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Long-Term Ecological Effects of Exposure to Uranium

by

Wayne C. Hanson
Felix R. Miera, Jr.

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

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CONTENTS

Abstract

I. Introduction 1

II. The LASL Area 2

III. LASL Uranium Study Sites 3

IV. Methods 3

A. Sample Collection 3

B. Sample Analyses 6

C. Comparison of Eberline and LASL Chemical Analyses of Soil Uranium 6

V. Results and Discussion 7

A. Uranium Concentrations in EAFB Soil Samples 7

B. Uranium Concentrations in LASL Soil Samples 8

C. Uranium Concentrations in LASL Biota 11

VI. Biotic Survey of LASL Study Sites 13

A. Plant Community Analysis at the Study Sites 13

B. Small Mammal Populations Associated with the Plant Communities 19

C. Small Macrofauna of Soil and Litter at LASL Study Sites 22

1. Populations and Characteristics 22

2. Abundance of Various Species and Groups in Test and Control Areas 23

VII. Summary and Conclusions 24

Acknowledgments 24

References 25

Appendix A. LASL Uranium Study Sites 26

Appendix B. Results of Uranium Analyses of Soil Samples 28

Appendix C. Quality Control Data for LASL Uranium Analyses 34

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ABSTRACT

The consequences of releasing natural and depleted uranium to terrestrial ecosystems during development and testing of depleted uranium munitions were investigated. At Eglin Air Force Base, Florida, soil at various distances from armor plate target butts struck by depleted uranium penetrators was sampled. The upper 5 cm of soil at the target bases contained an average of 800 ppm of depleted uranium, about 30 times as much as soil at 5- to 10-cm depth, indicating some vertical movement of depleted uranium. Samples collected beyond about 20 m from the targets showed near-background natural uranium levels, about 1.3±0.3 µg/g or ppm.

Two explosives-testing areas at the Los Alamos Scientific Laboratory (LASL) were selected because of their use history. E-F Site soil averaged 2400 ppm of uranium in the upper 5 cm and 1600 ppm at 5-10 cm. Lower Slobovia Site soil from two subplots averaged about 2.5 and 0.6% of the E-F Site concentrations. Important uranium concentration differences with depth and distance from detonation points were ascribed to the different explosive tests conducted in each area.

E-F Site vegetation samples contained about 320 ppm of uranium in November 1974 and about 125 ppm in June 1975. Small mammals trapped in the study areas in November contained a maximum of 210 ppm of uranium in the gastrointestinal tract contents, 24 ppm in the pelt, and 4 ppm in the remaining carcass. In June, maximum concentrations were 110, 50, and 2 ppm in similar samples and 6 ppm in lungs. These data emphasized the importance of resuspension of respirable particles in the upper few millimeters of soil as a contamination mechanism for several components of the LASL ecosystem.

I. INTRODUCTION

An estimated 75 000-100 000 kg of uranium was expended during conventional explosive tests at several Los Alamos Scientific Laboratory (LASL) testing areas during 1949-1970. Of this, about 35 000-45 000 kg of natural uranium was used during 1949-1954, and 40 000-50 000 kg of depleted uranium was used during 1955-1970.[1]

Natural uranium is of concern because of its radioactivity. However, the principal concern about depleted uranium is the effect of its chemical toxicity and weapons-associated pyrophoric properties on terrestrial ecosystems.

This report describes preliminary findings on the ecological effect of natural and depleted uranium dispersed during explosives tests at selected LASL areas, and gives analytical results on soils from Eglin Air Force Base (EAFB), Florida, firing ranges slightly contaminated during testing of depleted uranium penetrators. Objectives of this preliminary report are to:

2. Describe the uranium concentrations and distribution at LASL testing sites, determined by analyzing soil and biota samples;
3. Describe small mammal populations and vegetative communities at selected LASL firing sites and surrounding areas exposed to various amounts and physical forms of uranium;
4. Analyze plant and invertebrate soil communities associated with various amounts of uranium at LASL testing sites to determine responses to uranium's chemical toxicity; and,
5. Compare results from studies of uranium in LASL's semiarid environment and EAFB's semitropical environment as a function of uranium concentration, to provide a basis for broader extrapolation to use of depleted uranium munitions.

At LASL this initial study consisted of describing the ecosystem and determining the uranium concentrations in soils, plants, and small mammal communities at the selected firing sites to provide an integrated picture of food chain transmission potential. Maureen Romine of New Mexico Highlands University compiled and evaluated vegetative canopy coverage data on the LASL firing sites, to compare plant community responses to various uranium concentrations in the soil. Donald C. Lowrie of Santa Fe, New Mexico, identified and evaluated invertebrate soil populations.

II. THE LASL AREA

LASL consists of 27 000 acres in north-central New Mexico on the Pajarito Plateau, on the eastern slopes of the Jemez Mountains west of the Rio Grande

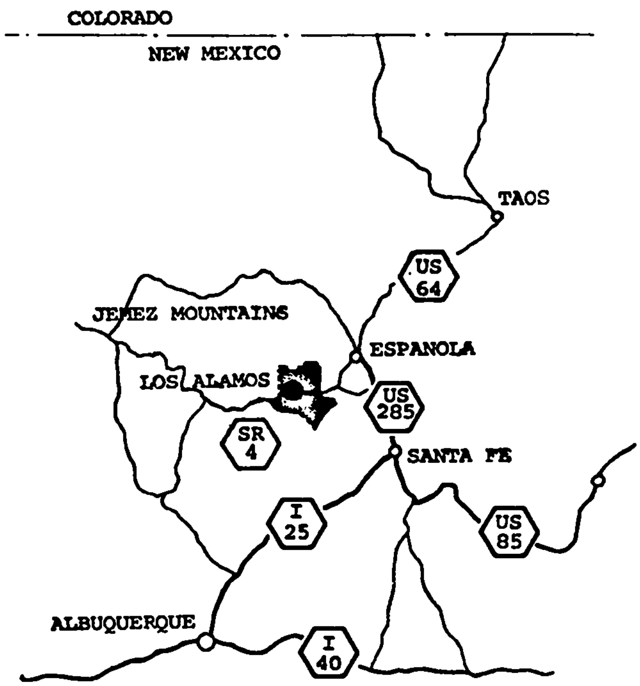

Fig. 1. North-central New Mexico.

(Fig. 1). A brief description of the area, adapted from Hanson,[2] is as follows.

"The general area has an east-west elevational gradient of 1500 m within 25 airline km from 1700 m above sea level at the Rio Grande to 3200 m in the Jemez Mountains. LASL is located atop the mesas at about 2000-2600 m. Three Life Zones (Merriam, 1894) are represented: Upper Sonoran, 1700-1950 m; Transitional, 1950-2400 m; and Canadian, 2400-3200 m. Sheer cliffs, steep forested slopes, and flat mesas and canyon bottoms within each Zone contain diversified habitats and many ecotones, or transition areas of overlapping plant and animal communities. This "edge effect" is heightened by the east-west topographic orientation that produces great differences in solar input and soil moisture between north and south slopes.

"The climate is semiarid, with approximately 46 cm of annual precipitation. Nearly 75% of this occurs during spectacular May-October thundershowers and accounts for much of the canyon erosion.

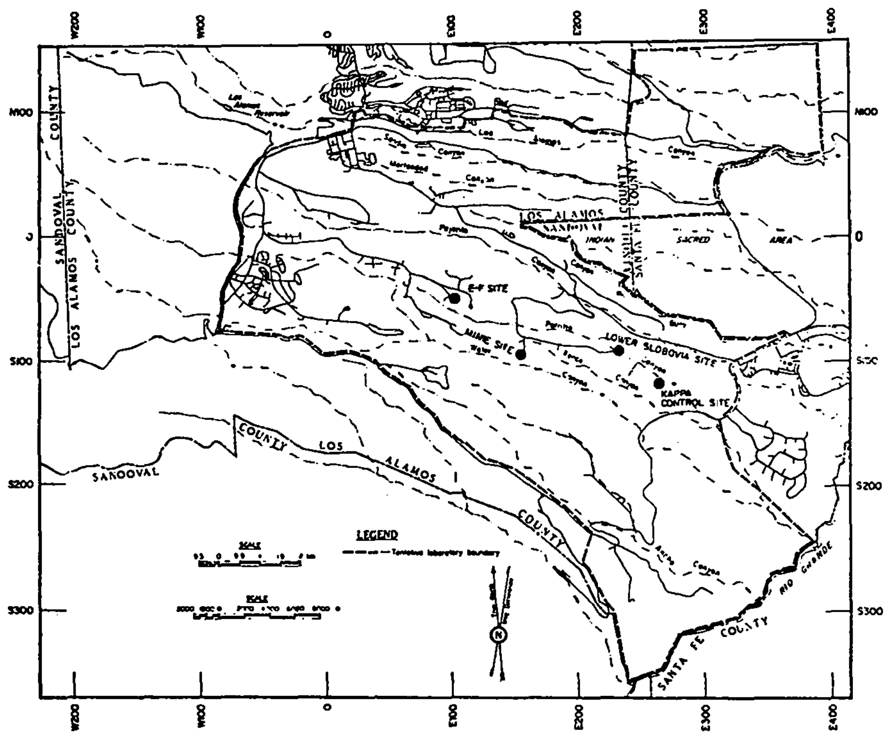

Fig. 2. The LASL area and study sites.

"The area soils have not, for the most part, been characterized. They are forming in basic igneous materials, and there is a generally repeated soil pattern directly related to landscape features and the effects of climate, time, topography, parent material, and vegetation."

Los Alamos area fauna includes 4 species of fish, 9 of reptiles, 187 of birds, and 37 of mammals. Plants include 139 species of 37 families.

III. LASL URANIUM STUDY SITES

Four LASL sites (Fig. 2) were chosen for this study in October 1974. Three, presently used as firing sites, were selected on the basis of use history. The fourth was a control area. E-F Site at 2190-m elevation was selected as having potentially high uranium concentrations; there are large pieces of depleted uranium scattered throughout the site. Minie Site at 2100 m was chosen as having potentially moderate uranium concentrations, and Lower Slobovia (LS) at 2000 m was chosen as a potentially low concentration site. The explosives tests at Minie and LS Sites scattered smaller particles than those at E-F Site. Control Site was also at approximately 2000-m elevation. Each study site measured 500 by 500 m.

All firing sites evidence depleted uranium's pyrophoric properties and resultant explosives properties, in that the overstory vegetation surrounding them has been burned and is now in various recovery stages. Appendix A contains photographs of the study sites; the aerial photographs are enlarged from a scale of 1:6000.

To study the selected sites more intensively, we eliminated Minie Site after the November sampling, because species composition of vegetation and small mammals there and at Lower Slobovia was similar.

IV. METHODS

A. Sample Collection

Soil, vegetation, and rodents were collected at LASL for uranium analyses.

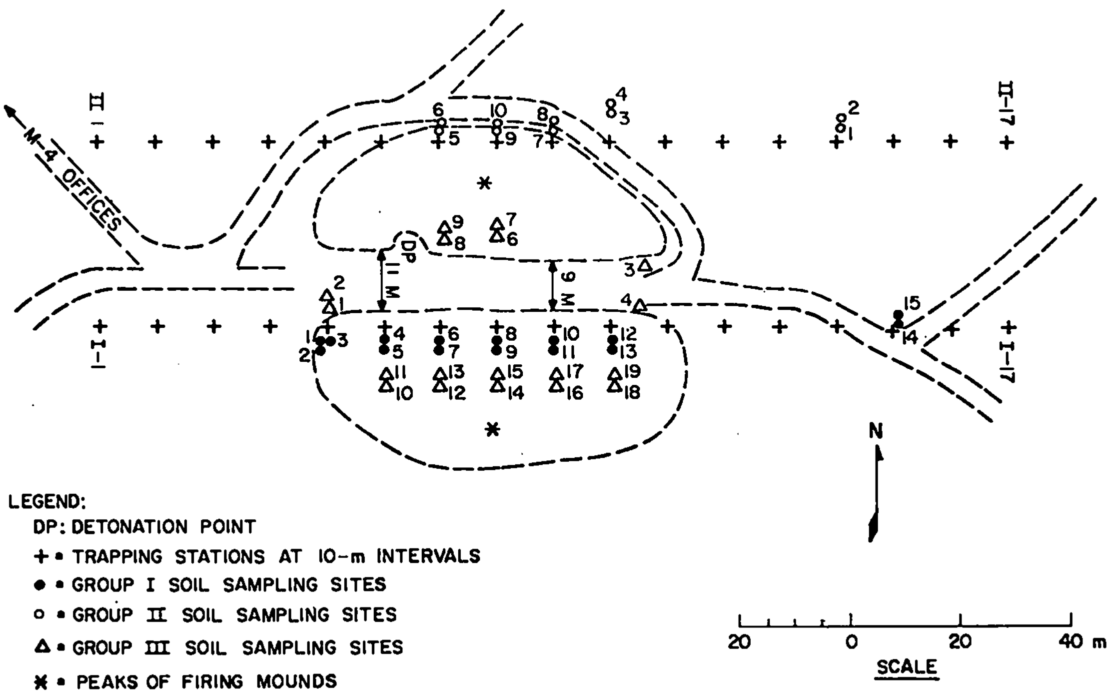

Fig. 3. Map of E-F study site, showing soil and small mammal collection sites.

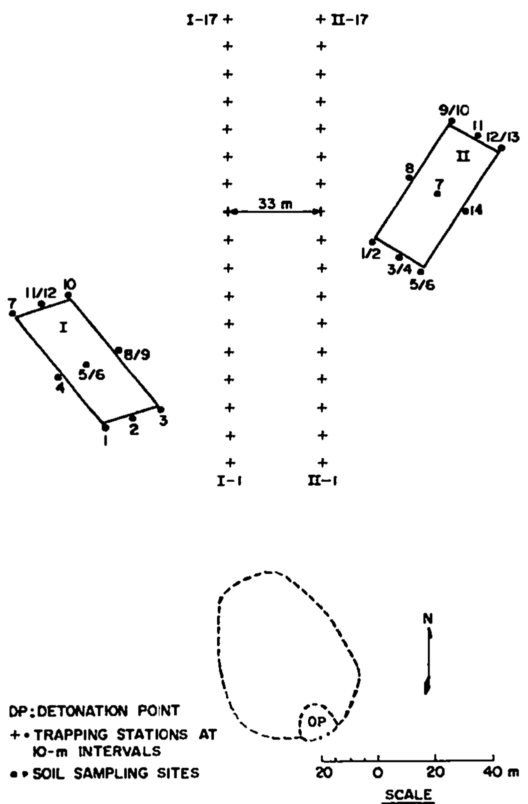

Fig. 4. Map of Kappa Lower Slobovia Site, showing location of soil and small mammal collection sites.

EAFB soil samples were collected by Air Force personnel and sent to LASL for analyses.

LASL soil samples collected in November 1974 and EAFB samples collected at about the same time were gathered using similar spatula techniques. The samples were 1- by 1- by 0.5-dm^3 units, usually two per location. Each consisted of an upper 0- to 5- or a lower 5- to 10-cm horizon taken so as to avoid cross-contamination. EAFB soils consisted of 50 samples from ADTC Range C 74L. Samples were collected from the base of the target butt and 60, 120, 180, and 240 ft (18, 37, 55, and 73 m) from it. Control samples also were collected from a suitable nearby location.

LASL soil samples were collected from 6-10 locations on a 500-m transect and also adjacent to vegetation, small mammal, and soil invertebrate sampling sites. Soil sampling locations at E-F and LS Sites are shown in Figs. 3 and 4. Samples collected in June 1975 were 1-dm^3 units taken at similar sites.

TABLE I

ESTIMATED SOIL, VEGETATION, AND SMALL MAMMAL MASSES AT LASL SITES IN NOVEMBER 1974 AND JUNE 1975

			E-F		Minie		Lower Slobovia Plot I		Lower Slobovia Plot II		Control	
Component	Date	Unit	n	$\bar{x}$ ± S.E.[a]	n	$\bar{x}$ ± S.E.	n	$\bar{x}$ ± S.E.	n	$\bar{x}$ ± S.E.	n	$\bar{x}$ ± S.E.
Soil-Top 0-5 cm	Nov 74	Dry g/cm^3	41	1.3 ± 0.03	9	1.1 ± 0.01	18	1.2 ± 0.07			2	1.4 ± 0.05[b]
-Lower 5-10 cm			42	1.5 ± 0.05			8	1.3 ± 0.13				
Standing Vegetation	Nov 74	Dry g/m^2	11	51.5 ± 4.6	10	99.7 ± 21.8	9	173.1 ± 26.2	9	70.2 ± 18.5	9	115.6 ± 14.1
	Jun 75		4	71.7 ±10.8			4	145.9 ± 30.1	4	131.9 ± 63.7	4	64.1 ± 5.6
Small Mammals	Nov 74	Wet g/m^2	21	0.010	56	0.026	30	0.013			16	0.007
	Jun 75		39	0.023			41	0.021			46	0.023

[a] n = number of samples; $\bar{x}$ = mean; S.E. = standard error of the mean.
[b] Samples taken to a depth of 1 dm.

LASL vegetation samples were collected from 1-m^2 plots. All standing vegetation within each plot was clipped at ground level, and all species were composited as one sample for analyses. Loss of the first set of vegetation samples collected in November 1974 during chemical analysis necessitated resampling in February 1975. A corresponding set of samples were collected in June 1975.

All snap-trapped rodents collected in November 1974 and random individuals sacrificed during live-trapping in June 1975 were carefully dissected to avoid cross-contaminating the soft tissues with hair or soil from the pelt. Tissues collected in November were divided into three groups: the pelt, carcass (skeleton, skeletal muscle, and internal organs), and the gastrointestinal (GI) contents. The GI system tissues were discarded. June rodent samples were further subdivided to permit determination of uranium concentrations in individual organs. Tissues and organs analyzed included the pelt, muscle, bone, lungs, and liver. In pocket gophers, the GI contents and kidneys also were analyzed.

Table I gives soil and vegetation mass estimates and a minimal estimate for small mammals. The term "minimal" is used because not all small mammals were removed from any area. Soil (g/cm^3) and vegetation (g/m^2) mass estimates are expressed as dry weights; small mammal (g/m^2) estimates, as wet carcass weight. A mean vegetation mass estimate for both LS plots would be comparable to that for Minie Site. November 1974 small mammal biomass estimates were greatest at the firing sites and lowest at Control Site; however, no such difference was found in the June 1975 results.

Descriptive analyses of plant communities subjected to long-term uranium deposition were performed. These analyses included determination of species diversity, canopy coverage, frequency, and density of understory plants at the four study sites; all sites are located in ponderosa pine/piñon-juniper ecotones.

Three vegetation test plots and one control plot, each 20 by 50 m with zero slope, were established and permanently marked. One test plot was approximately 100 m southeast of the firing mound at Minie Site. The other two were approximately 100 m northeast (plot 1) and 100 m southeast (plot 2) of the Lower Slobovia firing mound. The Control Site plot was 0.5 km southeast of the LS firing mound. All four plots were in the same vegetation type.

Vegetation test and control lines were established at E-F Site. All test lines were on a man-made hill directly south of the detonation point. Test Line 1 was on the north-facing slope, and Test Line 2 was on the south-facing slope, both 3 m up from the base of the hill, and both 40 m long. Test Line 3 ran north to south over the top of the hill and was 30 m long. Control Line 1 (zero slope and 40 m long) was southwest of the firing mound. Control Lines 2 (south-facing slope and 46 m long) and 3 (east-facing slope and 50 m long) were south and southeast, respectively, of the firing mound.

Canopy coverage (% coverage/plot), species frequency (% of plots containing species), and plant density (rooted plants/plot) were determined using forty 20- by 50-cm sample plots at 1-m intervals outside one 50-m side of each test and control plot and along test and control lines at E-F Site, except for Test Line 3 where 30 sample plots were used for canopy coverage analysis according to Daubenmire's method.[3] These lines of small plots were designated "Test Line" at Minie Site, Test Lines I and II at LS, and Control Line at Control Site. Vegetative sample plots were so placed as to avoid disturbing the main plots. Grass densities were not determined. All values given are mean values.

Scientific names are from Harrington,[4] and common names are from the Forest Service checklist.[5]

B. Sample Analyses

Soil samples were oven-dried at 100° C for 24 h, and the dry weight was recorded. The sample was then passed through a 6-mm screen to remove large pieces of rock and uranium, and the fine fraction was ground to less than 100 mesh in a pulverizer (Bico Pulverizer Type UA) and thoroughly blended to provide a homogenous sample. Replicates were prepared at the same time. An approximately 5-g aliquot of the pulverized soil and the larger pieces of material were then leached separately in a hydrofluoric and nitric acid solution. The leachates were combined and analyzed for total uranium (natural uranium plus depleted uranium) by a standard fluorometric technique.[6,7] Results were expressed in micrograms of uranium per gram of total sample, equivalent to parts per million.

Vegetation samples were oven-dried at 100° C for 24 h to determine standard dry weight and then burned in a muffle furnace at 450° C until a white ash was obtained. The ash was dissolved in 7.2 N HNO_3, and an aliquot was analyzed. Animal samples also were oven-dried at 100° C for 24 h and then dissolved in 7.2 N HNO_3 and H_2O_2, and an aliquot was analyzed.

Replicate aliquots of 100 soil samples and biotic sample leachates from the November sampling, with blanks and standards, were sent to Eberline Instrument Company in Albuquerque for comparative uranium analysis. Replicates of all 50 EAFB soil samples were included.

Detection limits of LASL analyses made with the fluorometric technique used were 0.3 μg of uranium per g of sample of rodents or vegetation, with ±7% standard deviation due to analytical error. The procedure gave an analytical error of 100% for samples that contained <0.3 μg of uranium. The detection limit for soils was 0.6 μg of uranium per g of sample, with a standard deviation of ±10%.

C. Comparison of Eberline and LASL Chemical Analyses of Soil Uranium

Aliquots of 50 homogenized soil samples from EAFB, and 50 similar aliquots of LASL soil samples, with suitable blind replicates and standards, were analyzed by Eberline Instrument Company to provide interlaboratory comparison of uranium results. The LASL soil samples were selected from 120 taken in November 1974 and 21 taken in June 1975. Both Eberline and LASL used acid-leach digestion followed by

TABLE II

MEAN URANIUM SOIL CONCENTRATIONS AT EAFB, FLORIDA

Sample[a]	Distance from target (m)	LASL $\bar{x}$[b] (µg U/g dry)	LASL CV[c]	LASL n[d]	Eberline $\bar{x}$ (µg U/g dry)	Eberline CV	Eberline n
0 - A	0	795.0	0.20	2	645.0	0.56	2
- B		33.0	0.30	2	28.8	0.11	2
1 - A	18	20.3	1.50	8	12.1	1.11	8
- B		1.9	2.00	8	1.9	1.16	8
2 - A	37	7.0	1.20	4	2.4	0.54	4
- B		1.5	1.22	4	3.5	0.65	4
3 - A	55	2.2	0.67	5	1.3	0.71	5
- B		1.0	1.45	5	0.6	0.77	5
4 - A	73	0.7	0.76	4	0.7	0.20	4
- B		1.2	0.77	4	0.2	0.71	4
5 - A		N.D.	----	1	0.7	----	1
- B		N.D.	----	1	0.3	----	1
Control A		4.8	----	1	0.3	----	1
B		3.0	----	1	0.3	----	1

[a] A = upper 0-5 cm soils; B = lower 5-10 cm soils.
[b] $\bar{x}$ = mean.
[c] CV - Coefficient of variation = standard deviation/sample mean.
[d] n = number of samples taken at that radius of a circle around the target.

TABLE III

MEAN CONCENTRATIONS OF URANIUM (µg U/g Dry) AND COEFFICIENT OF VARIATION[a] FOR REPLICATE SOIL SAMPLES

Sample	Eberline Replicate Analyses				$\bar{x}$	SD	CV
Eglin							
1-3-B	0.3	1.7			1.0	0.99	0.99
1-11-A	40.5	40.5			40.5	0	0
2-12-A	1.6	1.7			1.65	0.07	0.04
2-2-B	0.3	0.2			0.25	0.07	0.28
E - F							
EF-FP 17-L-5	1230	1110			1170.0	84.85	0.07
EF-FP 12-L-5	345	280			312.5	45.96	0.15
Lower Slobovia							
LS8-1E-T-5	32	23			27.5	6.36	0.23
LS3-2SC-T-5	2.6	2.0			2.3	0.42	0.18
Standards							
S-4	2850	1680			2265.0	827.3	0.37
S-3	2760	3210			2985.0	318.2	0.11
S-1633	1520	1580			1550.0	42.4	0.03
	LASL Replicate Analyses						
E - F							
III-11-T-5	7550	920	1550	1660	2920	3103.8	1.06
III-14-T-5	1470	1210	2100	2100	1720	451.4	0.26
III-18-T-5	1760	980	1460	1590	1447.5	335.0	0.23
I-2-T-5	2900	2900	3800		3200	519.6	0.16
I-11-L-5	3700	3700	3500		3633.3	115.5	0.03
S-1[b]	580	771	1240		863.7	339.6	0.39
N-1-6[b]	660	993	830		827.7	166.5	0.20
II-3-T-5	7200	3500			5350	2616.3	0.49
II-8-L-5	1360	520			940	594.0	0.63
Lower Slobovia							
I-SE[b]	70.0	50.0	50.0		56.7	11.6	0.20
II-SW[b]	28.4	36.0	34.0		32.8	3.94	0.12
II-1-SW-T-5	19.0	26.0			22.5	4.95	0.22
II-12-NE-T-5	4.8	13.4			9.1	6.1	0.67

[a] Coefficient of variation = standard deviation/sample mean.
[b] Samples taken to depth of 1 dm.

fluorometric analysis. Results for individual soil samples are given in Appendix B.

Eberline and LASL values for EAFB soil aliquots are compared in Table II. The LASL values were generally higher than Eberline's and more variable. Eberline's coefficient of variation (CV) is 11-116%, compared to LASL's 20-200%, and individual values are evenly distributed throughout these ranges. This variation can be attributed partly to nonuniform dispersion from the target butt of uranium in a variety of particle sizes; soil samples from areas of lower uranium deposition varied less.

Both Eberline and LASL analyzed replicate 5-g aliquots of individual homogenized soil samples to evaluate the variability of their respective procedures. Eberline's results from 11 such samples, including three standards, are presented in Table III. The CV was 0-99%, all but one value being below 37%. Standard values showed CV's of 3, 11, and 37%, or about the same as those for replicates.

LASL analyzed replicates of 13 individual homogenized samples in groups of 4, 3, and 2 samples each (Table III). CV's were 3-106%, all but four values being <39%. Three of the most variable values were in replicates from E-F Site, where soils contained the highest uranium concentrations. Quality control data for LASL analyses are presented in Appendix C.

V. RESULTS AND DISCUSSION

A. Uranium Concentrations in EAFB Soil Samples

The maximum uranium concentrations in the Eglin soil samples that LASL analyzed were in the upper 0-5 cm of soil from the base of the target butt (Table II). However, there seemed to be no appreciable uranium penetration or migration into the soil; concentrations in the lower 5-10 cm were only about 4% of those in the top 5 cm. A similar relationship with depth was observed 18 m from the target butt, where the 5- to 10-cm profiles contained <10% of

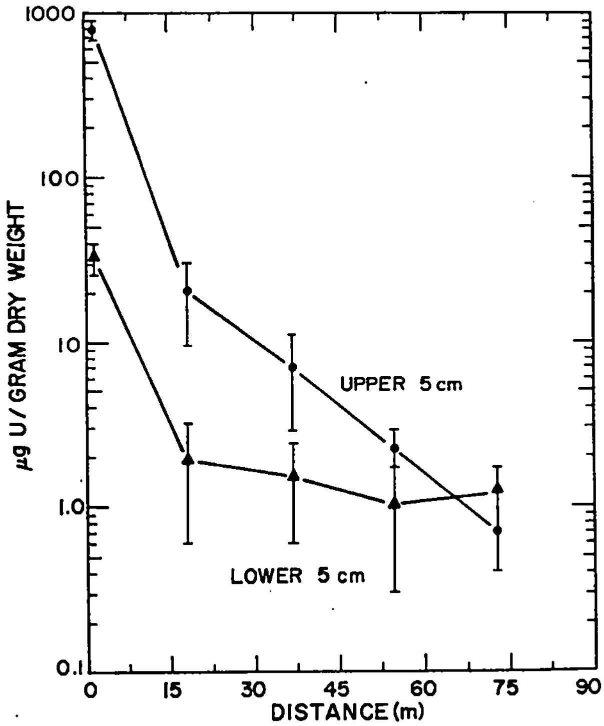

Fig. 5 Mean uranium concentrations (±1 S.E.) in soil at various distances from target butts at EAFB in November 1974.

the uranium in the samples. The uranium concentrations in soil >20 m from the target butt averaged 2.3±1.0 (S.E.) μg/g (= ppm), and in almost all instances were lower than control values at both depths which averaged 3.9±0.9 μg/g, but were not significantly different ($P \leq 0.05$).* The results, graphically presented in Fig. 5, demonstrate the observed relationship of uranium concentrations in upper and lower soil horizons.

B. Uranium Concentrations in LASL Soil Samples

The uranium concentrations in LASL soils collected in November 1974 and June 1975 are shown in Tables IV and V, respectively.

Uranium concentrations in E-F Site soils taken at both sampling times averaged 40-100 times higher than those in soils from the other study areas, reflecting past use histories of the respective sites. The E-F Site explosive tests apparently involved about 39 times more uranium than tests at all the other sites combined.

Uranium in E-F soils averaged about 2400 and 1600 μg/g at 0- to 5- and 5- to 10-cm depths. Differences between upper and lower depths although not statistically significant ($P \leq 0.05$), reflected vertical movement of the uranium into the soil. The mechanisms for this movement could be erosion processes, mechanical disturbances, and/or penetration of uranium fragments into the soil during the explosive tests.

Uranium concentrations in the top 5 cm of Lower Slobovia soils were significantly higher ($P \leq 0.05$), than those at 5-10 cm. The vertical concentration gradient contrasts with that observed at E-F Site although both areas were used for explosive testing for about the same length of time.

Important differences between E-F Site tests and those at the other sites may partly explain the observed uranium distribution patterns. Explosive tests at E-F Site deposited relatively large fragments; particles range from about 2 mm to several cm in diameter. Tests at Lower Slobovia produced consistently smaller dispersed uranium particle size ranges.

The greater particle size range at E-F Site is apparent in the variability of uranium concentrations in its soil. The CV in E-F soils ranged from 1.54 in the surface 5 cm to 2.85 in the 5- to 10-cm profiles, reflecting considerable inhomogeneity of the uranium in the soil. At least some of this extreme variation comes from samples containing relatively large pieces of uranium.

Although variability in soil uranium at the other areas was also great (CV's of 0.93-1.7), it averaged somewhat less than at E-F Site.

The lesser variation in Minie and LS Site soils which is indicative of relatively

*P = probability of rejecting a null hypothesis.

TABLE IV

NATURAL AND DEPLETED URANIUM CONCENTRATIONS
IN LASL SOILS, VEGETATION, AND SMALL MAMMALS (NOVEMBER 1974)
(μg/g dry)

Ecosystem Component	Sample	E - F Mean	E - F Min.	E - F Max.	E - F CV[a]	E - F n[b]	Minie Mean	Minie Min.	Minie Max.	Minie CV	Minie n
Soils	Top 0.5 dm	2390	265	23400	1.54	42	3.6	0.6	12.3	1.04	9
	Lower 0.5 dm	1600	26	30000	2.85	43					
Vegetation	Standing Vegetation ($1-m^2$ plot)	320	220	470	0.29	5	2.8	0.8	4.6	0.80	4
Small Mammals											
Peromyscus	GI	210	10	890	1.13	17	1.0	ND[c]	4.1	1.24	37
Reithrodontomys		--[d]	--	--	--	1	0.5	ND	3.3	2.07	19
Peromyscus	Pelt	24	2.2	74	0.91	17	0.3	ND	1.5	1.42	37
Reithrodontomys		--	--	--	--	1	0.7	ND	8.8	3.03	19
Peromyscus	Carcass	4	0.6	15	0.95	17	<0.3	ND	0.3	2.71	37
Reithrodontomys		--	--	--	--	1	ND	ND	ND		19

Lower Slobovia

Ecosystem Component	Sample	Area I Mean	Area I Min.	Area I Max.	Area I CV	Area I n	Area II Mean	Area II Min.	Area II Max.	Area II CV	Area II n
Soils	Top 0.5 dm	64	5.1	220	1.25	9	17	1.7	46	0.84	9
	Lower 0.5 dm	12	2.6	24	0.93	3	4	ND	14	1.69	5
Vegetation	Standing Vegetation ($1-m^2$ plot)	3	0.5	5.1	0.73	4	3	1.5	4	0.39	4
Small Mammals		Line I and II Combined									
Peromyscus	GI	0.3	ND	1.2	1.55	18					
Reithrodontomys		2.3	ND	11.0	1.41	12					
Peromyscus	Pelt	<0.3	ND	0.8	2.37	18					
Reithrodontomys		<0.3	ND	0.8	1.40	12					
Peromyscus	Carcass	<0.3	ND	0.3	2.07	18					
Reithrodontomys		<0.3	ND	0.3	1.30	12					

Control

Ecosystem Component	Sample	Mean	Min.	Max.	CV	n
Soil	Top 0.5 dm	1.2	0.6	1.9	0.73	2
Vegetation	Standing Vegetation ($1-m^2$ plot)	0.4	0.2	0.6	0.31	4
Small Mammals						
Peromyscus	GI	0.7	ND	4.1	1.67	11
Reithrodontomys		1.0	ND	2.3	1.16	5
Peromyscus	Pelt	0.4	ND	0.8	0.68	11
Reithrodontomys		1.0	ND	2.3	1.25	5
Peromyscus	Carcass	<0.3	ND	0.3	0.62	11
Reithrodontomys		<0.3	ND	0.9	1.09	5

[a] Coefficient of variation = standard deviation/mean.
[b] n = number of individual samples used to compute mean.
[c] Not detectable.
[d] Not analyzed.

TABLE V

NATURAL AND DEPLETED URANIUM CONCENTRATIONS
IN LASL SOILS, VEGETATION, AND SMALL MAMMALS (JUNE, 1975)
(ug/g dry)

Ecosystem Component	Sample	Mean	Min.	Max.	CV[a]	n[b]	Mean	Min.	Max	CV	n
		E - P									
Soils	1 dm³	2340	66	16000	1.82	13					
Vegetation	Standing Vegetation (1-m² plot)	124	11	300	1.02	4					
SMALL MAMMALS											
Peromyscus	Pelt	49	1.7	190.0	1.26	9					
Thomomys		27	19	33.0	0.27	3					
Peromyscus	Lung	6.0	N.D.[c]	33.0	1.86	9					
Thomomys		0.8	N.D.	2.3	1.72	3					
Peromyscus	Muscle	2.2	0.7	5.6	0.86	7					
Thomomys		2.9	1.0	5.1	0.73	3					
Peromyscus	Bone	2.8	N.D.	5.9	2.14	9					
Thomomys		1.7	0.9	2.7	0.52	3					
Peromyscus	Liver	4.5	N.D.	19.0	1.50	9					
Thomomys		0.8	N.D.	2.5	1.44	3					
Thomomys	GI	110	74	171	0.48	3					
Thomomys	Kidney	1.4	N.D.	2.9	1.06	3					
		Lower Slobovia									
		Area I					Area II				
Soils	1 dm³	28	5.6	70	1.02	4	11	2.5	28	1.03	4
Vegetation	Standing Vegetation (1-m² plot)	0.5	N.D.	1.2	0.96	4	0.5	N.D.	1.2	0.46	4
SMALL MAMMALS											
Peromyscus	Pelt	1.0	N.D.	2.5	1.21	5					
Reithrodontomys		1.8	N.D.	3.6	1.41	2					
Thomomys		1.1	0.4	3.0	0.85	6					
Peromyscus	Lung	17	N.D.	69.0	1.99	4					
Reithrodontomys		36	N.D.	71.0	1.41	2					
Thomomys		N.D.	N.D.	N.D.		6					
Peromyscus	Muscle	1.3	N.D.	4.3	1.4	6					
Reithrodontomys		N.D.	N.D.	N.D.		2					
Thomomys		0.1	N.D.	0.2	0.52	6					
Peromyscus	Bone	0.2	N.D.	0.6	1.32	6					
Reithrodontomys		N.D.	N.D.	N.D.		2					
Thomomys		0.2	N.D.	0.5	1.26	6					
Peromyscus	Liver	2.3	N.D	5.7	1.17	4					
Reithrodontomys		N.D.				2					
Thomomys		N.D.	N.D.	0.2	2.45	6					
Thomomys	GI	0.9	N.D.	2.0	0.92	6					
Thomomys	Kidney	1.1	N.D.	3.8	1.53	6					
		Control									
Soils	1 dm³	2.2	1.9	2.5	0.13	4					
Vegetation	Standing Vegetation (1-m² plot)	0.1	0.1	0.2	0.47	4					
SMALL MAMMALS											
Peromyscus	Pelt	N.D.	N.D.	N.D.		5					
	Lung	8.2	N.D.	33	2.0	4					
	Muscle	N.D.	N.D.	N.D.		4					
	Bone	N.D.	N.D.	N.D.		4					
	Liver	N.D.	N.D.	N.D.		5					

[a]Coefficient of variation = Standard deviation/mean.
[b]n = number of individual samples used to compute mean.
[c]Not detectable.

greater homogeneity of soil uranium is consistent with our knowledge of the particle sizes generated during explosive tests there. Neither site exhibited the mechanical disturbances of the soils which were common at E-F Site. Uranium movement into the soil was probably governed by weathering processes and burrowing by small mammals, rather than explosive force.

Elevated uranium content was detected in soils 90 m from the E-F detonation points and 225 m from the LS point. These are the greatest distances at which samples were taken, not necessarily the greatest at which uranium debris was deposited.

Soil collected northwest of the Lower Slobovia detonation point (Area I) in both sampling periods exhibited three to four times higher uranium concentrations in the upper and lower 0.5-dm samples (Tables IV and V) than soil from the northeast quadrant (Area II). These distributions apparently reflect local wind direction patterns.

Background concentrations of natural uranium at Control Site ranged from 0.6 to 2.5 μg/g, slightly higher than those reported (0.16-1.24, averaging 0.58) in northern New Mexico.[8]

C. Uranium Concentrations in LASL Biota

The highest uranium concentrations in LASL biota (Tables IV and V) were found in samples from E-F Site, whose soil also had the highest concentrations. Vegetation collected in November 1974 and February 1975 was standing dead vegetation that had been exposed to uranium-contaminated soil for at least 6 months. No explosive tests involving uranium had been conducted at E-F Site for more than 1 yr at that time. Vegetation sampled in June 1975 was late spring growth, mainly green material that had been only briefly exposed to external uranium deposition or uptake. Observed concentration ratios (plant U ÷ soil U), presented in Table VI, show a general decrease in the new growth. The high ratios in the November samples

TABLE VI

RATIOS OF PLANT:SOIL URANIUM CONCENTRATIONS IN FALL AND SPRING SAMPLES

Location	Sampling Period	Plant U / Soil U
E - F	November 1974	0.08
	June 1975	0.05
Lower Slobovia Area I	November 1974	0.04
	June 1975	0.02
Lower Slobovia Area II	November 1974	0.13
	June 1975	0.04
Control	November 1974	0.34
	June 1975	0.06

from both Lower Slobovia Area II and Control Site are attributable to high U and DU concentrations in vegetation at that time. These results were consistent with Cannon's[9] in which "uranium indicator" plants had ratios of 0.01-1.0. This relationship should be studied further to evaluate the importance of resuspension in field studies of plant:soil ratios.

During the June sampling, we tried to determine the uranium concentrations within plant roots, compared to uranium particles that were adsorbed on the root surfaces, and to determine relative concentrations in dominant plant species. One-dm^2 subplots were established 1 m from the 1-m^2 vegetation sampling plots, and the vegetation was totally removed. The intact soil was then removed to a depth of 1 dm, yielding a 1-dm^3 sample with plant roots in place. This material was then passed through a 2-mm-mesh sieve to separate soil from roots. The soil was treated as previously described; the roots were washed in a sonic bath of distilled water for 2-3 min, rinsed with distilled water, microscopically examined for adhering particulates, and then analyzed like a vegetation sample. The above-ground parts of the plants removed from the 1-dm^2 area were analyzed similarly. Results are presented in Table VII. Uranium concentrations in E-F Site soils obtained under these special conditions were higher than those shown elsewhere in this report because of the influence of a single sample that contained 16 000 μg/g of uranium. Soils from LS Area I contained less uranium than indicated in Table IV, reflecting the variable

TABLE VII

MEAN URANIUM CONCENTRATIONS (μg/g dry) IN AERIAL PARTS, ROOTS, AND ROOTING LAYER SOILS OF SELECTED VEGETATION

		Aerial Parts			Roots			Soil		
Location	Taxon	$\bar{x}$	CV	n	$\bar{x}$	CV	n	$\bar{x}$	CV	n
E - F	*Sitanion hystrix*	1.0	0.98	4	1370	1.03	4	4870	1.53	4
Lower Slobovia Area I	*Bromus tectorum*	2.7	1.06	4	16.6	0.29	4	3.2	0.76	4
Lower Slobovia Area II	*Artemisia dracunculus*	0.7	0.75	4	2.0	1.34	4	3.0	0.86	4
Control	*Artemisia dracunculus*	0.4	1.26	4	0.1	0.54	4	2.2	0.13	4

distribution of uranium in these study areas. Root:soil uranium ratios were highly variable: 0.28 at E-F Site; 5.26 at LS Area I; 0.64 at LS Area II; and 0.05 at Control Site. At least part of this variability was caused by several small particles of soil and, presumably, uranium adhering to roots; the particles were found by microscopic examination. Furthermore, uranium colloids would not be seen but may well have been sorbed on the root surface. This fact further complicated the differentiation of "in" vs "on" uranium components in plant roots, despite efforts to separate the two. Roots of cheatgrass (*Bromus tectorum*) at LS Area I contained a greater uranium concentration than did the surrounding soil, probably reflecting higher concentrations in fine particles that adhered to roots; and aerial parts of grasses at E-F and Area I contained higher concentrations than did associated forbs, possibly owing to surface area and particle size differences.

June trapping samples suggested similar trends in small mammals. Uranium concentrations in pelts of E-F and LS *Peromyscus* were higher in June than in November by factors of 2 and 10, respectively. Concentrations in *Reithrodontomys* pelts were also elevated by a factor of 10 at LS Site. The GI contents of *Thomomys* analyzed in June also showed lower concentrations than similar *Peromyscus* and *Reithrodontomys* samples analyzed in November. These differences were attributed to drier soils and possible soil texture differences between LS Site and E-F Site, which enhanced resuspension contamination.

Of the small mammal internal tissues analyzed (muscle, bone, liver, and kidney), *Peromyscus* livers had the highest mean uranium concentrations. Results of *Thomomys* internal tissue analyses are not clear. However, the data suggest that mean uranium concentrations at E-F Site were greater in *Peromyscus* than in *Thomomys*, although not significantly so. A similar case may apply to LS Site, where differences among animal species were most obvious in comparisons of pelt, lung, and liver samples. We expect future analyses of GI contents also to bear out this relationship. The subterranean activities of pocket gophers (*Thomomys*) suggest that, although they are in close contact with elevated uranium concentrations in soil, the top few millimeters of soil contain the more resuspendable uranium fraction. Therefore, the surface activities and different food preferences of deer mice (*Peromyscus*) cause their greater exposure to particulate uranium.

The variation of uranium concentrations in almost all biotic samples was generally greater than that in soil samples, and it was attributed to biological magnification of the biota's heterogeneous exposures.

In all three species of small mammals sampled at all sites, the GI contents had the highest mean uranium concentrations; lesser amounts were found in pelts, carcasses, and lungs. Lungs analyzed as separate samples in June contained higher concentrations than did carcasses. Samples from E-F Site generally had higher mean uranium concentrations than those from other sites, except for high concentrations in Peromyscus and Reithrodontomys lungs sampled in June at LS Site. This ranking of values in the tissues suggests that uranium resuspension is important in rodent contamination. Whole carcasses sampled in the fall, which consisted of internal tissues unexposed to external contamination, reflected values found in control animals, again with the exception of E-F Site. Small mammal pelts from plutonium-contaminated areas of the Nevada Test Site had higher plutonium concentrations than GI tract samples, indicating that resuspension also was operant in that situation.[10]

VI. BIOTIC SURVEY OF LASL STUDY SITES

A. Plant Community Analysis at the Study Sites

Results of E-F Site plant analyses are shown in Table VIII. Three species, Kochia scoparia, Salsola kali, and Sitanion hystrix were found in at least one sample plot of each test line. K. scoparia had the highest coverage values (40.3%, Line 1; 20.8%, Line 2; and 28.3%, Line 3). Highest frequency values on Test Line 1 were K. scoparia and S. hystrix, both of which scored 72.5%. K. scoparia was most frequent on Line 3 (85.0%); S. Hystrix and K. scoparia, most frequent on Line 2 (both 73.3%). K. scoparia also showed the greatest density values in sample plots on Test Lines 1 and 3 (47.9 and 11.4 plant/plot, respectively). The S. kali density (7.6 plants/plot) was only 2.9 plants higher than the K. scoparia value on Line 2. Sample plots on control lines yielded 15 species of plants, S. hystrix being the only species common to both test and control lines. The grasses had the highest coverage and frequency values on all control lines. Separate grass species were not analyzed for coverage and frequency. Two sagebrush species, Artemisia cana (0.7 plants/plot, Lines 1 and 2) and A. dracunculus (0.3 plants/plot, Line 3) showed the greatest density.

Plant community data for Minie, LS, and Control sites are shown in Table IX. The sampling design was basically the same as at E-F Site, including use of three test lines and one control line along one 50-m side of test or control plots. The single control line functioned for all test lines. Eleven species were found on the Test line at Minie Site; ten species each on Test Lines 1 and 2 at Lower Slobovia; and nine species on the control line at Control Site. Two species, Artemisia dracunculus and Bahia dissecta, and the grasses, which were handled as a single type, were found on all test and control lines. Fallugia paradoxa, Salsola kali, Chenopodium leptophyllum, Cryptantha fendleri, Erigeron flagellaris, Rhus trilobata, Vicia spp., Ribes cereum, and Physalis spp. were found in sample plots on test, but not control, lines. Two species, Castilleja integra and Solanum spp. were found on the control line only. The grasses had the highest coverage and frequency values on all test and control lines. C. fendleri, E. flagellaris, and grass plants were too numerous for density determinations, but their coverage and frequency were evaluated. Excluding these species, S. kali had the highest density value (0.6 plants/plot) on the Test line at Minie Site. A. dracunculus was densest on Test Line 1 (0.3 plants/plot), Test line 2 (1.5 plant/plot), and the Control Site line (1.4 plants/plot).

We attempted to determine whether plant distribution, as reflected by species diversity, canopy coverage, frequency, and density, was affected by long-term uranium

TABLE VIII

E - F SITE VEGETATION ANALYSES, NOVEMBER 1974

Plant Taxon	Test Line 1 Coverage (%/Plot)	Test Line 1 Frequency (% of Plots)	Test Line 1 Plants/ Plot	Test Line 2 Coverage (%/Plots)	Test Line 2 Frequency (% of Plots)	Test Line 2 Plants/ Plot	Test Line 3 Coverage (%/Plot)	Test Line 3 Frequency (% of Plot)	Test Line 3 Plants/ Plot
Chenopodiacea[a]									
<u>Kochia</u> <u>scoparia</u>-Belvedere summer-cypress[b]	40.3	72.5	47.9	20.8	60.0	4.7	28.3	85.0	11.4
<u>Salsola</u> <u>Kali</u>-Russian thistle	4.8	52.5	2.2	15.3	70.0	7.6	8.1	60.0	1.7
Compositae									
<u>Tragopogon</u> <u>dubius</u>-Salsify							0.1	2.5	—
Graminae									
<u>Sitanion</u> <u>hystrix</u>-Bottlebrush Squirreltail	23.0	72.5	—	9.1	73.3	—	9.2	47.5	—
	Control Line 1			Control Line 2			Control Line 3		
Anacardiaceae									
<u>Rhus</u> <u>trilobata</u>-Skunkbush Sumac							4.0	5.0	—
Boraginaceae									
<u>Cryptantha</u> <u>fendleri</u>-Fendler Cryptantha							0.1	2.5	<0.1
Compositae									
<u>Artemesia</u> <u>cana</u>-Silver Sagebrush	2.4	35.0	0.7	1.6	25.0	0.6	0.2	10.0	0.1
<u>Artemisia</u> <u>dracunculus</u>-False Tarragon Sagebrush	1.4	7.5	0.2	3.6	22.5	0.4	4.0	30.0	0.3
<u>Artemisia</u> <u>frigida</u>-Fringed Sagebrush							0.6	12.5	0.2
<u>Bahia</u> <u>dissecta</u>-Ragleaf Bahia	0.1	2.5	<0.1				0.1	2.5	<0.1
<u>Chrysopsis</u> <u>villosa</u>-Hairy Goldaster	0.5	7.5	0.5	1.4	7.5	0.1	2.7	12.5	0.2
<u>Gutierrezia</u> <u>sarothrae</u>-Broom Snakeweed							0.9	2.5	<0.1
<u>Hymenoxys</u> <u>richardsonii</u>-Pinque							2.2	15.0	0.2
Fagaceae									
<u>Quercus</u> <u>turbinella</u>-Shrub Live Oak	14.4	32.5	0.4	19.6	25.0	0.3			
Graminae	38.8	92.5	—	58.2	97.5	—	57.9	92.5	—
Leguminosae									
<u>Luminus</u> <u>argenteus</u>-Silvery Lupine							0.4	5.0	<0.1
<u>Vicia</u> <u>sp</u>.-Vetch							1.7	30.0	0.5
Polygonaceae									
<u>Eriogonum</u> <u>racemosum</u>-Redroot Eriogonum							0.4	2.5	<0.1
Rosaceae									
<u>Cercocarpus</u> <u>montanus</u>-True Cercocarpus	0.4	2.5	—						

[a]Family name.
[b]Genus, species, and common name.

TABLE IX

MINIE, LOWER SLOBOVIA, AND CONTROL SITE VEGETATION ANALYSES, NOVEMBER 1974

	Minie Site			Lower Slobovia Test Line 1			Lower Slobovia Test Line 2			Control		
Plant Taxon	Coverage (%/Plot)	Frequency (% of Plots)	Plants/ Plot	Cov. (%/Plot)	Freq. (% of Plots)	Plants/ Plot	Cov. (%/Plot)	Freq. (% of Plots)	Plants/ Plot	Cov. (%/Plot)	Freq. (% of Plots)	Plants/ Plot
Anacardiaceae[a]												
Rhus trilobata-Skunkbush Sumac[b]				3.8	7.5	0.1	7.1	10.0	<0.1			
Boraginaceae												
Cryptantha fendleri-Fendler Cryptantha	16.6	62.5	---	0.9	22.5	---	0.1	2.5	---			
Chenopodiaceae												
Chenopodium leptophyllum-Slimleaf Goosefoot	0.1	5.0	<0.1									
Salsola kali-Russian Thistle	15.0	40.0	0.6									
Compositae												
Artemisia cana-Silver Sagebrush							0.2	5.0	---	0.6	12.5	0.2
Artemisia dracunculus-False Tarragon Sagebrush	12.5	45.0	0.5	7.1	32.5	0.3	17.9	62.5	1.5	12.1	55.0	1.4
Artemisia frigida-Fringed Sagebrush				0.1	5.0	0.1	2.1	12.5	0.5	1.3	15.0	0.2
Aster novae-angliae-Aster				0.1	2.5	---	0.1	2.5	---	0.6	5.0	0.1
Bahia dissecta-Ragleaf Bahia	0.4	2.5	0.1	0.1	5.0	<0.1	0.4	2.5	0.1	0.2	7.5	0.1
Fallugia paradoxa-Apache-plume				1.0	5.0	0.1						
Hymenoxys richardsonii-Pinque	0.5	7.5	<0.1				0.1	5.0	<0.1	2.0	17.5	0.2
Taraxacum officinale-Dandelion				0.9	10.0	0.1						
Tragopogon dubius-Salsify	0.1	2.5	---									
Euphorbiaceae												
Euphorbia sp.-Euphorbia	0.4	2.5	<0.1									
Fagaceae												
Quercus turbinella-Shrub Live Oak	0.1	2.5	---									
Graminae	27.4	85.0	---	63.9	100.0	---	33.8	87.5	---	46.8	90.0	---
	27.4	85.0	---	63.9	100.0	---	33.8	87.5	---	46.8	90.0	---
Leguminosae												
Vicia sp.-Vetch							0.8	7.5	0.1			
Saxifragaceae												
Ribes cereum-Wax Currant				0.1	2.5	---						
Scrophulariaceae												
Castilleja integra-Wholeleaf Paintbrush										0.4	2.5	0.2
Solanaceae												
Physalis sp.-Groundcherry	0.1	2.5	<0.1									
Solanum sp.-Nightshade										0.1	2.5	<0.1

[a]Family name.
[b]Genus, species, and common name.

deposition, and, possibly, to establish uranium indicator plants. Cannon[9] did related work on how uranium ore deposits affected vegetation on the Colorado Plateau. She noted that plants such as milk-vetch (Astragalus spp.) and Indian ricegrass (Oryzopsis hymenoides) that accumulate selenium and sulfur could be used as indicators of uranium ore deposits. Other uranium indicator plants, which were not selenium and sulfur accumulators, were rabbitbrush (Chrysothamnus viscidiflorus), shadscale saltbrush (Atriplex confertilolia), Mormon tea (Ephedra viridis), and grasses, such as galleta (Hilaria jamesii), cheatgrass (Bromus tectorum), and fendler three-awn (Aristida fendleriana). Those plants were found at an altitude of 4900 ft (1494 m). Studies in areas containing uranium ore on higher mesas in southwestern Colorado at altitudes of 6000-8000 ft (1829-2438 m) showed uranium-tolerant vegetation to be predominately juniper (Juniperus monosperma), scrub-oak (Quercus gambelii), serviceberry (Amelanchier utahensis), and cliffrose (Cowania mexicana). Plants found to be particularly intolerant to uranium deposits were sagebrush (Artemisia begelovii) and hop-sage (Grayia brandegei). Correlations of Cannon's results with the present study are not clear because each is concerned with different forms of uranium, different geographic locations, and different lengths of exposure to uranium.

On test lines at all the sites, plants with the highest canopy coverage, frequency, and/or density values included grasses such as bottlebrush squirreltail (Sitanion hystrix), sagebrush (Artemisia dracunculus), Russian thistle (Salsola kali), and Belvedere summer-cypress (Kochia scoparia). Grasses and two species of sagebrush (Artemisia dracunculus and A. cana) showed the highest canopy coverage, frequency, and/or density values on control lines at all sites. Russian thistle, Belvedere summer-cypress, and bottlebrush squirreltail are common in disturbed areas such as roadsides.[11] Apparently, the most significant factors affecting plant distribution and the results of this study are disturbances, such as burning resulting from weapons tests, and the construction of the mounds at E-F Site, rather than uranium concentrations in these areas. The control areas were not adequate for determining how uranium affects plants. This was particularly noticeable at E-F Site, where the test lines were on a man-made hill and the control lines were in undisturbed areas. To provide proper comparisons between test and control areas, control sites should be located in areas more similar to test areas, with the same amount of disturbance and same degree and direction of slope. Such siting would reduce, or possibly eliminate, the effects of factors other than uranium concentrations on plant distributions.

Plant community analyses were continued during June 1975 to determine vegetative changes as a function of season. All plots permanently marked in November 1974, except Minie Site, were reread using the techniques and analyses previously described. Results are shown in Tables X and XI. Test lines at E-F Site yielded six species of plants, compared to only four found the previous fall. K. scoparia, S. kali, and S. hystrix were again found on all three test lines, along with Sisymbrium altissimum. Coverage by the three dominant species was considerably reduced from November 1974, indicating that these species had not reached maturity, as was verified by observation. S. kali (87.5%) and S. hystrix (85%) were most frequent on Test Lines 1 and 2, respectively; K. scoparia was most frequent on Test Line 3. S. kali and S. hystrix had increased on Test Line 1 and 3, and decreased on Line 2, compared to November values. K. scoparia occurred less often on all three lines, although these decreases are probably not significant. Density of the three dominant plant species was not recorded in June.

TABLE X

E-F SITE VEGETATION ANALYSES. JUNE 1975

Plant Taxon	Test Line 1			Test Line 2			Test Line 3		
	Coverage (%/Plot)	Frequency (% of Plot)	Plants/ Plot	Coverage (%/Plot)	Frequency (% of Plot)	Plants/ Plot	Coverage (%/Plot)	Frequency (% of Plot)	Plants/ Plot
Chenopodiacea									
Kochia scoparia-Belvedere Summer-cypress	2.8	67.5	—	1.1	42.5	—	1.9	82.5	—
Salsola kali-Russianthistle	1.0	87.5	—	1.0	60.0	—	0.7	65.0	—
Compositae									
Grindelia spp.-Gumweed							0.5	5.0	0.1
Cruciferae									
Sisymbrium altissimum-Tumble Mustard	0.6	27.5	0.5	0.2	12.5	0.1	0.3	15.0	0.1
Graminae									
Bromus tectorum-Downy Brome				<0.1	2.5	—			
Sytanion hystrix-Bottlebrush Squirreltail	2.3	85.0	—	1.3	67.5	—	1.4	65.0	—
					Control Lines				
Anacardiaceae									
Rhus trilobata-Skunkbush Sumac				0.1	5.0	—	0.1	2.5	—
Boraginaceae									
Cryptantha fendleri-Fendler Cryptantha	<0.1	2.5	<0.1				0.3	30.0	0.8
Compositae									
Artemisia cana-Silver Sagebrush	0.2	20.0	0.5	0.3	25.0	0.3	<0.1	2.5	<0.1
Artemisia drancunculus-False Tarragon Sagebrush	0.1	7.5	0.1	0.5	25.0	1.0	0.4	27.5	0.5
Artemisia frigida-Fringed Sagebrush							0.2	17.5	0.4
Chrysopsis villosa-Hairy Goldaster	0.8	5.0	0.1	0.1	7.5	0.1	0.3	20.0	0.1
Erigeron divergens-Spreading Fleabane				0.1	5.0	0.1			
Hymenoxys richardsonii-Pinque				<0.1	2.5	<0.1	0.2	12.5	0.2
Tragopogon dubius-Salsify							0.1	5.0	0.1
Fagaceae									
Quercus gambelii-Gambel Oak	1.2	37.5	0.0	1.23	27.5	0.0			
Quercus turbinella-Shrub Live Oak				0.5	10.0	0.0			
Graminae	2.2	80.0	—	3.5	95.0	—	3.4	97.5	—
Geraniaceae									
Geranium spp.-Geranium							<0.1	2.5	<0.1
Leguminosae									
Lupinus argenteus-Silvery Lupine							0.5	5.0	0.0
Vicia spp.-Vetch							0.7	42.5	0.6
Melilotus officinalis-Sweetclover				<0.1	2.5	<0.1			
Linaceae									
Linum spp.-Yellow Flax	<0.1	2.5	<0.1				0.2	17.5	0.3
Polemonicaeae									
Scarlet gilia	<0.1	2.5	<0.1						
Polygonaceae									
Eriogonum racemosum-Redroot Eriogonum							<0.1	2.5	<0.1
Rosaceae									
Cercocarpus montanus-True Cercocarpus	0.1	7.5	0.0						
Scrophylariaceae									
Castilleja integra-Wholeleaf Painthrush							0.1	7.5	0.2

TABLE XI

LOWER SLOBOVIA AND CONTROL SITE VEGETATION ANALYSES, JUNE 1975

Plant Taxon	CONTROL			LOWER SLOBOVIA-LINE 1			LOWER SLOBOVIA-LINE 2		
	Coverage (%/Plot)	Frequency (% of Plot)	Plants/ Plot	Coverage (%/Plot)	Frequency (% of Plots)	Plants/ Plot	Coverage (%/Plot)	Frequency (% of Plot)	Plants/ Plot
Anacardiaceae									
Rhus trilobata-Skunkbush Sumac				0.2	5.0	0.0	0.4	12.5	0.0
Boraginaceae									
Cryptantha fendleri-Fendler Cryptantha	0.1	5.0	0.1	0.3	22.5	0.5	0.1	5.0	0.1
Compositae									
Artemisia dracunculus-False Tarragon Sagebrush	1.1	60.0	1.4	0.4	15.0	0.4	1.5	60.0	1.5
Artemisia frigida-Fringed Sagebrush	0.4	30.0	0.6	0.1	2.5	0.1	0.3	20.0	1.1
Bahia dissecta-Ragleaf Bahia	0.3	2.5	0.5						
Fallugia paradoxa-Apache-plume				0.5	2.5	0.0			
Hymenoxys richardsonii-Pinque	0.3	15.0	0.3	<0.1	2.5	<0.1			
Tragopogon dubius-Salsify	0.3	2.5	0.0	<0.1	2.5	0.0	<0.1	2.5	<0.1
Cruciferae									
Sisymbrium altissimum-Tumble mustard				0.3	20.0	0.3	0.1	10.0	0.1
Graminae	2.8	92.5	—	2.9	97.5	—	2.4	85.0	—
Leguminosae									
Lupinus argenteus-Silvery Lupine	0.5	5.0	<0.1						
Vicia spp.-Vetch							0.3	2.5	0.0
Polemoniaceae									
Gilia aggregata-Skyrocket Gilia							0.3	2.5	0.3
Scrophylariaceae									
Castilleja integra-Wholeleaf Paintbrush	0.2	15.0	0.2						

An increase of six plant species was recorded on E-F control lines. Again, only S. hystrix was common to both test and control lines. Members of the grass family, Graminae, showed the highest coverage and frequency values on control lines. Grass coverage on the control lines was drastically reduced from November values; frequency values showed no major difference.

Other than the grasses, three members of the family Compositae which had been found on all three control lines in November were also found on all lines in June. These were Artemisia cana, A. dracunculus, and Chrysopsis villosa. These species also showed generally reduced coverage; but frequency and density were about the same as in November.

Nine species of plants were found on each of the three lines at LS and Control Sites, which was a one-species decrease on each of the two lines at Lower Slobovia. Three new species of plants not encountered in November were identified on the Control Site plots in June. Two and four new species were also identified on Lines 1 and 2, respectively, at Lower Slobovia. Four species, Cryptantha fendleri, Artemisia dracunculus, A. frigida, and Tragopogon dubins, were found on all three lines in June. The grasses gave highest coverage and frequency on all three lines, and were too numerous for density determinations. As was true at E-F Site, coverage by grasses and most other plant species was much reduced in June, but frequency was generally about the same. Five species, Rhus trilobata, Fallugia paradoxa, Sisymbrium altisimum, Vicia spp., and Gilia aggregata, were identified on one or both lines at Lower Slobovia, but not at Control Site. Three species, Bahia dissecta, Lupinus argenteus, and Castilleja integra were found only at Control Site.

Other than the grasses which were again all analyzed as a group, A. dracunculus was the forb that had the highest coverage, frequency, and density on all lines, except for coverage on Line 1.

Plant data gathered in November must be more carefully studied in conjunction with present and future data before definitive responses to elevated uranium concentrations can be identified. Present results, however, indicate dominant species at each site which can be studied for uranium concentrating processes on a species level and seasonal basis. At E-F Site, S. hystrix is the dominant species in the spring and early summer, whereas K. scoparia and S. kali do not mature until late summer. At the other sites, A. dracunculus, the dominant forb, matures after the summer rains start in July or August. Bromus tectorum is the important spring and early summer grass, which gives way to Bouteloua eripoda (black grama) in late summer and fall.

B. Small Mammal Populations Associated with the Plant Communities

This initial small mammal study was to determine species composition and diversity, densities, minimal biomass, and uranium concentrations in this component of the ecosystem. Modified North American Census of Small Mammals (NACSM) trapping lines[12] (Figs. 3 and 4) in the four study areas were permanently marked in November 1974. Two parallel trap lines 33 m apart were established at each site. Each line was 160 m long and consisted of 17 stations at 10-m intervals. Three snap traps baited with peanut butter were placed within 1 m of each station in positions most likely to catch small mammals. The trap lines were operated for three consecutive nights.

In June 1975, only one line at each site was operated. Live-trapping was used so that data on movement patterns could be accumulated for this and future trapping sessions. The one trap line at each site was extended from 17 stations to the standard 20 stations/line.

Data recorded on all animals at time of capture included capture location, species identification, sex, age, class, reproductive condition, weight, and presence of ectoparasites. The snap-trapped animals were then packaged individually and frozen pending dissection. Measurements of each specimen at dissection included lengths of total body, tail, ear, and hind foot.

The LASL study sites were trapped during November and December 1974 (late fall trapping session) and June 1975 (late spring trapping session). A total of 1224 trap-nights at four sites during the fall yielded two species and 124 animals captured at all sites by snap-trapping. The spring live-trapping session at three sites yielded 126 individuals in 203 total captures of two species during 640 trap-nights.

Both the deer mouse (Peromyscus maniculatus) and the western harvest mouse (Reithrodontomys megalotis) were trapped at all sites (Table XII). Nine pocket gophers (Thomomys bottae) were captured in dead-traps in June 1975. Peromyscus comprised 70.2% of captures in the fall and 87.7% in the spring.

Trap line positions were determined by anticipated fallout pathways of particulate material from the firing sites. Therefore, the distance between parallel trap lines was less than that used for standard NACSM estimates of home ranges and populations.

The size of the area sampled for rodent populations (Table XIII) was determined using Brandt's procedure.[13] His procedure uses home ranges, or average distance between successive points of capture. Initial home range values were also obtained from Brandt by assuming that the differences in different habitats were not significant for these calculations. The values, 52.4 m for Peromyscus and 32.9 m for Reithrodontomys, were averages for both sexes during five trapping periods on a grid. The 33-m distance between the parallel trap lines was treated as an overlapping home range area for both species.

Estimated Peromyscus and Reithrodontomys densities, expressed as number per hectare, are presented in Table XIII. Data on Thomomys are incomplete. In June, there were significant density differences among

TABLE XII

SMALL MAMMAL TRAPPING AT LASL URANIUM STUDY SITES IN NOVEMBER 1974 AND JUNE 1975

Site/ Date	Total Species Captured	Total Individuals Captured	Peromyscus[a] maniculatus M:F	Reithrodontomys megalotis M:F	Thomomys bottae M:F
E - F	3	64			
Nov 74			15:6	0:1	
Jun 75			20:19	---	2:1
Minie	2	56			
Nov 74			20:17	13:6	---
Jun 75			---	---	---
Lower Slobovia	3	77			
Nov 74			11:7	6:6	---
Jun 75			18:18	3:2	1:5
Control	2	62			
Nov 74			5:6	3:2	---
Jun 75			24:18	4:0	---

[a]Sex ratios expressed as male:female.

TABLE XIII

ESTIMATED SMALL MAMMAL DENSITIES AND MINIMAL BIOMASSES AT LASL URANIUM STUDY SITES

Site	Genus	Area Sampled per Site (hectares) Nov 74	Jun 75	Density (number/hectare) Nov 74	Jun 75	Biomass (wet carcass/mg/m²) Nov 74	Jun 75
E - F	Peromyscus	3.67	2.83	5.7	13.8	10.3	23.3
	Reithrodontomys	2.35	1.60	0.4	----	----	----
Minie	Peromyscus	3.67		10.1	----	17.6	----
	Reithrodontomys	2.35		8.1	----	8.0	----
Lower Slobovia	Peromyscus	3.67	2.83	4.9	12.7	7.8	17.6
	Reithrodontomys	2.35	1.60	5.1	3.1	5.0	3.4
Control	Peromyscus	3.67	2.83	3.0	14.8	5.3	20.1
	Reithrodontomys	2.35	1.60	2.1	2.5	2.0	2.8

TABLE XIV

WEIGHTS OF ADULT SMALL MAMMALS CAPTURED AT LASL URANIUM STUDY SITES

(Values are expressed as mean ± 1 std dev for that number (n) of animals.)

Site	Sampling Period	Peromyscus maniculatus M	Peromyscus maniculatus F	Reithrodontomys megalotis M	Reithrodontomys megalotis F
E - F	Nov 74	17.0±2.0 (13)	17.8±5.3 (6)	---	---
	Jun 75	17.2±1.9 (18)	19.0±3.4 (14)	---	---
Minie	Nov 74	17.8±2.7 (17)	21.6±3.2 (11)	10.0 ±2 (13)	9.83±1.2 (6)
Lower	Nov 74	15.9±2.5 (7)	20.6±4.8 (5)	10.42±2.0 (6)	9.17±0.6 (6)
Slobovia	Jun 75	16.1±2.1 (11)	17.1±3.6 (10)	10.8 ±2.6 (2)	13.8 ±0.4 (2)
Control	Nov 74	15.4±1.8 (4)	24.6±3.9 (4)	8.67±1.5 (3)	10.25±1.8 (2)
	Jun 75	15.5±1.4 (9)	17.8±2.0 (9)	---	11.0 ±2.3 (4)

species as measured by Student's t test (t value = 10.6, 4 degrees of freedom) at the 95% confidence level; however, there was no such significant difference in the November 1974 trapping results. Total Peromyscus captures per site were significantly greater than Reithrodontomys captures in both the fall trapping session ($t = 1.84$, 6 d.f., $P \leq 0.10$) and the spring session ($P \leq 0.01$, $t = 15.6$, 4 d.f.).

Mean adult weights by species are listed in Table XIV. Peromyscus males in the DU study sites seemed generally heavier than those at Control Site. A one-way analysis of variance of initial fall trapping results indicated that males from E-F and Minie Sites were significantly ($P \leq 0.10$) heavier than those from Control Site (E-F, F value = 3.4; 1 and 14 d.f.; Minie, F = 3.0; 1 and 19 d.f.). Males captured in the spring at E-F Site were again significantly ($P \leq 0.05$) heavier than Control Site males (F = 5.7; 1 and 25 d.f.). For Peromyscus females, this trend was reversed; females from Control Site generally weighed more than those from E-F and LS Sites, although the differences were not significant at the 90% confidence interval. Higher mean female weights and the larger standard deviations were attributable to pregnant females in the autumn population.

Mean adult Reithrodontomys weights showed the same trends, although the differences were not significant ($P \leq 0.10$) in the fall samples. Males were generally heavier at the uranium sites; females, at Control Site. Too few Reithrodontomys were trapped in the spring for meaningful comparisons.

Peromyscus male:female ratios greater than 1 were recorded at all but one site (Table XII) during each trapping session. This finding was consistent with Peromyscus data in the literature.[14] Reithrodontomys sex ratios also seemed to favor males, as anticipated.[15] Explanations offered include real differences, sex differences in above-ground activity, and larger male home range, which results in greater trap exposure.

Valley pocket gophers, Thomomys bottae, were captured at E-F and Lower Slobovia Sites. Pocket gopher activity was noted at all sites, and they could conceivably make up a significant portion of the small mammal biomass. Their continuous burrowing and pushing of soil to the surface promotes vertical cycling and mixing of soil constituents and probably redistributes uranium. Future small mammal studies will emphasize T. bottae.

C. Small Macrofauna of Soil and Litter at LASL Study Sites

Litter- and soil-inhabiting invertebrates were extracted by use of the Tullgren funnel technique[16] from 1-dm^3 soil cores removed from areas of uranium contamination and nearby control areas at E-F and LS Sites. As far as possible, soil, vegetation, and topography of the experimental and control areas were similar at each site. The distributions of the organisms were characterized and compared to ascertain possible differences that might be due to ecological changes caused by presence of uranium.

The organisms obtained were 0.2-2.0 mm long. Microfauna <0.2 mm long, particularly microscopic forms, were not sampled, and few of the larger (>2.0 mm) animals, which would be better sampled by pitfall traps or other methods, were not studied.

1. Populations and Characteristics.

At least 70 species of invertebrates were collected from the limited number of soil cores extracted; we anticipate that >100 species will be identified as studies progress.

About 10 common species dominated the specimens. Relative densities of the major groups, expressed as per cent of all specimens extracted, were as follows:

Acarina (several species of mites)	70
Collembola (3 species of springtails)	16
Thysanoptera (1 specie of trips)	3
Hemiptera and Homoptera (many species)	1
Coleoptera (several species of beetles)	1
Diptera (flies, mainly one species)	3
Hymenoptera (mainly one species of ant)	3
Miscellaneous (10 groups, 20-30 families)	3

Table XV is a complete phylogenetic listing of the groups and an estimate of the numbers of species in each. The variety of animals did not differ greatly from that reported in other North American studies, although there seemed to be fewer Psocoptera (book lice), Chelonethida

TABLE XV

MACROFAUNA RECOVERED FROM LITTER AND SOIL SAMPLES AT LASL

Phylum	Class	Order	Family	No. of Species
1. Annelida	Oligochaeta			1
2. Nematoda				1
3. Arthropoda	Arachnida	Acarina		25 - 50
4.	Arachnida	Araneida		3
5.	Chilopoda		Lithobiidae	Lithodius?
6.	Symphyla			1
7.	Insecta	Thysanura		1
8.	Diplura	Iapygidae		1
9.		Collembola	Sminthuridae	1
10.			Poduridae	1
11.			Entomobryiidae	1
12.		Psocoptera		1
13.		Thysanoptera		1 - 3
14.		Hemiptera		1 - 3
15.		Homoptera	Cicadellidae	1 - 2
16.		Homoptera		2 - 4
17.		Coleoptera	Elateridae	1
			Staphylinidae	2
			Carabidae	1
			Scarabaeidae	1
			Phynchophoran	1
			Anthicidae	Notoxus
			Miscellaneous	1 - 3
18.	Lepidoptera			2 - 5
19.	Diptera		Cecidomyiidae	(7)
			Phoridae	10 - 15
			Tachinidae	
			Mycetophilidae	
			Muscidae	
20.		Hymenoptera	Formicidae	2
21.			Tiphiidae	2

(pseudoscorpions), and Araneida (spiders) than are commonly found in chaparral, desert, piñon-juniper, and coniferous forests of the western United States. This apparently reduced number is not presently considered significant.

A total of 3218 specimens was isolated from 97 valid litter and soil samples. Nearly 2300 of these were mites; with a relative density (RD = per cent of total animals) of 71% and a frequency (F = per cent of occurrence in samples) of 91%. The mites included 25-50 species, of which 10 were common. More than 500 springtails (RD = 16%, F = 68%) of 5 species (of which 2 were very common) were collected. The mean number of specimens per sample was 33. About half the samples contained <15 specimens, 5 contained 112-505 specimens, and the rest contained 15-90. Specimens were fewest in samples collected during dry periods, and the greatest numbers were found in cores taken during a 4-day period when rainfall totaled 0.88 cm. Most litter animals are sensitive to rainfall and soil moisture, and the greater numbers of animals found in the last samples were probably due to increased soil moisture.

2. Abundance of Various Species and Groups in Test and Control Areas. The frequency of an organism, or the per cent of samples in which it occurred, was considered a measure of its abundance because the various animals encountered in this phase of the study were of the same general size. Such frequencies are presented in Table XVI, along with a second value, relative frequency, for each group of animals to facilitate comparison with all other groups. In general, the data indicate that one is equally likely to find any group at the test areas and the control areas. Diptera were more abundant at the test areas, perhaps because of the more open habitat resulting from fires started during past tests.

The invertebrate studies were to determine whether animal populations in close contact with uranium would demonstrate

TABLE XVI

FREQUENCIES OF MAJOR MACROFAUNA GROUPS IN 97 CORE SAMPLES

(Relative frequencies, RF, are an expression of the per cent of each taxon relative to the frequency (F) for all groups).

Taxon	Index	Test Areas E-F	Test Areas Lower Slobovia	Control Areas E-F	Control Areas Control Site
Acarina (mites and ticks)	F	75	100	92	96
	RF	31	26	24	30
Collembola (springtails)	F	29	83	96	61
	RF	12	22	25	19
Thysanoptera (thrips)	F	17	17	8	30
	RF	7	4	2	10
Homoptera and Hemiptera (bugs)	F	33	17	31	7
	RF	7	4	8	5
Coleoptera (beetles)	F	25	21	12	30
	RF	10	5	6	10
Diptera (flies)	F	54	88	54	52
	RF	22	23	14	16
Hymenoptera (ants)	F	12	33	42	17
	RF	5	9	11	5
Miscellaneous	F	--	--	--	--
	RF	6	7	10	5
TOTALS	RF	100	100	100	100

measureable differences within each exposure level. The number of samples is inadequate to show whether such differences exist. Population densities of all groups except Acarina were less in the control areas than in the test areas.

The two control areas had generally similar invertebrate populations, although Collembola species were much fewer at Control Site. This reduction may be due to temperature and moisture factors that will require selection of a different sampling location.

Invertebrate populations in the intermediate uranium test site, Lower Slobovia, contained more individuals and taxonomic groups than those in the high uranium test site, E-F Site. However, the variety of species in the two sites was not significantly different. Throughout the study, there was difficulty in interpreting the data because of inconsistent trends due to an insufficient number of samples and interference of several environmental parameters other than a uranium difference among sites.

There was no evidence that observed differences in invertebrate populations were caused by toxic responses to uranium.

Similar results would be expected because of the physical disturbances of firing mound construction, fires, or other common human activities.

VII. SUMMARY AND CONCLUSIONS

The ecological consequences of releasing uranium to terrestrial ecosystems during development and testing of depleted uranium munitions were investigated. Soil samples from EAFB, Florida, were collected 60, 120, 180, and 240 ft (18, 37, 55, and 73 m) from armor plate target butts struck by depleted uranium penetrators. These were separate samples of the upper and lower 5 cm at each location. The highest uranium concentrations were in the top 5 cm. Samples from beyond about 20 m showed near-background levels of natural uranium, or about 2.3±1.0 μg/g (ppm). Samples taken at target bases contained an average of 800 ppm of uranium in the upper 5 cm; generally 30 times as much as in the lower 5 cm, indicating modest vertical movement of depleted uranium into the soil. Samples taken at 18 m contained averages of 20 and 2 ppm in the upper and lower 5 cm, respectively.

Two explosives-testing areas at LASL were selected for study on the basis of their use history: E-F Site, with averages of 2400 ppm of uranium (natural and depleted) in the upper 5 cm of soil and 1600 ppm at 5-10 cm; and two subplots at Lower Slobovia in which soil uranium concentrations were about 2.5 and 0.6% of the E-F Site values. Important concentration differences with depth and distance from detonation points were ascribed to the different explosive test designs peculiar to each area.

Vegetation samples at E-F Site contained about 320 ppm in November 1974 and about 125 ppm in June 1975. These differences were probably due to (1) variable external deposition over considerable time; (2) different species of plants available at different times; and (3) greater amounts of fresh growth in the June samples. Ratios of plant:soil uranium concentrations varied from 0.08 in November to 0.05 in June, within the range reported from other studies of plants in high uranium areas.

Small mammals trapped in November contained a maximum of 210 ppm of uranium in GI tract contents, 24 ppm in the pelt, and 4 ppm in the remaining carcass. In June, maximum concentrations were 110, 50, and 2 ppm in similar samples and 6 ppm in lungs. These data emphasize the importance of resuspension of respirable particles in the upper few millimeters of soil as a contamination mechanism in several components of the ecosystem.

Vegetation community analyses and initial results of the soil invertebrate studies did not reveal conclusive differences in the effects of the various gradients of uranium in the study and control sites. Soil and litter macrofauna diversities and populations seemed reduced at the high uranium study area compared to the adjacent control area, but more samples are required to determine the significance of the observation. The anamolous character of the E-F firing mound complicated the faunistic studies because it strongly influenced soil moisture, absorbed solar radiation, and aspect responses. The study areas may have to be moved to achieve similarity.

Both EAFB and LASL soil analyses indicated that relatively large fragments as well as fine particulates from uranium explosive tests corrode readily and then migrate into the soil at variable rates. Weathering is apparently faster in the humid environment and porous soil at EAFB than at LASL.

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Fig. A-1. Aerial view of E-F Site showing the firing mound (arrow). Note lack of vegetative overstory which has been burned and cleared.

Fig. A-2. Aerial view of Lower Slobovia (arrow) showing elimination of most of the overstory north of the firing mound. Control Site is in the lower right-hand corner of the photograph.

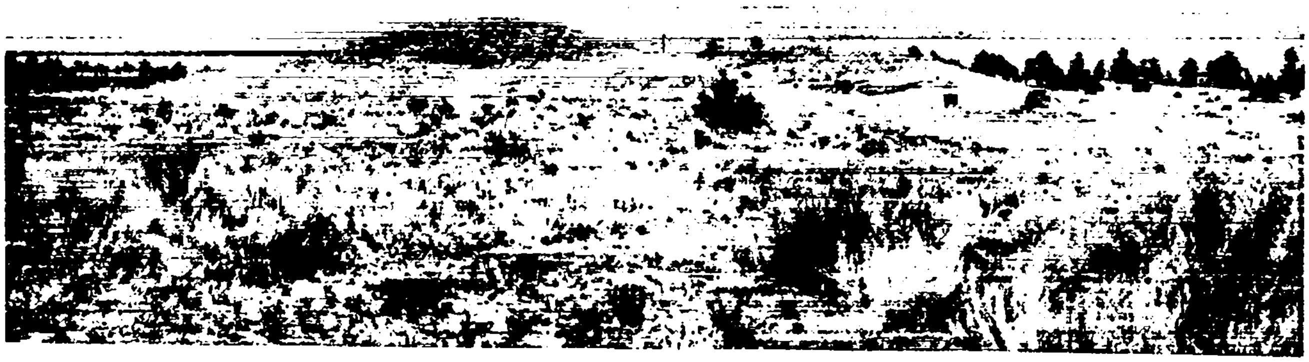

Fig. A-3. E-F Site from the southeast, again showing lack of overstory vegetation surrounding the Site. Weapons tests are conducted between the two man-made mounds.

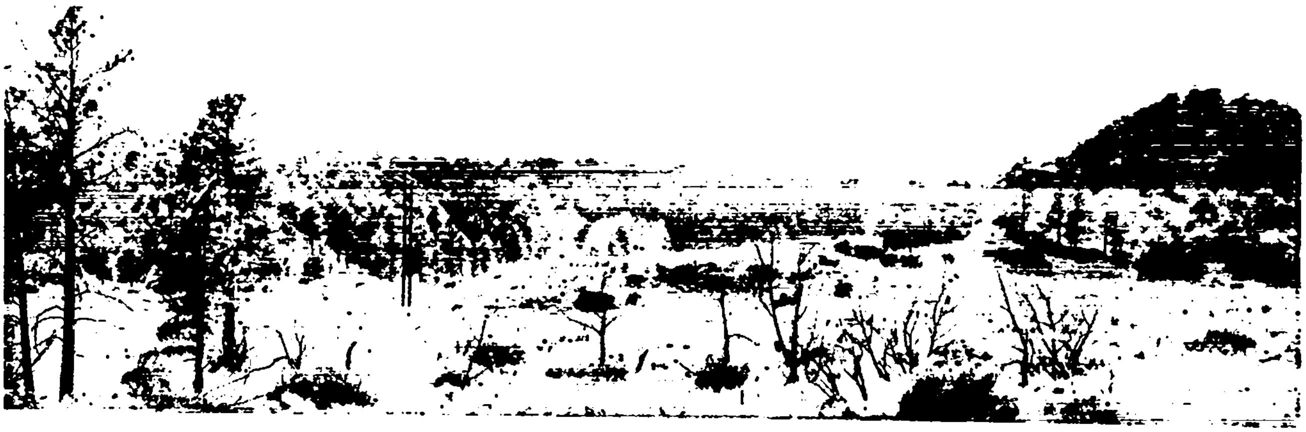

Fig. A-4. Lower Slobovia from the northeast. The firing mound is in the center. Again, most of the overstory vegetation has been burned.

Fig. A-5. Control Site from the east. The overstory is Ponderosa Pine (Pinus ponderosa), Juniper (Juniperus spp.), and Piñon Pine (Pinus edulis).

APPENDIX B

RESULTS OF URANIUM ANALYSES OF SOIL SAMPLES

TABLE B-I

NATURAL AND DEPLETED URANIUM IN SOIL SAMPLES
(Comparison of LASL and Eberline Analyses)

Sample	Designation[a]	LASL No.	Eberline No.	LASL (μg U/g)	Eberline (μg U/g)
Eglin	0-0-A	102	1	910	900
Standard	S-3		2	4270	3210
Eglin	0-0-B	103	3	26	31
	1-1-A	98	4	20	9.2
	1-1-B	91	5	N.D.	0.5
	1-3-A	93	6	6.7	4.2
	1-3-B	85	7	N.D.	0.3
	1-3-B[b]	85	8	N.D.	1.7
	1-5-A	89	9	2.0	2.0
	1-5-B	99	10	2.0	1.6
	1-7-A	87	11	0.8	2.9
Standard	S-4		12	3770	2850
Eglin	1-7-B	94	13	1.2	0.6
	1-9-A	95	14	11	12.7
	1-9-B	97	15	0.9	1.4
	1-11-A	96	16	94	40.5
	1-11-A[b]	96	17	94	40.5
	1-11-B	88	18	11	7.2
	1-13-A	92	19	18	22.5
	1-13-B	90	20	N.D.	1.3
	1-15-A	84	21	10	2.5
Standard	1633		22	1615	1580
Eglin	1-15-B	86	23	N.D.	1.5
	2-10-A	75	24	5.4	4.3
	2-10-B	74	25	4.1	0.9
	2-12-A[b]	72	26	19	1.6
	2-12-A[b]	72	27	19	1.7
	2-12-B	73	28	1.2	0.4
	2-2-A	78	29	1.8	2.0
	2-2-B[b]	76	30	N.D.	0.3
	2-2-B[b]	76	31	N.D.	0.2
Eglin	4-2-A	79	32	N.D.	0.6
	2-4-A	80	33	1.4	1.6
	4-2-B	77	34	N.D.	0.2
	3-9-A	68	35	4.3	2.6
	3-9-B	67	36	N.D.	0.1
	3-13-A	65	37	1.0	0.2
	3-13-B	66	38	N.D.	N.D.
	3-1-A	71	39	0.8	0.9
	3-1-B	64	40	N.D.	0.6
	3-5-A	69	41	2.0	1.0
Standard	S-3		42	4270	2760
Eglin	3-5-B	70	43	1.8	0.8
	3-7-A	63	44	2.9	1.6
	3-7-B	62	45	3.1	1.9
	4-10-A	60	46	0.6	0.7
	4-10-B	61	47	1.2	0.3
	4-12-A	58	48	1.0	0.9
	4-12-B	59	49	1.4	0.3
	2-4-B	81	50	N.D.	0.3
Sand 1	Blank		51	N.D.	0.3
Standard	S-4		52	3770	1680

TABLE B-I (Continued)

Sample	Designation	LASL No.	Eberline No.	LASL (μg U/g)	Eberline (μg U/g)
Eglin	4-4-A	56	53	1.2	0.6
	4-4-B	57	54	2.3	N.D.
	Control A	54	55	4.8	0.3
	Control B	55	56	3.0	0.3
	0-0-A	100	57	680	390
	0-0-B	101	58	40	26.5
	Ditch 5-3-A	82	59	N.D.	0.7
	Ditch 5-3-B	83	60	N.D.	0.3
EF-FP	III-3-L-5	52	61	1780	2.8
Standard	1633		62	1615	1520
LS	I-9-E-L-5	51	63	24	17.5
EF-FP	II-17-L-5[b]	24	64	1590	1230
EF-FP	III-17-L-5[b]	24	65	1590	1110
	III-7-L-5	50	66	220	133
	III-4-L-5	49	67	2200	1760
	III-9-L-5	46	68	78	44
	III-14-L-5	48	69	1470	940
	III-2-T-5	47	70	5100	3390
	III-3-T-5	44	71	2930	1180
Sand 1			72	N.D.	1.0
LS	I-8-E-T-5[b]	21	73	220	32
	I-8-E-T-5[b]	21	74	220	23
	I-5-C-T-5	41	75	139	16
	II-4-SC-L-5	42	76	19	1.2
EF-FP	III-9-T-5	43	77	386	420
	III-13-L-5	5	78	660	620
	III-10-T-5	38	80	886	940
	III-11-L-5	39	81	158	164
Sand 1			82	N.D.	0.2
EF-FP	III-17-T-5	40	83	1460	1230
	III-12-L-5[b]	35	84	264	345
	III-12-L-5[b]	35	85	264	280
LS	I-SW-T-5	45	86	5.1	3.4
EF-FP	III-11-T-5	34	87	7550	590
	III-13-T-5	36	88	1810	880
	III-10-L-5	37	89	250	295
	III-18-T-5	10	90	1760	760
	III-6-L-5	14	91	252	130
Sand 1			92	N.D.	0.6
LS	I-4-W-T-5	20	93	139	190
EF-FP	III-16-T-5	53	94	1840	1080
	III-6-T-5	12	95	646	510
	III-8-L-5	9	96	75	130
	III-12-T-5	1	97	1240	880
	III-15-L-5	29	98	285	320
LS	II-3-SC-T-5[b]	31	99	2.7	2.6
	II-3-SC-T-5[b]	31	100	2.7	2.0

[a]A = upper 0.5 dm; B = lower 0.5 dm.
[b]Replicate samples submitted to Eberline
AEC Ref. Sample S-3 0.418%
AEC Ref. Sample S-4 0.375%
U. S. Bureau of Standards Fly Ash 1633 11 μg/g

TABLE B-II

LASL URANIUM ANALYSIS OF EGLIN AFB SOILS

EAFB Sample No.[a]	LASL Lab No.	Field Weight No.	Lab Sample (grams)	μg U/g
0-0-A	102	910	5.574	910 ±91
0-0-A	100	684	8.921	680 ±68
0-0-B	103	784	6.264	26 ±3
0-0-B	101	676	6.432	40 ±4
1-1-A	98	869	5.268	20 ±2
1-1-B	91	490	6.249	<0.6 ±0.6
1-3-A	93	770	8.314	6.7 ±0.7
1-3-B	85	840	6.904	<0.6 ±0.6
1-5-A	89	973	7.338	2.0 ±0.2
1-5-B	99	990	7.347	2.0 ±0.2
1-7-A	87	955	5.362	0.84±0.1
1-7-B	94	690	5.541	1.19±0.1
1-9-A	95	746	5.993	10.8 ±1.1
1-9-B	97	808	6.735	0.90±0.1
1-11-A	96	771	5.133	94 ±9
1-11-B	88	733	6.476	11.2 ±1.1
1-13-A	92	846	6.854	17.5 ±1.8
1-13-B	90	562	5.240	<0.6 ±0.6
1-15-A	84	880	5.861	10.2 ±1.0
1-15-B	86	765	6.228	<0.6 ±0.6
2-2-A	78	1006	7.905	1.83±0.2
2-2-B	76	698	6.646	<0.6 ±0.6
2-4-A	80	905	6.598	1.44±0.2
2-4-B	81	820	4.746	0.6 ±0.6
2-10-A	75	818	5.788	5.4 ±0.5
2-10-B	74	796	6.569	4.1 ±0.4
2-12-A	72	950	8.259	19.4 ±2.0
2-12-B	73	783	8.009	1.25±0.2
3-1-A	71	1018	7.362	0.75±0.1
3-1-B	64	522	7.408	<0.6 ±0.6
3-5-A	69	796	3.224	1.95±0.2
3-5-B	70	726	7.132	1.82±0.2
3-7-A	63	1485	8.033	2.9 ±0.3
3-7-B	62	806	4.362	3.1 ±0.3
3-9-A	68	711	8.442	4.3 ±0.4
3-9-B	67	846	6.692	<0.6 ±0.6
3-13-A	65	527	8.392	1.01±0.1
3-13-B	64	522	7.408	<0.6 ±0.6
4-2-A	79	929	4.738	<0.6 ±0.6
4-2-B	77	794	4.080	<0.6 ±0.6
4-4-A	56	878	6.496	1.23±0.2
4-4-B	57	872	7.098	2.3 ±0.3
4-10-A	60	644	6.623	0.6 ±0.1
4-10-B	61	697	6.641	1.2 ±0.2
4-12-A	58	713	5.274	1.04±0.2
4-12-B	59	618	5.539	1.44±0.2
5-3-A Ditch	82	526	6.657	<0.6 ±0.6
5-3-B Ditch	83	868	6.273	<0.6 ±0.6
Control A	54	809	7.562	4.8 ±0.5
Control B	55	1085	5.705	3.0 ±0.3

[a]A = upper 0.5 dm; B = lower 0.5 dm.

TABLE B-III

LASL URANIUM ANALYSIS RESULTS: E-F SITE

LASL Sample No.	Sample Depth[a]	Lab No.	Field Weight (grams)	Lab Sample (grams)	μg U/g
I-1	T-5	175	780	7.591	1100±110
I-1	L-5	147	613	8.840	255±26
I-2	T-5	174	823	7.154	23400±2340
I-2	L-5	176	552	6.377	1030±103
I-3	T-5	159	735	7.651	2500±250
I-3	L-5	169	571	7.426	800±80
I-4	T-5	142	661	6.523	780±78
I-4	L-5	140	538	6.573	213±21
I-5	T-5	132	597	6.276	1300±130
I-5	L-5	136	580	6.160	320±32
I-6	T-5	146	538	6.845	416±42
I-6	L-5	150	457	5.438	276±28
I-7	T-5	152	530	5.781	1700±170
I-7	L-5	172	522	5.730	670±67
I-8	L-5	139	951	6.238	149±15
I-9	T-5	135	431	8.730	265±27
I-9	L-5	163	715	6.276	104±11
I-10	T-5	128	543	6.140	2300±230
I-10	L-5	129	739	8.196	323±33
I-11	T-5	134	451	5.357	1100±110
I-11	L-5	153	755	5.169	2500±250
I-12	T-5	133	690	6.791	1900±190
I-12	L-5	131	760	7.491	1215±122
I-13	T-5	167	618	6.325	1450±145
I-13	L-5	154	788	6.536	1230±123
I-14	T-5	170	619	5.630	2130±213
I-14	L-5	130	706	7.296	2400±240
I-15	T-5	151	837	5.664	2030±203
II-1	T-5	155	628	6.206	1600±160
II-1	L-5	160	645	5.772	171±17
II-2	L-5	168	696	7.479	26±3
II-3	T-5	157	656	6.247	7200±720
II-3	L-5	148	734	5.434	1240±124
II-4	T-5	165	534	6.500	1000±100
II-4	L-5	161	565	5.713	2300±230
II-5	T-5	171	538	6.526	1840±184
II-5	L-5	162	652	7.870	2000±200
II-6	T-5	177	537	6.737	1300±130
II-6	L-5	173	628	7.664	326±33
II-7	T-5	158	572	5.407	1120±112
II-7	L-5	145	914	7.234	263±26
II-8	T-5	144	645	8.435	865±87
II-8	L-5	143	1008	8.634	625±63
II-9	T-5	156	613	6.386	3500±350
II-9	L-5	137	614	8.066	1430±143
II-10	T-5	138	536	7.056	600±60
II-10	L-5	166	740	7.919	215±22
III-1	T-5	4	646	4.314	4520±450
III-1	L-5	33	896	6.363	5500±550
III-2	T-5	47	921	8.948	5100±510
III-2	L-5	3	1100	5.422	30000±3000
III-3	T-5	44	853	6.310	2930±290
III-3	L-5	52	912	7.012	1780±178

TABLE B-III (Continued)

LASL Sample No.	Sample Depth[a]	Lab No.	Field Weight (grams)	Lab Sample (grams)	µg U/g
III-4	T-5	8	802	3.381	1660±166
III-4	L-5	49	913	9.035	2200±220
III-6	T-5	12	596	4.800	646±65
III-6	L-5	14	716	5.350	252±25
III-7	T-5	11	546	4.947	950±95
III-7	L-5	50	689	5.207	220±22
III-8	T-5	13	626	4.855	525±53
III-8	L-5	9	833	3.412	75±8
III-9	T-5	43	514	6.348	386±39
III-9	L-5	46	862	5.811	78±8
III-10	T-5	38	628	4.513	886±89
III-10	L-5	37	628	4.211	250±25
III-11	T-5	34	678	4.369	7550±755
III-11	L-5	39	761	6.657	158±16
III-12	T-5	1	746	4.350	1240±124
III-12	L-5	35	849	6.446	264±27
III-13	T-5	36	607	5.185	1810±181
III-13	L-5	5	671	4.182	660±66
III-14	T-5	26	516	5.151	1710±171
III-14	L-5	48	646	8.528	1470±147
III-15	T-5	30	552	6.597	675±68
III-15	L-5	29	739	5.430	285±29
III-16	T-5	53	579	6.789	1840±184
III-16	L-5	6	982	5.440	983±98
III-17	T-5	40	642	5.072	1460±146
III-17	L-5	24	780	4.153	1590±159
III-18	T-5	10	653	5.326	1760±176
III-18	L-5	27	626	6.659	116±12
III-19	T-5	32	779	5.586	1350±135
III-19	L-5	18	891	5.003	320±32

[a]T-5 = upper 0.5 dm; L-5 = lower 0.5 dm.

TABLE B-IV

LASL URANIUM ANALYSIS RESULTS

Lower Slobovia

Sample No.	Sample Depth[a]	Lab No.	Field Weight (grams)	Lab Sample (grams)	μg U/g
I-SW	T-5	45	547	5.309	5.1± 0.5
I-2-S	T-5	23	580	4.924	9.3± 0.9
I-3-SE	T-5	19	564	5.885	9.5± 1.0
I-4-W	T-5	20	601	5.783	139 ±14
I-5-C	T-5	41	608	5.336	139 ±14
I-6-C	L-5	28	674	6.283	8.8± 0.9
I-7-NW	T-5	17	654	5.011	16 ± 1.6
I-8-E	T-5	21	565	6.114	220 ±22
I-9-E	L-5	51	661	6.128	24 ± 3
I-10-NE	T-5	106	404	6.149	30 ± 3
I-11-N	T-5	105	1035	7.638	8.2± 0.8
I-12-N	L-5	115	1084	5.607	2.6± 0.3
II-1-SW	T-5	22	493	4.675	19 ± 2
II-2-SW	L-5	7	569	4.541	14 ± 1.4
II-3-SC	T-5	31	802	6.390	2.7± 0.3
II-4-SC	L-5	42	660	5.326	0.6± 0.6
II-5-SE	T-5	110	576	6.027	1.74± 0.2
II-6-SE	L-5	108	632	5.226	0.9± 0.1
II-7-C	T-5	104	592	4.612	27 ± 3
II-8-W	T-5	116	478	5.395	46 ± 5
II-9-NW	T-5	117	491	5.331	7.5± 0.8
II-10-NW	L-5	118	470	4.452	2.7± 0.3
II-11-E	T-5	107	518	7.112	23 ± 2
II-12-NE	T-5	109	508	4.094	4.8± 0.5
II-13-NE	L-5	111	613	7.139	0.6± 0.6
II-14-E	T-5	114	609	5.822	25 ± 3
Control (1)		112	1333	7.983	1.88± 0.2
Control (2)		113	1437	8.745	0.6± 0.6

Minie Site

Sample No.	Sample Depth[a]	Lab No.	Field Weight (grams)	Lab Sample (grams)	μg U/g
1-NW	T-5	127	539	5.639	5.9 ±0.6
2-W	T-5	126	513	6.610	5.3 ±0.5
3-SW	T-5	120	422	8.172	0.71±0.07
4-N	T-5	123	468	4.977	12.3 ±1.2
5-NE	T-5	121	576	8.561	0.99±0.10
6-E	T-5	124	719	6.435	1.79±0.18
7-SE	T-5	122	579	5.369	0.6 ±0.6
8-S	T-5	125	604	6.818	2.3 ±0.2
9-C	T-5	119	620	7.021	2.8 ±0.3

[a]T-5 = upper 0.5 dm; L-5 = lower 0.5 dm.

APPENDIX C

QUALITY CONTROL DATA FOR LASL URANIUM ANALYSES

Sample	Weight (grams)	Sample Fluorometric Readings (mg U/g)				Spiked Sample[a] (mg U/g)		mg U/g Sample[b]		CV
0-0-A-(A)	4.676	1.11	1.06	1.02	1.02	1.03	1.05	1.05	±0.03	0.03
0-0-A-(B)	4.604	1.22	1.10	0.87	0.97	1.00	1.09	1.04	±0.12	0.12
0-0-A-(C)	4.415	7.9	8.3	7.9	8.3	7.8	7.8	8.0	±0.2	0.03
1-1-A-(A)	4.994	0.027	0.027	0.029	0.029	0.039	0.042	0.032[c]	±0.007	0.22
1-1-A-(B)	4.616	0.015	0.011	0.009	0.019	0.011	0.015	0.013[c]	±0.004	0.31
1-1-A-(C)	4.717	0.012	0.012	0.012	0.010	0.033	0.039	0.020[c]	±0.013	0.65
5 LS-1C-T-5 (A)	4.262	0.019	0.018	0.023	0.025	0.049	0.025	0.026	±0.011	0.04
5 LS-1C-T-5 (B)	4.388	0.016	0.011	0.013	0.013	0.014	0.004	0.012	±0.004	0.33
5 LS-1C-T-5 (C)	4.155	0.014	0.013	0.014	0.013	0.037	0.052	0.024	±0.017	0.71
2 EF-FP-T-5 (A)	4.371	4.3	4.3	4.6	4.7	4.3	4.6	4.5	±0.19	0.04
2 EF-FP-T-5 (B)	4.332	2.5	3.3	2.9	2.7	3.7	3.8	3.2	±0.5	0.16
2 EF-FP-T-5 (C)	4.369	4.5	5.6	4.7	4.9	4.3	4.6	4.6	±0.20	0.04
3 EF-FP-T-5 (A)	4.402	2.7	2.7	2.4	2.4	2.4	2.5	2.5	±0.15	0.06
3 EF-FP-T-5 (B)	4.516	2.8	2.8	2.2	2.2	2.5	2.3	2.5	±0.28	0.11
3 EF-FP-T-5 (C)	4.157	2.6	2.5	2.3	2.3	2.5	2.5	2.4	±0.12	0.05
12 EF-FP-T-5 (A)	4.642	1.23	1.16	0.81	1.11	1.21	1.06	1.10	±0.15	0.14
12 EF-FP-T-5 (B)	4.255	1.18	1.23	1.12	1.18	1.19	1.22	1.19	±0.04	0.03
12 EF-FP-T-5 (C)	4.117	1.18	1.14	1.15	1.09	1.17	1.15	1.15	±0.03	0.03
6 EF-FP-T-5 (A)	4.332	0.39	0.58	0.58	0.42	0.57	0.57	0.52	±0.09	0.17
6 EF-FP-T-5 (B)	4.575	0.56	0.52	0.67	0.75	0.62	0.69	0.64	±0.09	0.14
6 EF-FP-T-5 (C)	4.238	0.58	0.59	0.73	0.67	0.67	0.54	0.63	±0.07	0.11

[a] 2 μg/g U added before analysis and later substracted from the results to check iron interferences with fluorometric data.

[b] Mean value ±1 standard deviation.

[c] Near detectable limit.