and ecological phenomena noted above have important implications to radiological health aspects of the ^{137}Cs body burdens herein described. The unusual dietary patterns that resulted in decreased amounts of ^{137}Cs in the village food supplies reduced the attendant radiation exposure by as much as 35% from one year to the next. This will be discussed in more detail in a later section of this Dissertation.

Comparison of Our Results With Other Circumpolar Radiation Ecology Studies

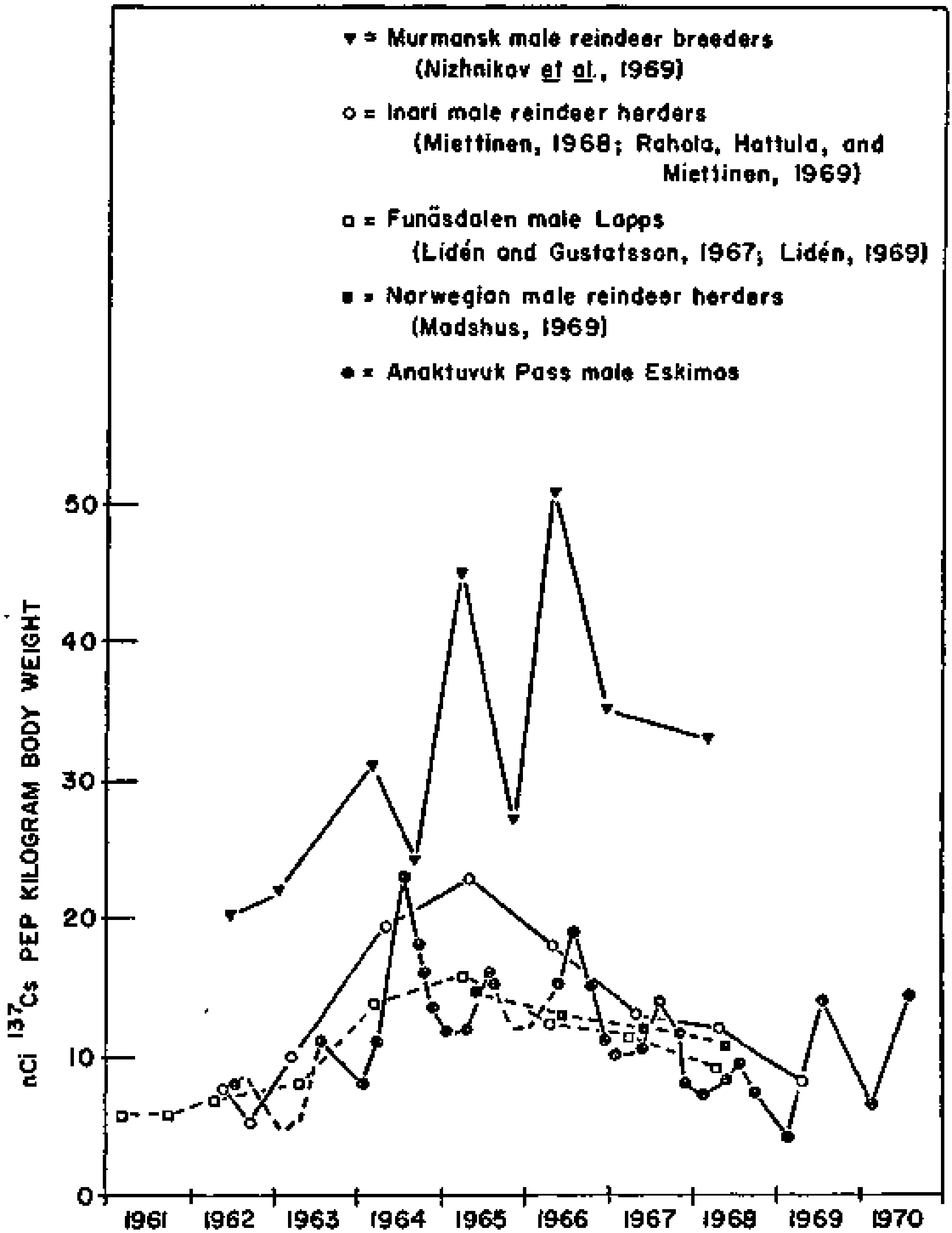
Most of the studies of radionuclides in arctic and subarctic areas of the world have been oriented towards measurement of ^{137}Cs body burdens in human populations and definition of radiation doses. Radiological health aspects have been emphasized rather than basic radiation ecological studies, probably because of the greater difficulty in working with natural systems and because of administrative decisions to expeditiously extract minimal information to satisfy public concern over radiation exposures of northern peoples. A consideration of no small importance has also been the differing economic bases from which various nations operate. The United States Atomic Energy Commission has been a principal supporter of radiation ecology studies in arctic regions, particularly in Alaska and in Finland. The Finnish studies have been strongly oriented toward radiological health aspects of those worldwide fallout radionuclides that are efficiently enriched by the lichen-reindeer-man food chain, such as ^{55}Fe, ^{90}Sr, ^{137}Cs, ^{210}Po, and ^{210}Pb. Special attention was given to ^{137}Cs because of its major contribution to radiation exposure of the people in Lapland. Several measurements were made in conjunction with Swedish investigators, due to the contiguous nature of the countries and the integrated nature of the Lapp cultures.

A summary of ^{137}Cs body burdens in several arctic human populations has been reported (Rahola, Hattula, and Miett-inen, 1969), and the conclusion drawn that the general situation in which substantial ^{137}Cs human body burdens were associated with the lichen-caribou/reindeer-man food chain was very similar everywhere, although there were minor differences in levels and seasonal variations. While it seems logical that many of the same processes are responsible for the efficient transfer of ^{137}Cs through the arctic food webs, substantial differences were noted between data reported from the reindeer herding societies of northern Europe and the subsistence hunting of caribou represented by the Anaktuvuk Pass people. Considerable care must, therefore, enter into comparisons of ^{137}Cs concentrations of reindeer/caribou and reindeer breeders/Eskimos. Just as there were substantial ethnic differences in food-gathering practices in northern Alaska, so there were similar differences among the peoples of Lapland and northern Russia (Leeds, 1965). Without the finer details to complete the overall picture of radionuclide accumulation within the various compartments of the arctic ecosystems involved, much remains to conjecture. Interpretations of ecological data are frequently tenuous, and the application to the northern Russian cultural groups would be especially difficult. Any treatment of information reported from Soviet primitive minorities must be considered to be subject to political influences and, therefore, incomplete (Armstrong, 1966).

Data reported to summarize Russian investigations in northern areas during the years 1962-1968 (Nizhnikov *et al.*, 1969) indicated that maximum levels in all trophic levels of the lichen-reindeer-man food chain were found in the Murmansk region. This was attributed to its greater precipitation than the eastern areas; the Murmansk region is about 1,500 km west of the Novaya Zemlya nuclear test site. An effective half-time of 2.5 years for ^{137}Cs in lichens from the Murmansk and Komi Districts was cited as the important determinant in regulating the concentrations in the other trophic levels of the food chain and predicting the "radiation environment of the far north".

Concentrations of fallout ^{137}Cs in reindeer-breeder components of northern human populations in Finland, Norway, Russia, Sweden, and the Anaktuvuk Pass Eskimos during the period 1961-1970 are shown in Figure 20. The Russian values are two to three times those of the other populations, which are about equal. The Anaktuvuk Pass values appear more variable only because we have performed more

Figure 20. Cesium-137 concentrations in northern human populations of Finland, Norway, Sweden, Russia, and Anaktuvuk Pass during 1961-1970.


▼ = Murmansk male reindeer breeders
(Nizhnikov et al., 1969)
○ = Inari male reindeer herders
(Miettinen, 1968; Rahola, Hattula, and Miettinen, 1969)
□ = Funäsdalen male Lapps
(Lidén and Gustafsson, 1967; Lidén, 1969)
■ = Norwegian male reindeer herders
(Madshus, 1969)
● = Anaktuvuk Pass male Eskimos
nCi ^{137}Cs PER KILOGRAM BODY WEIGHT
0
10
20
30
40
50
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970

frequent measurements than other investigators for the purposes of defining the various seasonal factors influencing ^{137}Cs concentration through the food chain. Applying our results to these other measurements made annually at times of maxima, I estimate the similar seasonal changes would be observed and would reduce the area under the curves by about 50%; this would be significant in terms of radiation dosage calculations. Most of the nations shown in the graph have assumed such a basis for dosage calculation on the basis of our original report of such seasonal variation (Hanson and Palmer, 1965) and a few measurements to confirm the magnitude and season of annual low values.

CHAPTER VII

RADIOLOGICAL HEALTH CONSIDERATIONS

Radiation Exposure of Caribou from Internal Cesium-137

The rather appreciable concentrations of cesium-137 in caribou and reindeer flesh in arctic regions have been a prime factor in fostering interest in radiological health considerations of human populations. Little if any literature exists on radiation exposures received by caribou or reindeer, probably because seasonal variability and lack of certain biological parameters hampered calculation. Moiseyey et al. (1967) embedded thermoluminescent dosimeters in various organs and tissues of a reindeer carcass that was subsequently kept frozen for 4 1/2 months and the cumulative dose then measured. Maximum measured doses of 234 mrad/year in the abdominal cavity contrasted with calculated exposure of 96 mrad/year, the latter assuming homogeneous distribution of ^{137}Cs in the animal. They further assumed that an average specific concentration of 1 nCi/kg produced 4.0 mrad/year in a cylinder of height and radius corresponding to that of a reindeer; thus, the mean concentration of 24 nCi/kg body weight yielded the 96 mrad/year value.

Using an average ^{137}Cs concentration in caribou flesh of 75 pCi/g standard dry weight (= 17.6 pCi/g wet weight) as a year-round estimate for caribou in northern Alaska for the period 1962-1970 (Fig. 18), an average radiation exposure was calculated for caribou. The body burden (Q) of ^{137}Cs was calculated by the formula:

$$Q = \frac{C\ W\ f_m}{f_t} \qquad (6)$$

where

Q = ^{137}Cs body burden (nCi)

C = ^{137}Cs concentration in caribou muscle (nCi/kg wet wt)

W = total body weight of an average caribou (kg)

f_m = fraction of total body weight that is muscle

f_t = fraction of total body ^{137}Cs that is in muscle

The value for C was 17.6 pCi/g wet weight, as previously noted. An average body weight of 75 kg was used for W, as it was in the previous calculation of lichen ingestion rates; this value was that given in Skoog (*op. cit.*) for an adult cow caribou of the Arctic Herd. The values of f_m = 0.41 and f_t = 0.8 are from Holleman, Luick, and Whicker (*op. cit.*). These numerical values yielded a mean ^{137}Cs body burden (Q) of 677 nCi. This value was then used to calculate the dose rate by the following formula, assuming that an effective radius of 30 cm and the corresponding 0.59 MeV/disintegration summation energy of the beta and gamma radiation (ICRP, 1960) is reasonable for a 75 kg caribou:

$$\text{Dose} = (677\ \text{nCi})(2.22 \times 10^3\ \text{dis/min-nCi})(0.59\ \text{MeV/dis}) \cdot$$

$$\cdot \frac{(1.6 \times 10^{-6}\ \text{erg/MeV})(5.256 \times 10^5\ \text{min/year})}{(10^2\ \text{ergs/g-rad})(7.5 \times 10^4\ \text{g/caribou})}$$

$$= 0.099 \text{ rad/year}$$

$$\approx 99 \text{ mrad/year}$$

This exposure is about that normally received by humans in the United States from natural background sources (NAS-NRC, 1972).

Radiation Exposure of Human Populations in Northern Alaska

Radiation doses to Anaktuvuk Pass residents during the study period 1962-1970 were calculated on the basis of the area under the curve of ^{137}Cs body burdens shown in Figure 18. Several formulas have been proposed for such calculations; however, the most complete is that recommended by the International Commission of Radiological Protection (1960), which is based on a permissible dose-rate of 0.1 rad per week to the whole body, in the case of ^{137}Cs. The basic formula used to calculate the dose rate to caribou was simplified and applied to the Anaktuvuk Pass human situation, resulting in the simplified equation:

$$W = \underline{q}\ (3.35 \times 10^{-3} \text{ rad/week-}\mu\text{Ci}) \qquad (7)$$

where

W = absorbed dose rate (rad/week)

$\underline{q}$ = ^{137}Cs body burden (μCi)

$$3.35 \times 10^{-3} \text{ rad/week-}\mu\text{Ci} = \frac{(3.7 \times 10^{4} \text{ dis/sec-}\mu\text{Ci})}{(10^{2} \text{ ergs/g-rad})} \cdot$$

$$\cdot \frac{(1.6 \times 10^{-6} \text{ erg/MeV})(6.05 \times 10^{5} \text{ sec/week})(0.59 \text{ MeV/dis})}{(63 \text{ kg body wt})(10^{3} \text{ g/kg})}$$

For instance, the measured area under the curve in Figure 18 for the year 1964 (year of maximum body burdens) contained 290 microcurie-days, or an average of 0.792 μCi. Inserting this value into the simplified equation:

$$W = 0.792\ (3.35 \times 10^{-3}\ \text{rad/week-uCi})$$

and solving for W, a value of 2.65 mrad per week or 140 mrad per year resulted. Similar calculations for the other years of study yielded the following annual exposures:

1962:	60 mrad	1967:	100 mrad
1963:	90 mrad	1968:	70 mrad
1964:	140 mrad	1969:	100 mrad
1965:	130 mrad	1970:	100 mrad
1966:	140 mrad		

The significant reduction of dose during 1968 as a result of the summer consumption of fall-killed caribou stored in permafrost cellars is readily apparent. The comparison study of three villages during October 1966-October 1968 also showed how the caribou utilization patterns affected the radiation exposure of northern subsistence hunting villages. During the first year (October 1966-October 1967) of study, exposures from average ^{137}Cs body burdens at Anaktuvuk Pass, Ambler, and Arctic Village were 110, 110, and 60 mrad, respectively; and during the second year of study (October 1967-October 1968) the values were 70, 70, and 60 mrad. Thus, ecological factors were principally responsible for unusual dietary patterns that resulted in decreased amounts of ^{137}Cs in the village food supplies and reduced the radiation exposure of the people from that source by as much as 35% from one year to the next.

In addition to the radiation exposure from ^{137}Cs, Anaktuvuk Pass residents receive annual dose rates of about 100 mrad from natural ^{210}Po (Holtzman, 1968) and a few mrad from ^{55}Fe (Palmer and Beasley, 1967). These exposures are within the same range of exposures received by most world populations from natural sources. The exposure from ^{90}Sr for which we have had until now little more than an approximation, has been based upon estimated ^{90}Sr ingestion rates. From a radiological health standpoint, the standard of comparison for ^{90}Sr has usually been the Federal Radiation Council Radiation Protection Guide (1961); this provides categories of ^{90}Sr ingestion rates adopted by national and international agencies for regulation of appropriate action. Based upon the caribou meat consumption rates, previously calculated from ^{137}Cs concentrations in the meat supplies of the people (Table 22), and assuming that those rates held throughout the year, the ^{90}Sr ingestion rates were calculated for the four population subgroups at Anaktuvuk Pass (Table 25). Results during the period 1962-1968 indicated that the ^{90}Sr ingestion rates of these people were within Range II (20 to 200 pCi/day) most of the time and for most of the population. The appropriate action in that case called for regular surveillance of the population.

Table 25. Estimated daily ^{90}Sr intake via caribou meat by Anaktuvuk Pása Eskimos during the years 1962-1968.

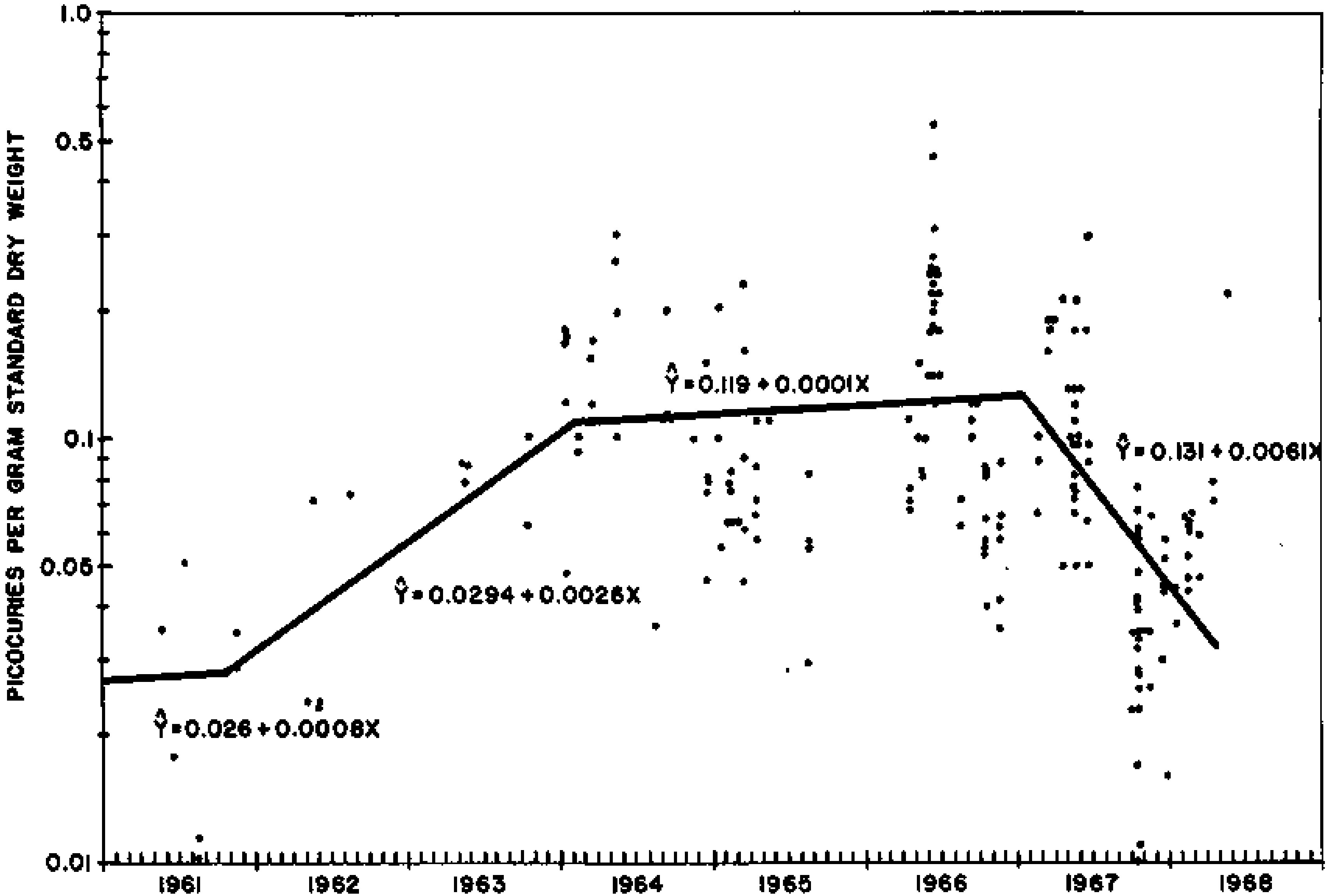
Year	Estimated Daily ^{90}Sr Intake (pCi) Men	Women	Minors	Children
1962*	76	46	48	12
1963*	140	80	90	30
1964	190	110	140	33
1965	300	160	170	46
1966	200	120	120	35
1967	130	80	80	24
1968*	40	24	22	8

* Caribou meat consumption rates approximated from nearest years for which values were calculated in Table 22.

Such guides are based on the philosophy that there exists an appropriate balance between the requirements of health protection and of the beneficial uses of radiation and atomic energy.

A more rigorous estimate of ^{90}Sr radiation exposures to the Anaktuvuk Pass population was made by combining (1) the ^{90}Sr concentrations in caribou flesh, (2) the caribou flesh ingestion rates of the people during various age categories and various years, (3) a three-compartment mathematical model describing ^{85}Sr retention (Rundo, 1967); and (4) a computer program that performed a sliding strip method of numerical convolution (Cooper and McGillem, 1947) of a step-function input of ^{90}Sr into the model. It was assumed (1) that ^{90}Sr in the northern Alaska caribou originated with the first thermonuclear test in November 1952 and gradually increased to the concentrations first measured in the Cape Thompson region (Fig. 6); and that these and subsequent concentrations (Fig. 21) were representative of those in Brooks Range caribou; (2) that the caribou flesh ingestion rates of the Anaktuvuk Pass residents prior to 1964 were constant at an average of their 1964-1965 rates (Table 22); and (3) that the ^{85}Sr retention model was suitable for ^{90}Sr and for all age categories. Strontium-90 body burdens were calculated for adult males, adult females, and for persons born on 1 October 1952, 1 October 1957, and 1 October 1962; the latter three categories represented children born at the time of the first input of ^{90}Sr, five years hence and

Figure 21. Strontium-90 concentrations in caribou flesh 1961-1968. Units of X in regression equations are in months.



PICOCURIES PER GRAM STANDARD DRY WEIGHT
1.0
0.5
0.1
0.05
0.01
1961
1962
1963
1964
1965
1966
1967
1968
Ŷ=0.026+0.0008X
Ŷ=0.0294+0.0026X
Ŷ=0.119+0.0001X
Ŷ=0.131+0.0061X

ten years hence. Results are presented in Figures 22 and 23, and indicated that maximum ^{90}Sr body burdens were attained during the period 1 October 1966–January 1967. Adult males then contained 7 nCi, adult females contained 4.5 nCi, four-year old children contained 1.65 nCi, nine-year-olds contained 1.8 nCi, and fourteen-year-olds contained 2.7 nCi. In terms of dose rate to the skeleton, the formula used by the ICRP (1960: 3) for calculating dose rate to the skeleton due to a body burden of 0.1 μCi of radium-226 is applicable. This was considered to correspond to a dose rate of 0.56 rem/week or 29 rem/year. The Maximum Permissible Body Burden of ^{90}Sr is 2 μCi, which delivers the 29 rem/year, and by simple ratio the dose rate from the adult male body burden of 0.007 μCi ^{90}Sr is:

$$\frac{2\ \mu Ci}{29\ rem/year} = \frac{0.007\ \mu Ci}{0.102\ rem/year} = 102\ mrad/year$$

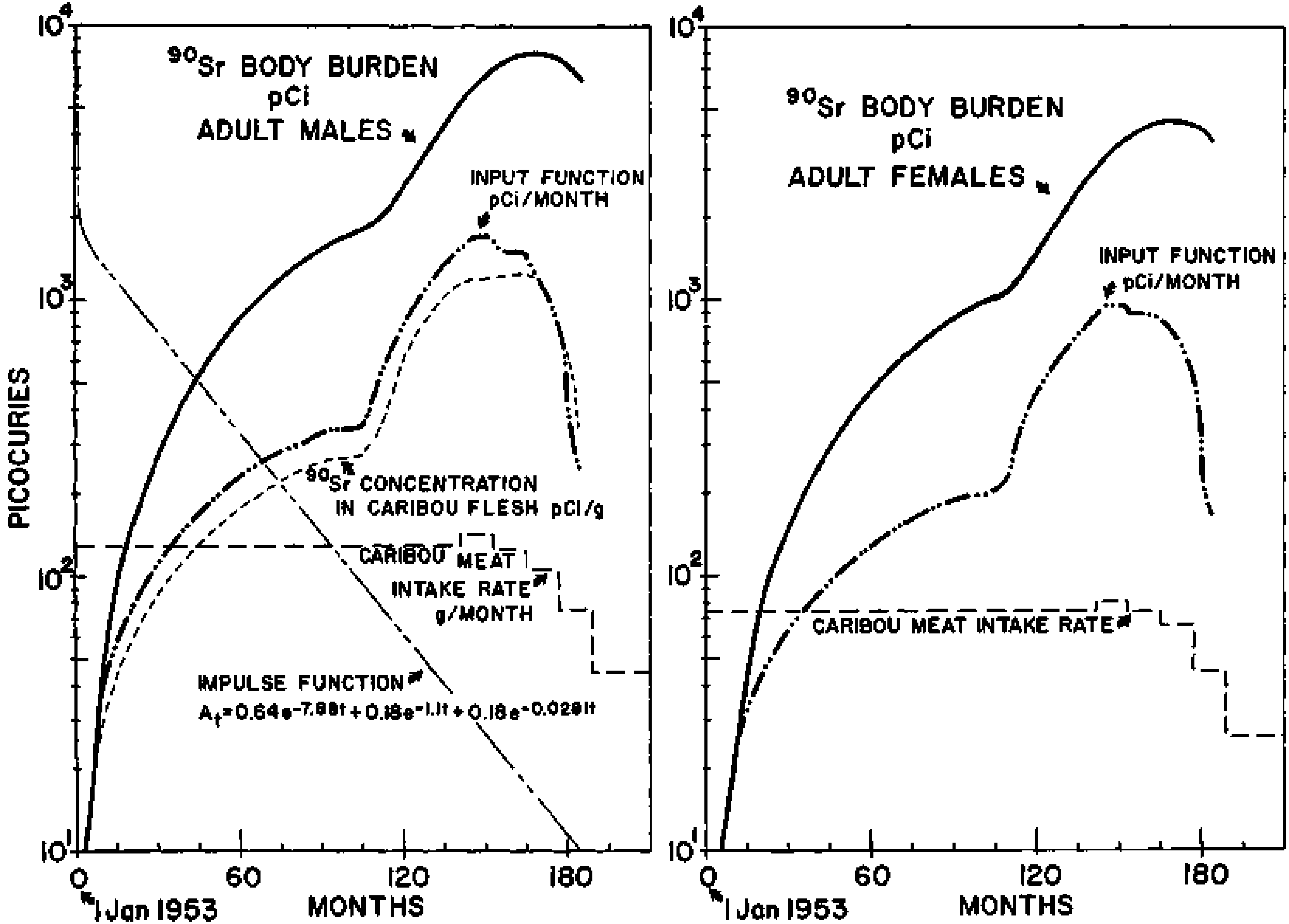
The dose rate can be more precisely calculated by the standard formula used previously to calculate dose rates to humans and caribou, with the average weight of 63 kg for adult Anaktuvuk Pass residents inserted, as follows:

Dose rate =

$$\frac{(0.007\ \mu Ci)(2.22 \times 10^{6}\ dis\text{-}min)(5.5\ MeV)(1.6 \times 10^{-6}\ erg)}{\mu Ci \qquad\qquad dis \qquad\qquad MeV} \cdot$$

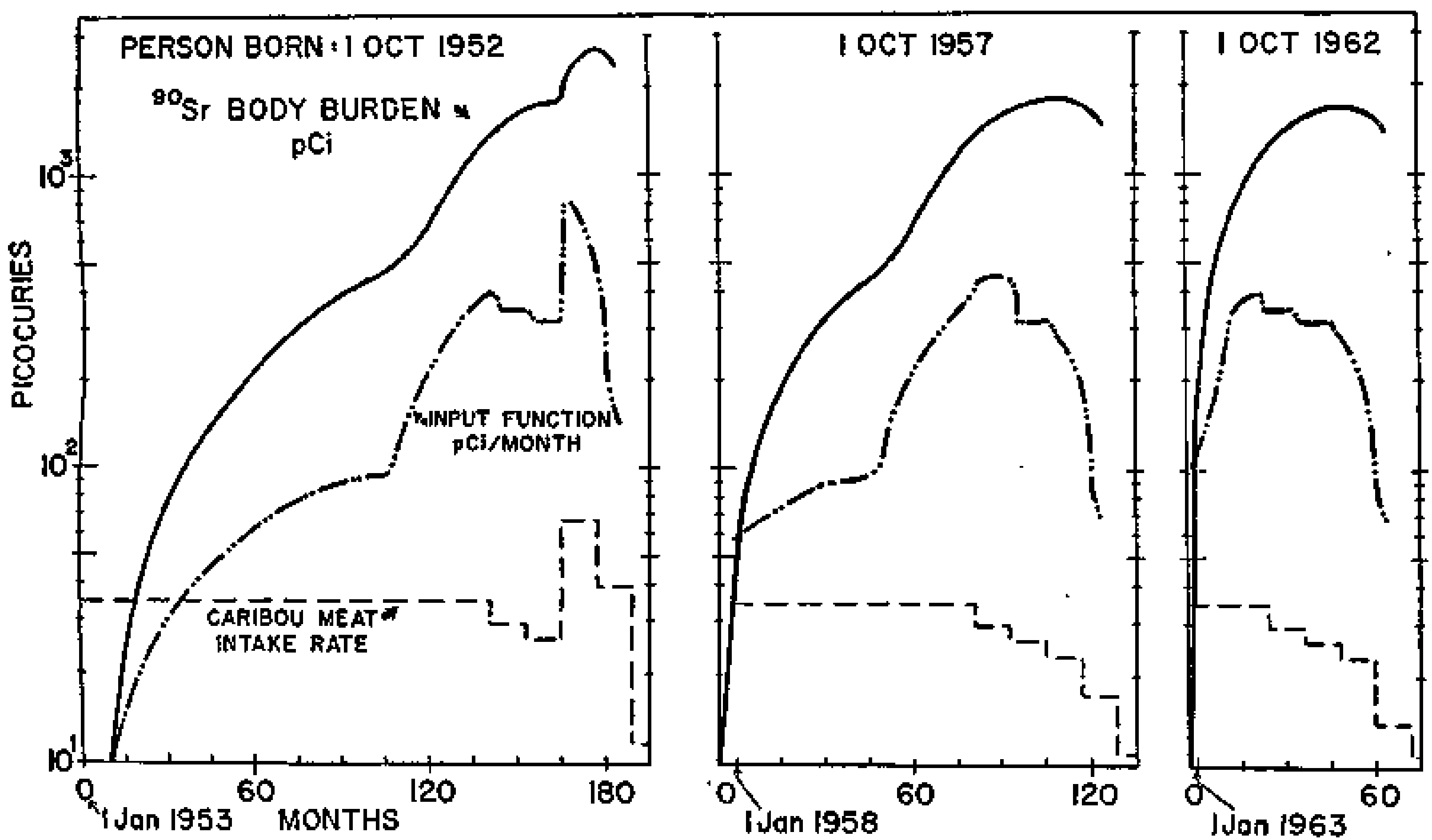
$$\cdot \frac{(g\text{-}rad)(5.256 \times 10^{5}\ min)\ bone}{100\ erg\ (63 \times 10^{3}\ g)\ year\ 0.1} = 0.114\ rad/yr = 114\ mrad/yr$$

Figure 22. Computed ^{90}Sr body burdens of adult males and females at Anaktuvuk Pass 1953-1969.



^{90}Sr BODY BURDEN
pCi
ADULT MALES
INPUT FUNCTION
pCi/MONTH
^{90}Sr CONCENTRATION
IN CARIBOU FLESH pCi/g
CARIBOU MEAT
INTAKE RATE
g/MONTH
IMPULSE FUNCTION
$A_t = 0.64e^{-7.98t} + 0.18e^{-1.1t} + 0.18e^{-0.0291t}$
PICOCURIES
10^4
10^3
10^2
10^1
0
60
120
180
MONTHS
1 Jan 1953
^{90}Sr BODY BURDEN
pCi
ADULT FEMALES
INPUT FUNCTION
pCi/MONTH
CARIBOU MEAT INTAKE RATE
10^4
10^3
10^2
10^1
0
60
120
180
MONTHS
1 Jan 1953

Figure 23. Computed ^{90}Sr body burdens of persons born 1952, 1957, and 1962 at Anaktuvuk Pass.



PERSON BORN: 1 OCT 1952
90Sr BODY BURDEN
pCi
INPUT FUNCTION
pCi/MONTH
CARIBOU MEAT
INTAKE RATE
PICOCURIES
MONTHS
1 Jan 1953
1 OCT 1957
1 Jan 1958
1 OCT 1962
1 Jan 1963

The plausibility of the computed ^{90}Sr body burdens was indicated by calculating ^{90}Sr body burdens from observed ^{90}Sr concentrations in 8 individual rib samples reported from Alaska (Chandler and Snavely, 1966). During 1964 and 1965, these contained a mean value of 2.72 pCi ^{90}Sr/g Ca, or 0.82 pCi/g wet weight. Assuming these rib samples contained marrow and that such bone and marrow comprised 0.14 of total body weight, a total body burden of about 7.2 nCi ^{90}Sr is indicated; the computed value for adult males at that time (June 1964-April 1965) was 5.6 nCi. The general agreement of the results also substantiated the other parameters, such as caribou meat ingestion rates by the Eskimos and the 750-day effective half-time of the long ^{90}Sr retention component.

Estimated annual dose rates to adult male residents of Anaktuvuk Pass from ^{90}Sr body burdens according to the model were as follows:

1959:	20 mrad/year	1964:	70 mrad/year
1960:	24 mrad/year	1965:	110 mrad/year
1961:	28 mrad/year	1966:	130 mrad/year
1962:	34 mrad/year	1967:	130 mrad/year
1963:	34 mrad/year	1968:	100 mrad/year

A limited number of bone samples from Alaskan natives have been analyzed for ^{90}Sr. Schulert (1962) reported an average of 0.5 pCi ^{90}Sr/g Ca in 35 samples of unspecified origin in Alaska during the period November 1959-December 1960. This compared to 0.3 pCi ^{90}Sr/g Ca in North American samples (Kulp and Schulert, 1962). However, on the basis of ^{90}Sr content in the diet (Schulert, 1961), it was predicted that during February 1961 Eskimos of the Shungnak region were forming bone at a concentration of 12 pCi ^{90}Sr/g Ca. This was more than four times the U. S. average and comparable to that observed in three of the highest human bone samples noted above. The previously cited individual rib samples obtained from natives of undetermined origins in Alaska during 1964 and 1965 that contained an average of 2.72 pCi ^{90}Sr/g Ca were similar to the conterminous U. S. yearly and quarterly averages for all bones collected during 1964 and 1965 through the U. S. Public Health Service Human Bone Network (Public Health Service, 1965). It is thus apparent that considerable variance is associated with most estimates of ^{90}Sr concentrations in bones of Alaskan natives, and that little information is available concerning their ethnic background so that an estimate of their caribou meat intake can be related to the reported human bone values. Using the factor of 1 pCi ^{90}Sr/g Ca as yielding a dose to bone marrow of 0.9 mrad/year (Federal Radiation Council, 1965) to 1.13 mrad/year (Spiers, 1966) and assuming linear proportionality, values of 440 to 560 nCi ^{90}Sr/g Ca would result in an individual attaining the Protective Action Guide (500 mrad) in one year. The maximum value reported in the Alaskan native bone samples discussed above was about 2-3% of the RPG value, or about 10 to 15 mrad/year. Swedish reindeer breeders were estimated to receive 25-82 mrad/year

(Gustafsson, 1969) on the basis that (1) the ^{90}Sr content of Lapps in 1950-1970 was 1.5 to 5 times that of people of the same part of the world with ordinary food habits and (2) the calculation was made according to the assumption of 1.13 mrad/year delivered to bone marrow at a ^{90}Sr content of 1 pCi/g Ca.

Gustafsson (op. cit.) estimated that the average annual whole body absorbed dose rate to reindeer breeding Lapps of northern Finland during the period 1951-1970 from internally deposited ^{137}Cs and from all natural and artificial sources ranged from 95 mrad/year in 1951 to 195 mrad/year in 1965. Sources other than ^{137}Cs contributed 95-100 mrad/year throughout the period and at the maximum (1965) ^{137}Cs contributed about 50% of the total. During 1970, the total exposure was estimated at 140 mrad/year, of which only 31% was due to internally deposited ^{137}Cs. Assuming that the Anaktuvuk Pass people received radiation exposures of about 100 mrad/year from natural sources at approximately the same rate as the Lapps and as the U. S. population (NAS-NRC, 1972), and that they received an additional 20 to 130 mrad/year from ^{90}Sr body burdens, their total radiation exposures will exceed by 120 to 230 mrad/year the values calculated and presented on page 127; this totals to about 190 mrad/year in 1962 and to 310-370 mrad/year during the 1964 to 1966 period of maxima. This can be compared to an estimated 140-250 mrad/year received from natural sources by about one-sixth of the French population and 850 mrad/year by 100,000 persons in Kerala and Madras, India (UNSCEAR, 1962) due to high natural environmental radioactivity.

Several of the Anaktuvuk Pass residents have undergone extensive treatment for tuberculosis, which included appreciable x-ray exposure. Several lengthy interviews with former patients at the USPHS hospitals in Alaska suggested that this source of radiation exposure was of greater magnitude than exposures received from their natural caribou meat diet and that it more closely approached being an acute exposure. Therefore, it is concluded that cytogenetic studies of the consequences of radioactive fallout upon these people should include such important considerations as the individual x-ray exposure history, which will undoubtedly exceed the 72 mrad/year average medical exposure for the U. S. population (NAS-NRC, op. cit.).

CHAPTER VIII

RELATIONSHIPS OF RADIONUCLIDES TO ECOLOGICAL CONCEPTS

Throughout the studies reported herein there was an attempt to apply meaningful concepts to complete a scheme from the store of facts about the ecosystems under investigation. Foremost of these ecological concepts was that of <u>niche</u>, used to describe the functional status of an animal in its community (Elton, 1927). This term has, over the years since its initial description, been refined to definitions of <u>spatial</u> niche (microhabitat) (Grinnell, 1917 and 1928), the <u>trophic</u> niche (energy relations) (Elton, <u>op</u>. <u>cit</u>.), and the <u>multidimensional</u> or <u>hypervolume</u> niche (Hutchinson, 1957 and 1965). An example of spatial niche might be the various lichen species in Table 11, some of which are dominant in the Arctic Coastal Plain province and others are dominant in the Arctic Foothills and Brooks Range provinces. Trophic niche is classically represented by the lichen (producer)-caribou (consumer)-wolf (predator) food chain. The hypervolume concept of the ecological niche may be illustrated by the several carnivores of the Anaktuvuk Pass region that shared the caribou resource during certain years and then withdrew to their divergent niches when the caribou migrated northward to summer range.

Radiation ecology aspects of niche occupancy were often extremely important. The comparative studies of caribou and moose collected from the same general area (spatial niche) compared two herbivores (trophic niche) occupying non-overlapping niches, as one was a grazer and the other a browser. The caribou, by utilizing different food plants than the moose, concentrated 3 to 50 times more ^{137}Cs than neighboring moose and underwent appreciable seasonal changes whereas the concentrations in moose were lower and seasonally more stable. Similarly, fish samples taken from the Arctic Ocean, an estuarian lagoon near Cape Thompson, the Noatak and Kukpuk Rivers, and inland lakes in northwestern Alaska showed a ranking of ^{137}Cs concentrations. Highest values were in lake fish, which were ten times greater than those from rivers and the lagoon, and ^{137}Cs was undetectable in marine species (Watson and Rickard, 1963). These findings were somewhat parallel to those from Finnish lakes, in which ^{137}Cs concentrations in freshwater fish of the same species varied inversely with the potassium content of the lake water (Kolehmainen, Häsänen, and Miettinen, 1966). The transiting of several zones of varying radionuclide availability by anadromous fish, such as arctic char (Salvelinus alpina), is its journey from ocean to estuary to river to lake environments is akin to that of the migratory journey of the caribou across the physiogeographic provinces, in which were often found significant differences in ^{137}Cs concentrations of lichens.

Physiognomy (or growth-form) of lichens provided examples of niche adaptations with radionuclide concentration overtones. Cetraria delisei, the snowpatch lichen, colonized protected habitats and had access to appreciable amounts of melting snow in springtime; and perhaps obtained their radionuclides several months later than did *Cornicularia divergens*, which colonized ridgetops. The finer structure of *Cornicularia* as compared to *Thamnolia vermicularis* provided means of entrapping airborne particles that were characteristic of its exposed spatial niche. Although it did not contain statistically greater ^{137}Cs concentrations than other species, *Cetraria richardsonii* often was one of the more radioactive species, perhaps because of its specializations of growing as the overstory to other lichen species and its physiological adaptation of unrolling to expose more surface area during humid periods and rolling up into a ball when dry. Differences in growth form among lichens, as among the vascular plants of a community, are incomplete expressions of niche-differences in resource use, manner of competition, and seasonal timing (Whittaker and Woodwell, 1972). The distinctiveness of the several lichen species studied represent additions to the lichen communities of growth-forms over and above the range of growth-forms already present; and thereby provide adaptability to minor niche changes in a rigorous environment. Structural differentiation then, like species diversity, may increase through evolutionary time and tend toward stability.

Tables 1-5 express ^{137}Cs concentrations and other fallout radionuclides in a variety of biota that occupied to varying degrees the terrestrial, freshwater, and marine niches of northwestern Alaska. All three major classes of niches were represented, foremost of which was the trophic niche concept that was of most interest from radiological health standpoints. As with the fish studies previously cited, lowest amounts occurred in marine species because of (1) the discrimination against the relatively meager number of ^{137}Cs atoms relative to stable cesium and potassium, the chemical analog of cesium; and (2) the appreciable dilution that follows fallout deposition upon the ocean surface. The antithesis of these phenomena is seen in the retention and concentration of ^{137}Cs by lichens, which were also relatively low in potassium; therefore, the caribou were provided not only with food supply rich in ^{137}Cs but one with low discriminatory function. This led to enhanced ^{137}Cs uptake and a longer effective half-time, which fostered its efficient transfer up the food web.

Further evidence of the importance of niche was noted in the relative ^{137}Cs and ^{90}Sr concentrations in samples of the carnivores of the Anaktuvuk Pass region (Figs. 16 and 17). Wolves, the top carnivore of the region, tended to contain about twice the concentrations of both radionuclides as those values measured in foxes and wolverines. Both of those species primarily function as scavengers upon caribou kills made by the wolves and Eskimos, who take many of the internal organs and choice pieces (Kuyt, op. cit.; Mech, 1971). During the period October 1968-April 1969, ^{137}Cs concentrations in all three of these carnivores were unusually stable for no apparent reason.

The variable food habits of several of the coastal and river village Eskimo groups and the Fort Yukon and Arctic Village Indians can be considered as more examples of the multidimensional or hypervolume niche in view of their shifting from one food source to another. These groups often responded to food abundance regulated by migration patterns of caribou or local population increases of moose, fish, and abundance of wild berries. All of these factors had variable effects upon radionuclide concentrations in ecological equivalents, or similar groups occupying equivalent niches in different geographical locations (Odum, op. cit.); and often were, in turn, the result of environmental influences. Snowfall patterns were observed to govern to some degree where the caribou would winter and whether or not native groups would utilize food stores, such as at the village of Ambler during the 1968 season. Extreme cold or unusual periods of warm weather denied the Arctic Village people food sources on the one hand and delayed caribou migration through Anaktuvuk Pass until the storage of caribou carcasses was too arduous, due to lack of snow cover. Ambler residents discontinued use of fall-killed caribou when excessive snow cover hampered their recovery and a plentiful supply of moose was at hand. These responses to environmental parameters exemplified a major concept of the word "ecology" - the study of animals in relation to their environment, and provided insight into the field of behavioral ecology that has recently become more popular.

The concentration of radionuclides within the various components of the northern Alaskan food webs provided clear evidence that we (and all animals) reflect what we eat, and what we eat is often rigorously defined by our environment. The arctic and subarctic cultures studied herein exemplified this to varying degrees by virtue of their geographic and ethnic placement; however, the native groups encountered during the study period showed increasing evidence of culture change. It has here been principally considered in its context as an ecological factor that has had important influences upon the life-style of the Anaktuvuk Pass Eskimos and therefore, upon their radionuclide concentration patterns. As an integral part of the Brooks Range ecosystems within which they lived, hunted, and strived for a better life for their children, the nunamiut represent a unique cultural entity that underwent drastic change in the short space of twenty years.

CHAPTER IX

SUMMARY AND CONCLUSIONS

These studies were conducted during the period 1959 through 1970 to provide information about cycling routes, rates of transport, and resultant concentrations of the fallout radionuclides ^{90}Sr and ^{137}Cs in northern Alaskan biota. Major emphasis was placed on the lichen-caribou-Eskimo food chain at Anaktuvuk Pass because, at the beginning of the studies, it represented a region little complicated by outside influences and because of the great dependence of those people upon subsistence hunting and trapping. Results of studies at Anaktuvuk Pass were compared with analogous investigations of other ecosystems throughout northern Alaska. Cultural aspects of the nunamiut Eskimos of Anaktuvuk Pass were accentuated because of the pronounced effect their food-gathering practices, particularly caribou utilization, had upon seasonal whole-body burdens of ^{137}Cs. Increasing culture change of the people was documented and related to the radionuclide studies because of the close relationship of those two aspects and because the various cultural groups studied were of prime consideration in the overall investigation.

Data are reported for ^{90}Sr and ^{137}Cs with reference to (1) estimated deposition upon and retention within the major producer (lichen and sedge) communities of northern Alaska; (2) temporal and spatial distribution in 9 lichen communities at 20 sampling sites situated in 5 major physiogeographic provinces of the 389,000 km^2 study area; (3) the transfer and concentration within representative samples of primary consumers (caribou, Dall sheep, and moose) and secondary consumers (wolves, wolverines, foxes and man); (4) controlled experiments using strontium and cesium radioisotopes applied to natural lichen communities to investigate effective half-times and cycling phenomena in that important fallout radionuclide reservoir; (5) direct and indirect estimates of ^{137}Cs effective half-times in Anaktuvuk Pass Eskimos by dietary substitution of beef for caribou and by relating changes in whole-body burdens to radionuclide concentration in caribou meat supplies during specific time periods; (6) estimation of lichen forage ingestion rates by caribou, caribou meat ingestion rates by Eskimos, and ^{90}Sr body burdens of Anaktuvuk Pass Eskimos utilizing suitable mathematical models and estimates for the model parameters; (7) estimates of radiation exposures received by the Anaktuvuk Pass people from worldwide fallout and natural radionuclides and their comparison with other world populations; and (8) relationships between radionuclide concentrations and ecological-cultural phenomena of northern Alaska.

Two major periods of ^{90}Sr and ^{137}Cs deposition upon northern Alaskan ecosystems occurred; the first and most sustained during 1953-1959 and the second during 1961-1964, reflecting the atmospheric nuclear weapons test regimes of Britain, Russia, and the United States. Periods of lesser deposition occurred during 1967-1970 as a result of nuclear weapons tests by France and China.

Strontium-90 in natural <u>Cladonia</u>-<u>Cetraria</u> carpets tended to move much slower than did ^{137}Cs, apparently due to ion exchange complexes, and once into the A_0 horizon below the lichen thalli it was tightly bound and unavailable. Droplets of strontium-90 applied to individual lichen podetia yielded effective half-times of 1.0-1.6 years. Cesium-137 apparently cycled fairly rapidly, with little loss of the radionuclide from the A_0 horizon (humus layers) to lower strata. Cesium-137 droplets applied to single podetia and sampled annually for four years yielded an average effective half-time of 6.7 years; however, ^{134}Cs sprinkled on lichens and wetted by a heavy rain immediately following application showed no decrease after four years, and it was concluded that an effective half-time of ^{137}Cs in lichens of more than 10 years was reasonable.

A spring pulse of ^{137}Cs in lichens was usually observed and was credited with causing increased ^{137}Cs concentrations in caribou harvested by Anaktuvuk Pass Eskimos during each spring migration of caribou from their winter ranges on the Kobuk-Selawik Lowland some 150 km south of Anaktuvuk Pass. Lichen samples were collected at 20 locations across the study area during July-August 1967 and again during the same period of 1972. Analysis of variance of samples of three ubiquitous species (<u>Cetraria</u> <u>cucullata</u>, <u>C</u>. <u>richardsonii</u>, and <u>Dactylina</u> <u>arctica</u>) indicated no significant difference between those species, the three physiogeographic provinces from which they were collected, or sampling years. However, Student's *t* test of combined means of all 9 lichen species studied during the two years consistently yielded highly significant ($P < 0.01$) differences between years in all three provinces. Similar tests between provinces within each sampling year indicated that there were highly significant differences ($P < 0.001$) between ^{137}Cs concentrations in provinces. Extensive sampling of lichens at Anaktuvuk Pass showed that ^{137}Cs in Cladonia-Cetraria carpets gradually increased until mid-1965, remained at a high level until early 1966, and have since slowly decreased.

Cesium-137 concentrations in caribou flesh samples from Anaktuvuk Pass showed an annual cycle with low values consistently near 10-20 nCi/kg dry weight each autumn and high values consistently in the 100-200 nCi/kg dry weight range. A plateau of median values usually occurred about midway between minima and maxima during January-April of each year. At that time the caribou had been on lichen forage for several months and ^{137}Cs concentrations in their flesh were at more than 90% equilibrium.

This provided an opportunity to calculate the first estimates of lichen forage ingestion rates of free-roaming caribou with ^{137}Cs, utilizing a two-compartment mathematical model and eight parameters, each of which was defined by a normal frequency distribution described by means and variances. A computer procedure was used to generate 1000 numbers at random from the designated normal distributions for data during 1965 and 1968, to examine those years in detail. Results of the frequency distributions for those two years, as well as the deterministic data for all years of the period 1964-1970, suggested that the true value for the average daily ingestion rate of lichen forage by adult caribou was in the range of 4.5-5.0 kg dry weight. Applying this to data on lichen biomass in Cladonia-Cetraria carpets at Anaktuvuk Pass, it was estimated that the average daily winter grazing requirement in Arctic Herd caribou was 10 m^2 per animal for a vigorous lichen stand. This estimate has important implications because of the finite carrying capacity for caribou/reindeer on northern ranges, and represents the first quantitative measurement of lichen consumption by natural caribou herds.

At any one time the ^{137}Cs concentrations in caribou flesh samples from the northern, central, and southern Alaskan herds were generally correlated with amounts of annual precipitation in those areas; least amounts of ^{137}Cs occurred in northern animals and highest amounts in southern animals. Unusually high ^{137}Cs concentrations in caribou flesh at Anaktuvuk Pass were observed during the spring of 1964 and were believed due to weather conditions serving as a controlling factor in the deposition of fallout. Comparison of reported values from other samples in the interior and southern parts of Alaska suggested that the sudden increase in northern Alaskan caribou occurred some six months after a similar increase in the central and southern areas. This delay may have been due to short-term deposition during the winter of 1963, when snow cover shielded the lichens in northern Alaska from the fallout until late spring whereas the central and southern caribou herds had prompt access to the new contamination.

Comparison of ^{137}Cs in flesh of caribou, moose and Dall sheep taken from the same areas and at the same time showed that sheep and moose values were fairly constant throughout the year but that the sheep contained four times the concentrations in moose, and about one-fourth to one-tenth the concentrations in caribou flesh.

Strontium-90 concentrations in caribou flesh were highly variable and in a range of about 0.01-0.001 those in caribou bone. Levels in northern caribou flesh increased from zero (presumably) prior to the first thermonuclear explosion in November 1952 to 0.025 nCi/kg dry weight during 1961, then rapidly increased during 1962-1963 to 0.10 nCi/kg, stabilized at about 0.12 nCi/kg during 1964-1966, and then sharply decreased through the sampling period ending April 1968. Strontium-90 in bone samples showed a much slower turnover than in caribou flesh and reached maximum values about 18 months later. Concentrations of ^{90}Sr in bone generally increased from about 10 nCi/kg dry weight in 1960 to about 20 nCi/kg in 1961, sharply increased to about 70 nCi/kg in 1965, and then decreased very slightly until the end of the sampling period ending October 1969.

The animals sampled during the 1966-1969 period of maxima were near 0.99 equilibrium, assuming an effective half-time of 0.5 years for ^{90}Sr in bone.

Samples of flesh and bone from 213 wolves, 166 foxes, 73 wolverines, and 7 lynx were obtained at Anaktuvuk Pass during the period 1964-1969 and analyzed for radionuclides. Highly variable seasonal patterns for ^{137}Cs in flesh and ^{90}Sr in bone were observed. A slight but continuously downward trend occurred in ^{137}Cs values and a much slower decline was noted in ^{90}Sr values. Wolves tended to contain higher concentrations of both ^{90}Sr and ^{137}Cs than did foxes and wolverines, which contained nearly equal values. The ^{90}Sr concentrations in wolf bone attained maxima about 18 months before and at a level of about one-half the maximum caribou bone values, illustrating the blocking of ^{90}Sr transmission up the food chain and suggesting that the main source of ^{90}Sr in the wolves was some food source other than caribou flesh. Concentration factors for ^{137}Cs at the times near equilibrium were 2.5-2.7 for each step of the lichen to caribou to wolf food chain, and 1.6-2.2 for the caribou to man step prior to appreciative acculturation of the Eskimos. Concentration factors for ^{90}Sr were calculated to be 7.6 for the caribou bone/lichen step at or near equilibrium and 0.4 for the wolf bone/caribou flesh step at 0.5 equilibrium.

Cesium-137 body burdens of Anaktuvuk Pass Eskimos were closely related to the seasonal pattern of ^{137}Cs in caribou flesh, with a period of minimum values about 1 February as a result of consuming the mid-September caribou kill and maximum values in July-August from consuming the May kill. The maxima in summer represented 0.59-0.75 equilibrium. Controlled studies of effective half-times in Eskimo subjects by dietary manipulation and successive whole-body counts indicated values of about 70 days in adults (more than 21 years old) and minors (14-20 years old) and about 45 days in children (less than 14 years). Caribou meat consumption rates by the various age categories during the winter period of minimum values and the summer period of maximum values when the people were approaching equilibrium with stored caribou meat were calculated from measured ^{137}Cs body burdens of the people and ^{137}Cs concentrations in caribou flesh to be about 2 kg wet weight per day for men, 1 kg/day for women, 1.2 kg/day for minors, and 0.45 kg/day for children during 1964-1965. It was assumed that these values were valid during the pre-measurement years; these consumption rates declined to one-half or less by 1970, presumably because of increased consumption of processed food made possible by food stamps and welfare payments. The caribou meat intake rates were used to model ^{90}Sr build-up by Eskimos that chronically utilized caribou meat containing typical ^{90}Sr concentrations. Maximum values occurred during late 1966-early 1967, and adult males reached body burdens of about 8 nCi. Adult females contained about 4.5 nCi at the maximum and were about equal to minors. These values closely agreed with ^{90}Sr body burdens calculated from a very limited number of biopsy samples reported in the literature and provide the first realistic estimates of ^{90}Sr body burdens in the northern Alaskan native population.

Total radiation dose rates of Anaktuvuk Pass adults during the period 1962-1970 were estimated at 180 to 390 mrad/year, including 100 mrad/year from natural sources and fallout radionuclides other than ^{137}Cs. Maximum exposures from measured ^{137}Cs body burdens were about 130-140 mrad/year during the 1964-1966 period of maxima. A study of ^{137}Cs body burdens in native residents of three villages of contrasting food-gathering cultures showed that ecological factors were principally responsible for unusual dietary patterns that resulted in decreased amounts of ^{137}Cs in the village food supplies and reduced the radiation exposure of the people from that source by as much as 35% from one year to the next.

Results of the radionuclide investigations were applied to the ecological concept of niche, especially that of trophic niche. This concept was classically represented by the lichen (producer)-caribou (consumer)-wolf (carnivore). Comparative studies of caribou and moose (two herbivores) collected from the same general area (spatial niche) revealed that caribou contained 3-50 times more ^{137}Cs than moose and that the ^{137}Cs concentrations in the caribou flesh underwent appreciable seasonal changes whereas the concentrations in moose were lower and seasonally more stable. Similarly, the importance of niche was shown in fish samples taken from the Arctic Ocean, an estuarian lagoon, two large rivers, and inland lakes in northwestern Alaska; highest ^{137}Cs content was in lake fish, which were ten times greater than those from rivers and the lagoon, and ^{137}Cs was undetectable in marine species. This ranking generally follows a gradient of increasing natural potassium content of the waters. Similarly, ^{137}Cs concentrations in a variety of biota sampled from terrestrial, freshwater, and marine niches of the study area showed lowest amounts in marine species because of discrimination against ^{137}Cs by stable cesium and potassium and because of dilution. The opposite occurred in the terrestrial situation, where lichens provided the caribou with a food source rich in ^{137}Cs and low in competitive or discriminatory potassium; thus, the caribou showed enhanced ^{137}Cs uptake and a longer effective half-time, which fostered its efficient transfer up the food web.

Detailed cultural observations were made during the study, particularly at Anaktuvuk Pass. These provided insight into the important relationships of subsistence hunting patterns and culture patterns of the people to their concentration of fallout radionuclides. Coastal Eskimos that inhabited villages along the Bering Strait and the shores of the Arctic Ocean had greater flexibility in food-gathering than most other groups and contained lowest amounts of ^{137}Cs, the most important fallout radionuclide in the people. River village Eskimos and Athapascan

Indians that lived along major river systems in the Alaskan interior contained median ^{137}Cs body burdens, due to their utilization of moose and fish in addition to caribou. Maximum ^{137}Cs body burdens consistently occurred in the inland Eskimos of Anaktuvuk Pass because of their reliance upon caribou for their major subsistence. A decline of ^{137}Cs body burdens occurred in the latter half of the 1962-1970 study period due to the combination of declining radionuclide concentrations in caribou tissues and culture changes that decreased caribou meat consumption. These changes included the more obvious aspects such as food stamps, welfare payments, free fuel, and "improved" housing; in addition, elementary schooling, high school attendance in distant cities, and introduction of the snowmobile had pronounced influences beyond their apparent effects upon the peoples' life-style.

Comparison of these studies with those of other circumpolar regions during the 1961-1970 period showed that Anaktuvuk Pass human whole body ^{137}Cs burdens were generally comparable to those reported in northern Scandinavia, and one-half to one-third of those reported in the Murmansk region of Russia.

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