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Wayne C. Hanson
Felix R. Miera, Jr.
Environmental Science Group (H-12)

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A third year of study of the ecological consequences of exposure of terrestrial ecosystems at the Los Alamos Scientific Laboratory to elevated soil concentrations of natural and depleted uranium was completed. A uranium analytical technique that uses instrumental epithermal neutron activation analysis was developed and tested. It provided more accurate and expeditious results for soil and biota samples that contain >10-ng total uranium than did our other two techniques.

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Spatial variability in sampling for soil uranium distribution by a polar coordinate system was evaluated in randomly selected soil cores. Variations for surface (0- to 2.5-cm-deep) soils were 0.18 at 10 m from the detonation point and 0.96 at 50 m. Results were strongly influenced by past uranium dispersal patterns, variable leaching of uranium debris, and surface water runoff.

A total surface (0- to 5-cm) soil uranium inventory within a 12.6-ha circle centered on the E-F detonation point was estimated to be 3000 kg when calculated by soil uranium concentration isopleths and 4500 kg when using annuli of a polar coordinate sampling system.

Uranium concentrations in tissues of deer mice (Peromyscus maniculatus) and pocket gophers (Thomomys bottae) were sufficiently different to conclude that the greater bioavailability of uranium in the top few millimeters of soil at E-F Site, combined with the difference in grooming and food habits of the animals, resulted in greater contamination of deer mice than of pocket gophers.

Invertebrate populations inhabiting areas of high and medium soil uranium concentrations at LASL sites were sampled by pitfall trapping and insect net sweeps. There was no conclusive evidence of a differential population response to areas of relatively high uranium concentrations and to control areas.

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FURTHER STUDIES OF LONG-TERM ECOLOGICAL EFFECTS OF EXPOSURE TO URANIUM

by

Wayne C. Hanson and Felix R. Miera, Jr.

ABSTRACT

A third year of study of the ecological consequences of exposure of terrestrial ecosystems at the Los Alamos Scientific Laboratory to elevated soil concentrations of natural and depleted uranium was completed. A uranium analytical technique that uses instrumental epithermal neutron activation analysis was developed and tested. It provided more accurate and expeditious results for soil and biota samples that contain >10-ng total uranium than did our other two techniques.

Spatial variability in sampling for soil uranium distribution by a polar coordinate system was evaluated in randomly selected soil cores. Variations for surface (0- to 2.5-cm-deep) soils were 0.18 at 10 m from the detonation point and 0.96 at 50 m. Results were strongly influenced by past uranium dispersal patterns, variable leaching of uranium debris, and surface water runoff.

A total surface (0- to 5-cm) soil uranium inventory within a 12.6-ha circle centered on the E-F detonation point was estimated to be 3000 kg when calculated by soil uranium concentration isopleths and 4500 kg when using annuli of a polar coordinate sampling system.

Uranium concentrations in tissues of deer mice (*Peromyscus maniculatus*) and pocket gophers (*Thomomys bottae*) were sufficiently different to conclude that the greater bioavailability of uranium in the top few millimeters of soil at E-F Site, combined with the difference in grooming and food habits of the animals, resulted in greater contamination of deer mice than of pocket gophers.

Invertebrate populations inhabiting areas of high and medium soil uranium concentrations at LASL sites were sampled by pitfall trapping and insect net sweeps. There was no conclusive evidence of a differential population response to areas of relatively high uranium concentrations and to control areas.

I. INTRODUCTION

This report summarizes research from October 1, 1976, through September 30, 1977, on the ecological effects of exposure to uranium. Included are (1) a comparison of three different analytical techniques employed for uranium determinations; (2) analytical results from three sets of soil samples from test ranges at Eglin Air Force Base (EAFB), Florida; (3) an inventory estimate for uranium in the top 5 cm of soil from a 12.6-ha circle as well as the distribution of uranium in soil size fractions at the Los Alamos Scientific Laboratory (LASL) E-F Site; and (4) biotic responses to the chemical toxicity of environmental uranium.

The general scope and objectives of this study and the site descriptions were presented in the 1976 and 1977 completion reports.[1,2] Objectives of the research efforts reported here were:

(1) To describe the spatial variations of uranium concentrations in soil at E-F Site as functions of the soil depth and distance from the detonation point;

(2) To determine the distribution of uranium in soil size fractions as a function of soil depth and distance from the detonation point at E-F Site;

(3) To estimate the uranium inventory within a 200-m radius of the E-F detonation point in the 0- to 5-cm horizon;

(4) To examine the potential for redistribution of uranium from this site by creep and saltation; and

(5) To evaluate the responses of soil and vegetative invertebrates to uranium chemical toxicity at LASL sites.

These data have application to field situations at both EAFB and LASL, where substantial amounts of uranium have been expended in weapons testing programs.

II. METHODS

A. Analytical Procedures Development for Determination of Uranium in Soils

Rapid analysis for uranium in various matrices has become increasingly important with the advent of the energy crisis. The need for appreciable production of uranium to supply the nuclear facilities that offer alternatives to fossil fuel power plants has prompted hydrogeochemical survey programs to discover subsurface ore bodies in several countries.[3-6] Decontamination of areas in which radioactive materials have been stored or discharged usually involves uranium, though the chemical toxicity aspects of that element are often more important than radiological considerations. Such is the case in the military testing of depleted-uranium ($^{235}U/^{238}U < 0.0072$) penetrators at EAFB, where varying amounts of uranium are expended over test ranges that receive appreciable rainfall (155 cm/yr). Ecological consequences of uranium in the environment then are magnified because of weathering of uranium fragments and increased mobility of uranium in drainage areas.

The need for prompt definition of uranium concentrations in EAFB soils to monitor the movement of uranium and for a more expeditious means of processing appreciable LASL samples motivated our chemists to investigate and compare three uranium analytical techniques.[7] Fluorescence analysis (FA)[8] was used for all previously reported uranium determinations but requires that the sample be dissolved in HNO_3/HF mixture and retained in solution. FA is also very sensitive to quenching interferences and to exact conditions during pellet fusion and may occasionally exhibit poor precision. Thermal-neutron-induced delayed neutron counting (DNC)[9] methods are based on the assumption of a fixed uranium isotopic ratio ($^{235}U/^{238}U$) because ^{238}U does not participate in neutron production. If the ratio departs from 0.0072 (crustal abundance), large errors may occur in the determination of total uranium.

The availability of the pneumatic epithermal neutron facility at the LASL Omega West Reactor provided a unique capability to analyze soil samples by a third method,

instrumental epithermal neutron activation analysis (IENAA).[10] Both the IENAA and DNC methods are nondestructive; thus the same sample aliquot could also be examined by FA. Two-gram aliquots of 33 soil samples were randomly selected from a set of EAFB samples submitted for uranium determination and subjected to IENAA, DNC, and finally FA.

In the IENAA analysis, samples were first irradiated with epithermal neutrons (energy range ~280 to 1000 eV) for 2 min. After 2 to 4 days' decay, the samples were counted for 5 min each on a large Ge(Li) detector (FWHM = 1.9 keV at 1332 keV). The 228- and 278-keV transitions from the decay of ^{239}Np (physical half-life 2.35 days) were observed and used for quantitative analysis. Spectra of gamma rays were accumulated on pulse height analyzers, the regions of interest punched on paper tape, and the data reduced by electronic computer programs. International Atomic Energy Agency (IAEA) soils with certified uranium concentrations were used to standardize the analyses.

DNC measurements were performed on each sample by irradiating the sample for 20 s in a thermal-neutron flux. Irradiations were made at different reactor power levels, but in all cases, the thermal-neutron flux was monitored during the exposure by a fission ion chamber. The sample was pneumatically transferred to a neutron detector[11] of 27% efficiency and counted for 20 s following a 10-s delay. The neutron data were normalized to a constant flux, and the system was calibrated to samples of NBS SRM-1933, a soil of standardized uranium concentration. Uranium concentrations were calculated with the assumption that the ^{235}U abundance was normal.

In the FA method, soil samples were dissolved by standard techniques using acid digestion. Small volumes were pipetted onto 50-mg NaF/LiF pellets and fused for 2 min at 1200°C using a burner similar to that of Price et al.[12] The pellets were allowed to cool for 15 min and then the fluorescence at 245 nm was "read" on a fluorometer. The resulting data were reduced by computer to final concentrations.

B. Determination of Uranium in EAFB Soils

Sets of 83, 63, and 52 EAFB soil samples were received for uranium analyses at LASL as a part of EAFB range cleanup operations. The small size of the samples (20 g) precluded the usual grinding and homogenizing of the soil before aliquoting and analysis; therefore, 2-g aliquots were directly processed by the IENAA technique.

A portion of the second set of samples was used for the comparison of the three uranium analytical techniques described in the previous section.

C. Inventory Estimate and Distribution of Uranium in LASL E-F Site Soils

The polar coordinate sampling system devised for determining the soil uranium inventory at the LASL E-F Site study area was described in the 1977 completion report.[2] Briefly, samples were taken at intersections of radii that extended from the detonation point at each 45° azimuth and concentric circles 10, 20, 30, 40, 50, 75, 100, 150, and 200 m from the detonation point. A polyvinylchloride coring tube (2.5-cm-i.d.) was used to collect two 30-cm-deep soil cores spaced 0.5 m apart at each sampling location, yielding 144 soil cores total. The cores were subdivided into six vertical segments, beginning at the lower end of the core to minimize cross-contamination.

Thirty per cent of the duplicate cores collected from the NE, SE, SW, and NW quadrants were randomly selected for uranium analyses of whole samples to define the spatial variability of uranium with distance from the detonation point and with depth into the soil profile.

Forty randomly selected soil samples representing duplicate 0- to 5-cm- and 5- to 10-cm-deep cores collected from the N, E, S, and W quadrants at distances of 10, 20, 50, 100, 150, and 200 m from the detonation point were processed for soil

particle size analysis. They were mechanically separated into six size fractions by a sonic sifter that yielded sample components of <53-μm, 53- to 105-μm, 105- to 500-μm, 500- to 1000-μm, 1- to 2-mm, and 2- to 23-mm diameter. Small soil particles were blown from the larger soil separates with an air hose during sifting to minimize their carryover. The particle diameters may be further described according to US Department of Agriculture Soil Conservation Service standard soil size categories as follows.

Particle Diam (μm)	Size Fraction
<53	Silt and clay
53-105	Very fine sand
105-500	Medium and fine sand
500-1000	Coarse sand
1000-2000	Very coarse sand
2000-23000	Coarse fragments

Bagnold dust collectors (Fig. 1) were used to evaluate uranium particle movement by saltation and creep. Two such instruments were placed at the E-F Site, one near the detonation point and the other approximately 40 m NE, in the downwind vector of prevailing winds. These instruments are designed to collect wind-suspended particles at six separate 15-cm heights ranging from ground level (0 to 0.5 cm) to 75 cm above the ground surface. Samples were collected at monthly intervals beginning in April 1977; however, it was necessary to composite the first 3 months' collections to provide sufficient mass for chemical analysis. All samples were separated into size fractions of <100 μm and >100 μm before uranium chemical analyses.

An estimate of the uranium inventory in surface (0- to 5-cm-deep) soil within the 200-m-radius (12.6-ha) circle centered on the E-F Site detonation point was calculated by two different methods, both of which basically employed the same equations used in calculating the Potrillo Canyon uranium inventory reported last year.[2] The first method consisted of calculating the surface area enclosed by an annulus at the midpoint between each sampling distance (that is, the surface area from 0 to 5 m, 5 to 15 m, etc.) and applying a median uranium concentration derived from all sampling points within each area.

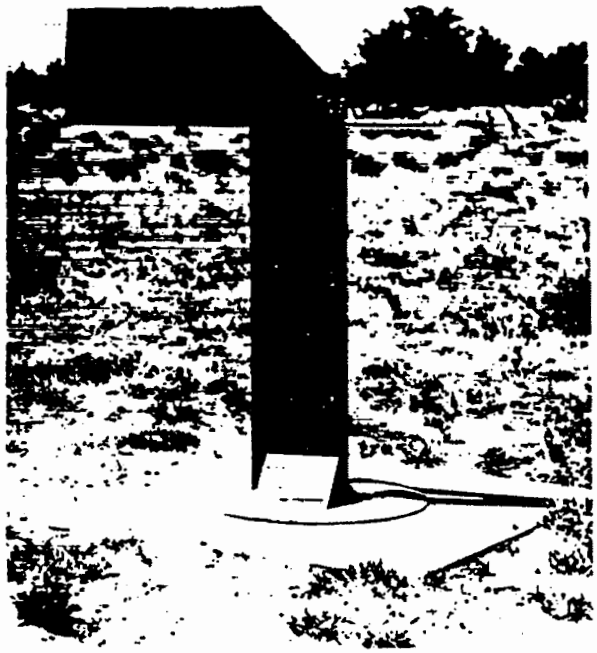

Fig. 1. Bagnold dust collector apparatus installed at field sampling location. Collection ports are located along upwind (right) edge. Collection boxes are situated in base.

The second method involved calculating the surface areas of six soil uranium concentration isopleths ranging from <30 to >3000 μg/g and multiplying by the median uranium concentration for each isopleth. The surface soil uranium concentrations were log-transformed and the location data converted from polar coordinate values to Cartesian coordinate values. A plane surface was generated by an electronic data processing program that interpolated between data points to establish isopleths for six

arbitrarily selected concentration gradients. In each method, the total uranium inventory was obtained by summing the values of the individual segments.

D. Uranium Determinations in Small Mammal Samples

Samples of two sympatric small mammal species *Peromyscus maniculatus* (deer mouse) and *Thomomys bottae* (valley pocket gopher), were trapped at E-F Site during April and May 1977. Deer mice were taken by snap traps in lines parallel to the two earth mounds that bracket the detonation point,[1] and pocket gophers were trapped at their mounds of freshly excavated dirt within a radius of 100 m from the detonation point. The trapping was done over a 3-week period to preclude immigration of transient animals. The animals were carefully dissected to minimize cross-contamination of internal organs and tissues by soil particles adhering to the fur.

Ashed (450°C) samples of the pelt, gastrointestinal (GI) contents, lungs, liver, kidneys, and carcass (skeleton and muscle) were pooled from pairs of animals to provide sufficient mass for IENAA.

E. Macrofauna Sampled at LASL Study Sites

Studies of the invertebrate communities at E-F and Lower Slobovia (LS) Sites were continued to evaluate possible effects of exposure to elevated levels of uranium upon populations. Sampling was accomplished by (1) pitfall traps, to sample the wandering forest-floor invertebrates, and (2) insect sweep nets, to collect the invertebrates associated with the understory vegetation in areas of high and medium levels of uranium in soil. Samples were collected at the same four locations from which soil cores were taken during 1975 and 1976 for extraction of soil- and litter-inhabiting invertebrates by Tullgren funnel techniques.

Five pitfall traps were installed at 10-m intervals along transects at E-F and LS Sites and at each of their control sites. Each trap was made of a 1-ℓ polyethylene bottle, the bottom of which was replaced by a funnel and apron that allowed it to be inverted and set flush with the ground surface within a permanently placed metal can. About 100 mℓ of 70% ethyl alcohol was placed in each trap as a collecting and preserving medium. Collection periods of 72 h each were made during 1976, one in March, three in May, one in June, two in September, and one in November.

A standard insect net was used to obtain three 50-sweep samples through understory vegetation at each of the four study sites during November 1975 and February, March, May, September, and November 1976.

III. RESULTS

A. Analytical Procedures Development

Comparisons of uranium concentrations determined by IENAA, DNA, and FA are presented in Table I. With the exception of 6 samples, the DNA results were low compared to the values obtained by the other two methods. This was expected because DNA measures ^{235}U and calculates a uranium concentration assuming normal isotopic abundance; these particular samples were EAFB soils slightly contaminated with depleted uranium rather than natural uranium, hence the low results.

With a few exceptions, the comparison of data obtained by IENAA and FA was very good, as shown in the ratio of the two sets of results. Deviations of this ratio from 1.0 indicate relative variations of the results. The mean of the ratio was 0.91 ± 0.24 (std dev), or if the very low ratio obtained for Sample No. 1868 was excluded, the ratio was 0.94 ± 0.19 (std dev). A least squares fit of a line through these data points was $y = 27.4 + 0.91x$, with a coefficient of determination (r^2) of 0.99. This indicated a slightly lower but trivial bias of the IENAA/FA ratio. Analysis of two standards also showed good agreement between the results obtained by IENAA, FA, and DNA and the certified value.

Considering these results, the significant reduction in cost and time, and the

TABLE I

URANIUM CONCENTRATIONS IN 20-g SOIL ALIQUOTS

DETERMINED BY THREE TECHNIQUES

Sample No.	IENAA (ppm)	DNA (ppm)	FA (ppm)	IENAA/FA
1651	14500	4370	14400	1.04
52	18800	5210	21500	0.87
60	1500	654	1680	0.89
1707	3.2	3.9	4.5	0.71
08	62	59	63	0.98
31	4600	2020	5500	0.84
33	2200	774	2400	0.92
34	3100	1056	3900	0.79
30	600	375	620	0.97
40	1440	712	1700	0.85
47	3.4	3.7	2.6	1.31
48	29	20	23	1.27
71	3400	1480	3500	0.97
72	5300	2090	6800	0.78
73	2000	678	2000	1.00
74	2200	726	2200	1.00
79	440	255	500	0.88
80	1000	484	1400	0.71
87	2.2	4.0	2.7	0.81
88	26	19	22	1.18
1811	3100	1280	3000	1.03
12	3600	1200	4200	0.86
13	2700	930	3300	0.82
14	2900	790	2600	1.11
19	330	225	360	0.92
27	1.3	3.9	3.1	0.58
28	9.0	7.5	6.6	1.36
51	2200	866	2000	1.10
52	8200	4630	8850	0.93
53	2200	823	2400	0.92
54	2200	701	2000	1.10
67	1.1	3.7	2.4	0.46
68	1.1	6.1	10	0.11
				$\bar{x}$ = 0.91
				s_x = 0.24
Standards				
NBS	10.6±0.6	10.6±0.6	8.6±1.0	(Certified Value = 11.6±0.2)
IAEA	118±5	128±2	112±7	(Certifed Value = 119)

increased reliability, IENAA was selected as the method to be used in most future uranium analyses in our laboratory. The detection limit for both FA and IENAA is considered to be 10-ng total uranium; however, results from materials that contain less than 1.0 ppm (= μg/g) are considered to be highly variable.[7]

B. Uranium Concentrations in EAFB Soils

Analytical results for the three sets of EAFB soil samples are presented in the Appendix as Tables A-I, A-II, and A-III. The samples were collected by EAFB personnel as a part of test range cleanup operations or other activities and our interpretation is limited to the analytical parameters of the data.

The data in Table A-I are mosly near-background levels of uranium contained in 2-g aliquots taken from six soil samples, each collected to a depth of 5 cm at the various sampling points. The small aliquot

masses precluded the soil sample grinding and homogenizing that usually precede our analyses and may have been a factor in creating greater variation in results than expected.

Table A-II presents uranium analytical results of samples taken from barrels of contaminated soil removed from EAFB test ranges by a contractor. Uranium concentrations ranged from 30 to 4900 ppm, and duplicate aliquots had Coefficients of Variation (CV = standard deviation/mean) of 0 to 0.68. Variability was usually greatest in samples that had uranium concentrations near the detection limit of 10 ng total.

Results presented in Table A-III are for samples taken in the same manner as those in Table A-I and are generally similar.

C. Soil Uranium Distribution at LASL E-F Site

1. Spatial Variability in Sampling for Uranium Distribution. Our 1977 completion report[2] discussed uranium distribution in E-F soils based on analyses of single samples taken at each sampling location. A "within sample" variability, due to sample processing and chemical analysis factors, was reported to range from 0 to 0.12. We now report data obtained from randomly selected duplicate samples, which were taken at locations 0.5 m from, and parallel to, those reported last year, so that we can determine the spatial variability occurring in our polar coordinate sampling.

CVs for surface (0- to 2.5-cm-deep) soils at various distances from the detonation point are shown in Table II. Values for sample pairs taken 0.5 m apart were lowest (0.18) at the 10-m distance and greatest (0.96) at 50 m. The variation for individual sampling locations ranged from 0.04 to 1.06 and showed no consistent pattern related to distance from the origin of the uranium. These data illustrated the strong influence of the past programs at E-F Site upon uranium distribution patterns, particularly when all samples at a given distance from the detonation point were averaged. Greatest variation then occurred in samples 100 m or farther from the detonation point, reflecting the frequent inclusion of samples that contained large uranium particles and those that contained little or no uranium above background levels.

Uranium concentrations in various depth increments of duplicate 30-cm soil cores taken 0.5 m apart at E-F Site (Table III) showed a trend toward greater variability among samples of the deeper (>10-cm) horizons. Values were between 0.44 and 0.57 in the depths to 10 cm and between 0.71 to 0.94 in soil from 10 to 30 cm below the surface.

These data suggest that results from the soil sampling are probably influenced by the variable deposition of uranium debris from past explosive tests (fragments from 2 mm to several centimeters in diameter), by the subsequent variable leaching processes that transport the uranium to deeper soil profiles, and by surface water runoff that transports the uranium away from the site. The tentative conclusions drawn from the comparison of CVs in this section are constrained by the small number of samples relative to those needed to reasonably estimate such variance.[13]

2. Uranium in Soil Separates. Soil samples collected at 10 m from the detonation point were obtained from areas in which the vegetative cover was very sparse, soil profiles were moderately eroded by wind and water, and particle sizes characteristic of coarse sand, very coarse sand, and coarse fragments constituted 30% of the soil mass. Soils at greater distances, such as 150 and 200 m, contained finer material and showed little water erosion effects; they were characterized by 40% silt-clay, 35% sand, and small amounts of the larger size fractions, as shown in Fig. 2. The distribution of the uranium inventory particle size categories

TABLE II

VARIATION IN E-F SITE SURFACE (0- to 2.5-cm-DEEP) SOIL SAMPLES AT VARIOUS DISTANCES FROM THE DETONATION POINT

Distance (m)	Sample Pairs CV (Mean)	Sample Pairs N	All Samples CV	All Samples N
0	--		0.62	2
10	0.18	2	0.89	8
20	0.51	1	0.65	6
30	0.87	2	0.65	8
40	0.30	2	0.56	7
50	0.96	2	0.69	8
75	--		0.73	7
100	--		1.29	8
150	0.58	1	2.33	8
200	--		0.95	6

in soil cores were calculated by multiplying the uranium concentration by the mass of each fraction. Those taken at 10 m from the detonation point tended to closely parallel the soil masses in those categories, but they showed a shift toward more small uranium (<53-μm) particles and fewer large particles than in the soil mass. Only 2% of either the uranium or the soil mass in the 53- to 105-μm size range at the 10-m distance. This suggested that we may have encountered soil particles contaminated with uranium rather than uranium particles *per se*. However, uranium particles of <500-μm diameter constituted a greater fraction of the total uranium inventory with increasing distance from the detonation point than did soil particles, indicating appreciable deposition of relatively small uranium particles over the past several years of tests at E-F Site.

The per cent of uranium in the three smallest size fractions was consistently greater than the masses of those fractions in both depth increments, illustrating the predominance of particles <500-μm diameter therein.

Uranium concentrations in the six soil size fractions from the 0- to 5-cm and 5- to 10-cm depths are graphically presented in Figs. 3 and 4. The appreciable variation in uranium values as a function of both distance from the firing point and depth in the soil profile constrains a strict interpretation of the data. However a general decrease of uranium concentration in soil with distance is apparent and a generalized interpretation may be made that small uranium particles predominated at the 10-m distance in both soil column increments; larger (1- to 2-mm) particles assumed major importance in the 20- to 50-m distances, with a fair representation of intermediate-sized (105- to 500-μm) particles; and most of the uranium at the periphery of the circular study area was again associated with <1000-μm particles. The distribution with distance may have been

TABLE III

COEFFICIENTS OF VARIATION OF URANIUM CONCENTRATION IN VARIOUS DEPTH INCREMENTS OF DUPLICATE SOIL CORES SAMPLED 0.5 m APART AT E-F SITE

Soil Depth (cm)	CV (mean)	N
0-2.5	0.57	10
2.5-5	0.44	9
5-10	0.52	9
10-15	0.71	8
15-20	0.94	5
20-30	0.78	3

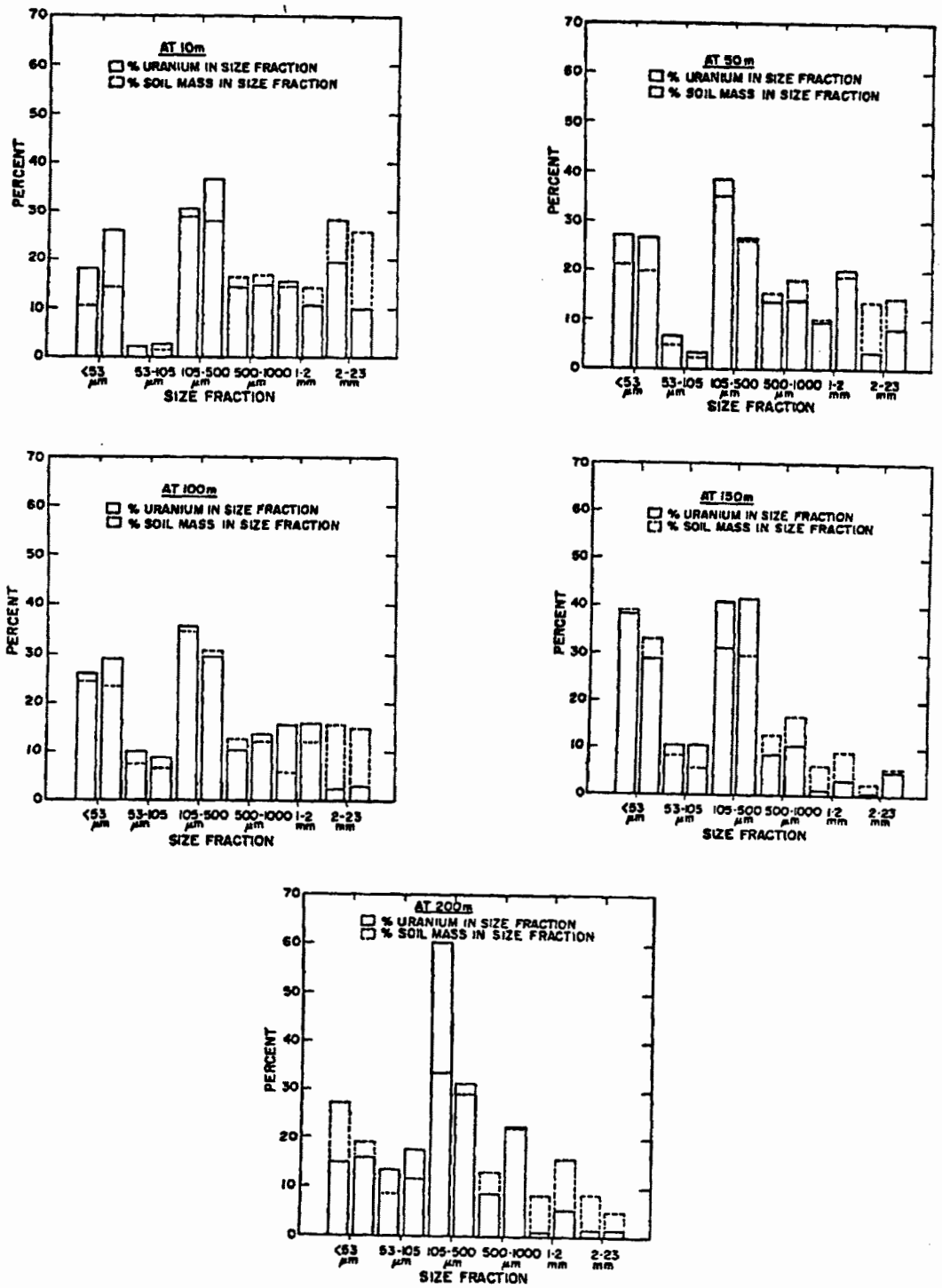

Fig. 2. The per cent of the total uranium and per cent soil mass associated with each size fraction as a function of soil depth at 10, 50, 100, 150, and 200 m from the detonation point. The left-side bar for each size fraction is for the 0- to 5-cm depth and the right-side bar is for the 5- to 10-cm depth.

affected to an unknown degree by the placement of the detonation point at the base of the northern mound (see Fig. 3, of Ref. 1), which would have caused an asymmetical dispersion of uranium and other debris from explosive tests.

3. Uranium Inventory Estimates by Annuli and Isopleth Methods. The parameters used to estimate the uranium inventory in E-F Site surface (0- to 5-cm-deep) soils by the two different techniques are presented in Tables IV and V. The method in which the median uranium concentration at each of 10 sampling distances from the detonation point was used (Table IV) to calculate an inventory within that annulus yielded an estimated 4480 kg within a surface area of 125 590 m^2, including about 6000 m^2 in annuli south of the 150-m sampling point. The second inventory estimate of about 2970 kg within a surface area of 119 140 m^2 was obtained by using areas within uranium concentration isopleths (Fig. 5) and their respective median uranium concentrations (Table V). As noted, the 6000-m^2 discrepancy in total surface areas used in the calculations resulted from the lack of data from the 200-m sampling location south of the detonation point because that location falls within Potrillo Canyon and prevented extrapolation of the isopleths to that region. If we assume that the 100- to 300-μg/g uranium isopleth is applied to that area, the estimate is changed by only 2%.

The total uranium (in kilograms) and the per cent of the estimated uranium inventory within each annulus (Table IV) reflects the magnification produced by surface area and soil mass parameters used in obtaining the estimate by the first method. Note that the 125- to 175-m segment contained 37.5% of the surface area and 54% of the uranium inventory, or a ratio of 1.4 between the per cent of the total uranium and the per cent of total surface area in

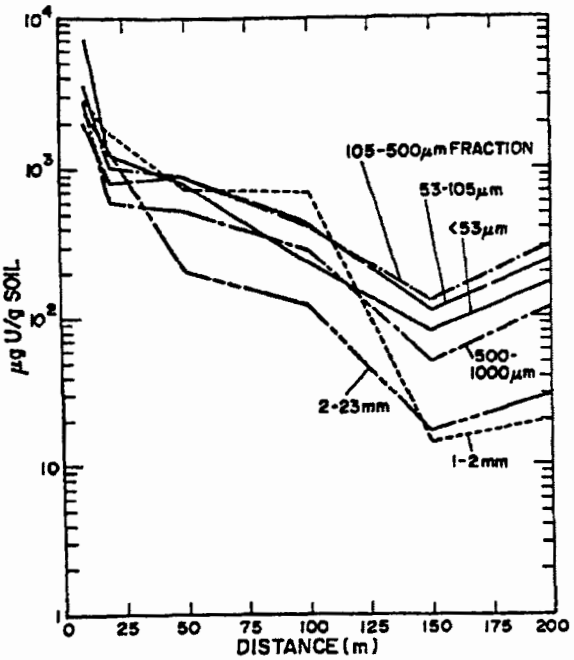

Fig. 3. Uranium concentrations in soil size fractions as a function of distance in the 0- to 5-cm horizon at E-F Site.

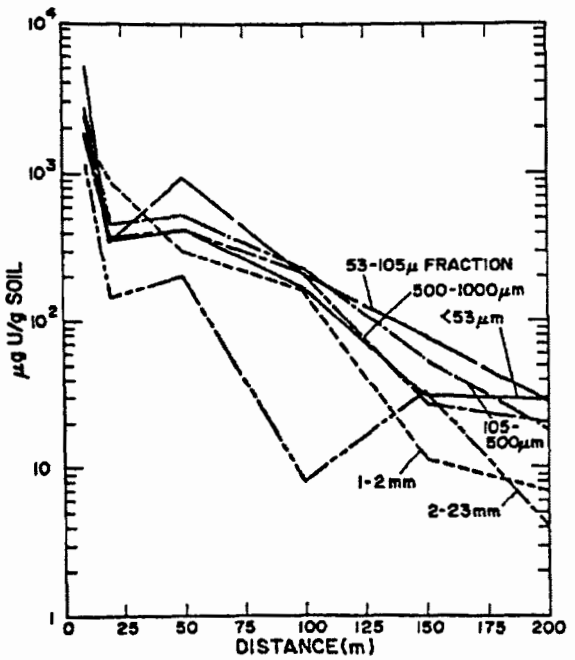

Fig. 4. Uranium concentrations in soil size fractions as a function of distance in the 5- to 10-cm horizon at E-F Site.

TABLE IV

ESTIMATED URANIUM INVENTORY IN SURFACE SOILS (0- to 5-cm) AT E-F SITE DETERMINED BY SUMMING URANIUM CONCENTRATIONS IN ANNULI

Distance (m)	Number of Samples	Surface Area of Annulus (m^2)	Per Cent of Total Surface Area in Annulus	Median Uranium Concentration (μg/g)	Total Uranium in Annulus (kg)	Per Cent Uranium in Annulus	% Uranium/ % Surface Area
0-5	2	78	0.06	4750	26.1	0.6	10
5-15	8	628	0.5	4915	215.6	4.8	9.6
15-25	6	1257	1.0	835	73.6	1.6	1.6
25-35	8	1885	1.5	1330	175.4	3.9	2.6
35-45	7	2513	2.0	710	124.7	2.8	1.4
45-55	8	3142	2.5	475	104.5	2.3	0.9
55-87.5	7	14550	11.6	350	358.5	8.0	0.7
87.5-125	8	25035	19.9	370	651.9	14.5	0.7
125-175	8	47124	37.5	730	2414.7	53.8	1.4
175-200	7	29453	23.4	165	340.2	7.6	0.3
Totals 0-200	69	125592	100	1240±186	4485.2	100	

the circular study area, as shown in the last column. Such ratios were generally proportional to the changes in the uranium concentrations more than to changes in the surface area. This illustrated that an overestimate of the inventory might well have been introduced by a single large uranium concentration value that sharply increased the mean uranium value for that particular segment. By deleting that datum, the mean uranium value for the 125- to 175-m segment was decreased by a factor of 5, and similarly reduced the uranium inventory estimate to about 2600 kg. However, we believe that such anomolies represent a "real world" situation that results from the common occurrence of large uranium particles away from the detonation point.

In the isopleth method of estimating the uranium inventory, over 90% of the surface area was associated with two concentration gradients; 60% was within the 100- to 300-μg U/g soil isopleth and 31% was in the 300- to 1000-μg U/g soil isopleth. The respective portions of the uranium inventory within these areas was 56 and 25%. The ratio of per cent uranium inventory to surface area determined by the isopleth method shown in the last column of Table V was less consistent than in the annulus method but also showed a rapid decrease with distance from the detonation point.

From these exercises we have estimated that the uranium inventory in the 0- to 5-cm soil horizon at E-F Site is between 3000 and 4500 kg, not including particles >6 mm in size, which were screened from the samples during processing for whole soil sample analyses. The uranium inventory in the >6-mm particle size fraction could not be

TABLE V

ESTIMATED URNAIUM INVENTORY IN SURFACE SOILS (0- to 5-cm) AT E-F SITE AS DETERMINED BY THE USE OF CONCENTRATION GRADIENTS

Isopleth (μg/g)	Number of Sampling Locations Within Isopleth	Surface Area (m^2)	Per Cent Surface Area in Isopleth	Median Uranium Concentration (μg/g)	Total Uranium in Isopleth (kg)	Per Cent Uranium in Isopleth	% Uranium/ % Surface Area
>3000	3	611.6	0.5	6100	261.2	8.8	17.6
1000-3000	14	2629.9	2.2	1500	276.1	9.3	4.2
300-1000	32	36746.8	30.8	650	1672	56.3	1.8
100-300	11	70965.5	59.6	150	745.1	25.1	0.4
30-100	3	2729.3	2.3	65	12.4	0.4	0.2
Totals	67	119141.7			2972.3		

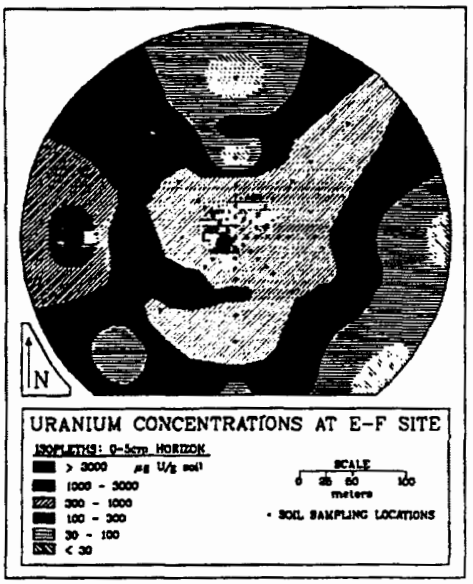

Fig. 5. Calculated isopleths of uranium concentrations in the 0- to 5-cm soil horizon at E-F Site.

reasonably estimated because of its highly irregular distribution over the land surface.

D. Bagnold Collection of Redistributed Uranium Particles

Winds can initiate three basic types of soil movement that cause redistribution of particulate materials: surface creep, saltation, and suspension.[14] Surface creep involves particles in the 500- to 1000-µm-diam range that are pushed along the ground surface by strong winds or by absorption of momentum from smaller particles in saltation. Saltation consists of wind-driven 100- to 500-µm-diam particles that bounce within a few centimeters of the ground surface. Suspension, or reflotation, is the lifting and becoming completely airborne of fine particles <100 µm, with those <10 µm possibly being suspended almost indefinitely. Several different mechanisms are involved in these three phenomena and their interpretation is often highly technical, depending upon the nature of the particulate material and the environmental setting being considered. Two very important considerations are surface soil texture and moisture content, the latter of which we have not examined because of the highly variable soil moisture at E-F Site.

Initial results from the Bagnold collectors (Table VI) maintained for 3 months at the E-F Site detonation point and 40 m downwind suggested that uranium particles >100 µm in diameter or those expected to move by surface creep and saltation, were most active at the ground surface of the detonation point. Fine particulates with relatively high uranium concentrations predominated in the heights above 0.5 cm, demonstrating the importance of suspension in redistribution of uranium. Samples from the collector located 40 m from the detonation point were more uniform in uranium concentration and per cent of uranium in the two size fractions, except for those from the highest collection slot. The larger particle sizes predominated in samples of airborne soil <30 to 45 cm above the ground surface and the smaller size fraction became increasingly important above that height. Essentially all of the uranium sampled at 60 to 75 cm above the surface was in particles of <100-µm diameter.

A total of 38.6-mg uranium was sampled by the Bagnold apparatus at the detonation point during the 3 months of exposure compared to 7.9-mg uranium obtained from the instrument located 40 m downwind. The per cent of uranium associated with the two size fractions at each height indicated that a greater sample mass was collected in the >100-µm fraction and that 62% of the uranium was collected within 30 cm of the ground surface at the detonation point. At the more distant Bagnold sampler, about 50% of the uranium was collected at ground level and 94% was collected within 30 cm of the surface. The soil particle size analyses reported earlier[1,2] also showed that the >100-µm particles compose the largest portion of the soil mass near the two sampling locations. Although the meteorological data

TABLE VI

SOIL URANIUM CONCENTRATIONS AND PER CENT URANIUM IN TWO SIZE FRACTIONS COLLECTED FROM BAGNOLD DUST COLLECTORS MAINTAINED AT E-F SITE FROM APRIL TO JULY 1977

		Collection Location			
		Detonation Point		40 m NE of Detonation Point	
Height (cm)	Size Fraction (μm)	Uranium Concentration (μg/g)	Per Cent Uranium in Size Fraction	Uranium Concentration (μg/g)	Per Cent Uranium in Size Fraction
0-0.5	<100	481	21	1500	48
	>100	7555	79	1060	52
0.5-15	<100	12700	57	750	48
	>100	1420	43	810	52
15-30	<100	11900	55	2710	42
	>100	1780	45	3100	58
30-45	<100	10800	59	1500	50
	>100	1510	41	1010	50
45-60	<100	10700	56	2300	54
	>100	1380	44	1000	46
60-75	<100	14000	50	4400	100
	>100	1420	50	19	<1

have not been reduced to the summary form necessary to assess the implications of wind speed and direction to the redistribution of uranium, the above data indicate that surface creep and saltation are important natural agents affecting surface transport of uranium at E-F Site. Surface water runoff was previously implicated as the major means of uranium movement in the transfer of about 58 kg of uranium from E-F Site to a 9000-m sector of adjacent Potrillo Canyon over a 23-yr period.[2]

E. Uranium Concentrations in Small-Mammal Tissues

Our 1976 report,[1] which contained a very limited number of analyses from pocket gopher (*Thomomys bottae*) tissues collected during November 1974, indicated a difference in uranium concentrations between that subterranean species and the surface-active deer mice (*Peromyscus maniculatus*). To extend this observation, a more intensive simultaneous collection of the two species was made during April and May 1977 and uranium analyses were obtained for six sample types. Results (Table VII) indicated that there was a difference between uranium concentrations in the several tissue types and that deer mice generally contained higher mean uranium concentrations in their tissues than did pocket gophers. These data are consistent with the 1976 results and confirmed our previous observations in most areas; however, several aspects of the data require amplification. An important difference between 1976 and 1977 (Table VII) results is the much higher uranium concentration in the 1977 samples except in the lungs of deer mice. In most cases the current levels are 2 to 100 times those measured in the animals collected during November 1974 or June 1975, even though no additional releases of uranium occurred at E-F Site during the interim. Therefore, we can only speculate about the reasons for the higher levels.

TABLE VII

URANIUM CONCENTRATIONS IN TISSUE SAMPLES FROM TWO SYMPATRIC SPECIES OF SMALL MAMMALS AT LASL E-F SITE (APRIL - MAY 1977)

Species	Sample	Uranium Concentration (μg/g) Mean	Median	Minimum	Maximum	CV	N
Peromyscus	GI	900	380	140	3600	1.49	6
Thomomys		220	75	<0.5[a]	720	1.15	8
Peromyscus	Pelt	500	300	140	1530	1.07	6
Thomomys		200	120	9.1	460	0.91	8
Peromyscus	Lung	4.4	<0.5	<0.5	24	2.18	6
Thomomys		5.7	<0.5	<0.5	42	2.44	8
Peromyscus	Carcass	6.8	2.9	<0.5	30	1.69	6
Thomomys		4.3	1.0	<0.5	16	1.23	8
Peromyscus	Kidney	30	<0.5	<0.5	140	1.85	6
Thomomys		21	<0.5	<0.5	160	2.45	8
Peromyscus	Liver	23	18	<0.5	60	1.02	6
Thomomys		10	<0.5	<0.5	58	1.90	8

[a]Minimum detectable limit.

Several environmental and physiological parameters are substantially affected by the seasonal differences that are represented by the November 1974 and April-May 1977 collection periods. Soil moisture varies strongly with season and is probably one of the major factors that influences the bioavailability of uranium in the upper few millimeters of soil. This possibility is suggested by the appreciable differences between Peromyscus pelt samples taken in November 1974 (24 μg/g), June 1975 (49 μg/g), and April-May 1977 (500 μg/g). Food habits of the small mammals vary appreciably; the pocket gopher is a vegetarian heavily dependent upon plant roots and other vegetative plant parts, whereas the deer-mouse diet shifts from a preponderance (94%) of seeds, fruits, and roots during winter to mostly animal foods (76% large insects and other invertebrates) during spring and then to mostly plant foods (68%) during summer.[15] Although the food habits would presumably influence the concentrations of uranium in internal organs, appreciable amounts of soil and uranium are ingested by small mammals during their normal grooming. The relatively low fraction ($<10^{-4}$) of uranium transferred from the GI track to blood presumably accounts for the modest concentrations found in carcass and lung samples and mitigates the consequences of ingestion of uranium from whatever source. The amounts of uranium in deer mouse and pocket gopher lung samples collected during 1977 were similar to one another and to carcass values, arguing against appreciable inhalation of uranium particles; positive values occurred in only one specimen of each species.

The uranium concentrations for tissue samples presented in Table VII illustrate that the range of values was extremely large, often positively skewed, and highly variable. Such characteristics are indicated by CVs almost consistently >1.0, which complicates the strict interpretation of the data and suggests that a much larger number of samples would be necessary to provide conclusive results. The variation apparently results from the particulate nature of uranium, its density and mobility

in the environment, and the variable habits of the animals.

A possible explanation for some of the differences between the 1977 data and that obtained in 1974-1975 is the change of analytical methods that was discussed in Sec. II.A. The earlier samples were processed by FA, which is less sensitive than IENAA and requires that the sample be put in solution. This offers the possibility for some variable portion of the uranium to become adsorbed in the residue matrix and to be missed when an aliquot of the dissolved sample is analyzed.

The results for both mammalian species showed that the highest uranium concentrations were in GI tract contents and that slightly lower values were in pelts. Kidneys and livers contained about 5 to 10% of pelt values, and lungs and carcass samples contained amounts that were slightly above background. The data substantiate our previous report that the greater bioavailability of uranium in the top few millimeters of soil at E-F Site results in greater contamination of the deer mouse population than of the pocket gopher population.

F. Macrofauna Studies

1. Numbers of Individuals and Species Taken by Various Collection Methods. There was no consistent difference between either the numbers of individual invertebrates or the numbers of species captured in pitfall traps (Table VIII). The taxonomic orders Acarina, Hymenoptera, and Hemiptera were most strongly represented. Acarina were most abundant during April, decreased during warmer months, and then increased during November. Hymenoptera and Hemiptera showed a reverse pattern of abundance, with low population densities during spring and autumn months and greatest abundance during summer months.

Sweep net results are summarized in Table IX. A greater number of individual invertebrates were usually captured in the test areas rather than in their controls during the sampling periods, even though the mean number of species per sample and the total number of species per sampling period were similar for both test and control areas. A total of 63 species were identified at the E-F test area and 61 species at its control area; at the LS test area, 43 species were collected compared to 53 species at its control area.

Relative densities (RD = per cent of total animals) of most single species or larger taxa indicated that there were preferences toward individual sampling sites rather than selection against test areas. For example, Thysanoptera had an overall RD of 48% at the E-F test area and 4% at its control area. This order showed an opposite relationship at LS Site, where RDs of 0.3 and 14% occurred at the test and control areas, respectively. Coreid, mirid, and cicadellid bugs were the only species whose abundance suggested a preference for control rather than test areas and aphids were the single taxon with greater abundance at both E-F and LS test areas.

Herbivorous species constituted >65% of the total individuals collected by sweep net and carnivores made up ~10% of the total; the remainder consisted of omnivores, scavengers, or species whose food habits are unknown or ill-defined.

Therefore, the overall comparisons of numbers of individuals and numbers of species obtained by pitfall traps and sweep nets revealed no conclusive evidence of a gross differential response to the areas of relatively high uranium concentrations in soils and to nearby control areas.

2. Distributions of the Major Invertebrate Orders. Analysis of the results obtained by the three sampling techniques used during the various years of study (Tullgren funnel extraction of invertebrates from soil cores, pitfall trapping, and insect net sweeps) indicated that the greatest numbers of animals were obtained from soil cores and pitfall trapping, that only 10 to 20% as many animals were obtained by sweep net, and that results from

TABLE VIII

MEAN NUMBERS OF INDIVIDUALS AND SPECIES OF INVERTEBRATES COLLECTED BY PITFALL TRAPS AT LASL SITES DURING 1976

	Test Areas		Control Areas	
Sampling Period	E-F	LS	E-F	LS
April 1976				
Individuals per Sample	72	130	83	93
Species per Sample	24	23	20	22
Total Species	55	55	49	44
May 1976				
Individuals per Sample	27	43	39	62
Species per Sample	14	16	16	25
Total Species	39	39	39	42
June 1976				
Individuals per Sample	90	120	60	123
Species per Sample	30	28	22	23
Total Species	75	80	53	59
September 1976				
Individuals per Sample	36	66	22	71
Species per Sample	14	16	12	14
Total Species	40	34	45	40
November 1976				
Individuals per Sample	51	65	58	53
Species per Sample	12	18	13	13
Total Species	30	40	34	34
Monthly Average				
Individuals per Sample	52	85	52	80
Species per Sample	19	20	16	19
Total Species	48	50	44	44

the test areas and their controls were inconsistent among the three techniques. At E-F Site, the numbers of individuals and numbers of species collected from control area soil cores were greater than from test area cores. Sweep net results were exactly the opposite, with more than twice as many individuals per sample from the test area compared to the control area but with a similar number of species obtained from both areas. LS sample compositions were the reverse of those from E-F Site, with the LS test area yielding more individuals compared to the LS control area but with a greater number of species in the soil cores. Pitfall collections were similar in both test and control areas.

Specific distributions of the various orders were as follows:

a. Acarina (Ticks and Mites). This order was most abundant in soil cores and pitfalls and nearly absent in net sweeps. It consisted of 30 to 50 species and constituted from 50 to 90% of the total invertebrates obtained from soil and pitfall samples during all sampling periods. Population densities determined from pitfall

TABLE IX

MEAN NUMBERS OF INDIVIDUALS AND SPECIES OF INVERTEBRATES COLLECTED BY SWEEP NET AT LAST SITES DURING 1975 AND 1976

	Test Areas		Control Areas	
Sampling Period	E-F	LS	E-F	LS
November 1975				
Individuals per Sample	1.7	94	10	11
Species per Sample	1.7	3.3	1.7	4
Total Species	4	6	4	11
February 1976				
Individuals per Sample	12	1	1	1
Species per Sample	4.7	0.7	1.3	0.3
Total Species	10	2	4	1
March 1976				
Individuals per Sample	2	4.7	--	3.7
Species per Sample	1.3	2.3	--	1.7
Total Species	3	6	--	3
May 1976				
Individuals per Sample	24	7	28	34
Species per Sample	8.3	4.7	5.3	10
Total Species	21	9	13	22
September 1976				
Individuals per Sample	146	80	33	73
Species per Sample	18	18	18	16
Total Species	32	27	42	35
November 1976				
Individuals per Sample	18	6	5	12
Species per Sample	12	18	13	13
Total Species	30	40	34	34
Monthly Average				
Individuals per Sample	34	32	15	23
Species per Sample	7.7	7.8	7.9	7.5
Total Species	17	15	19	18

collections were similar for all sites and did not confirm earlier soil core results that showed significantly greater densities of Acarina at the E-F control area than at the test area and a reverse situation at the LS Site. Populations were highest during autumn, winter, and early spring, then decreased during warm months. About two-thirds of the identified species were carnivores.

b. Araneida (Spiders): The spiders were usually most abundant in pitfall collections; and were taken less often in understory vegetation sweep samples. A few transients were collected from soil cores. Population densities were similar in both

test and control areas, as determined by all three collection techniques. Although the spiders consitituted a greater portion of the catch from net sweeps at the E-F areas, they represented only 8% of the total animals at the control area. Their actual abundance was greater in the pitfall collections than in collections by the other capture methods. Forty-five species of spiders were identified, most of them classified as predators.

c. Collembola (Springtails). This order was most abundant in pitfall collections, was less common in soil cores, and was seldom taken in sweep net samples from vegetation. They were most abundant at the LS test area, where soil cores contained twice as many individuals as were in the pitfall samples. The E-F test and control area results showed an opposite trend, with significantly greater densities in control site soil cores and similar abundances in both test and control area pitfall collections. Collembola were usually most abundant during late spring and summer months. Most species of this order are scavengers.

d. Hymenoptera (Ants and Wasps). Collections of this order consisted mostly of ants, which were most commonly taken in pitfall traps, reflecting their status as a wandering part of the insect community. Their relative densities were greater at LS than at E-F Site, and they were especially abundant in summer, when they made up 71 to 99% of the total individuals collected. Wasps constituted the major portion of sweep net samples; they are generally omnivores, but many species are herbivores whose larvae are carnivorous.

e. Hemiptera (Homoptera and Heteroptera)(Bugs). This is the major taxon associated with vegetation; its members represented 50 to 80% of the total specimens collected by sweep net. They were also common in pitfall samples, with a relative density of about 10% at all four areas. They occurred at very reduced densities in soil cores. The Hemiptera were more abundant at test areas than at control areas, a finding which contrasts with results from the soil core extractions reported last year. This order is mainly herbivorous.

f. Thysanoptera (Thrips). These animals were collected at about the same densities by all three methods, but were slightly more abundant in sweep net collections at the LS test area. Despite their low population densities they constituted 30 and 27% of samples at the LS test and control areas and 4 and 12% at the E-F test and control areas, respectively. This contradictory relationship of samples from test and control areas appeared in the 1976 results. This order is also mainly herbivorous.

g. Diptera (Flies). Population densities of flies were generally low, probably because the sampling techniques used in our studies were not efficient at capturing representative samples of flies. No consistent similarities or differences were noted in samples from experimental and control areas.

h. Coleoptera (Beetles). This largest order of insects was poorly represented in our samples, as illustrated by their relative density of <2%. As with the Diptera, other sampling techniques are required to obtain more representative samples. Greater densities were recorded in pitfall collections, but there were no consistent similarities or differences between control and test areas.

3. Population Responses to Uranium. These results substantiate our 1976 observations of invertebrate population densities in soil cores taken from LASL test and control areas. The 1976 and 1977 data taken by the three methods of collection indicate that environmental gradients other than the uranium concentration in surface soils affect invertebrate populations to such an extent that we cannot interpret their fluctuations as a response to uranium chemical toxicity.

IV. SUMMARY AND CONCLUSIONS

A third year of study of the ecological consequences of exposure of terrestrial ecosystems at LASL to elevated soil concentrations of natural and depleted uranium was completed. Specific accomplishments included (1) development of a more accurate and expeditious method of uranium analysis, IENAA; (2) determination of natural and depleted-uranium concentrations in three sets of EAFB soils collected during range cleanup; (3) evaluation of inventory estimates, spatial distribution, and particle size correlations of uranium in soils at LASL E-F Site by annuli and isopleth methods; (4) demonstration of different uranium concentrations in organs and tissues of deer mice and pocket gophers from an area of high uranium concentrations in soils; (5) evaluation of surface transport of particulate uranium by the processes of surface creep, saltation and reflotation (suspension); and (6) summarization of two years' results of invertebrate population measurements made by soil core extractions, pitfall trapping, and insect net sweeping at two LASL test areas and their controls to evaluate the consequences of exposure to uranium.

Comparisons of uranium concentrations in a set of 33 soil samples and 2 standards determined by IENAA, DNA, and FA showed good agreement. A mean ratio of results from IENAA and FA methods was 0.94 ± 0.19 (std dev), indicating a slightly lower but trivial bias of the ratio. Considering these results, the significant reduction in cost and time for sample processing, and the increased reliability, IENAA was selected as the method to be used in most future uranium analyses in our laboratory.

The EAFB soil samples consisted of a set taken from barrels of contaminated soil removed from test ranges by a contractor and two sets of near-background samples. Uranium concentrations in the cleanup materials ranged from 30 to 4900 μg/g (= ppm) and duplicate aliquots had CVs of 0 to 0.68.

Spatial variability in sampling for uranium distribution by a polar coordinate system was evaluated by analysis of uranium concentrations in randomly selected duplicate soil cores taken at locations 0.5 m from and parallel to those reported last year. Variations for surface (0- to 2.5-cm-deep) soils averaged lowest (0.18) in samples collected at 10 m from the detonation point and greatest (0.96) at 50 m. The individual variations ranged from 0.07 to 1.06 and showed no consistent pattern related to distance from the origin of the uranium, illustrating a strong influence of past chemical explosive tests conducted between 1943 and 1972. Uranium concentrations in deeper (30-cm) soil cores showed that soil sampling results are strongly influenced by the variable deposition of past uranium debris, fragments from 2 mm to several centimeters in diameter, by the subsequent variable leaching processes that transport uranium to deeper soil profiles, and by surface water runoff of uranium to distant locations.

Uranium concentrations in six soil size fractions determined from forty 0- to 5-cm- and 5- to 10-cm-deep cores showed considerable variation but suggested that small (<53-μm) uranium particles predominated at 10 m from the detonation point; larger (1- to 2-mm) particles assumed major importance at the 20- to 50-m distances, with a fair representation of intermediate-sized (105- to 500-μm) particles; and most of the uranium at the periphery of the 12.6-ha study area was again associated with small particles.

Two methods were used to calculate a total uranium inventory within a 12.6-ha circle centered on the E-F Site detonation point. The first consisted of calculating the surface area enclosed by an annulus at the midpoint between each sampling distance and applying a median uranium concentration derived from all sampling points within each area. The second method involved

calculating the surface areas of soil uranium concentration isopleths and multiplying by the median uranium concentration for each isopleth. Inventory estimates of 4500 kg by the first method and 3000 kg were obtained.

Initial results from Bagnold dust collectors maintained for 3 months at two locations near the E-F Site detonation point indicated that uranium particles in the >100-μm-diam range, or those expected to move by surface creep and saltation, were most active at the ground surface. Fine particulates with relatively high uranium concentrations predominated in collector heights above 0.5 cm, demonstrating the importance of suspension in the redistribution of uranium.

Uranium concentrations in tissues of deer mice (Peromyscus maniculatus) and pocket gophers (Thomomys bottae) collected at E-F Site indicated that there was a difference between amounts in several tissue types and that deer mice generally contained higher mean uranium concentrations in their tissues than did pocket gophers. The 1977 results were 2 to 100 times those measured in similar samples collected during November 1974 and June 1975; however, the range of values was highly variable and reinforced our previous observations that an appreciably larger number of samples would be necessary to provide conclusive results. Highest uranium concentrations were in GI tract contents and slightly lower values were in the pelts. Kidneys and livers contained about 5 to 10% of pelt values, and lungs and carcass samples contained amounts that were slightly above background. These data support our previous conclusion that the greater bioavailability of uranium in the top few millimeters of soil at E-F Site resulted in greater contamination of the deer mouse population than of the sympatric pocket gopher population.

Invertebrate populations in areas of high (2400- to 16 000-μg/g) and medium (20- to 80-μg/g) uranium concentrations in soils were sampled by pitfall trapping and insect net sweeps to evaluate possible effects of exposure to such levels upon those animals. The overall comparisons of numbers of individuals and numbers of species in the study areas revealed no conclusive evidence of a gross differential response to the areas of relatively high uranium concentrations in soils and to control areas.

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APPENDIX

TABLE A-I

ANALYTICAL RESULTS FOR EAFB SOIL SAMPLES COLLECTED ON VARIOUS DATES IN 1976 AND 1977

Date	EAFB No.	LASL No.	Uranium Concentration (ppm = μg/g) Result	± Uncertainty
28 June 76	0-0	77.05071	1	0.4
	1-1	5072	3	0.5
	1-3	5073	23	0.8
	1-5	5074	9	1
	1-7	5075	8	0.7
	1-9	5076	70	32
	1-11	5077	2	0.6
	1-13	5078	0.9	0.3
	1-15	5079	0.5	0.4
	1-17	5080	0.8	0.4
	1-17 (Replicate)	5154	0.6	0.5
	2-0	5081	7	0.6
	2-2	5082	38	1
	2-4	5083	1	0.3
	2-6	5084	2	0.4
	2-8	5085	1	0.3
	2-10	5086	2	0.5
	2-12	5087	4	0.5
	2-14	5088	30	1
	2-16	5089	0.8	0.3
	3-1	5090	3	0.7
	3-1 (Replicate)	5155	2	0.5

TABLE A-I (cont)

Date	EAFB No.	LASL No.	Uranium Concentration (ppm = μg/g) Result	±	Uncertainty
	3-11	77.05091	0.6		0.3
	3-13	5092	3		0.1
	3-15	5093	49		2
	4-0	5094	0.7		0.3
	4-12	5095	2		0.4
	4-14	5096	50		0.8
	5-13	5097	2		0.4
	5-15	5098	21		0.4
6 Dec 76	0-0	5099	1160		136
	1-1	5100	5		0.3
	1-1 (Replicate)	5156	7		0.6
	1-3	5101	36		4
	1-5	5102	34		1
	1-7	5103	46		1
	1-9	5104	4		0.3
	1-11	5105	3		0.3
	1-13	5106	16		0.4
	1-15	5107	21		0.5
	1-17	5108	0.6		0.2
	2-0	5109	4		0.3
	2-2	5110	48		0.8
	2-2 (Replicate)	5157	105		3
	2-4	5111	16		0.4
	2-6	5112	3		0.3
	2-8	5113	2		0.3
	2-10	5114	1		0.2
	2-12	5115	2		0.3
	2-14	5116	0.9		0.4
	2-16	5117	2		0.5
	3-1	5118	3		0.5
	3-3	5119	95		3
	3-5	5120	1		0.4
	3-5 (Replicate)	5158	1		0.5
	3-7	5121	2		0.5
	3-9	5122	2		0.4
	3-11	5123	2		0.5
	3-13	5124	3		0.5
	3-15	5125	21		0.9
	3-17	5126	1		0.4
	4-0	5127	5		0.6
	4-2	5128	3		0.6
	4-4	5129	2		0.6
	4-6	5130	2		0.4
	4-6 (Replicate)	5159	2		0.4
	4-8	5131	1		0.4
	4-10	5132	1		0.4
	4-12	5133	3		0.5
	4-14	5134	29		0.8
	4-16	5135	1		0.4
	5-1	5136	2		0.5
	5-3	5137	3		0.5
	5-5	5138	2		0.6
	5-7	5139	0.7		0.4
	5-9	5140	2		0.7
	5-9 (Replicate)	5160	1		0.3

TABLE A-I (cont)

Date	EAFB No.	LASL No.	Uranium Concentration (ppm = μg/g) Result	±	Uncertainty
	5-11	77.05141	1		0.4
	5-13	5142	3		0.5
	5-15	5143	23		0.9
	5-17	5144	0.5		0.4
	6-0	5145	0.4		0.3
	6-2	5146	0.6		0.3
	6-4	5147	1		0.3
	6-6	5148	1		0.3
	6-8	5149	0.9		0.3
	6-10	5150	0.7		0.5
	6-10 (Replicate)	5160	2		0.5
	6-12	5151	1		0.3
	6-14	5152	2		0.5
4 April 77		5153	0.8		0.2

TABLE A-II

ANALYTICAL RESULTS FOR EAFB SOIL SAMPLES COLLECTED FROM RANGE CLEANUP OPERATIONS DURING JUNE 1977

EAFB No.	Barrel	LASL No.	Sample Wt (g)	Uranium Concentration (ppm = µg/g) Result	± Uncertainty
C-64A	35	77.05177	2.47	90	7
C-64A	45	5178	2.50	120	12
C-64A	56	5179	2.42	170	12
C-64A	40	5180	2.50	80	8
C-64A	33	5181	2.49	200	15
C-64A	55	5182	2.12	60	6
C-64A	23	5183	2.86	120	9
C-74L	60	5184	2.43	70	7
C-64A	20	5185	2.40	190	13
(Replicate)	20	5240	2.77	170	13
C-64	12	5186	2.83	480	42
C-80B	II	5187	2.50	30	3
C-64	13	5188	3.32	100	10
C-64A	48	5189	2.45	80	6
C-64	3	5190	2.41	970	85
C-64A	44	5191	2.36	70	6
C-64A	51	5192	2.54	90	8
C-64A	50	5193	2.30	40	4
(Replicate)	50	5243	2.24	70	6
C-64A	18	5194	2.36	740	65
C-64	8	5195	2.29	3200	200
(Replicate)	8	5240	2.35	4900	436
C-64A	24	5196	2.60	190	17
C-64A	49	5197	2.33	80	6
C-64A	26	5198	2.57	100	11
C-64A	30	5199	2.51	140	10
C-64A	34	5200	2.69	90	9
C-64A	38	5201	2.13	80	6
C-64	11	5202	2.62	880	77
C-64A	28	5203	2.24	120	9
C-80B	III	5204	2.54	920	80
C-64A	15	5205	2.32	340	24
C-64A	31	5206	2.20	220	20
C-64A	52	5207	2.46	40	4
C-64A	39	5208	2.21	100	10
(Replicate)	39	5246	2.63	230	21
C-64	4	5209	2.37	560	38
(Replicate)	4	5244	2.77	500	48
C-64A	27	5210	2.40	240	21
C-64	6	5211	2.69	500	37
C-64A	37	5212	2.27	50	6
C-64A	32	5213	2.58	500	37
C-64A	36	5214	2.77	160	15
C-64A	19	5215	2.70	60	5
C-64A	22	5216	2.64	170	16
C-64A	41	5217	2.55	80	6
C-64A	57	5218	2.67	70	7
C-64	2	5219	2.44	130	11
C-64	14	5220	2.65	1090	95
C-64	7	5221	2.34	180	14
C-64A	17	5222	2.93	110	11
C-64	10	5223	2.33	270	21
C-64A	16	5224	2.65	340	30

TABLE A-II (cont)

EAFB No.	Barrel	LASL No.	Sample Wt (g)	Uranium Concentration (ppm = μg/g) Result	±	Uncertainty
C-64A	21	77.05225	2.81	100		8
C-64A	54	5226	2.18	120		11
(Replicate)	54	5242	2.19	100		10
C-64	9	5227	2.58	230		17
C-64A	46	5228	2.20	110		10
C-64A	1	5229	2.30	430		32
C-74L	59	5230	2.76	200		18
C-74L	58	5231	2.47	80		7
C-64A	43	5232	2.64	40		4
C-64A	47	5233	2.48	70		6
C-64	5	5234	2.87	2030		176
C-64A	25	5235	2.58	220		17
C-64A	53	5236	2.39	170		16
C-64A	42	5237	2.35	80		7
C-64A	29	5238	2.55	220		20
Control	-	5239	3.00	1		1
(Replicate)		5245	2.46	0.6		2

TABLE A-III

ANALYTICAL RESULTS FOR EAFB SOIL SAMPLES COLLECTED

DURING THE PERIOD JUNE 14-17, 1977

EAFB No.	LASL No.	Sample Wt (g)	Uranium Concentration (ppm = µg/g) Result	± Uncertainty
0-0	77.06228	2.33	300	30
1-1	229	2.06	8.7	1.2
1-3	230	2.12	25	3
1-5	231	2.31	42	4
1-5 (Replicate)	232	2.28	39	4
1-7	233	2.27	183	19
1-9	234	2.44	10	1.3
1-11	235	1.94	162	16
1-13	236	2.21	44	5
1-15	237	2.14	13.9	1.7
1-17	238	2.16	<1.0	
2-0	239	2.20	46	5
2-2	240	2.42	75	8
2-4	241	2.18	21	2
2-6	242	1.96	9.4	1.3
2-8	243	2.01	4.5	0.9
2-10	244	1.92	3.2	0.8
2-12	245	2.50	2.2	0.9
2-14	246	2.41	8	1.4
3-1	247	2.27	3.4	0.9
3-3	248	2.06	19	2
3-5	249	2.13	2.3	0.7
3-7	250	2.30	2.3	0.8
3-7 (Replicate)	283	2.46	1.5	0.9
3-9	251	2.09	<1.0	
3-11	252	2.19	3.2	0.8
3-13	253	2.25	2.6	0.9
3-15	254	2.11	10.6	1.4
3-17	255	2.09	1.7	0.8
3-17 (Replicate)	284	2.07	1.4	0.7
4-0	256	1.92	3.2	0.7
4-0 (Replicate)	257	2.41	3.5	0.8
4-2	258	2.36	3.8	0.8
4-4	259	2.31	<1.0	
4-6	260	2.24	<1.0	
4-8	261	2.06	1.1	0.7
4-10	262	2.27	1.2	0.7
4-12	263	2.38	2.0	0.7
4-14	264	2.27	7.7	1.1
5-1	265	2.35	2.2	0.8
5-3	266	2.17	<1.0	
5-3 (Replicate)	267	2.19	1.3	0.7
5-5	268	2.09	<1.0	
5-7	269	2.20	<1.0	
5-9	270	1.98	<1.0	
5-11	271	2.11	1.1	0.7
5-15	272	2.16	6.4	1.0
5-17	273	2.23	1.0	0.7
6-0	274	2.28	1.7	0.8
6-2	275	2.26	3.4	0.9
6-4	276	2.40	1.7	0.7
6-6	277	2.09	<1.0	
6-8	278	2.13	<1.0	
6-10	279	2.22	<1.0	
6-10 (Replicate)	280	2.14	<1.0	
6-12	281	2.32	<1.0	
6-14	282	2.31	1.6	0.8

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NWC Env Eng (Mr. Ouimette)
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