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

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TENTH
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DEPARTMENT OF RADIOLOGY AND RADIATION BIOLOGY
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RADIOECOLOGY OF SOME NATURAL ORGANISMS
AND SYSTEMS IN COLORADO

FOR THE PERIOD: January 1, 1971 - April 31, 1972

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I. SUMMARY

I. Summary

The broad purpose of this research is to provide information on the behavior of radionuclides in, and radiation sensitivity of, selected organisms and natural ecosystems in Colorado. Components of alpine tundra, montane forests, shortgrass plains and freshwater lakes and streams are currently under investigation with respect to behavior and effects of radionuclides. This research is conducted primarily by graduate students and faculty of the Department of Radiology and Radiation Biology at Colorado State University. Dr. W. C. Nelson and W. J. Adrian, Colorado Division of Game, Fish and Parks and W. S. Ferguson, Department of Chemistry CSU collaborate on portions of the aquatic studies and Dr. D. A. Klein, Department of Microbiology at CSU is collaborating on studies of soil microbes in the irradiated grassland plots.

This report summarizes project activities and major findings during the calendar year 1971. Concerning the mule deer work, a three year study on the kinetics and distribution of strontium and calcium in captive deer is nearing completion, although some analytical work and interpretation and modeling remain as major activities in 1972. The goal of this study is a model of strontium-calcium accumulation in deer of various ages under specified circumstances of season, including modifications due to antler growth and lactation. Retention of intravenously administered ^{134}Cs by mule deer was investigated so that a two compartment model for cesium accumulation could be developed. Such a model will permit a calculation of forage intake by free-roaming deer using existing fallout ^{137}Cs data. Gastrointestinal retention of ingesta was investigated in captive deer using ^{51}Cr to provide additional data for models of radionuclide accumulation. As part of long-term studies on the persistence of fallout ^{137}Cs in mule deer, tissues from five animals collected in November-December, 1971 were assayed for ^{137}Cs and ^{131}I .

Concerning the aquatic studies, the detailed investigation on the in situ kinetics of stable cesium in East Twin Lake was essentially completed. The results of the study are only briefly summarized in this report. A Ph.D. Thesis covering this work in depth should be in print by September, 1972. A substantial effort was made during 1971 to examine levels of lead and mercury in trout from remote montane and alpine lakes and to investigate the importance of atmospheric fallout as a transport vector.

The pika studies were completed in 1971 and the work culminated in a Ph.D. Thesis covering the radiation sensitivity investigations and several manuscripts covering natural history of the animal in the wild

and in captivity. Only abstracts of the pika work appear in this report, since the complete manuscripts accompany this document.

Placement of an 8,750 curie ^{137}Cs source in a native shortgrass plains plant community in 1969 afforded the opportunity to study radiation effects on the in situ ecosystem. The study was designed primarily to investigate the effects of chronic and seasonal semi-acute irradiation on vegetative structure. The initial phase of this study was completed in August, 1971 and the results are embodied in a Ph.D. thesis which accompanies this report. In addition to vegetation, arthropods, soil microorganisms and soil cores for chemical analysis have been sampled across the radiation gradient. Preliminary findings of these studies are presented in this report.

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

II. RADIONUCLIDE STUDIES WITH MULE DEER

II. A. Strontium-Calcium Metabolism

R. G. Schreckhise and F. W. Whicker

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

Schultz¹ demonstrated a correlation between ⁹⁰Sr concentration of the mandible and antlers of white-tailed deer. He indicated that due to the unknown extent of ⁹⁰Sr translocation from bone to antler during antler development, antlers were not a good source of data on fallout levels during the period of antler growth.

For study of the extent of dietary and skeletal translocation of Ca and Sr to the antler of male deer, the year was divided into three segments in reference to antler development. First, the early antler growth period, from April through June, is the start of new antler development with the visual growth relatively slow. At this time, as reported by McIntosh², the trabecular bone volume is at a minimum suggesting a rather large mobilization of skeletal bone mineral for the developing antlers. Second is the late antler growth period, from July, when growth is very rapid, through September when the velvet is stripped off the mature antlers. During this time, as found by McIntosh², the trabecular bone volume returns to normal. The dietary requirements of Ca would be greatest during mid-late antler growth due to the rather large amount of antler and bone being formed. Third, is the dormancy or quiescence period from October through February at which time the old mature antlers are shed and new growth begins. At this time the mature antlers are "dead" bone. This is also the period of "rut," the breeding season and return to normal behavior. The influence of time in relation to the stage of antler development on the kinetics and transfer of Ca and Sr were studied by administering ⁸⁵Sr, ⁹⁰Sr and ⁴⁵Ca to buck deer in various seasons and determining retention and distribution through several subsequent seasons.

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

²McIntosh, J. E. 1972. Cyclic trabecular bone changes in mule deer, Odocoileus hemionus hemionus. In abstracts of papers presented at the 48th Annual Meeting, Southwestern and Rocky Mountain Division, American Association for the Advancement of Science held in Fort Collins, Colorado, 26-29 April, 1972.

Also of interest was the Ca and Sr kinetics in the female deer, especially with regard to doe-fetus and doe-fawn transfer of bone minerals. For the study of the effect of gestation on Ca and Sr metabolism the following three time periods were selected for administering radiotracer doses to the does:

1. Pre-gestation -- first of November -- the ^{85}Sr , ^{45}Ca and ^{90}Sr in a fawn from a doe spiked at this time would have been translocated almost entirely from the doe's skeleton;
2. Mid-gestation -- first of March; and
3. Pre-parturition -- first of June -- at this time and at mid-gestation, Sr and Ca directly from the diet would probably be found in the fawn's skeleton. The various bone formation and development rates in the fetus may affect Sr and Ca kinetics in the doe at the various dosage dates.

We had hoped to include another time period, one during lactation in July to obtain information on the translocation of Ca and Sr from the doe to the nursing fawn. We were unable to carry this out due to problems encountered with handling the does and their nursing fawns.

The captive deer herd and facilities used for this study were previously described^{3, 4}. Deer of various ages were given oral doses of approximately $450\mu\text{Ci } ^{85}\text{Sr}$, $100\mu\text{Ci } ^{45}\text{Ca}$ and $10\mu\text{Ci } ^{90}\text{Sr}$ during one of the described periods. They were then confined in a metabolic cage⁵ for approximately 2 weeks and their excreta collected daily. During this time they were also whole body counted daily in a chute⁴ designed to accommodate the antlered buck. The time periods between whole body counts were progressively lengthened until deer were counted once every two weeks. This schedule was maintained for approximately 270 days after dosage. At this time the activity in the deer usually became undetectable or the deer was selected for dosing again. After the first two weeks the deer were confined every one or two months in the metabolic cage to make 24 hour excreta collections for ^{45}Ca and ^{90}Sr assay.

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

⁴Schreckhise, R. G. and F. W. Whicker. 1971. Strontium and calcium metabolism in mule deer. p. 5-9. In Ninth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Department of Radiology and Radiation Biology, Colorado State University, Ft. Collins.

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

In October the mature antlers were removed from the bucks with a bone saw, leaving nubs 2-3 cm long which were then collected the following February when the antlers are normally shed. The antlers were cut into 2 to 5 cm sections and analyzed for ^{85}Sr content.

All of the scheduled trials have been completed. In 1969, one buck was spiked during the early antler growth period and four bucks during the late antler growth period. In 1970, three bucks were dosed during the period of early antler growth, four in the late antler growth period, two does in the pre-parturition period and two does during the pre-gestation time period. Six bucks were spiked during the dormancy period and 1 doe during the mid-gestation time interval in 1971.

The following two component model was used to describe the ^{85}Sr retention curve obtained by whole body counting:

$$A_t = A_1 e^{-\lambda_1 t} + A_2 e^{-\lambda_2 t}$$

where, A_t = fraction of the ingested dose retained at time t , A_1 and A_2 are fractions of the initial dose represented by the short and long components respectively, and λ_1 and λ_2 equals $\ln 2$ divided by the biological half-times of the short and long components respectively. A computer program was written to fit the data with the two component model. The method used is a modification of a "peeling" method described by Sheppard⁶. In this method the whole body retention curve is visually divided into two parts at various "flag points". The long component parameters are estimated by least squares method and then the parameters are used to describe a curve which is "peeled" or subtracted from the remaining data points. The parameters of the short component are then estimated by least squares. Combinations of the various selected flag points are then run and the flag point combination with the minimum value for the sum of the squared deviations is selected as the best estimate of the parameters.

Preliminary results from these experiments are given in Table II. A. 1. Some of the values given by Schreckhise and Whicker⁴ for the same animals differ from those given here. The differences are due to the longer whole body counting periods not included in the 1971 report, and reanalyzing the 1969 data with the improved computer program.

Attempts to date to find simple correlations between age and fraction of the ingested dose in the antlers, and age versus retention half time have

⁶Sheppard, C. W. 1962. Basic principles of the tracer method. John Wiley & Sons, Inc., New York. p. 245-246.

Table II. A. 1. Preliminary results of ^{85}Sr retention and translocation in mule deer following acute oral ingestions of approximately $450\mu\text{Ci } ^{85}\text{SrCl}_2$. (All appropriate values are corrected for physical decay to time of ingestion.)

Deer	Sex	Age at time of spiking (mo.)	Weight at time of spiking (kg)	Period* and date of spiking	Elapsed days from time of spiking to last whole body count	Approx. antler length at spiking as a fraction of the final main beam length	Intercept of the long component (A_2)	Biological half-life of the long component (days)	Fraction of the ingested dose in the mature antlers ($\times 10^{-3}$)	Total ashed weight of the mature antlers (gm)	μCi per gm ashed antler per μCi ingested ($\text{gm}^{-1} \times 10^{-5}$)
S-24	M	8	41.8	DOR, 2/9/71	361	0.00	0.0638	200	1.70#	137.2#	1.24#
S-25	M	9	32.7	DOR, 3/4/71	338	0.00	0.0868	166	0.264#	80.9#	0.326#
S-8	M	11	42.2	EAG, 5/17/70	230	0.37	0.0925	200	3.40#	149.4#	2.27#
S-1	M	12	45.4	EAG, 6/19/69	156	0.40	0.0922	159	2.01	115.9	1.73
S-14	M	14	62.7	LAG, 7/31/70	176	0.92	0.0930	197	14.4	165.0	8.73
S-15	M	14	59.0	LAG, 8/14/70	540	0.99	0.118	214	18.6	169.0	11.0
S-20	M	19	56.4	DOR, 1/2/71	399	0.00	0.0400	133	1.01#	482.1#	0.210#
S-23	M	20	70.5	DOR, 1/24/71	377	0.00	0.0416	175	##		
S-6	M	23	60.8	EAG, 5/4/70	257	0.01	0.112	256	12.0	292.8	4.09
S-2	M	25	56.8	LAG, 7/6/69	139	0.48	0.0460	314	3.29	455.7	0.721
S-3	M	25	45.4	LAG, 7/30/69	71	0.83	0.0817	140	14.6	177.7	8.23
S-4	M	26	56.8	LAG, 8/14/69	100	0.95	0.0600	154	9.47	184.6	5.13
S-17	M	27	76.3	LAG, 7/24/70	49	Died 49 days after spiking					
S-22	M	31	70.5	DOR, 1/16/71	46	Died 46 days after spiking					

* DOR = Dormancy, EAG = Early Antler Growth, LAG = Late Antler Growth.

Does not include the antler nubs either not found or not yet analyzed.

Have not completed analysis of his antlers at this time.

Table II. A. 1, concluded

Deer	Sex	Age at time of spiking (mo.)	Weight at time of spiking (kg)	Period* and date of spiking	Elapsed days from time of spiking to last whole body count	Approx. antler length at spiking as a fraction of the final main beam length	Intercept of the long component (A_2)	Biological half-life of the long component (days)	Fraction of the ingested dose in the mature antlers ($\times 10^{-3}$)	Total ashed weight of the mature antlers (gm)	μCi per gm ashed antler per μCi ingested ($\text{gm}^{-1} \times 10^{-5}$)
S-7	M	35	89.0	EAG, 5/9/70	245	0.11	0.0471	293	10.8	819.3	1.31
S-21	M	43	72.7	DOR, 1/9/71	31	Died 31 days after spiking					
S-5	M	51	90.8	LAG, 9/2/69	81	0.99	0.133	136	17.4	847.2	2.05
S-16	M	61	106.2	LAG, 7/15/70	351	0.88	0.0617	286	48.4	828.4	5.85
S-18	F	16	44.9	PRG, 10/30/70	463		0.0391	235			
S-19	F	16	65.4	PRG, 11/7/70	349		0.0407	168			
S-10	F	24	52.2	PRP, 6/13/70	199		0.104	153			
S-26	F	45	57.7	MID, 3/13/71	312		0.0334	117			
S-9	F	60	61.7	PRP, 6/6/70	280		0.0229	171			

* DOR = Dormancy, EAG = Early Antler Growth, LAG = Late Antler Growth, PRG = Pre-Gestation, MID = Mid-Gestation, PRP = Pre-Parturition.

not been successful. It seems at this time that no one factor per se is directly related to or is a function of only one parameter, suggesting the possible necessity of multivariate analysis.

Of interest are the patterns of ^{85}Sr concentrations found in the antlers as related to the degree of antler development at the time of ^{85}Sr ingestion. As previously stated, the antlers were sectioned into 2-5 cm lengths. A plot was then made of the antler concentration ($\mu\text{Ci/gm}$ ash) versus cumulative ashed antler weight moving distally from the base to the tip of the antlers. In a deer that was spiked after antler growth began, ^{85}Sr concentration was low at the proximal end, increasing to a maximum at the point of antler length at time of ingestion. This seems to imply that at the proximal end calcification had begun, decreasing the available exchangeable Ca and Sr, allowing less ^{85}Sr to be deposited, while distally the ^{85}Sr was exchanged with the Ca and then bound in the antler matrix during ossification. After dosage the antler which was then grown was found to decrease in concentration distally out to the tip of the antlers. This is probably because the available ^{85}Sr in the deer's skeleton is also decreasing in proportion to the biological elimination rate. The decreasing pattern of ^{85}Sr antler concentration was also found with the bucks dosed during the dormancy period, which can also possibly be explained by the decreasing amount of available skeletal ^{85}Sr .

Strontium-90 and calcium-45 radiochemical analyses being done at this time should provide valuable information which may assist in the interpretation of data on the whole body retention and bone to antler translocation of ^{85}Sr .

II. B. Fallout ^{137}Cs and ^{131}I in Mule Deer, 1971
F. W. Whicker

Tissue samples from 5 wild mule deer killed within the Cache la Poudre Drainage of north-central Colorado were obtained during November and December, 1971. All animals were killed by rifle on winter range shrub communities of the lower montane forest at elevations between 6,500 and 7,600 feet. Muscle tissues were assayed for ^{137}Cs , thyroids for ^{131}I , and metacarpals were stored for future ^{90}Sr assay.

Results of the ^{137}Cs and ^{131}I determinations are given in Table II. B. 1. The ^{137}Cs values, which ranged from 44 to 91 pCi/Kg (wet) were considerably lower than the previous year. A summary of mean ^{137}Cs values for mule deer collected on Poudre Canyon winter range during November and December from 1963 through 1971 is given in Table II. B. 2. for a trend analysis. A regression analysis of the trend data indicates that muscle ^{137}Cs levels have decreased since 1963 with an observed half time of about 2.3 years. If near-equilibrium can be assumed between deer and winter range forage,¹ then the observed half time in deer would also be applicable to the winter range browse, which consists primarily of woody shrub species.

Inasmuch as the fallout rate decreased during the 1963 to 1971 period with a half time of about 0.82 years,² it can be argued that the half time of fallout ^{137}Cs on winter range vegetation approaches 2.3 years, but likely does not exceed that value.

The ^{131}I which was observed in thyroids of the three deer collected in late December likely originated from the reported³ Chinese atmospheric nuclear explosion detonated in the vicinity of Lop Nor on November 18, 1971.

¹This is probably a reasonable assumption since the biological half time of ^{137}Cs in deer is about 14 days and most of the animals had been on winter range at least 1.5 months prior to collection.

²Wilson, D. W. and G. M. Ward. 1968. Radiological Health Data and Reports 9: 602.

³Radiological Health Data and Reports 12(12): 665.

Table II. B. 1. Concentrations of ^{137}Cs and ^{131}I in mule deer collected from the Cache la Poudre Drainage, Colorado, 1971.

No.	Date	Sex	Age Class	Location			Elevation (feet)	pCi ^{137}Cs /Kg Fresh Muscle	pCi ^{131}I /g Fresh Thyroid
				S	T	R			
71-00	11/2	M	Yearling	18	9 N	70 W	6,500	---	N.D.*
71-0	11/2	M	Mature	12	9 N	71 W	7,350	91	N.D.
71-1	12/28	M	Mature	32	9 N	72 W	7,400	63	133
71-2	12/29	F	Mature	31	9 N	72 W	7,600	58	91
71-3	12/29	F	Mature	31	9 N	72 W	7,600	44	121

* N. D. - Not Detectable

Table II. B. 2. Mean ^{137}Cs values for mule deer collected on Poudre Canyon winter range during November and December from 1963 through 1971.

Year	No. Sampled	pCi ^{137}Cs /Kg wet muscle		
		Mean	$\pm$ S. E.	Range
1963	7	1217	155	913-1944
1964	7	786	90	508-1265
1968	5	373	78	134-603
1969	4	366	126	130-630
1970	7	163	39	75-324
1971	4	64	10	44-91

II. C. Retention of Intravenously Administered ^{134}Cs in Mule Deer
A. W. Alldredge, F. W. Whicker, and T. E. Hakonson

This study involved two mature female mule deer (18 mo. old) and was conducted to further evaluate previously observed elimination patterns of ^{134}Cs in deer.¹ Of specific interest was whether the two-component exponential retention curve observed from oral cesium administration would be observed following intravenous injection of the nuclide. Application of a two component model for mule deer as observed in reindeer² required this experiment. The deer colony, counting facilities and metabolic cage used in this study have been previously described.^{3, 4}

Due to availability of only one metabolic cage, these experiments were not conducted simultaneously but followed the same general procedure. The deer was placed in the metabolic cage for a period of adjustment (deer 1, 3 days; deer 2, 6 days) before 20 microcuries of ^{134}Cs (carrier free $^{134}\text{CsCl}$ in physiological saline) was injected into the jugular vein. Whole body counting was begun immediately after injection and continued at six hour intervals for the first day at which time daily counting was conducted. Feces and urine were collected daily for the duration of confinement in the metabolic cage. Animals were transferred from the metabolic cage after a week to a 20 foot square pen for approximately another week. Food and

¹Hakonson, T. E. and F. W. Whicker. 1969. Uptake and Elimination of ^{134}Cs in Mule Deer. pp. 616-622. In Symposium on Radioecology (ed. D. J. Nelson and F. C. Evans). Clearinghouse for Federal and Scientific Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia 22151.

²Holleman, D. F., J. R. Luick and F. W. Whicker. 1971. Transfer of radiocesium from lichen to reindeer. *Health Physics* 21(5): 657-666.

³Schreckhise, R. G., A. W. Alldredge, and F. W. Whicker. 1970. Strontium and calcium metabolism in mule deer. p. 5-8. In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Department of Radiology and Radiation Biology. Colorado State University, Fort Collins.

⁴Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M.S. Thesis. Colorado State University, Fort Collins. 121 p.

water was offered ad libitum and consumption is reported in Table II. C. 1. After the two weeks of confinement, the animals were returned to the main deer colony and counted every second or third day with no measurement of food and water intake.

Fecal samples were placed in a dehydrator (163° F) for approximately 120 hours. Dried samples were weighed to the nearest gram, homogenized, and slurried with 0.5 N HCl for comparison to liquid standards of comparable density and configuration. Urine samples were analyzed in one liter plastic bottles and compared to liquid standards. All samples were counted with a 5 x 5 inch NaI crystal attached to a single channel analyzer.

Results of urine and fecal analysis indicated that deer 1 excreted about 16% of the total dose via the urine and 31% by way of the feces in 9 days, while in 7 days deer 2 excreted 15% and 36% in the urine and feces respectively. These results are not greatly different from those obtained from oral administration of ^{134}Cs in deer, with the exception that peak elimination in both urine and feces occurred in less than the 3 days observed in the oral experiment.⁴ The delay in peak elimination in the oral experiments could be explained by the time required for passage of ^{134}Cs from the gut to the blood. A study presented in this report on mean retention times of ingesta in deer indicates that ^{51}Cr peaks in fecal elimination in less than one day and is eliminated entirely in three days. Assuming the ingested ^{134}Cs has a gut residence time similar to the chromium tagged particles, it would be expected that uptake of cesium could occur for three days at which time potential uptake would have been maximized and cesium that remained in the gut would have been eliminated. Beyond three days only elimination of cesium from the body pool would occur. When the cesium is placed directly into the blood "uptake" is instantaneously maximized at time of spike.

Whole body counting data indicated that retention of cesium from an intravenous dose followed the two component type elimination observed in data collected from orally administered doses.³ Data from the intravenous experiment are summarized in Table II. C. 1.

Assuming the two compartment model valid and applying the relationships presented in Holleman, et al.² to the data in Table II. C. 1., the following expression was obtained to estimate total body burden, Q_T (in μCi), of a deer with a continuous intake of cesium:

$$Q_T = C_1 I - \left[C_2 I e^{-\lambda_1 t} + C_3 I e^{-\lambda_2 t} \right]$$

Table II. C. 1. Summarized data from intravenous cesium-134 experiment in mule deer.

<u>Deer No.</u>	<u>Weight (Kg)</u>	<u>Sex</u>	<u>MEAN DAILY FOOD INTAKE (gm dry)</u>			<u>Mean Daily Water Intake (ℓ)</u>	<u>Half time (days)</u>		<u>% Intercept</u>	
			<u>Grain</u>	<u>Hay</u>	<u>Vegetables</u>		<u>Short</u>	<u>Long</u>	<u>Short</u>	<u>Long</u>
1*	48.7	female	1225	181	28	2.6	0.86	15.0	15	85
2	49.3	female	709	480	29	2.16	0.36	10.0	19	81

*Deer died 89 days after administration of intravenous dose. Cause of death unknown.

where: I = intake rate in $\mu\text{Ci/day}$

t = time in days

$C_1 = 15.106 \text{ day}$

$C_2 = 0.1495 \text{ day}$

$C_3 = 14.96 \text{ day}$

$\lambda_1 = 1.137 \text{ day}^{-1}$

$\lambda_2 = 0.0556 \text{ day}^{-1}$

Intake rate is a product of the rate of food consumption (R), the concentration of the nuclide in food (c), and the amount of nuclide assimilated from contaminated food into the body (a). The λ_2 in our equation is obtained from the long component elimination data and is therefore valid only for deer exhibiting the same body weight and food consumption as deer in our experiment. In order to increase the resolution of our model, λ_2 may be expressed as¹:

$$\lambda_2 = (0.693)/(5.97 - 4.1R + 0.28W)$$

where: R = food intake (Kg/day)

W = body weight (Kg)

Data collected on this project since 1962 provide us with reliable estimates for fallout cesium-137 concentrations in deer forage and muscle tissue.⁵ Studies with captive deer have enabled us to develop the above model and evaluate kinetics of cesium in mule deer. We are now in a position to apply this knowledge and data to develop a model to estimate food consumption rates of free ranging mule deer. Such data will be valuable to the wildlife manager, especially in view of the current public demands for more wildlife on continually decreasing ranges.

⁵Whicker, F. W. 1965. Fallout Cesium-137 in Mule Deer. Ph.D. Thesis. Colo. State Univ., Fort Collins, Colorado. 220 pp.

II. D. Gastrointestinal Retention of Ingesta in Mule Deer and Domestic Sheep. A. W. Alldredge and D. E. Reeder¹

Colorado, like many states, is confronted with the problem of maintaining big game populations on ranges that continue to be reduced in size due to inundations by human populations and activities. Principal inundations occur on winter ranges, severely restricting forage availability during the "pinch period." Winter feeding of game animals has been suggested as one method of maintaining animals in excess of winter range carrying capacity.

The mule deer, a selective feeder, has trouble adapting to sudden changes in diet and problems such as impaction of the omasum and ulceration of the abomasum and small intestine occur when these animals are fed diets high in crude fiber such as alfalfa hay. The domestic sheep, on the other hand, appears capable of utilizing high crude fiber diets without the complications observed in deer. This observation led to the hypothesis that deer and sheep might possibly have varying retention times for ingesta and varying degrees of control over this retention time. The nutritional value of food to an animal is dependent upon digestibility and retention time of the ingested material.

From a radioecological standpoint, the retention time of ingesta is important in evaluating and defining observed kinetics of ingested radionuclides. For example, the gut residence time of fallout contaminated browse would most likely influence the availability and uptake of contaminants, thus influencing subsequent nuclide body burden. A knowledge of retention times of ingesta is also helpful in the interpretation of observed elimination patterns of radionuclides.

To test the hypothesis that deer and sheep illustrate varying retention times and varying ability to adjust retention times with alterations in fiber intake, an experiment involving six adult deer and six adult sheep was conducted. Animals were placed in 3 x 4 x 6 foot metabolic cages designed to collect fecal material and allowed to adjust to a control diet of 30% crude fiber, 15% protein and no alfalfa hay. When food and water intake appeared stable the animals were given a 0.5 gm portion of food containing 2 to 5 microcuries of chromium-51 (⁵¹Cr Cl₃). Fecal collection was begun six

¹D. E. Reeder is with the Department of Fisheries and Wildlife Biology, Colorado State University. This study was conducted on a cooperative basis between the Department of Radiology and Radiation Biology, the Department of Fisheries and Wildlife Biology and the Colorado Game, Fish and Parks Division, and was funded in part by Colorado Federal Aid Project W-38-R-24.

hours post-spike and continued at two hour intervals to twenty hours, when the interval was changed to four hours. Four hour collections were maintained until 64 hours post-spike. Eight hour collections were made from 64 hours until 96 hours when trials were concluded. Subsequent trials followed this scheme with dietary proportions of alfalfa increasing from 0% to 15%, 35%, and 50% alfalfa in a pelleted ration. A repetition on the control diet was conducted after the 50% alfalfa trial. Prior to initiation of each trial, animals were conditioned for ten days to the trial diet. Food and water were given ad libitum and daily food consumption is summarized in Table II. D. 1. Urine samples collected from two animals contained no chromium-51.

In conjunction with the use of chromium-51 as an inert marker for ingesta, a method using stained particles was also employed. The comparison of these two techniques will be the subject of a future report.

Fecal samples were placed in a dehydrator (163° F) for 24 to 48 hours then weighed to the nearest 0.1 gram. Samples were homogenized and aliquots of 1 to 3 grams were removed from the total sample to be used for stained particle analysis. The remaining sample was slurried with 0.5N HCl for comparison to liquid standards of similar density and configuration and assayed with a 5 x 5 inch NaI crystal attached to a single channel analyzer. Duration of counts was such that the standard deviation of the difference between the sample and the background did not exceed 5% of the net sample count rate.

Net counts per minute were converted to microcuries per gram of dry sample and plotted as a net cumulative excretion curve. The mean retention time was calculated using the 5-95% elimination method of Castle.² Also to be analyzed from our data will be the dry matter digestability of consumed rations.

Results of completed analysis are presented in Table II. D. 2. These data indicate that the deer in our experiment did have a retention time of ingesta which was generally less than that of the sheep and this retention time changed only slightly as the percentage of alfalfa in the diet changed. Variation between animals may, however, mask any statistical significance in these data. Another interesting trend in data is the tendency for all animals to increase food consumption as the percentage of alfalfa in the diet increased. The increase in intake with no decrease in retention time in the deer may, in part, cause the observed impaction of the omasum.

²Castle, Elizabeth J. 1956. The rate of passage of foodstuffs through the alimentary tract of the goat. 1. Studies on adult animals fed on hay and concentrates. British J. Nutrition 10(1): 15-23.

Table II. D. 1. Mean daily food consumption (g) of deer and sheep feeding on diets with varying percentages of alfalfa hay.

		<u>Trial I</u> <u>0% Alfalfa</u>	<u>Trial II</u> <u>15% Alfalfa</u>	<u>Trial III</u> <u>35% Alfalfa</u>	<u>Trial IV</u> <u>50% Alfalfa</u>	<u>Trial V</u> <u>0% Alfalfa</u>
Deer	1	841	901	910	1172	788
	2	1095	1498	1513	1306	500
	3	488	820	1027	1062	458
	4	250	474	473	721	779
	5	827	951	1013	1075	798
	6	<u>685</u>	<u>954</u>	<u>1018</u>	<u>326</u>	<u>706</u>
	Means	698	933	992	944	672
Sheep	1	1313	1176	819*	---	---
	2	1579	1678	1739	1881	1591
	3	774	1329	1301	1464	1190
	4	1469	1636	1447	1839	1609
	5	1201	1319	1426	1531	1279
	6	<u>1325</u>	<u>1582</u>	<u>1550</u>	<u>1588</u>	<u>1397</u>
	Means	1277	1453	1493	1660	1413

*Animal ceased to eat and subsequently died.

Table II. D. 2. Mean retention time (hrs) of ingesta in deer and sheep feeding on 0% to 50% Alfalfa diets.

		<u>Trial I</u> <u>0% Alfalfa</u>	<u>Trial II</u> <u>15% Alfalfa</u>	<u>Trial III</u> <u>35% Alfalfa</u>	<u>Trial IV</u> <u>50% Alfalfa</u>	<u>Trial V</u> <u>0% Alfalfa</u>
<u>Deer</u>	1	23.7	25.7	23.6	23.5	26.9
	2	20.0	16.3	13.3	18.2	23.3
	3	27.3	21.6	20.4	24.8	30.3
	4	19.9	30.8	29.9	24.9	15.5
	5	27.0	22.3	25.6	18.0	20.6
	6	23.4	24.2	21.3	21.1	21.9
	$\bar{x} =$	<u>23.55</u>	<u>23.48</u>	<u>22.35</u>	<u>21.75</u>	<u>23.08</u>
<u>Sheep</u>	1	29.3	31.3	30.1	*	*
	2	24.0	21.1	18.4	18.0	25.5
	3	37.7	33.6	26.3	22.5	33.4
	4	32.0	29.0	21.3	20.3	29.4
	5	35.3	36.2	30.0	20.5	32.2
	6	36.8	27.2	26.1	21.9	30.6
	$\bar{x} =$	<u>32.52</u>	<u>29.73</u>	<u>25.37</u>	<u>20.64</u>	<u>30.22</u>

*Animal ceased to eat and subsequently died.

Decreased retention time in the sheep is not proportional to the increase in food intake and is probably more closely associated with the digestability of the high alfalfa rations and a laxative effect produced by increases in dietary bulk.

III. RADIONUCLIDE STUDIES OF AQUATIC SYSTEMS

III. A. Kinetics of Cesium in a Montane Lake Ecosystem T. E. Hakonson and F. W. Whicker

This study was designed to measure the in situ kinetics of cesium in East Twin Lake, a natural semi-drainage, 5 hectare body located in the montane zone of the Colorado Front Range at an elevation of 2880 meters. The lake has a maximum depth of about 7 meters and is characterized by its extensive littoral and emergent zones, emergent aquatic plants, and dyseutrophic appearance.

On September 15, 1970, one Kg stable cesium as CsCl was introduced into the lake and periodic sampling of the major ecosystem components was initiated and continued for 393 days. Cesium was measured in all components by neutron activation analysis.

The concentrations of Cs decreased in water through the study period and correspondingly increased in sediments with a transfer half time of about 130 days. At the end of the 393 day sampling period, about 82 percent of the total system Cs was associated with the sediment. Also at that time, about 3 and 14 percent of the Cs was in the dissolved phase and in seston, respectively.

Amphipods and zooplankton reached equilibrium with the water within about 3 weeks after the Cs was administered and achieved concentration factors of the order of 700 and 150, respectively. During mid-winter, however, these organisms showed increased concentrations of Cs with concentration factors ranging up to 2,800 and 400 for amphipods and zooplankton, respectively.

Trout accumulated the Cs more slowly than the smaller animals and reached a maximum concentration factor of about 3,000 some 260 days following the dosing event. The major parameters governing Cs accumulation in trout, namely the Cs retention half time and food intake, were shown to vary greatly during the year. For example, based upon observed data and theoretical considerations, trout consumed only 0.5% of their body weight daily in mid-winter, but up to 4% in early summer. Retention half-times ranged from about 90 days in summer to 650 days in mid-winter, based upon water temperatures, body weight and growth. This work indicated that food organisms contained sufficient Cs to account for the observed levels in trout, and other potential sources, such as sediment intake, were not apparently significant. This is counter to the earlier findings of Gallegos (1969)¹, but the findings of both investigations may not be mutually exclusive. Gallegos made his observations

¹Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph.D. Thesis, Colorado State University, Fort Collins. 342 p.

on fallout ^{137}Cs which had been in the lake system much longer than the stable Cs in this study. In several years, according to its present behavior, stable Cs will be considerably higher in sediment and lower in the water and invertebrates, and at that time, sediment ingestion may be of major importance.

A systems analysis of the kinetic behavior was undertaken and a simulation model based upon constant transfer rate constants was developed which fit the general pattern of the observed data extremely well. However, seasonal fluctuations observed in the data could not be built into the simulation due to a lack of knowledge and data. A high-precision model must face up to the fact that the transfer rate constants are variable with season.

The study of cesium kinetics with stable Cs proved to be valid as a tracer for ^{137}Cs and practical from an analytical standpoint. Furthermore, the stable tracer obviates the radiation protection problems that would arise from contaminating a public water with a radioisotope of cesium.

This study will be presented in detail in a Ph. D. thesis by T. E. Hakonson which should be completed by September, 1972.

III. B. Cesium-137, Lead, and Mercury in Trout from Colorado Mountain Lakes, 1971

F. W. Whicker and W. C. Nelson

During 1971, trout were collected from 17 montane and alpine lakes in Colorado for assay of ^{137}Cs , lead, and mercury. Five of the lakes were sampled during previous years; the remainder of the lakes were not. The purposes of the 1971 sampling were to further define the temporal trends in ^{137}Cs burdens, to measure concentrations of lead and mercury, and to determine whether any relationships exist between ^{137}Cs and lead or mercury. In addition, snow samples were collected in 1971 and 1972 for lead and mercury assay in a preliminary attempt to assess atmospheric input of these metals.

Methods of sample collection and analysis, as well as data on ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado are found in Whicker, Nelson and Gallegos¹. Liver, bone, muscle, and snow samples were assayed for lead by atomic absorption photometry by Dr. William S. Ferguson, Analytical Chemistry Facility, Colorado State University. To achieve adequate sensitivity for the sub-microgram quantities of lead which were encountered in most samples, Delves Microsampling Cups were used to introduce wet-ashed samples into the instrument flame. The standard deviation for a single determination was estimated as $0.05\mu\text{g/g}$ wet tissue, based upon duplicate assays of 10 different samples. Liver, muscle and snow samples were determined for mercury by William J. Adrian, Colorado Division of Game, Fish and Parks using atomic absorption techniques.

Concentrations of ^{137}Cs , lead, and mercury in fish tissues are tabulated in Table III. B. 1. The quantities of ^{137}Cs are similar to those measured in previous years (Table III. B. 2). The quantities of lead and mercury generally ran less than $1\mu\text{g/g}$ wet tissue, although concentrations were usually in a quantitatively determinable range ($>0.05\mu\text{g/g}$). Highest concentrations of lead were found in bone, while lowest concentrations were measured in muscle. Liver tissues were intermediate in lead content. Liver tissue was much more convenient for both lead and mercury assay than bone or muscle because of its ease of wet ashing and the quantities of these metals present. Bone samples presented analytical difficulties because of the large quantities of spectrally interfering minerals.

¹Whicker, F. W., W. C. Nelson, and A. F. Gallegos. Fallout ^{137}Cs and ^{90}Sr in trout from mountain lakes in Colorado. Health Physics (In Press).

Table III. B. 1. Cesium-137, lead and mercury in tissues of fish from 17 montane and alpine lakes in Colorado, 1971.

Lake	Species	Date of Collection	pCi ¹³⁷ Cs/Kg wet muscle	μ g Pb/g wet*			μ g Hg/g wet*	
				liver	bone	muscle	liver	muscle
Timber	Rainbow	7-8-71	591	---	---	---		0.04
Rainbow	Rainbow	8-10-71	48	0.33	0.48		0.64	0.09
Emerald	Rainbow	8-12-71	94	0.04			<0.06	0.28
Weller	Rainbow	8-13-71	247	0.10			<0.06	0.05
Timberline	Brook	8-14-71	1095	0.17			0.69	0.04
	Brown	8-14-71	1532	0.22	0.75			0.11
	Rainbow	8-14-71	304	0.27			0.85	
	Cutthroat	8-14-71	384	0.14			0.82	0.10
Norris Cr. (Pond)	Cutthroat	8-23-71	1347	0.38	0.69		<0.04	0.10
unnamed	Cutthroat	8-25-71	469	0.36	0.76		0.46	0.09
Ceanothus	Rainbow	8-26-71	697	0.22	0.40		0.28	0.09
Gore	Brook	8-25-71	297	0.07			<0.08	0.05
	Rainbow	8-25-71	55	0.30			<0.08	0.05
Cliff	Rainbow	8-26-71	192	0.24		0.05	0.35	0.05
Agnes	Brown	9-8-71	843	0.10	0.76		0.67	0.36
	Rainbow	9-8-71	805	0.12	0.36		0.22	0.04
	Cutthroat	9-8-71	816	0.15	0.49		0.27	<0.04
	Sucker	9-8-71	605	0.20	0.83		0.35	0.21
Snow	Rainbow	9-9-71	1405	0.57	0.95			0.06
	Cutthroat	9-9-71	1288	0.31	0.67		0.33	0.05
L. Fay	Cutthroat	9-16-71	595	0.11	0.22		0.31	0.12
L. of Clouds	Cutthroat	9-30-71	930	0.19	1.49			0.06
Island	Cutthroat	9-30-71	311	0.09		0.03	0.43	0.17
Goose	Cutthroat	10-4-71	433	0.39			0.71	0.06
E. Twin	Rainbow	10-13-71	2362	0.23	0.65		0.21	
Means			710	0.22	0.68	0.04	0.38	0.10
s $\bar{x}$			111	0.03	0.08	0.01	0.06	0.02

*Mean percent dry matter: 46% for bone, 25% for liver, and 23% for muscle.

Table III. B. 2. Trend comparisons of ^{137}Cs burdens of trout (all species) collected in 1971 versus previous years for five mountain lakes.

Lake	Range	Elev. (m)	Mean ^{137}Cs concentration (pCi/Kg wet) for year					
			1966	1967	1968	1969	1970	1971
East Twin	Medicine Bow	2882	3173	1799	1990	2310	930	2362
Snow	Never Summer	3511	---	3450	1564	1336	1274	1346
Lower Agnes	Never Summer	3251	1890	1340	1090	610	911	821
Goose	Front	3208	---	782	---	---	434	433
Island	Front	3141	616	318	---	---	321	311

It is apparent from the data on lead and mercury in liver tissues that 10 fold or greater variations can exist between samples from different lakes. In this initial survey, the causes of the differences cannot be determined. The concentrations of lead and mercury in liver tissues are not correlated with lake elevations, with the respective concentrations in other tissues, nor with each other in any of the tissues. When data from all lakes were considered, there were no correlations between lead or mercury in liver and ^{137}Cs in muscle. However, when only remote lakes accessible by foot and planted by aircraft are considered, significant ($\alpha = 0.05$) correlation did exist between ^{137}Cs in muscle and lead in liver (Fig. III. B. 1).

If the correlation between lead in liver and ^{137}Cs in muscle actually exists, then at least two interesting questions can be raised. First, why was the correlation improved by ignoring those lakes accessible to vehicular traffic? Conceivably, accessibility in some cases allows stocking of catchable sized trout whose tissues may not be reflective of conditions in the lakes. Also, increased human activities such as boating, camping, etc. may affect the lead but not the ^{137}Cs inventory. Second, since the source of ^{137}Cs is atmospheric fallout, does a positive correlation between lead and ^{137}Cs suggest that the lead is also of atmospheric origin? These questions cannot be answered from our data, but the data could be used to raise some provocative hypotheses concerning the origin of the lead and mercury.

The measurements of lead and mercury in snow that was carefully collected in remote areas suggests that atmospheric inputs of these metals can be quantified (Table III. B. 3). For example, the mean lead content of snow collected April 24, 1971 directly over the ice of Snow Lake was about $3.6 \mu\text{g/liter}$ of melt water. The volume of water in the form of snow over the ice was $1.85 \text{ m mean depth} \times 7.1 \times 10^4 \text{ m}^2 \text{ area} \times 0.41 \text{ m}^3 \text{ water/m}^3 \text{ snow} \times 10^3 \text{ l/m}^3 = 5.4 \times 10^7 \text{ liters}$. Thus the amount of lead in the snow pack over the lake amounted to $3.6 \mu\text{g/l} \times 5.4 \times 10^7 \text{ l} \times 10^{-6} \text{ g}/\mu\text{g} = 194 \text{ grams}$. If this lead were of atmospheric origin and if roughly 0.5 of the annual fallout were contained in the late April snow pack, one might expect an annual direct lead fallout rate of the order of 400 grams. Roughly 6 times as much runoff and snow melt from the barren, rocky watershed of Snow Lake enters the lake as from precipitation directly over the lake. Runoff would pose an additional source of lead, both atmospheric and terrestrial, but this source has not been evaluated.

Fig. III. B. 1. Lead in liver versus ¹³⁷Cs in muscle of trout collected from 9 remote mountain lakes in Colorado in 1971.

Table III. B. 3. Lead and mercury determinations of snow samples collected in remote sections of the Colorado Front (F), Never Summer (N), and Medicine Bow (M) Ranges.

Sample No.	Location Description		Depth Sample Taken (cm)	Date of Collection	Sample Preparation	Total Pb $\mu\text{g/liter}$	Total Hg $\mu\text{g/liter}$
	Locale (Range)	Elevation (m)					
Sn-1-a	Snow Lake (N)	3511	80-100	4-24-71	a ¹	3	
Sn-1-b	Snow Lake (N)	3511	60-80	4-24-71	a	3	
Sn-1-c	Snow Lake (N)	3511	40-60	4-24-71	a	3	
Sn-1-d	Snow Lake (N)	3511	20-40	4-24-71	a	7	
Sn-1-e	Snow Lake (N)	3511	0-20	4-24-71	a	2	
Pb 113	Sawmill Cr. (M)	3171	0-20	11-5-71	b ²	1.4	
Pb 114	Fall Cr. Ridge (M)	3110	0-20	12-9-71	a	9	
Pb 115	Montgomery Pass (M)	3063	0-20	1-6-72	a	3	
Pb 116	Dream Lake (F)	3020	0-20	1-26-72	b	1.1	
Pb 117	Dream Lake (F)	3020	0-20	1-26-72	b	0.8	
Pb 118	Dream Lake (F)	3020	0-20	1-26-72	b	0.4	
Hg 49	Dream Lake (F)	3020	0-20	1-26-72	a		2.4
Mean $\mu\text{g Pb/l} \pm s_{\bar{x}}$ method a						4.28 $\pm$	0.99
Mean $\mu\text{g Pb/l} \pm s_{\bar{x}}$ method b						0.84 $\pm$	0.29

¹Sample preparation a: Snow sample melted, acidified, extracted (Thus values represent Pb in total sample, including solid debris).

²Sample preparation b: Snow sample melted, centrifuged, supernate separated then extracted (Thus values represent Pb in snowmelt supernate only).

IV. STUDIES ON THE PIKA, OCHOTONA PRINCEPS

IV. A. Effects of Radiation and Social Interaction
O. D. Markham and F. W. Whicker

This work is summarized in the following abstract taken from a thesis by O. D. Markham¹.

Abstract

Estimates of the LD50₍₃₀₎ from ⁶⁰Co radiation were made for a group of pikas (Ochotona princeps) held in captivity and for another group observed in the natural environment near the summit of Mount Evans, Colorado. The LD50₍₃₀₎ estimate was 560 R (438-717 R; 95% confidence limits) for captive animals and 380 R (250-578 R) for pikas at Mount Evans. Mean survival times for irradiated pikas were 9 to 13 days in captivity and 5 to 7 days in the natural environment. Results are discussed in relation to artificial stresses resulting from captivity and natural stresses such as intra-specific competition and predation.

As a result of the LD50₍₃₀₎ studies, a series of studies were designed to demonstrate the detrimental effect of aggressive social interaction upon the response of pikas to 500 R of Cobalt-60 irradiation. Two one-acre enclosures were stocked with 15 and 31 pikas, and another group of experimental animals was held captive in individual cages. Results indicated that during the late summer and fall animals confined individually had a significantly higher survival rate and longer survival times than animals free to interact in each of the two enclosures. These results substantiate findings of the LD50₍₃₀₎ experiments. However, it appeared that animals irradiated in the spring during the breeding season survived equally in the individual cages and the enclosures.

¹Markham, O. D. 1971. Effects of ⁶⁰Co radiation and social interaction on the pika (Ochotona princeps). Ph.D. Thesis. Colorado State University, Fort Collins. 51 p. (COO-1156-48).

IV. B. Natural History

O. D. Markham and F. W. Whicker

In the course of studies on the effects of radiation and social interaction on the pika, opportunities developed so as to permit a variety of observations on the natural history of this species. Of greatest interest were observations which we were able to make concerning reproduction (in the wild and in captivity), burrowing behavior, and general behavior, especially aggressive activities, in captivity.

In the reproduction observations, it was found that the mean litter size was 3.2 ± 0.08 (S.E.) based upon 107 observations. The breeding season on Mt. Evans (elevations from 3590 to 4265 m) began in late April and terminated in late July. The breeding season commenced somewhat earlier for pikas maintained in outdoor enclosures near Fort Collins (elevation 1555 m). Considerable evidence for two litters annually was obtained for the Mt. Evans population. Considerable data on seasonal variations in body weights of male and female pikas were also obtained.

Prior to our observations, there had been no direct evidence that pikas dig and occupy their own burrows. In the outdoor enclosures at Fort Collins, numerous instances of the construction of burrows by pikas were documented. Several pikas lived in these burrows for extended periods of time. In addition to underground burrows, pikas were observed digging small craters in the soil surface and extensive tunnels beneath the snow during winter.

Our studies conducted with pikas in captivity led to methods for maintaining captive populations which appeared quite successful. These methods are described in a paper now in press¹. The outdoor enclosures which were developed permitted detailed, yearlong observations on aggressive behavior, hay gathering activities, and construction of trails, tunnels, and burrows.

¹O. D. Markham and F. W. Whicker. Notes on the behavior of the pika (Ochotona princeps) in captivity. Am. Midland Naturalist. In Press. (COO-1156-52).

V. RADIATION EFFECTS ON A SHORTGRASS
PLAINS ECOSYSTEM

V. A. The Plant Community

This work is summarized in the following abstract of a thesis prepared by L. Fraley, Jr.¹

Abstract

In order to determine the effect of radiation on the structure of native shortgrass plains vegetation, an 8750 Ci ^{137}Cs source was installed on the Central Plains Experimental Range near Nunn, Colorado. The experimental area was divided into 6 treatment sectors, a control, 2 sectors for chronic exposure (irradiation initiated April 1969 and continuing as of August 1971), and one each for spring, summer and late fall seasonal semi-acute (30 day) exposures which were administered during April, July and December, 1969, respectively.

Community structure was measured by coefficient of community and diversity index. Yield was determined by clipping plots in September 1970 and visual estimates in September 1969 and 1970 for the grass-sedge component of the vegetation. Individual species sensitivity was determined by density data recorded in April, June and September of 1969 and 1970 and by a phenological index recorded at weekly intervals during the 1969 and 1970 growing seasons.

The response of the vegetation was similar whether determined by coefficient of community or diversity with diversity being a more sensitive measure of effects. In the chronically exposed sectors, the exposure rate which resulted in a 50 percent reduction in these 2 parameters (CC50 or D50) was still decreasing the second growing season and was approximately 18 R/hr for the CC50 as of June 1970 and 10 R/hr for the D50 as of September 1970. For the seasonally exposed sectors, the late fall period (December, 1969) was the most sensitive, summer (July, 1969) the least sensitive and spring (April, 1969) intermediate with CC50 and D50 values of 195 and 90, 240 and 222, and 120 and 74 R/hr for the spring, summer and late fall exposed sectors, respectively.

¹Fraley, L., Jr. 1971. Response of shortgrass plains vegetation to chronic and seasonally administered gamma radiation. Ph.D. Thesis. Colorado State University, Fort Collins. 170 p. (COO-1156-45)

Yield and density data indicated a rapid revegetation of the spring and summer exposed sectors during 1970 as a result of an influx of invader species such as Salsola kali tenuifolia, Chenopodium leptophyllum and Lepidium densiflorum and the reappearance of perennials with underground perennating organs such as Lygodesmia juncea, Gaura coccinea, and Oenothera coronopifolia.

The most sensitive indicator of radiation damage was the phenological index with a chronic exposure rate of 1 R/hr delaying the development of Tradescantia occidentalis and Opuntia polycantha.

The shortgrass plains vegetation appears to be one of the most resistant community types studied to date with semi-acute exposures of 45 to 75 kR necessary to decrease diversity to 50 percent of the control value.

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

The role of insects and other arthropods in terrestrial communities is extremely complex. They, perhaps more than any other segment of the biota, are capable of shaping the structure of ecosystems. They affect plants as major herbivores, pollinators, and vectors of disease. Arthropods acting as parasites, predators and vectors influence the fate of animal populations. Oftentimes the first step in recycling vital nutrients is taken by detritus feeding insects. The ecological and economic importance of natural arthropod populations warrants the investigation of how they may be affected by ionizing radiation. The findings reported here resulted from a study on the effects of high intensity gamma radiation on natural insect populations.

This study was conducted within the enclosed irradiation field of an 8750 Ci cesium-137 irradiator facility. The site is located in Northcentral Colorado on land owned by the U. S. Department of Agriculture (For a detailed description of the location, physiognomy and facility, see Fraley.)¹ The vegetation is a native shortgrass plains plant community dominated by blue gamma (Bouteloua gracilis). Prior to securing the study area (spring, 1968) the land was subject to moderate summer cattle grazing.

This study was designed as a companion to a vegetation effects study with the requisite that each be compatible with the other. Insect sampling techniques needed to:

- 1) Provide samples representative of the treatment areas.
- 2) Be nondestructive to both the plant and arthropod communities.
- 3) Not rely on structures that would excessively perturb the radiation field or modify the plant growth.
- 4) Not require more on-site time than the maximum daily four-hour down period for the irradiator.

Upon reviewing the above criteria, it was decided that pit-fall trapping would best suit the purposes of this study. This sampling technique is selective in obtaining mainly cryptozoan arthropods. By sampling those

¹Fraley, L., Jr. 1971. Response of Shortgrass Plains Vegetation to Chronic and Seasonally Administered Gamma Radiation. Ph.D. Dissertation, Colorado State University, Fort Collins. 170 p.

arthropods which are habitual ground dwellers one seems more likely to capture resident arthropods as opposed to transients which may be more prevalent as flying and hopping forms. Pit-fall traps also offer the advantages of being non-destructive, inconspicuous and do not need attending during use. Therefore, trapping occurred through periods of irradiation with traps being attended during the four-hour daily allowable work period.

During March and early April of 1969, ground-level pit-fall traps were installed in each of the six treatment sectors. The traps (Fig. V. B. 1) consisted of 4 1/2 inch diameter circular cores 4 inches deep. The core was lined with a 4 inch section of P. V. C. pipe to provide permanent support for the trap walls. One-pint tin cans were inserted into the core during trapping periods to serve as collection vessels for the arthropods. Weather-proof Masonite collars with beveled outer edges were placed over the traps to bridge the gap from the soil surface to the rim of the collection vessel. When the traps were not in use, the collars were removed and replaced with Masonite covers. Figure V. B. 2 shows a pit-fall trap set for arthropod collection.

Location of the traps (Fig. V. B. 3) within the treatment sectors was dictated somewhat by design of the facility, by the configuration of vegetative quadrats within treatment sectors and by the desire to minimize the "edge effect" that might occur when sampling near the boundary of a treatment sector. Therefore, traps were located along the mid-line radius of each of the six pie-shaped treatment sectors. In order to minimize interference with the vegetative sampling, one trap was placed mid-way between each of the 22 consecutive vegetative sampling microplots and an additional trap beyond the last microplot. A total of 132 pit-fall traps (6 x 22) were located in the circular radiation field.

The irradiation treatments consisted of one control sector, two chronically irradiated sectors and one sector each of spring, summer and late fall treatments. Irradiation commenced in early April, 1969 for the chronic and 30-day spring treatments. Summer and late-fall treatments occurred in July and December, 1969. Figure V. B. 4 shows a schematic of a typical treatment sector.

Insects were trapped at approximate two week intervals from late April or early May through mid-September in 1969, 1970 and 1971. During the 1969 trappings all insects captured were labeled and preserved for identification. In 1970 and 1971 most of the living arthropods captured were recorded and released at the site of capture. Occasional type specimens were preserved for future identification.

Fig. V. B. 1 - A photograph of the pit-fall trap components consisting of a section of P.V.C. pipe (upper left), a Masonite trap cover (lower left), a bevel-edged Masonite collar (center), a one-pint tin can and a second view of a trap cover in place (upper right).

Fig. V. B. 2 - A photograph of a pit-fall trap set for arthropod collection.

Fig. V. B. 3 - Photograph taken in August, 1970 showing the irradiator, the location of the pit-fall traps (center foreground), the foot paths (horizontally near traps) and several of the treatment sectors including the control (right side of irradiator), one chronic sector (right rear), the spring sector (left rear), the summer sector (left), and the late fall sector (foreground).

Fig. V. B. 4 - A schematic of a typical treatment sector showing the distances from the irradiator and the exposure rates.

The trapping period was 24 hours during most of the study except for some 48-hour trial periods early in 1969. Traps were set and collected in mid-morning so as to minimize the number of trapped insects subject to confinement in the cans during the hottest part of the day.

The ants (family Formicidae) were by far the most abundant insects trapped during the study. They made up 81.3, 77.0 and 69.7 percent of the total arthropods caught in 1969, 1970 and 1971 respectively. Although at least six ant species were taken (Table V. B. 1), most were Pogonomyrmex occidentalis.

Other major groups represented in these samples were the ground beetles (family Carabidae), the darkling beetles (family Tenebrionidae) and the spiders (order Araneae). For a complete taxonomic list of arthropods captured, see Table V. B. 1.

Behavioral responses to radiation by animals may be of two general types--those immediate responses in which the radiation is detected or sensed, and those responses which occur secondarily as a result of physical or physiological damage. Brower² described a behavioral change observed in an ant colony exposed to chronic gamma radiation and suggested that it could have been a direct radiation-avoidance response.

This experiment provided a check for possible radiation avoidance reactions by natural insect populations. Table V. B. 2 shows the total number of arthropods captured in the summer treatment and control sectors just prior to and immediately after initiation of the summer irradiation treatment. Exposure of the summer treatment area was begun on July 2nd with traps being set July 3rd and collected July 4th. The expected numbers of arthropods for the summer treatment sectors were calculated by multiplying the fraction for that date of the total number of arthropods caught in the control sector by the total number of arthropods caught in summer sector. The chi-square value (corrected for continuity) is 0.08. At the 5 percent level, with one degree of freedom, a chi-square of 12.71 or greater would be required to reject the hypothesis that the distribution of arthropods after initiation of irradiation was equal to the control. The substantial increase in number of arthropods (Table V. B. 2) in both the summer treatment and the control sectors from late June to early July reflects better trapping conditions on the later date.

Since there was essentially no change in the relative numbers of arthropods caught prior to and after initiation of treatment for the summer

²Brower, J. H. 1966. Behavioral Changes in an Ant Colony Exposed to Chronic Gamma Irradiation. Amer. Midl. Nat. 75(2): 530-534.

TABLE V.B. 1

Taxonomic list of arthropods captured in the gamma irradiation field.

ARACHNIDA

Araneae

Clubionidae
Gnaphosidae
Lycosidae
Thomisidae

INSECTA

Coleoptera

Cantharidae

Chauliognathus scutellaris

Carabidae

Amara convexa
Agonum sp.
Bembidion nitidum
Cratacanthus dubius
Cymindis planipennis
Discoderus parallelus
Evarthrus constrictus
Harpalus amputatus
Harpalus desertus
Harpalus funerarius
Harpalus opacipennis
Pasimachus elongatus
Piosoma setosum
Selenophorus planipennis
Stenolophus conjunctus

Cerambycidae

Prionus integer

Chrysomelidae

Cicindelidae

Curculionidae

Cleonus sp.
Culandrinus insighis
Gerstaeckeria basalis
Gerstaeckeria porosa
Graphorhina radosus

TABLE V. B. 1 (Continued)

Coleoptera

Curculionidae

Ophryastes suloirastris

Sphenophorus compressirostris

Histeridae

Saprinus sp.

Spilodiscus sp.

Meloidae

Meloe sp.

Scarabidae

Cheiroplatys pyriformis

Diplotaxis haydeni

Lachnosteinus sp.

Silphidae

Nicrophorus vespilloides

Tenebrionidae

Asidopsis opaca

Blapstinus sp.

Endrotes sp.

Eleodes extricata

Eleodes fusiformis

Eleodes hispilabris

Eleodes longicollis

Eleodes obscura

Eleodes obsoleta

Eleodes suturalis

Eleodes tricostata

Embaphion muricatum

Embaphion planum

Glyptasida sp.

Gonasida elata

Trimytis pruinus

Collembola

Hemiptera

Hymenoptera

TABLE V. B. 1 (Concluded)

Hymenoptera

Formicidae

Formica neogagates

Formica obtusopilosa

Formica sp.

Monomorium minimum

Myrmica americana

Pheidole pilifera coloradensis

Pogonomyrmex occidentalis

Mutillidae

Dasymutilla fulvohirta

Pseudomethoca propinqua

Orthoptera

Gryllidae

Table V. B. 2 - Total arthropods captured prior to and after initiation of summer irradiation treatment (7-2-69).

Treatment	Date Collected		Total	Percent Increase
	6-21-69	7-4-69		
Summer	84	201	285	139.3
Control*	124	310	434	150.0
Summer (expected)	81.4	203.6	285	---

*Combined data for the regular control area and the fall treatment area, which at the time of these trappings was not irradiated.

sector, one might wonder whether there was a redistribution within the treatment sectors. Table V. B. 3 shows the relative distribution by percent of total arthropods captured within three arbitrarily selected zones of the summer treatment prior to and just after initiation of exposure. There appeared to be no immediate change in the distribution of the arthropod community as a whole after two days with exposure rates ranging from about 0.01 to 650 R/hr.

Table V. B. 3 also illustrates an anomaly that appears in much of the trapping data for all three years; namely that proportionately more arthropods were captured near the irradiation source than at a distance from it. This result is consistent in many of the treatment sectors and in the control sectors for all three trapping seasons. An examination of the trapping data by species reveals that the single most abundant insect, Pogonomyrmex occidentalis is responsible for the apparent insect abundance near the radiation source. Figure V. B. 5 shows a composite of the 1969 trapping results from the control sector and the late fall irradiation sector (which also served as a non-irradiated control during the 1969 trapping season). According to Wheeler³, P. occidentalis does not forage from its nest in files and hence there are no paths radiating from the nest. My field observations, coupled with the results from one trap located in an old cattle path suggest that this ant does, however, make use of available and existing paths in its foraging trips. Near the radiation source the traps in all six sectors are necessarily located in the walkways (Fig. V. B. 3) between macroplots. But at greater distances from the radiation source the traps are located further and further from those walkways or paths. Thus, the apparent explanation for the anomaly in trapping results is not connected with radiation itself, but rather with the relative location of the traps and the walkways frequented by P. occidentalis.

The analyses for long term radiation induced effects on the arthropod populations were based on total yearly captures in each of the four treatment types. Arthropods were grouped according to the lowest practical taxonomic group that provided sufficient numbers for meaningful interpretation. For example, the relatively scarce spiders were grouped together and analyzed as the order Araneae, whereas the ubiquitous ant, P. occidentalis was considered alone.

A cursory examination of the trapping data suggested that the arthropod community was most responsive to the extreme irradiation intensities. Brower² found that radiation induced death of vegetation

³Wheeler, W. M. 1910. *Ants, Their Structure, Development and Behavior*. Columbia University Press, New York. 663 p.

Table V. B. 3. Distribution of arthropods captured in the summer irradiation treatment by percent of total.

<u>Macroplots</u>	<u>Range of Dose rates (R/hr)</u>	<u>Date</u>	
		<u>6-21-69</u>	<u>7-4-69</u>
1-7	650-28	59.5	63.2
8-15	18-7.2	16.7	16.4
16-22	0.41-0.01	23.8	20.4

Fig. V. B. 5 - Total arthropod distribution for the non-irradiated (control) sector in 1969.

was responsible for reductions in an ant population. Thus, for this study, radiation-induced zonation in the plant community (as described by Fraley¹) was used as a basis for selecting zones of comparison for the arthropods. Within each treatment sector the arthropod captures were arranged in two cells, those caught in the plant "lethal" zone and those caught in the first 10 macroplots of the "no effects" zone. Captures occurring in the "effects" zone between the previously mentioned zones were not considered. Also captures beyond the 10th macroplot of the "no effects" zone were omitted. It was felt that those traps were relatively far removed from the "lethal" zone and likely to represent somewhat different natural populations.

Counts of arthropods captured from similarly located zones in the control sector allowed the calculation of expected values for both treatment cells. A chi-square test (corrected for continuity) was applied to each treatment-year for each "population." The ratio of the observed to the expected number of captures in the "lethal" zone for the treatments has been plotted. The value of this ratio is that it expresses both the magnitude and the direction (increase or decrease) of any population change. Table V. B. 4 summarizes the data used in the following analyses.

The statistical significance⁴ of differences in the arthropod distribution between the treatment and control sectors does not necessarily imply a radiation response. It would be naive indeed to assume that the initial distribution of insects from two areas, however similar, would be identical. Yet, the magnitude of the differences indicated by the chi-square tests are valuable indicators of probable cause. Since all six sectors were treated alike except for irradiation, the relative year to year changes were assumed to be radiation induced.

The following discussion on the response of various arthropod "populations" to radiation is augmented by casual descriptions of the status of the plant community. For a detailed presentation of the changes in the plant community, see Fraley¹.

The ground beetles (family Carabidae) were considered as a unit. Although this family is generally considered to be carnivorous, the major groups represented on the prairie uplands (Harpalini and Amarini) are largely herbivorous⁵. One of the plots in Fig. V. B. 6⁶ shows the relative

⁴Statistical significance as reported in this paper refers to chi-square values at $P = .95$ or above.

⁵Bell, R. T. 1971. Carabidae (Ground Beetles). U. S. Int. Biol. Prog., Grassland Biome, Tech. Rep. No. 66. Colorado State Univ. 58 p.

⁶Points in plots of relative abundance of the various arthropod groups represented by stars correspond to statistically significant ($\alpha = 0.05$) chi-square values obtained from Table V. B. 4.

Table V. B. 4 A summary of the pit-fall trapping data for 1969, 1970 and 1971.

Group	Treatment	Year	O_1^a	E_1^b	O_n^c	E_n^d	χ^2^e	P^f	O_1/E_1
Carabidae	Chronic	1969	12	9.7	28	30.3	0.44	---	1.24
	Chronic	1970	12	15.4	28	24.6	0.89	---	0.78
	Chronic	1971	8	5.0	11	14.0	1.70	---	1.60
	Spring	1969	10	5.2	9	13.8	4.90	0.973	1.92
	Spring	1970	7	6.5	20	20.5	0	---	1.08
	Spring	1971	12	8.5	24	27.5	1.39	---	1.41
	Summer	1970	6	5.0	10	11.0	0.07	---	1.20
	Summer	1971	11	5.1	9	14.9	7.67	0.994	2.16
	Fall	1970	6	5.7	10	10.3	0	---	1.05
	Fall	1971	10	6.1	18	21.9	2.42	---	1.64
Araneae	Chronic	1969	9	15.9	69	62.1	3.24	---	0.57
	Chronic	1970	10	11.1	38	36.9	0.04	---	0.90
	Chronic	1971	3	6.8	41	37.1	0.31	---	0.44
	Spring	1969	9	9.3	27	26.7	0	---	0.97
	Spring	1970	6	6.2	15	14.8	0.01	---	0.97
	Spring	1971	9	4.9	14	18.1	3.36	0.933	1.84
	Summer	1969	8	5.7	14	16.3	0.77	---	1.42
	Summer	1970	4	5.8	25	23.2	0.07	---	0.69
	Summer	1971	11	6.0	23	28.0	4.10	0.957	1.83
	Fall	1970	7	6.8	26	26.2	0.02	---	1.03
	Fall	1971	8	5.1	15	17.9	1.45	---	1.57

a) O_1 - observed number of individuals captured in the plant "lethal" zone

b) E_1 - expected number of individuals from the plant "lethal" zone

c) O_n - observed number of individuals captured in the plant "no effects" zone

d) E_n - expected number of individuals from the plant "no effects" zone

e) χ^2 - with one degree of freedom (corrected for continuity)

f) P - probability value associated with the calculated χ^2 when greater than 0.90 (three asterisks represent a P value of 0.999 or greater)

Table V. B. 4 (Concluded)

<u>Group</u>	<u>Treatment</u>	<u>Year</u>	<u>O₁^a</u>	<u>E₁^b</u>	<u>O_n^c</u>	<u>E_n^d</u>	<u>χ^{2e}</u>	<u>P^f</u>	<u>O₁/E₁</u>
<u>Pogonomyrmex</u>									
<u>occidentalis</u>	Chronic	1969	83	136.6	174	120.4	44.10	***	0.61
	Chronic	1970	132	145.9	131	117.1	2.76	0.903	0.90
	Chronic	1971	101	86.1	94	108.9	4.31	0.962	1.17
	Spring	1969	87	124.5	127	89.5	26.29	***	0.70
	Spring	1970	126	104.3	66	87.7	9.43	0.998	1.21
	Spring	1971	52	40.8	42	53.2	4.96	0.974	1.27
	Summer	1969	66	56.4	31	40.6	3.51	0.939	1.17
	Summer	1970	182	151.6	97	127.4	12.91	***	1.20
	Summer	1971	65	38.2	23	49.8	32.00	***	1.70
	Fall	1970	228	112.7	25	140.3	210.87	***	2.02
	Fall	1971	106	85.6	130	150.4	7.26	0.993	1.24
<u>Myrmica</u>									
<u>americana</u>	Chronic	1969	36	104.9	145	76.1	106.08	***	0.34
	Chronic	1970	7	52.6	96	50.4	79.03	***	0.13
	Chronic	1971	4	34.2	43	12.8	94.71	***	0.12
	Spring	1969	6	38.7	62	29.6	61.17	***	0.15
	Spring	1970	2	14.2	29	16.8	17.79	***	0.14
	Summer	1969	5	20.9	32	16.1	26.08	***	0.23
	Summer	1970	4	15.1	29	17.9	13.72	***	0.26
	Summer	1971	5	18.8	20	6.2	37.94	***	0.27
	Fall	1970	3	7.1	20	15.9	2.64	---	0.42

Fig. V. B. 6 - Relative abundance of the ground beetles (family Carabidae) in the chronic and seasonal irradiation treatment areas. (Stars represent ratios in which chi-square tests show significantly [$\alpha = 0.05$] different distributions from control sector.)

response of the ground beetles in the plant "lethal" zone of the chronic sectors. By the end of the 1969 trapping season, and continually thereafter, all vegetation had been killed. Although there is some year to year fluctuation in relative numbers, the differences are not statistically significant. Perhaps the most noteworthy point is that there has been no avoidance of the area in spite of the fact the plants have been killed and that the chronic irradiation is extreme. The Carabids thus exhibited no primary or secondary negative radiation response to chronic exposure.

In the spring sector nearly twice the expected number of ground beetles were captured in 1969 (Fig. V. B. 6). The above ground vegetation was initially killed back with some regrowth of perennials by the end of the trapping season. The cause of this apparent preference for the irradiated area remains obscure. In 1970 and 1971 the Carabids showed only a slight (but not significant) affinity for the spring irradiated sector. The plant recovery was dominated by invading annuals in both the spring and summer sectors (Fig. V. B. 7).

Too few Carabids were captured after the initiation of the summer treatment to allow tests for the 1969 season. For 1970 the result is similar to the spring treatment sector. The relative abundance for 1971 is significantly greater than expected.

Little or no plant recovery during 1970 (Fig. V. B. 3) from the late fall sector seems to have left the ground beetle "population" unaffected that year (Fig. V. B. 6). The similarity in response for both this sector and the chronic sector in 1970 again points to a lack of any radiation avoidance response. Some relative increase in Carabids during 1971 may be associated with plant recovery beginning that year. However, it should be restated at this point that abundances given are relative to the control sector population. A chance occurrence of fewer individuals being captured one year in the control plot would appear as a relative increase in the treatment sectors. The plotted points for the Carabidae in 1971 suggest that this may have occurred. Thus the occurrence of any secondary response to radiation by the Carabidae seems uncertain.

The spiders (order Araneae) are predaceous. Their response (Fig. V. B. 8) to chronic and semi-chronic irradiation was relatively low level. Although the population in the chronic sectors was consistently lower than the expected value, the difference was not statistically significant. During 1970 the relative abundance of the spiders in all three semi-chronic treatment areas was normal.

Fig. V. B. 7 - Photograph taken in August, 1970, showing the denuded chronic treatment area (left of the irradiator), the recovering spring (foreground) and summer (right of irradiator) sectors.

RELATIVE ABUNDANCE - ARANEAE

Fig. V. B. 8 - Relative abundance of the spiders (order Araneae) in the chronic and seasonal irradiation treatment areas. (Stars represent ratios in which chi-square tests show significantly [$\alpha = 0.05$] different distributions from control sector.)

Recall that at this time the spring and summer treatment sectors were showing vigorous plant recovery while in the fall sectors the vegetation consisted mainly of the previous years' standing dead and litter. A trend of increased relative numbers of spiders in 1971 for all three semi-chronic treatments occurred. Only the summer treatment area showed a significant increase. Thus there is an implication that the predaceous spiders have an affinity for the second year successional stages following seasonal irradiation. It seems somewhat peculiar that increased numbers were not observed in the luxuriant recovery growth of 1970, but if the 1971 increase resulted from higher carrying capacity rather than immigration, the one-year lag is understandable.

The responses of the western harvester ant (Pogonomyrmex occidentalis) to both chronic and semi-chronic seasonal irradiation were striking. The trapping results from the chronically exposed sectors (Fig. V. B. 9) show significantly fewer of these ants captured in 1969, "normal" numbers in 1970, and significantly greater than expected numbers in 1971. This seemingly nonsensical pattern can be readily resolved if considered in terms of the natural behavior patterns of this ant. From the end of the 1969 through the 1971 trapping seasons the plant cover in the chronic lethal zone was reduced from standing dead plus litter to a barren condition. Thus the clearing of all plant remains through time perhaps made the chronic lethal zone increasingly attractive as an avenue for this foraging ant. Also the proximity of spring treatment area (which became attractive to this ant during the 1970 and 1971 plant recovery stages [Fig. V. B. 7]) probably provided the motivation to use the area. Another factor that could have contributed to the relative increase in harvester ants captured in the chronic areas was the formation of a new colony in the "effects" zone just beyond the "lethal" zone. This colony was first observed in mid-summer of 1970 and increased its mound size through the 1971 season.

The similarity in response of this ant during 1969 to chronic and spring treatment (Fig. V. B. 9) clearly points to modifications in the plant community rather than radiation as the causal factor. Through 1969 the zones of comparison for the chronic and spring sectors were nearly identical in terms of vegetative effect; namely, total lethality resulting in only a standing dead crop. However, radiation was continual in the chronic area and absent through most of the trapping season (May through September) in the spring treatment.

The positive response of P. occidentalis during the first year of plant recovery (1970) for the seasonal treatments suggests that the ants were attracted to these areas. This is contrary to the results reported above for the predaceous spiders, but logical in regard to this ant's foraging habit.

Fig. V. B. 9 - Relative abundance of the Western harvester ant (*Pogonomyrmex occidentalis*) in the chronic and seasonal irradiation treatment areas. (Stars represent ratios in which chi-square tests show significantly [$\alpha = 0.05$] different distributions from control sector.)

The unusually high relative abundance in the late fall sector for 1970 resulted mainly from the presence of a single annual plant (Chenopodium sp.) located along the mid-line radius near the irradiation source in sector 6 (Fig. V. B. 3). Again in 1971 for all seasonal treatments the abundance of harvester ants was significantly higher than in the control area.

The second most abundant insect captured at the irradiation facility was also an ant, Myrmica americana. Figure V. B. 10 shows an altogether different response pattern for this ant than for the western harvester ant. The relative numbers collected were extremely low in all treatments for all years. In fact, the missing data points from spring and late fall treatments in 1971 resulted from too few captures to permit chi-square calculations. The total lack of any positive response to successional plant growth following cessation of irradiation indicates that these ants may be associated in some way with plants that were originally present in the treatment sectors, but not among the early invaders. Dr. Theodore Thatcher, who is with the Colorado State University Entomology Department, observed (personal communication) ants of the genus Myrmica associated with grass root aphids in the vicinity of this study area. Also Wheeler and Wheeler⁷ reported observing these ants feeding on plant exudates, damaged fruits, dead insects, as well as being "found with aphids on the roots of grass." Although the degree of association with grass root aphids is unknown, a substantial dependence by these ants upon the aphids could explain the very low numbers of M. americana subsequent to irradiation. The grasses were among those plants that did not show recovery or revegetation in the treatment areas.

In summary, pit-fall trapping was carried out for three seasons to obtain information on the response of natural arthropod populations to external gamma irradiation. No indication of any recognition of, or avoidance response to radiation was obtained from the arthropods as a whole nor from the several groups considered separately. Rather complex and varied long term responses were observed. These appear to be secondary responses linked to the arthropod groups through their behavior patterns and trophic relationships.

⁷Wheeler, G. C. and Jeanette Wheeler. 1963. The Ants of North Dakota. University of North Dakota Press, Grand Forks. 326 p.

RELATIVE ABUNDANCE MYRMICA AMERICANA

Fig. V. B. 10 - Relative abundance of the ant, *Myrmica americana* in the chronic and seasonal irradiation treatment areas. (Stars represent ratios in which chi-square tests show significantly [$\alpha = 0.05$] different distributions from control sector.)

V. C. Soil Microorganisms

D. A. Klein and F. W. Whicker

In a preliminary attempt to survey microbial populations inhabiting the soil within the chronic irradiation sector at the grassland radiation site, soil cores were sampled on October 18, 1971. Six cores, each 20 cm deep and 6.5 cm in diameter were taken across the irradiation gradient. The first two samples were taken nearest the source in an area which has been totally denuded of higher plants by the radiation for over two years. The next two samples were taken further from the source in a zone which has been partially affected by radiation¹. The last two samples were taken still further out from the source in a zone in which no radiation effects on the higher plant community have been observed.

The soil cores were carefully taken with 6.5 cm diameter corers and sealed in polyethylene bags. The cores were immediately transported to the laboratory, where they were sectioned in 5 cm depth increments. Weighed aliquots of soil were thoroughly shaken with buffered sterile water. Appropriate decimal dilutions were prepared from the suspension and aliquots of the dilutions were plated directly on sodium caseinate agar for total bacteria and actinomycetes, and on rose bengal agar for enumeration of fungi. Following incubation at 25°C for 5 days, the plates were examined and the number of colonies were recorded. Three replicates of each dilution were prepared and data from each replicate were averaged.

Results for bacteria, actinomycetes and fungi are given in Table V. C. 1. In some cases, considerable variation in microbe numbers existed between soil depths, although no one soil horizon was consistently higher or lower than the others, except for bacteria. From Fig. V. C. 1 it appears that both actinomycetes and fungi are significantly depressed in the first two plots, while bacteria, if anything, increase near the source. This suggests that some soil bacteria are more resistant to radiation or its secondary effects on other ecosystem components, than actinomycetes and fungi. This observation corroborates the findings of Kashkina and Abaturov² concerning the relative radiosensitivities of bacteria, fungi and actinomycetes. On the

¹Fraley, L., Jr. 1971. Response of shortgrass plains vegetation to chronic and seasonally administered gamma radiation. Ph.D. Thesis. Colorado State University, Fort Collins. 170 p.

²Kashkina, G. B. and Yu. D. Abaturov. 1967. The survival of soil microorganisms upon gamma irradiation of the soil. AEC-tr-6887. U. S. Atomic Energy Commission, Translation of Radiobiologiya VII (2): 170-174

Table V. C. 1. Results of plate counts for soil microorganisms in the grassland irradiation field as of October 18, 1971. Chronic irradiation initiated 4/1/69.

Sample No.	Distance from source (m)	Chronic exposure rate at soil surface (r/hr)	Soil depth (cm)	Plate counts (cells / g dry soil)		
				Bacteria	Actinomycetes	Fungi
1-1	3	315	0-5	1.4×10^7	4×10^5	5.2×10^3
1-2			5-10	1.3×10^7	3×10^5	4×10^2
1-3			10-15	1.6×10^7	2×10^5	1×10^2
			mean	1.4×10^7	3×10^5	1.9×10^3
2-1	6	68	0-5	9.4×10^6	---	2.2×10^3
2-2			5-10	1.0×10^6	6.6×10^5	4×10^2
2-3			10-15	1.2×10^6	9.3×10^5	1.0×10^3
			mean	3.9×10^6	5.3×10^5	1.2×10^3
3-1	9	18	0-5	6.9×10^6	2.3×10^6	1.0×10^4
3-2			5-10	3.0×10^6	1.7×10^6	2.7×10^4
3-3			10-15	5.1×10^6	3.3×10^6	3.2×10^4
			mean	5.0×10^6	2.4×10^6	2.3×10^4
4-1	12.8	4.8	0-5	5.4×10^7	8.0×10^6	6.0×10^4
4-2			5-10	3.1×10^6	2.2×10^6	3.1×10^4
4-3			10-15	7.0×10^6	3.3×10^6	3.1×10^4
			mean	2.1×10^7	4.5×10^6	4.1×10^4
5-1	20.5	0.72	0-5	9.5×10^6	2.7×10^6	4.1×10^4
5-2			5-10	3.3×10^6	2.5×10^6	4.2×10^4
5-3			10-15	7.2×10^6	3.6×10^6	1.9×10^4
			mean	6.7×10^6	2.9×10^6	3.4×10^4
6-1	30	0.11	0-5	4.0×10^6	3.4×10^6	1.9×10^4
6-2			5-10	3.7×10^6	2.5×10^6	1.2×10^4
6-3			10-15	6.8×10^6	3.8×10^6	1.3×10^4
			mean	4.9×10^6	3.2×10^6	1.5×10^4

Fig. V. C. 1 - Abundance of grassland soil micro-organisms across the chronic gamma irradiation gradient as of October 18, 1971. Points represent mean of plate counts from three soil depth horizons (0-5, 5-10, and 10-15 cm) within each core sampled. Dose rates indicated are measured at the soil surface. Chronic irradiation was initiated April 1, 1969.

other hand, Kashkina and Abaturov³ reported an increase in soil bacteria and a decrease in soil fungi at a chronic gamma exposure rate of 0.1-0.25 r/hr and a decrease in all soil microflora at 4-6 r/hr. Our data do not suggest any significant reductions in microbial populations at exposure rates less than 18 r/hr.

Earlier observations concerning the apparent persistence of dead plant root and crown matter near the source suggested possible soil sterilization. These data, however, shed some doubts upon that postulation. Perhaps the prevailing xeric condition of the soil is, more than anything else, preventing the rapid decay of dead roots and crowns near the source. Of course, it is also possible that the 10-fold reduction in fungi and actinomycetes near the source is contributing to the persistence of dead plant matter, especially as fungi are the chief source of phenyloxidase-related enzymes responsible for initial steps in lignin degradation. Respiration measurements on soil core aliquots did not suggest any marked reduction of activity with increased chronic radiation exposure levels.

It appears from these pilot studies, that significant microbiological changes have occurred within the radiation field. More detailed studies with better control and replication are definitely indicated inasmuch as the literature on this subject is very scant. Relative microbe sensitivities through the year, as well as diversity measurements would be extremely interesting.

³Kashkina, G. B. and Yu. D. Abaturov. 1969. Influence of chronic irradiation of the microflora of the soil of a gamma field. AEC-tr-7026. U. S. Atomic Energy Commission, Translation of Radiobiologiya IX (3): 185-188.

V. D. Soil Chemistry
F. W. Whicker and D. A. Klein

On October 18, 1971, six 6 cm diameter x 20 cm deep soil cores were taken in chronic irradiation sector 2 at various distances from the ^{137}Cs source at the grassland radiation site. The cores were studied for soil microorganisms, with separate aliquots being withheld for chemical analysis. Each core was sectioned into three depth horizons (0-5 cm, 5-10 cm, and 10-15 cm). The soil samples were submitted to the Soil Testing Laboratory at Colorado State University for routine analysis for organic matter, available phosphorus, nitrate, potassium, zinc and iron. We measured relative dry root mass gravimetrically. This study was intended as a pilot effort to guide future efforts, and since no replicate samples were taken, the results can only be construed as tentative.

The analytical results are summarized in Table V. D. 1. In nearly all cases, the 0-5 cm horizon was considerably higher in nutrients and organic matter than the deeper horizons. This indicates that the specific depth measured in subsequent sampling must be rigorously defined and obtained with care. If one plots the mean nutrient concentrations versus the chronic exposure rate, it appears that phosphorus and potassium values increase near the source as radiation exposure increases. Iron seems to be depressed at the highest exposure level, while no discernable trend exists for zinc or organic matter. Nitrate seems to increase markedly as one approaches the source, then decreases drastically at the highest exposure.

Of general interest, and of possible significance, is the comparative abundance of nutrients in the two soil samples receiving the highest radiation exposures. These samples were within the zone where the radiation had been completely lethal to the higher plant community and where the soil surface was completely denuded, except for remnant dead plant crowns¹. One might postulate that nutrients once maintained in the vegetative biomass were released to the soil following death of the higher plants. Soil bacteria and the semi-arid climate may be acting to prevent nutrient depletion of these soils by leaching processes.

The kinds and numbers of soil microorganisms may also have considerable influence upon the soil chemistry, and this question will likely

¹Fraley, L. Jr. 1971. Response of shortgrass plains vegetation to chronic and seasonally administered gamma radiation. Ph. D. Thesis. Colorado State University, Fort Collins. 170 p.

Table V. D. 1 Dry root mass, organic matter, and available nutrients in soil cores taken in a chronic irradiation sector at the Pawnee Site, October 18, 1971*.

Sample	Surface Dose rate (r/hr)	Sample Depth (cm)	Dry root mass (%)	Organic matter (%)	P (ppm)	NO ₃ (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)
1	315	0-5	1.74	1.2	29	4.3	317	2.6	21
2		5-10	0.39	0.7	24	3.3	263	0.4	15
3		10-15	0.15	0.5	21	4.6	268	0.2	12
		mean	0.76	0.8	25	4.1	283	1.0	16
4	68	0-5	0.71	1.3	22	91	288	1.2	30
5		5-10	0.34	0.7	16	18	177	0.3	15
6		10-15	0.18	0.8	17	22	203	0.2	13
		mean	0.41	0.9	19	43	223	0.6	19
7	18	0-5	0.34	1.0	27	13	238	0.7	24
8		5-10	0.30	0.7	17	4.0	218	0.2	19
9		10-15	0.05	0.7	16	5.4	228	0.2	18
		mean	0.23	0.8	20	7.5	228	0.4	20
10	4.8	0-5	1.35	1.9	21	35	317	2.9	31
11		5-10	0.32	0.7	13	5.6	182	0.3	14
12		10-15	0.16	0.6	11	6.0	167	0.3	12
		mean	0.61	1.1	15	16	222	1.1	19

*Organic matter and chemical constituents determined by the Soil Testing Laboratory, Colorado State University.

Table V. D. 1. (Concluded)

Sample	Surface Dose rate (r /hr)	Sample Depth (cm)	Dry root mass (%)	Organic matter (%)	P (ppm)	NO ₃ (ppm)	K (ppm)	Zn (ppm)	Fe (ppm)
13	0.72	0-5	0.58	0.9	18	14	192	1.2	26
14		5-10	0.21	0.6	11	2.6	152	0.1	17
15		10-15	0.17	0.7	15	3.3	203	0.2	14
		mean	0.32	0.7	15	6.5	182	0.5	19
16	0.11	0-5	0.59	1.0	16	9.0	143	1.9	25
17		5-10	0.62	0.7	13	1.6	100	0.4	21
18		10-15	0.17	0.6	10	2.6	123	0.2	16
		mean	0.46	0.8	13	4.4	122	0.8	21

be investigated more fully. Another aspect which should be followed is the longer-term nutrient profile. After several more years, the nutrients may be leached into deeper soil horizons if rains of sufficient duration occur.

VI. FOOD WEBS AND FEEDING RATES OF
GRASSLAND ARTHROPODS

VI. Food Webs and Feeding Rates of Grassland Arthropods
L. L. Cadwell and F. W. Whicker

The food web studies of native grassland arthropods initiated in 1970 using radiotracers was not continued in 1971. A review of the first year's results indicated that increased manpower, more equipment and new techniques would be necessary to adequately determine the major arthropod trophic relationships. It was not felt that these expenditures could be met and still continue the feeding rate and radiation effects phases of the grassland arthropod study.

The radiotracer experiments to determine the feeding rates of two grasshopper species (Arphia conspersa and Arphia pseudonietana) on the shortgrass prairie of Colorado were continued. Both laboratory and field work was carried out to obtain estimates of the parameters Q , a , λ , and C for the following relationship:

$$Q = \frac{ICa}{\lambda}$$

Where Q is the body burden at steady state; C is the activity density of the food; a is the fraction of the nuclide assimilated; λ is the effective loss constant; and I is the ingestion rate.

Blue gramma (Bouteloua gracilis), an important rangeland grass, was labeled with ^{32}P for both field and laboratory feeding. Adult grasshoppers were captured from the field study site.

Chronic feeding on labeled grass was allowed to determine equilibrium body burdens under natural conditions (field enclosures). Acute ingestion studies were carried out under various controlled light and temperature conditions in order to estimate the importance of some environmental factors on food consumption. The grasshoppers were periodically whole body counted with shielded G. M. counters. Also the weights of individual grasshoppers were recorded so that ingestion rates may be expressed per unit biomass. A series of computer programs is being adapted to perform the tedious correction calculations for counter efficiency, background and physical decay. The computer program will also strip and plot excretion and build-up curves and calculate the associated slope and intercept values.

In general, retention time was found to be inversely related to temperature as expected. Excretion from acute ingestion showed a two component loss curve.

More information is needed on the range of temperature extremes that affect feeding rates of these grasshoppers. Also a field determination of the amount of forage destroyed but not consumed by these insects is planned to help evaluate their total impact upon the plant community. Some reruns are also planned for equilibrium value determinations that showed unexpected patterns last year.

VII. LIST OF PUBLICATIONS

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

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

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

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

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

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

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

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

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

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

- Farris, G. C., F. W. Whicker, and A. H. Dahl. 1967. Effect of age on radioactive and stable strontium accumulation in mule deer bone, p. 93-102. In J. M. A. Lenihan, J. F. Loutit, and J. H. Martin (Ed.). Strontium Metabolism, Academic Press, London. (COO-1156-17)
- Whicker, F. W., G. C. Farris, and A. H. Dahl. 1968. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards, p. 1105-1110. In W. S. Snyder (Ed.). Radiation Protection, Pergamon Press, New York. (COO-1156-18)
- Remmenga, E. E. and F. W. Whicker. 1967. Sampling variability in radionuclide concentrations in plants native to the Colorado Front Range. Health Physics 13: 977-983. (COO-1156-19)
- Whicker, F. W. and C. M. Loveless. 1968. Relationships of physiography and microclimate to fallout deposition. Ecology 49(2): 363-366. (COO-1156-20)
- Nelson, W. C. and F. W. Whicker. 1969. Cesium-137 in some Colorado game fish, 1965-66, p. 258-265. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-21)
- Farris, G. C., F. W. Whicker, and A. H. Dahl. 1969. Strontium-90 levels in mule deer and forage plants, p. 602-608. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-23)
- Hakonson, T. E. and F. W. Whicker. 1969. Uptake and elimination of cesium-134 by mule deer, p. 616-622. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-24)
- Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M. S. Thesis. Colorado State University, Fort Collins. 121 p. (COO-1156-25)
- Farris, G. C. 1967. Factors influencing the accumulation of strontium-90, stable strontium, and calcium in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins, 189 p. (COO-1156-26)

- Hakonson, T. E. and F. W. Whicker. 1971. Tissue distribution of radiocesium in the mule deer. *Health Physics* 21(6): 864-866. (COO-1156-27)
- Hakonson, T. E. and F. W. Whicker. 1971. The contribution of various tissues and organs to total body mass in the mule deer. *J. Mammalogy* 52(3): 628-630. (COO-1156-29)
- Gist, C. S. 1969. Iodine-131 retention in mule deer. M. S. Thesis. Colorado State University, Fort Collins. 75 p. (COO-1156-31)
- Markham, O. D. and F. W. Whicker. 1970. Radiation LD50₍₃₀₎ of pikas (Ochotona princeps) in the natural environment and in captivity. *Am. Midland Naturalist*. 84(1): 248-252. (COO-1156-32)
- Markham, O. D., F. W. Whicker, and R. M. Hansen. 1970. Radiation LD50₍₃₀₎ of Richardson ground squirrels. *Health Physics* 18(6): 731-732. (COO-1156-33)
- Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph. D. Dissertation. Colorado State University, Fort Collins. 342 p. (COO-1156-34)
- Nagy, J. G., T. E. Hakonson, and K. L. Knox. 1969. Effects of food quality on food intake in deer. *Trans. 34th North Am. Wild. and Natural Resources Conf.* 34: 146-154.
- Allredge, A. W. 1971. Those bottle fawns. *Colorado Outdoors* 20(3): 19-21. (COO-1156-36)
- Gallegos, A. F., F. W. Whicker, and T. E. Hakonson. 1971. Accumulation of radiocesium in rainbow trout via a non-food chain pathway. *Proceedings, Fifth Ann. Midyear Topical Symposium, Health Phys. Soc., Health Physics Aspects of Nuclear Facility Siting II*: 477-498. (COO-1156-37)
- Gist, C. S. and F. W. Whicker. 1971. Radioiodine uptake and retention by the mule deer thyroid. *J. Wildlife Mgmt.* 35(3): 461-468. (COO-1156-38)
- Whicker, F. W., W. C. Nelson, and A. F. Gallegos. Fallout ¹³⁷Cs and ⁹⁰Sr in trout from Colorado's mountain lakes. *Health Physics*. In Press (COO-1156-39).

- Hakonson, T. E., A. F. Gallegos and F. W. Whicker. Use of ^{133}Cs and activation analysis for measurement of cesium kinetics in a montane lake. Proceedings, Third National Symposium on Radioecology, May, 1971, Oak Ridge, Tenn. In Press (COO-1156-41).
- Gallegos, A. F. and F. W. Whicker. Radiocesium retention by rainbow trout as affected by temperature and weight. Proceedings, Third National Symposium on Radioecology, May 1971, Oak Ridge, Tenn. In Press (COO-1156-42).
- Markham, O. D. and F. W. Whicker. Intraspecific competition and response of pikas (*Ochotona princeps*) to radiation. Proceedings, Third National Symposium on Radioecology, May 1971, Oak Ridge, Tenn. In Press (COO-1156-43).
- Fraley, L., Jr. and F. W. Whicker. Response of a native shortgrass plant stand to ionizing radiation. Proceedings, Third National Symposium on Radioecology, May 1971, Oak Ridge, Tenn. In Press (COO-1156-44).
- Fraley, L., Jr. 1971. Response of shortgrass plains vegetation to chronic and seasonally administered gamma radiation. Ph.D. Thesis. Colorado State University, Fort Collins. 170 p. (COO-1156-45).
- Schultz, V. and F. Ward Whicker. 1971. A selected bibliography of terrestrial, freshwater and marine radiation ecology. USAEC Report TID-25650. USAEC Division of Technical Information Extension. Oak Ridge, Tenn. 185 p. (COO-1156-46).
- Adams, C. E., D. Lund and D. Markham. 1971. A chromosome study of the pika, *Ochotona princeps*. Mammalian chromosomes Newsletter 12(3): 77-78 (COO-1156-47).
- Markham, O. D. 1971. Effects of ^{60}Co radiation and social interaction on the pika (*Ochotona princeps*). Ph.D. Thesis. Colorado State University, Fort Collins. 51 p. (COO-1156-48).
- Markham, O. D. and F. W. Whicker. Burrowing in the pika. J. Mammalogy. In Press (COO-1156-49).
- Markham, O. D. Observations on an aggressive blue grouse. Colo. Field Ornithologist. In Press (COO-1156-50).
- Markham, O. D. and F. W. Whicker. Seasonal data on reproduction and body weights of pikas (*Ochotona princeps*). Submitted to J. Mammalogy (COO-1156-51).

Markham, O. D. and F. W. Whicker. Notes on the ecology of the pika (*Ochotona princeps*) in captivity. Am. Midl. Naturalist. In Press (COO-1156-52).

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

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

VIII. LIST OF ORAL PRESENTATIONS

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

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

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

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

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

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

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

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1966. Concentration patterns of Sr-90, Cs-137, and I-131 in a wild deer population and environment. Presented at the Symposium on Radioecological Concentration Processes, April 25-29, 1966, Stockholm, Sweden. (COO-1156-13)

Farris, G. C., F. W. Whicker, and A. H. Dahl. Effect of age on radioactive and stable strontium accumulation in mule deer. Presented at the International Symposium on Some Aspects of Strontium Metabolism, May 5-6, 1966, Chapelcross, Scotland. (COO-1156-17)

- Whicker, F. W., R. A. Walters, and A. H. Dahl. Fallout radionuclides in Colorado deer livers. Eleventh Annual Meeting, Health Physics Society, June 27-30, 1966, Houston, Texas. P/79.
- Whicker, F. W., G. C. Farris, and A. H. Dahl. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards. Presented at the First International Congress of IRPA, September 5-10, 1966, Rome, Italy. (COO-1156-18)
- Nelson, W. C. and F. W. Whicker. Cesium-137 concentrations in some Colorado game fish, 1965-66. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/54. (COO-1156-21)
- Farris, G. C., F. W. Whicker, and A. H. Dahl. Strontium-90 levels in mule deer and forage plants. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/42. (COO-1156-23)
- Hakonson, T. E. and F. W. Whicker. Uptake and elimination of cesium-134 by mule deer. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/44. (COO-1156-24)
- Hakonson, T. E. Uptake and elimination of cesium-134 by mule deer. Presented at the Institute of Arctic Biology, University of Alaska, College, Alaska, March 22, 1968.
- Farris, G. C., F. W. Whicker, and A. H. Dahl. Factors influencing the accumulation of Sr-90, stable strontium and calcium in mule deer. Presented at the Thirteenth Annual Meeting, Health Physics Society, June 16-20, 1968, Denver, Colorado. P/114.
- Whicker, F. W. and C. M. Loveless. Relationships of physiography and microclimate to fallout deposition. Presented at the AAAS-Ecological Society Meeting, June 24-29, 1968, Logan, Utah. P/36.
- Gallegos, A. F. Curve fitting of biological models to ingrowth type equations. Presented April 26, 1969 at the Student Conference, American Nuclear Society, University of New Mexico, Albuquerque.
- Gist, C. S. and F. W. Whicker. Radioiodine retention in mule deer. Presented May 9, 1969 at the AAAS-Colorado Wyoming Academy of Science Meetings, Colorado Springs, Colorado. P/204.

Gallegos, A. F. Radiocesium kinetics in a montane lake ecosystem. Presented May 10, 1969 at the AAAS-Colorado Wyoming Academy of Science Meetings, Colorado Springs, Colorado. P/240.

Whicker, F. W. Investigations in radioecology at Colorado State University. Presented June 6, 1969 at the Institute of Arctic Biology, University of Alaska, College.

Fraley, L. Response of a shortgrass plains community to ionizing radiation. Presented October 24, 1969 at the IBP Pawnee Site Research Seminar. Southern Colorado State College, Pueblo, Colorado.

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