ANNUAL CONSUMPTION OF CESIUM-137 AND COBALT-60 LABELED PINE SEEDS BY SMALL MAMMALS IN AN OAK-HICKORY FOREST

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ABSTRACT

ANNUAL CONSUMPTION OF CESIUM-137 AND COBALT-60 LABELED PINE SEEDS BY SMALL MAMMALS IN AN OAK-HICKORY FOREST

BY

John Beatty Mathies

Annual and seasonal consumption of eastern white pine seeds was determined radioisotopically in both laboratory and free-ranging populations of small forest mammals within a 2-ha oak-hickory forest in eastern Tennessee. White-footed mice were chronically-fed ^{137}Cs and ^{60}Co-labeled pine seeds in the laboratory, and the resultant uptake, equilibrium, and excretion patterns in mice were used to infer food consumption rates. Seed-ingestion rates, of from 2 to 100 seeds per day, were highly correlated with equilibrium levels of ^{137}Cs. Lowering the ambient temperature resulted in lower equilibria, through a range of 21.1 C to 4.4 C; equilibria in males was lower than in female mice.

Free-ranging mice rapidly acquired radioactive body burdens of both isotopes. The ratio of the body burdens between these two radioisotopes was used to determine the day of excretion for animals trapped in the field. A laboratory-to-field comparison yielded similar excretion rates of ^{137}Cs, indicating that metabolic stimuli such as temperature or feeding rate did not overtly influence the rate of excretion. Snap-trapped mice from a second chronically-fed field population indicated a similar tissue distribution of ^{137}Cs in

mice from both the laboratory and field. Based upon these similarities, a direct correlation was made between the laboratory and field to predict equilibrium levels for mice in the field.

Field equilibria of ^{137}Cs were then correlated to the laboratory data to estimate seed consumption rates. Estimates for consumption of this specific food source, by individual white-footed mice, ranged from a maximum of 2.3 g/day in summer, to a minimum of 0.4 g/day in winter. The drop in consumption coincided with availability of the mast crop in autumn. Yearly average consumption of seeds was 1.6 g/day per mouse, or 7.0 kcal/day. Caloric input of this specific food was approximately 50% of the daily food requirement for this species.

Survival of the short-tailed shrew was excellent in the field plot, compared to previous studies. On one plot, only 16 shrews died out of a total of 242 captured, with 4 shrews captured at least 12 times; thus allowing reliable estimates of pine seed consumption by this "insectivorous" species. Shrews were twice as numerous as mice and acquired body burdens of radioisotopes equivalent to or greater than those observed in mice. Insects, mice, and seeds were considered as potential food sources for this shrew; however, seed consumption proved to be the source of radioactivity. Individual shrews consumed a maximum of this specific food of 4.1 g/day in autumn, and a minimum of 2.1 g/day in summer. Yearly average consumption of seeds was 3.0 g/day per shrew, or 13.2 kcal/day.

Of the total pine seed removed from feeders on the field plot, the white-footed mouse population consumed 17% and the short-tailed

shrew population accounted for 64%, or approximately four times the consumptive importance of the granivorous mouse. These two species accounted for 81% of all seeds removed from feeders. It appeared that sufficient seeds would escape detection by these two species, and that the disappearance of white pine in mixed forests, such as these, was not completely due to their consumption of seeds.

From a radioecological and health physics aspect, the results from chronic feeding of radioisotopes in a food base indicated:

1. ^{137}Cs was excreted at a faster rate after injection or single-feeding studies than after chronic feeding.
2. Excretion of ^{137}Cs after chronic feeding could not be used to predict chronic uptake adequately in the same animal.
3. Radiation-dose estimates would be higher if body burdens after chronic feeding were used rather than body burdens after injection.

Application of this equilibrium technique would be of value in energy flow studies to characterize the total importance of a consumer within an ecosystem.

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John Beatty Mathies

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I. INTRODUCTION

Estimating rates of food consumption is a major problem in studies of energy or nutrient flow through free-ranging animals in natural environments. Food-consumption rates derived from laboratory studies often form the basis for extrapolation to field situations. While such extrapolations have proven effective with microorganisms and invertebrates, those involving vertebrates are confounded by behavioral and metabolic changes. Consequent effects of such changes on food ingestion are difficult to identify or measure accurately.

Both direct and indirect field techniques have been used in range and wildlife research to avoid errors of laboratory-to-field extrapolations (USDA, 1970). Examples of direct observations are the feeding-minute, bite-count, and grazed-plant methods employed with ruminants. Chemical methods, such as dyes and chromic oxide, are commonly used indirect techniques. These techniques are primarily concerned with feeding and assimilation estimates for ruminants with high rates of ingestion.

While stable chemicals have had widespread application in food consumption and assimilation trials, the use of radionuclides has been limited in forest and range research. Radioisotopes have been used successfully to determine food consumption rates in insects and to follow movements of nocturnal and fossorial species which are difficult to observe directly. Evidence from human body burdens of ^{137}Cs suggests

a dependence between the acquired body burden and the fallout levels of radionuclides in human foods (ICRP, 1960). This led to a thesis hypothesis that the equilibrium body burden acquired from chronic ingestion of a "tagged" food base would allow an accurate estimation of food-ingestion rates in secretive species such as small mammals under natural field conditions.

Granivorous mammals have long been recognized as a biotic factor limiting the success of both natural and artificial regeneration practices on forest lands. Whereas laboratory studies have estimated consumption rates of rodents, field quantification has rarely been attempted due to the lack of a reliable technique. This study attempted to identify consumers of eastern white pine (Pinus strobus) seeds and to quantify their importance as granivores in an oak-hickory forest ecosystem. Seed consumers potentially have an important role in affecting stand composition and distribution by their seed consumption preferences. The economic value of white pine and the successional disappearance of pine in climax oak-hickory forests prompted the use of white pine in this study.

The objectives of this study were twofold:

1. to develop a radioisotopic technique for predicting consumption rates of white pine seeds by the white-footed mouse (Peromyscus leucopus) in the laboratory, and,
2. to apply the radioisotopic technique in determining consumption rates of white pine seed by small forest mammals in an oak-hickory forest of eastern Tennessee.

II. LITERATURE REVIEW

Ecological applications of radioisotopes have been reported in studies of: 1) dispersal of organisms, 2) determination of food chains and trophic levels, 3) biological concentration factors of elements within organisms, 4) ingestion-excretion rates and equilibrium levels of chemical substances, and 5) tagging of food substances and identification of consumers.

Early applications of radioisotopes were primarily dispersal studies of insects (Jenkins and Hassett, 1950; Arnason et al., 1950). Mammalian studies were also conducted with wild rodents which were either externally tagged with radioactive pellets and their movements traced with Geiger-Muller counters (Griffin, 1952; Godfrey, 1954), or internally tagged and their excreta located on "dropping boards" (Miller, 1957). Studies of animal dispersal using radioactive tags have continued (Kaye, 1961; Tester, 1963; Jenkins, 1963; Lamb et al., 1971).

Radionuclides have been successfully applied in determining food chains and trophic levels, primarily in insects. Individual plants were injected with an isotope, and sequential examinations were then made to determine which insects acquired radioactivity (Pendleton and Grundmann, 1954; Wiegert and Lindeborg, 1964; Paris and Sikora, 1965). Radioactive insects were thus part of a food chain based upon the injected plant species. Time delays between plant injection

and maximum radioactivity in various insect species were used to indicate trophic relationships (Marples, 1966; Wiegert et al., 1967; Shure, 1970).

Animals accumulate body pools of elements, including radioisotopes, and the ratio of the element in the animal to the element in the animals' food is termed the concentration factor. This factor varies considerably depending upon the trophic level, organism, and specific activity of the radioisotope (Kaye and Nelson, 1968; Reichle et al., 1970). Concentration factors decrease in terrestrial vertebrate food chains for many radionuclides, but more emphasis has been placed upon those radioisotopes which concentrate as they move through the trophic levels (Odum, 1959). The concentration factor appears to be a consistent parameter for a specific step in a food chain (Reed and Nelson, 1969). Numerous studies indicate that under chronic ingestion regimes, as in a fallout-contaminated zone, certain isotopes, such as ^{137}Cs, will build up in the body pool to an equilibrium level corresponding to the daily ingestion rate multiplied by this concentration factor (Richmond et al., 1962; Furchner et al., 1965; Pendleton et al., 1965). The concentration factor for ^{137}Cs between two trophic levels has been reported to range from 0.3 to 15.9, with an average of 3 appearing commonly (Pendleton et al., 1965; Jenkins et al., 1969).

The basic formula for predicting equilibrium body burdens of radioisotopes has been used successfully in several studies (Davis and Foster, 1958; ICRP, 1960; Kaye and Dunaway, 1962):

$$Q_e = ra/\lambda,$$

where Q_e = equilibrium body burden, r = ingestion rate, a = assimila-

tion, and λ = the elimination rate coefficient.

Generally, the elimination rate coefficient (λ) is estimated from the whole-body retention curve after a single feeding of radioactive food. Retention curves for nonbone-seeking radioisotopes are characterized as exponentials with one or more components in the form:

$$R_t = \sum_{i=1}^{n} (a_i e^{-\lambda_i t}),$$

where R_t = retention at time t, a_i = quantity of total isotope participating in the i^{th} component, λ_i = elimination rate coefficient of the i^{th} component, t = time after feeding or injection, and n = number of components (Richmond, 1958). Further refinements of this retention technique have allowed estimates of food consumption in insects (Crossley, 1963; Reichle and Crossley, 1965; Reichle, 1967, 1968, and 1969; Van Hook and Crossley, 1969; Crossley and Reichle, 1969; Crossley and Van Hook, 1970; Van Hook et al., 1970), and fish (Kolehmainen and Nelson, 1969).

There are at least three assumptions made in using this method. One assumption is that a radioisotope behaves identically during uptake as it does during excretion. Another assumption is that a radioisotope mixes thoroughly with stable isotopes of the element and is not discriminated for or against by these same stable isotopes (Robertson, 1957). A third is that radionuclide assimilation and incorporation after single feeding or injection simulates assimilation and incorporation after chronic feeding.

Many investigators have examined excretion patterns in mammals after injection of various isotopes (Reichle et al., 1970; Stara

et al., 1971). The major emphasis of such studies was to determine radiation dosages delivered to mammals by long-term retention of radioisotopes. Reduced retention of injected ^{137}Cs has been significantly correlated with lowered temperature (Furchner and Richmond, 1963; Mahlum and Sikov, 1968), lowered body weight (Eberhardt, 1967; Reichle et al., 1970; Stara et al., 1971), younger ages (Matsusaka et al., 1967; Lengemann, 1970), higher potassium levels in the diet (Mraz and Patrick, 1957; Mraz, 1959), smaller species (Richmond, 1958), and increased X-irradiation (Kereiakes et al., 1961).

Several experiments have utilized an oral method for delivery of the isotope into the mammal. The purpose of these studies was to determine whether excretion data derived from investigations with injected animals could be extrapolated accurately to chronic-feeding studies. The animals were provided with contaminated drinking water rather than actual food. The inherent assumption was that drinking simulated the same process as food consumption, with absorption and assimilation occurring in a similar manner and location throughout the gastrointestinal tract. These investigations indicated general agreement between the two methods (Cook et al., 1956; Ballou and Thompson, 1958; Bernard et al., 1963). Equilibrium level was influenced by age and temperature in laboratory animals (Richmond et al., 1962; Furchner et al., 1965).

A few studies attempted administration of the isotope directly in a food base (Nold et al., 1962; French et al., 1965; Comar et al., 1967). The general procedure has been to reduce dry food pellets to

a gruel by addition of the isotope in liquid form, reforming the pellets in various ways, and drying (Finkel et al., 1960; Van Hook and Crossley, 1969; Crossley and Van Hook, 1970). Others have soaked vegetable foods with or in an isotopic solution and fed the food after drying (Hubbell et al., 1965; Kitchings et al., 1969). Seeds have been used as a food base after spraying or painting the isotope on the seed coat (Tagami, 1962; French et al., 1965; Orr, 1967; Quink et al., 1970). Kitchings et al. (1969) found that the mode of ingestion and food type influenced retention of ^{134}Cs, with chronic ingestion resulting in longer biological half-lives than single feeding. They also observed differences in excretion of ^{134}Cs between laboratory-born and wild-caught cotton rats (Sigmodon hispidus), presumably due to differences in musculature. French (1967) concluded that the food base influenced the quantity of ingested radioactivity under fallout conditions, with herbivores consuming more radioactivity than granivores. Summaries of excretion in various species, combining all modes of entry, suggested that ruminants excrete ^{137}Cs faster than other mammals (Reichle et al., 1970; Stara et al., 1971). A recent study of ^{60}Co in rats indicated a fourfold increased absorption when rats were given $^{60}CoCl_2$ by gastric intubation instead of by their drinking water (Smith et al., 1971).

Several investigators suggested a dependence between ingestion rates of radioactivity and equilibrium body burden (Langham and Anderson, 1959; Scott, 1964; Pendleton et al., 1965; Whicker et al., 1967). Such a dependence would be of interest in food consumption

studies, since the readily-measured equilibrium could be used to predict the ingestion rates of foods. One such application would be a determination of which mammals were consuming seeds used in forest regeneration efforts.

While success of regeneration efforts is dependent upon favorable abiotic or environmental conditions, it is also often dependent upon the absence of various biotic stresses. Willis (1914) concluded that rodents "...must be controlled or seeding must be given up." Later studies have also emphasized the same problems (Wahlenberg, 1925; Smith and Aldous, 1947; Schroeder, 1950; Shaw, 1954; Hagar, 1960; Seidel and Rogers, 1965; Schubert et al., 1970). Tree seedlings have been a primary means of reforestation, but high costs have prompted repeated attempts at direct seeding and research into development of mechanical and chemical procedures to enhance these attempts (Keyes and Smith, 1943; Kverno, 1954; Spencer, 1954; Russell, 1968; Mann, 1970).

A few investigators have examined the causative agents of seed loss, but a reliable technique has not been available for determining the ultimate fate of all seeds. Although consumers were identified by examination of seed-coat fragments (Turcek, 1956; Derr and Mann, 1959; Stevenson et al., 1963), other studies indicated a large percentage of seed missing, for which no causative agent was apparent (Stein, 1957; Abbott, 1961; Boyer, 1964; Graber, 1969).

The difficulty in relocating seeds after dispersal in the environment prompted the use of radioisotopes to assist in determining

the fate of individual seeds. Lawrence and Rediske (1960, 1962) were the first to use an isotope to determine the fate of sown seeds. They soaked 440 Douglas-fir seeds for 1 hr in ^{46}Sc, tagging the seed coat, and placed them in a grid of seed spots within a recently clearcut forest area. After 22 weeks exposure they recovered 96% of the seeds or their remains and estimated an 8% loss to rodents, based upon characteristics of the seed-coat fragments. Total loss to all agents was about 45%. As their study was undertaken concurrently with the aerial seeding of the 16-ha clearcut, using endrin-treated seeds, the low percentages attributed to rodents was probably due to the repellent qualities of such treated seeds on the clearcut area.

Radvanyi (1966) examined the fate of sown white spruce seeds, using seeds soaked for 4 hr in ^{46}Sc, and recovered 91% of the seeds after 98 to 118 days in the field. Breakdown of seed consumption by granivores was accomplished by comparison of the seed-coat remains with those obtained in laboratory-feeding trials. After examination of the recovered seeds or their fragments, mice and voles were estimated to have destroyed 35% of the seeds, while chipmunks and shrews accounted for another 12%. Total loss to mammals was 47%. Radvanyi (1970) later reported an average of 34% destroyed by all agents, based upon 7,800 radio-tagged white spruce seeds (6,838 recovered) in seven separate studies. He attributed 24% of the losses to mice, and 4% to shrews.

Abbott and Quink (1970) used eastern white pine seeds tagged with ^{46}Sc to locate caches of seeds removed from feeders. After

mixing uncontaminated seeds with tagged seeds, in a ratio of 38:1, they recovered a maximum of 10% of the tagged seeds. Abbott (1961) determined ad libitum ingestion rates for rodents in the laboratory. White-footed mice and red-back voles consumed 109 and 97 eastern white pine seeds per day, respectively. He then conducted a field test and determined total seed consumption from feeder losses. Trapping on his 0.2-ha field plot produced 22 mice and voles, and by attributing all seed losses to them, Abbott estimated a consumption rate of 260 seeds per day for the white-footed mouse and 232 seeds per day for the red-back vole. Abbott and Quink (1970) used similar methods to determine a consumption rate of 374 white pine seeds per day for the white-footed mouse.

Apparently no attempt was made in any of these studies to see if the mammals living on the tagged areas contained any radioactivity. Virtually no information exists on chronic food consumption and ingestion-excretion rates of radioisotopes by small forest mammals under both laboratory and field conditions.

III. METHODS AND MATERIALS

A. Development of Radioisotopic Techniques

There was little information in the literature concerning preparation of a radionuclide-tagged natural food base, and the major portion of a developmental study (Appendix A) was directed towards obtaining a uniform co-distribution of two radioisotopes in seeds. A natural food of the white-footed mouse was desired, with radioisotopes incorporated evenly throughout the food. For this purpose, a small seed was desired to enhance the uniformity of isotopic concentration throughout the seeds. White pine seeds were selected because of their uniform size, and commercial availability in large quantities. This species is fairly tolerant, economically important, and is found in mixed forests in eastern Tennessee.

General procedures were to soak pine seeds for variable periods of time in a solution of distilled water and the chloride form of one of four radioisotopes: ^{137}Cs, ^{60}Co, ^{54}Mn, or ^{22}Na. Radioactivity was assayed to determine total uptake as a function of time, and location in the seeds. An acid-leach procedure was employed to remove excess radioisotopes from the seed coats.

After these single-isotope tests were completed, ^{137}Cs and ^{60}Co were selected for use during the study. The first, ^{137}Cs, would act as a tissue integrator of the animals' periodic food ingestion, whereas the second, ^{60}Co, would be used as a food tag with very low

tissue assimilation. Two tests were made using both isotopes in a dual-soaking procedure, to establish the final techniques (Appendix A).

Transfer of radioactivity from seeds to consumer was examined to establish desired radioisotopic levels in seeds. These tests involved feeding pine seeds to white-footed mice to determine what portion of the seed and resultant radioactivity was ingested, and the accumulation factors that could be expected for these radioisotopes in mice. Equilibrium levels for ^{137}Cs were 4.3 times the first days radioactivity, and 1.7 times for ^{60}Co.

B. Preparation of the Food Base

The white pine seed originated from the Adirondack Mountains of New York, 1967 seed crop, and germination was certified as 73% (Seed Lot 4163, Herbst Bros., Brewster, New York). A total of 59 kg of seed was used during both the laboratory and field portions of the study (Appendix A).

A total of 71 mCi of ^{137}Cs and 554 mCi of ^{60}Co were used for tagging the 59 kg of pine seed. These radioisotopes were ordered from the Isotopes Division, Oak Ridge National Laboratory (ORNL). Radiation levels were too high to complete this work inside the Ecological Sciences Division facilities, and a field area within a radioactivity liquid waste disposal area (adjacent to Chemical Waste Pit No. 2) was used. A 380-liter stainless steel kettle with a bottom drain was used for the soaking procedure. A drainage line fed into a vertical, 9-m crushed limestone pit for disposal of waste isotope solutions. The general layout of the area is shown in Fig. 1.

Figure 1. Seed-tagging location in an area for disposal of waste radioactive liquids. a = drain to remove waste isotope solution; b = kettle modified for soaking seeds; and c = checking radiation from the cobalt-60 shipping container.

Soaking procedures were supervised by the Health Physics Division (ORNL) and were begun after 183 liters of distilled water and both isotopes had been well mixed in the kettle. The pH of this solution was 4.5. A plastic lid, cut to the size of the kettle, was placed over the seeds and forced down until all seeds were submerged in the solution throughout the 48-hr soaking period. A plastic tarp and metal lid were placed on top of the kettle to prevent evaporation. Seed samples were removed periodically to quantify isotopic location and movement throughout the tagging procedures. Temperature of the soaking solution varied from 24.0 to 29.5 C. Dry ice was placed on top of the kettle to cool the contents during the first day when air temperatures exceeded 32 C. All seeds were dried for 1 1/2 hr, and then stored in refrigerators at 5 C for one week. At the end of this period, the seeds were soaked for 2 hr in 0.75 N H_2SO_4. Seed samples were removed at 1/2-hr intervals for analysis of isotopic loss during this procedure. The seeds were then washed three times using 75 liters of distilled water for each rinse and allowed to drain overnight. On the following day, the seeds were spread on blotter paper for 6 hr of air-drying. All seeds were then stored in garbage cans lined with blotter paper for four days while moisture content was determined. As the moisture content was still high, all seeds were dried again on the fourth day to reduce moisture content to the desired level of 5%.

Aliquots of each isotope were assayed by Analytical Chemistry Division personnel (ORNL). The assay for ^{137}Cs indicated a total of 71 mCi had been delivered on an order of 70 mCi. However, the ^{60}Co assay revealed a serious error in the quantity delivered. A total

of 200 mCi was ordered, but the assay indicated that 554 mCi had been delivered. The result of this error was an increase in radiation dosage during the soaking procedures, with two personnel exceeding the weekly maximum specified by the health physicist present. The seeds contained more ^{60}Co than desired, increasing my exposure throughout the study. My dose rate averaged approximately 250 mrad/3 months, or about 50% of the quarterly maximum specified by the Health Physics Division, throughout the data collection period.

C. Laboratory Procedures

This portion of the study was designed to determine uptake and equilibrium characteristics of ^{137}Cs and ^{60}Co in white-footed mice fed tagged pine seeds chronically. Variables examined were feeding rate, sex, and temperature.

The influence of feeding rate on ^{137}Cs equilibrium was the primary unknown variable in the study. Earlier studies assumed a high correlation between ingestion rate of radioisotopes and body burden, but no positive correlation was explicitly determined under controlled laboratory conditions. Four feeding levels were established to span the expected range of seed consumption during the field portion of the study. These were 2, 10, 50, and 100 seeds per day. Seeds were taken out of refrigeration and kept at room temperature for three days before use. All seeds fed to laboratory animals were individually counted into appropriate seed lots, weighed, and stored in numbered plastic boxes corresponding to the animals' number, feeding rate, and day fed. Radioactivity measurements were made on 100 undamaged

whole endosperm, which were shelled by experimental animals, in order to estimate actual ingested radioactivity.

Sex has not been shown to be a significant factor in injection studies, but was shown to be significant in humans ingesting fallout levels of ^{137}Cs (Scott, 1964). Consequently, each treatment combination was composed of equal numbers of males and females, to ascertain if sex was a variable in chronic feeding studies.

Four temperatures were selected corresponding to the seasonal mean temperatures for this vicinity. Environmental chambers were used to control temperatures at 4.4, 10.0, 15.6, and 21.1 $\pm$ 1 C for winter, autumn, spring, and summer, respectively. Mice were acclimated for one month at the appropriate temperature before initiation of the experiment.

White-footed mice used in the study were live-trapped from various locations on the Reservation. Each seasonal study used 24 mice, with 3 males and 3 females randomly assigned to each of the four feeding rates.

Mice were housed individually in clear plastic disposable cages (Maryland Plastics, # 21 Econo-cage and # 22 Econo-lid) with an elevated hardware cloth floor above a layer of blotter paper. Each animal was provided with one-half of a soft drink can, secured to the 0.3-cm mesh hardware cloth, which served as a retreat for the mice. Nesting material was three cotton balls (1 to 1 1/2 g) and was changed weekly. Cages and hardware cloths were cleaned of urine and feces each counting period, and new blotter paper was provided each week during the uptake phase. Laboratory chow (Purina Laboratory

Chow) and water were provided ad libitum ; tagged pine seeds were fed at 1800 hr each day.

Experimental animals were placed in the environmental chamber in a modified Latin Square design (Fig. B-1), which remained the same at all temperatures. In order to control the influence of variables other than temperature as much as possible, all seasonal studies were conducted in the same environmental chamber for the duration of the uptake phase. When the next seasonal study was initiated, the prior season's excretion phase was not complete, and the animals were transferred into a second chamber for the duration of the excretion study. Both chambers were operated on a 12-hr light (0600-1800 hr), 12-hr dark (1800-0600 hr) regime. No humidity control was present for these chambers, and recorded humidities were slightly moderated from ambient relative humidity.

Mice were counted for radioactivity 12 times during 49 days chronic feeding of pine seed. The 24 mice in each seasonal study could not be counted on the same day due to time limitations, and 12 mice were counted on each of 2 consecutive days. With few exceptions, counting periods were from 0800 hr to 1130 hr each morning.

At the end of the 49-day uptake period, two mice in each treatment combination (one male and one female) were sacrificed for tissue analyses. Major body organs were weighed immediately upon removal from the carcass, dried at 50 C for a minimum of 48 hr, reweighed, and then counted for radioactivity. Tissue analyses were used to characterize isotopic distribution in mice at equilibrium body burdens of radioisotopes.

The remaining four mice in each treatment combination were counted for radioactivity fifteen times during a 100-day excretion period. The animals were transferred into new uncontaminated cages on day 49 of excretion. These new cages contained an absorbent animal bedding, a tin can (8 x 8 x 11 cm) for housing, and three cotton balls for nest material. Sunflower seeds were provided throughout the excretion phase in amounts approximately equivalent to the number of pine seeds each mouse had been fed previously.

Short-tailed shrews were not considered for laboratory study until field results indicated that they contained substantial amounts of radioactivity. A single treatment combination was established to ascertain whether short-tailed shrews would consume pine seeds if given a choice of various foods. Four shrews were maintained at 22 C, but in a communal animal room rather than an environmental chamber. These shrews were fed 10 tagged pine seeds per day for a period of 49 days. All shrews were housed in similar plastic cages as were the mice, but with wire mesh tops (Maryland Plastics, # 28 Econo-lid). These cages contained absorbent animal bedding and a piece of grass sod as a retreat, and were changed weekly. Shrews were fed laboratory chow, sunflower seeds, and water ad libitum, and 2-4 g of mouse meat daily. Shrews were counted for radioactivity on the same schedule as mice, but none were sacrificed at the end of the uptake phase. Excretion was examined for 49 days.

D. Field Procedures

1. Area Description

Climate. The Oak Ridge area lies within the warm temperate rainy climate (Koppen's classification in Petterssen, 1958). As such, the climate is characterized as having moderate winters, hot summers, and no dry season. Normal temperatures at Oak Ridge National Laboratory (X-10 site) range from 31.1 C in July to -0.4 C in January with a yearly average temperature of 14.7 C. Extremes range from -22.2 C recorded in January, 1963 to 39.4 C recorded in September, 1954. Seasonal mean temperatures were 6.0 C in winter, 19.1 C in spring, 23.5 C in summer, and 9.3 C in autumn. The average growing season is about 200 days.

Normal precipitation ranges from a low of 7.16 cm for October to a bimodal maximum of 13.82 cm for March and 13.49 cm in July. Total precipitation averages 130.86 cm yearly. Mean seasonal precipitation totals 40.82 cm in winter, 27.94 cm in spring, 32.82 cm in summer, and 29.29 cm in autumn.

Prevailing winds parallel the valleys in this region, averaging 7.9 km per hr. Spring and summer winds are generally southwesterly, whereas autumn and winter winds are predominately northeasterly.

Weather measurements were made on all three plots including weekly maximum-minimum temperatures, and weekly precipitation. Additionally, hygrothermograph measurements were recorded on the live-trapping plot. Rain gauges were placed in pairs in clearings adjacent to each field plot. These gauges were constructed from 3-liter Nalgene bottles with

the top removed and a 12.7-cm plastic funnel glued into the top. A hole was melted into the side of each bottle for removal of accumulated precipitation, and was stoppered at all other times.

Soils. Soils of this region are primarily Utisols (Red-yellow podzolic soils) derived from Knox Dolomite. Ridges generally form similar soils due to geologic folding of the parent material, and the field plots were located along one ridge to reduce variation due to extreme changes in soil type and consequent chemical composition (especially potassium concentrations) of the vegetation. Peters et al. (1970) described the soils of Walker Branch watershed, which is located on the same ridge (Chestnut Ridge) approximately 1.6 km northeast of the nearest field plot used in this study. This 97-ha watershed was intensively surveyed by U. S. Soil Conservation Service personnel in 1967. Seven soil series were classified on this area with 90 to 96% of the total watershed classified as either Fullerton or Bodine soil series. These soils were found along the ridge with Fullerton commonly above Bodine in slope position. As the field plots were located so as to saddle Chestnut Ridge, it is likely that these two soil series predominate on the plots.

Vegetation. The field work was conducted in mature hardwood forests of the Eastern Deciduous Forest. These forests originally were of the Oak-Chestnut association (oak-deer-chestnut fasciation), changing to an oak-hickory forest since the disappearance of American chestnut (Shelford, 1963). More commonly, this forest is within the Ridge and Valley Province of the Oak-Chestnut Forest region (Braun, 1950). It was typified as oak-chestnut forests on the ridges, with

predominately oak forests in the valleys. Braun (1950) considered "...each ridge is more or less a unit..." which served to increase the uniformity of the forests growing thereupon. The Knoxville area was considered part of the valley floor vegetation, with low relief formed by dissection of the valley floor. Vegetation was classified as very uniform, with white oak predominating in the climax community despite the low ridges. These cherty ridges were considered to be predominately white oak-black oak-hickory with a scattering of other species.

Three field plots were selected during the winter of 1968-69, based upon similarities in the following criteria: basal area (prism estimates), dbh (diameter at breast height, or 1.4 m above the ground), total height, species composition, aspect, position on the ridge, number of stumps and logs on the ground, and visible ground cover. Vegetation was subsampled on 10 randomly selected, 10-m square subplots in each field plot. All trees over 2.5 cm dbh were tallied by species and dbh. Trees over 12.7 cm dbh were also measured for total height with a Haga altimeter. Ground cover was visually estimated on each subplot for each of three height classes of vegetation. These classes were: 0-30 cm height, 30-122 cm height, and 122 cm height to 2.4 cm dbh. Basal areas were calculated using published tables (Avery, 1967).

Animals. Primary mammalian species observed on the field plots were the short-tailed shrew (Blarina brevicauda), white-footed mouse, and eastern chipmunk (Tamias striatus). Numerous other species of vertebrates were present on the plot at various times, but all were typical of the region. Species lists have been prepared for mammals

(Howell and Dunaway, 1959), summer birds (Howell, 1958), herpetofauna (Johnson, 1964), and insects (Howden and Crossley, 1961), which inhabit portions of the ORNL Reservation.

Trapping was conducted prior to the study to determine normal populations in the forests. Trapping during the autumn of 1968 was very productive. Between August 29th and December 13th, a total of 905 trap nights produced 64 white-footed mice, 46 eastern chipmunks, 26 southern flying squirrels (Glaucomys volans), and 2 golden mice [Peromyscus (Ochrotomys) nuttalli] for a total of 14.14 animals/100 trap nights. The traps were located on trees at a height of 1.8 to 2.4 m, using wooden shelves supported by metal brackets. A piece of rubber tubing held traps and shelter cans in place. All traps were baited with sunflower seeds and sufficient cotton for nesting material. The large number of white-footed mice captured on these shelves indicated that these nocturnal mice have no aversion to limited amounts of climbing, at least to a height of 2 m. This propensity for arboreal activity has been examined by several investigators (Hamilton, 1941; Taylor and McCarley, 1963; Getz and Ginsberg, 1968).

During selection of the potential study plots, a short series of live-trappings were undertaken in 1969 to determine postwinter relative abundance of small mammals. Two of the three field plots were sampled for eight nights using 25 traps placed near stumps, bases of trees, and other areas where small mammal activities were observed. Only 2 white-footed mice and 1 eastern chipmunk were captured in 399 trap nights during February and March, 1969, for a total of 0.75 animals/100 trap nights. The winter of 1968-69 was a poor mast year, and it

was obvious that the granivorous mammals had practically disappeared.

Due to the low populations, adults trapped in forested areas the previous autumn were introduced into these three plots in an attempt to restore the mouse populations to levels similar to those prior to the mast failure. Eleven pairs, and any of their unweaned juveniles, were released in nest boxes on each field plot in May, 1969. A total of 36 were released on the control, 45 on the live-trap, and 39 on the snap-trap plot. Subsequent trapping revealed that 6 of these released adults were still living on each of the live-trap and control plots at the start of the field work. None of the juveniles were recaptured after their release.

2. Field Plot Preparation and Techniques

The three 140-m square forested plots were: 1) control; 2) live-trap plot; and 3) snap-trap plot. No additional food was placed on the control plot, which was used to examine only the populational changes in mice and shrews. Both remaining plots each received 435.2 g of radioactive seed at weekly intervals for 58 weeks. The live-trapping plot was trapped periodically to examine uptake, equilibrium, and excretion characteristics of small forest mammals, as well as populational changes. The snap-trap plot was trapped seasonally, using Museum Special snap-traps to obtain animals for tissue analyses.

All three plots were located along the crest of Chestnut Ridge in Roane County, Tennessee, on the Atomic Energy Commission Reservation. In relation to Building 2001 at ORNL, the control plot was located 2.96 km on a bearing of S84°W; the live-trap plot was located

1.35 km on a bearing of N36°W; and the snap-trap plot was located 2.51 km on a bearing of N49°E. A distance of at least 2 km separated each plot so that movement of small mammals between plots would be unlikely.

All plots were located with a transit, and a 10-m grid was established within each plot. Relative elevations were computed for each surveyed point. Forty-eight percent of each grid was established with a maximum allowable closure of ± 1 m. Remaining grid points were located by taping between previously established transit points. All 225 grid locations on each plot were marked with aluminum stakes and numbered in a two-dimensional array code (e.g., Station 1-1 to 15-15 in Fig. 2).

Nest boxes were designed and installed on each plot at stakes with "even-even" numbers (Fig. 2 and 3). The purpose of the nest boxes was to provide ready access to seed caches and to potential litters born on the plot. These nest boxes were constructed of white oak, with two compartments (15.2 x 15.2 x 15.9 cm for the nest compartment and 7.6 x 15.2 x 15.9 cm for an entrance chamber), a marine plywood overhanging roof (30.5 x 40.6 cm and removable), and an 18-kg concrete block to prevent movement or raiding of the boxes by predators.

Feeders were installed at "odd-odd" numbered grid locations (Fig. 2 and 4). These feeders were constructed from clear plastic boxes (17.1 x 12.1 x 6.0 cm) modified by melting six 2.2-cm entrances in all four sides, with a plastic dish (4.1 cm dia. x 1.3 cm depth) glued near the center of the bottom. Abbott (1961) used wooden

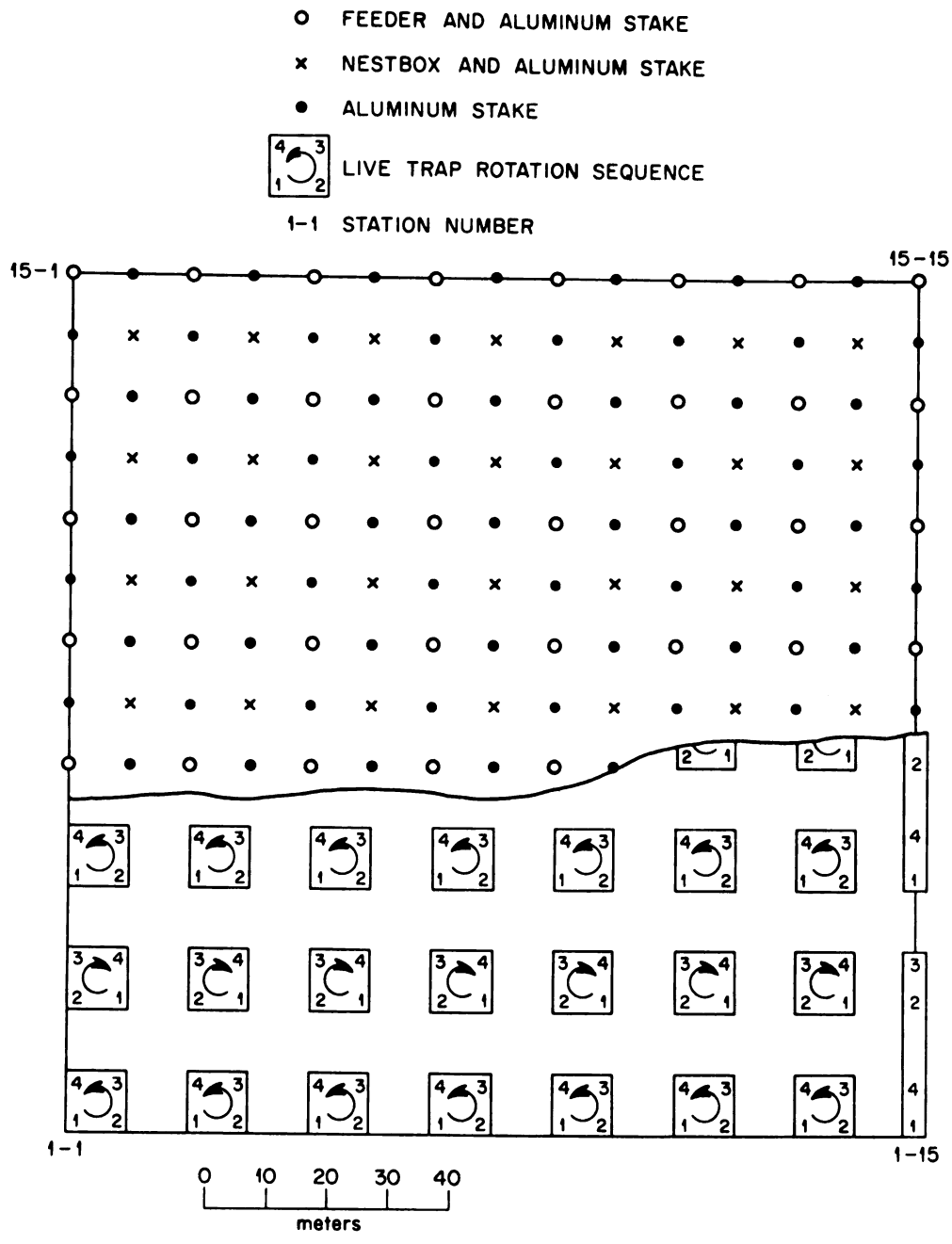

Figure 2. General layout of the live-trapping field plot, indicating trapping patterns and locations of nest boxes and feeders.

Figure 3. Nest box, Sherman live-trap in protective metal can, and aluminum stake used on the live-trap area. High-density concrete block on cover of nest box used to prevent disturbance by large mammals.

Figure 4. Feeder used for disbursing pine seeds on the field areas. Lid (top center) removed, and wire wickets left in place. Most of the seeds were removed from the plastic dish, and seed fragments indicated shelling by Peromyscus leucopus. Mouse feces at tips of forceps.

feeders which concealed mice from view, and recorded 50% consumption of seeds within them. For this study, removal and storage of pine seeds was desirable. It was assumed that these secretive mice would remove seeds rather than consume them within the clear plastic feeders. Seeds were placed in the dish to prevent soaking by precipitation and to reduce the loss expected from larger mammals reaching through the entrances. These entrances were designed to allow access only to animals smaller than about 40 g in whole-body weight. Holes were drilled or melted in the dish and corners of each box to allow for drainage of liquids. All feeders were pinned to the ground with 10-gauge galvanized wire "wickets" to prevent disturbance by larger mammals.

This feeder design was field-tested during autumn, 1968. White-footed mice used the feeders, but 4 of 6 feeders were chewed sufficiently by larger mammals to allow access to chipmunks and gray squirrels (Sciurus carolinensis). This problem occurred only during the mast failure in 1968-69.

Seeds were dispersed at 7-day intervals in 64 feeders on the live-trap and snap-trap plots. Total weight of seed per plot was 435.2 g per week, or 6.8 g per feeder. All seeds were weighed the day before being placed on the plot, and were stored in numbered containers (4.4 x 4.4 x 1.6 cm) for transportation to the plots. All unused seeds in feeders were removed from the plots each week, feeders cleaned, the next week's seeds placed in the dish, and then the feeders were repinned to the ground. Records were kept of the estimated percent of seeds completely removed from the feeders, and

the percent of seeds eaten in feeders. These percentages were estimated to the nearest 25% for each feeder.

Mammal populations were live-trapped periodically on the control and live-trap field plots. Trapping during the winter was restricted to those nights when the predicted minimum temperatures were above 0 C. Sherman live-traps (8 x 9 x 30 cm) protected by shelter cans (11 x 11 x 30 cm) were used, with each trap rotated through one of four locations each trapping period in an attempt to reduce recaptures of trap-prone individuals (Fig. 2). Each trapping period was of two nights duration on each plot, with the second night on the control plot concurrent with the first night on the live-trap plot. Trapping on the live-trap plot was during the two nights prior to the next feeding of pine seeds, and this fixed trapping time served to normalize sampling times for comparison of radioactivity between trapping periods. Traps were baited with a few sunflower seeds on the trap door, with cotton batting and sunflower seeds provided in the rear of the trap. Traps were usually set after 1800 hr and run at about 0700 hr. In an effort to reduce shrew mortality in the live-traps, mouse meat was given to captured shrews as the traps were run in the mornings. Shrews were given water until refusal each time they were handled in the laboratory. All captured animals were brought to the laboratory, identified, counted for radioactivity, weighed, sexed, toe-clipped, reproductive status noted, and, with a few exceptions, returned the same day to the point of capture.

E. Radioactivity Determinations

All animals were counted for radioactivity in a 400-channel Packard pulse-height gamma-spectrometer (Fig. C-1), coupled to a single sodium-iodide crystal (7.6 cm dia. x 7.6 cm depth, Tl activated). During counting, animals were confined in plastic vials (3.2 cm dia. x 7.6 cm depth) lined with blotter paper, with air holes melted into both ends of the vials. Each vial was inserted into a second plastic dish (8.4 cm dia. x 3.3 cm depth) which was then placed on top of the crystal (Fig. C-2). This procedure was necessary to control geometry of the animals with respect to the crystal during counting and thereby reduce variance of the measurements. Animals were counted for up to a maximum of 20 min. depending upon radioactivity levels.

Isotopic standards were prepared from aliquots of each isotope saved for that purpose. These standards were contained in 30-ml Nalgene bottles, which were filled with 20 ml of distilled water and placed in vials like those used to hold animals. All radioactivity analyses were based upon these standards. Radioactivity of the standards was determined in a gamma ion chamber by the Analytical Chemistry Division (ORNL). Corrections for background and physical decay of the isotopes were made, and all data were converted to disintegrations per minute (dpm).

All animal tissues, excretory products, insects, and individual seeds were counted in a similar system, with the following changes. Tissues were oven-dried at 50 C and then placed in test tubes (25 x

150 mm) for counting. The Packard analyzer was coupled to an automatic sample changer with a well-type crystal. Standards for these analyses were prepared by drying the isotopic solution onto small sponge cubes, which were then placed in test tubes.

Output from both of these Packard systems was in the form of paper tape, which was then converted to magnetic tape for computer analysis by the RESAP program (Brooks et al., 1970). This program utilized a least squares analysis to reduce gamma spectra to estimates of radioactivity contained in the samples. The computed estimates served as the basic radioactivity data used throughout the study (Appendix C).

F. Statistical Procedures

Basic statistics were used for obtaining treatment combination means and confidence intervals (Snedecor, 1956). Three-way or four-way factorial analyses of variance (Hull, 1967) were used to determine significance of the treatments and interactions at isotopic equilibria in the mice. Significant variables from the ^{137}Cs analysis were employed in a predictive equation using a multiple linear regression program (Van Dyne, 1965) modified by Sollins (1971).

Uptake and retention curves are generally considered as reflective of the differential movement of isotopes into and out of various body pools or organs. Thus analyses for these whole-body curves are combinations of exponential accumulation or decay components using either linear regression analyses for each separated component ("stripping" each linear segment from the curve until the final

component is linear), or nonlinear regression analyses of the entire curve. The "stripping" technique has been severely criticized by Van Liew (1962), who found that multicomponent curves would reduce to three-component, and occasionally, four-component models through stripping the curves. The nonlinear approach was used in this study to avoid subjective judgment of each component, although some problems still existed.

Uptake curves were analyzed by two-component models of the form:

$$A_t = Q_e + a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t},$$

where A_t = radioactivity at time t, Q_e = equilibrium body burden, a_1 = radioactivity participating in the first component, λ_1 = elimination rate coefficient of the first component, a_2 = radioactivity participating in the second component, and λ_2 = elimination rate coefficient of the second component.

Retention curves were analyzed by three-component models of the form:

$$A_t = a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t} + a_3 e^{\lambda_3 t},$$

where a_3 = radioactivity participating in the third component, and λ_3 = elimination rate coefficient of the third component. Both of these equations were analyzed with a nonlinear least squares program written by Goldstein (1971). Computer analyses were performed on an IBM 360/75 or 91; RESAP computer analyses were performed on IBM 7090 or 7091 models.

IV. RESULTS

A. Seed Consumption and Radionuclide Turnover by White-footed Mice in the Laboratory

1. Food Base

Uptake and distribution of ^{137}Cs and ^{60}Co in white pine seeds was followed throughout the soaking and leaching procedures (Fig. 5). The seeds acquired 62% of the ^{137}Cs and 74% of the ^{60}Co during the soaking procedure. Uptake of ^{137}Cs during the soaking procedures occurred between 5 and 10 hr and decreased after that time; ^{60}Co was primarily taken up between 20 and 30 hr of soaking (Table B-1). The indication of a doubling in ^{137}Cs radioactivity between 45 and 48 hr had not occurred previously through 96 hr (Appendix A), and probably was a result of sampling error. The acid-leaching and rinsing procedures reduced the concentration in the seeds to 19% for ^{137}Cs and 21% for ^{60}Co of the initial soaking solution. The acid leach did not remove as much ^{60}Co as expected, but this was thought to be due to the much greater concentration of ^{60}Co in seeds compared to that used earlier.

Distribution of isotope between the seed coat and endosperm was determined by counting 100 undamaged endosperm shelled by white-footed mice during the laboratory study. Mean endosperm concentrations were $4.70 \pm 2.30 \times 10^3$ (dpm $\pm$ 1 S. E.) for ^{137}Cs and $2.99 \pm 2.17 \times 10^4$

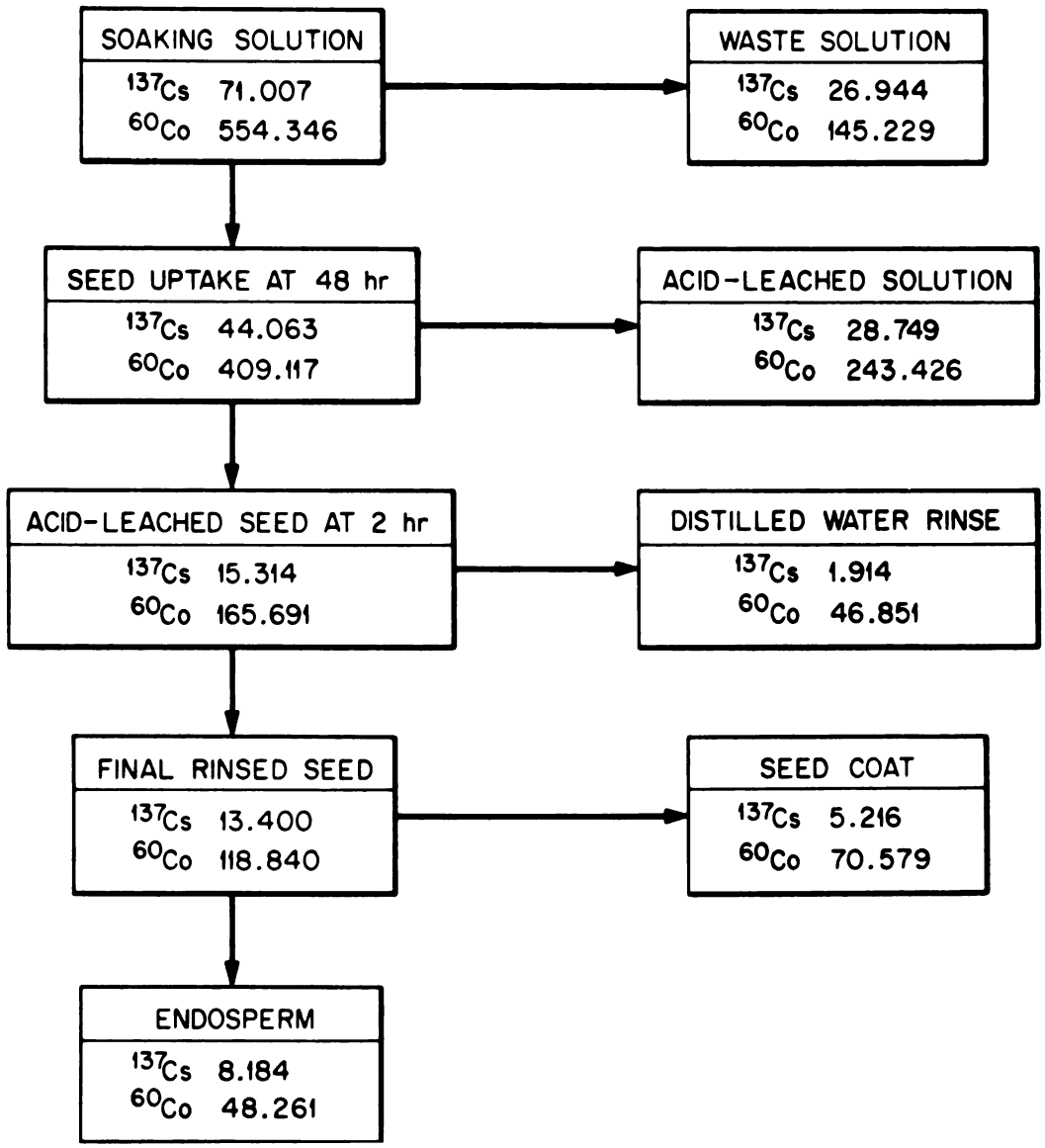

Figure 5. Flow diagram for location and distribution of ^{137}Cs and ^{60}Co during Pinus strobus seed-soaking procedures; values are mCi.

for ^{60}Co (dpm/g was $4.35 \pm 2.08 \times 10^5$ for ^{137}Cs and $2.76 \pm 2.00 \times 10^6$ for ^{60}Co). Endosperm comprised 59.4% of the seeds' weight, 61.1% of the ^{137}Cs, and 40.6% of the ^{60}Co. The correspondence of ^{137}Cs to weight does not indicate equal availability of the isotope from both endosperm and seed coat, due to the acid-leaching procedure removing readily-available ^{137}Cs from the seed coats. The influence of consumed but unassimilated ^{137}Cs and ^{60}Co contained in seed coats appeared to be minimal due to this acid-leaching procedure (Appendix A).

At the end of the field study, a germination check was made using both radioactive and uncontaminated seeds (100 seeds each). In 60 days, 60% of the controls had germinated, compared to 0% for radioactive seeds. The radiation dose received by the radioactive seeds during the study was not determined exactly, but an estimation was made of 30 rads/day for combined beta-and-gamma dose from both internal and external sources. At the end of the study the accumulated dose was approximately 12 krads. The LD_{50} for seeds of several pine species has been reported to range from 5-15 krads (Osborne and Lunden, 1961) for acute irradiation. Chronically-irradiated seeds apparently have a higher LD_{50} (Mergen and Johansen, 1964). Thus the nongermination of tagged seeds during the study may in part have resulted from excessive radiation and/or a combination of the procedures used to tag the seeds. No germinated seeds were observed on the field plots during the study.

Feeding rates for mice in the laboratory were summarized for 190,470 pine seeds (mean seed weight = 18.25 mg air-dry) used

during the laboratory study (Table B-2). To determine whether numbers or biomass of seeds should be used in further analyses, mean weekly weight per seed was examined in a three-way factorial analysis (Table B-3). Both feeding rate and temperature were significant as well as the interaction between these two variables. Therefore, it was decided that weight of seed fed per unit time would be used in further analyses. Time (or week fed) was not significant, and analyses concerning uptake characteristics for each treatment combination through the 49-day uptake period would not require consideration of weight of seed fed.

2. Equilibrium Body Burdens of ^{137}Cs and ^{60}Co

Equilibrium body burdens for ^{137}Cs and ^{60}Co in white-footed mice were highly correlated with the seed ingestion rate (Table 1). Effects of sex and temperature were also observed, with higher equilibria in females and in both sexes at higher temperatures. Equilibrium for ^{137}Cs occurred within the first 15 days of uptake in mice. Theoretically, equilibrium body burdens should be the asymptote of uptake curves for each radioisotope during chronic feeding. To avoid problems associated with analyses of nonlinear data, the uptake period prior to equilibrium was excluded from this analysis. Data were normalized for variable live-body weights of the experimental animals through use of dpm/g values. The influence of the primary factors (sex, temperature, and feeding rate) and day of uptake were examined in a four-way factorial analysis with the goal of eliminating day of uptake as a factor.

Table 1. Equilibrium of ^{137}Cs and ^{60}Co in Peromyscus leucopus during chronic ingestion of Pinus strobus seeds for 49 days.[a]

Ingestion Rate:[b]	2	10	50	100	Mean
Temperature (C)	Radioactive Equilibrium (dpm X 10^3/g)				
			^{137}Cs: Females		
4.4	0.80	3.97	20.44	53.56	19.69
10.0	0.94	4.26	21.02	56.32	20.63
15.6	0.79	4.40	33.16	61.93	25.07
21.1	1.14	5.98	36.55	81.41	31.27
Mean	0.92	4.65	27.80	63.30	24.17
			^{137}Cs: Males		
4.4	0.58	3.34	18.54	36.65	14.78
10.0	0.80	3.69	24.84	44.59	18.48
15.6	0.77	4.50	24.02	59.98	22.32
21.1	1.36	3.70	28.16	65.52	24.69
Mean	0.88	3.81	23.89	51.68	20.07
			^{60}Co: Females		
4.4	0.48	2.89	15.27	56.39	18.76
10.0	0.53	2.27	18.38	57.47	19.66
15.6	0.35	3.11	21.83	51.81	19.27
21.1	0.42	2.84	29.41	76.14	27.20
Mean	0.45	2.78	21.22	60.45	21.23
			^{60}Co: Males		
4.4	0.54	2.46	15.79	44.25	15.76
10.0	0.46	2.32	17.72	68.68	22.30
15.6	0.36	2.57	15.15	67.04	21.28
21.1	0.88	2.43	15.71	43.60	15.66
Mean	0.56	2.45	16.09	55.89	18.75

[a]Standard errors given for both sexes combined during chronic ingestion in Tables B-33 through B-40.

[b]Ingestion rate = number of seeds ingested per day.

The first analysis, including day 8 of uptake, resulted in a significant effect for day of uptake, which indicated that mice were not at equilibrium by day 8. The data were then run without day 8, but including all data between days 15 and 49 of uptake. Day of uptake was eliminated as a significant variable with deletion of day 8 from the analysis. Subsequent uptake by long-term compartments (e.g., hair and bone) apparently was minimal compared to the soft-tissue body burden, and probably was masked by normal variation in the data.

The four-way factorial analysis for ^{137}Cs dpm/g indicated the primary importance of feeding rate over any other variable (Table B-4). Other variables which were significant were temperature, sex, and three interaction terms. These interactions were: (sex X temperature), (temperature X feeding rate), and (sex X temperature X feeding rate). Results for ^{60}Co dpm/g confirmed all significant relationships above, but generally, to a lesser extent than for ^{137}Cs (Table B-5). One interaction term, (sex X feeding rate), was significant for ^{137}Cs but not for ^{60}Co.

Variables which were significant in the ^{137}Cs factorial analysis were used in a multiple linear regression model for later correlation with the field data. To avoid problems with nonindependence of six successive measurements made on the same mouse, only the mean equilibrium body burden was used in this regression. As in usual practice in handling radioactivity data, the variance nonhomogeneity (variance was proportional to count rate) was corrected by transforming all dpm/g data to natural logarithms (ln) before analysis. The overall

regression was significant, but individual degree-of-freedom regressions indicated that only the feeding rate and those interaction terms involving the feeding rate made significant contributions to the total regression (Table B-6). The r^2 for the total regression was 0.984. Maximum deviations from the model ranged from -0.53 to +0.48, with a standard error of estimate of $\pm$ 0.21 (Fig. B-2). In terms of number of seeds, the reliability of this technique at an ingestion rate of 50 seeds per day was $\pm$ 13 seeds. Thus there was a good correlation between ingestion rate and ^{137}Cs equilibrium level in white-footed mice under laboratory conditions.

3. Internal Radiation Dosages

Potential internal radiation insult from beta- and gamma-emitters was estimated for the maximum ^{137}Cs and ^{60}Co body burdens in white-footed mice. The maximum radioactivity acquired by mice from either the laboratory or field was 184,400 dpm/g for ^{137}Cs and 92,040 dpm/g for ^{60}Co. Based upon computational procedures described by DiGregorio et al. (in press), the maximum beta-plus-gamma dose rate experienced was 1.5 rads/day. The maximum time span for contamination at this level was 405 days. Thus the maximum dose should not have exceeded 600 rads during the study. The LD_{50-30} for an acute gamma-irradiation was 1,070 rads for the white-footed mouse (Dunaway et al., 1969). A radiation dose is less effective when delivered chronically rather than acutely, and early radiation mortality was not likely in either the field plots or the laboratory. Based upon results of French et al. (1969), possible effects of the

radiation doses in this study might have been a shortening of life span and reduction in fertility, but no evidence of such effects was obtained in this study.

4. Parameters for Chronic Ingestion of ^{137}Cs and ^{60}Co

Each ^{137}Cs treatment combination was averaged for each day of uptake from day 1 through day 49 before analysis using a two-component exponential equation (Fig. 6 and Table B-7). There appeared to be a correlation between equilibrium body burden of ^{137}Cs and temperature, but only slight changes in the other parameters were observed. The elimination rate coefficient for the first component also appeared to follow a fairly consistent trend with changing temperature, with a more rapid clearance of radioactivity at lower temperatures. There was no obvious trend between the allocation of radioactivity to each component, except for a general statement that the first component was larger than the second. The first component apparently reflected a rapidly-clearing compartment, often considered to be the gastrointestinal tract contents (Orr, 1967; Kitchings et al., 1969). But ^{137}Cs has such a high assimilation from the gastrointestinal compartment into the blood (ICRP, 1960), that this first component appeared to be a combination of the unassimilated fraction in the gastrointestinal tract plus some of the more rapidly-clearing body pools. The gastrointestinal tract was essentially clear after 64 hr, based upon the fecal radioactivity analysis (Fig. A-6). This clearance time was converted to a rough estimate of the gastrointestinal clearance rate by assuming that five biological half-lives, or

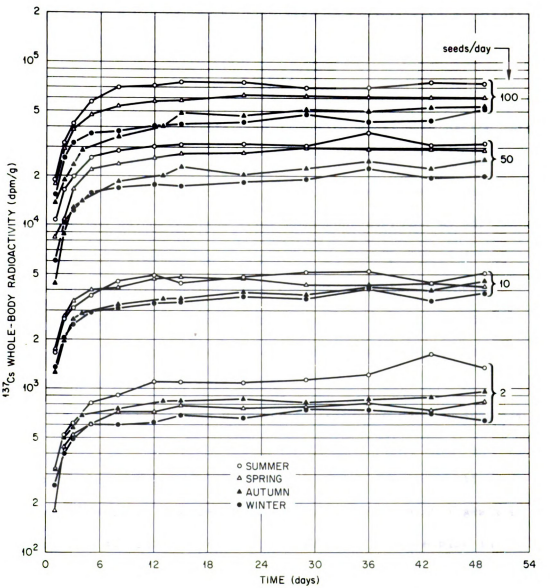

Figure 6. Mean accumulation of ^{137}Cs in Peromyscus leucopus at sixteen treatment combinations of temperature and chronic ingestion of Pinus strobus seeds. Each point represents the mean of six mice. Winter = 4.4 C; autumn = 10.0 C; Spring = 15.6 C; and summer = 21.1 C. Data from Tables B-33 through B-36.

clearance of 96.9% of the total radioactivity, occurred within this 64-hr period. By division, this biological half-life should be approximately 12.8 hr and can be converted to an estimated elimination rate coefficient by the following relationship:

$$T_b = \frac{0.693}{\lambda_b},$$

where T_b = biological half-life, and λ_b = biological elimination rate coefficient (equivalent to λ_1 of the uptake equation). Solving for (λ_b) gave a value of -1.30 for the gastrointestinal compartment. Computer-derived values for the first component averaged -0.48. Thus the computer-derived first component apparently included more than just the gastrointestinal tract clearance. This component seemed to reflect a continuum of excretion rates from a combination of body pools. Variability of the data was too great to attempt derivation of a three-component model.

A main objective of this work was to determine seed consumption rates by mice. The equilibrium body burdens for ^{137}Cs from the laboratory were subsequently plotted against the ingestion rate (Fig. 7). This curve appeared to be leveling out at high ingestion rates, and was subjected to a nonlinear analysis to determine the asymptote of the equilibrium curve. This asymptote should represent the ad libitum ingestion rate under laboratory conditions, and was calculated as 194 seeds per day, or 3.54 g/day. This relationship appeared to be a reliable method for estimating seed ingestion rates from a readily-measured parameter, the body burden of ^{137}Cs at equilibrium.

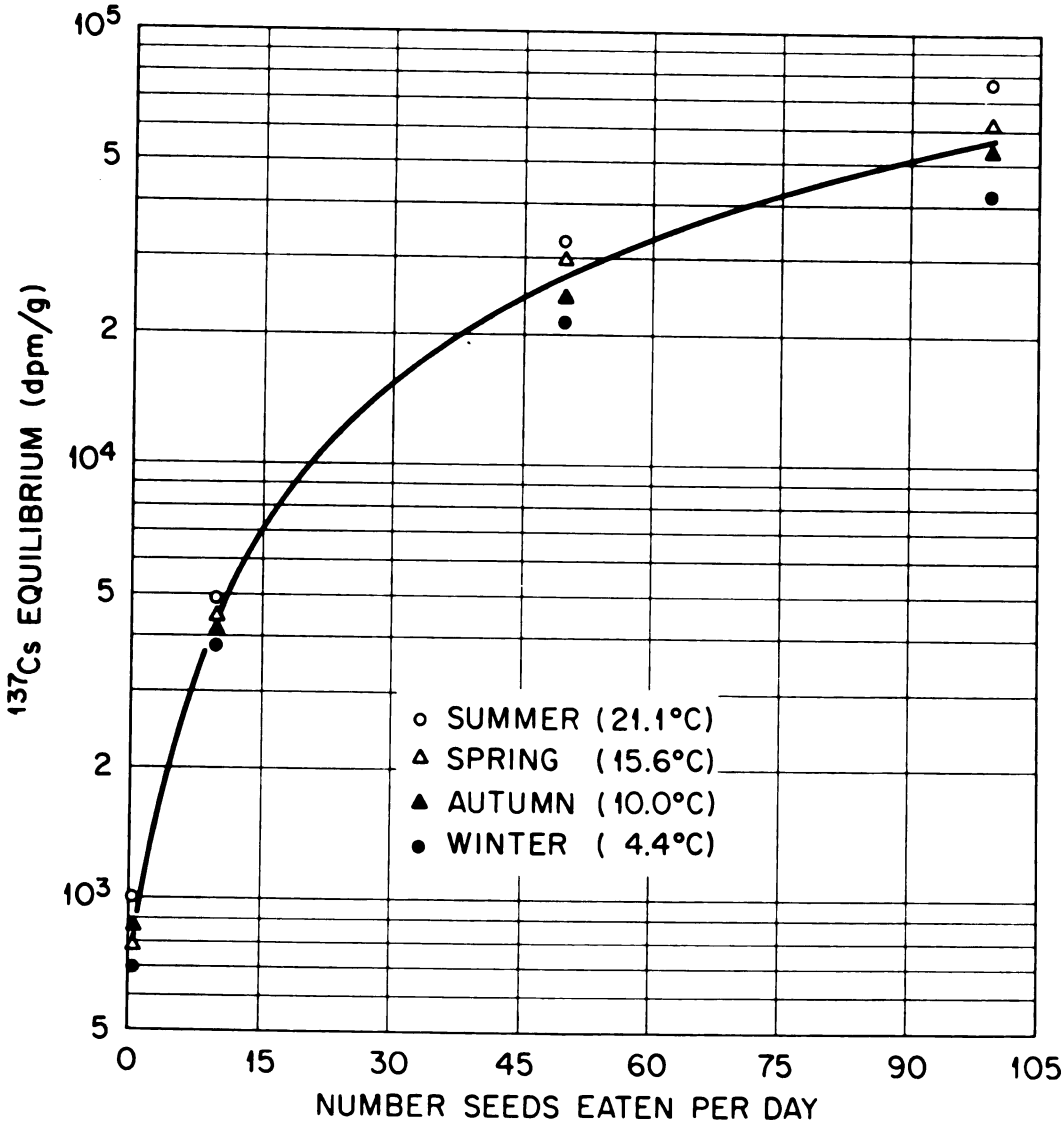

Figure 7. Mean equilibrium of ^{137}Cs in Peromyscus leucopus as a function of ingestion rate and temperature in the laboratory.
Data are equilibrium values from Table B-7.

Uptake of ^{60}Co could not be fitted by computer analysis, apparently due to the large variability in the data. The only analysis for ^{60}Co appears in Table 1, and represents the mean radioactivity between days 15 and 49 of uptake. Similar trends were apparent for ^{60}Co as were reported for ^{137}Cs, but there were more exceptions between temperature levels. This was expected due to the mode of excretion of ^{60}Co and the problems associated with fecal excretion as mentioned earlier.

5. Parameters for Retention of ^{137}Cs and ^{60}Co After Chronic Ingestion

Daily retention means for mice, after cessation of chronic ingestion of radioactive seeds, were analyzed for each treatment combination by a nonlinear three-component model for both ^{137}Cs dpm/g and ^{60}Co dpm/g (Tables 2 and 3, respectively). Results from the ^{137}Cs analysis indicated rather consistent but small changes in most of the retention parameters, with the elimination rate coefficients more closely correlated to temperature than feeding rate. Most of the treatment combinations indicated the presence of a small first component for ^{137}Cs, whereas the elimination rate coefficient for this component was less consistent. Both the second and third components for each feeding rate were generally reduced by lowering the temperature, although the effect was small. The mean biological half-life for ^{137}Cs was 0.6 days for the first component, 3.5 days for the second, and 20.9 days for the third component. Based upon the whole-body burden of ^{137}Cs after 49 days of chronic feeding, 14% was excreted in the first component, 82% in

Table 2. Retention parameters for ^{137}Cs in Peromyscus leucopus after chronic ingestion of Pinus strobus seeds for 49 days. Ingestion rate = number of seeds ingested per day.

Equation is $A_t = a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t} + a_3 e^{\lambda_3 t}$.

Ingestion Rate	Temp (C)	Parameters of the Retention Equation					
		a_1 (dpm X 10^3/g)	λ_1 (day^{-1})	a_2 (dpm X 10^3/g)	λ_2 (day^{-1})	a_3 (dpm X 10^3/g)	λ_3 (day^{-1})
2	4.4	0.05	-1.268	0.58	-0.284	0.04	-0.0415
	10.0	0.18	-0.784	0.85	-0.207	0.05	-0.0346
	15.6	0.23	-0.849	0.66	-0.189	0.02	-0.0274
	21.1	1.22	-0.271	0.09	-0.089	0.02	-0.0165
10	4.4	1.22	-0.684	2.63	-0.225	0.11	-0.0267
	10.0	1.33	-0.578	3.76	-0.198	0.09	-0.0217
	15.6	2.48	-0.311	1.73	-0.147	0.07	-0.0160
	21.1	0.30	-2.127	4.73	-0.159	0.13	-0.0221
50	4.4	3.17	-1.911	16.63	-0.219	0.64	-0.0308
	10.0	5.29	-1.250	20.96	-0.188	1.61	-0.0457
	15.6	1.49	-1.222	25.08	-0.177	1.93	-0.0411
	21.1	3.02	-1.994	27.42	-0.155	1.28	-0.0323
100	4.4	1.74	-1.870	54.83	-0.251	2.59	-0.0432
	10.0	1.99	-2.195	56.06	-0.249	1.42	-0.0349
	15.6	5.72	-3.245	54.41	-0.180	1.51	-0.0265
	21.1	10.48	-1.111	63.58	-0.144	1.03	-0.0187
Mean:							
%		14.00		82.13		3.82	
λ_i			-1.091		-0.198		-0.0332
± 1 S. E.		3.06	0.340	2.76	0.007	0.52	0.0027

Table 3. Retention parameters for ^{60}Co in Peromyscus leucopus after chronic ingestion of Pinus strobus seeds for 49 days. Ingestion rate = number of seeds ingested per day.
Equation is $A_t = a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t} + a_3 e^{\lambda_3 t}$.

Ingestion Rate	Temp (C)	Parameters of the Retention Equation					
		a_1 (dpm X 10^3/g)	λ_1 (day^{-1})	a_2 (dpm X 10^3/g)	λ_2 (day^{-1})	a_3 (dpm X 10^3/g)	λ_3 (day^{-1})
2	4.4	0.36	-1.718	0.05	-0.099	0.02	-0.0074
	10.0	0.42	-1.338	0.06	-0.076	0.03	-0.0043
	15.6	0.38	-1.785	0.05	-0.115	0.02	-0.0066
	21.1	0.38	-2.160	0.06	-0.151	0.03	-0.0060
10	4.4	2.03	-1.732	0.25	-0.107	0.14	-0.0111
	10.0	4.01	-1.436	0.29	-0.086	0.16	-0.0076
	15.6	2.40	-1.896	0.34	-0.071	0.15	-0.0044
	21.1	2.69	-1.942	0.24	-0.102	0.15	-0.0105
50	4.4	14.98	-1.571	1.24	-0.114	0.84	-0.0121
	10.0	21.06	-1.635	2.05	-0.188	0.93	-0.0120
	15.6	19.52	-1.858	1.00	-0.084	0.67	-0.0094
	21.1	18.36	-2.414	1.32	-0.079	0.92	-0.0098
100	4.4	61.85	-2.104	3.25	-0.139	2.16	-0.0122
	10.0	60.44	-1.426	13.39	-0.299	2.97	-0.0136
	15.6	46.12	-1.949	3.73	-0.108	2.45	-0.0100
	21.1	43.99	-1.801	4.77	-0.164	3.15	-0.0100
Mean:							
%		86.65		8.28		4.99	
λ_i			-1.795		-0.134		-0.0110
± 1 S. E.		2.09	0.090	1.08	0.036	0.64	0.0021

the second, and 4% in the third component.

Whereas ^{60}Co could not be fitted to the uptake equation, retention of this radionuclide was readily fitted by a three-component model. But there was little correlation of ^{60}Co retention parameters to either temperature or feeding rate. The mean biological half-life for ^{60}Co was 0.4 days for the first component, 5.2 days for the second, and 63.3 days for the third component. The fractions of the total body burden excreted in each component were 87%, 8%, and 5% for each successive component.

Thus, it appeared that excretion of ^{137}Cs and ^{60}Co was not greatly influenced by temperature or feeding rate in white-footed mice following chronic feeding.

6. Effect of Mode of Entry on Retention of ^{137}Cs

The lack of an obvious influence of temperature or feeding rate on elimination of ^{137}Cs prompted a comparison of this data with the results of other investigators.

Retention of ^{137}Cs was examined in white-footed mice by Baker (1970) with no significant differences in retention, for the long-term component, attributable to temperature or confinement. It should be pointed out that he dealt only with day 6 through day 33 of retention, and used intraperitoneal injection of the isotope. He concluded that the early component of excretion, prior to day 10, was significantly correlated to metabolism, based upon projected intercept values for that component. A comparison was made between Baker's data for injected mice and my data for chronically-fed mice (Fig. 8). The 9 C

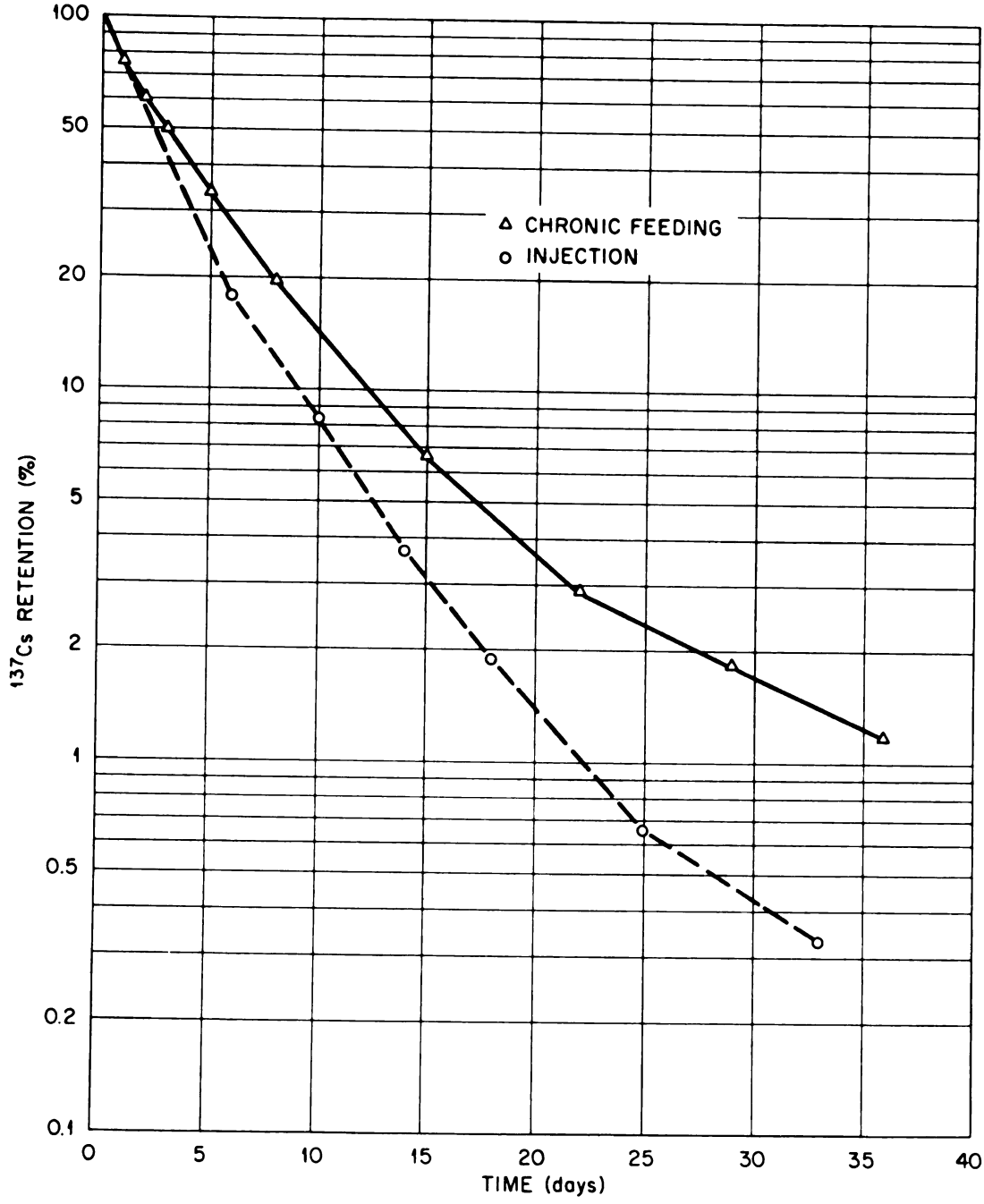

Figure 8. Retention of ^{137}Cs after intraperitoneal injection and 49 days of chronic feeding of Pinus strobus seeds. Injection data from Baker (1970), with permission to use unpublished data.
Mean temperatures: injection = 22 C; chronic = 12.8 C.
Data from Table B-8.

difference in temperature should have resulted in faster excretion in the chronically-fed mice, if temperature was the overriding factor. As excretion was slower in the chronically-fed mice, the differences apparently are not an indication of temperature changes, but a reflection of inherent differences in isotopic behavior between injected and chronically-fed mice.

As there was no other comparable information concerning ^{137}Cs in white-footed mice, or other small cricetids in the literature of which I am aware, data for an extensively studied and similarly-sized murid (the laboratory mouse, Mus musculus), was compared to the data for this study (Table 4). Laboratory mice are slightly larger than white-footed mice and, based upon Richmond's (1958) work, should have a greater retention of ^{137}Cs. In fact, the converse was apparent, with the data for the white-footed mouse indicating a greater retention than observed in the laboratory mouse. One study did approximate my data between days 8 and 22, and was a chronic-intake study which used the tagged drinking water technique.

The length of time that a study is conducted affects the resultant values derived by the three-component excretion equation. One laboratory mouse study was of 57 days duration, with the remaining two studies terminating at approximately day 37 and 38 of excretion. Although I extrapolated the data by three-component equations to day 100 (Table 4), the data cannot be adequately extrapolated beyond the termination of each experiment. For example, Richmond et al. (1962) show a consistent divergence after day 27, with the actual data indicating a greater retention than predicted by their equation,

Table 4. Effect of mode of entry upon ^{137}Cs retention in Peromyscus leucopus and the laboratory mouse (Mus musculus).

Day of Excretion	^{137}Cs Retention (%)			
	P. leucopus	M. musculus		
	Chronic Oral Food[a]	Chronic Oral Water[b]	Acute Injection Saline[c]	Acute Injection Saline[d]
0	100.00	99.89	100.00	99.90
1	75.67	57.77	53.03	60.59
2	60.46	44.13	35.77	44.04
3	49.72	36.98	27.16	34.93
5	33.86	27.51	17.64	24.02
8	19.57	18.16	10.18	14.63
15	6.67	7.29	3.61	5.29
22	2.89	3.09	1.55	2.15
29	1.83	1.34	0.71	0.93
36	1.19	0.59[e]	0.34	0.41[e]
43	0.96	0.26	0.16	0.18
49	0.80	0.13	0.08	0.09
57	0.45	0.05	0.04[e]	0.04
71	0.32	0.01	0.008	0.007
85	0.26	0.002	0.002	0.001
100	0.21	0.0004	0.0004	0.0003

[a]From this study, terminated on day 100 of excretion.

[b]From Richmond et al. (1962), terminated on day 37 of excretion.

[c]From Richmond (1958), terminated on day 57 of excretion.

[d]From Furchner and Richmond (1963), terminated on day 38 of excretion.

[e]Values after line are extrapolations from authors' data.

usually indicative of the presence of another component in the equation.

Another difference in retention occurred during the first 8 days of excretion, when chronically-fed white-footed mice had a much greater retention than injected laboratory mice. This difference in retention apparently reflected the mode of entry into the animal. Injected mice showed a more rapid excretion during the first few days than chronically-fed animals. Thus, it appeared that the curves between and within these two species were not consistent, probably due to differences in the mode of entry into the animal.

7. "Mirror Image" of Uptake and Retention of ^{137}Cs

Respective parameters for uptake and retention data varied considerably, even for the same treatment combination. This prompted an examination of the chronic uptake curve superimposed over the inverse of the retention curve (Fig. 9). Although the apparent differences between the two curves were not great, it is clear that the gastrointestinal compartment acquired radioactivity more rapidly than expected from the inverse of the retention data. The differences were more apparent when subjected to computer analysis. Both curves were analyzed by the same two-component uptake equation with the following results:

$$A_t = 98.69 - 11.08\ e^{-1.500t} - 87.59\ e^{-0.196t},$$

for excretion, and

$$A_t = 100.38 - 69.66\ e^{-0.475t} - 30.70\ e^{-0.064t},$$

for uptake. The importance of these differences will be considered in the Discussion.

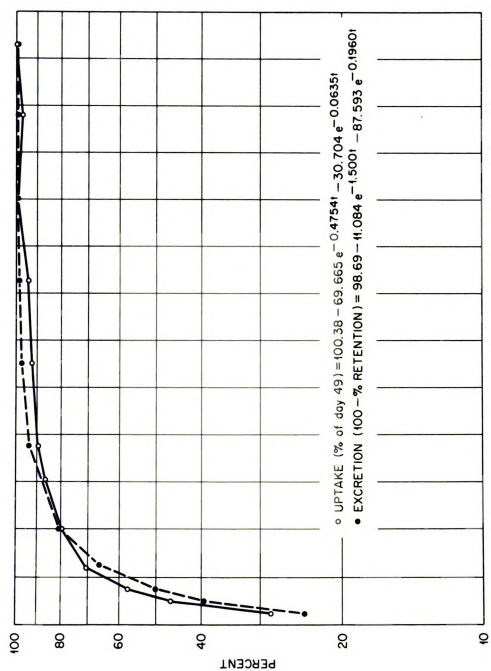

Figure 9. "Mirror image" of ^{137}Cs uptake and excretion in Peromyscus leucopus during and after 49 days chronic ingestion of Pinus strobus seeds. Uptake curve based on day 49 radioactivity = 100%; excretion data based upon 100% - % retention from day 0 of excretion.
N = 96 during uptake and N = 64 during excretion.
Data summarized from Table B-7 for uptake, and Table 4 for excretion.

8. Ratio Between ^{137}Cs and ^{60}Co

An extremely interesting and useful parameter found in this study was the ratio between the radioactivity of these two isotopes. For convenience, this will be referred to as the Cs/Co ratio and is a dimensionless number. This parameter had a characteristic pattern in white-footed mice fed chronically on tagged pine seeds (Fig. 10). During isotopic uptake, this ratio resembled the ^{137}Cs uptake pattern, and increased up to a maximum of about 1.5 after 49 days of chronic feeding. The pattern after the first three days of excretion was more similar to the ^{60}Co excretion curve and was still decreasing at 100 days of excretion.

The immediate value of this parameter, for my purposes, was to enable a determination of elapsed time since the last ingestion of pine seeds. The cause of fluctuation in this ratio was the mode of excretion of the two isotopes (Fig. A-5). Decrease of ^{137}Cs was almost linear for the first 30 days of excretion, compared to a much more rapid decrease in ^{60}Co, which created a very rapid peaking of the Cs/Co ratio during the first few days of excretion. As field animals were fed once weekly, versus the once-daily feeding in laboratory-maintained mice, the rapid fluctuation in this ratio during the first three days of excretion enabled determination of a correction factor for day of excretion in the field animals.

Results of the Cs/Co ratio emphasized the differences in mode of excretion for ^{137}Cs and ^{60}Co, and allowed a determination of the day of excretion for white-footed mice.

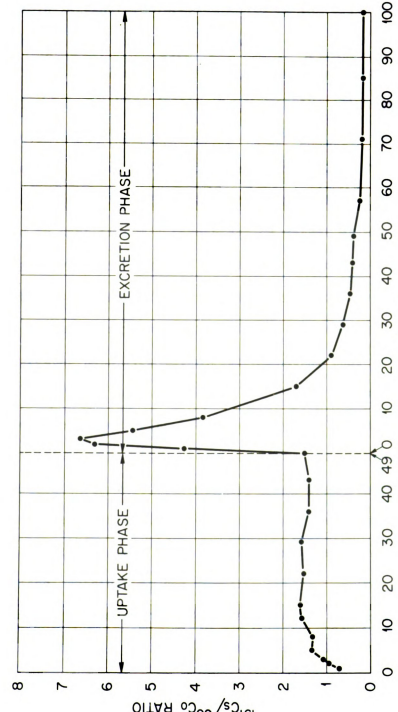

Figure 10. Mean $^{137}Cs/^{60}Co$ ratio in Peromyscus leucopus during and after 49 days chronic ingestion of Pinus strobus seeds. Data from Table B-9.

9. Tissue Distribution of Radioisotopes

Muscle is generally considered to be the critical organ for dose estimates of ^{137}Cs due to a slow excretion by that compartment (ICRP, 1960). The lower large intestine is generally considered to be the critical organ for ^{60}Co (Smith et al., 1971). Distribution of ^{137}Cs and ^{60}Co in organs or tissues of white-footed mice at equilibrium was measured (Table 5). To compare distributions for various tissues, the percent of equilibrium body burden appearing in each tissue was compared to that tissue's percentage by weight of the whole body, based upon oven-dry weights. If there was perfect correlation of the isotope to weight of the tissue, a ratio of 1.0 was expected. Tissues accumulating more radioactivity than average were those with ratios greater than 1.0; tissues accumulating less radioactivity than average had ratios less than 1.0. For ^{137}Cs, the most divergent organ was the bladder with 6.4 times more ^{137}Cs than expected on the basis of a 1.0 ratio. Other organs or tissues with ratios greater than 1.0 for ^{137}Cs were, in decreasing order of importance: testes, muscle, kidneys, intestinal contents, heart, and brain. Tissues which accumulated less ^{137}Cs than average were, in decreasing order: skin, blood, epididymis, and femur.

Samples accumulating ^{60}Co were, in order: cecum content, large intestinal content, stomach content, cecum, bladder, large intestine, and small intestinal content. Nearly all of the tissues accumulated less than expected concentrations of ^{60}Co, except for the bladder, gastrointestinal tract tissues, kidneys, spleen, and ovaries.

Table 5. Distribution of oven-dry weight, ^{137}Cs, and ^{60}Co in organs or tissues of Peromyscus leucopus after 49 days of chronic feeding of Pinus strobus seeds in the laboratory.

Organ or Tissue	N	Weight[a] (%)	Radioactivity In Organ (% ± 1 S. E.)[b] ^{137}Cs		^{60}Co	
Blood[c]	23	1.48	0.63	± 0.04	0.56	± 0.34
Heart	31	0.54	0.81	0.03	0.22	0.04
Liver	31	4.81	5.17	0.22	3.94	0.54
Spleen	31	0.09	0.12	0.01	0.13	0.03
Kidneys	31	1.14	2.12	0.06	1.74	0.16
Lungs	31	0.72	0.76	0.05	0.28	0.07
Muscle[d]	31	0.40	1.08	0.04	0.12	0.03
Femur	31	0.46	0.27	0.02	0.15	0.04
Brain	31	1.79	1.97	0.07	0.14	0.03
Testes	16	0.92	2.84	0.15	0.42	0.06
Ovaries	14	0.10	0.09	0.02	0.12	0.03
Epididymis	13	2.98	1.38	0.13	0.46	0.10
Urogenital	15	0.84	0.68	0.12	0.24	0.06
Bladder	24	0.07	0.45	0.12	0.18	0.05
Skin	31	20.74	7.93	0.38	1.68	0.18
Carcass[e]	31	55.02	63.99	0.83	5.66	0.58
Stomach	31	0.88	0.82	0.07	0.91	0.21
Sm. intestine	31	0.51	0.45	0.04	0.74	0.12
Lg. intestine	31	0.32	0.28	0.03	0.64	0.07
Cecum	31	0.23	0.17	0.02	0.67	0.08
Gastrointestinal contents:						
Stomach	31	3.21	2.57	0.38	19.34	1.75
Sm. intestine	31	1.68	2.90	0.21	3.49	0.34
Lg. intestine	31	1.69	2.95	0.16	24.41	1.70
Cecum	31	1.87	2.12	0.16	34.52	1.65
Totals:						
Tissue	31	91.53	89.46	0.46	18.24	1.86
Gastrointestinal contents	31	8.47	10.54	0.46	81.76	1.86

[a]Body weight percentages from Table B-10.

[b]Percent of whole-body radioactivity.

[c]Blood sample from thoracic cavity.

[d]Gastrocnemius muscle only.

[e]Residual carcass after removal of the listed organs.

A chi-square test was performed on the distribution data to determine if the ratio of (% of total ^{137}Cs in tissue/% of total body weight in tissue) differed from an expected ratio of 1.0 (Table B-11). When all means were combined in one analysis, the statistic was 39.86, and significant. Values for individual tissues varied from 0.0 to 4.5, except for the bladder, which contributed 28.92 to the total chi-square. The bladder was emptied but not washed during preparation, and urine contamination was suspected for this organ. If the bladder was eliminated from the analysis, the statistic was 10.95, and nonsignificant. The conclusion of this analysis was that ^{137}Cs distribution was proportional to the dry weight of the organ or tissue considered, with the exception of the bladder.

A similar analysis was performed for ^{60}Co. The chi-square statistic was significant when all tissues and gastrointestinal contents were combined, but became nonsignificant when only tissues were considered (gastrointestinal contents not included).

Distribution of ^{137}Cs at equilibrium in white-footed mice appeared to be directly proportional to the oven-dry weight of the organ or tissue considered. Distribution of ^{60}Co was clearly associated with the gastrointestinal contents.

B. Environmental and Biotic Factors in an Oak-hickory Forest

1. Climate and Vegetation

Meteorological data for each field plot were summarized during the study and compared with the ORNL (X-10 site) weather station

data in Table 6. The mean yearly temperature was 13.6 C and was 1.1 C below normal. Winter temperatures averaged 3.0 C below normal. Yearly precipitation averaged 135.66 cm, and was slightly greater than normal, with a dry autumn offset by a wet spring. Relative humidity has not been recorded for the X-10 weather station or nearby stations, but a yearly mean of 83% was recorded on one field plot. Wind speed during the winter was less than normal. The weather during the study year was considered within the range of variability for the Oak Ridge area.

Vegetational characteristics on the three field plots were summarized in Table 7. Trees in these plots averaged 24.6 $\pm$ 0.8 cm dbh, 21.0 $\pm$ 0.5 m total height, and a basal area of 26.9 $\pm$ 2.0 m^2/ha for all trees over 2.5 cm dbh. The species composition was similar to Braun's (1950) description of this oak-hickory type, with the exception of greater amounts of yellow poplar, black gum, and shortleaf pine (Table B-12). Understory species were typical of this area and complete species lists have been prepared (Olson *et al.*, 1966).

2. Species Trapped on the Field Plot

A total of 6,419 trap nights was spent live-trapping animals on both the control and live-trap plots (Tables 8 and 9). Two-hundred and three mammals of all species were captured 683 times (10.64/100 trap nights) over a period of 19 months. Short-tailed shrews comprised 51% of total captures, white-footed mice totaled 38%, and eastern chipmunks made up 8%. The remaining 3% were pine voles (*Microtus pinetorum*) and southern flying squirrels (2 and 1%, respectively).

Table 6. Comparison of climatic data during the study with normal data from the ORNL weather station (X-10 site).

Item	Location	Period of Record	Season				
			Autumn	Winter	Spring	Summer	Year
Average Temp (C)	X-10	Normal	9.63	6.26	19.22	23.89	14.75
	X-10	69-70	9.78	2.58	18.10	24.52	13.75
	Con[a]	69-70	10.00	3.19	18.75	23.59	13.88
	L-t[a]	69-70	9.64	3.40	17.77	23.17	13.50
	S-t[a]	69-70	9.48	3.26	17.76	23.32	13.45
Maximum Temp (C)	X-10	Normal	32.78	30.56	37.22	39.44	39.44
	X-10	69-70	29.44	25.00	34.44	36.67	36.67
	Con	69-70	27.80	23.30	33.40	33.20	33.40
	L-t	69-70	26.70	24.70	32.40	32.40	32.40
	S-t	69-70	26.20	22.40	30.70	32.30	32.30
Minimum Temp (C)	X-10	Normal	-20.56	-22.22	-4.44	0.56	-22.22
	X-10	69-70	-7.78	-17.78	-3.33	10.00	-17.78
	Con	69-70	-8.10	-17.80	-1.40	13.30	-17.80
	L-t	69-70	-8.80	-19.00	-5.90	13.00	-19.00
	S-t	69-70	-8.10	-17.60	-1.40	13.80	-17.60
Total Precipitation (cm)	X-10	Normal	29.29	40.82	27.94	32.82	130.86
	X-10	69-70	17.14	36.07	37.69	26.16	117.07
	Con	69-70	20.35	40.79	40.97	33.32	135.43
	L-t	69-70	19.48	39.90	42.39	33.63	135.41
	S-t	69-70	19.96	42.77	44.22	29.36	136.32
Average Relative Humidity (%)	L-t	69-70	82.96	81.24	79.15	88.58	82.98
Average Wind Speed (km/hr)	X-10	Normal	4.7	6.1	5.1	3.7	4.9
	X-10	69-70	4.1	2.8	3.8	2.8	3.4
Average Wind Direction	X-10	Normal	NE	NE	SW	NE	NE
	X-10	69-70	NE	NE	SSW	NE	NE

[a]Con = control; L-t = live-trap; and S-t = snap-trap field plot.

Table 7. Mean vegetational characteristics by size class on the control, live-trap, and snap-trap field plots. Species listing in Table B-12.

Item	Size Class (dbh in cm)	Field Plot (mean ± 1 S. E.) Control	Live-trap	Snap-trap	Mean
Basal Area (m^2/ha)	2.4-12.6	3.65 ±0.34	3.23 ±0.53	2.73 ±0.42	3.21 ±0.25
	12.6-27.8	11.12 1.85	7.83 1.26	6.72 1.50	8.56 0.93
	> 27.8	10.28 2.73	18.35 4.15	16.85 4.28	15.16 2.21
	Total	24.96 2.50	29.40 3.92	26.30 3.88	26.89 1.98
Number of Trees/ha	2.4-12.6	1,050 ±62	950 ±152	1,020 ±125	1,007 ±67
	12.6-27.8	360 45	260 37	240 37	287 24
	> 27.8	120 33	170 26	170 37	153 18
	Total	1,530 87	1,380 131	1,430 125	1,447 66
Average dbh (cm)	> 12.6	22.73 ±1.04	25.83 ±1.60	25.35 ±1.50	24.56 ±0.79
Average Height (m)	> 12.6	20.4 ±0.5	20.1 ±0.9	22.5 ±1.0	21.0 ±0.5
Ground Cover (%)	0-30[a]	20.51[b]	23.57	39.39	27.82
	30-122[a]	20.31	18.88	35.51	24.90
	122-2.4[c]	21.84	19.08	43.67	28.20

[a]Size class by height in cm.

[b]Replicated visual estimates of percent cover on 100 plots gave a S. E. of ± 1.4% over all size classes.

[c]Size class from 122 cm height to 2.4 cm dbh.

Table 8. Seasonal trapping summary of Peromyscus leucopus, Blarina brevicauda, and Tamias striatus on the live-trap and control field plots.

Period or Season	Total Trap Nights	Total Captures P.l.	B.b.	T.s.	Total	Blarina Mortality (%)	Total Individuals P.l.	B.b.	T.s.	Total
				Live-trap plot						
Prestudy	240	10	6	1	17	0.00	5	6	1	12
Uptake[a]	847	28	37	3	68	5.41	12	14	2	28
Autumn	796	13	48	4	65	10.42	7	21	4	32
Winter	284	13	26	1	40	3.85	6	20	1	27
Spring	450	20	20	3	43	10.00	8	15	3	26
Summer	458	27	16	11	54	0.00	9	11	6	26
Excretion[b]	512	40	89	9	138	6.74	23	37	5	65
Totals:	3,587	151	242	32	425	6.61	46	78	14	138
				Control plot						
Prestudy	240	6	4	0	10	50.00	4	4	0	8
Uptake[a]	734	44	23	6	73	27.27	8	12	2	22
Autumn	623	43	21	1	65	23.81	12	13	1	26
Winter	335	13	1	0	14	0.00	7	1	0	8
Spring	450	49	0	0	49	0.00	17	0	0	17
Summer	450	36	5	2	43	0.00	8	1	1	10
Totals:	2,832	191	54	9	254	24.53	32	26	3	61
Grand totals	6,419	342	296	41	679	9.83	78	104	17	199

[a]Period from July 24, 1969 to September 25, 1969.

[b]Period from September 1, 1970 to December 10, 1970, on the live-trap plot only.

Table 9. Percent distribution of trapping effort and captures of Peromyscus leucopus and Blarina brevicauda at various field locations. Data summarized by period or season on the live-trap and control plots. Refer to Table B-13 for captures per 100 trap nights.

Period or Season	Live-trap Plot Trapping at: Feeder	Nest Box	Stake[a]	Control Plot Trapping at: Nest Box	Stake[a]
	Trapping effort (%)				
Prestudy	53.33	0.00	46.67	0.00	100.00
Uptake[b]	30.22	20.66	49.12	20.98	79.02
Autumn	32.16	17.59	50.25	19.10	80.90
Winter	33.80	19.72	46.48	25.07	74.93
Spring	28.44	21.78	49.78	21.78	78.22
Summer	34.94	15.28	49.78	21.78	78.22
Total:	33.30	17.53	49.17	19.53	80.47
	Peromyscus leucopus captures (%)				
Prestudy	70.00	0.00	30.00	0.00	100.00
Uptake[b]	42.86	28.57	28.57	34.09	65.91
Autumn	7.69	23.08	69.23	39.53	60.47
Winter	46.15	38.46	15.39	53.85	46.15
Spring	35.00	35.00	30.00	42.86	57.14
Summer	29.63	22.22	48.15	27.78	72.22
Total:	36.94	26.12	36.94	36.65	63.35
	Blarina brevicauda captures (%)				
Prestudy	83.33	0.00	16.67	0.00	100.00
Uptake[b]	51.35	24.32	24.33	17.39	82.61
Autumn	52.08	18.75	29.17	33.33	66.67
Winter	88.46	0.00	11.54	100.00	0.00
Spring	60.00	10.00	30.00	0.00	0.00
Summer	68.75	0.00	31.25	60.00	40.00
Total:	62.09	13.07	24.84	27.78	72.22

[a]Aluminum stake only, no nest box or feeder present.

[b]Period from July 24, 1969 to September 25, 1969.

Autumn captures of mice in the live-trapping plot were low despite the relatively large number of trap nights (Table B-13). It was felt that mice became trap-shy during this period, since signs of mouse activity were found on trap doors, but mice did not enter the traps. The trap-shyness hypothesis was supported by the capture locations during autumn, 1969 (Table 9). Mice appeared to be trapped in accordance with the proportional distribution of trapping effort during all seasons except autumn, when captures at feeder locations were much lower than expected. This was probably associated with the abundance of natural foods during this period, or possibly correlated to the increase in human activities on the plot. Trapping effort during the winter season was severely restricted due to low temperatures, and captures were low. The proportional distribution of captures returned to normal during this period.

The shrew population on the control plot essentially disappeared during winter and had not returned by the end of the following summer. The cause for the shrew disappearance was not apparent, since I had good success in trapping shrews and keeping them alive. Out of 296 captures of shrews during this study, only 29 individuals were either found dead in the trap, or succumbed before they could be returned to the field (Table 8). Not all of these were victims of their metabolic demands or exposure, as 7 out of these 29 shrews were killed by the trap door closing on them. Four shrews were captured at least 12 times during 13 months of trapping (Table B-14). And 20 shrews were captured two consecutive days without mortality. Such results were unexpected since many studies have reported high mortality rates

among captured shrews.

The maintenance of a shrew population through winter appeared to be correlated with the availability of added pine seeds. Both the live-trap and snap-trap plots maintained high populations of shrews, as evidenced by trapping success and fecal remains in the feeders. Shrew captures on the live-trap plot were not in proportion to the trapping effort at various sites, but occurred twice as frequently as the trapping effort at feeder locations. Whatever the reason for the loss of shrews on the control plot, I do not believe that they were eliminated by trapping. No signs of their activity could be found during this period on the control plot.

3. Disappearance of Pine Seeds from Feeders

The disappearance of seeds from feeders was estimated weekly during the field study (Fig. 11). A total of 18,713 g of seeds was removed or consumed in feeders on the live-trap plot compared to 23,622 g on the snap-trap plot. This represented 74% utilization of the total available seeds on the live-trap plot and 94% on the snap-trap plot (mean for both plots was 84%).

Collections of seeds from 330 feeders (containing whole seeds only) were brought to the laboratory after exposure on the plot for 7 days, and weighed to determine the error of visual estimates of feeder usage (Table B-16). On the basis on each 25% class of feeder usage, estimates were within 0.3 g of actual weight. Offsetting errors in various use classes would reduce the total error of each weekly estimate, as the sum of all visual estimates was within 0.16%

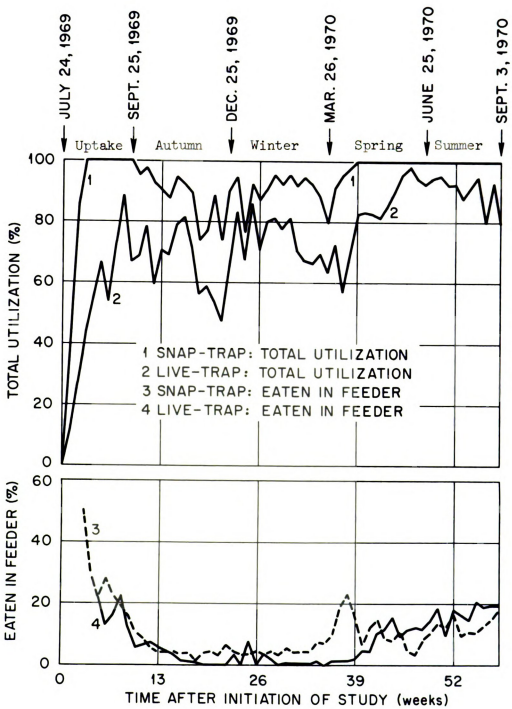

Figure 11. Weekly Pinus strobus seed utilization and ingestion in feeders by small mammals on the live-trap and snap-trap field plots.
Data from Table B-15.

of the actual weight. Another check was made during the third week of feeding. All uneaten seeds were separated from fragments of eaten seeds and weighed. The visual estimate of whole uneaten seeds was 235 g compared to an actual weight of 242 g, or an error of 2.9%. It was felt that the visual estimates of weekly seed usage were within 5% of the actual values.

Percent utilization of seeds rapidly increased during the uptake portion of the study (July 24 to September 25, 1969). Animals on the snap-trap plot consistently utilized approximately 20% more seeds than did animals on the live-trap plot throughout the year, with less than 100% utilization occurring only in autumn and winter on the snap-trap plot. A sign test was performed on the weekly trend of percent utilization during this period when populations on both plots utilized less than 100% of the available seeds. A (+) was assigned if utilization on both plots either increased or decreased the same week; a (-) was assigned if the trends differed. The result of this test was significant, indicating that both populations were behaving similarly in terms of percent utilization (Fig. 11 and Table B-15). Apparently an exogenous influence, such as weather, was acting on both populations so that if seed utilization changed on one plot, it also changed in a similar manner on the other plot. The overall greater utilization by the snap-trap population, however, compared to the live-trap population, indicated a higher population on the snap-trap plot.

Percent of seeds eaten in feeders was also estimated weekly for both plots (Fig. 11). After the first two weeks, the amount of seeds eaten in feeders rarely exceeded 20% of the total amount utilized.

One noticeable and abnormally high period occurred during mid-April, 1970 on the snap-trap plot. At this time a new power line right-of-way adjacent to an established power line was being cleared. When the clearing and burning was closest, within a few hundred meters of the plot, the small mammal population was incremented by numerous pine voles, presumably from the old right-of-way. A snap-trap period in March, 1970 removed more pine voles than any other species, and was the only time that this occurred on any of the field plots. Thus, pine voles apparently were consuming seeds in the feeders.

In order to identify consumers, feeder remains were compared with seed coat fragments from granivores fed in the laboratory, using techniques of Fitch (1954) and Kangur (1954). In almost all cases, when a quantity of seeds was eaten in a feeder, the fragments were similar to seeds shelled by mice. In general, shrews apparently removed entire seeds from the feeders (also observed in the laboratory). Mice and voles either removed seeds or consumed them in the feeders (Fig. 4).

Evidences of shrew activities began to appear around nearly every feeder during the first month of the study. These included excavation of underground tunnels to the vicinity of, or under, feeders; formation of tunnels in the litter layer (Fig. 12); seed fragments similar to shrew shelling, which were detectable in the tunnels with a scintillometer; and fecal remains inside the feeders. The reduction in the amount of seeds eaten in feeders during the first few weeks of the study (Fig. 11) appeared to be correlated with the

Figure 12. Tunneling activities of the short-tailed shrew adjacent to a feeder (bottom left) in the live-trap plot.

initiation and presence of shrew activities around feeders. The gradual increase in amounts of seeds eaten in feeders during the summer of 1970 reflected an increasing size of the mouse populations.

C. Radioisotopic Body Burdens for Small Mammals in an Oak-hickory Forest

1. Body Burdens in White-footed Mice

Background levels found in white-footed mice prior to the study (sampled from March to July, 1969) averaged 2 dpm/g for ^{137}Cs and 8 dpm/g for ^{60}Co. After feeding of radioactive seeds began on July 24, 1969, mice rapidly acquired significant radioactivity ranging from 20 to 50 dpm X 10^3/g for ^{137}Cs (Fig. 13). The ^{60}Co data were more variable than that for ^{137}Cs in the field animals and were not used to characterize body burdens throughout the year. The seasonal pattern was similar to that of ^{137}Cs (Table B-17).

Mice continued to increase in radioactivity up to the maximum (125 dpm X 10^3/g) observed during the study near the end of September, 1969. Considering that mice in the laboratory equilibrated within 15 days at a specific feeding rate, it appeared that this 62-day period (from July to September, 1969) in the field would have been more than sufficient for these mice to have equilibrated also. As live-trapped mice continued to increase in radioactivity after the first 15 days, it was assumed that their diet was changing during this period to include an increasingly greater proportion of tagged pine seeds.

After the end of September, 1969, mice rapidly decreased to

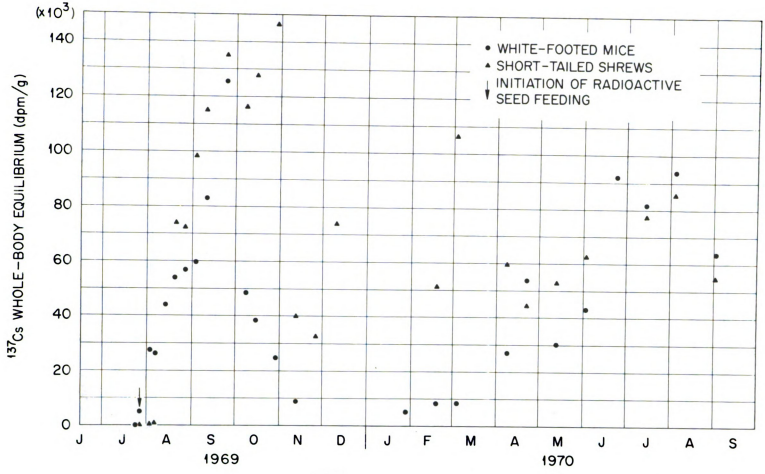

Figure 13. Mean whole-body burden of ^{137}Cs per trapping period for Peromyscus leucopus and Blarina brevicauda on the live-trap field plot containing Pinus strobus seeds. Only individuals known to have been present for more than 15 days were included in means. Data from Table B-17.

approximately 50 dpm X 10^3/g, for ^{137}Cs, or less than half their previous equilibrium levels. This was observed for individual mice as well (Fig. B-3). Mean daily temperatures were decreasing during autumn, at the same time that a better-than-average mast crop became available on the ground. The effect of temperature, as determined in the laboratory, was not pronounced and did not appear to be sufficient to create the large decrease in ^{137}Cs equilibria. The decrease appeared to be correlated more with a change in food habits than to the effect of lowered temperature.

A systematic examination of nest boxes was made on December 31, 1969, to determine if pine seeds were being cached on the snap-trap plot. Of 49 nest boxes examined, 24.5% contained nothing, 14.3% contained nesting material or mice, 2.0% contained remains of pine seeds, 67.3% contained hickory nuts, and 4.1% contained acorns. The average number of hickory nuts was 11.1 per nest box used for storage (Fig. 14). The prevalence of hickory nuts may have indicated either a preference by mice for these foods over any other available food, or removal of this food to locations where it could be more thoroughly worked. Storage of pine seeds had been expected, as clear plastic feeders were used in an attempt to encourage mice to remove and store pine seeds. It was probable that mice ate pine seeds at feeders or other adjacent feeding sites, rather than returning to nest boxes to consume them. Feeders were located a maximum distance from the nest boxes (14.4 m), and closer and more numerous escape avenues were revealed when mice were released near feeders and ran to nearby hiding places.

Figure 14. Food storage by Peromyscus leucopus in a nest box. Foods are mostly hickory nuts (pignut and mockernut) with a few sunflower seeds. Sunflower seeds were used as trap bait. Small nest in upper right corner of the nest box. Hickory nut in glove shows typical chewing.

Whole-body equilibria in mice continued to decline after the September, 1969 peak, to a low of 5 dpm X 10^3/g for ^{137}Cs occurring in January, 1970. By April, consumption began to increase significantly above the winter minimum and had returned to approximately 90 dpm X 10^3/g for ^{137}Cs by the end of June, 1970, which was nearly equivalent to the levels of September, 1969. This maximum rate of ingestion continued until feeding was terminated on September 1, 1970.

The snap-trap plot was used to sample animals through each season in order to determine distribution of the isotopes at equilibrium levels in mouse tissues. The total population of small mammals apparently was denser on this plot, based upon the 20% greater utilization of feeder contents. Trapping success was low in this plot until traps were placed at feeder locations near the center of the plot (Table B-18). Thereafter, success was comparable to the live-trap plot, but I felt that the trapping success did not reflect the true population level, even though a total of 51 small mammals were removed from the 2-ha plot over the span of one year. Trapping success may have reflected a difference between the efficiency of live-traps compared to snap-traps.

Of the 51 captures on the snap-trap plot, 7 snap-trapped mice were sampled for tissue distribution of radioisotopes to determine whether the contents of their gastrointestinal tracts contained a similar amount of radioisotopes as did mice sacrificed in the laboratory (Table 10). Although the sample size was small, the agreement of organ weight and ^{137}Cs tissue distribution between laboratory and field was readily apparent (compare to Table 5). Cobalt-60 differed

Table 10. Distribution of oven-dry weight, ^{137}Cs, and ^{60}Co in organs or tissues of Peromyscus leucopus after chronic feeding of Pinus strobus seeds on the snap-trap field plot.

Organ or Tissue	N	Weight[a] (%)	Radioactivity in Organ (% ± 1 S. E.)[b] ^{137}Cs		^{60}Co	
Heart	6	0.64	0.74 ±	0.08	0.61 ±	0.10
Liver	6	4.74	5.02	0.58	11.65	1.56
Spleen	5	0.17	0.26	0.03	0.17	0.03
Kidneys	6	1.16	1.64	0.14	2.46	0.22
Lungs	6	0.95	1.12	0.18	0.64	0.07
Muscle[c]	6	0.63	1.09	0.10	0.22	0.06
Femur	6	0.55	0.35	0.04	0.16	0.03
Brain	6	2.11	2.36	0.43	0.27	0.04
Testes	2	0.77	1.99	1.67	1.06	0.91
Ovaries	3	0.08	0.06	0.02	0.16	0.11
Epididymis	2	5.02	2.78	0.67	6.95	4.92
Urogenital	3	0.45	0.31	0.20	0.30	0.06
Bladder	5	0.08	0.17	0.10	0.16	0.06
Skin	6	17.31	9.99	1.58	3.84	0.37
Carcass[d]	6	54.38	60.91	2.52	18.94	3.41
Stomach	6	1.03	0.57	0.15	0.76	0.09
Sm. intestine	6	0.54	0.50	0.17	0.57	0.11
Lg. intestine	6	0.24	0.17	0.05	0.45	0.09
Cecum	6	0.21	0.21	0.06	1.10	0.43
Gastrointestinal contents:						
Stomach	6	8.06	2.49	0.50	11.90	7.45
Sm. intestine	6	2.44	3.79	0.61	4.02	0.99
Lg. intestine	6	1.15	3.03	0.78	7.05	1.63
Cecum	6	1.72	3.91	0.79	32.18	8.74
Totals:						
Tissue	6	86.64	86.79	1.73	44.86	6.00
Gastrointestinal contents	6	13.36	13.21	1.73	55.14	6.00

[a]Body weight percentages from Table B-19.

[b]Percent of whole-body radioactivity.

[c]Gastrocnemius muscle only.

[d]Residual carcass after removal of the listed organs.

considerably in distribution between tissues and gastrointestinal contents. The diminution of ^{60}Co in the gastrointestinal tracts of field animals indicated a dilution of radioactive food with a greater amount of uncontaminated food than found in the laboratory animals. This lower gastrointestinal concentration was also indicated by the Cs/Co ratio, which was slightly higher in the field than in the laboratory (1.99 and 1.50, respectively), meaning that more of the ^{60}Co had been passed through the tract than for a comparable day of excretion in the laboratory.

Mice captured from the live-trap plot had been excreting radioisotopes for one-half to one day longer than snap-trapped mice, although the interval between feeding and trapping was identical. This conclusion was derived from 15 recaptures of old resident mice on two consecutive days during a trapping period (Table B-20). Mean Cs/Co ratios were 3.41 on the first day and 5.28 on the second day. This general trend was normally found during the first three days of excretion, and consisted of a decrease in body burdens of both radioisotopes, but an increase in the Cs/Co ratio. Thus, the mice trapped in the field were not at equilibrium, but at some point during the first few days of excretion, and their whole-body radioactivity required correction before estimating seed consumption rates.

To summarize, the white-footed mouse population had varying body burdens of ^{137}Cs, with a maximum of 125 dpm X 10^3/g occurring just prior to availability of the 1969 mast crop. Minimal body burdens of 5 dpm X 10^3/g occurred from January through March, 1970, and then increased to 90 dpm X 10^3/g through summer, 1970. Tissue

distribution of ^{137}Cs was similar to that observed in the laboratory, whereas ^{60}Co apparently was diluted in the gastrointestinal tract by consumption of other foods. The Cs/Co ratio indicated that mice were not at equilibrium when captured in the field but had been excreting radioisotopes for about one day.

2. Body Burdens in Short-tailed Shrews

A totally unexpected result of the field study was the high body burdens of radioisotopes acquired by the short-tailed shrew. Background levels found in shrews prior to the study averaged 3 dpm/g for ^{137}Cs and 15 dpm/g for ^{60}Co. Initial uptake of ^{137}Cs occurred about two weeks later than in mice (refer to Fig. 13). This lag apparently was correlated to the period of time when shrews were extending their tunnel systems and locating feeders. A rapid increase from background levels up to 70 dpm X 10^3/g for ^{137}Cs occurred in mid-August, 1969, and body burdens continued to increase up to the maximum of 145 dpm X 10^3/g by the end of October, 1969. Winter levels of radioactivity fluctuated greatly and did not decrease drastically as did radioactivity in mice (Fig. B-4). In general, the body burdens averaged 70 dpm X 10^3/g for winter, spring, and summer without a great amount of variation. In comparison to the mice, shrews had lower body burdens in late spring and summer of 1970, and higher body burdens during autumn and winter.

Cs/Co ratios were examined in 20 shrews captured twice during the two-day trapping periods. The mean Cs/Co ratio was 4.00 on the first day and 3.98 on the second day (Table B-21). These ratios

were similar to those observed in mice (3.41 on the first day and 5.28 on the second) but were more erratic, and shrews apparently had been excreting radioisotopes for several days.

There were three potential sources of radioactivity for shrews: seeds, mice, and insects. To determine whether short-tailed shrews would consume pine seeds in the laboratory, a single treatment combination (22 C and 10 seeds per day) with four shrews was initiated in May, 1970 (Fig. 15). For comparison, mean uptake and excretion of ^{137}Cs were plotted with the appropriate mouse data for the same treatment combination. The similarities in the uptake curve indicated that shrews did consume pine seeds. This was also confirmed by direct observation.

Initial uptake proceeded more slowly in these shrews, primarily due to only two of the four shrews ingesting any seeds before day 3. By day 5 of uptake, shrews contained more ^{137}Cs than did mice. Body burdens of shrews continued to exceed those of mice throughout the uptake period. The Cs/Co ratio in shrews was 4.00 compared to 1.50 for mice. The higher ratio in shrews was thought to be correlated with the shorter length of the gastrointestinal tract compared to that of mice. Total length in shrews was 273 $\pm$ 15 mm compared to 416 $\pm$ 29 mm for mice (Dunaway, 1971). Excretion proceeded at a faster rate in shrews than in mice (Fig. 15), which may reflect a difference in size of the animals, or general differences in metabolic rates between these two species. Thus, shrews did ingest pine seeds, even when offered sufficient volumes of alternative foods in the laboratory.

Although these shrews were fed limited quantities of mouse meat,

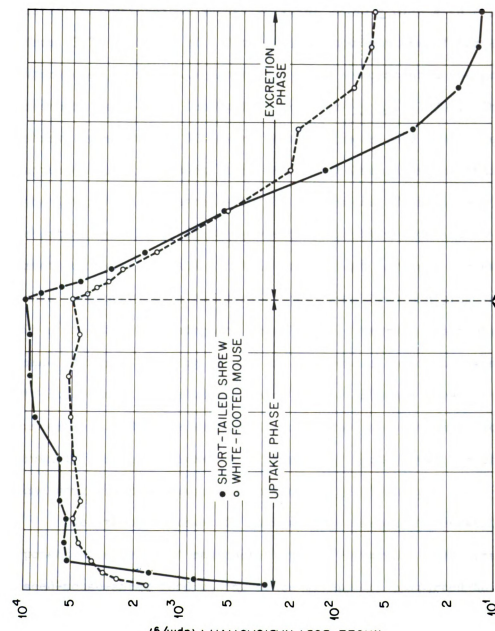

Figure 15. Mean accumulation and retention of ^{137}Cs under laboratory conditions in short-tailed shrews and white-footed mice chronically ingesting 10 Pinus strobus seeds at 22 and 21.1 C, respectively. Data from Tables B-22 and B-34.

in the range of 10-20% of their body weight per day, they were obese throughout the study. Mean weight of shrews captured in the field was 12.34 ± 0.10 g (N = 290, range from 8.78 to 17.68 g), compared to laboratory-maintained shrews weighing 20.48 ± 0.39 g (N = 96, range from 13.79 to 27.28 g). Pathological examinations of three shrews which died during this laboratory study demonstrated the presence of necrotic fat bodies internally (Cosgrove et al., 1970). Thus, these shrews on a limited diet were obtaining more food than necessary and appeared to have a much lower mean metabolism than was indicated by the literature. I agree with the conclusion of Martinsen (1969) that short-tailed shrews can be adequately maintained on a diet of mouse meat equivalent to 10% of their body weight per day. Shrews kept in this laboratory were hoarders of both sunflower and pine seeds, even when provided with adequate mouse meat. Numerous observations were made of shrews storing seeds, and the general procedure was for a shrew to locate a single seed and carry it to a storage location (usually under sod). Storage was usually continued until no more seeds were readily located. Shrews were singularly occupied with storing seeds and would continue even when purposefully disturbed.

Even though shrews did consume pine seeds, the remaining two potential sources of radioactivity were examined. The first was the seed-mouse-shrew food chain, since shrews are purported to be voracious killers of mice and voles (Babcock, 1914). For example, Martinsen (1969) reported that "...a 17-g shrew killed a 37-g vole in 18 min." An adjunctive study by a 1970 Oak Ridge Associated Universities Summer Research Participant examined the transfer of ^{137}Cs and ^{60}Co from

white-footed mice into the short-tailed shrew (Kokx and Dunaway, in prep.). These shrews did not acquire body burdens equivalent to those of mice; in fact, the concentration factor, based upon dpm/g under equilibrium conditions, was less than 1.0 from mouse to shrew. The Cs/Co ratio in shrews which were fed mice averaged 68 (Kokx, 1971), a value which was four times greater than all field-trapped shrews, except for one individual. The combination of these results indicated that the seed-mouse-shrew pathway was not the primary route of uptake for field populations of shrews.

The antagonistic behavior between white-footed mice and short-tailed shrews was then examined. One or more of each species were confined together within plastic cages (38 x 33 x 17 cm), and left together until only one species survived. This resulted in 8 shrews and 14 mice dying (Table B-23). Death of shrews was not attributable to mouse antagonism. A healthy mouse that had occupied a cage with a shrew for over a week was killed by the shrew within 10 min. after being immobilized by the author. Predation of juvenile mice by shrews was common during the trials, except for one instance where two mice were born in an 8 x 8 x 11 cm tin can occupied by their mother and a shrew (Fig. 16). These two juveniles survived the 86-day trial, while continually living in the same cage, and often in the same nest-can with the shrew. The general conclusion of these studies was that a healthy adult mouse could escape all but the most determined shrew in confined cage experiments such as these. In the field plots, I believe that the only deaths of mice attributable to shrews would be by accident, poor health, or nest predation of unguarded juveniles.

Figure 16. Example of nonantagonistic behavior between short-tailed shrews and white-footed mice. A female mouse, her two young, and a shrew were nesting in this can (nest removed) inside a larger cage.

These findings, combined with the strong evidence of the similarity of Cs/Co ratios in mice and shrews, were sufficient to confirm that the seed-mouse-shrew food chain was not important on the field plot.

The last route of radioisotopic entry examined was through a feces-insect-shrew food chain. While no specific entomological studies were conducted, 73 miscellaneous arthropods found in feeders during each weekly inspection were collected, sacrificed, and measured for radioactivity (Table 11). No insect, except for a single katydid, acquired more than 1,200 dpm of ^{137}Cs; average radioactivity was 285 dpm of ^{137}Cs and 2,075 dpm of ^{60}Co per insect. The Cs/Co ratio in all insects was low, only once exceeding 1.0. The high proportion of ^{60}Co indicated that the insects' food source was either tagged seeds and/or fecal remains. Carabid beetles have been reported as consumers of Douglas-fir seeds (Dick and Johnson, 1958). Feeder examinations revealed few fecal remains in them during either summer of study; whereas remains were commonly found in winter. This was indirect evidence for removal of feces by some organism or organisms active during warm weather. Occasionally, ants (Camponotus pennsylvanicus) were observed in the act of removing mouse feces. It seemed that shrew feces were removed less often, but this cannot be supported with evidence.

It was informative to compare the field radioactivity of shrews with the periods when insects were active. Shrews maintained high body burdens of radioisotopes during winter when insects would probably be least available to them. When insects did become available the following spring, the radioactivity levels in shrews decreased

Table 11. Body burdens of ^{137}Cs and ^{60}Co in arthropods collected from feeders on the live-trap and snap-trap field plots.

Order	Family	N	Radioactivity (dpm ± 1 S. E.)				Cs/Co Ratio
			^{137}Cs		^{60}Co		
Diplopoda[a]	b	13	175	± 28	1,031	± 184	0.17
Araneae	b	3	56	22	386	155	0.15
Lepidoptera	b	7	213	163	1,137	878	0.19
Orthoptera	Tettigoniidae (katydids)	8	1,281	1,127	10,612	9,634	0.12
	Gryllidae (Nemobius)	20	212	41	1,396	257	0.15
	Acrididae	3	90	49	299	185	0.30
	Blattidae	1	669	---[c]	8,320	---	0.08
Hymenoptera	Formicidae	8	84	18	411	107	0.20
Hemiptera	b	2	4	1	83	27	0.05
Coleoptera	b	5	32	15	214	50	0.15
Diptera	b	3	9	4	94	18	0.10
Total:		73	277	125	2,046	1,068	0.14

[a] Subclass.

[b] Families combined.

[c] No S. E. available.

rather than increased as would be expected if this food chain were the primary source of radioactivity for shrews.

The potential sources of radioactivity for shrews required consideration with the populational data presented earlier. Although the extent of food available from insect and mouse predation sources was unknown, the amount of pine seeds available as a food source was increased on both the live-trap and snap-trap plots by 25.2 kg. The live-trap and snap-trap plots maintained a high shrew population, whereas the control plot population seemingly disappeared. This direct and indirect evidence was sufficient to confirm that shrews on the tagged field plots were ingesting a considerable quantity of seeds.

Thus, in both the laboratory and field, it appeared that the short-tailed shrew was an "opportunist" in its eating habits, and consumed white pine seeds when available. Body burdens of shrews in both the laboratory and field were generally greater than those of mice in the laboratory. Body burdens of ^{137}Cs for shrews in the field increased up to 145 dpm X 10^3/g in October, 1969, and decreased thereafter to approximately 70 dpm X 10^3/g for the remainder of the year.

3. Body Burdens in Miscellaneous Vertebrates

Eastern chipmunks were the only other species with sufficient captures to follow radionuclide levels throughout the study (Table 12). Body burdens of ^{137}Cs in these mammals never attained the levels of the two primary species on the plot; in fact, ^{137}Cs dpm/g never

Table 12. Body burdens of ^{137}Cs and ^{60}Co in miscellaneous vertebrates captured on the live-trap and snap-trap field plots.

Date	Day of Study	Species	N	Body Weight (g ± 1 S. E.)		Radioactivity (dpm X 10^3/g ± 1 S. E.) ^{137}Cs		^{60}Co	
				Mammalia					
7/26/69	2	Tamias striatus[a]	1	101.0 ±	---[b]	0.003 ±	---	0.005 ±	---
8/12	19		1	95.4	---	0.004	---	0.003	---
9/23	61		1	92.2	---	0.018	---	0.506	---
11/26	125		1	108.6	---	0.007	---	0.003	---
6/3/70	314		1	104.8	---	0.11	---	0.09	---
6/24	335		1	112.5	---	0.12	---	0.04	---
7/14	355		3	100.4	9.45	3.44	2.15	3.56	3.33
8/4	376		2	104.8	13.00	5.87	5.61	4.78	4.66
9/2	405		3	88.2	3.04	5.04	3.07	2.68	2.03
2/24	215	Microtus pinetorum	1	26.28	---	13.37	---	13.58	---
3/17	236		3	27.38	0.76	11.15	3.83	12.56	4.54
6/30	341		1	22.50	---	12.76	---	9.43	---
9/2	405		2	21.66	2.75	5.89	3.48	13.17	8.84
2/24	215	Sorex longirostris	2	2.64	0.14	1.59	1.00	2.59	0.04
3/17	236		1	2.76	---	0.01	---	0.12	---
				Aves					
2/11	202	Thryothorus	1	2.08	---	0.004	---	0.017	---
2/24	215	ludovicianus	1	3.52	---	0.002	---	0.005	---
6/13	324	Corvus brachyrhynchos	1	400.0	---	0.0004	---	0.0003	---
				Reptilia					
6/18	329	Terrapene carolina	1	363.6	---	0.003	---	0.0006	---
6/23	334	Sceloporus undulatus	1	13.99	---	0.008	---	0.017	---
				Amphibia					
4/22	272	Bufo americanus	1	7.32	---	0.006	---	0.024	---

[a] Common names appear in Table B-42.

[b] No S. E. available.

exceeded 8% of the mouse levels throughout the study. The Cs/Co ratio fluctuated between 0.04 and 3.0; however, most chipmunks were less than 1.0, indicating a radioactivity source other than seeds. The low levels of radioactivity probably reflected the gradually increasing contamination of the field plot through June, 1970. Possible routes of entry for chipmunks with ratios greater than 1.0 were by secondary consumption of radioactive materials (probably insects), location of seeds occasionally dropped outside feeders by other consumers, or actual raiding of feeders. The last three sampling periods in late summer, 1970, included an individual chipmunk which, based upon the Cs/Co ratio, apparently was successful in obtaining seeds from feeders or caches. When this one chipmunk was removed from consideration, the mean values for ^{137}Cs did not exceed 2,000 dpm/g, or approximately 4% of the body burdens of mice.

Several other vertebrate species were captured at various times throughout the year (Table 12). The only other mammal with significant uptake of radioisotopes was the pine vole, which was small enough to enter the feeders freely. Voles were not commonly trapped in any of the plots except for one period of invasion of the snap-trap plot when a nearby right-of-way for a power line was cleared. Equilibrium levels in pine voles appeared to be similar to levels in mice and shrews.

None of the remaining species trapped on the plots contained body burdens suggestive of seed consumption (Table 12). Three southeastern shrews (Sorex longirostris) were snap-trapped, and two contained some radioactivity. But all contained less ^{137}Cs than ^{60}Co, which would not be expected in animals which were primary consumers of tagged pine

seeds. The suspected entry route was through insects which this genera commonly prey upon (Buckner, 1964). Several species of birds were captured, and none contained more than background levels of radioactivity.

Although pine mice and some chipmunks did consume pine seeds, there was insufficient information to determine seed consumption rates or seasonal patterns. None of the remaining vertebrates which were trapped contained radioactivity levels indicative of seed consumption.

D. Bases for Determining Seed Consumption in the Field

1. Correlation Technique Between the Laboratory and Field Data

It appears necessary to summarize what is already known, and what must be done in order to derive estimates of seed consumption from the field data. The laboratory data are the bases for the following conclusions:

1. ingestion rates may be determined from the equilibrium body burden of ^{137}Cs in mice,
2. the Cs/Co ratio can be used to predict the day of excretion,
3. excretion rate of ^{137}Cs varies minimally with temperature and feeding rate, and maximally with the mode of entry into the mouse.

The field data give the following:

1. measured body burdens of ^{137}Cs and ^{60}Co in mice which were not at equilibrium,
2. none of the field data would allow a prediction of seed ingestion rates without correlation to laboratory data.

In order to determine seed consumption rates in the field, a correlation between field body burdens of ^{137}Cs and the laboratory regression of equilibrium to seed ingestion rates was essential. Direct laboratory-to-field extrapolations have not proven valid for mammals. An alternative method was to derive a correlation between animal metabolism and the rate of elimination of a radioisotopic body burden.

The question of whether elimination of injected radioisotopes can be correlated to metabolism has been examined with inconclusive results (Baker and Dunaway, 1969; Baker, 1970; Wagner, 1970). The only method which gave reliable results was the $D_2{}^{18}O$ method used by Mullen (1971). Differences in elimination of ^{137}Cs were significantly correlated to various metabolic parameters in both injection and chronic-feeding studies, as mentioned earlier. Differences due to the mode of ingestion were also emphasized earlier.

In contrast to these differences was a comparison between the laboratory and field excretion rates derived during this investigation (Fig. 17). These data were not plotted in terms of percent retention, but in terms of concentrations per gram of live-body weight. Thus intercepts differed, due to unequal or unknown feeding rates, whereas the slopes did not differ, regardless of the intercept, particularly during the first 20 days of excretion. This indicated that ^{137}Cs was not responding to the expected changes in metabolism between the laboratory and field, and a direct correlation could be used to correct the field body burden to the equilibrium body burden.

Whole-body retention for 8 mice captured alive from the snap-trap plot was followed in the laboratory to compare with retention by animals

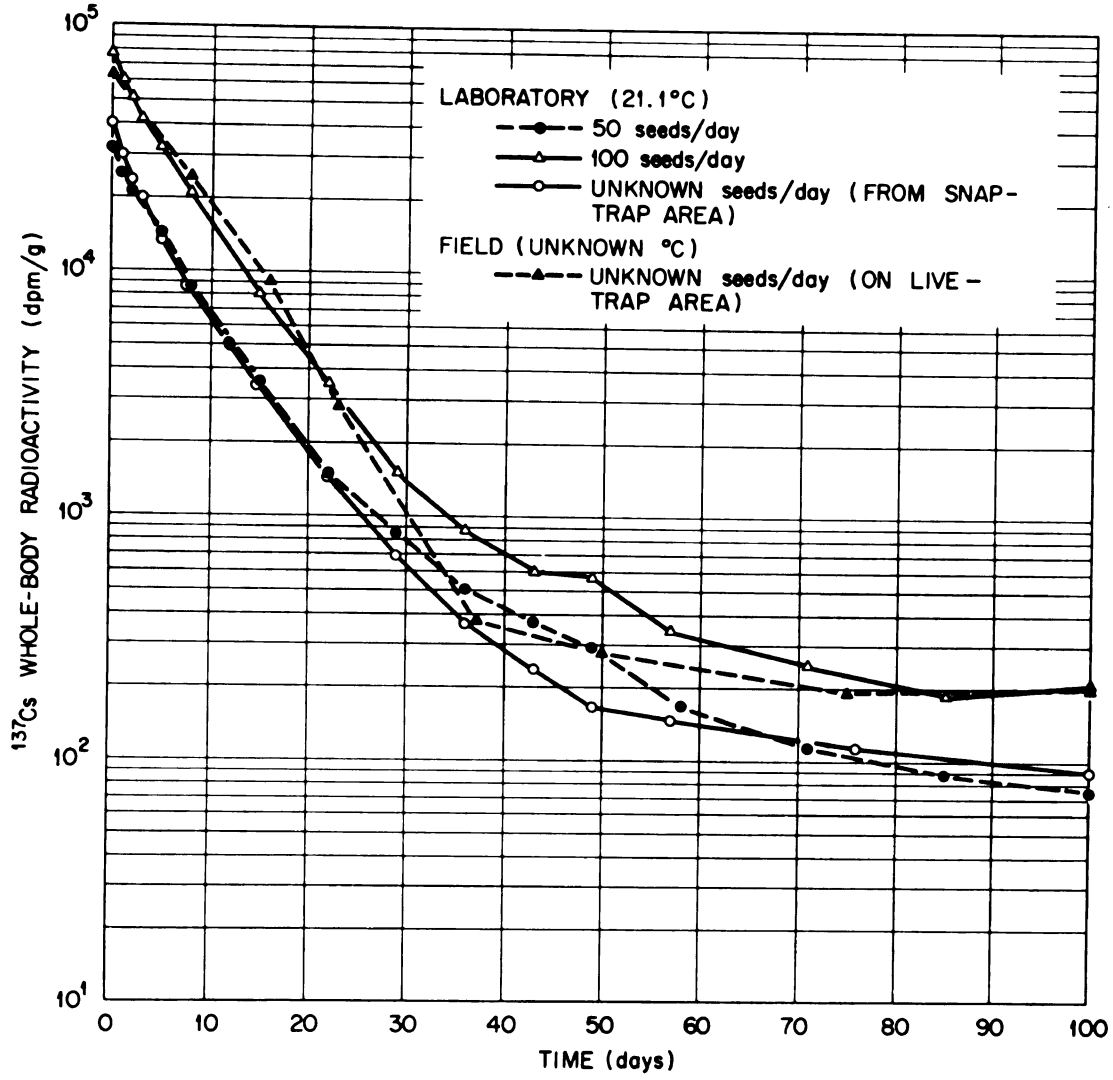

Figure 17. Mean retention of ^{137}Cs in Peromyscus leucopus from the laboratory and field.
Data from Tables B-24, B-35, and B-36.

remaining on the radioactive live-trap field plot. If mice remaining in the field had greater whole-body retention than that of the laboratory-maintained animals from the snap-trap plot, it would have suggested a delay in initiation of excretion due to consumption of tagged pine seeds from caches available on the plot. The similar excretion rates for both laboratory and field indicated that both ^{137}Cs and ^{60}Co were excreted immediately upon termination of feeding tagged seeds in the live-trap plot. Thus it seemed that mice had not cached pine seeds on the plot, or had consumed such caches prior to termination of feeding on September 1, 1970.

Another explanation of the similarity between the laboratory and field data was possible. Suppose that the rate of excretion was greater in the field due to an increased metabolism and greater activity. Then the equality between excretion rates would indicate a slightly greater ingestion of contaminated food in the field compared to the laboratory. This was possible in the field, as seeds taken from feeders were not relocated and removed from the plot. Other food sources ingested by the white-footed mouse could have radioactive levels which would maintain the field retention of the mice at a level higher than expected. If such were the case, however, it was highly unlikely that retention would have been similar throughout the 100 days of excretion that were followed in both the laboratory and field.

These results indicated that for chronically-fed mice, excretion rates of ^{137}Cs were not severely influenced by confinement in the laboratory or by temperature differences. The comparison of radioisotopic tissue distribution, discussed earlier, also suppported this

parallelism between the laboratory and field. These similarities allowed a direct correlation to be made for the excretion rates of ^{137}Cs between the laboratory and field. Excretion rates after injection, single-feeding, or chronic ingestion of tagged water would not be as reliable as excretion after chronic feeding for this correlation.

2. Conversion of Field Data to Estimated Seed Consumption Rates in White-footed Mice

Seed consumption rates were calculated from the ^{137}Cs dpm/g body burdens, since the ^{60}Co dpm/g data were too variable to be used exclusively in determining seed consumption. The field data were corrected through use of three empirical calculations between the laboratory and field data. These calculations were to: 1) determine the day of excretion in the field, 2) estimate the equilibrium body burden in the field, and 3) correlate the field equilibrium with the laboratory equilibrium.

The first calculation was to determine day of excretion for the field animals. It was obvious that mice trapped on the live-trap plot were not at day 0 of excretion (Table B-25 and B-9), thus measured equilibrium values (Table B-17) were actually lower than true field equilibrium by approximately one day of excretion, based upon the Cs/Co ratios. A regression was established between the Cs/Co ratio and the first three days of excretion in the laboratory (Table B-9), which was then solved for time:

$$t = (Y - 2.407) / 1.6227,$$

where Y = Cs/Co ratio measured in the field animal, and t = day of excretion, with a constraint that (t) was valid only between day 0 and day 3. Any predicted day greater than 3.0 was arbitrarily assigned day 3.0, as this was when the maximum Cs/Co ratio occurred in the laboratory. The r^2 of this regression was 0.992.

Once the day of excretion was determined, the second calculation was employed using the familiar three-component equation to convert the body burden on the day it was measured to the estimated radioactivity (or equilibrium body burden) on day 0. The retention equation was derived from percent retention data averaged for all laboratory animals (Table 2):

$$A_0 = A_t \; / \; (0.1400 \; e^{-1.091t} + 0.8213 \; e^{-0.198t} + 0.0382 \; e^{-0.0332t}),$$

where A_0 = equilibrium body burden at time 0, A_t = radioactivity measured in the field at time t, and t = day of excretion as determined by the Cs/Co ratio. Once this had been determined, the laboratory equilibrium had to be correlated to the field equilibrium by the third calculation.

Minimal differences were observed between the laboratory and field excretion rates, particularly during the first 20 days. The nonmetabolic behavior of ^{137}Cs in these mice formed the basis for using a direct correlation to estimate consumption rates in the field. The regression equation determined for mice maintained under laboratory conditions was applied to estimate the grams of seed consumed per day:

$$\ln (A_0) = 5.15279 + 0.216386(\text{sex}) + 0.016724(\text{temp}) + 1.034891(\ln \text{seed}) - 0.002674(\text{sex X temp}) + 0.000096(\text{temp X ln seed}) + 0.000559(\text{sex X temp X ln seed}),$$

where ln (A_0) = natural logarithm of the equilibrium body burden as determined in the previous equation, sex = 1.0 for males and 2.0 for females, temp = temperature in F, and ln seed = natural logarithm of the total seed weight (g) eaten during the last 42 days in the laboratory. This equation was solved for the weight of seed eaten, by a process of iterative solutions until the estimate of (ln seed) changed less than 0.0002 g. The derived seed weight was divided by 42, as the values used in the derivation of the equation were the sum of 42 days of ingesting seeds. The average seed weight was 18.25 mg and was used to convert weight to an estimated number of seeds eaten per day.

E. Estimated Seed Consumption by Small Forest Mammals

1. White-footed Mice

Ingestion rates ranged from 4 to 390 seeds per day within the same mouse from the field plot (Table B-26). Mean seed ingestion throughout the year was 87 $\pm$ 8 seeds per day for 101 captures on the live-trap plot. The ingestion rates were only slightly modified, by the effects of temperature, sex, and feeding rate, from the pattern indicated for the body burden of ^{137}Cs (Fig. 13). Thus the mice consumed more pine seeds in summer and autumn than in winter or spring.

Predicted values of seed consumption rates are realistic except

for those animals at very high ingestion rates. The ad libitum ingestion rate in the laboratory was predicted as 194 seeds per day (see Fig. 7 and discussion). If the literature estimates of approximately 50% increased energy expenditure in the field are realistic, then estimates up to approximately 290 seeds per day may be valid for the field data.

When the raw data for mice predicted to be ingesting more than 290 seeds per day was examined, the ^{137}Cs body burdens did not appear to be abnormally high. For example, the maximum body burden was found in a dominant male mouse who was trapped on the field plot over a period of 377 days. This body burden was 184,400 dpm/g for ^{137}Cs, which would correlate directly to about 200-250 seeds per day without a correction for the Cs/Co ratio. Whereas the ^{137}Cs levels were within reason, the ^{60}Co values appeared to be extremely low. The reason for this was not clear. Tissue analyses of animals from both the laboratory and field indicated that about 1/3 of the whole-body ^{60}Co was contained in the cecum contents. Perhaps cecal blockage occurred in these low ^{60}Co animals, but there was no indication of such happening in any tissue-sampled animal. More likely, these mice had high ingestion rates of food and passed the ^{60}Co out of their gastrointestinal tracts much more rapidly than did the average animal. An ad libitum study of pine seed consumption in the laboratory would have been of value for these mice.

2. Short-tailed Shrews

The importance of the short-tailed shrew as a seed consumer was unsuspected and greatly underestimated before the study began, and equilibrium response in the laboratory was not investigated as thoroughly for this species as for white-footed mice. Shrews acquired approximately twice as much ^{137}Cs dpm/g and 90% as much ^{60}Co dpm/g at equilibrium as did mice at the same ingestion rate (Fig. 15). Differences for ^{137}Cs may be due to ingestion of a greater proportion of the seed coat while shelling seeds, whereas the lower ^{60}Co body burden may be due to the shorter gastrointestinal tract and/or lack of a cecum in shrews. Therefore, an overestimate of seed consumption by shrews would be derived by employing the same computational procedures as were applied for mice.

Shrews are purported to be highly active metabolically, but when elimination rates of ^{137}Cs were compared with those of mice, ^{137}Cs was lost at only a slightly faster rate (Fig. B-5). As with mice, the initial 15 days excretion of ^{137}Cs was similar for shrews in the laboratory and field (Fig. 18). The similarity in excretion patterns between laboratory and field supported the seed consumption theory for shrews, and also indicated a noncaching behavior.

The characteristic Cs/Co relationship differed between mice and shrews, with shrews usually having the higher ratios (Table B-25). The peak Cs/Co ratio occurred on day 1 of excretion in the laboratory (Table B-22), and an arbitrary assumption of day 1 was employed for all shrew calculations. This would serve to underestimate seed

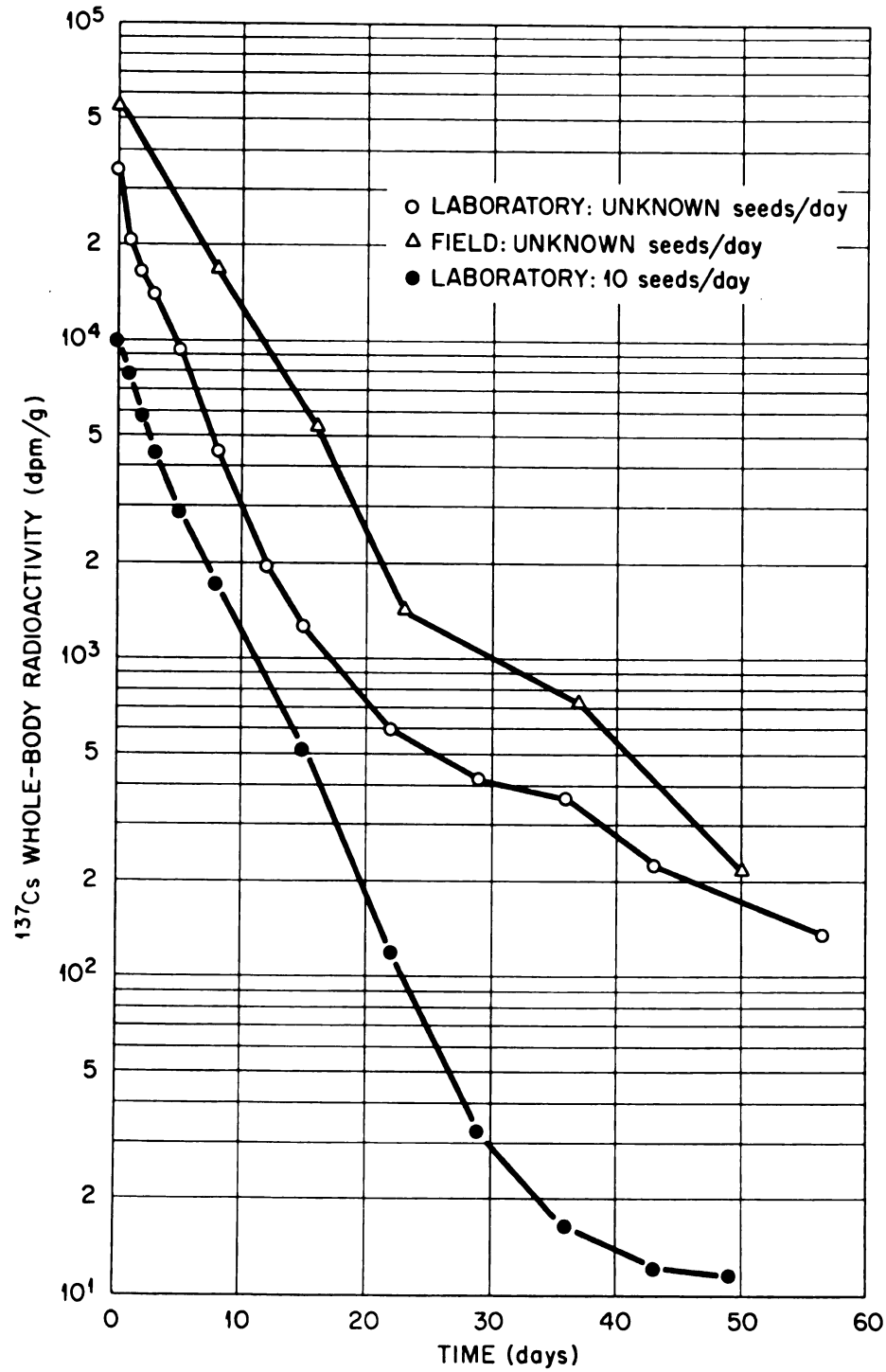

Figure 18. Mean retention of ^{137}Cs in Blarina brevicauda from the laboratory and field. Data from Table B-27.

consumption by shrews in the field, since a majority of shrews had passed the peak Cs/Co ratio (Table B-21).

These assumptions were used to determine seed consumption rates for short-tailed shrews on the live-trap field plot (Table B-28), using the same seed consumption equation as used for mice. Seed consumption varied from 1 to 770 seeds per day with a mean of 158 ± 10 seeds per day for 149 captures on the live-trap field plot. These estimates appeared to be realistic except for highest rates of ingestion. This same problem was observed in mice. The seasonal pattern of ingestion was not altered from that for the body burdens (Fig. 13), with high ingestion rates from late summer through winter and lower rates in spring and summer. The results confirmed a greater rate of seed consumption by shrews than for mice.

3. Seasonal Aspects of Seed Consumption by Small Forest Mammals

Employing estimates of seed consumption for these two species, a yearly average of 1.60 g of pine seeds was consumed per mouse-day by white-footed mice, and 3.00 g per shrew-day by short-tailed shrews on the live-trap plot (Table 13). Estimated seasonal rates of food consumption per mouse ranged from 0.38 g/day in winter to 2.26 g/day in summer. The shrews were similarly estimated to be consuming from 2.10 g/day in summer to 4.13 g/day in autumn.

The "calendar of captures" method of Petrusewicz and Andrzejewski (1962) was used to determine residence time on the plot for each individual. The method assumed continual residence on the plot between the first and last captures, even if the animal

Table 13. Estimates of seasonal and yearly consumption of Pinus strobus seeds by Peromyscus leucopus and Blarina brevicauda populations on a 2-ha field plot.

Item	Species	Period or Season of the Year				
		Uptake[a]	Autumn	Winter	Spring	Summer	Yearly
Seed obtained from feeders (g)	Total	2,120	3,749	4,201	4,724	3,920	18,713
Estimated days on field plot	P.l.	419	302	361	442	484	2,008
	B.b.	567	965	1,156	857	467	4,012
	Total	986	1,267	1,517	1,299	951	6,020
Estimated seed consumption (g)	P.l.	771	504	138	697	1,093	3,204
	B.b.	1,381	3,982	3,795	1,896	981	12,034
	Total	2,152	4,487	3,932	2,593	2,074	15,238
Accountability (%)[b]	Total	101.5	119.7	93.6	54.9	52.9	81.4
Average seed consumption (g/day)	P.l.	1.84	1.67	0.38	1.58	2.26	1.60
	B.b.	2.44	4.13	3.28	2.21	2.10	3.00
Average caloric ingestion per day (kcal/day)[c]	P.l.	8.10	7.35	1.67	6.95	9.94	7.04
	B.b.	10.74	18.17	14.43	9.72	9.24	13.20

[a]Period given to insure equilibrium body burden, from July 24, 1969 to September 25, 1969.

[b]Percent attributed to P. leucopus and B. brevicauda.

[c]Estimates derived from Pinus monticola caloric values (7,400 cal/g) from Smith (1968). For example: 1.84 X 0.594 = 1.093 endosperm g/day X 7.4 = 8.10 kcal/day.

was not captured. Half the time between trapping periods before the first capture and after the last capture was added to the residence time. On a yearly basis, the mouse population spent 2,008 days on the live-trap plot, whereas the shrew population spent 4,012 days (Table 13).

Mean seasonal consumption of seeds for each species was then multiplied by the seasonal residence time for that species to estimate total seed consumption and ingestion rates for each season. For the year, the mouse population consumed 3.2 kg of seeds, whereas the shrew population consumed 12.0 kg of seeds, for a total consumption by both species of 15.2 kg. An independent check of this consumption was derived from the feeder utilization data (Table B-15). A total of 18.7 kg of seeds was removed from or consumed within the feeders (Table 13). These two species of mammals accounted for 81.4% of the quantity of seeds utilized. This estimate would be closer to 100% if other consumers had been followed more closely. Such potential consumers were transient small mammals, sciurids on the area, birds, and granivorous insects. Seed accountability was lowest during spring and summer and indicated that the problems may either have been due to seasonally active species, such as eastern chipmunks and insects, or caching of seeds.

Caloric measurements were not made for the pine seeds used in this study, but a close estimate can be made using 7,408 cal/g of endosperm in Pinus monticola, a closely-related species (Smith, 1968). Based upon this conversion factor, the yearly average consumption of pine seeds by mice was 7.0 kcal/day. McNab (1963)

estimated the daily food requirement of Peromyscus maniculatus as 14.0 kcal/day. Drozdz (1967) reported consumption rates of 12.1 to 13.2 kcal/day for 22-g Clethrionomys glareolus and 12.1 to 17.0 kcal/day for the 29-g Apodemus flavicollis in beech forests of Poland. Pearson (1960) estimated a consumption rate for a 9-g Reithrodontomys megalotis at 8.6 kcal/day in December and 6.6 kcal/day in June. The expected daily consumption rate for white-footed mice should be in the range of 12-14 kcal/day. The ad libitum ingestion rate predicted for mice in the laboratory was 194 seeds/day, which may be converted to an estimate of 15.6 kcal/day for the white-footed mouse. Thus, this single food source of white pine seeds provided approximately 45-50% of the daily food requirement of mice. Shrews apparently were consuming seeds almost exclusively, as their yearly average consumption rate of pine seeds was 13.2 kcal/day. This can be compared to laboratory-determined values of 12.7 kcal/day derived by Pearson (1947), or 9.7 $\pm$ 0.9 kcal/day reported by Buckner (1964).

It appeared that this equilibrium technique provided reasonable estimates of the fate of eastern white pine seeds, and of the consumers of these seeds. Mice consumed 17% of the seeds, whereas shrews accounted for 64%, or approximately 3.8 times more consumption than the mouse. The remaining 19% was unaccounted for but could have been lost in caches or consumed by other species of vertebrates and insects which were active during the summer.

V. DISCUSSION

A. Estimation of Seed Consumption

Many parameters affecting seed consumption of free-ranging mammals are difficult to define. Factors such as behavior, daily activity, time of feeding, and climate could influence movement of ^{137}Cs and ^{60}Co through free-ranging mice. The nature of these factors require a synthesis of information from the disciplines of mammalogy, health physics, and radioecology. The goal of this synthesis was an ecological statement concerning seed consumption as determined by radioisotopic techniques.

Most mammalogists and ecologists would contend that results for a confined laboratory animal can not be directly correlated with data for a free-ranging wild animal of the same species, and that "...we must extrapolate from laboratory to field conditions" (Golley, 1968). Most studies assume a factor of approximately 1.4 to 2.0 in correlating the laboratory to the field, whether the variable is food ingestion, respiration, or energy flow (Pearson, 1960; Odum et al., 1962; Johnson and Maxell, 1966). Darnell (1968) suggested that we simply use the best estimates available for the correlation. Ryszkowski and Petrusewicz (1967) estimated the error at less than 100% if no correction was made, but measured a 320% difference based upon maximum and minimum respiration rates in bank voles (Clethrionomys glareolus). Their conservative estimate was based upon the premise that all

factors would not be operating to either increase or decrease metabolism at the same time, and that each variable acted independently of other variables operating at the same time.

Radioecologists and health physicists would contend that excretion of a radioisotope is dependent upon many variables which have been shown to be significant in laboratory studies. These variables include temperature, body weight, age, species, and X-irradiation. Sex has not generally been recognized as a variable except for ^{137}Cs in humans (Hanson et al., 1964; Scott, 1964).

A few radioecological studies have described significant differences between laboratory and field excretion rates for mammals handled identically (Orr, 1967; Dunaway and Story, in prep.). Such studies generally have been injection studies. The almost universal conclusion of isotope-oriented studies is that there are, or should be, differences between laboratory and field excretion rates. Thus, most mammalogists, ecologists, and health physicists would agree that such laboratory versus field differences are to be expected and perhaps reflect real processes in organisms.

For these reasons, the findings of identical excretion rates of ^{137}Cs between mice in the laboratory and field was completely unexpected. In fact, the field study was undertaken with the hope that a correlation could be made between ^{137}Cs excretion rates and metabolism based upon another study conducted at the same laboratory (Baker et al., 1970). Such a correlation was not proven for the long-term retention component for free-ranging animals with ^{137}Cs. Other investigators have experienced difficulties in attempting to establish correlations between

excretion rates of radioisotopes and metabolism. For example, ^{137}Cs was purported to be an analog of potassium in mammalian organisms (Davis, 1963), with similar metabolic behavior and location in cells, but has not been readily correlated with oxygen consumption (Baker, 1970). Various laboratory studies with mammals have shown temperature to be an important variable with faster excretion of ^{137}Cs at lower temperatures, i.e., higher metabolism. Thus some information suggests a metabolic behavior of ^{137}Cs, where other data have been unable to confirm any correlation between excretion and metabolism.

Two results for ^{137}Cs in this study need to be emphasized. First and most important was the nonsignificant differences in excretion after chronic feeding, no matter what the temperature within the range examined, or whether the animal was maintained in the laboratory or captured from the field. Secondly was the almost uniform distribution of ^{137}Cs in all tissues of animals that were at equilibrium with their radioactive food source. Thus it appeared that ^{137}Cs, obtained from a normal food base, moved freely throughout the organism and did not overtly respond to environmental stimuli such as temperature or feeding rate.

This conclusion suggested that ^{137}Cs was an ideal element to use in determining food consumption rates in free-ranging mammals. Equilibrium levels and excretion rates of ^{137}Cs in mice did not appear to be influenced by metabolic parameters which severely influence the interpretation of such radioisotopic techniques.

This equilibrium technique was applied with laboratory and field populations of white-footed mice and short-tailed shrews. The labora-

tory study established a highly significant correlation between equilibrium of ^{137}Cs and its ingestion rate in mice.

Extrapolation of the field data resulted in an estimated yearly consumption of 7 kcal/day for mice, or approximately 50% of the expected daily consumption of all foods. Maximum consumption occurred in summer just prior to the availability of the new mast crop, and decreased to a minimum during winter. Classically, late winter through early spring is thought of as the period of greatest food stress, with overwintering populations dependent upon the amount of available food. The decline in seed consumption rates suggested that mice were not food-limited during the winter period, but that their food habits changed when the mast crop became available. The prevalence of chewed hickory nuts in nest boxes indicated that this food formed a substantial portion of the winter diets in mice. Nonstorage of the readily-available pine seeds, even allowing for a change in food habits, led to a consideration of winter activity, especially food gathering during winter months. The impression obtained from all evidence was that mice severely reduced all unnecessary activity, and remained in the nest most of the time. Mice perhaps were living off their body reserves, occasionally supplementing their reserves with a hickory nut or acorn. It appeared that the home range was smaller during winter, also an energy-conserving mechanism. This lack of winter activity has also been suggested by Gebczynski (1966).

The shrew population was responsible for consuming approximately four times as many seeds as were white-footed mice. That shrews might be more important than mice as seed consumers has not been

reported previously. In fact, Campbell (1970) reported that the short-tailed shrew did not damage longleaf pine seeds sufficiently to prevent germination in a laboratory study, in direct contrast to results of this study using the smaller and softer-shelled white pine seed as food.

It is of interest that Williams (1936) considered the short-tailed shrew as the most influential mammal, in terms of abundance, activity, and food consumption, in beech-maple forests of Ohio. It appears that this small but numerous mammal is of major importance as a food consumer throughout the Eastern Deciduous Forest. Future studies of seed loss or forest regeneration problems should include this species as an important member of the consumer community.

The problems of handling this species in the laboratory and field were numerous, and an explanation of some techniques developed in this work might aid future studies. Shrew mortality is typically high in live-trapping studies. Graber (1969) examined seed loss to rodents in Maine, and observed an 88% mortality and no recaptures of his shrew population (Blarina brevicauda and Sorex cinereus) by live-trapping. Campbell (1970) trapped 104 shrews (B. brevicauda and Cryptotis parva) in 18,000 trap nights but experienced a 62% trap mortality and an additional 11% mortality "...before they could be observed in the laboratory." Kangur (1954) also experienced mortality problems with three species of Sorex in Oregon, as only 5 animals out of 29 lived as long as four days in captivity, with 40% being found dead in the traps. Rood (1958) trapped 20 short-tailed shrews in a Michigan study, but had 35% die in the

traps even though he checked them at 4-hr intervals.

Differences in mortality between this study and those in the literature cannot be definitive as to cause, but a partial explanation can be offered. Traps were entirely dry, since sunflower seeds were used as bait, as practiced by Blair (1940), and cotton batting provided a retreat away from the metallic trap. Shrews are hyperactive, especially when trapped, and I felt that the hygroscopic oatmeal-peanut butter bait often used in other studies fouled the shrews' fur in their attempts to escape from the trap, thereby reducing the insulative qualities of their fur. The practice of setting traps late in the day, running them early, and providing shrews with mouse meat probably contributed to the high survival obtained. Then, during counting or weighing procedures in the laboratory, every shrew was given water until refusal. I believe that live-trapped short-tailed shrews die more from a loss of insulation and water deprivation than from food starvation.

Shrew mortality in the live-trap plot was approximately 27% that of the control plot even though approximately five times more shrews were captured on the live-trap plot. These differences perhaps can be attributed to two factors. The second day of each trapping period on the control was also the first day of trapping on the live-trap plot. With twice as many traps set on this day, the control was the first plot set and the second plot run the following morning. This factor probably contributed to a higher mortality of the control shrews, as they were confined for a longer average time in the trap before being checked.

The second factor was part of the study design, and appeared to be an influence of using sunflower seeds as bait. The live-trap plot had white pine seeds distributed over the 2-ha plot each week, whereas the control received no additional food. Sunflower seeds served as trap bait in both plots and was provided in approximately equivalent amounts. Either shrews on the control did not recognize sunflower seeds as food, or shrews on the pine-seed-laden live-trap plot more readily accepted sunflower seeds as food. The snap-trap plot also maintained a high shrew population all year, based upon fecal remains found in feeders. Since a variety of seeds normally form a portion of the shrew diets (Hamilton, 1930; Moore, 1942), they should have recognized sunflower seeds as food.

B. Impact of Small Mammals on Forest Regeneration

Artificial regeneration of forest lands has a history of repeated failures. Environmental factors are extremely important in seed survival, but loss of seed to rodent consumers seems to have received much emphasis. Recent studies have examined the effectiveness of various measures to protect seeds against rodents (Lawrence and Rediske, 1962; Graber, 1969), time of sowing (Radvanyi, 1970, 1971), and consumption rates (Abbott, 1961; Abbott and Quink, 1970).

The importance of small mammals as seed consumers can be compared in the following table:

Seed Species	Loss to Mammals	Reference
Picea alba	28%	Radvanyi, 1970
Pseudotsuga menziesii	14%	Lawrence and Rediske, 1962
	28%	Gashwiler, 1971
	41%	Gashwiler, 1970
Pinus contorta	19%	Radvanyi, 1971
Pinus strobus	100%	Abbott, 1961
	61%	Graber, 1969
	84%	Abbott and Quink, 1970
	84%	This study

Species with low losses to mammals generally have an increased loss to other factors. Survival of 10% of the seed through the first year would be considered satisfactory.

This study examined the potential consumption of pine seeds by natural mouse and shrew populations in a mature oak-hickory forest. A total of 25.2 kg of seed was placed on each of two plots over a 58-week period. Of this amount, an average of 21.2 kg (84%) was removed by the animal populations. Shrews and mice consumed 15.2 kg (81%) of the seeds removed on the live-trap plot, and this consumption was estimated to be 50% of the daily food requirement for mice and approximately 90% for the shrews. An estimated 10-11 kg/ha of seeds would be consumed annually by these two species.

Estimates of yearly tree seed production in pure stand of pines range from 10-15 kg/ha (Turcek, 1967; Abbott and Quink, 1970). Hardwood forests generally produce greater amounts of seed; estimates from Polish forests range from 44 to 55 kg/ha (Gorecki and Gebczynska, 1962; Drozdz, 1966). It appeared that there was more than sufficient

food available for the mammal population on the live-trap plot. In a natural situation, the influence of other consumers (e.g., deer, sciurids, and insects) would reduce the seed supply for rodents, but could not be quantified in this study.

An intrinsic pattern of consumption of pine seeds may be outlined from this study, with the lowest rate of consumption occurring in late autumn through winter, and the highest rates occurring in summer and early autumn. Radvanyi (1970, 1971) reported a low rate of seed destruction during the winter months, and I concur with his recommendation that direct seeding, in similar forest ecosystems, should be attempted only in the winter months, in order to avoid the greatest loss to small mammals.

A goal of this study was to determine if the disappearance of white pine from mixed hardwood-pine stands might in part be due to the seed-consumption habits of small forest mammals. Based upon one year of field data, mice appeared to prefer white pine seeds during the summer months only. Pine seeds were essentially ignored by mice during winter after the mast crop became available. The shrew population appeared to increase their consumption of pine seeds during the periods when mice were consuming other foods. Shrews are probably unable to consume the large and thick-shelled hickory nuts and acorns, and presumably were more dependent upon the smaller seeds and insects available on the forest floor. Tunneling of shrews into new areas was restricted during winter, and probably only those seeds landing near tunnels would be discovered by shrews. The ease with which mice and shrews could locate feeders probably overestimated potential seed

consumption, in comparison to the dissemination of seeds under natural forest conditions. The importance of the short-tailed shrew in this respect is difficult to evaluate, but potentially, shrews may be more important than mice as consumers of pine seeds, particularly after the hardwood mast crop becomes available. Sufficient seeds should escape detection by shrew and mouse populations however, and the loss of white pine from mixed forests such as these probably is not caused through seed consumption.

C. Effect of Mode of Entry Upon ^{137}Cs Uptake and Retention Parameters

The nonmetabolic behavior of chronically-fed ^{137}Cs led to a consideration of the metabolically-correlated results observed in other studies. Differences between other studies and this study seemingly were associated with the mode of entry into the animal. Health physics studies usually have been conducted with injected animals to determine excretion parameters. These parameters are then integrated in an uptake equation to predict equilibrium and radiation dosages for that body burden. The reason for using excretion data to predict uptake characteristics has been an assumption that the movement of elements is governed by rate constants, whether the movement is incorporation into, or excretion from, the body pool under consideration. Robertson (1957) has criticized extrapolation from injection studies due to the invalid acceptance of assumptions basic to tracer studies.

The logic of the practice of integrating data from excretion studies can be questioned due to the processes affecting the mode of entry. There appear to be two offsetting errors in this method, if excretion

after chronic feeding is used as the base of comparison. One concerns the "mirror image" comparison of the chronic uptake curve to the subsequent excretion curve observed in the same animal; the second compares excretion after injection to excretion after chronic feeding. The first is the "mirror image" comparison. After a period of chronic ^{137}Cs uptake, all excretion pathways are operating maximally, and excretion will be normal from day 0 on throughout the study. But during the first few days of chronic uptake, a significant change must occur in excretion. The amount of ^{137}Cs excreted will initially be nearly zero, reflecting only the loss of "background" radioisotopes obtained through normal diets; but then must undergo an exponential increase up to the maximum which occurs at equilibrium with the ingestion rate. The gastrointestinal tract will act as a "sink" for the first few days, until the radioactivity is evenly distributed through the tract. Thus, retention of ^{137}Cs, during the first few days of uptake, should be greater than would be expected from use of excretion data. This contention was substantiated by the mirror image comparison between mean percent uptake and the inverse of mean percent retention (Fig. 9). If these differences can be observed using the same animal as its control in both uptake and excretion equations, then the widespread use of injection studies to determine excretion parameters can be questioned. And one of the basic assumptions of tracer methodology, that of identical behavior in both uptake and excretion, can be proven invalid.

The second error in using excretion to predict chronic uptake was indicated by a comparison between chronic feeding and injection studies. Injected animals excrete ^{137}Cs faster than in chronically-fed animals

(Table 4 and Fig. 8). The error will be in the same direction as the error observed during chronic uptake and, upon integrating the excretion equation, will create a closer correlation to chronic uptake than will the excretion rate seen after chronic feeding.

It seems probable that the rate of isotope movement was involved in these differences. In the acute case of intraperitoneal injection, the entire quantity of isotope competes at the same time to cross a particular membrane (peritoneal or cellular). If the maximum rate of incorporation into tissues has been exceeded in injected animals, the excess would be sloughed off via other pathways. One potential pathway could be a reversal of the uptake from intestinal contents, with more isotope excreted in the fecal material than found in chronically-fed animals. Of the tissues which do incorporate the radioisotope, the short-component, rapidly-cycling tissues are the only body pools which incorporate much of the tag after injection. These short-component tissues will, of course, also excrete the isotope rapidly, resulting in faster excretion curves. Chronically-fed animals have a greater percentage of the total isotope incorporated into long-component body pools, compared to injected animals, and have a greater retention during the first few days of excretion. These theories were not examined during the study, and while admittedly hypothetical, perhaps explain some of the observed differences.

The correlation between the integrated curve derived from injection studies of excretion and the chronic uptake curve may be a coincidental relationship of these two offsetting errors, thereby allowing the close predictability reported by various investigators.

The importance of the errors in the present methodology become apparent by reference to ^{137}Cs excretion curves observed after single feeding and chronic feeding (Fig. A-3 and A-5). Retention in chronically-fed ^{137}Cs animals was 2.8 times greater than for single feeding after 20 days of excretion. The importance of this elevated long-term retention of ^{137}Cs is in determining total radiation dosage. Excretion data from injection studies underestimates the total dose, based upon this reasoning. Whether the processes of food ingestion, digestion, and assimilation can be equated with injection or ingestion of radioisotopes in water, is a subject which needs more investigation. If such a difference does occur, as was found in this study, then radio-ecologists should consider its importance in radionuclide cycling, and health physicists may need to reconsider their estimates of dose rates to man from ingested food stuffs.

VI. SUMMARY AND CONCLUSIONS

Consumption rates of white pine (Pinus strobus) seeds by white-footed mice (Peromyscus leucopus) and short-tailed shrews (Blarina brevicauda) were determined in the laboratory and field. Pine seeds were uniformly tagged with ^{137}Cs and ^{60}Co and then fed chronically to the mammals at specific ingestion rates. An equilibrium technique was then used whereby seed consumption was predicted from the equilibrium body burdens of ^{137}Cs. Laboratory variables affecting equilibrium levels were the feeding rate, and to a lesser extent, sex and temperature. As ingestion rates were increased (2, 10, 50, and 100 seeds per day), equilibrium body burdens of ^{137}Cs and ^{60}Co also increased proportionally. Similarly, as temperature was increased, between 4.4 and 21.1 C, the equilibrium body burden at each ingestion rate was also increased. For any temperature-ingestion rate combination, females acquired higher equilibria than males.

This equilibrium technique was then applied to a mammal population in a mature second-growth oak-hickory forest of eastern Tennessee during July, 1969 to September, 1970. This area is characterized as a warm temperate rainy climate, and the soils are primarily Utisols. Principal mammalian species studied in this forest type were the white-footed mouse and short-tailed shrew. The 2-ha field plots were located along the crest of one ridge of this dissected valley floor at elevations of about 300 m.

Tagged white pine seeds were dispersed in feeders at a rate of 222 g/ha per week for 58 weeks. Small mammals were live-trapped periodically to determine body burdens of radioisotopes and were then released at their point of capture.

Field application of this technique was successful only because a dual-isotope tag was employed, using one isotope (^{137}Cs) which accumulated in tissues, and the second (^{60}Co) as a food tag with low assimilation. The ratio between the two isotopes during excretion in the laboratory was used to determine day of excretion for the field animals. A direct correlation of seed consumption from laboratory to field was indicated, based upon identical excretion rates of ^{137}Cs in both the laboratory and field. The derived day of excretion, determined from the ratio between the two radioisotopes, was then incorporated in the excretion equation from the laboratory to estimate equilibrium of ^{137}Cs for mice in the field. The equilibrium level was then corrected for the influences of sex and temperature, and solved for the seed ingestion rate.

Seed ingestion rates per mouse varied seasonally with a maximum consumption rate in summer of 2.3 g/day, and a minimum of 0.4 g/day in winter. Average yearly consumption rate was 1.6 g/day or 7.0 kcal/day. This was estimated to be approximately 45-50% of the total food consumption for this species. Thus the equilibrium technique provided realistic estimates for consumption of a single food source in a field situation with free-ranging populations of white-footed mice.

The importance of the short-tailed shrew as a seed consumer has

been underestimated. Numerous studies have indicated that the shrew does consume seeds, but more interest has been shown in this as a curiosity of the species rather than in light of the destructive effect of such consumption. Seasonal seed consumption was maximum in autumn (4.1 g/day), and minimal in summer (2.1 g/day). Average yearly consumption of pine seeds was 3.0 g/day, or 13.2 kcal/day. Relative consumer importance was derived from two factors: the seed consumption rate per individual combined with the population level of each species. Shrews had consumption rates approximately 1.9 times greater than mice and maintained a population about twice as large as the mouse population. Thus, the shrew was responsible for approximately four times as much seed consumption as the white-footed mouse.

A total of 25.2 kg of seed was placed in each plot, with 21.2 kg (84%) removed or consumed in the feeders. Mice and shrews consumed 15.2 kg or 81% of those seeds which were utilized. The populations of both mice and shrews were estimated to be able to consume 10-11 kg/ha of seed annually. The disappearance of white pine from mixed forests, such as this oak-hickory type, does not appear to be attributable to consumption of pine seeds by the mouse and shrew populations.

Another important finding relates to the radioecological and health physics aspects of chronic feeding. Apparently there is a difference between the excretion parameters for injected wild mammals and chronically-fed wild mammals. In general, the present methodology utilizes a determination of excretion parameters from injected animals

to establish the characteristics and equations for chronic uptake. This study indicated that:

1. excretion curves of injected ^{137}Cs do not adequately represent actual excretion curves after chronic feeding,
2. excretion of ^{137}Cs after single-feeding was faster than after chronic feeding,
3. excretion curves after chronic feeding of ^{137}Cs do not adequately characterize the uptake curve as observed in the same animal,
4. equations derived from excretion curves after injection of ^{137}Cs probably predict chronic uptake more closely than actual excretion after chronic feeding due to a coincidental similarity of two separate processes, and
5. estimates of radiation dosages derived from excretion studies after injection are probably lower than those derived from excretion studies after chronic feeding.

Further applications of this method could be used to characterize total energy flow through a consumer. By identifying an isotope which would be directly proportional to energy or nutrient levels in foods available to a consumer, the total importance of the consumer within an ecosystem could be more fully understood.

VII. LITERATURE CITED

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VIII. APPENDIX A

This appendix presents the results and discussion of the developmental study, emphasizing the radioisotopic uptake and location in pine seeds, and the transfer of radioisotopes into white-footed mice.

VIII. DEVELOPMENT OF RADIOISOTOPIC TECHNIQUES FOR PREDICTION OF SEED CONSUMPTION

A. Isotope Requirements

Measurement of food consumption rates has been attempted using excretion or turnover of specific radionuclides in heterotherms. Excretion rates of radioisotopes in homeotherms have been employed to estimate body burdens, primarily to determine radiation dosages. Excretion of radionuclides has been correlated with many metabolic parameters in homeotherms, but has not been correlated with ingestion rate, and has been critically questioned as an indicator of metabolism in free-ranging mammals. Essentially no information is available on parameters of radioisotopic movement in homeotherms as a function of ingestion rate.

Two radionuclide approaches appeared feasible for estimating food consumption in mammals. The first was dependent upon the concentration-factor concept where a readily assimilated isotope will build up in the body pool to an equilibrium level during chronic feeding. The second was a radiochemical-indicator technique using an unassimilated food tag and determining ingestion by differences in isotopic concentrations in the food and feces. The latter technique was not examined, but the first technique was modified to include two isotopes, so that if the first approach did not work, the second could be examined. One isotope, with virtually complete assimilation, would be used as an

attempt was made to reduce this potential error as much as possible by obtaining seed coats with radioactive levels similar to levels in endosperm. An acid leach was used to determine if seed coat radioactivity could be removed without a substantial loss from the endosperm (Fig. A-1 and Table A-1). The excess seed coat radioactivity was removed by a 1 1/2 hr soak in 1.0 N HCl, leaving a concentration equivalent to the endosperm. All seed coat radioactivity could not be removed without affecting endosperm concentrations. A 2 1/2 hr leach began removing ^{137}Cs from the endosperm.

A second radioisotope was required for the study as a gastrointestinal or food tag. A literature survey eliminated ^{65}Zn, due to its immobilization in hair (Rice, 1963; Strain et al., 1965) and its rapid leaching from seeds (Radvanyi, 1970). The remaining isotopes were ^{54}Mn, ^{22}Na, and ^{60}Co; all were examined for conformity with the action of ^{137}Cs in pine seeds (Tables A-2, A-3, and Fig. A-2). As the total radioactivity taken up by seeds differed greatly, all data were expressed in terms of percent retention (Fig. A-2). A high retention was observed for ^{54}Mn and was probably due to the very low radioactivity of the soaking solution, which was 0.0045 μCi/ml compared to the other solutions with 0.5 μCi/ml. Thus, a greater percentage of ^{54}Mn was "bound" to the seeds, in comparison to the other solutions. The high cost of ^{54}Mn (approximately $125/mCi), combined with a need for mCi quantities of isotope, necessitated removal of this isotope from consideration. Radioactive sodium (^{22}Na) was also removed from consideration due to its erratic behavior in seeds, very low uptake during the soaking procedure at similar specific

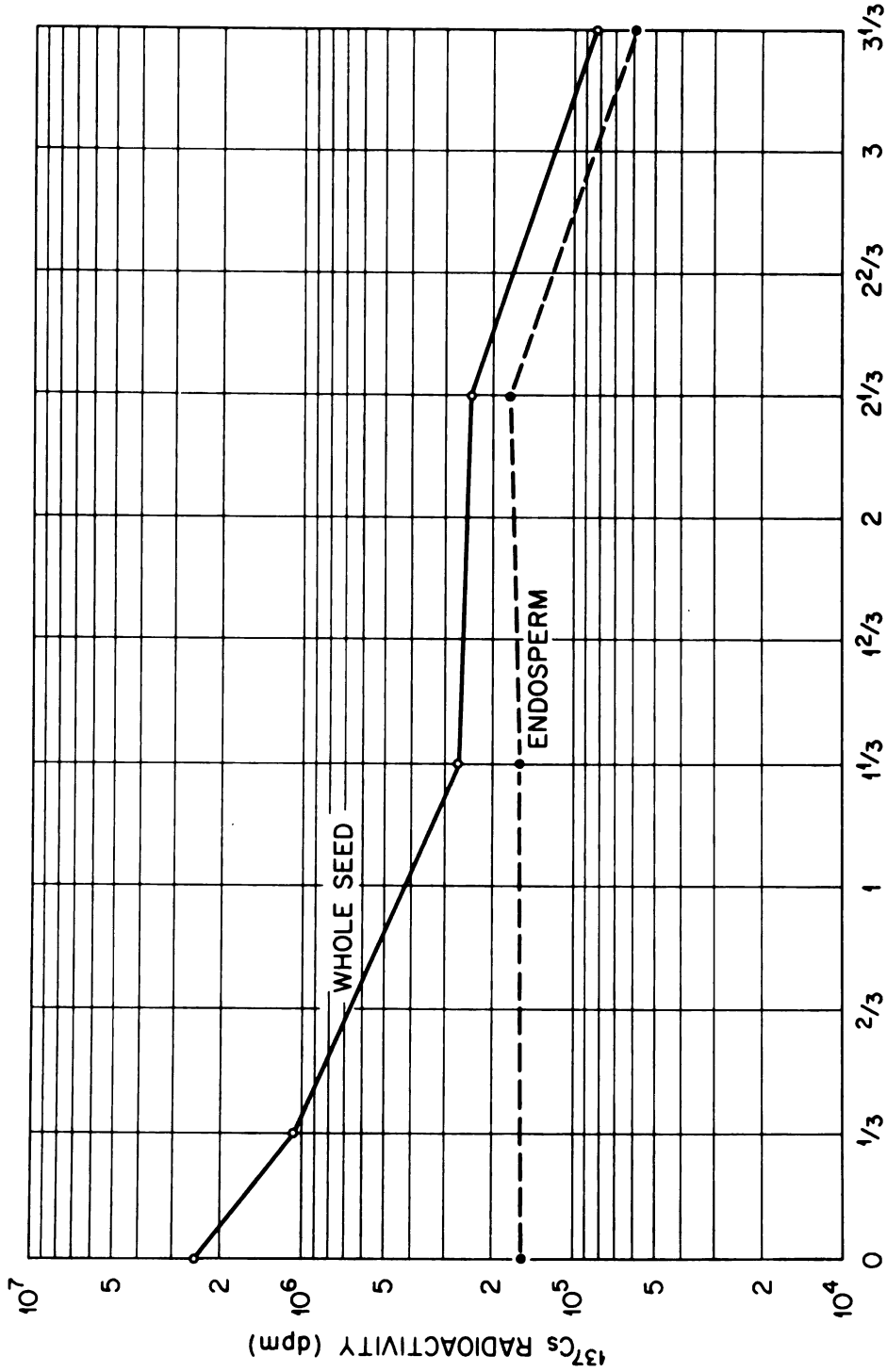

Figure A-1. Removal of ^{137}Cs from Pinus strobus seeds soaked in pure HCl for 1/3 hr and then in 1.0 N HCl for variable times. Data from Table A-1.

Table A-1. Removal of ^{137}Cs from Pinus strobus seeds soaked in pure HCl for 1/3 hr and then in 1.0 N HCl for various times.

Time Soaked in HCl Acid		N	Radioactivity per Seed (dpm X 10^3 ± 1 S. E.)		
Pure	1.0 N		Whole seed	Endosperm	Seedcoat[a]
0	0	80	2,456 ± 58	155 ± ---[b]	2,343 ± ---
1/3	0	80	1,071 31	--- ---	--- ---
1/3	1	20	263 0.6	158 0.1	158 0.7
1/3	2	20	240 0.5	172 0.3	93 0.1
1/3	3	20	82 0.6	58 0.3	37 0.1

[a]Endosperm + seed coat ≠ whole seed due to changing geometry of counting, caused by static electricity holding seed coat fragments to the walls of the counting container.

[b]No S. E. available or not sampled.

Table A-2. Accumulation of ^{60}Co, ^{54}Mn, and ^{22}Na in Pinus strobus seeds and subsequent removal by 1.0 N HCl acid.

Isotope	Time Soaked (hr)	Acid Leach (hr)	Sample Size (N)	Radioactivity Per Seed (dpm X 10^3 ± 1 S. E.) Whole Seed	Endosperm	Seed Coat
^{60}Co	24	0	10	1,982.88 ± 3.67	---[a]	---
	24	1/2	5	366.22 1.16	32.90 ± 0.28	331.15 ± 0.66
	24	1	5	249.54 0.37	---	---
	48	0	10	2,257.23 1.58	---	---
	48	1/2[b]	10	694.07 1.70	---	---
	48	1/2	10	886.74 1.96	---	---
	48	1	10	442.11 0.82	113.04 0.75	310.67 0.80
	48	1 1/2	10	226.11 0.56	54.45 0.16	171.02 0.85
	96	0	10	2,292.86 3.76	---	---
^{54}Mn	24	0	10	210.93 0.12	---	---
	48	0	--[c]	246.40		
	48	1/2[b]	10	96.23 0.91	6.31 0.03	89.63 0.63
	48	1/2	10	146.21 0.01	19.58 0.01	128.12 0.53
	48	1	10	85.54 0.40	13.23 0.06	72.02 0.22
	48	1 1/2	10	50.63 0.28	---	---
^{22}Na	24	0	10	766.02 1.11	---	---
	48	0	10	476.63 0.83	---	---
	48	1/2[b]	10	42.29 0.18	---	---
	48	1/2	10	151.77 0.42	---	---
	48	1	10	62.08 0.25	---	---
	48	1 1/2	10	84.90 0.44	---	---
	96	0	10	546.75 0.88	---	---

[a]Seeds not separated into seed coat and endosperm.
[b]Acid soak performed immediately after seeds removed from isotope soaking solution without allowing seeds to dry. All other samples were dried before acid leach applied.
[c]Radioactivity estimated from uptake at 24 hr.

Table A-3. Percent retention of ^{137}Cs, ^{60}Co, ^{54}Mn, and ^{22}Na by Pinus strobus seeds soaked in 1.0 N HCl for various periods of time.

Time Soaked in Acid (hr)		Retention (%)			
Pure	1.0 N	^{137}Cs[a]	^{60}Co	^{54}Mn	^{22}Na
0	0	100.00	100.00	100.00[b]	100.00
1/3	0	43.62	---[c]	---	---
0	1/2	---	39.28	59.34	31.84
0	1	---	18.70	34.72	13.02
1/3	1	10.70	---	---	---
0	1 1/2	---	10.02	20.55	17.81
1/3	2	9.79	---	---	---
1/3	3	3.33	---	---	---

[a]Seeds soaked only 28 hr in the ^{137}Cs solution, all others were soaked for 48 hr.

[b]Value for time 0 was estimated from 24 hr uptake of ^{54}Mn.

[c]Not sampled.

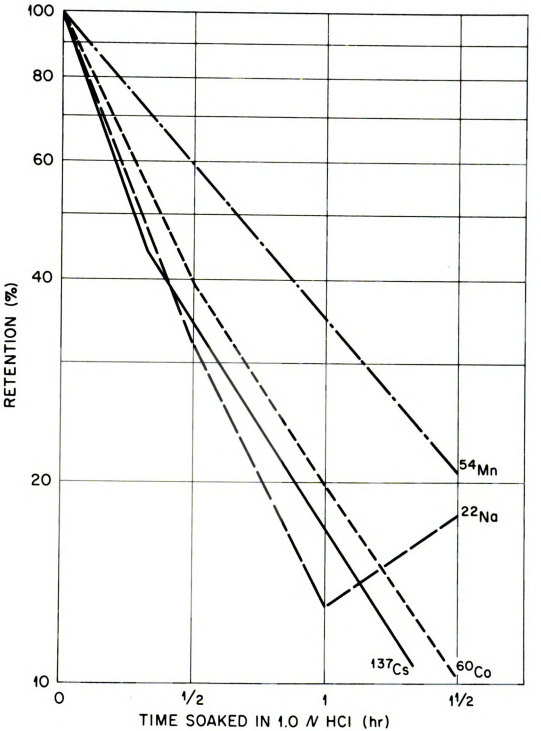

Figure A-2. Percent retention of ^{137}Cs, ^{60}Co, ^{54}Mn, and ^{22}Na by Pinus strobus seeds soaked in 1.0 N HCl. Data from Tables A-2 and A-3.

activities, faster leaching during the acid soak, and high cost (approximately $300/mCi).

Behavior of ^{60}Co was similar to that of ^{137}Cs in pine seeds. Both radioisotopes were absorbed and/or adsorbed by seeds at similar rates during both uptake and leaching procedures. The only apparent difference was a greater loss of ^{60}Co from endosperm during the acid leach. Comparison of isotope retention between seeds which were dried before acid leaching and those which were subjected immediately to the acid leaching (Table A-2) indicated that seeds should be dry before the acid-leaching procedure. The HCl acid leach was changed to a H_2SO_4 leach in order to approximate normal pretreatment procedures for breaking seed-coat dormancy (USDA, 1948).

Two trials of concurrent ^{137}Cs and ^{60}Co uptake were conducted (Table A-4). The first soaking solution contained 279,500 dpm/seed of ^{137}Cs combined with 201,400 dpm/seed of ^{60}Co in 200 ml of distilled water. Concentrations of both isotopes increased in seeds through time. The Cs/Co ratio in seeds declined with increasing time, indicating a preferential uptake of ^{60}Co. A problem with this trial was the changing concentration of both isotopes in the soaking solution as seeds were removed through time.

The second trial was conducted while attempting to maintain a constant radioisotopic concentration per seed in the soaking solution. This solution contained 87,200 dpm/seed of ^{137}Cs combined with 150,400 dpm/seed of ^{60}Co. In this instance the seeds gradually decreased in ^{137}Cs concentration while ^{60}Co increased; a reversal of the ^{137}Cs pattern observed in the first trial. Combined radioactivity

Table A-4. Concurrent accumulation of ^{137}Cs and ^{60}Co by whole Pinus strobus seeds after various times.

Time Soaked (hr)	N	Solution Concentration[a] (dpm X 10^3/seed) ^{137}Cs	Solution Concentration[a] (dpm X 10^3/seed) ^{60}Co	Cs/Co Ratio	Seed Concentration (dpm X 10^3/seed ± 1 S. E.) ^{137}Cs	Seed Concentration (dpm X 10^3/seed ± 1 S. E.) ^{60}Co	Cs/Co Ratio	Uptake (%)[b] ^{137}Cs	Uptake (%)[b] ^{60}Co
				200-seed trial					
24	40	279.52	201.39	1.39	98.63 ±3.96	119.96 ±2.26	0.82	35.29	59.56
48	50	339.79	228.55	1.49	111.27 ±6.26	195.00 ±5.73	0.57	32.75	85.32
72	30	796.84	295.64	2.70	138.43 ±2.78	215.59 ±2.68	0.64	17.37	72.92
				6000-seed trial					
18	10	87.22	150.42	0.58	80.27 ---[c]	113.84 ---	0.71	92.03	75.68
24	10	87.24	150.48	0.58	70.88 ---	178.84[d] ---	0.40	81.25	118.84
42	10	87.26	150.43	0.58	53.14 ---	123.95 ---	0.43	60.89	82.40
45	10	87.32	150.48	0.58	60.19 ---	164.39[d] ---	0.37	68.93	109.25
48	30	87.37	150.45	0.58	59.59 ±3.33	136.65 ±7.18	0.44	68.20	90.82

[a]Concentrations are corrected for seeds removed at each time interval.
[b]Percent uptake in seeds from solution.
[c]No S. E. measurement.
[d]High ^{60}Co radioactivity due to nonviable seeds included in samples.

of both isotopes at 48 hr was within 1% of the combined radioactivity at 18 hr, but the Cs/Co ratio decreased from 0.71 to 0.44. This result also indicated a greater affinity of seeds for ^{60}Co, with a gradual replacement of ^{137}Cs by ^{60}Co.

On the basis of these findings, ^{137}Cs and ^{60}Co were selected for use in the study, provided that they would transfer into the white-footed mouse. All seeds were to be soaked at the same time in the dual-tagging solution for a period of 48 hr, followed by air-drying for one afternoon. After one week of cold storage, all seeds were to be soaked in 1.0 N H_2SO_4 for 2 hr, followed by air-drying of the seed down to 5% moisture content before subsequent storage at 5 C.

C. Estimated Seed Supplies Required for the Study

Quantities of seed desired for the study were based upon supplying one-third of the daily food requirement for an average population of small forest mammals on 4 ha of land. Reliable density estimates for white-footed mouse populations range from 7 to 27 per ha (Snyder, 1956; Stickel and Warbach, 1960). The extra food would support a higher population, and 30 mice/ha was used as the population estimate.

To determine the seed weight consumed per mouse, a single white-footed mouse was fed 3,600 uncontaminated seeds over a 21-day period. Periodically, uneaten seeds, seed-coat fragments, and excreta were collected, separated, and weighed. Remains of entire seeds could be identified in the fragments, and accounted for 98% of the seeds which were eaten. Of 2,037 fresh seeds consumed by this white-footed mouse, 63.5% was endosperm. Air-dry weight of 100 undamaged endosperm shelled

by white-footed mice was 10.83 mg, or 59.4% of the mean whole seed weight. It appeared that approximately 4% of the seed coat was consumed by white-footed mice engaged in shelling white pine seeds. The percentage of endospermous tissue determined from this study agreed favorably with Abbott and Quinks' (1970) value of 66% for the same species from Massachusetts. Other studies with the same genera have resulted in values of 71% (Turcek, 1956), and 73% (Grodzinski and Sawicka-Kapusta, 1970; using oven-dry weights).

This same 21-day feeding study with the white-footed mouse was used to determine a daily ingestion of 97 seeds/day in the laboratory. Abbott (1961) reported an average of 109 seeds/day ingested by five white-footed mice during 140 days of laboratory feeding. Conversion of these ingestion rates to percent of body weight ingested per day gave 7.6% for the 21-day feeding trial, and 10.5% for Abbott's (1961) study (a 20 g mouse assumed for this case). These values are comparatively lower than published values of 10-29% (Gorecki and Gebczynska, 1962), or 4.7-31% (Turcek, 1956) of body weight ingested per day by European mice and voles of similar size. The average food ingestion rate from the latter two studies was 15% of whole-body weight and was used to estimate a yearly average of 3 g of food consumed per day by 20-g white-footed mice under field conditions. To supply a population of 30 mice per hectare, on two 2-ha field plots, with 1/3 of the total food requirement, or 1 g per mouse-day, I estimated that the one-year study would require 44 kg of pine seeds. This quantity was increased to 59 kg to allow for adjunctive feeding trials in the laboratory.

D. Effect of Acid-leached Seeds on Ingestion

This feeding trial was to determine how important the acid-leaching procedure was in contributing to the total consumed radioactivity by white-footed mice. Four male mice were each fed 50 dual-tagged seeds during a single feeding (Table A-5 and Fig. A-3). Two mice were fed acid-leached seeds; the remaining two were fed seeds without the acid leach. Mice fed nonleached seeds, with 6.04 times as much ^{137}Cs, ingested 1.53 times more ^{137}Cs than mice fed acid-leached seeds. Similarly, ^{60}Co, with 4.35 times as much radioactivity in nonleached seeds, was 1.54 times greater than in mice fed acid-leached seeds. As the endospermous radioactivity was not changed by the acid-leach procedure (Fig. A-1), the increased radioactivity ingested by mice fed nonleached seeds indicated the importance of the ingested seed coat radioactivity. Although mice fed nonleached seeds did consume approximately 50% more radioactivity, it was not in proportion to the amount available.

The delay in ^{60}Co excretion, exemplified by the abrupt change in slope at day 1, indicated that some of the excretion pathways had not achieved normal rates of excretion (Fig. A-3). As ^{60}Co was excreted primarily in the feces, in contrast to the urinary excretion of ^{137}Cs, it was assumed that the delay was due primarily to the gastrointestinal turnover rate. In this case, the turnover took more than one day, which was the sampling interval. This assumption was supported by the inversion of the acid-leached versus nonleached groups of mice at day 2 (Fig. A-3). The cause appeared to be the ingestion of seed coat fragments with a lower assimilation than the endosperm. Higher

Table A-5. Ingestion and retention of ^{137}Cs and ^{60}Co in four Peromyscus leucopus after one-day feeding of nonleached or acid-treated Pinus strobus seeds.

	Nonleached Seed			Acid-treated Seed			Ratio of N:A[a]	
	^{137}Cs	^{60}Co	Cs/Co Ratio	^{137}Cs	^{60}Co	Cs/Co Ratio	^{137}Cs	^{60}Co
Ingestion								
Item								
Total Radioactivity In Seed (dpm X 10^3)	3,194	7,518	0.42	529	1,727	0.31	6.04	4.35
Ingestion (dpm X 10^3)	492	402	1.22	311	260	1.19	1.53	1.54
Ingestion (%)	15.4	5.4		58.8	15.1			
Retention (%)								
Time (hr)								
0	100.00	100.00	1.22	100.00	100.00	1.19	1.53	1.54
16	73.47	67.64	1.33	82.74	63.36	1.56	1.40	1.65
40	60.02	2.30	31.95	69.82	4.93	16.91	1.36	0.72
64	47.22	0.70	81.92	57.17	0.83	82.63	1.30	1.32
88	37.49	0.43	106.78	43.56	0.58	89.05	1.36	1.13
112	29.75	0.32	113.93	35.84	0.42	103.06	1.31	1.19
159	20.14	0.30	82.39	22.59	0.33	82.68	1.41	1.41
424	2.01	0.07	33.51	2.43	0.17	20.39	1.11	0.67
544	0.86	0.09	12.29	1.01	0.16	9.03	1.15	0.84

[a]Ratio of nonleached seed:acid-treated seed.

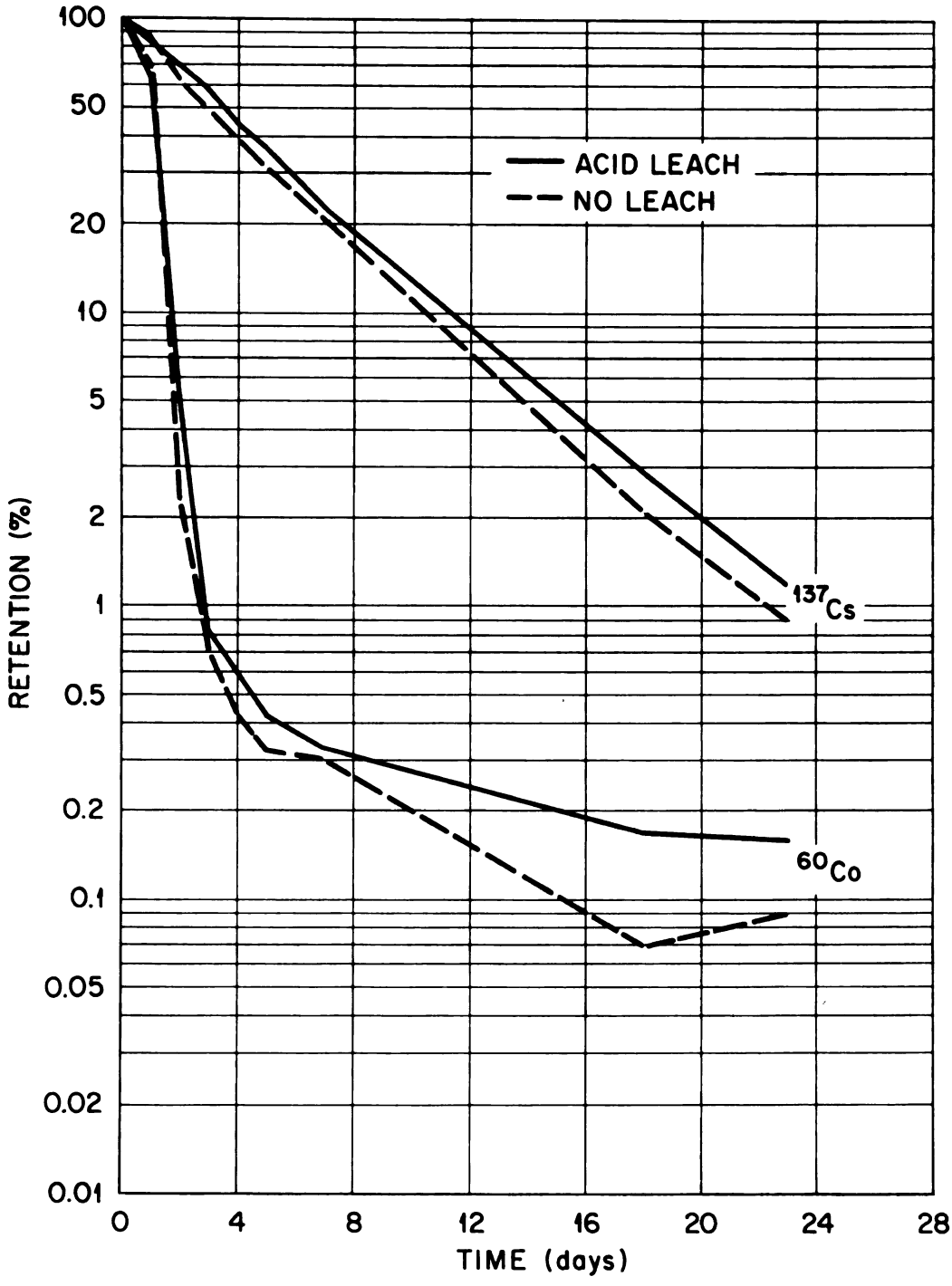

Figure A-3. Percent retention of ^{137}Cs and ^{60}Co in Peromyscus leucopus after one-day feeding of Pinus strobus seeds. Comparison between mice fed with seed leached by 1.0 N HCl or with unleached seed. Data from Table A-5.

radioactivity of mice fed untreated seeds indicated that a combination of assimilated and unassimilated radioisotopes were contained in the seed coats.

Presumably, for mice fed acid-leached seeds, very little seed-coat radioactivity was removed by the 0.5% HCl digestive juices of the mouse (Prosser and Brown, 1950). After the seeds passed through the 1.8% acid-leaching solution, most of the remaining seed coat radioactivity would not have been readily removed by the lesser acidity of the digestive tract of the mouse. For mice fed nonleached seeds, the higher radioactivity was apparently due to the amount of radioactivity leached by the digestive fluids, combined with an additional quantity of unavailable radioisotopes which just passed through the digestive tract. This unassimilated portion was the quantity which would have been removed by the acid-leach procedure, but was not removed by the 0.5% digestive fluids of the mouse. Excretion in mice fed nonleached seeds paralleled that of mice fed acid-treated seeds except for higher quantities of radioisotopes in the whole body during day 0 and day 1. Thus, in order to minimize the potential influence of seed-coat radioactivity and to reduce the total amount of radioactivity released into the environment, the acid leach was applied to all seeds prior to the start of the study.

E. Isotopic Transfer from Seed to Consumer

Another test was conducted with four male mice chronically fed 100 dual-tagged pine seeds per day for 14 days and subsequently examined for 106 days during excretion (Table A-6, Fig. A-4 and A-5).

Table A-6. Whole-body accumulation and excretion of ^{137}Cs and ^{60}Co in Peromyscus leucopus during and after 14-day chronic feeding of Pinus strobus seeds.

Day	Radioactivity (dpm X 10^3 ± 1 S. E.)		Cs/Co Ratio	Retention (%)	
	^{137}Cs	^{60}Co		^{137}Cs	^{60}Co
		Uptake phase			
1	168.72 ± 23.08	144.43 ± 2.32	1.17	---[a]	---
2	290.53 15.46	190.23 15.81	1.53	---	---
3	404.03 35.80	182.61 32.64	2.21	---	---
4	497.11 50.34	201.55 37.58	2.47	---	---
6	602.88 36.69	217.34 36.44	2.77	---	---
8	695.05 54.74	269.14 45.33	2.58	---	---
10	725.57 52.13	223.48 31.46	3.25	---	---
12	729.23 80.80	261.15 46.28	2.79	---	---
14	722.12 79.84	241.96 33.90	2.98	---	---
		Excretion phase			
0	722.12 ± 79.84	241.96 ± 33.90	2.98	100.00	100.00
1	577.82 76.02	64.33 28.02	8.98	80.02	26.59
2	508.98 70.52	27.02 8.81	18.84	70.48	11.17
3	411.39 60.59	13.55 3.21	30.37	56.97	5.60
4	363.25 58.06	9.54 1.20	38.07	50.30	3.94
5	317.78 54.77	8.30 0.53	38.30	44.01	3.43
8	191.09 36.32	8.21 1.02	23.27	26.46	3.39
9	168.97 34.24	5.12 0.35	32.97	23.40	2.12
12	115.73 24.83	5.38 0.53	21.53	16.03	2.22
15	80.74 19.50	7.67 3.39	10.53	11.18	3.17
22	28.51 7.38	3.32 0.32	8.57	3.95	1.37
29	12.37 2.96	2.83 0.29	4.37	1.71	1.17
36	7.52 1.55	2.38 0.10	3.16	1.04	0.98
43	5.31 1.04	1.88 0.16	2.82	0.74	0.78
57	2.83 0.52	1.55 0.04	1.83	0.39	0.64
106	1.08 0.30	0.85 0.05	1.26	0.15	0.35

[a]Not applicable during isotope uptake.

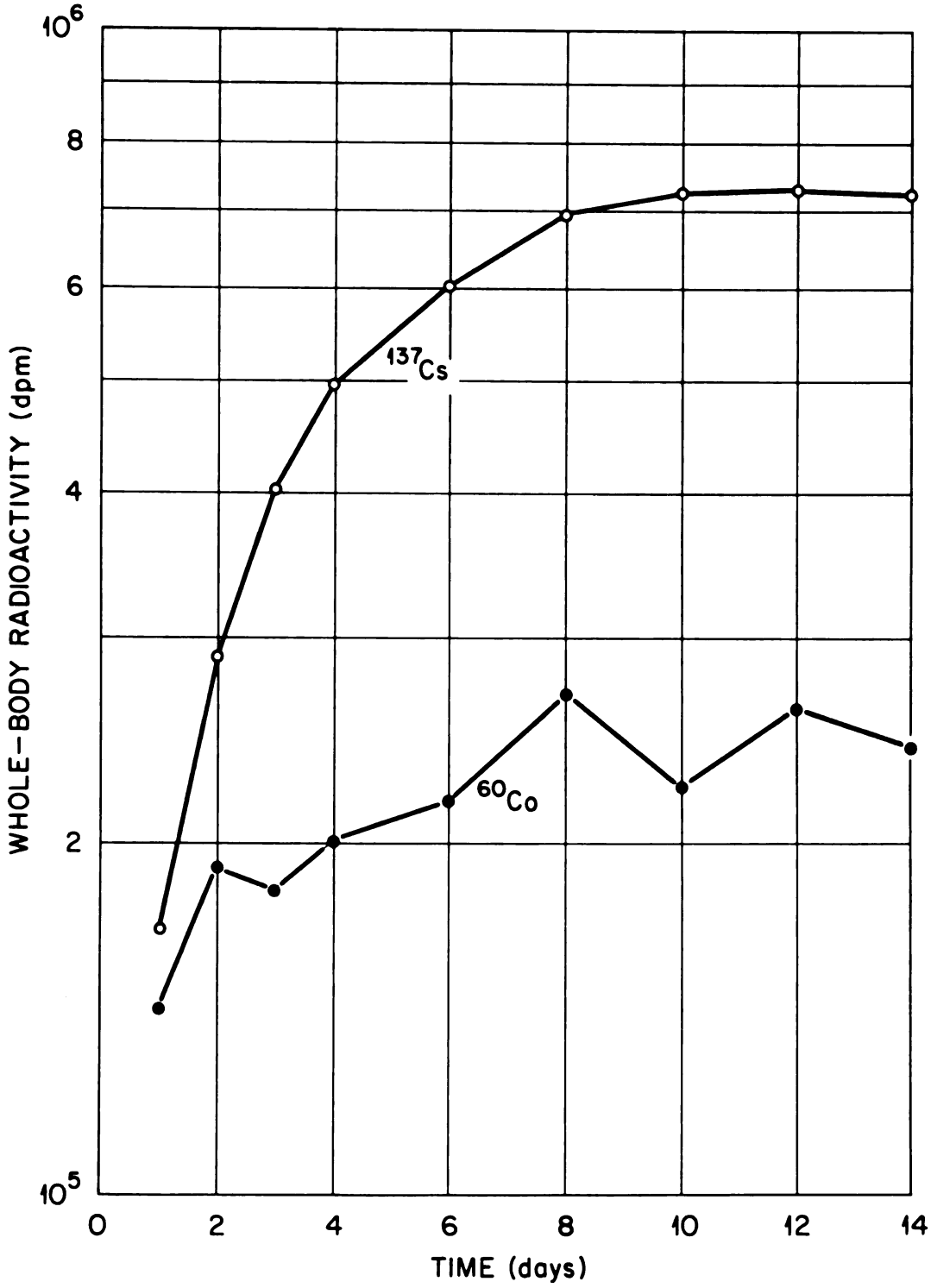

Figure A-4. Accumulation of ^{137}Cs and ^{60}Co in Peromyscus leucopus through fourteen-day chronic feeding of Pinus strobus seeds. Data from Table A-6.

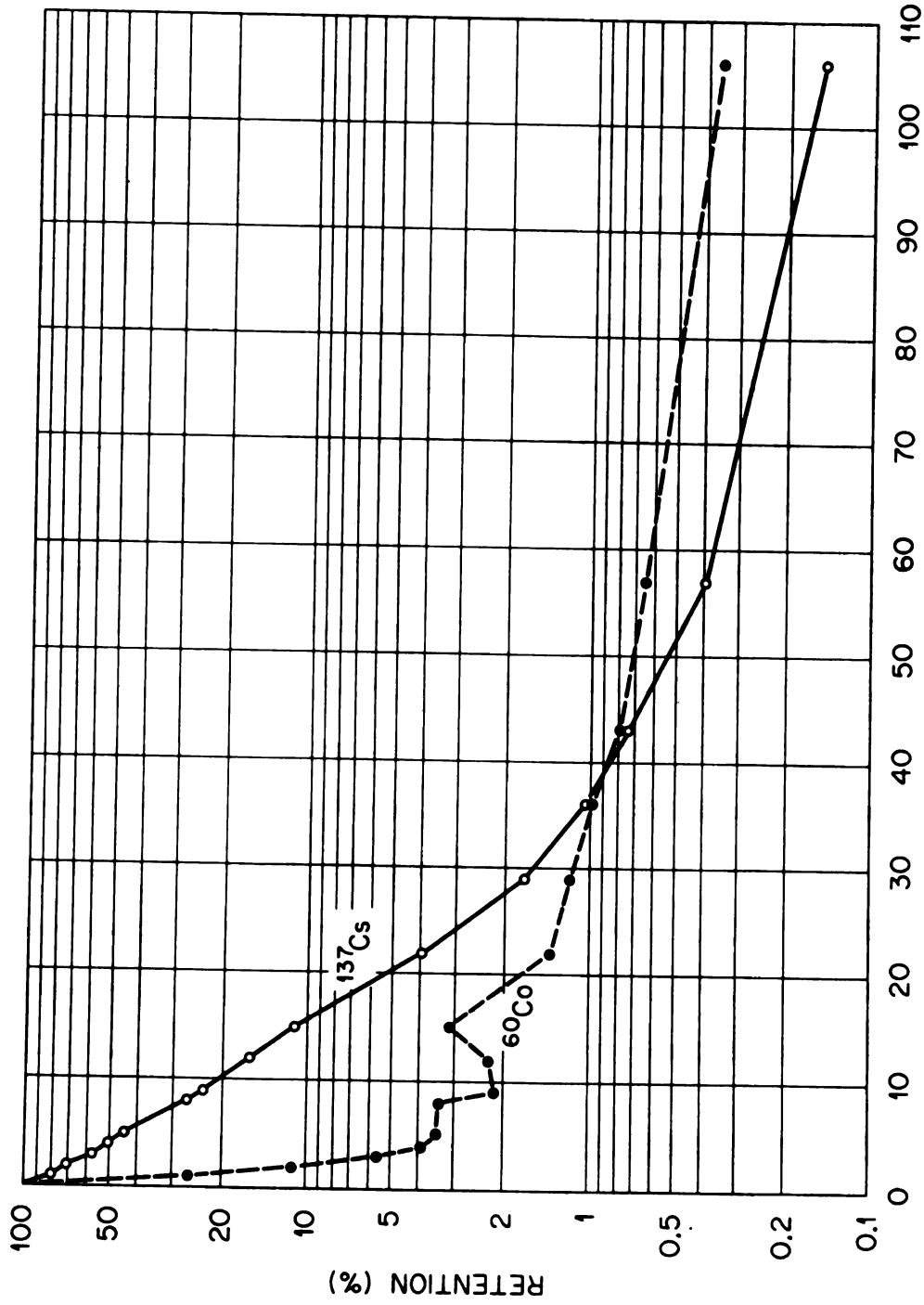

Figure A-5. Retention of ^{137}Cs and ^{60}Co by Peromyscus leucopus after chronic ingestion of tagged Pinus strobus seeds for fourteen days. Data from Table A-6.

Accumulation of ^{137}Cs after 14 days was 4.3 times the daily ingestion (predicted by the day 1 radioactivity), and 1.7 times for ^{60}Co. Equilibrium, when ingestion was equal to excretion, occurred after 10 days for ^{137}Cs. Equilibrium probably was not attained for ^{60}Co in this experiment, judging from the results of Smith et al. (1971), but the body burden did not appreciably change after day 8. Assimilation was nearly complete for ^{137}Cs, and approximately 2% for ^{60}Co. Fluctuations in the ^{60}Co radioactivity during uptake were primarily due to the mode of excretion. It would have been necessary to count mice for radioactivity at the same time, relative to their digestive processes, in order to smooth out the ^{60}Co curves. Although mice were fed at 1800 hr each evening, and counted from 0900 hr to 1130 hr each morning, individual variability in eating habits and rates of digestion of the mice created the problems in determining ^{60}Co equilibrium after the first day of ingestion. This problem did not occur with ^{137}Cs due to its high assimilation by mice. The soft tissues effectively integrated the ^{137}Cs body burden and smoothed the resultant curves. Results of these feeding tests indicated a favorable transfer and accumulation of ^{137}Cs in the soft tissues of mice. The food tag, ^{60}Co, also appeared to transfer satisfactorily.

F. Isotopic Retention of Chronic Versus Single Ingestion

Fecal excretion was examined to determine the pattern of excretion after single-feeding and at the end of the uptake portion of the chronic-feeding test (Fig. A-6 and Table A-7). After termination of chronic feeding, fecal excretion of ^{137}Cs was constant through the first few

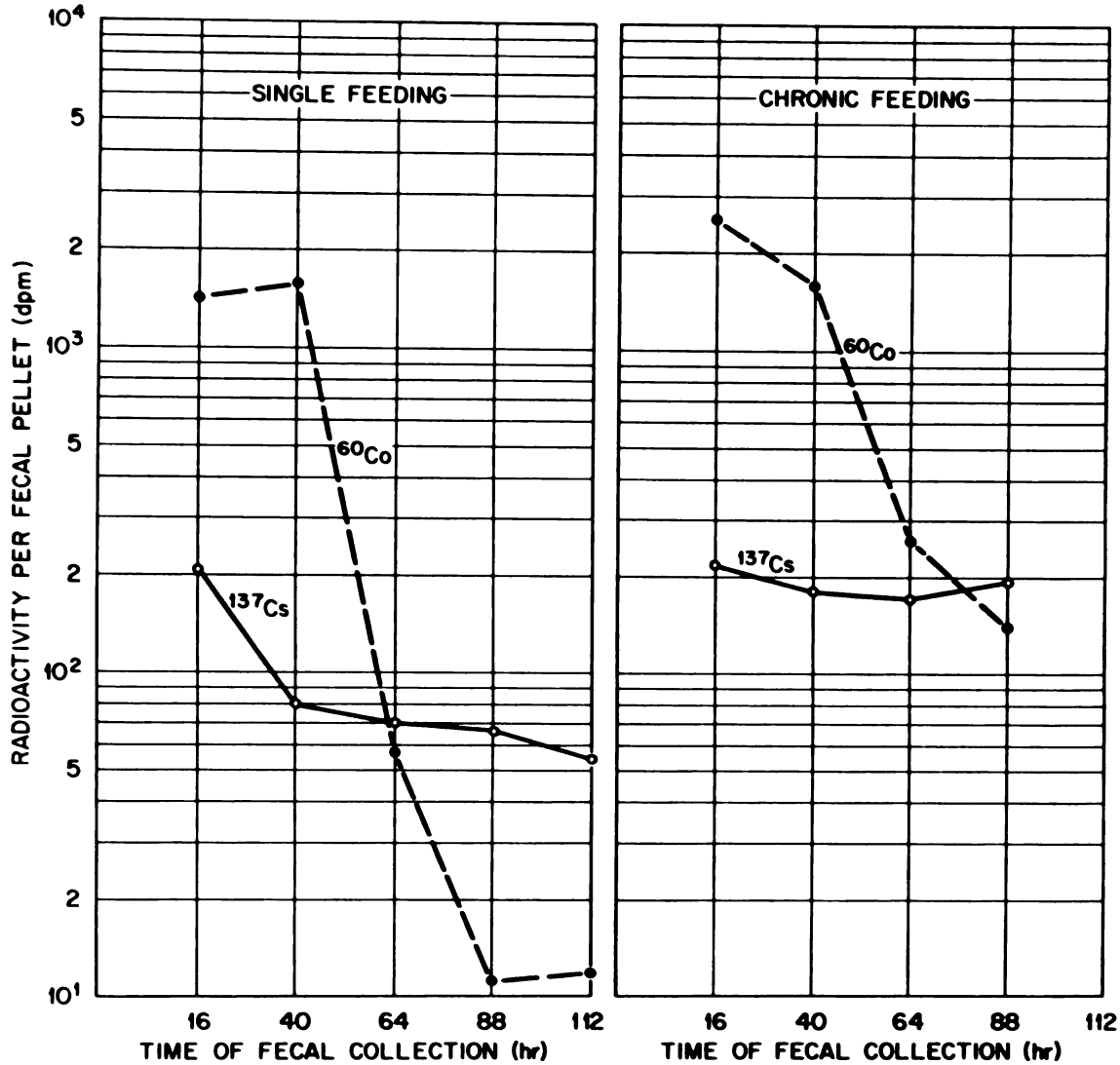

Figure A-6. Fecal excretion of ^{137}Cs and ^{60}Co by Peromyscus leucopus after consumption of Pinus strobus seeds for one or fourteen days. Data from Table A-7.

Table A-7. Fecal excretion of ^{137}Cs and ^{60}Co by four Peromyscus leucopus after consumption of Pinus strobus seeds for one or fourteen days.

Time of Fecal Collection[b] (hr)	Number of Feces[a] (total ± 1 S. E.)	Radioactivity per Fecal Pellet (dpm ± 1 S. E.)	
		^{137}Cs	^{60}Co
	One day		
16	72 ± 12	209 ± 114	1,410 ± 395
40	127 19	79 29	1,567 408
64[c]	109 21	70 24	56 1
88	106 8	66 8	11 1
112	120 8	53 16	12 6
	Fourteen day		
16	250 ± 20	217 ± 34	2,528 ± 550
40	126 14	181 21	1,590 268
64	179 24	170 37	256 120
88	138 23	190 48	140 57

[a]Number of feces collected per period.

[b]Time after last feeding of tagged seeds.

[c]N = 3.

days, while ^{60}Co was initially much higher (11 times greater than ^{137}Cs), and then rapidly decreased to a level consistent with ^{137}Cs. This decrease had occurred by 64 hr and was indicative of the gastrointestinal clearance of radioactive foods. An hourly collection of feces would have been necessary to determine this parameter more accurately. However, this turnover time was similar to that of another cricetid, Sigmodon hispidus, with a 66-hr turnover (Kitchings et al., 1969).

Whole-body retention of both radioisotopes was greater after chronic feeding than single feeding (Figs. A-3 and A-5). Differences, by day 22 of excretion, amounted to 2.8 times more ^{137}Cs retention and 8.5 times more ^{60}Co retention in mice fed chronically compared to those fed once. These whole-body retention differences may reflect the importance of various uptake compartments in the body. Those compartments which cycle elements slowly would not acquire significant radioactivity during the short period of access during single-feeding experiments. Thus, if these slowly-cycling compartments have not acquired a proportional share of the whole-body radioactivity, the excretion must reflect those faster-cycling compartments which did acquire a significant amount of radioactivity. Excretion curves for single-feeding experiments with mice should reflect faster excretion rates than excretion curves for chronically-fed mice, as was shown for these feeding experiments.

IX. APPENDIX B

The following series of tables and graphs were deemed of sufficient importance to include in the thesis as an aid to the explanation of text figures and tables.

Figure B-1. Modified latin square design for individual Peromyscus leucopus in each treatment combination. Location in the environmental chamber.

2[a] - Female	100 - Female	50 - Female	10 - Female	2 - Female	100 - Male	50 - Control
10 - Male	2 - Male	100 - Female	50 - Male	10 - Male	2 - Female	100 - Control
50 - Female	10 - Male	2 - Male	100 - Male	50 - Male	10 - Female	2 - Control
100 - Female	50 - Female	10 - Female	2 - Male	100 - Male	50 - Male	10 - Control

TOP SHELF BOTTOM SHELF[b]

[a]Number of seeds fed per day.

[b]Bottom shelf centered under top shelf.

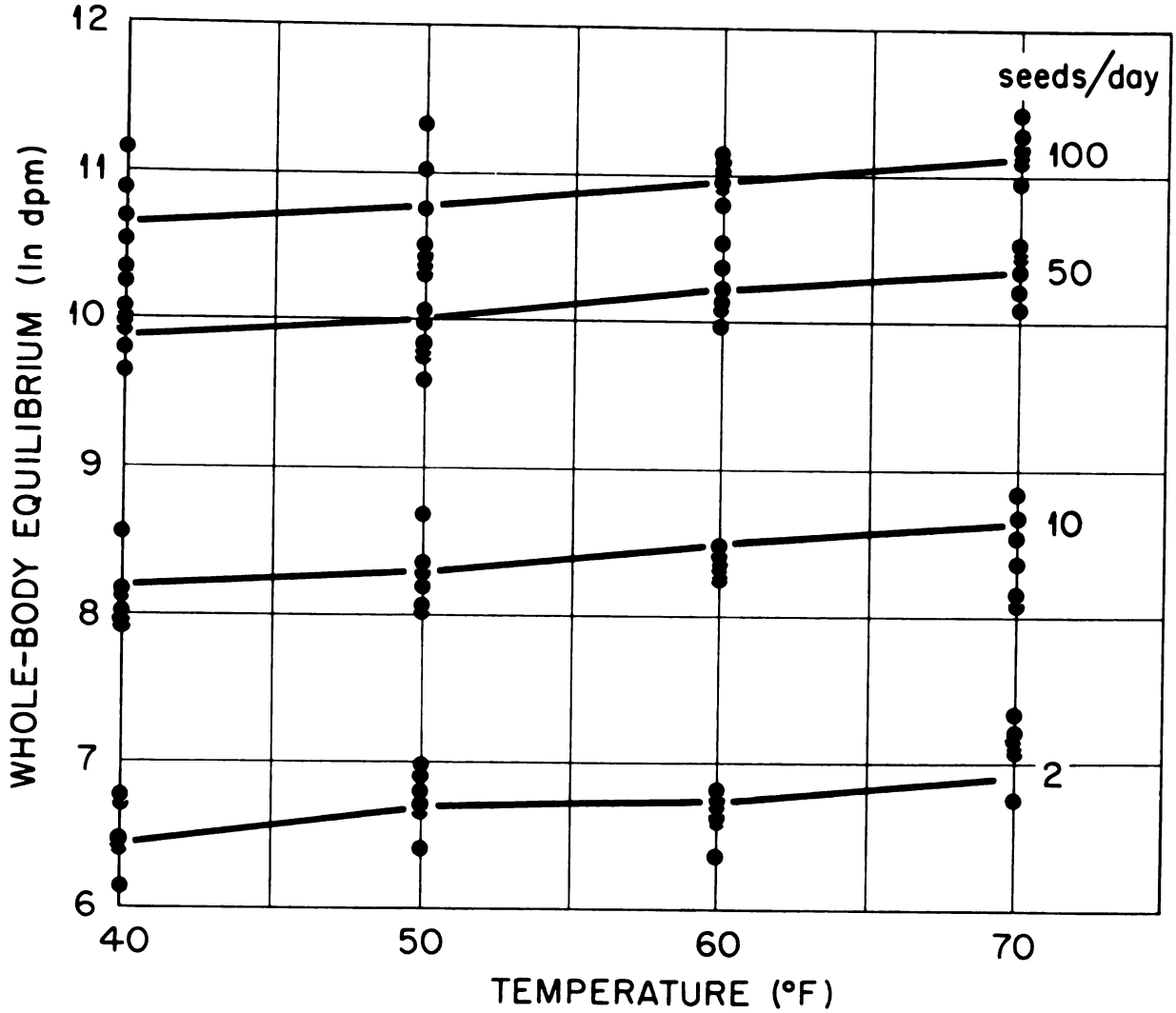

Figure B-2. Whole-body equilibrium in Peromyscus leucopus as influenced by temperature and ingestion rate. Data from Table 1.

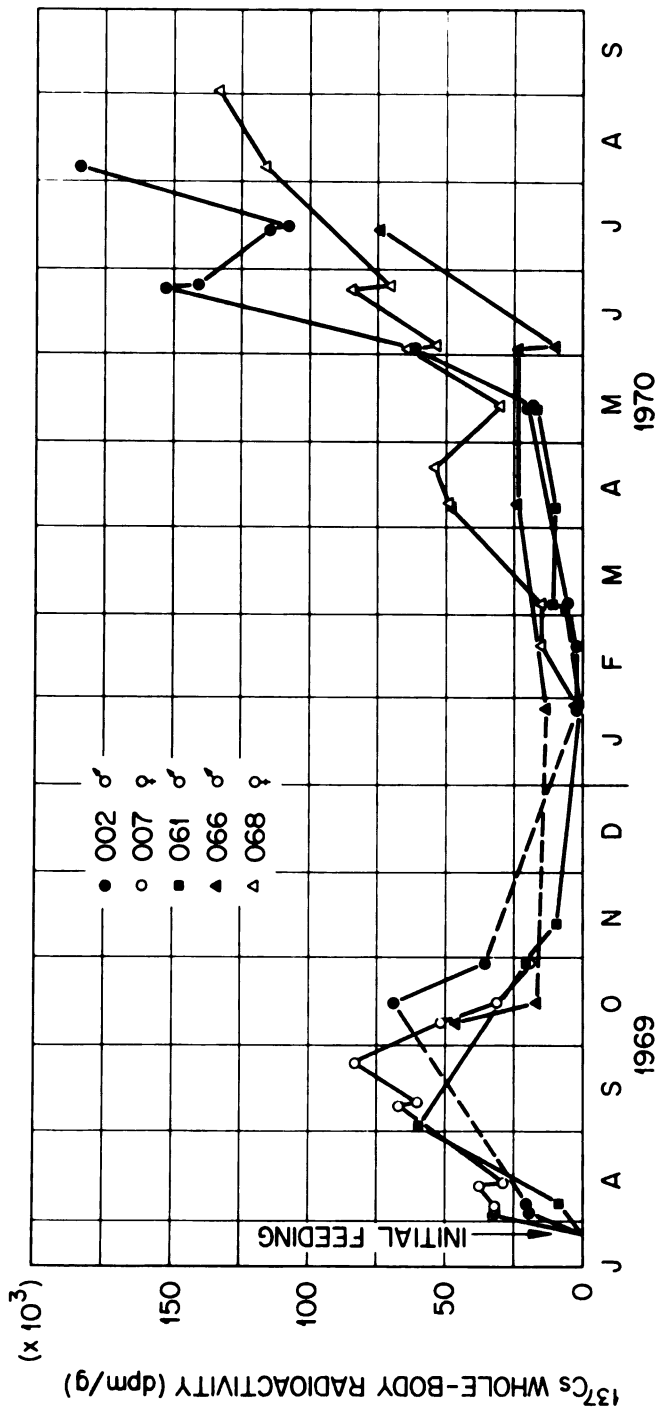

Figure B-3. Whole-body burden of ^{137}Cs for individual Peromyscus leucopus from the live-trap field plot throughout 58 weeks of feeding Pinus strobus seeds. Dashed lines connect animals which were not trapped for long periods of time. Data from Table B-26.

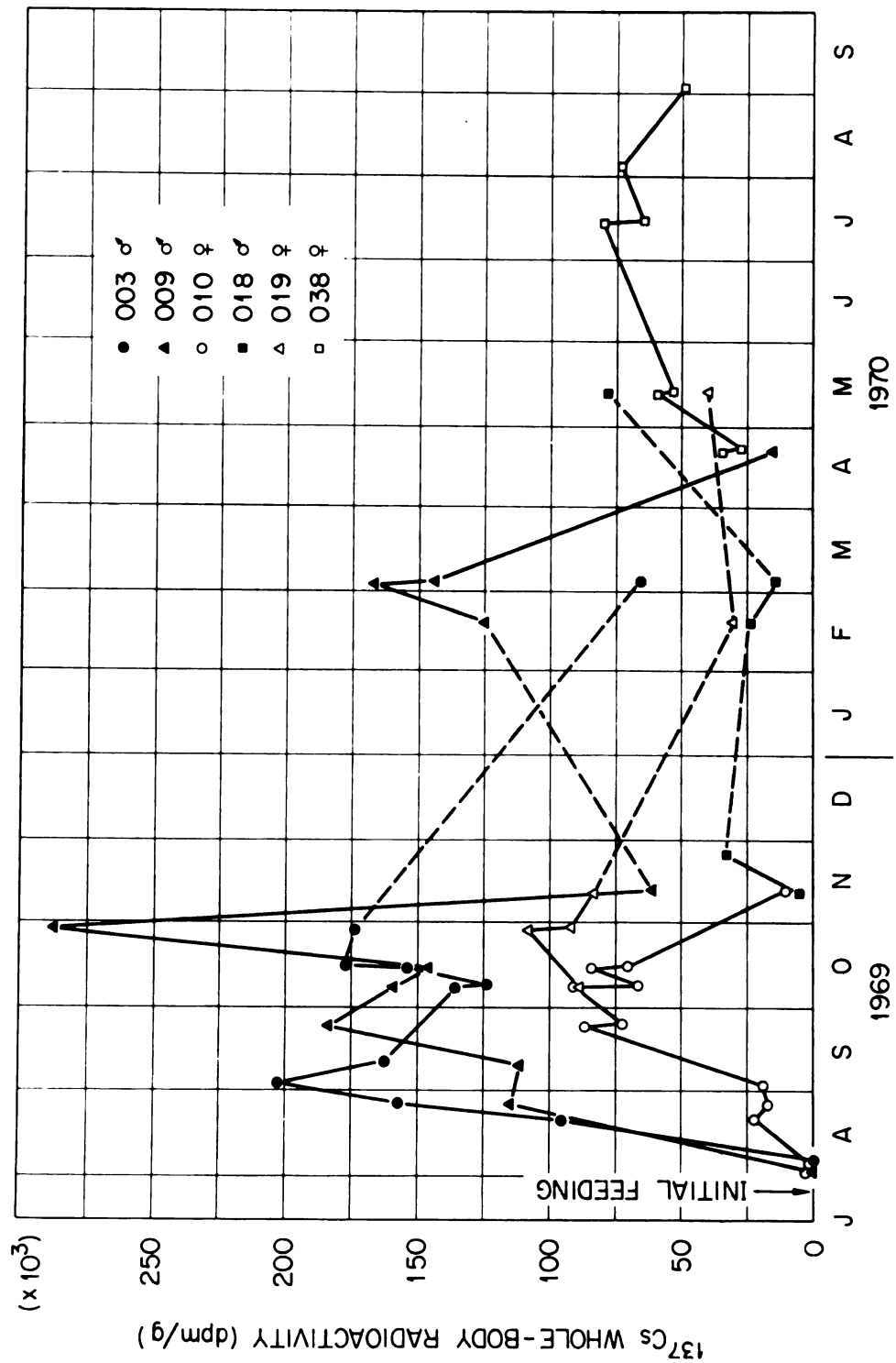

Figure B-4. Whole-body burden of ^{137}Cs for individual Blarina brevicauda from the live-trap field plot throughout 58 weeks of feeding Pinus strobus seeds. Dashed lines connect animals which were not trapped for long periods of Time. Data from Table B-28.

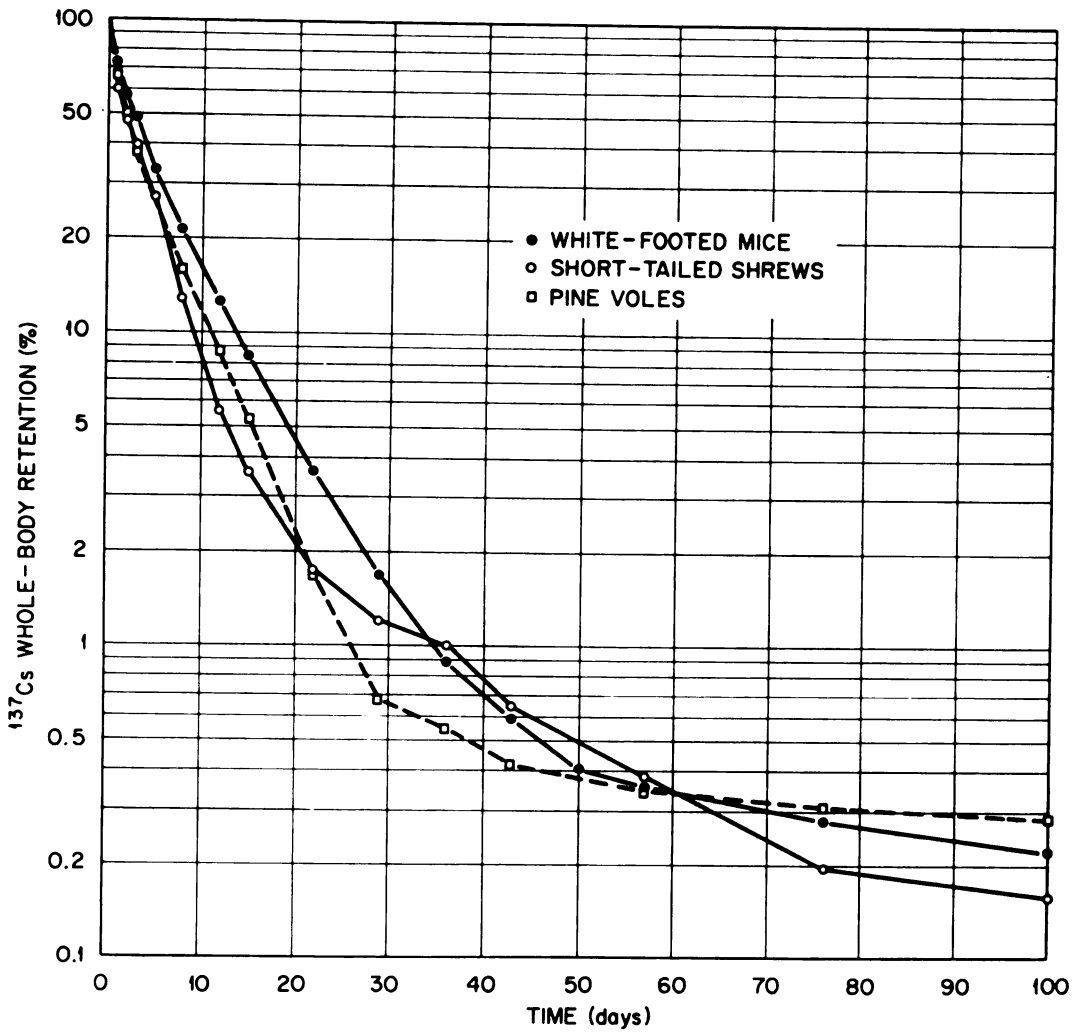

Figure B-5. Comparison of ^{137}Cs retention by three species of mammals. White-footed mouse data from the laboratory study after chronic feeding, N = 64; Blarina brevicauda and Microtus pinetorum data from field animals brought into the laboratory at the end of chronic feeding, N = 7 and 2, respectively.

Table B-1. Concurrent accumulation of ^{137}Cs and ^{60}Co in Pinus strobus seeds and subsequent removal by 0.75 N H_2SO_4 after various times.

Time (hr)	Radioactivity Per Seed (dpm X 10^3 ± 1 S. E.)[a] ^{137}Cs			^{60}Co		
			Uptake phase			
1/6	4.87	±	1.23	35.64	±	7.42
5	4.89		0.12	37.08		2.34
10	17.25		0.50	42.25		1.97
20	13.94		0.56	35.71		4.06
30	13.20		0.99	309.89		37.30
46	12.73		0.16	377.96		26.30
48	29.86		0.51	277.24		12.44
			Acid treatment phase			
0	29.86	±	0.51	277.24	±	12.44
1/2	17.19		1.15	133.57		3.92
1	12.55		0.72	99.85		13.73
1 1/2	13.47		0.56	84.27		6.42
2	9.08		0.56	80.53		26.16

[a]Radioactivity averaged for 50 seeds measured in 5 lots of 10 seeds each. S. E. = (S. E. of 10 seeds)/10.

Table B-2. Mean weight per *Pinus strobus* seed fed to *Peromyscus leucopus* in each treatment combination in the laboratory.

Ingestion Rate:		2[a]	10	50	100	Means
Season	Week Fed	Mean Seed Weight (mg)				
Winter	1	18.50	18.12	18.19	18.20	
(4.4 C)	2	18.85	18.64	18.09	18.33	
	3	19.40	18.11	17.93	18.36	
	4	18.52	19.09	18.20	18.30	
	5	18.81[b]	18.55	18.55	18.32	
	6	18.81[b]	18.28	18.50	17.73	
	7	18.29[b]	19.12	18.50	18.50	
	Mean	18.74	18.56	18.28	18.25	18.28
		±0.14	±0.16	±0.09	±0.09	±0.07
Autumn	1	19.51	17.17	17.25	17.22	
(10.0 C)	2	20.98	18.08	17.74	17.72	
	3	20.39	18.39	18.23	17.70	
	4	19.47	17.78	18.07	17.79	
	5	20.28	18.60	18.12	18.04	
	6	21.55	17.83	17.78	18.18	
	7	21.10	18.19	18.23	18.06	
	Mean	20.47	18.01	17.92	17.82	17.89
		±0.30	±0.18	±0.13	±0.12	±0.23
Spring	1	19.18	19.61	18.40	18.34	
(15.6 C)	2	18.82	19.06	18.44	18.09	
	3	18.78	19.30	18.11	18.57	
	4	18.87	18.97	18.82	18.41	
	5	18.41	18.55	18.65	18.27	
	6	19.02	19.08	18.48	18.25	
	7	19.51	18.29	18.54	18.20	
	Mean	18.94	18.98	18.49	18.30	18.30
		±0.13	±0.17	±0.08	±0.06	±0.08
Summer	1	19.65	18.53	18.29	18.46	
(21.1 C)	2	20.00	19.53	18.66	18.50	
	3	19.22	18.52	17.85	18.50	
	4	19.78	18.84	17.89	18.26	
	5	19.57	19.07	18.40	18.46	
	6	18.31	18.15	18.74	18.42	
	7	21.02	18.45	18.34	18.28	
	Mean	19.65	18.73	18.31	18.41	18.42
		±0.31	±0.17	±0.13	±0.04	±0.14
Means:		19.46	18.55	18.25	18.20	18.25
		±0.17	±0.11	±0.07	±0.06	±0.07

[a] N for each week = (ingestion rate X 6 mice X 7 days).
[b] Only 5 mice in this treatment combination.

Table B-3. Three-way factorial analysis of variance for seed weight fed to Peromyscus leucopus during the laboratory study.

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F Ratio	Probability
Feeding rate (F)	3	28.26	9.42	56.66	< 0.001
Temperature (T)	3	1.64	0.55	3.29	0.025 < Pr < 0.05
Week fed (W)	6	1.44	0.24	1.44	
(F X T)	9	17.47	1.94	11.68	< 0.001
(F X W)	18	2.19	0.12	0.73	
(T X W)	18	4.79	0.27	1.60	
Residual	54	8.98	0.17		
Total	111	64.77			

Table B-4. Four-way factorial analysis of variance of ^{137}Cs dpm/g at equilibrium in Peromyscus leucopus during 49 days of chronic ingestion of Pinus strobus seeds.

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F Ratio	Probability
Sex (S)	1	2,423	2,423	42.19	< 0.001
Temperature (T)	3	9,679	3,226	56.17	< 0.001
Feeding Rate (FR)	3	293,139	97,713	1,701.14	< 0.001
Day of Uptake (D)	5	176	35	0.61	
(S X T)	3	448	149	2.60	0.05 < Pr < 0.10
(S X FR)	3	3,012	1,004	17.48	< 0.001
(S X D)	5	44	9	0.15	
(T X FR)	9	10.838	1,204	20.97	< 0.001
(T X D)	15	208	14	0.24	
(FR X D)	15	375	25	0.44	
(S X T X FR)	9	1,840	204	3.56	< 0.001
(S X T X D)	15	81	5	0.09	
(S X FR X D)	15	84	6	0.10	
(T X FR X D)	45	591	13	0.23	
(S X T X FR X D)	45	329	7	0.13	
Within Replicates	384	22,057	57		
Total	575	345,324			

Table B-5. Four-way factorial analysis of variance of ^{60}Co dpm/g at equilibrium in Peromyscus leucopus during 49 days of chronic ingestion of Pinus strobus seeds.

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F Ratio	Probability
Sex (S)	1	884	884	5.20	0.01 < Pr < 0.025
Temperature (T)	3	1,526	509	2.99	0.025 < Pr < 0.05
Feeding Rate (FR)	3	308,361	102,787	605.04	< 0.001
Day of Uptake (D)	5	343	69	0.40	
(S X T)	3	4,632	1,544	9.09	< 0.001
(S X FR)	3	817	272	1.60	
(S X D)	5	756	151	0.89	
(T X FR)	9	2,642	294	1.73	0.05 < Pr < 0.10
(T X D)	15	1,698	113	0.67	
(FR X D)	15	1,489	99	0.58	
(S X T X FR)	9	9,842	1,094	6.44	< 0.001
(S X T X D)	15	539	36	0.21	
(S X FR X D)	15	1,423	95	0.56	
(T X FR X D)	45	3,772	84	0.49	
(S X T X FR X D)	45	1,730	38	0.23	
Within Replicates	384	65,235	170		
Total	575	405,688			

Table B-6. Multiple linear regression of ^{137}Cs dpm/g at equilibrium in Peromyscus leucopus.

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F Ratio	Probability
Regression	6	246.55	41.09	898.71	< 0.001
Deviations	88	4.02	0.05		
Independent Variables:					
Sex	1	1.00	1.00	0.37	
Temperature	1	1.83	1.83	0.69	
ln (Seeds)[a]	1	243.17	243.17	3,055.53	< 0.001
(Sex X Temp)	1	2.11	2.11	0.79	
[Temp X ln (Seeds)]	1	224.11	224.11	787.57	< 0.001
[Sex X Temp X ln (Seeds)]	1	168.25	168.25	190.08	< 0.001
Total	94	250.57			

[a] ln of the total weight of seeds ingested in 42 days.

Table B-7. Uptake and equilibrium parameters for ^{137}Cs in Peromyscus leucopus during chronic ingestion of Pinus strobus seeds. Ingestion rate = number of seeds ingested per day.

Equation is: $A_t = Q_e + a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t}$.

Ingestion Rate	Temp (C)	Parameters of the Uptake Equation				
		Q_e (dpm X 10^3/g)	a_1 (dpm X 10^3/g)	λ_1 (day^{-1})	a_2 (dpm X 10^3/g)	λ_2 (day^{-1})
2	4.4	0.70	-0.52	-0.596	-0.16	-0.1072
	10.0	0.86	-0.54	-0.725	-0.33	-0.1698
	15.6	0.78	-4.06	-3.137	-0.53	-0.2314
	21.1	1.07	-0.82	-0.315	-0.32	-0.0640
10	4.4	3.78	-2.59	-0.647	-1.17	-0.0779
	10.0	4.12	-3.12	-0.617	-1.28	-0.0578
	15.6	4.46	-0.99	-1.041	-3.55	-0.4055
	21.1	4.92	-3.62	-0.354	-0.77	-0.1078
50	4.4	21.46	-16.26	-0.534	-6.09	-0.0380
	10.0	24.11	-17.50	-0.421	-8.88	-0.0750
	15.6	29.54	-22.10	-0.299	-5.80	-0.0647
	21.1	32.87	-24.73	-0.355	-5.21	-0.0788
100	4.4	42.13	-36.43	-0.692	-10.24	-0.1448
	10.0	53.28	-13.52	-0.458	-34.14	-0.0871
	15.6	61.49	-36.46	-0.535	-26.38	-0.1611
	21.1	76.37	-74.71	-0.287	-3.35	-0.0350
Mean:						
%		100.38	-69.66		-30.70	
λ_i				-0.475		-0.0635
± 1 S. E.		1.69	4.35	0.031	3.30	0.0161

Table B-8. Effect of mode of entry upon ^{137}Cs retention in Peromyscus leucopus.

Day of Excretion	N	Retention After Injection[a] (% ± 1 S. E.)		N	Retention After Chronic Feeding (% ± 1 S. E.)	
0	5	100.00	± 0.00	64	100.00	± 0.00
1	0	---[b]	---	64	75.67	0.79
2	0	---	---	64	60.46	1.24
3	0	---	---	64	49.72	1.44
5	0	---	---	64	33.86	1.70
6	5	17.87	2.32	0	---	---
8	0	---	---	64	19.57	1.32
10	5	8.33	1.74	0	---	---
14	5	3.70	1.05	0	---	---
15	0	---	---	64	6.67	0.64
18	5	1.90	0.69	0	---	---
22	0	---	---	64	2.89	0.26
25	4	0.66	0.22	0	---	---
29	0	---	---	64	1.83	0.16
33	2	0.33	0.04	0	---	---
36	0	---	---	64	1.19	0.08

[a]Data from an injection study by Baker (1970), with permission to use unpublished information.

[b]Not sampled.

Table B-9. Mean $^{137}Cs/^{60}Co$ ratio in *Peromyscus leucopus* during and after chronic ingestion of *Pinus strobus* seeds for 49 days.

Ingestion Rate[a]	Temp (C)	Day of Uptake 1	2	3	5	8	12	15	22	29	36	43	49
2	4.4	0.62	0.86	1.15	1.46	1.11	1.71	1.67	1.32	1.26	1.30	1.46	1.23
	10.0	1.52	2.50	2.12	2.72[b]	1.61	2.99[c]	2.38	1.92	1.90	2.22	0.98	2.15
	15.6	1.23	1.33	1.27	1.61	2.45	2.57	2.46	2.18	2.75	1.97	1.98	2.03
	21.1	1.66	1.45	1.72	2.51	1.45	2.71	2.58	2.21	3.51	0.76	2.32	3.39
10	4.4	0.48	0.73	0.71	0.96	0.82	1.08	1.38	1.33	1.08	1.74	1.29	1.50
	10.0	0.93	1.07	0.74	1.30[b]	2.16	1.33[c]	2.00	2.06	1.65	1.93	1.89	1.26
	15.6	0.71	1.56	1.73	1.55	1.13	1.62	1.92	1.52	1.80	1.39	1.61	1.31
	21.1	0.66	0.84	1.29	1.18	1.10	1.27	1.74	1.97	2.00	1.69	1.82	1.83
50	4.4	0.45	0.60	0.70	0.99	1.19	1.22	1.16	1.28	1.40	1.37	1.19	1.17
	10.0	0.59	0.63	0.68	1.08[b]	1.31	1.46[c]	1.47	1.36	1.20	1.45	1.17	1.09
	15.6	0.52	0.64	1.15	1.40	1.39	1.46	1.65	1.75	1.47	1.49	1.56	1.43
	21.1	0.39	0.91	1.14	1.38	1.61	1.65	1.40	1.48	1.63	1.08	1.59	1.71
100	4.4	0.47	0.44	0.60	0.65	0.75	0.86	0.94	0.87	1.01	0.94	0.82	0.84
	10.0	0.42	0.55	0.81	0.77[b]	0.77	0.90[c]	0.78	0.93	0.75	0.87	0.73	0.78
	15.6	0.41	0.54	0.74	1.08	1.18	1.22	1.00	1.05	0.92	1.06	1.04	1.11
	21.1	0.35	0.63	0.85	0.89	1.23	1.35	1.34	1.04	1.12	1.31	1.18	1.46
Mean	12.8	0.71	0.95	1.09	1.35	1.33	1.59	1.62	1.52	1.59	1.41	1.42	1.52

Table B-9 (cont'd)

Ingestion Rate[a]	Temp (C)	Day of Excretion 0	1	2	3	5	8	15	22	29	36	43	49	57	71	85	100
2	4.4	1.54	3.69	4.59	4.54	3.19	2.00	0.89	0.61	0.53	0.54	0.42	0.39	0.11	0.18	0.14	0.11
	10.0	2.13	4.34	5.99	6.28	5.36	3.36	1.62	0.75	0.84	0.54	0.50	0.46	0.25	0.20	---[d]	0.10
	15.6	2.04	5.19	7.08	7.01	5.85	3.90	1.76	0.96	0.63	0.54	0.45	0.34	0.25	0.18	0.21	0.18
	21.1	2.85	8.03	9.96	8.96	6.61	4.06	1.68	0.86	0.63	0.42	0.39	0.48	0.26	0.25	0.22	0.17
10	4.4	1.63	3.95	4.91	4.81	3.61	2.24	0.97	0.58	0.47	0.42	0.59	0.40	0.26	0.23	0.22	0.21
	10.0	1.16	2.89	4.59	5.62	4.50	3.17	1.08	0.61	0.43	0.33	0.31	0.33	0.19	0.19	0.17	0.17
	15.6	1.48	4.09	5.22	5.04	3.73	2.47	1.00	0.57	0.36	0.31	0.27	0.26	0.20	0.17	0.16	0.16
	21.1	1.67	5.35	8.55	8.96	7.82	6.17	2.80	1.34	1.28	0.70	0.64	0.59	0.41	0.33	0.28	0.28
50	4.4	1.20	2.88	4.59	5.03	4.09	2.72	1.14	0.58	0.43	0.36	0.47	0.33	0.20	0.17	0.17	0.14
	10.0	1.16	3.10	4.95	6.36	5.56	4.74	2.14	1.15	0.84	0.50	0.54	0.44	0.20	0.14	0.12	0.10
	15.6	1.34	5.06	9.79	10.75	9.24	6.79	3.36	1.88	1.13	0.87	0.71	0.68	0.37	0.26	0.23	0.23
	21.1	1.54	6.66	9.99	9.73	7.40	5.62	3.02	1.60	1.00	0.70	0.56	0.47	0.31	0.27	0.22	0.20
100	4.4	0.88	3.52	6.13	6.66	4.92	3.04	1.23	0.67	0.43	0.49	0.28	0.29	0.17	0.13	0.11	0.10
	10.0	0.77	1.62	2.51	3.09	2.95	2.28	0.84	0.33	0.33	0.22	0.20	0.27	0.12	0.08	0.08	0.07
	15.6	1.18	3.86	5.90	6.43	5.44	3.77	1.53	0.81	0.52	0.40	0.32	0.29	0.20	0.16	0.21	0.14
	21.1	1.45	4.15	6.30	6.80	6.55	5.05	2.48	1.22	0.63	0.39	0.30	0.30	0.20	0.16	0.14	0.15
Mean	12.8	1.50	4.27	6.31	6.63	5.43	3.84	1.72	0.91	0.65	0.48	0.43	0.40	0.23	0.19	0.18	0.16

[a]Ingestion rate = number of seeds ingested per day.

[b]Day 4 instead of day 5.

[c]Day 13 instead of day 12.

[d]Not sampled.

Table B-10. Weights of organs and tissues of Peromyscus leucopus after 49 days of chronic feeding of Pinus strobus seeds in the laboratory.

Organ or Tissue	N	Wet Weight (g ± 1 S. E.)		N	Oven-dry Weight[a] (g ± 1 S. E.)		(%)[b]
Blood[c]	16	0.58	± 0.03	16	0.12	± 0.007	1.48
Heart	31	0.16	0.007	31	0.04	0.002	0.54
Liver	31	1.26	0.05	31	0.37	0.01	4.81
Spleen	31	0.03	0.002	31	0.007	0.0004	0.09
Kidneys	31	0.32	0.01	31	0.09	0.003	1.14
Lungs	31	0.21	0.02	31	0.06	0.005	0.72
Muscle[d]	31	0.11	0.004	31	0.03	0.002	0.40
Femur	31	0.06	0.002	31	0.04	0.001	0.46
Brain	31	0.60	0.008	31	0.14	0.002	1.79
Testes	16	0.42	0.03	16	0.07	0.004	0.92
Ovaries	13	0.02	0.004	13	0.008	0.002	0.10
Epididymis	13	0.58	0.06	13	0.23	0.02	2.98
Urogenital	15	0.18	0.02	15	0.06	0.01	0.84
Bladder	15	0.02	0.004	15	0.006	0.001	0.07
Skin	31	2.79	0.09	31	1.61	0.07	20.74
Carcass[e]	17	10.14	0.32	31	4.26	0.18	55.02
Stomach	30	0.41	0.02	30	0.07	0.002	0.88
Sm. intestine	31	0.29	0.02	31	0.04	0.002	0.51
Lg. intestine	31	0.15	0.006	31	0.02	0.001	0.32
Cecum	31	0.15	0.007	31	0.02	0.0005	0.23
Gastrointestinal contents:							
Stomach	20	0.59	0.05	31	0.25	0.02	3.21
Sm. intestine	19	0.83	0.04	31	0.13	0.006	1.68
Lg. intestine	20	0.38	0.03	31	0.13	0.01	1.69
Cecum	19	0.64	0.05	31	0.15	0.009	1.87
Totals:							
Tissue	17	18.04	0.52	31	7.09	0.26	91.53
Gastrointestinal contents	19	2.43	0.14	31	0.66	0.03	8.47
Whole body	31	21.95	0.48	31	7.74	0.27	100.00

[a] Dried for a minimum of 48 hr at 50 C.
[b] Organ or tissues percentage of total oven-dry weight.
[c] Sample of blood, not total amount.
[d] Gastrocnemius muscle only.
[e] Residual carcass after removal of listed organs and tissues.

Table B-11. Chi-square test of radioisotopic distribution in organs or tissues of Peromyscus leucopus after 49 days of chronic feeding of Pinus strobus seeds in the laboratory.

Organ or Tissue	^{137}Cs Observed Ratio[a]	Chi-square Contribution	^{60}Co Observed Ratio[a]	Chi-square Contribution
Blood[b]	0.43	0.33	0.38	0.39
Heart	1.50	0.25	0.41	0.35
Liver	1.07	0.01	0.82	0.03
Spleen	1.33	0.11	1.42	0.18
Kidneys	1.86	0.74	1.53	0.28
Lungs	1.06	0.003	0.38	0.38
Muscle[c]	2.71	2.92	0.30	0.50
Femur	0.57	0.18	0.32	0.46
Brain	1.10	0.01	0.08	0.85
Testes	3.10	4.41	0.46	0.30
Ovaries	0.92	0.007	1.21	0.04
Epididymis	0.46	0.29	0.16	0.71
Urogenital	0.81	0.04	0.29	0.51
Bladder	6.38	28.92	2.54	2.36
Skin	0.38	0.38	0.08	0.84
Carcass[d]	1.16	0.03	0.10	0.80
Stomach	0.93	0.005	1.04	0.001
Small intestine	0.88	0.02	1.44	0.20
Large intestine	0.88	0.01	2.00	1.01
Cecum	0.74	0.07	2.92	3.68
Gastrointestinal contents:				
Stomach	0.80	0.04	16.14	229.14
Small intestine	1.72	0.52	1.81	0.65
Large intestine	1.75	0.56	22.72	471.91
Cecum	1.13	0.02	32.64	1,001.20
Total:		39.86		1,716.77
Total without bladder:		10.95		
Total without gastrointestinal contents:				13.87

[a]Ratio is (percent of isotope in sample/percent of total body weight in sample).

[b]Sample of blood, not total amount.

[c]Gastrocnemius muscle only.

[d]Residual carcass after removal of listed organs and tissues.

Table B-12. Distribution of tree species by size class for three field plots.[a]

Species[b]	Size Class (dbh in cm)															
	2.4 to 12.6				12.6 to 27.8				> 27.8				Total			
	Con	L-t	S-t	Total	Con	L-t	S-t	Total	Con	L-t	S-t	Total	Con	L-t	S-t	Total
Black gum	17	29	15	61	1	7	0	8	0	0	0	0	18	36	15	69
Yellow poplar	18	5	5	28	15	2	7	24	3	0	7	10	36	7	19	62
White oak	16	3	8	27	7	2	3	12	2	1	0	3	25	6	11	42
Sourwood	12	8	11	31	1	3	2	6	1	1	0	2	14	12	13	39
Sugar maple	0	22	6	28	0	4	1	5	0	0	0	0	0	26	7	33
Pignut hickory	10	2	11	23	0	0	4	4	1	3	1	5	11	5	16	32
Red maple	8	13	4	25	1	1	1	3	0	0	0	0	9	14	5	28
Black oak	5	3	0	8	7	1	2	10	3	1	5	9	15	5	7	27
Dogwood	8	4	12	24	0	0	0	0	0	0	0	0	8	4	12	24
White ash	2	0	12	14	0	0	3	3	0	0	2	2	2	0	17	19
Mockernut hickory	4	1	2	7	1	0	0	1	0	1	0	1	5	2	2	9
Shortleaf pine	0	0	0	0	0	1	0	1	1	4	2	7	1	5	2	8
Chestnut oak	0	0	0	0	0	2	0	2	0	5	0	5	0	7	0	7
Wild grape	2	1	2	5	0	0	0	0	0	0	0	0	2	1	2	5
Sassafras	1	1	0	2	0	2	0	2	0	0	0	0	1	3	0	4
Red mulberry	0	1	2	3	0	0	0	0	0	0	0	0	0	1	2	3
Persimmon	1	0	1	2	0	0	1	1	0	0	0	0	1	0	2	3
Black cherry	0	1	1	2	1	0	0	1	0	0	0	0	1	1	1	3
Crabapple	0	0	3	3	0	0	0	0	0	0	0	0	0	0	3	3
Post oak	0	0	0	0	0	0	0	0	1	1	0	2	1	1	0	2
Eastern redbud	0	0	2	2	0	0	0	0	0	0	0	0	0	0	2	2
Eastern white pine	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Hophornbeam	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Nannyberry	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
American elm	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Rock elm	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
Carolina buckthorn	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1
Southern red oak	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1
Shagbark hickory	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1
Black walnut	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	1
Sweet gum	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Total:	105	95	102	302	36	26	24	86	12	17	17	46	153	138	143	434

[a]Con = control; L-t = live-trap; and S-t = snap-trap field plot.
[b]Scientific names are listed in Table B-41.

Table B-13. Seasonal captures per 100 trap nights for *Peromyscus leucopus*, *Blarina brevicauda*, and *Tamias striatus* on the live-trap and control field plots.

Period or Season	Live-trap Plot				Control Plot			
	P.l.	B.b.	T.s.	Total	P.l.	B.b.	T.s.	Total
				Total captures				
Prestudy	4.17	2.50	0.42	7.08	2.50	1.67	0.00	4.17
Uptake[a]	3.31	4.37	0.35	8.03	5.99	3.13	0.82	9.95
Autumn	1.63	6.03	0.50	8.17	6.90	3.37	0.16	10.43
Winter	4.58	9.15	0.35	14.08	3.88	0.30	0.00	4.18
Spring	4.44	4.44	0.67	9.56	10.89	0.00	0.00	10.89
Summer	5.90	3.49	2.40	11.79	8.00	1.11	0.44	9.56
Excretion[b]	7.81	17.38	1.76	26.95	---[c]	---	---	---
Total:	4.21	6.75	0.89	11.85	6.74	1.91	0.32	8.97
				Total individuals				
Prestudy	2.08	2.50	0.42	5.00	1.67	1.67	0.00	3.33
Uptake[a]	1.42	1.65	0.24	3.31	1.09	1.63	0.27	3.00
Autumn	0.88	2.64	0.50	4.02	1.93	2.09	0.16	4.17
Winter	2.11	7.14	0.35	9.51	2.09	0.30	0.00	2.39
Spring	1.78	3.33	0.67	5.78	3.78	0.00	0.00	3.78
Summer	1.96	2.40	1.31	5.68	1.78	0.22	0.22	2.22
Excretion[b]	4.49	7.23	0.98	12.70	---[c]	---	---	---
Total:	1.28	2.17	0.39	3.85	1.13	0.92	0.11	2.15

[a]Period from July 24, 1969 to September 25, 1969.

[b]Period from September 1, 1970 to December 10, 1970.

[c]No trapping conducted during this period.

Table B-14. Recaptures of small mammals on the live-trap plot and control plot.

Number of Captures	*Peromyscus leucopus*		*Blarina brevicauda*		*Tamias striatus*	
	L-t[a]	Con	L-t	Con	L-t	Con
1	25	8	30	14	7	0
2	5	5	16	5	2	1
3	5	2	13	2	1	1
4	2	0	5	1	2	1
5	2	3	3	2	1	0
6	0	0	2	0	0	0
7	2	3	3	0	1	0
8	0	1	1	0	0	0
9	1	2	2	0	0	0
10	0	1	0	1	0	0
11	1	1	0	0	0	0
12	0	2	3	0	0	0
13	0	1	1	0	0	0
14	1	2	0	0	0	0
15	0	0	0	0	0	0
16	1	0	0	0	0	0
17	0	0	0	0	0	0
18	1	0	0	0	0	0
19	0	1	0	0	0	0

[a]L-t = live-trap plot; Con = control plot.

Table B-15. Weekly Pinus strobus utilization from feeders by small forest mammals on the live-trap and snap-trap field plots.
Weekly seed weight fed = 435.2 g/plot.

Week	Date Examined	Total Utilization (%)		Eaten in Feeder (%)	
		Live-trap	Snap-trap	Live-trap	Snap-trap
		Uptake[a]			
1	7/31/69	12.27	42.65	---[b]	---
2	8/7	26.95	85.55	---	---
3	8/14	44.26	100.00	---	50.39
4	8/21	54.69	100.00	---	30.47
5	8/28	66.41	100.00	22.08	21.88
6	9/4	53.91	100.00	12.89	28.12
7	9/11	73.44	100.00	16.02	22.27
8	9/18	88.28	100.00	22.27	19.15
9	9/25	66.80	100.00	12.11	15.23
		Autumn			
10	10/2	68.75	95.31	5.47	10.55
11	10/9	78.52	97.65	6.25	8.20
12	10/16	59.38	92.58	7.03	5.08
13	10/23	70.70	90.24	5.47	3.91
14	10/30	69.14	87.89	4.30	3.91
15	11/6	79.30	94.53	3.13	4.30
16	11/13	81.64	92.19	1.17	3.52
17	11/20	71.48	89.45	0.78	3.90
18	11/27	56.25	73.83	0.39	1.17
19	12/4	58.98	76.95	0.00	3.90
20	12/11	53.91	88.67	0.00	4.30
21	12/18	47.27	74.61	0.00	3.12
22	12/25	66.02	90.23	0.00	6.64
		Winter			
23	1/1/70	83.20	94.53	3.12	4.30
24	1/8	67.19	76.56	0.00	3.51
25	1/15	85.94	92.19	7.42	3.91
26	1/22	71.09	87.11	0.00	4.69
27	1/29	80.08	90.63	3.52	3.91
28	2/5	81.25	95.31	1.95	4.69
29	2/12	77.73	92.19	0.00	3.52
30	2/19	81.25	95.31	0.39	5.47
31	2/26	70.70	91.80	0.39	4.30
32	3/5	67.19	94.53	0.39	4.69
33	3/12	66.41	92.58	0.39	4.30
34	3/19	69.53	88.28	1.17	7.42
35	3/26	63.67	80.08	0.00	7.03
		Spring			
36	4/2	72.65	91.41	1.17	9.77
37	4/9	57.03	95.31	1.17	18.75
38	4/16	69.53	97.66	1.17	23.05

Table B-15 (cont'd)

Week	Date Examined	Total Utilization (%)		Eaten in Feeder (%)	
		Live-trap	Snap-trap	Live-trap	Snap-trap
		Spring			
39	4/23	82.81	100.00	1.95	16.02
40	4/30	83.20	100.00	4.69	6.64
41	5/7	82.81	100.00	4.30	12.11
42	5/14	81.64	100.00	10.16	14.84
43	5/21	85.16	100.00	11.72	8.59
44	5/28	90.23	100.00	15.23	7.81
45	6/4	95.70	100.00	9.37	10.94
46	6/11	98.05	100.00	11.33	4.69
47	6/18	94.14	100.00	12.11	3.52
48	6/25	92.58	100.00	11.72	8.20
		Summer			
49	7/2	94.53	100.00	14.06	10.55
50	7/9	95.31	100.00	18.36	13.67
51	7/16	92.19	100.00	9.38	12.11
52	7/23	92.19	100.00	17.97	16.02
53	7/30	87.89	100.00	16.02	9.38
54	8/6	91.40	100.00	14.84	10.94
55	8/13	94.92	100.00	20.31	10.55
56	8/20	80.08	100.00	18.75	12.89
57	8/27	92.97	100.00	19.14	14.84
58	9/3	79.30	100.00	19.14	17.97
		Excretion[c]			
1	9/10	94.63		4.55	
2	9/17	94.74		2.83	
3	9/24	92.56		6.61	
4	10/1	98.14		2.23	
5	10/8	95.39		1.54	
6	10/15	95.41		1.53	
7	10/22	98.49		1.50	
8	10/29	95.88		0.00	
9	11/5	96.90		3.10	
10	11/12	96.23		5.66	
11	11/19	91.73		4.35	
12	11/26	95.83		4.52	
13	12/3	91.23		6.32	
14	12/10	97.19		9.13	

[a]Period from July 24, 1969 to September 25, 1969.
[b]No data collected.
[c]Nonradioactive sunflower seed used in feeders during the excretion phase in amounts equivalent to Pinus strobus seeds. No seed used on the snap-trap plot as the population of small mammals was removed at the end of feeding pine seed.

Table B-16. Comparison of visual estimation of feeder utilization to actual utilization.

Estimated Utilization Class	N	Estimated Remaining (g)	Actual Remaining (g ± 1 S. E.)
0 Removal	195	6.8	6.60 ± 0.02
1/4 Removal	63	5.1	5.37 0.09
1/2 Removal	33	3.4	3.66 0.12
3/4 Removal	39	1.7	1.97 0.14

Table B-17. Mean body burden of ^{137}Cs and ^{60}Co per trapping period for Peromyscus leucopus and Blarina brevicauda on the live-trap field plot containing Pinus strobus seeds.

Date	Day of Study	P. leucopus (dpm X 10^3/g ± 1 S. E.) N	^{137}Cs	^{60}Co	B. brevicauda (dpm X 10^3/g ± 1 S. E.) N	^{137}Cs	^{60}Co
7/24/69	0	5	0.002 ± 0.0004	0.008 ± 0.0008	6	0.003 ± 0.0003	0.015 ± 0.002
7/26	2	2	4.73 4.72	1.02 1.01	2	0.006 0.005	0.028 0.004
8/2	9-10	3	27.51 4.03	18.07 11.45	1	0.40 ---[a]	0.036 ---
8/5	12-13	3	25.95 3.30	7.70 3.32	2	0.83 0.83	0.28 0.24
8/12	19-20	4	44.01 3.42	11.33 2.74	0	---[b] ---	--- ---
8/19	26-28	1	53.95 ---	14.52 ---	5	74.26 21.53	13.57 4.28
8/26	33	3	56.75 7.65	7.93 2.68	5	72.69 27.74	9.90 4.13
9/2	40-41	1	59.70 ---	22.00 ---	5	98.42 36.69	16.61 6.50
9/9	47-48	2	82.78 15.72	24.88 1.69	4	115.00 21.86	19.78 5.09
9/23	61-62	2	125.58 42.62	12.17 3.51	2	135.15 48.35	17.22 5.19
10/7	75-76	2	48.66 2.68	13.66 5.06	5	116.22 23.29	26.68 6.61
10/14	82-83	3	38.57 15.65	8.43 0.39	3	127.91 21.86	24.67 5.51
10/28	96-97	3	24.57 5.32	8.20 1.49	4	146.47 56.98	31.22 5.82
11/11	110-111	1	8.92 ---	7.02 ---	4	39.99 19.13	23.99 6.51
11/25	124-125	0	--- ---	--- ---	1	32.70 ---	17.99 ---
12/9	138-139	0	--- ---	--- ---	4	73.98 25.04	24.47 3.41
1/27/70	187-188	3	5.06 3.97	3.34 0.78	0	--- ---	--- ---
2/18	209	2	8.24 6.25	3.08 0.60	6	51.31 17.48	32.01 2.61
3/3	222-223	3	8.26 3.12	2.94 0.56	8	106.44 22.72	35.38 4.93
4/7	257-258	3	26.98 11.17	5.72 1.61	1	59.25 ---	22.30 ---
4/21	271-272	1	53.77 ---	11.58 ---	4	44.34 21.01	23.66 2.41
5/12	292-293	4	30.11 8.84	6.33 2.73	5	52.63 7.89	25.85 3.79
6/2	313-314	4	43.09 11.35	12.44 1.39	1	62.49 ---	22.69 ---
6/23	334-335	4	91.67 24.16	49.82 17.32	0	--- ---	--- ---
7/14	355-356	3	81.66 17.73	19.23 7.16	4	76.99 6.41	25.14 2.61
8/4	376-377	6	93.54 20.83	26.16 3.79	4	85.06 7.52	19.76 1.73
9/1	404-405	5	63.74 19.93	28.02 8.05	2	54.69 5.35	21.89 0.91

[a] No standard error available.
[b] No animals captured.

Table B-18. Seasonal captures of individual small forest mammals on the snap-trap field plot.

Period or Season	Trap Nights	Captures[a]					
		P.l.	B.b.	M.p.	S.l.	T.s.	Total
Prestudy	380[b]	2	0	0	0	1	3
Autumn	38	0	2	0	0	0	2
Winter	87	1	0	1	2	0	4
Spring	58	1	0	5	1	0	7
Summer	58	5	6	0	0	0	11
Autumn	192[b]	8	13	2	0	1	24
Total:	813	17	21	8	3	2	51
Captures per 100 trap nights:		2.09	2.58	0.98	0.37	0.25	6.27

[a]Species are P.l. = Peromyscus leucopus; B.b. = Blarina brevicauda; M.p. = Microtus pinetorum; S.l. = Sorex longirostris; and T.s. = Tamias striatus.

[b]Live-traps used instead of Museum Special snap-traps.

Table B-19. Weights of organs and tissues of Peromyscus leucopus from the snap-trap field plot.

Organ or Tissue	N	Wet Weight (g ± 1 S. E.)		N	Oven-dry Weight[a] (g ± 1 S. E.)		(%)[b]
Heart	7	0.15 ±	0.01	7	0.04 ±	0.004	0.64
Liver	7	1.06	0.20	7	0.30	0.06	4.74
Spleen	6	0.05	0.01	6	0.01	0.002	0.17
Kidneys	7	0.28	0.04	7	0.07	0.01	1.16
Lungs	7	0.22	0.02	7	0.06	0.004	0.95
Muscle[c]	7	0.14	0.02	7	0.04	0.006	0.63
Femur	7	0.06	0.01	7	0.03	0.004	0.55
Brain	7	0.55	0.05	7	0.13	0.01	2.11
Testes	2	0.30	0.23	2	0.05	0.04	0.77
Ovaries	3	0.02	0.004	3	0.004	0.001	0.08
Epididymis	2	1.11	0.15	2	0.33	0.08	5.02
Urogenital	4	0.13	0.03	4	0.03	0.01	0.45
Bladder	4	0.03	0.01	4	0.005	0.001	0.08
Skin	6	2.47	0.30	7	1.03	0.12	17.31
Carcass[d]	5	9.68	1.21	7	3.25	0.30	54.38
Stomach	7	0.34	0.06	7	0.06	0.01	1.03
Sm. intestine	7	0.18	0.02	7	0.03	0.01	0.54
Lg. intestine	7	0.10	0.01	7	0.01	0.003	0.24
Cecum	7	0.09	0.02	7	0.01	0.003	0.21
Gastrointestinal contents:							
Stomach	7	1.25	0.40	7	0.50	0.15	8.06
Sm. intestine	5	0.98	0.26	7	0.15	0.03	2.44
Lg. intestine	6	0.33	0.10	7	0.07	0.02	1.15
Cecum	5	0.59	0.21	7	0.10	0.02	1.72
Totals:							
Tissue	5	15.32	1.92	7	5.21	0.44	86.64
Gastrointestinal contents	5	3.24	1.12	7	0.82	0.20	13.36
Whole body	7	19.89	2.13	7	6.03	0.59	100.00

[a]Dried for a minimum of 48 hr at 50 C.

[b]Organ or tissues percentage of total oven-dry weight.

[c]Gastrocnemius muscle only.

[d]Residual carcass after removal of listed organs and tissues.

Table B-20. Radioactivity and Cs/Co ratios of individual *Peromyscus leucopus* for consecutive captures during the same trapping period on the live-trap field plot.

Date of First Capture	Days of Uptake	First Capture ^{137}Cs (dpm X 10^3/g)	First Capture ^{60}Co (dpm X 10^3/g)	First Capture Cs/Co Ratio	Second Capture ^{137}Cs (dpm X 10^3/g)	Second Capture ^{60}Co (dpm X 10^3/g)	Second Capture Cs/Co Ratio	Change in Ratio
8/2/69	9-10	32.01	40.14	0.80	31.63	9.98	3.17	Increase
8/12	19-20	37.50	10.91	3.44	28.82	3.00	9.61	Increase
8/19	26-27	53.95	14.52	3.72	45.70	8.12	5.62	Increase
9/9	47-48	67.06	23.20	2.89	59.84	12.24	4.89	Increase
1/27/70	187-188	1.34	3.56	0.38	1.18	2.79	0.42	Increase
3/3	222-223	5.26	3.63	1.45	11.35	21.89	0.52	Decrease
4/7	257-258	47.91	3.71	12.92	48.64	3.01	16.14	Increase
5/12	292-293	19.49	3.25	5.99	17.85	3.06	5.83	Decrease
6/2	313-314	23.07	9.98	2.31	19.47	4.49	4.33	Increase
6/2	313-314	63.90	10.86	5.88	52.59	7.02	7.49	Increase
6/23	334-335	84.61	38.54	2.20	69.96	11.53	6.07	Increase
6/23	334-335	153.00	92.04	1.66	140.80	100.30	1.40	Decrease
7/14	355-356	115.40	33.54	3.44	97.85	14.39	6.80	Increase
9/1	404-405	32.70	10.03	3.26	28.38	6.58	4.31	Increase
9/1	404-405	47.72	53.78	0.89	40.74	15.35	2.65	Increase
Mean				3.41			5.28	

Table B-21. Radioactivity and Cs/Co ratios of individual Blarina brevicauda for consecutive captures during the same trapping period on the live-trap field plot.

Date of First Capture	Days of Uptake	First Capture ^{137}Cs (dpm X 10^3/g)	First Capture ^{60}Co (dpm X 10^3/g)	First Capture Cs/Co Ratio	Second Capture ^{137}Cs (dpm X 10^3/g)	Second Capture ^{60}Co (dpm X 10^3/g)	Second Capture Cs/Co Ratio	Change in Ratio
6/5/69	12-13	1.67	0.52	3.21	2.69	0.52	5.20	Increase
9/9	47-48	130.80	24.03	5.44	113.00	17.10	6.61	Increase
9/23	61-62	86.80	12.03	7.22	72.32	10.34	6.99	Decrease
10/7	75-76	135.70	36.47	3.72	124.40	33.92	3.67	Decrease
10/7	75-76	14.50	4.20	3.45	56.71	16.23	3.49	Increase
10/7	75-76	90.50	16.05	5.64	66.59	13.70	4.86	Decrease
10/14	82-83	153.60	32.44	4.74	177.80	32.14	5.53	Increase
10/14	82-83	84.44	14.01	6.03	70.47	13.28	5.31	Decrease
10/28	96-97	108.00	23.76	4.54	91.77	19.78	4.64	Increase
11/11	110-111	83.25	34.06	2.44	80.33	29.80	2.70	Increase
11/11	110-111	5.23	12.33	0.42	4.33	11.70	0.37	Decrease
2/18/70	209-210	15.09	33.81	0.45	10.18	26.73	0.38	Decrease
3/3	222-223	166.90	44.85	3.72	143.70	34.46	4.17	Increase
3/3	222-223	97.02	25.21	3.85	67.03	19.88	3.37	Decrease
3/3	222-223	193.00	38.27	5.04	130.80	27.35	4.78	Decrease
4/21	271-272	34.73	11.04	3.15	27.69	10.43	2.66	Decrease
4/21	271-272	105.20	21.99	4.78	77.45	19.70	3.93	Decrease
5/12	292-293	59.17	12.95	4.57	53.54	12.72	4.21	Decrease
7/14	355-356	78.32	22.65	3.46	53.75	19.13	2.81	Decrease
7/14	355-356	79.90	19.59	4.08	64.81	16.60	3.89	Decrease
Mean				4.00			3.98	

Table B-22. Accumulation and retention of ^{137}Cs and ^{60}Co by Blarina brevicauda chronically ingesting 10 Pinus strobus seeds per day at 22 C in the laboratory.

Day	N	Weight (g ± 1 S. E.)	Radioactivity (dpm X 10^3/g) ^{137}Cs	Radioactivity (dpm X 10^3/g) ^{60}Co	Cs/Co Ratio
		Uptake phase			
1	4	21.08 ± 1.55	0.29 ± 0.19	0.57 ± 0.52	0.51
2	4	21.36 1.45	0.82 0.64	0.23 0.13	3.58
3	4	21.54 1.36	1.56 1.38	0.46 0.44	3.42
5	4	21.11 1.49	5.30 1.37	1.70 0.87	3.12
8	4	21.90 1.40	5.52 1.37	0.74 0.30	7.47
12	4	21.22 1.40	5.33 1.35	0.45 0.19	11.79
15	4	21.37 1.33	5.93 2.21	0.41 0.16	14.50
22	4	21.57 1.51	5.96 2.00	1.26 0.59	4.72
29	4	19.52 2.34	8.65 3.36	1.75 0.48	4.94
36	4	20.14 2.34	9.34 4.22	0.93 0.41	10.08
43	4	19.90 1.95	9.38 3.50	2.32 1.11	4.04
49	3	19.16 2.06	10.08 2.91	2.52 1.87	4.00
		Retention phase			
0	3	19.16 ± 2.06	10.08 ± 2.91	2.52 ± 1.87	4.00
1	3	18.72 2.24	7.89 2.18	0.89 0.51	8.85
2	3	19.03 1.96	5.85 1.39	0.74 0.39	7.93
3	3	19.00 2.24	4.44 0.88	0.64 0.31	6.91
5	3	18.49 2.57	2.88 0.78	0.60 0.30	4.84
8	3	18.69 2.75	1.71 0.51	0.53 0.27	3.22
15	3	17.86 2.41	0.53 0.18	0.40 0.16	1.34
22	3	18.68 2.86	0.12 0.03	0.32 0.12	0.37
29	3	19.28 3.44	0.03 0.005	0.27 0.09	0.12
36	2	20.51 4.39	0.02 0.004	0.15 0.06	0.11
43	2	20.05 4.76	0.012 0.005	0.14 0.07	0.08
49	2	19.17 4.92	0.011 0.004	0.14 0.06	0.08

Table B-23. Caging trials to observe antagonistic behavior between Blarina brevicauda and mice in the laboratory.

Trial	Duration (days)	Mouse N	Mouse Species[b]	Mouse Age	Animal Dying	Food[a]	Remarks
1	1	1	P.l.	25-d	shrew	AB	No food for 7 hr.
2	1 5/6	1	P.l.	28-d	mouse	B	No antagonism until shrew shelter (sod) placed in corner occupied by mouse. Death within 4 hr.
3	1/2	1	P.l.	30-d	mouse	B	Same shrew as in trial 2. Killed mouse overnight.
4	1/4	1	P.l.	8-d	mouse	B	No antagonism until lights turned off, then shrew killed mouse within 10 min.
5	20	1	P.l.	Ad.	None	BCDE	Mouse with bloody feet and tail for first few days.
6	102	2	P.l.	Ad.	shrew	BCDE	Same as trial 5 but second mouse added. Both mice with shortened tails (4 cm), chewed by shrew.
7	16	1	P.l.	Ad.	None	BCDE	No antagonism
8	16	2	P.l.	Ad.	shrew	BCDE	Same as trial 7 but second mouse added. Obesity was probable cause of death.
9	13	5	P.l.	Juv.	shrew	BCDE	No mouse meat provided for 2 days before death.
10	12	1	P.l.	Ad.	mouse	BCDE	Mouse immobilized by author, shrew killed mouse in 5 min.
11	12	2	P.l.	21-d Ad.	Ad. mouse	BCDE	Mouse immobilized by author, shrew killed mouse in 10 min.
12	86	1	P.l.	Ad.	None	BCDE	Pregnant mouse gave birth to litter of two on day 1, separated litter on day 85. Shrew and three mice nesting in same 8 X 8 X 13 cm tin can.

Table B-23 (cont'd)

Trial	Duration (days)	Mouse N	Mouse Species[b]	Mouse Age	Animal Dying	Food[a]	Remarks
13	4	1	P.l.	Ad.	None	BCE	
14	5	5	P.l.	Ad. 14-d	4 juv.	BCE	Mother attacked shrew on sight, but shrew killed one juvenile each day.
15	3	2	P.l.	Ad. 21-d	juv. mouse	BCE	Same as trial 14.
16	2	2	P.l.	Ad.	shrew	BCE	Same as trial 14. Shrew very obese at death.
17	1 1/2	1	P.l.	Ad.	shrew mouse	BCD	Mouse in poor health and died 7 hr after shrew.
18	5	1	P.l.	Ad.	shrew	BCD	
19	24	1	P.l.	Ad.	shrew	BCD	
20	4	1	P.l.	Juv.	mouse	BC	Two shrews in cage.
21	4	1	P.l.	Ad.	mouse	BC	Same as trial 20.
22	1/6	1	M.m.	Juv.	mouse	BCD	Same as trial 20. Mouse evaded shrews until wetted with water.

[a]Food code: A = no food; B = sunflower seed; C = laboratory chow; D = frozen laboratory mice; and E = cockroaches.

[b]Species code: P.l. = Peromyscus leucopus; M.m. = Mus musculus.

Table B-24. Retention of ^{137}Cs and ^{60}Co in Peromyscus leucopus from the field plots. One population brought from the field into the laboratory; second population trapped periodically in the field.

Day	Radioactivity (dpm X 10^3/g ± 1 S. E.)							
	Laboratory (Unknown Ingestion Rate)				Field (Unknown Ingestion Rate)			
	N	^{137}Cs		^{60}Co		N	^{137}Cs		^{60}Co	
0	6	40.55	± 5.80	15.85	± 2.41	5	63.74	± 19.93	28.02	± 8.05
1	6	29.74	4.68	9.53	1.53	0	---[a]	---	---	---
2	7	23.38	3.98	8.27	1.32	0	---	---	---	---
3	7	19.71	3.37	7.73	1.28	0	---	---	---	---
5	7	13.47	2.41	7.00	1.20	0	---	---	---	---
8	7	8.67	1.83	6.38	1.19	2	24.30	14.34	8.91	3.81
12	7	5.11	1.25	5.82	1.12	0	---	---	---	---
15	7	3.45	0.98	5.36	1.22	0	---	---	---	---
16	0	---	---	---	---	4	9.09	3.44	8.48	2.37
22	7	1.46	0.47	4.60	1.02	0	---	---	---	---
29	7	0.69	0.22	4.11	0.96	0	---	---	---	---
36	7	0.37	0.11	3.78	0.95	0	---	---	---	---
37	0	---	---	---	---	4	0.37	0.08	4.23	1.17
43	7	0.24	0.06	3.56	0.93	0	---	---	---	---
50	7	0.16	0.04	3.37	0.90	3	0.28	0.14	3.97	1.75
57	7	0.15	0.03	3.06	0.81	0	---	---	---	---
75	0	---	---	---	---	3	0.19	0.06	2.71	0.98
76	7	0.11	0.03	2.57	0.75	0	---	---	---	---
100	7	0.09	0.02	2.32	0.65	1	0.20	---	1.79	---

[a]Animals not sampled on this day.

Table B-25. Mean $^{137}Cs/^{60}Co$ ratios for *Peromyscus leucopus*, *Blarina brevicauda*, and *Tamias striatus* at various times after beginning of tagged seed placement on the live-trap field plot. N for each ratio appears in Tables 11 and B-16.

Date	Day of Uptake	$^{137}Cs/^{60}Co$ Ratio		
		P.l.	B.b.	T.s.
7/24/69	0	0.20	0.21	---[a]
7/26	2	4.65	0.23	0.62
8/2	9-10	1.52	10.99	---
8/5	12-13	3.37	2.96	---
8/12	19-20	3.88	---	1.42
8/19	26-28	3.72	5.47	---
8/26	33	7.16	7.34	---
9/2	40-41	2.71	5.92	---
9/9	47-48	3.33	5.82	---
9/23	61-62	10.32	7.85	0.004
10/7	75-76	3.56	4.36	---
10/14	82-83	4.58	5.18	---
10/28	96-97	3.00	4.69	---
11/11	110-111	1.27	1.67	---
11/25	124-125	---	1.82	2.85
12/9	138-139	---	3.02	---
1/27/70	187-188	1.51	---	---
2/18	209	2.68	1.60	---
3/3	222-223	2.81	3.01	---
4/7	257-258	4.72	2.66	---
4/21	271-272	4.64	1.87	---
5/12	292-293	4.75	2.04	---
6/2	313-314	3.46	2.75	1.34
6/23	334-335	1.84	---	3.48
7/14	355-356	4.25	3.06	0.97
8/4	376-377	3.58	4.31	1.23
9/1	404-405	2.28	2.50	1.88
Mean		3.59	3.80	1.53

[a]No mammals of this species trapped during this period.

Table B-26. Estimation of consumption rates of Pinus strobus seeds by individual Peromyscus leucopus on the live-trap field plot.

Animal Number	Day of Study	Body burden (dpm/g) ^{137}Cs	Body burden (dpm/g) ^{60}Co	Cs/Co Ratio	Sex	Temp (C)	Day of Excretion	Equilibrium Body Burden ^{137}Cs (dpm/g)	Seed consumption (g/d)	Seed consumption (seeds/day)
P1 002	10	19.47	1.78	10.93	M	22.2	3.00	39.41	1.15	63.1
	13	20.41	4.03	5.07		22.2	1.64	31.22	0.93	50.9
	83	68.71	9.02	7.62		14.5	3.00	139.10	4.62	253.0
	97	35.19	11.01	3.20		8.4	0.49	40.63	1.75	95.7
	188	1.18	2.79	0.42		5.0	0.00	1.18	0.07	3.8
	209	1.99	2.48	0.80		11.7	0.00	1.99	0.10	5.2
	223	5.01	3.35	1.49		14.5	0.00	5.01	0.21	11.5
	292	19.49	3.25	5.99		22.2	2.21	33.65	1.00	54.6
	293	17.85	3.06	5.83		22.2	2.11	30.20	0.90	49.4
	313	61.57	12.69	4.85		20.0	1.51	91.44	2.67	146.2
	334	153.00	92.04	1.66		23.3	0.00	153.10	3.90	213.9
	335	140.80	100.30	1.40		23.3	0.00	140.9	3.62	198.1
	355	115.4	33.54	3.44		26.6	0.64	138.80	3.24	177.7
	356	97.85	14.39	6.80		26.6	2.71	186.9	4.26	233.7
	377	184.40	29.82	6.18		26.6	2.33	326.3	7.11	389.8
P1 007	9	32.01	40.14	0.80	F	22.2	0.00	32.02	0.82	44.8
	10	31.63	9.98	3.17		22.2	0.47	36.36	0.91	50.1
	12	31.84	4.76	6.69		22.2	2.64	60.03	1.43	78.3
	19	37.50	10.91	3.44		23.3	0.64	45.07	1.08	59.0
	20	28.82	3.00	9.61		23.3	3.00	58.34	1.35	74.2
	47	67.06	23.20	2.89		16.6	0.30	73.42	1.98	108.6
	48	59.84	12.24	4.89		16.6	1.53	89.33	2.36	129.6
	62	82.97	14.68	5.29		18.9	1.78	130.8	3.13	171.7
	76	51.33	18.72	2.74		16.6	0.21	54.71	1.52	83.4
	83	30.81	7.68	4.01		14.5	0.99	40.54	1.23	67.5
	96	18.67	5.96	3.13		8.4	0.45	21.32	0.80	44.1

Table B-26 (cont'd)

Animal Number	Day of Study	Body burden (dpm/g) ^{137}Cs	Body burden (dpm/g) ^{60}Co	Cs/Co Ratio	Sex	Temp (C)	Day of Excretion	Equilibrium Body Burden ^{137}Cs (dpm/g)	Seed consumption (g/d)	Seed consumption (seeds/day)
Pl 061	13	8.52	2.45	3.47	M	22.2	0.66	10.30	0.33	18.3
	40	59.70	22.00	2.71		23.3	0.19	63.30	1.73	94.8
	97	19.85	7.62	2.60		8.4	0.12	20.63	0.93	50.7
	111	8.92	7.02	1.27		11.1	0.00	8.93	0.39	21.5
	188	0.86	1.89	0.46		5.0	0.00	0.86	0.05	2.8
	222	5.26	3.63	1.45		14.5	0.00	5.26	0.22	12.0
	223	11.35	21.89	0.52		14.5	0.00	11.35	0.45	24.6
	257	9.73	8.90	1.09		12.2	0.00	9.74	0.41	22.6
	292	16.26	2.84	5.72		22.2	2.04	27.12	0.82	44.7
Pl 066	76	45.98	8.60	5.35	M	16.6	1.81	73.05	2.38	130.5
	83	16.18	8.59	1.88		14.5	0.00	16.19	0.62	34.2
	187	12.99	4.58	2.84		5.0	0.26	14.08	0.71	38.9
	258	23.31	4.56	5.11		12.2	1.66	35.85	1.39	76.3
	313	23.07	9.98	2.31		20.0	0.00	23.08	0.75	40.9
	314	19.47	4.49	4.33		20.0	1.19	26.86	0.86	47.1
	355	74.20	12.03	6.17		26.6	2.32	131.00	3.08	168.6
Pl 068	188	0.54	0.72	0.75	F	5.0	0.00	0.54	0.03	1.6
	209	14.49	3.67	3.95		11.7	0.95	18.87	0.66	36.3
	223	14.50	1.83	7.93		14.5	3.00	29.35	0.92	50.4
	257	47.91	3.71	12.92		12.2	3.00	96.98	2.88	157.8
	258	48.64	3.01	16.14		12.2	3.00	98.46	2.92	160.0
	271	53.77	11.58	4.64		18.9	1.38	77.56	1.96	107.5
	293	29.43	4.81	6.11		22.2	2.28	51.63	1.25	68.5
	313	63.90	10.86	5.88		20.0	2.14	108.9	2.58	141.3
	314	52.59	7.02	7.49		20.0	3.00	106.5	2.53	138.5
	334	84.61	38.54	2.20		23.3	0.00	84.65	1.88	103.2
	335	69.96	11.53	6.07		23.3	2.26	122.0	2.61	142.8
	377	115.9	35.17	3.30		26.6	0.55	136.1	2.62	143.8
	404	133.0	31.70	4.20		26.6	1.10	179.8	3.36	183.9

Table B-27. Retention of ^{137}Cs and ^{60}Co in Blarina brevicauda from the field plots. One population brought from the field into the laboratory; second population trapped periodically in the field.

Day	Radioactivity (dpm X 10^3/g ± 1 S. E.)							
	Laboratory (Unknown Ingestion Rate)			Field (Unknown Ingestion Rate)				
	N	^{137}Cs	^{60}Co	N	^{137}Cs	^{60}Co		
0	7	34.70 ± 4.89	21.05 ± 1.76	2	54.69 ± 5.35	21.89 ± 0.91		
1	7	20.88 3.89	15.49 1.70	0	---[a] ---	--- ---		
2	7	16.45 3.46	14.74 1.66	0	--- ---	--- ---		
3	7	13.90 3.25	14.21 1.75	0	--- ---	--- ---		
5	7	9.38 2.52	13.21 1.61	0	--- ---	--- ---		
8	7	4.46 1.56	11.02 1.42	8	16.77 3.79	17.86 3.09		
12	7	1.95 0.82	9.56 1.19	0	--- ---	--- ---		
15	7	1.26 0.52	9.04 1.16	0	--- ---	--- ---		
16	0	--- ---	--- ---	7	5.32 1.24	16.01 2.59		
22	7	0.61 0.21	7.54 0.94	0	--- ---	--- ---		
23	0	--- ---	--- ---	9	1.41 0.39	11.35 2.46		
29	7	0.42 0.09	7.01 0.93	0	--- ---	--- ---		
36	5	0.37 0.08	6.39 0.83	0	--- ---	--- ---		
37	0	--- ---	--- ---	18	0.72 0.18	7.78 1.32		
43	3	0.22 0.05	5.82 0.57	0	--- ---	--- ---		
50	0	--- ---	--- ---	19	0.22 0.06	4.75 1.13		
57	3	0.13 0.05	4.77 0.49	0	--- ---	--- ---		
75	0	--- ---	--- ---	14	0.03 0.01	4.29 0.95		
76	3	0.07 0.02	3.58 0.12	0	--- ---	--- ---		
100	2	0.05 0.01	3.00 0.15	15	0.03 0.01	1.75 0.65		

[a]Animals not sampled this day.

Table B-28. Estimation of consumption rates of Pinus strobus seeds by individual Blarina brevicauda on the live-trap field plot.

Animal Number	Day of Study	Body Burden (dpm/g) ^{137}Cs	Body Burden (dpm/g) ^{60}Co	Cs/Co Ratio	Sex	Temp (C)	Day of Excretion	Equilibrium Body Burden ^{137}Cs (dpm/g)	Seed Consumption (g/d)	Seed Consumption (seeds/day)
Bb 003	27	95.76	19.57	4.89	M	24.4	1.00[a]	126.3	3.17	173.6
	33	157.50	25.48	6.18		23.3		207.7	5.17	283.4
	40	202.7	34.61	5.86		23.3		267.4	6.53	357.6
	48	162.2	32.15	5.05		16.6		213.9	6.45	353.6
	75	135.7	36.47	3.72		16.6		179.0	5.47	299.7
	76	124.4	33.92	3.67		16.6		164.1	5.04	276.5
	82	153.6	32.44	4.73		14.5		202.6	6.55	358.8
	83	177.8	32.14	5.53		14.5		234.5	7.50	411.1
	96	173.9	36.22	4.80		8.4		229.4	8.81	483.0
	223	66.10	38.25	1.73		14.5		87.19	2.99	163.9
Bb 005	10	0.40	0.04	10.99	F	22.2	1.00	0.52	0.02	1.2
	33	17.02	5.69	2.99		23.3		22.45	0.58	31.8
	75	37.48	8.59	4.37		16.6		49.44	1.39	76.1
	223	41.48	19.27	2.15		14.5		54.71	1.62	88.5
	257	59.25	22.30	2.66		12.2		78.15	2.37	129.8
	271	105.2	21.99	4.78		18.9		138.8	3.30	181.0
	272	77.45	19.70	3.93		18.9		102.2	2.51	137.6
Bb 007	12	1.67	0.52	3.21	M	22.2	1.00	2.20	0.08	4.4
	13	2.69	0.52	5.19		22.2		3.55	0.12	6.8
	28	87.81	17.25	5.09		24.4		115.8	2.92	160.3
	75	158.6	45.02	3.52		16.6		209.2	6.32	346.3
	223	108.3	45.68	2.37		14.5		142.9	4.73	259.3
Bb 009	33	114.7	10.43	11.00	M	23.3	1.00	151.3	3.86	211.6
	47	111.1	13.93	7.98		16.6		146.5	4.54	248.9
	61	183.5	22.41	8.19		18.9		242.0	6.78	371.4
	75	158.8	27.29	5.82		16.6		209.5	6.33	346.7

Table B-28 (cont'd)

Animal Number	Day of Study	Body Burden (dpm/g) ^{137}Cs	Body Burden (dpm/g) ^{60}Co	Cs/Co Ratio	Sex	Temp (C)	Day of Excretion	Equilibrium Body Burden ^{137}Cs (dpm/g)	Seed Consumption (g/d)	Seed Consumption (seeds/day)
Bb 009	82	145.7	27.57	5.28	M	14.5	1.00	192.2	6.24	341.7
	96	287.4	45.15	6.37		8.4		379.1	14.10	772.5
	111	61.02	36.40	1.68		11.1		80.49	3.06	167.4
	209	124.8	40.21	3.10		11.6		164.6	5.86	321.0
	222	166.9	44.85	3.72		14.5		220.1	7.07	387.6
	223	143.7	34.46	4.17		14.5		189.5	6.16	337.3
	271	15.30	27.72	0.55		18.9		20.18	0.68	37.2
Bb 010	9	3.04	0.11	28.75	F	22.2	1.00	4.01	0.13	7.0
	12	1.41	0.05	31.04		22.2		1.86	0.06	3.5
	28	22.56	1.97	11.46		24.4		29.76	0.72	39.7
	33	17.07	1.68	10.17		23.3		22.52	0.58	31.8
	40	19.72	2.77	7.11		23.3		26.01	0.66	36.2
	61	86.80	12.03	7.22		18.9		114.5	2.78	152.4
	62	72.32	10.34	6.99		18.9		95.39	2.36	129.4
	75	90.50	16.05	5.64		16.6		119.4	3.07	168.2
	76	66.59	13.70	4.86		16.6		87.83	2.33	127.7
	82	84.44	14.01	6.03		14.5		111.4	3.07	168.1
	83	70.47	13.28	5.31		14.5		92.95	2.61	142.8
	111	10.47	13.16	0.80		11.1		13.81	0.50	27.7
Bb 018	75	14.50	4.20	3.45	F	16.6	1.00	19.13	0.59	32.4
	76	56.71	16.23	3.49		16.6		74.80	2.02	110.5
	83	27.40	11.16	2.46		14.5		36.14	1.11	60.83
	110	5.23	12.33	0.42		11.1		6.90	0.27	14.7
	111	4.33	11.70	0.37		11.1		4.71	0.23	12.4
	124	32.70	17.99	1.82		3.4		43.13	1.76	96.2
	209	23.99	37.25	0.64		11.6		31.64	1.06	58.0
	223	14.38	15.95	0.90		14.5		18.97	0.62	34.0
	292	78.36	34.53	2.27		22.2		103.4	2.32	127.0

Table B-28 (cont'd)

Animal Number	Day of Study	Body Burden (dpm/g) ^{137}Cs	Body Burden (dpm/g) ^{60}Co	Cs/Co Ratio	Sex	Temp (C)	Day of Excretion	Equilibrium Body Burden ^{137}Cs (dpm/g)	Seed Consumption (g/d)	Seed Consumption (seeds/day)
Bb 019	75	88.93	22.19	4.01	F	16.6	1.00	117.3	3.02	165.6
	96	108.0	23.76	4.55		8.4		142.5	4.57	250.2
	97	91.77	19.78	4.64		8.4		121.0	3.94	215.6
	110	83.25	34.06	2.44		11.1		109.8	3.33	182.3
	111	80.33	29.80	2.70		11.1		106.0	3.22	176.5
	209	30.20	31.27	0.97		11.6		39.83	1.30	71.4
	293	40.22	31.67	1.27		22.2		53.05	1.28	70.1
Bb 027	110	81.12	25.14	3.23	M	11.1	1.00	107.0	3.98	218.3
	138	122.4	31.62	3.87		16.1		161.4	5.05	276.8
	209	81.37	25.43	3.20		11.6		107.3	3.93	215.4
	222	97.02	25.21	3.85		14.5		128.0	4.27	234.1
	223	67.03	19.88	3.37		14.5		88.41	3.03	166.0
	272	39.48	17.59	2.24		18.9		52.08	1.64	89.6
Bb 038	271	34.73	11.04	3.15	F	18.9	1.00	45.81	1.22	67.1
	272	27.69	10.43	2.65		18.9		36.52	1.00	54.8
	292	59.17	12.95	4.57		22.2		78.05	1.80	98.9
	293	53.54	12.72	4.21		22.2		70.62	1.65	90.5
	355	79.90	19.59	4.08		26.6		105.4	2.09	114.7
	356	64.81	16.66	3.89		26.6		85.49	1.74	95.4
	376	73.05	17.87	4.09		26.6		96.35	1.93	106.0
	405	49.34	20.98	2.35		26.6		65.08	1.37	75.0

[a]Day of excretion arbitrarily determined as day 1.00 for all shrews.

Table B-29. Weights of *Peromyscus leucopus* ingesting 2 *Pinus strobus* seeds per day in the laboratory.
Means are for six mice during uptake and four mice during excretion.

Day	Weight (g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	21.17 ± 0.91	21.41 ± 1.13	21.78 ± 1.01	19.27 ± 1.05
2	21.19 0.94	22.55 1.01	21.74 1.18	19.08 1.00
3	20.89 0.79	22.25 0.83	21.77 0.99	19.47 1.00
5	21.52 0.89	22.53[a] 0.70	22.39 1.16	19.14 1.02
8	21.34 0.83	22.91 0.88	22.68 1.08	19.29 0.97
12	21.61 0.77	22.16[b] 0.81	22.80 0.99	19.71 1.03
15	21.50 0.96	22.84 0.98	22.33 0.82	19.62 0.99
22	22.31[c] 0.86	22.99 0.91	22.89 0.81	19.86 0.95
29	21.93 0.96	23.04 1.06	23.15 0.84	20.16 1.08
36	22.70 1.04	22.60 0.80	23.19 0.79	20.44 1.15
43	22.24 0.79	23.21 1.00	23.13 0.89	20.47 0.99
49	22.96 1.02	23.30 1.16	23.15 0.77	20.64 1.11
	Excretion phase			
0	23.07 ± 1.60	23.13 ± 1.81	23.66 ± 1.08	19.73 ± 1.43
1	22.93 1.76	22.05 1.34	23.66 1.41	19.31 1.26
2	22.62 1.64	22.04 1.36	23.50 1.28	19.23 1.30
3	22.35 1.61	21.81 1.28	23.41 1.34	18.77 1.15
5	22.98 1.55	22.06 1.49	23.53 1.32	18.96 1.24
8	22.86 1.51	21.42 1.29	23.62 1.28	19.18 1.31
15	22.60 1.57	21.24 1.56	23.64 1.30	19.24 1.30
22	22.43 1.54	21.45 1.33	23.57 1.24	18.96 1.41
29	22.16 1.34	21.68 1.63	23.76 1.21	19.38 1.38
36	21.74 1.64	21.68 1.62	23.95 1.33	19.26 1.39
43	22.26 1.48	21.41 1.76	23.25 1.31	19.22 1.35
49	21.83[c] 1.24	21.10 1.43	23.04 1.28	18.81 1.37
57	19.40 1.81	21.08 1.66	21.45 1.47	17.93 0.97
71	21.44 1.53	21.07 1.59	21.39 1.37	18.24 0.91
85	22.38 1.37	---[d] ---	21.28 1.30	18.43 1.11
100	22.74 1.54	20.49 1.50	21.60 1.42	18.27 1.20

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

[d] Not sampled.

Table B-30. Weights of Peromyscus leucopus ingesting 10 Pinus strobus seeds per day in the laboratory.
Means are for six mice during uptake and four mice during excretion.

Day	Weight (g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	20.76 ± 2.05	23.99 ± 0.58	20.46 ± 1.59	17.55 ± 0.97
2	20.53 1.87	23.63 0.51	20.76 1.41	17.72 0.90
3	20.52 1.83	23.06 0.84	20.30 1.70	17.75 0.93
5	20.99 1.81	23.74[a] 0.41	20.96 1.26	18.01 0.93
8	20.90 1.69	23.94 0.44	21.11 1.39	18.48 0.94
12	20.98 1.74	24.18[b] 0.64	21.47 1.32	18.46 0.85
15	21.15 1.60	23.82 0.49	21.16 1.28	18.83 0.85
22	21.37 1.58	24.35 0.65	21.79 1.33	19.18 0.73
29	21.55 1.51	24.32 0.66	21.94 1.41	19.27 0.79
36	21.20 1.43	24.87 0.78	21.75 1.35	19.49 0.80
43	21.52 1.36	24.80 0.84	21.81 1.23	19.99 0.82
49	21.63 1.33	24.83 0.81	21.90 1.52	19.79 0.83
	Excretion phase			
0	22.39 ± 1.96	24.16 ± 1.08	23.32 ± 1.92	19.19 ± 1.14
1	22.32 2.02	23.31 0.98	22.70 1.76	18.58 1.17
2	22.16 1.89	23.27 1.04	22.61 1.56	18.54 1.29
3	21.94 1.91	22.95 0.89	22.33 1.80	18.23 1.30
5	21.99 1.96	22.68 0.83	22.39 1.91	18.24 1.35
8	21.33 1.83	22.23 0.99	22.00 2.00	18.28 1.40
15	22.06 1.89	22.53 1.12	22.79 2.36	18.71 1.52
22	22.32 2.02	22.80 1.16	22.47 2.14	18.52 1.77
29	22.38 1.88	23.15 0.91	22.89 2.06	17.20 2.30
36	22.63 2.12	22.86 0.94	23.00 1.87	19.12 1.60
43	21.53 2.12	22.16 1.01	23.78 2.11	19.26 1.64
49	22.16 2.00	21.90 1.33	23.58 1.95	18.52 1.64
57	20.59 1.81	22.61[c] 0.82	20.97 1.38	19.29 2.22
71	20.65 1.78	22.82 0.67	20.53 1.45	20.06 2.82
85	20.80 1.82	22.28 0.85	20.45 1.23	21.05 3.32
100	22.65 2.23	23.21 1.09	20.43 1.20	21.26 2.87

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

Table B-31. Weights of Peromyscus leucopus ingesting 50 Pinus strobus seeds per day in the laboratory.
Means are for six mice during uptake and four mice during excretion.

Day	Weight (g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	23.83 ± 0.47	22.07 ± 1.31	21.39 ± 1.63	18.46 ± 1.85
2	23.57 0.39	21.60 1.38	21.05 1.60	18.55 1.74
3	23.81 0.42	21.93[a] 1.36	20.59 1.49	18.24 1.67
5	23.67 0.39	21.91 1.27	20.47 1.51	18.17 1.52
8	23.74 0.37	21.97 1.23	20.62 1.54	18.16 1.47
12	24.01 0.39	21.95[b] 1.13	20.69 1.50	18.13 1.43
15	23.81 0.39	21.79 1.36	20.64 1.51	17.83 1.33
22	23.80 0.27	22.53 1.27	20.90 1.56	17.92 1.24
29	23.65 0.37	21.62 1.16	20.72 1.58	18.69 1.41
36	23.28 0.40	21.51 1.17	20.79 1.56	18.88 1.60
43	23.50 0.31	21.82 1.19	20.98 1.66	19.40 1.58
49	23.38 0.50	21.91 1.19	20.88 1.70	19.35 1.67
	Excretion phase			
0	23.87 ± 0.35	20.63 ± 1.37	20.99 ± 2.45	19.12 ± 2.16
1	24.04 0.31	20.60 1.61	20.51 2.62	19.13 2.15
2	23.70 0.27	20.84 1.66	20.39 2.49	19.17 2.26
3	23.25 0.33	20.49 1.54	20.06 2.53	18.97 2.30
5	23.02 0.34	20.34 1.66	19.83 2.46	19.55 2.81
8	22.62 0.20	19.70 1.32	19.38 2.25	19.68 3.33
15	23.55 0.11	19.47 1.35	19.83 2.33	19.76 3.60
22	23.75 0.31	20.37 1.09	19.71 2.13	19.00 2.83
29	23.49 0.30	20.55 1.31	19.69 1.78	18.93 2.63
36	23.57 0.30	20.24 1.02	20.12 1.62	19.09 2.53
43	22.86 0.53	20.20 1.00	20.37 1.67	19.34 2.82
49	22.84 0.46	20.32 1.05	20.26 1.90	19.20 2.97
57	22.38 0.10	20.70 1.04	19.53 1.84	20.78 4.32
71	23.16 0.50	20.95 0.99	19.39 1.55	20.16 3.09
85	22.71 0.54	20.32 1.27	19.86[c] 1.86	21.76 4.89
100	23.93 0.62	19.90 1.03	19.76 1.92	19.80 2.95

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

Table B-32. Weights of Peromyscus leucopus ingesting 100 Pinus strobus seeds per day in the laboratory.
Means are for six mice during uptake and four mice during excretion.

Day	Weight (g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	19.75 ± 0.97	24.65 ± 1.67	19.36 ± 1.09	20.86 ± 2.08
2	19.88 0.96	24.15 1.72	19.34 1.13	21.37 1.90
3	19.87 0.96	23.89 1.72	19.22 1.06	20.71 2.10
5	20.04 0.87	23.46[a] 1.65	19.30 0.94	20.29 1.96
8	19.91 0.95	23.59 1.61	19.31 0.83	20.22 2.03
12	20.41 1.01	22.47[b] 1.74	19.51 0.71	20.45 1.95
15	19.82 1.25	22.55 1.80	20.23 0.33	20.32 1.99
22	20.61 1.05	23.27 1.67	19.45 0.58	20.60 2.09
29	20.57 1.04	22.89 1.58	19.47 0.66	21.01 2.08
36	20.78 0.96	22.71 1.63	19.45 0.63	21.69 2.17
43	20.77 1.10	22.99 1.73	19.40 0.67	21.34 2.02
49	20.95 1.10	22.57 1.54	19.54 0.78	21.40 2.06
	Excretion phase			
0	20.95 ± 1.61	20.99 ± 1.82	20.05 ± 0.43	21.33 ± 3.26
1	20.92 1.54	20.28 1.84	19.78 0.43	21.77 3.33
2	20.33 1.56	20.53 1.79	19.78 0.48	21.72 3.45
3	19.89 1.58	20.82 2.04	19.52 0.50	21.74 3.51
5	20.39 1.61	20.17 2.03	19.32 0.35	21.79 3.69
8	20.17 1.63	20.60 1.49	18.86 0.35	21.70 3.83
15	20.42 1.67	22.16 1.72	18.90 0.31	21.22 2.91
22	19.86 1.63	20.98 1.81	19.89 0.30	20.69 2.57
29	19.96 1.65	21.89 1.66	20.56 0.30	21.05 2.50
36	19.68 1.63	21.26 1.23	20.48 0.22	20.92 2.69
43	19.39 1.55	20.90 1.21	20.01 0.65	20.68 2.48
49	19.71 1.63	21.08 1.48	19.76 0.72	20.84 2.47
57	19.06 1.65	20.96 1.69	19.15 0.74	20.56 2.87
71	20.13 1.42	20.61 1.66	19.60 0.78	21.22 3.13
85	20.86 1.79	20.98 1.33	19.77 0.75	21.23 3.01
100	19.51 1.62	20.88 1.49	19.54 0.45	19.19 2.70

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

Table B-33. Body burden of ^{137}Cs in Peromyscus leucopus ingesting 2 Pinus strobus seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{137}Cs Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	0.27 ± 0.04	0.31 ± 0.07	0.18 ± 0.07	0.32 ± 0.02
2	0.40 0.05	0.50 0.04	0.44 0.06	0.51 0.03
3	0.49 0.06	0.58 0.06	0.51 0.05	0.61 0.03
5	0.61 0.07	0.69[a] 0.05	0.60 0.05	0.81 0.07
8	0.61 0.04	0.75 0.06	0.72 0.08	0.91 0.10
12	0.62 0.02	0.83[b] 0.10	0.72 0.05	1.10 0.05
15	0.68 0.10	0.84 0.10	0.79 0.07	1.10 0.08
22	0.66[c] 0.06	0.86 0.04	0.75 0.03	1.09 0.09
29	0.74 0.06	0.82 0.07	0.77 0.06	1.12 0.13
36	0.73 0.08	0.85 0.07	0.81 0.10	1.21 0.13
43	0.70 0.05	0.88 0.07	0.74 0.05	1.62 0.30
49	0.64 0.07	0.96 0.14	0.83 0.07	1.35 0.10
	Excretion phase			
0	0.67 ± 0.10	1.08 ± 0.16	0.91 ± 0.08	1.34 ± 0.16
1	0.49 0.09	0.82 0.12	0.66 0.05	1.02 0.15
2	0.36 0.07	0.64 0.10	0.52 0.04	0.79 0.15
3	0.28 0.06	0.52 0.09	0.41 0.03	0.64 0.13
5	0.17 0.04	0.34 0.07	0.28 0.03	0.39 0.08
8	0.09 0.02	0.20 0.04	0.16 0.02	0.20 0.04
15	0.03 0.01	0.08 0.01	0.05 0.007	0.05 0.014
22	0.02 0.004	0.03 0.006	0.02 0.003	0.03 0.005
29	0.012 0.002	0.027 0.003	0.014 0.002	0.017 0.003
36	0.011 0.002	0.016 0.002	0.011 0.001	0.011 0.002
43	0.007 0.001	0.013 0.002	0.008 0.001	0.009 0.002
49	0.004[c] 0.001	0.012 0.003	0.006 0.001	0.011 0.002
57	0.002 0.0005	0.006 0.002	0.004 0.001	0.006 0.001
71	0.002 0.0005	0.004 0.001	0.003 0.0003	0.005 0.001
85	0.002 0.0004	---[d] ---	0.003 0.0003	0.004 0.0002
100	0.001 0.0001	0.002 0.001	0.002 0.0003	0.003 0.0003

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

[d] Not sampled.

Table B-34. Body burden of ^{137}Cs in *Peromyscus leucopus* ingesting 10 *Pinus strobus* seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{137}Cs Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	1.35 ± 0.22	1.24 ± 0.16	1.74 ± 0.16	1.66 ± 0.17
2	2.07 0.20	1.99 0.17	2.74 0.14	2.57 0.22
3	2.48 0.25	2.64 0.35	3.40 0.33	3.10 0.35
5	2.95 0.24	2.86[a] 0.37	3.99 0.28	3.70 0.45
8	3.11 0.20	3.26 0.54	4.16 0.31	4.52 0.37
12	3.33 0.26	3.52[b] 0.46	4.65 0.22	4.91 0.47
15	3.38 0.33	3.51 0.45	4.78 0.17	4.40 0.49
22	3.64 0.32	3.87 0.40	4.67 0.21	4.79 0.56
29	3.53 0.38	3.73 0.35	4.30 0.19	5.12 0.53
36	4.08 0.33	4.17 0.39	4.32 0.13	5.22 0.68
43	3.45 0.26	4.00 0.41	4.43 0.07	4.46 0.57
49	3.85 0.42	4.58 0.66	4.21 0.12	5.05 0.67
	Excretion phase			
0	3.95 ± 0.64	5.19 ± 0.84	4.30 ± 0.13	5.16 ± 0.85
1	2.86 0.56	3.88 0.74	3.35 0.17	4.05 0.82
2	2.06 0.42	3.03 0.72	2.64 0.12	3.51 0.81
3	1.61 0.38	2.47 0.60	2.18 0.16	2.94 0.73
5	0.99 0.26	1.49 0.40	1.42 0.12	2.40 0.66
8	0.53 0.14	0.90 0.28	0.80 0.10	1.46 0.40
15	0.17 0.04	0.25 0.08	0.26 0.02	0.51 0.17
22	0.08 0.014	0.11 0.03	0.12 0.005	0.20 0.07
29	0.06 0.006	0.07 0.011	0.06 0.007	0.18 0.07
36	0.04 0.004	0.04 0.007	0.05 0.007	0.08 0.02
43	0.06 0.012	0.04 0.006	0.04 0.006	0.06 0.013
49	0.03 0.006	0.04 0.007	0.03 0.006	0.06 0.013
57	0.02 0.002	0.025[c] 0.005	0.026 0.004	0.03 0.007
71	0.015 0.003	0.018 0.007	0.020 0.004	0.024 0.006
85	0.013 0.002	0.015 0.007	0.016 0.004	0.018 0.004
100	0.010 0.002	0.012 0.006	0.015 0.003	0.015 0.005

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

Table B-35. Body burden of ^{137}Cs in Peromyscus leucopus ingesting 50 Pinus strobus seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{137}Cs Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	6.08 ± 0.43	4.40 ± 0.70	8.33 ± 0.80	10.75 ± 1.20
2	10.30 0.44	8.79 0.75	10.56 2.19	16.35 1.80
3	12.46 0.62	12.55 1.30	16.65 0.68	19.78 1.66
5	15.68 1.26	13.98[a] 1.56	21.94 0.93	25.75 2.48
8	16.88 1.08	18.48 2.27	23.71 1.12	28.52 2.84
12	17.70 1.22	20.04[b] 2.74	25.67 1.32	30.43 2.70
15	17.55 1.36	22.66 3.38	27.05 1.69	31.41 2.50
22	18.32 1.41	20.21 2.79	27.31 2.75	31.31 2.38
29	19.01 1.13	22.28 2.57	29.86 2.55	30.91 1.85
36	22.44 1.75	24.74 3.99	29.60 3.25	37.14 4.68
43	19.59 1.27	22.37 2.53	29.02 2.64	31.44 2.42
49	20.03 1.54	25.34 2.77	28.72 2.39	31.95 1.58
	Excretion phase			
0	20.44 ± 2.20	27.85 ± 3.59	28.43 ± 2.69	31.71 ± 1.30
1	14.43 1.73	20.56 3.54	23.42 2.93	25.25 2.11
2	11.44 1.33	15.86 3.30	19.38 2.63	20.94 2.07
3	9.21 1.18	14.02 3.31	16.92 2.65	18.50 1.91
5	6.07 0.82	9.12 2.20	12.09 1.98	14.21 1.85
8	3.39 0.53	5.92 1.59	7.16 1.05	8.60 1.45
15	1.05 0.15	2.06 0.77	2.97 0.62	3.48 0.36
22	0.44 0.05	0.88 0.38	1.35 0.30	1.50 0.21
29	0.28 0.025	0.57 0.21	0.70 0.18	0.86 0.08
36	0.21 0.020	0.29 0.10	0.48 0.15	0.50 0.05
43	0.24 0.019	0.30 0.12	0.34 0.10	0.37 0.06
49	0.15 0.010	0.22 0.06	0.29 0.09	0.29 0.05
57	0.08 0.005	0.08 0.02	0.15 0.03	0.17 0.02
71	0.06 0.003	0.05 0.011	0.08 0.007	0.11 0.015
85	0.05 0.005	0.04 0.007	0.07[c] 0.004	0.09 0.015
100	0.04 0.002	0.03 0.003	0.06 0.006	0.07 0.010

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

Table B-36. Body burden of ^{137}Cs in *Peromyscus leucopus* ingesting 100 *Pinus strobus* seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{137}Cs Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	15.16 ± 1.17	13.59 ± 1.40	17.78 ± 1.42	18.97 ± 1.71
2	24.64 2.11	18.68 1.81	29.30 2.67	31.84 2.72
3	31.71 2.88	23.17 2.89	38.51 3.28	41.97 3.50
5	36.55 4.11	28.54[a] 4.15	47.26 2.10	57.04 4.30
8	37.70 4.66	34.69 5.20	53.72 2.50	70.00 4.83
12	40.08 5.15	40.48[b] 6.30	57.29 3.09	71.26 4.58
15	41.38 5.59	48.10 8.14	58.09 3.33	75.33 3.69
22	42.78 4.30	46.92 7.51	62.74 4.84	75.14 5.47
29	47.75 7.03	50.98 7.14	62.10 4.10	69.92 5.03
36	43.15 5.43	50.26 6.78	61.78 3.86	70.19 4.67
43	44.06 6.27	53.09 9.72	60.66 2.63	75.93 4.43
49	51.52 7.80	53.38 9.35	60.35 2.67	74.28 5.61
	Excretion phase			
0	59.09 ± 9.68	59.46 ± 13.21	61.64 ± 2.82	75.16 ± 5.68
1	43.64 7.19	44.15 10.49	46.85 2.47	59.18 4.43
2	35.05 6.04	35.45 8.94	39.62 2.73	50.34 3.73
3	28.18 5.43	26.86 7.19	32.78 2.22	42.40 2.28
5	17.72 3.61	18.48 5.40	23.33 1.65	31.94 2.88
8	9.06 1.99	8.34 2.63	14.46 1.26	20.81 1.58
15	2.72 0.63	2.26 1.00	4.55 0.45	8.11 1.37
22	1.27 0.38	0.78 0.30	1.85 0.46	3.46 0.76
29	0.69 0.16	0.66 0.18	1.03 0.36	1.50 0.32
36	0.69 0.15	0.39 0.09	0.68 0.23	0.87 0.16
43	0.37 0.06	0.32 0.06	0.52 0.16	0.60 0.10
49	0.33 0.04	0.40 0.08	0.45 0.13	0.47 0.06
57	0.18 0.02	0.16 0.03	0.30 0.07	0.34 0.03
71	0.11 0.012	0.09 0.016	0.20 0.05	0.24 0.02
85	0.08 0.009	0.07 0.015	0.16 0.05	0.19 0.02
100	0.07 0.011	0.06 0.012	0.13 0.04	0.20 0.07

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

Table B-37. Body burden of ^{60}Co in Peromyscus leucopus ingesting 2 Pinus strobus seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{60}Co Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	0.43 ± 0.14	0.21 ± 0.04	0.15 ± 0.05	0.19 ± 0.05
2	0.47 0.11	0.20 0.03	0.33 0.09	0.36 0.09
3	0.42 0.11	0.27[a] 0.06	0.41 0.09	0.36 0.08
5	0.42 0.07	0.25 0.05	0.37 0.09	0.32 0.06
8	0.55 0.22	0.46 0.15	0.30 0.04	0.63 0.22
12	0.36 0.08	0.28[b] 0.02	0.28 0.03	0.41 0.11
15	0.41[c] 0.07	0.35 0.04	0.32 0.04	0.43 0.03
22	0.50 0.05	0.45 0.08	0.34 0.07	0.49 0.06
29	0.59 0.08	0.43 0.07	0.28 0.03	0.32 0.05
36	0.57 0.10	0.38 0.06	0.41 0.09	1.58 1.06
43	0.48 0.09	0.90 0.21	0.37 0.02	0.70 0.24
49	0.52 0.07	0.44 0.06	0.41 0.10	0.40 0.06
	Excretion phase			
0	0.44 ± 0.02	0.50 ± 0.08	0.45 ± 0.16	0.47 ± 0.05
1	0.13 0.006	0.19 0.025	0.13 0.03	0.13 0.008
2	0.08 0.007	0.11 0.014	0.07 0.013	0.08 0.011
3	0.06 0.007	0.08 0.014	0.06 0.010	0.07 0.013
5	0.05 0.007	0.06 0.009	0.05 0.007	0.06 0.010
8	0.04 0.007	0.06 0.009	0.04 0.005	0.05 0.009
15	0.032 0.004	0.046 0.007	0.031 0.004	0.032 0.008
22	0.026 0.004	0.036 0.005	0.025 0.004	0.034 0.007
29	0.023 0.003	0.032 0.004	0.022 0.002	0.028 0.006
36	0.021 0.003	0.029 0.003	0.020 0.002	0.026 0.006
43	0.018 0.002	0.025 0.003	0.018 0.002	0.023 0.005
49	0.011[c] 0.002	0.026 0.003	0.018 0.002	0.024 0.005
57	0.019 0.002	0.023 0.003	0.017 0.002	0.024 0.005
71	0.013 0.002	0.021 0.002	0.017 0.002	0.020 0.004
85	0.012 0.002	---[d] ---	0.014 0.001	0.018 0.003
100	0.012 0.002	0.019 0.003	0.012 0.001	0.019 0.004

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

[d] Not sampled.

Table B-38. Body burden of ^{60}Co in Peromyscus leucopus ingesting 10 Pinus strobus seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{60}Co Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	2.82 ± 1.18	1.34 ± 0.33	2.44 ± 0.51	2.52 ± 0.39
2	2.82 0.54	1.85 0.30	1.76 0.21	3.05 0.27
3	3.49 0.61	3.57[a] 0.87	1.96 0.22	2.40 0.38
5	3.06 0.42	2.20 0.67	2.57 0.36	3.13 0.59
8	3.79 0.68	1.51 0.28	3.68 0.81	4.13 0.75
12	3.10 0.37	2.66[b] 0.50	2.86 0.24	3.88 1.03
15	2.44 0.31	1.76 0.37	2.49 0.32	2.52 0.43
22	2.73 0.30	1.88 0.29	3.08 0.55	2.43 0.25
29	3.28 0.77	2.26 0.24	2.40 0.36	2.56 0.28
36	2.35 0.30	2.16 0.36	3.10 0.63	3.10 0.32
43	2.68 0.24	2.12 0.33	2.74 0.29	2.44 0.27
49	2.57 0.32	3.63 0.85	3.22 0.40	2.75 0.42
	Excretion phase			
0	2.43 ± 0.39	4.47 ± 1.03	2.89 ± 0.50	3.09 ± 0.56
1	0.72 0.13	1.34 0.28	0.82 0.11	0.76 0.07
2	0.42 0.08	0.66 0.12	0.51 0.09	0.41 0.03
3	0.34 0.06	0.44 0.07	0.43 0.09	0.33 0.03
5	0.28 0.05	0.33 0.05	0.38 0.09	0.31 0.04
8	0.24 0.04	0.28 0.04	0.32 0.08	0.24 0.03
15	0.18 0.03	0.23 0.04	0.26 0.07	0.18 0.021
22	0.13 0.025	0.18 0.03	0.21 0.05	0.15 0.020
29	0.12 0.024	0.16 0.02	0.18 0.04	0.14 0.016
36	0.10 0.021	0.13 0.012	0.15 0.036	0.11 0.015
43	0.10 0.021	0.12 0.013	0.14 0.033	0.09 0.009
49	0.08 0.017	0.12 0.016	0.12 0.027	0.10 0.014
57	0.08 0.015	0.10[c] 0.010	0.13 0.034	0.08 0.013
71	0.06 0.015	0.09 0.008	0.12 0.034	0.07 0.012
85	0.06 0.014	0.09 0.007	0.10 0.033	0.07 0.013
100	0.05 0.011	0.07 0.006	0.09 0.030	0.06 0.011

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

[c] One animal died.

Table B-39. Body burden of ^{60}Co in Peromyscus leucopus ingesting 50 Pinus strobus seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{60}Co Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
	Uptake phase			
1	13.49 ± 1.45	7.43 ± 1.55	16.10 ± 3.56	27.42 ± 5.65
2	17.26 2.79	14.03 0.37	16.58 1.99	18.05 2.90
3	17.89 1.43	18.57 1.79	14.47 1.86	17.39 2.45
5	15.79 1.07	12.97[a] 0.80	15.69 1.52	18.61 2.94
8	14.15 1.53	14.15 1.66	17.03 2.16	17.75 2.85
12	14.54 1.50	13.77[b] 1.37	17.53 2.43	18.39 3.32
15	15.16 1.61	15.41 1.12	16.43 1.42	22.38 4.66
22	14.36 1.45	14.82 2.27	15.57 1.92	21.14 3.50
29	13.61 0.83	18.63 2.94	20.32 2.78	18.94 3.00
36	16.43 1.63	17.05 1.81	19.84 2.46	34.54 14.62
43	16.44 1.23	19.14 1.46	18.65 1.78	19.72 3.24
49	17.18 0.97	23.25 2.69	20.12 2.85	18.64 2.48
	Excretion phase			
0	17.07 ± 1.49	24.06 ± 3.23	21.21 ± 4.31	20.58 ± 2.78
1	5.02 0.67	6.64 1.03	4.63 0.74	3.79 0.69
2	2.49 0.26	3.20 0.42	1.98 0.25	2.10 0.43
3	1.83 0.21	2.20 0.33	1.57 0.26	1.90 0.37
5	1.48 0.18	1.64 0.29	1.31 0.23	1.92 0.54
8	1.25 0.14	1.25 0.18	1.05 0.17	1.53 0.38
15	0.92 0.11	0.96 0.14	0.88 0.18	1.15 0.24
22	0.76 0.08	0.76 0.10	0.72 0.14	0.93 0.18
29	0.65 0.07	0.68 0.10	0.62 0.11	0.86 0.14
36	0.58 0.06	0.58 0.08	0.55 0.09	0.72 0.12
43	0.50 0.04	0.56 0.08	0.48 0.08	0.66 0.12
49	0.46 0.05	0.50 0.05	0.42 0.05	0.62 0.11
57	0.42 0.05	0.43 0.05	0.40 0.05	0.54 0.12
71	0.34 0.04	0.37 0.05	0.32 0.02	0.42 0.06
85	0.31 0.04	0.35 0.05	0.31[c] 0.02	0.40 0.07
100	0.26 0.03	0.31 0.04	0.28 0.01	0.37 0.06

[a]Day 4 instead of day 5.

[b]Day 13 instead of day 12.

[c]One animal died.

Table B-40. Body burden of ^{60}Co in Peromyscus leucopus ingesting 100 Pinus strobus seeds per day in the laboratory. Means are for six mice during uptake and four mice during excretion.

Day	^{60}Co Radioactivity (dpm X 10^3/g ± 1 S. E.)			
	Winter (4.4 C)	Autumn (10.0 C)	Spring (15.6 C)	Summer (21.1 C)
		Uptake phase		
1	32.07 ± 3.83	32.04 ± 3.48	43.00 ± 7.24	54.20 ± 9.19
2	55.70 3.46	33.99 6.49	53.84 6.79	50.20 7.08
3	52.50 4.82	28.71 5.91	51.75 6.05	49.49 8.63
5	56.21 5.21	37.11[a] 5.26	43.76 5.55	64.18 10.58
8	49.98 6.56	45.31 5.36	45.49 5.85	57.10 7.22
12	46.61 3.88	44.95[b] 8.41	47.00 4.47	52.68 8.92
15	43.79 4.12	61.37 21.09	58.14 6.58	56.29 5.18
22	49.37 5.36	50.30 9.10	60.00 6.60	72.03 14.91
29	47.48 6.92	68.16 18.19	67.61 6.08	62.25 11.59
36	45.92 3.80	57.64 11.75	58.52 5.56	53.43 10.52
43	54.06 4.46	72.65 15.05	58.08 6.66	64.31 12.17
49	61.30 9.14	68.32 13.87	54.18 4.03	50.92 5.45
		Excretion phase		
0	67.29 ± 12.65	76.83 ± 20.21	52.36 ± 5.99	51.96 ± 7.54
1	12.40 4.12	27.27 11.35	12.15 2.71	14.27 5.41
2	5.72 1.37	14.12 6.15	6.72 1.34	7.99 2.34
3	4.23 0.82	8.70 3.80	5.10 0.91	6.23 1.60
5	3.60 0.75	6.26 2.73	4.29 0.65	4.88 1.01
8	2.98 0.50	3.66 0.85	3.84 0.56	4.12 0.86
15	2.21 0.42	2.68 0.55	2.98 0.53	3.26 0.59
22	1.89 0.37	2.37 0.43	2.29 0.37	2.83 0.48
29	1.61 0.32	1.99 0.44	1.97 0.30	2.39 0.42
36	1.41 0.28	1.79 0.34	1.72 0.28	2.23 0.41
43	1.30 0.25	1.58 0.31	1.63 0.30	2.00 0.34
49	1.14 0.18	1.48 0.28	1.53 0.29	1.78 0.30
57	1.05 0.17	1.30 0.30	1.44 0.30	1.72 0.32
71	0.86 0.14	1.12 0.27	1.24 0.27	1.49 0.29
85	0.76 0.13	0.95 0.21	0.76 0.23	1.32 0.26
100	0.71 0.09	0.84 0.18	0.96 0.18	1.32 0.25

[a] Day 4 instead of day 5.

[b] Day 13 instead of day 12.

Table B-41. List of scientific and common names for plants mentioned in the text.[a]

Scientific Name	Common Name
Acer rubrum	Red maple
Acer saccharum	Sugar maple
Carya glabra	Pignut hickory
Carya ovata	Shagbark hickory
Carya tomentosa	Mockernut hickory
Cercis canadensis	Eastern redbud
Cornus florida	Dogwood
Crataegus spp.	Crabapple
Diospyros virginiana	Persimmon
Fraxinus americana	White ash
Juglans nigra	Black walnut
Liquidambar styraciflua	Sweet gum
Liriodendron tulipifera	Yellow poplar
Morus rubra	Red mulberry
Nyssa sylvatica	Black gum
Ostrya virginiana	Hophornbeam
Oxydendrum arboreum	Sourwood
Pinus echinata	Shortleaf pine
Pinus monticola	Western white pine
Pinus strobus	Eastern white pine
Prunus serotina	Black cherry
Quercus alba	White oak
Quercus falcata	Southern red oak
Quercus prinus	Chestnut oak
Quercus stellata	Post oak
Quercus velutina	Black oak
Rhamnus caroliniana	Carolina buckthorn
Sassafras albidum	Sassafras
Ulmus americana	American elm
Ulmus thomasii	Rock elm
Viburnum lentago	Nannyberry
Vitis spp.	Wild grape

[a]From Little, E. L. Jr. 1953. Checklist of Native and Naturalized Trees of the United States. U.S.D.A., Forest Service, Agr. Handbook 41, 472 pp.

Table B-42. List of scientific and common names for vertebrates listed in the text.

Scientific Name	Common Name
	Mammals[a]
Blarina brevicauda	Short-tailed shrew
Glaucomys volans	Southern flying squirrel
Microtus pinetorum	Pine vole
Peromyscus leucopus	White-footed mouse
Peromyscus nuttalli[b]	Golden mouse
Sciurus carolinensis	Gray squirrel
Sorex longirostris	Southeastern shrew
Tamias striatus	Eastern chipmunk
	Birds
Corvus brachyrhynchos	Crow
Thryothorus ludovicianus	Carolina wren
	Reptiles
Sceloporus undulatus	Fence lizard
Terrapene carolina	Eastern box turtle
	Amphibians
Bufo americanus	American toad

[a]From Hall, E. R. and K. R. Kelson. 1959. The Mammals of North America. Ronald Press, New York, 1,083 pp.

[b]Generic name of Ochrotomys also accepted.

X. APPENDIX C

Multichannel Analyzer System

X. APPENDIX C

To assist future studies using a multichannel analyzer system (Fig. C-1), a description of some of the potential errors is desirable. The procedures are applicable to samples containing two or more radioisotopes. The desirability of using two distinct radioisotopes was emphasized in this study where the ratio between two radioisotopes (Cs/Co ratio) was used to determine the day of excretion for mice trapped on the field plot. A single-isotope study would not have allowed correlation to the field study.

Unknown samples were counted for variable lengths of time, attempting to obtain total counts in the maximum channel (normally 0.66 Mev, the ^{137}Cs peak channel) of between 25,000 and the maximum of 99,999 counts. The counts in each channel were punched on paper tape and subsequently analyzed by a least squares regression program (Brooks *et al.*, 1970).

The counting geometry was critical with this system, due to a very low counting efficiency. For the crystal used to count animals, the efficiency in the maximum channel was approximately 1% of the total dpm. Lateral or vertical movements by the animals during counting were undesirable, and a set of containers (described in Methods and Materials) were used to restrict movement as much as possible without harming the animal (Fig. C-2). Mice and shrews withstood the restrictions of this small vial satisfactorily.

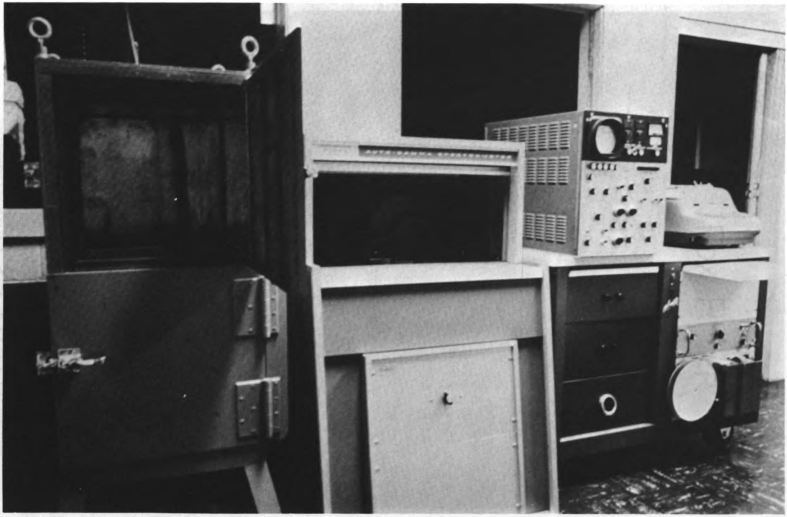

Figure C-1. Equipment utilized for radioactivity measurements. Unit at left is a lead shield for counting live animals. Middle unit is an automatic turntable for counting samples in test tubes. Unit on the right is the Packard Multichannel Analyzer with paper tape punch and take-up reel underneath.

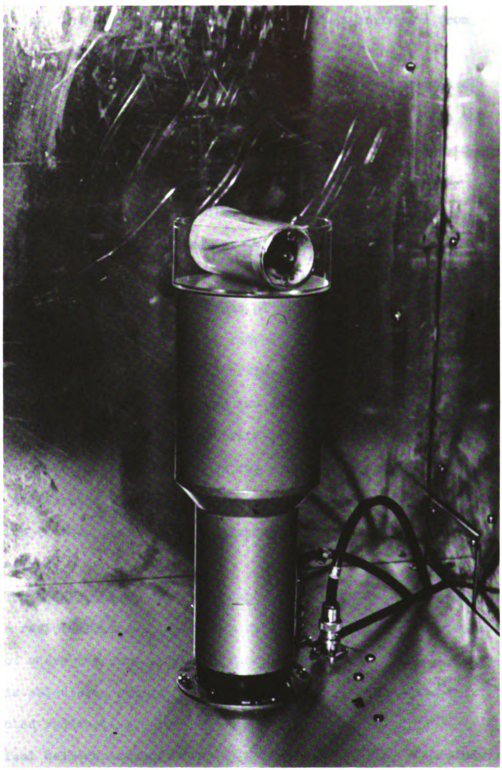

Figure C-2. Container used to control geometry of small mammals during radioactivity determinations. Container is on top of the NaI crystal and is contained within a copper-sheathed lead shield. White-footed mouse is in container.

To reduce the potential error due to count rates of less than 20,000 dpm, the time each sample was counted was increased from 5 min. up to a maximum of 20 min./sample.

The most serious error appeared to be an inherent amount of changing sensitivity within the analyzer. A slight change in the voltage resulted in the ^{137}Cs peak drifting from one channel to an adjacent channel while a series of samples were being counted. The analyzer was maintained on a voltage-regulated source of power, but this was not sufficient to prevent this error from appearing. In a test case, the amplification of the input signals was purposefully varied to create shifting locations of the ^{137}Cs peak, and the output was subsequently analyzed by comparison to a single ^{137}Cs standard, whose peak occurred in channel 65 (Fig. C-3). A shift of one complete channel, between the standard and the unknown sample, created an error of 8% in estimating the radioactivity of the unknown sample; a two channel shift resulted in up to a 16% error. Although a 10% or greater error is accepted by some investigators, there does appear to be a solution to this problem of shifting channels, if refined estimates are desired.

The RESAP program (Brooks et al., 1970) computed the concentration of the radioisotope and a standard deviation of the concentration regardless of where the peak of the unknown occurred. A coefficient of variation is calculated and printed with the output for each sample. If the predicted radioactivity is correlated to the coefficient of variation, a typical bell-shaped curve can be produced (Fig. C-4). If a mathematical expression of this correlation could be built into the computer

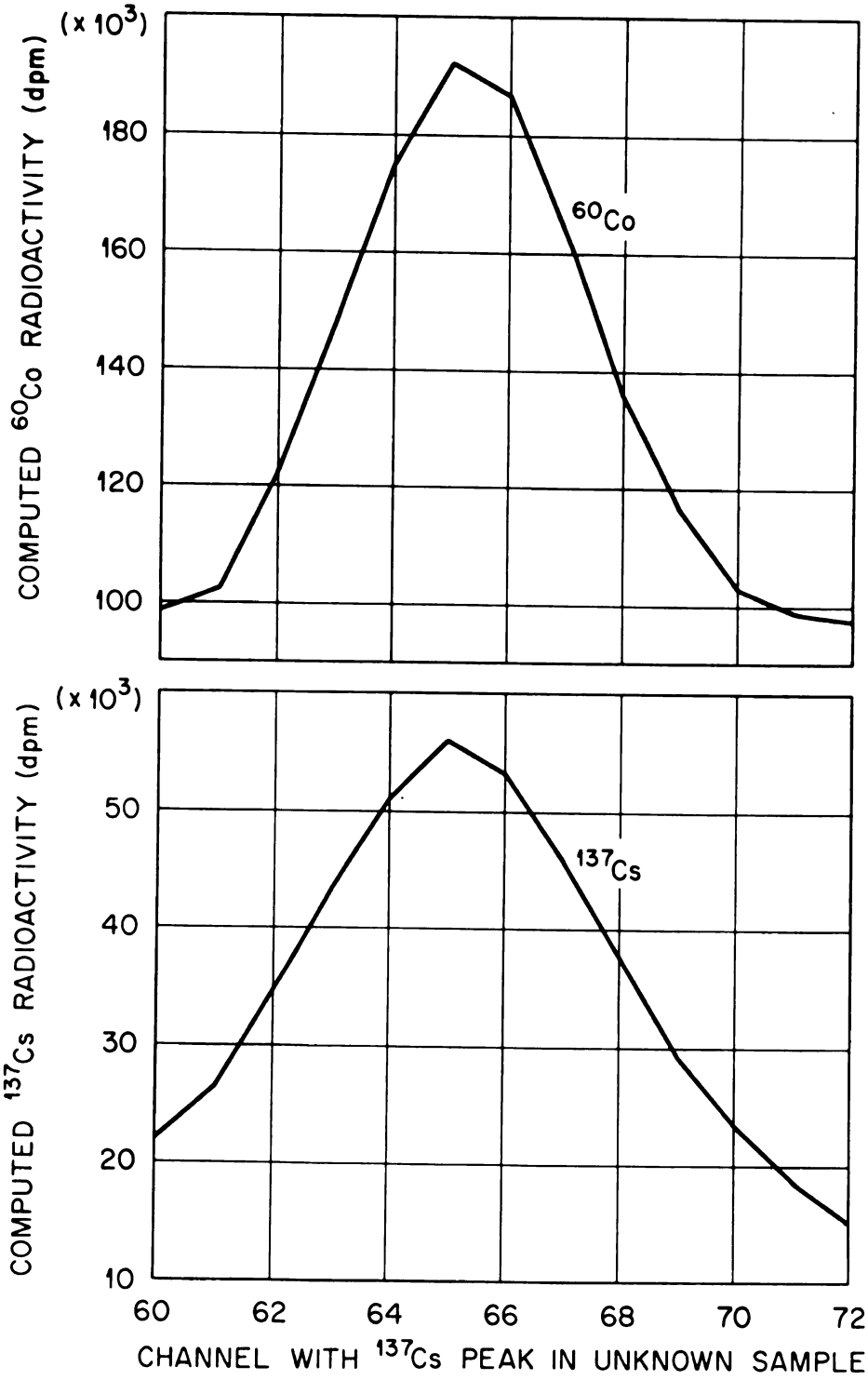

Figure C-3. Influence of channel drift of the ^{137}Cs peak upon computed radioactivity in the same sample using the RESAP analysis.

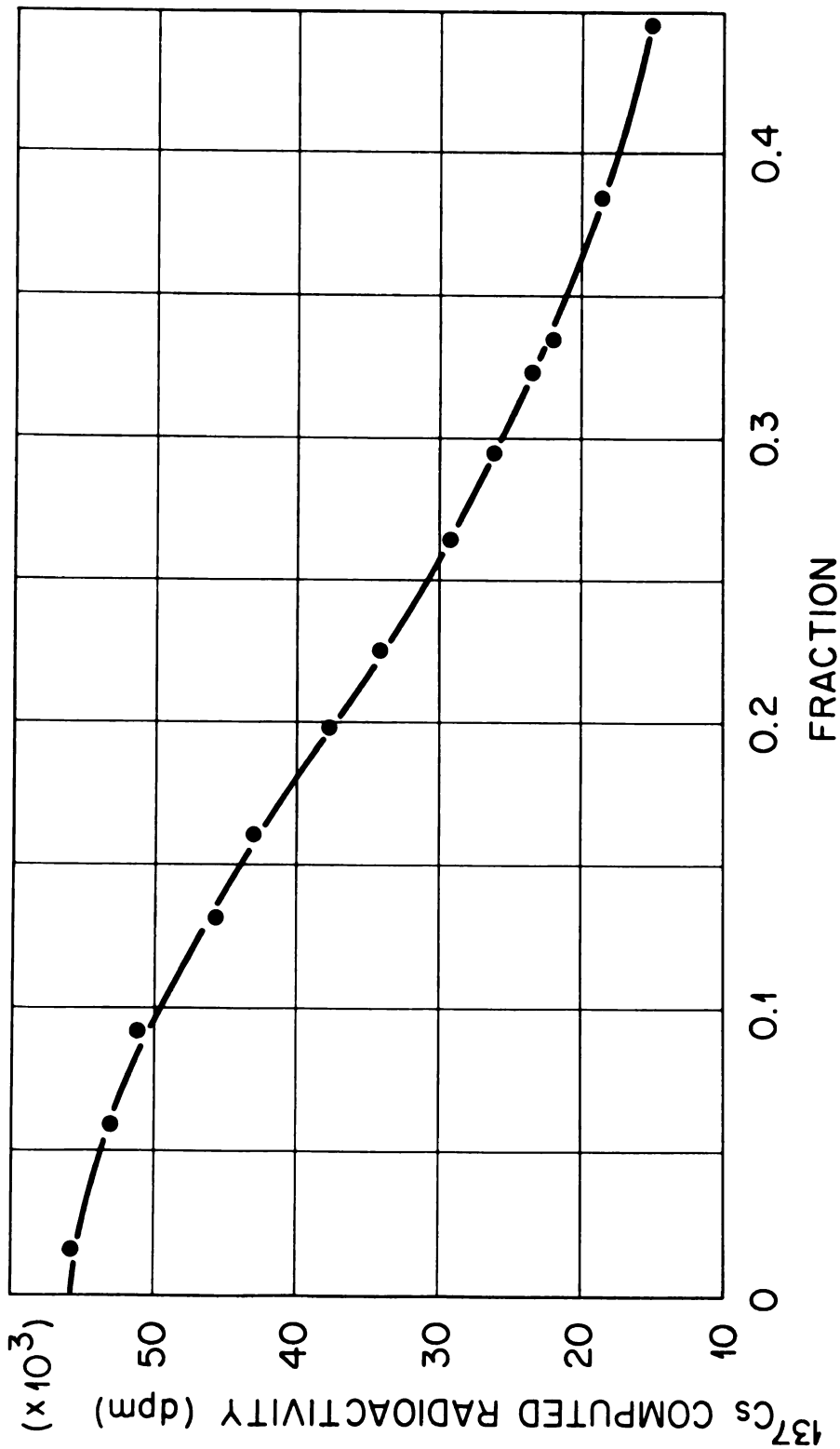

Figure C-4. Correlation of the computed ^{137}Cs radioactivity to the computed coefficient of variation using the RESAP analysis.

analysis, a much more sophisticated and accurate analysis might occur. The correlation, however, differs for each radioisotope counted, and appears to differ for varying concentrations of ^{137}Cs. Thus, the logical correction of this error would be the employment of a gain-shift correction (already used in a portion of the computer program) to shift the spectrum of the unknown sample until the isotopic peak is coincident with the standard for that isotope, and then calculate the radioactivity. The present gain-shift corrects only once and assumes that the remaining samples have the same error as the first.

XI. VITA

John Beatty Mathies

Candidate for the Degree of

Doctor of Philosophy

Final Examination:	May 26, 1971
Dissertation:	Annual consumption of cesium-137 and cobalt-60 labeled seeds by small mammals in an oak-hickory forest
Major Subject:	Forest Ecology
Minor Subject:	Biometrics
Biographical Items:	
Born	August 2, 1939 in Seattle, Washington
Undergraduate Studies:	Forest Management, University of Washington, B. S. Degree: 1962
Graduate Studies:	Forest Ecology, Michigan State University, M. S. Degree: 1967
Title:	Influence of the eastern cottontail on tree reproduction in sugar maple-beech stands of southern Michigan
Experience:	Forestry Aid, U.S.F.S., 1960 Forestry Technician, U.S.F.S., 1961 Forester, U.S.F.S., 1962-1965 Graduate Teaching Assistant, Michigan State University, 1965-1968 Graduate Fellow, Oak Ridge Associated Universities, 1968-1971
Member:	Society of American Foresters Xi Sigma Pi Ecological Society of America American Institute of Biological Sciences