AD-A061 727 LOS ALAMOS SCIENTIFIC LAB N MEX F/G 6/18
CONTINUED STUDIES OF LONG-TERM ECOLOGICAL EFFECTS OF EXPOSURE T--ETC(U)
JUN 77 W C HANSON, F R MIERA W-7405-ENG-36
UNCLASSIFIED LA-6742 AFATL-TR-77-35 NL

1 OF 1
ADA
061727

END
DATE
FILMED
2-79
DDC

LA-6742

/. AFATL-TR-77-35

Jun 77

LEVEL II

(1)

UC-11

Issued: June 1977

AD-A061727

Continued Studies of Long-Term Ecological Effects of Exposure to Uranium

Wayne C. Hanson

Felix R. Miera, Jr.

Environmental Studies Group (H-8)

los alamos scientific laboratory

of the University of California

LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

UNITED STATES

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

CONTRACT W-7405-ENG. 36

This is a completion report of Project Order ATL-6-169 to Reimbursable Activities Branch, US Energy Research and Development Administration, Albuquerque, New Mexico, from the US Air Force Armament Laboratory, Eglin AFB, Florida.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $3.50 Microfiche $3.00

CONTENTS

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

by

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

ABSTRACT

Studies of the long-term consequences of exposing terrestrial ecosystems to natural and depleted uranium dispersed during explosives tests at Los Alamos Scientific Laboratory (LASL) and test firing at Eglin Air Force Base (EAFB), Florida, were continued. Soils from EAFB, sampled before and after firing of depleted uranium penetrators against armor plate targets, indicated that the upper (0- to 5-cm-deep) soil usually contained more uranium than lower (5- to 10-cm-deep) soil. However, no significant changes were apparent in samples taken before and after the test firing.

E-F explosive testing site at LASL was selected for intensive study of uranium redistribution during its 33-yr use. Highest surface soil (0- to 2.5-cm-deep) uranium concentrations occurred 0 and 10 m from the detonation point and averaged 4500 ppm. Concentrations in surface soil 50 and 200 m from the firing point were usually <15% of that value. The uranium distribution to 30-cm depths showed significant penetration into the soil.

Alluvium collected 250 m from the E-F detonation area in Potrillo Canyon indicated that surface (0- to 2.5-cm-deep) uranium concentrations were about 10% of those at the detonation point, and at 2.8 km they were twice background levels.

I. INTRODUCTION

This report summarizes research from October 1, 1975, through September 30, 1976, on the ecological effects of exposure to uranium. Included are analytical results on soil samples from firing ranges at Eglin Air Force Base (EAFB), Florida, that were slightly contaminated during testing of depleted uranium penetrators, and preliminary findings on the distribution in soil of natural and depleted uranium dispersed during chemical explosives tests at selected Los Alamos Scientific Laboratory (LASL) areas.

The scope and objectives of this study were detailed in the 1976 completion report.[1] Initial studies described the vegetative, small mammal, and soil invertebrate communities at selected LASL firing sites, in relation to their uranium concentrations, to provide an integrated picture of possible responses to chemical toxicity of elevated uranium concentrations in soils and to evaluate the food chain transmission potential of uranium. Based on those results, current research efforts were to:

1. Describe the uranium concentrations in soil at E-F Firing Site relative to their depth and distance from the detonation point;

2. Describe uranium redistribution from E-F and other LASL firing sites by storm runoff;

3. Evaluate soil invertebrate community responses to uranium chemical toxicity at LASL sites where uranium was dispersed during some 30 yr of tests; and

4. Relate the results of the studies of uranium in LASL's semiarid environment to the semitropical environment of EAFB to provide a basis for projecting the ecological consequences of depleted uranium munitions expended in testing.

II. URANIUM STUDY SITES

A. Uranium Expended in Explosives Tests

LASL Weapons Division personnel familiar with the Laboratory's dynamic testing programs indicated that Group M-4 (Group GMX-4 until 1972) expended uranium most continuously, beginning in mid-1943. About 80% of the 35 000-45 000 kg of uranium expended before 1954 was assumed to have been fired by Group M-4*, mostly at E-F Firing Site. The more detailed records since 1954 (Table I) indicate that about 66% of the nearly 52 000 kg of uranium expended through 1973 also was fired by Group M-4. Therefore, E-F Site was selected for intensive study of uranium distribution in soil and its possible ecological consequences.

Surface water drainage from E-F Site is mainly into Potrillo Canyon, which also receives runoff from several other firing sites that disperse uranium (Fig. 1), including some used by Groups M-2 (formerly GMX-11) and M-3 (formerly GMX-8). No accounts of the uranium expended at individual sites during early LASL operations are available, but Groups M-2, M-3, and M-4 are estimated to have expended a total of 70 000 kg, of which about 95% is credited to Group M-4, mainly at E-F Site. We have assumed that this 70 000 kg of uranium is mostly available for surface transport, mainly by storm runoff, in the Potrillo Canyon drainage. The contributions from other sites are considered negligible.

*Personal communication by R. W. Drake to G. L. Voelz, Los Alamos Scientific Laboratory, 1971.

TABLE I

SUMMARY OF NORMAL AND DEPLETED URANIUM EXPENDED IN CONVENTIONAL EXPLOSIVE TESTS AT LASL FROM 1943 - 1973[a]

(Weights in kilograms)

Year	Group M-4	Group M-2	Group M-3	Others[b]
1943-53	35000[a]			10000
1954	4459			699
1955	3562			542
1956	2380			625
1957	3608			874
1958	3200		129	876
1959	1547		23	603
1960	2141		43	520
1961	1035	8	0	3133
1962	1361	58	30	1043
1963	1106	82	43	528
1964	1153	637	12	346
1965	1023	693	59	321
1966	1872	954	84	372
1967	1757	402	144	602
1968	1097	513	80	149
1969	1035	250	58	197
1970	629	293	19	154
1971	1139	346	30	6
1972	305	85	7	260
1973	--	--	0	166
TOTALS	64409	4321	761	22016

[a]Extrapolated from personal communication by R. W. Drake to G. L. Voelz, 1971.

[b]Total expenditures among four LASL groups.

B. Potrillo Canyon

The head of Potrillo Canyon is slightly more than 1 km west of E-F firing site at about 2250-m elevation. The canyon extends due east for about 9 km and joins Water Canyon just before it reaches the rim of the Rio Grande escarpment at 1950-m elevation. There, it drops rapidly to the Rio Grande at about 1650-m elevation. The upper parts of the canyon are narrow and rocky, and the stream channel contains relatively thin (2- to 20-cm-deep) sediments derived from weathering of the Bandelier Tuff, a series of rhyolitic ash flows. About 3 km below E-F Site, the canyon broadens and sediment depths increase to about 1-2 m.[2,3]

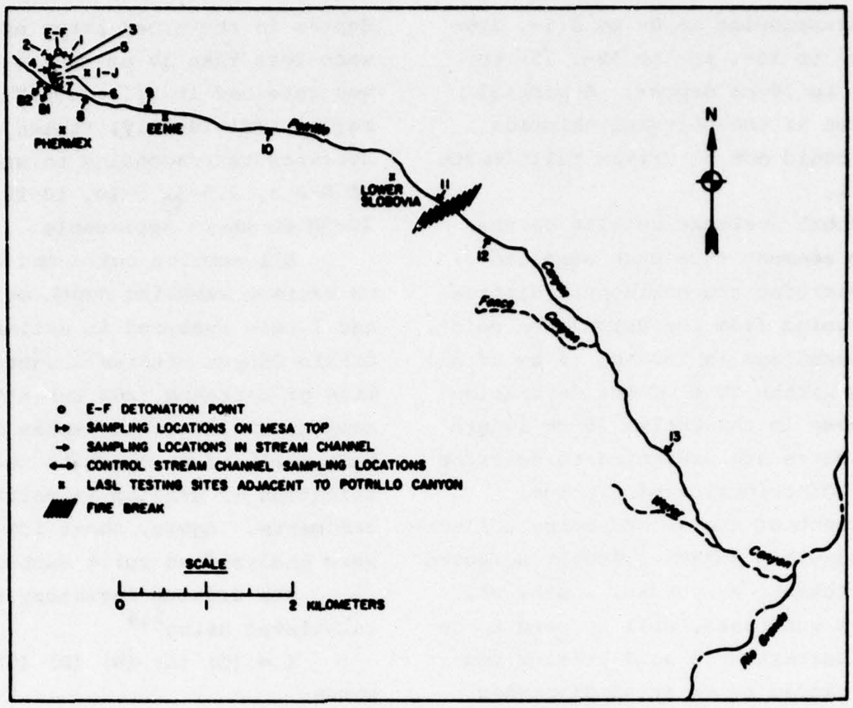

Fig. 1. Sampling locations for studying storm transport of uranium from LASL testing areas.

There is no continuous surface water flow in Potrillo Canyon. As in most intermittent streams, there is appreciable water flow after heavy rains, which carries sediment downstream. A firebreak extended across Potrillo Canyon about 5 km below E-F Site in the mid-1950s broke the stream channel continuity and caused sediment deposition. Consequently, the stream channel both west and east of the firebreak is undefined for about 100 m.

III. METHODS

A. Sample Collection

Soil was collected from E-F Site and the Potrillo Canyon stream channel. Water and sediment from storm runoff also were selected. EAFB soil was sent to LASL for analyses. Procedures for uranium analyses are described elsewhere.[4] The fluorometric technique used could detect 0.6 µg of uranium per gram of soil, with a standard deviation of ±10%.

1. E-F Site Uranium Inventory. A polar coordinate sampling pattern was devised for the 1976 soil uranium inventory at E-F Site. Samples were taken at the intersections of radii that extended from the detonation point ever 45° and of concentric circles 10, 20, 30, 40, 50, 75, 100, 150, and 200 m from the detonation point.

A 20- by 50-cm frame was laid along the outside of the tape that marked the concentric circle at each sampling site, and 30-cm-deep soil cores were collected at the outer corners of the frame, 50 cm apart. Each soil core was collected with a polyvinylchloride coring tube (2.5 cm i.d.) with a sharpened end. The maximum sampling depth and amount of compaction of each core were recorded, and the cores were then placed in plastic bags and frozen.

Later, the compaction percentage was distributed evenly over the sample length and one core from each site was cut into segments corresponding to 0- to 2.5-, 2.5- to 5.0-, 5.0- to 10-, 10- to 15-, 15- to 20-, and 20- to 30-cm depths. A partial core was taken if the polyvinlychloride coring tube could not be driven full length into the soil.

This report includes results on the 0- to 2.5-cm segment from each sampling point, to determine the horizontal distribution of uranium from the detonation point. Also, concentrations in the top 15 cm of all samples from within 50 m of the detonation point and those in the entire 30-cm length of selected cores are presented to describe the vertical distribution of uranium.

Ten percent of the second cores collected at each sampling point, randomly selected from the northeast, southeast, southwest, and northwest quadrants, will be used to determine the variation in soil uranium concentrations caused by material dispersed during the experimental explosions. About 13% of the samples were analyzed as split samples to determine the variation in uranium levels due to aliquoting and chemical analytical procedures. We will try later to determine the contribution of >6-mm-diam fragments to the total uranium inventory.

2. Potrillo Canyon Uranium Inventory. In 1975, a permanent sampling network was established from the E-F Site detonation point, along the drainage pathway from the mesa top, into Potrillo Canyon. Three sampling stations 0, 50, and 100 m from the detonation point were on the mesa top. Others were 150, 200, and 250 m from the detonation point in a tributary canyon that drains into Potrillo Canyon, and at 350, 700, 1400, 2800, 5000, 5600, and 9000 m within Potrillo Canyon. Two background stations were located 100 and 200 m above the confluence of the E-F Site effluent drainage canyon and Potrillo Canyon.

We used a coring tube like that used for the E-F Site inventory to extract duplicate cores 10 cm apart from the center of the stream channel. Some sampling depths in the upper parts of the canyon were less than 30 cm, but a partial core was obtained in all cases. All cores were bagged individually, frozen, and cut into segments corresponding to sampling depths of 0-2.5, 2.5-5, 5-10, 10-15, 15-20, and 20-30 cm where applicable.

All samples collected within the 15-cm maximum sampling depth at Stations 1 and 2 were analyzed in estimating the Potrillo Canyon uranium inventory as a function of distance from E-F Site. Selected samples collected to depths of 30 cm also were analyzed to describe the vertical distribution of uranium in Potrillo Canyon sediments. Again, about 13% of the samples were analyzed as split samples.

The uranium inventory estimate was calculated using[5,6]

$$I = (C)\ (L)\ (W)\ (D)\ (S),$$

where

I = uranium in stream segment L (mg),

C = weighted average of uranium concentrations (mg/g) at a given sampling location,

L = length of stream channel segment (m) over which C applied,

W = average stream width (m) in segment L,

D = depth (m) of sediment to which C applied,

S = specific gravity (g/m^3) of sediment.

The total inventory (TI) was

$$TI = \sum_{1}^{n} I,$$

where n is the number of stream channel segments.

3. Uranium Transport from E-F Site in Storm Runoff. Water and suspended sediment resulting from thunderstorms were collected at E-F Site on September 5, 1975, and September 17, 1976. In 1975 and 1976, respectively, precipitation totals of 3.5 cm over a several hour period and 1 cm during a span of about 30 min were

recorded at a station located approximately 1.2 km northwest of E-F Site.

A DH-48 stream flow sampler was used to collect water and suspended sediments from two standing pools on the mesa top and from 100 and 150 m below the E-F Site detonation point in 1975. Duplicate samples were collected similarly in 1976 from the same locations except for that 100 m below the detonation point. A small crater has been repeatedly formed and refilled by tests at the E-F Site detonation area. A water sample was taken from a 2-m-diam by 0.5-m-deep depression that contained about 0.3 m of water. A second sample of standing water was taken from a small depression about 20 m SW of the detonation area.

In 1975, we collected two samples of runoff water. The first was taken 100 m from E-F Site on the mesa top where the runoff flow rate was estimated to be 6-7 ℓ/s. The second was collected in the canyon where increased drainage area and slope increased the flow rate to approximately 30-35 ℓ/s. The brevity of the 1976 runoff did not permit measurements of maximum flow rates.

The DH-48 sampler collects suspended particulates up to 6 mm in diameter. Samples were collected in 500-mℓ glass containers and sealed. In the laboratory, individual samples were filtered through 0.45-μm Millipore membrane filters and the water sample was treated with concentrated HNO_3 immediately after filtration to reduce uranium plating on the container surface before analysis.

IV. RESULTS AND DISCUSSION

A. Uranium Concentrations in EAFB Soils

EAFB personnel submitted 51 soil samples for analysis during this study period. They took two series of samples, one before and one after test firing of 72 rounds of 30-mm depleted uranium penetrators against armor plate target butts on Range TA C-74 L. Analytical results are presented in Table II. Our interpretation is generally limited to the analytical parameters of the data.

The samples consisted of the upper 5 cm (A) or lower 5 cm (B) of a 10-cm^3 core from each sampling point. All samples were sieved to remove large fragments of depleted uranium and large particles of propellent before shipment to LASL. Upon arrival, the samples were pulverized and otherwise treated like the LASL soil samples. Duplicate aliquots of 6 (12% of the total) samples were submitted for analysis, and 10 (20%) of the sample leachates were replicated.

Coefficients of variation (CV = standard deviation/mean x 100) of the duplicate aliquots ranged from 13% to 42%, the greatest variation being near the lower detection limit of the fluorometric analysis method. Replicate analyses of leachates indicated good reproducibility, most of the values being within 10% CV.

Uranium concentrations in "control" soil samples averaged 0.6 ± 0.15 (std dev) μg/g in the upper 5 cm and 0.7 ± 0.2 μg/g in the lower 5 cm. These values are near the lower limit of control values reported last year (0.6-2.5 μg/g).[1]

Sampling points 8, 9, and 10 consistently yielded the highest uranium concentrations, and the upper soil horizons usually contained more uranium than the lower one. However, there seemed to be some downward movement as indicated by several uranium concentrations in lower horizons that were 10-100 times background.

B. Uranium Distribution in LASL E-F Site Soils

About half the 444 soil samples from the E-F Site study area have been analyzed. Table III shows that uranium concentrations in surface (0- to 2.5-cm) soils were highest within 10 m of the detonation point; mean values were about 4500 μg/g. Concentrations in surface soils beyond 50 m from the firing point (Fig. 2) were usually <15% of those within 10 m of the firing point.

TABLE II

LASL ANALYSES OF EAFB SOILS

EAFB No.	LASL No.	μg U/g±1 Std Dev[b]	Rep. 1[c]	Rep. 2[c]
EAFB Control Soil Samples				
13-10-17 A	2631	0.9±0.2		
13-10-17 B	2632	0.8±0.2		
13-10-21 A	2655	0.3±0.1		
13-10-21 B	2656	0.6±0.2		
Samples Taken October 17, 1975 (Before Test Firing)				
1-10-17 A	2608	40 ±5		
1-10-17 B	2609	3.0±0.4		
2-10-17 A	2610	12 ±2		
2-10-17 B	2611	1.0±0.1		
3-10-17 A	2612	3.0±0.4		
3-10-17 B	2613	2.0±0.3		
4-10-17 A	2614	7.0±0.7		
4-10-17 B	2615	1.0±0.3		
5-10-17 A[a]	2616	7.0±2.0		
	2660	9.2±0.4		
5-10-17 B	2617	2.0±0.3		
6-10-17 A	2618	30 ±2.0		
6-10-17 B	2619	3.0±0.3		
7-10-17 A	2620	11.0±0.5		
7-10-17 B	2621	2.0±0.2		
8-10-17 A	2622	12400 ±1000		
8-10-17 B	2623	570 ±50		
9-10-17 A	2624	2200 ±200		
9-10-17 B[a]	2625	145 ±10		
	2661	178 ±9		
10-10-17 A	2626	4400 ±300		
10-10-17 B	2627	154 ±8.0		
11-10-17 A	2628	13 ±2.0		
12-10-17 A	2629	64 ±2.0		
12-10-17 B	2630	84 ±5.0		
14-10-17 A	2633	111 ±6.0		
14-10-17 B[a]	2634	2.6±0.2	2.7±0.2	
	2659	1.8±0.2		
Samples Taken October 21, 1975 (After Test Firing)				
1-10-21 A	2635	18 ±1.0	15 ±1.0	
1-10-21 B	2636	2.2±0.2	2.2±0.2	1.95±0.2
2-10-21 A	2637	13.5±1.5	9.2±0.6	
2-10-21 B	2638	165 ±11		
3-10-21 A	2639	3.8±0.2		
3-10-21 B	2640	2.4±0.2		
4-10-21 A	2641	15 ±2.0	12 ±3.0	
4-10-21 B	2642	1.4±0.2	1.5±0.3	
5-10-21 A[a]	2643	12.5±0.5		
	2662	6.8±0.4		
5-10-21 B	2644	2.1±0.2		
6-10-21 A	2645	16.5±1.0		
6-10-21 B	2646	2.6±0.4		
7-10-21 A	2647	25 ±2		
7-10-21 B	2648	2.0±0.4		
8-10-21 A	2649	4600 ±300	4600 ±300	
8-10-21 B	2650	1450 ±100		
9-10-21 A	2651	3200 ±200	2900 ±200	
9-10-21 B[a]	2652	230 ±10		
	2663	191 ±10		
10-10-21 A	2653	1650 ±100		
10-10-21 B	2654	110 ±6	114 ±7	
14-10-21 A	2657	40 ±3		
14-10-21 B[a]	2658	3.6±0.2		
	2664	4.8±0.2		

STANDARDS

IAEA No. 25 1.06±0.10 mg U/g (5)[d]

IAEA No. 467 0.121±0.007 mg U/g (7)[d]

---

[a] Duplicate aliquots of soil sample submitted for analysis.
[b] ±1 std dev due to analytical error.
[c] Replicate analyses of sample leachate.
[d] Number in parentheses is number of analyses of standard.

TABLE III

URANIUM DISTRIBUTION (μg/g)
IN E-F SITE SURFACE (0- to 2.5-cm) SOILS

Distance (m)	Mean	CV	Number of Samples
0	4650	0.62	2
10	4520	0.89	8
20	1000	0.65	6
30	1800	0.65	8
40	745	0.56	7
50	395	0.69	8
75	350	0.73	7
100	520	1.29	8
150	725	2.33	8
200	165	0.95	6

Maximum and minimum values at 50-200 m, were 725 μg/g at 150 m and 165 μg/g at 200 m. CVs ranged from 56 to 89% for uranium concentrations in surface soil within 75 m of the firing point but increased markedly at 100 m and beyond. Surface uranium concentrations are shown in three- and two-dimensional plots in Figs. 3 and 4, respectively. The log-transformed data were first converted from the polar coordinate sampling array values to Cartesian coordinate values, and the plane surfaces were generated by an electronic data-processing program that interpolated between data points. These figures show that the highest uranium concentrations were at the detonation area and that higher-than-average concentrations occurred to the west, south, and northeast. Further analyses of the remaining soil samples will define more precisely spatial distributions of uranium dispersed from the detonation area.

Incomplete analyses of soil samples collected to depths of 30 cm within 50 m of the detonation area indicated that uranium has migrated into or penetrated the soil significantly to the maximum sampling depth. The uranium distribution at various depths, 0, 10, 20, 30, 40, and 50 m from the detonation area is shown in Fig. 5. Values in the upper, 0-2.5 and 2.5-5 cm varied more than those in deeper samples. The greatest departure was at 10 m, where a single value of 22 000 μg

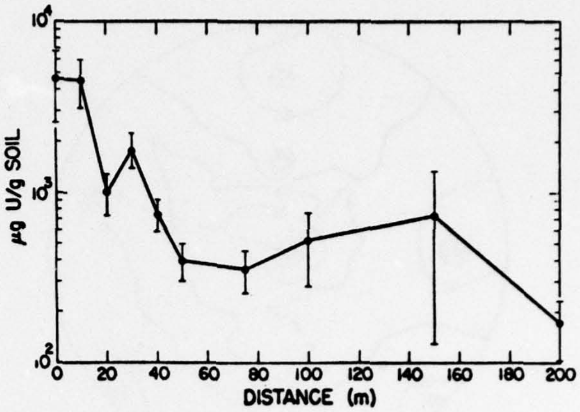

Fig. 2. Mean surface (0- to 2.5-cm deep) uranium concentrations (±1 std error) in soil at LASL's E-F Site, 1976.

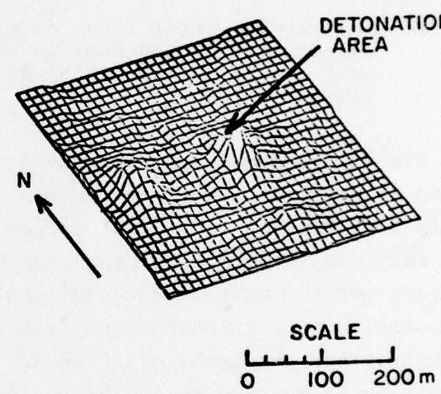

Fig. 3. Three-dimensional plot of uranium concentrations (μg/g) in E-F surface soil (0- to 2.5-cm depth).

of uranium per gram of soil in a 20- to 30-cm-deep sample introduced high variance in the population of samples. Deletion of this datum from calculation of a mean value for the 20- to 30-cm depth population restored the slope of that line in Fig. 5 to the pattern of decreasing uranium concentrations with increasing depth observed at most other distances from the detonation area. Note that the 100-μg/g mean radial value measured in the 50-m samples from 20- to 30-cm depths is about 50 times greater than the background uranium concentrations reported in this area, emphasizing uranium's mobility in the soil.

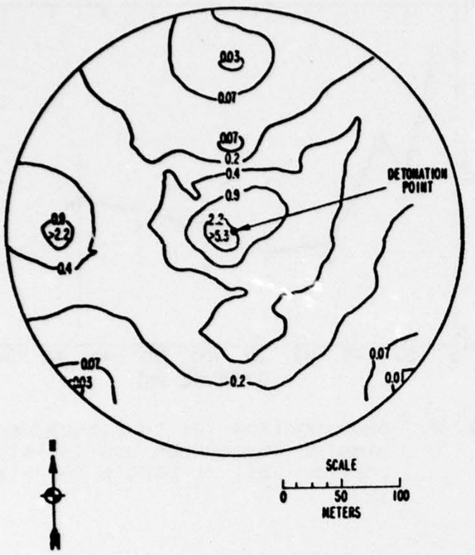

Fig. 4. Estimated contour lines of uranium concentrations (mg U/g) in surface soil (0- to 2.5-cm depth) at E-F Site.

CVs of uranium concentrations in soil beyond 20 m from the detonation area generally doubled with each depth increment. This fact complicates interpretation of physical and biological processes that may be operating in near-background uranium concentrations at depths of 10 to 30 cm, as well as in surface soils (0- to 10-cm) that contain concentrations several orders of magnitude above background.

The vertical partitioning of the total uranium within each profile segment was calculated at the various sampling distances. Largest percentages usually occurred in the top two (0- to 2.5- and 2.5- to 5-cm) segments and they were generally similar. At 0 and 10 m, 86 and 48% of the total uranium in the columns, respectively, was in the top 5 cm. Locations within 10 m of the detonation area were also most likely to be strongly influenced by mechanical disturbances and fragment penetration from the explosive tests. Total uranium in the top 5 cm at 20, 30, 40, and 50 m was 86, 71, 62, and 43%, respectively. This regular decrease with distance beyond 20 m is probably related to particle size; smaller particles are dispersed farther and are thereafter more mobile within the soil.

C. Sample Variability

Important in interpretation of uranium concentrations in environmental media is the variability due to sample processing and chemical analysis. This variability was evaluated by making 13% of the samples "split samples," of which duplicate aliquots were processed to determine their CVs. This exercise (Table IV) yielded CVs for all sampling depths which generally ranged from 0 to 12%, with only 3 values outside this range, in samples that contained from 6 to 10 450 μg of uranium per gram of soil. Thus, the error due to within-sample variability was insignificant relative to the spatial variability incurred by sampling along the several radii.

D. Potrillo Canyon Uranium Inventory

1. Uranium Concentrations in Sediments. Uranium concentrations in alluvium from the mesa top (0, 50, and 100 m from the E-F Site detonation point) and in Potrillo Canyon sediments are presented in Table V. Uranium levels were greatest (4850 μg/g dry) at the detonation point and decreased rapidly (Fig. 6) to the confluence

Fig. 5. Uranium distribution vs soil depth and distance from E-F Site. Concentrations are mean radial values obtained using a polar coordinate sampling system. Background concentrations averaged 0.6-2.7 μg/g.

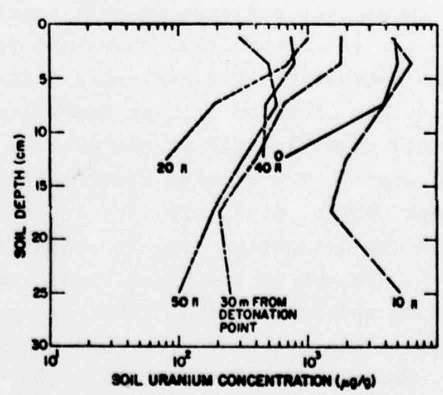

TABLE IV

URANIUM ANALYSIS OF SPLIT SAMPLES FROM E-F SITE

Soil Depth (cm)	Sampling Direction and Distance (m)	Mean Conc (μg/g)	CV
0-2.5	NE 10	633	0.05
	E 10	4750	0.07
	N 40	331	0.02
	NE 50	515	0.12
	S 50	96	0.21
	NW 50	105	0.05
	E 75	540	0.11
	N 150	9	0
	SE 150	65	0.02
2.5-5	SE 10	147	0.43
	NE 20	1950	0.04
	S 20	387	0.04
	W 50	510	0.08
5-10	SW 10	1 450	0.10
10-15	SE 30	762	1.00
	SW 30	554	0.06
	NE 40	391	0.07
	E 40	755	0.08
	S 40	77	0
	NW 40	569	0.02
15-20	SW 50	183	0.01
20-30	S 10	908	0.04
	SE 50	6	0

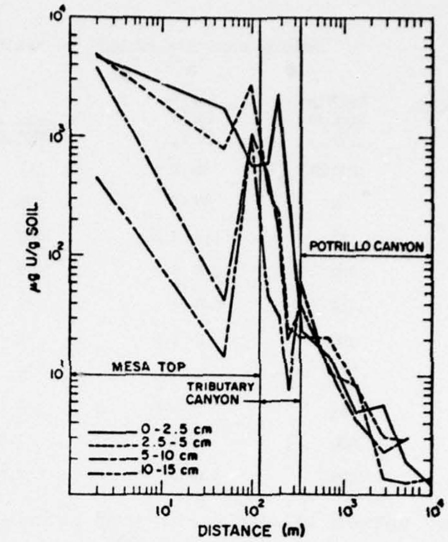

Fig. 6. Distribution of uranium from E-F Site into Potrillo Canyon as a function of distance and soil depth.

of the tributary and Potrillo Canyon (350-m station). Soil from the mesa top showed great concentration variability with depth. This contrasted with concentrations in the tributary canyon (at 150, 200, and 250 m), which generally were highest in the 0- to 2.5-cm-deep samples and decreased with depth. Concentrations were considerably diluted and more evenly distributed, to depths of at least 20 cm, from the 350-m station to 5000 m. Concentrations at the 2.8-km station were greater than background levels[1,7] (0.6-1.2 μg/g), which shows that transport to that distance has occurred during high runoff over the several years of site use.

Uranium in alluvial samples taken both west and east of the firebreak (5000- and 5600-m stations) was near background levels. Stations designated "background" (100- and

TABLE V

URANIUM IN POTRILLO CANYON ALLUVIUM FROM LASL WEAPONS TESTING AREAS

Distance from Firing Site	Micrograms of Uranium per Gram of Soil (dry weight) 0-2.5 cm	2.5-5 cm	5-10 cm	10-15 cm	15-20 cm	20-30 cm
-200 m	11 (0.18)[a]	--[b]	--	13 (0.08)		
-100 m	7.1 (0.07)	--	--	6.8 (0.07)		
0 m	4650 (0.62)	4850 (0.66)	3800 (0.33)	450 (0.06)		
50 m	1700 (0.12)	780 (1.12)	41 (0.3)	14 (0.05)		
100 m	560 (0.46)	2710 (0.73)	1000 (0.70)	1040 (0.22)	1300	
150 m	590 (0.65)	370 (0.07)	480 (1.48)	46 (0.66)	18	
200 m	2160 (1.21)	220 (1.42)	150 (1.34)	30 (0.83)	2.6	
250 m	330 (0.05)	24 (0.15)	19 (0.44)	7.2 (0.33)		
350 m	23 (0.22)	20 (0.73)	36 (0.33)	54 (0.41)		
700 m	14 (0.20)	20 (0.32)	11 (0.19)	10 (0.01)	10	3.3
1.4 km	4.7 (0.20)	7.9	4.1	8 (0.08)		
2.8 km	5.4 (0.59)	2.9	2.2	1.3 (0.69)		
5.0 km	1.8 (0.72)	2.7	2.8	1.2 (0.50)	0.6	0.8
5.6 km	1.0 (0.21)	--	--	1.1 (0.07)		0.8
9.0 km	1.2 (0.06)	--	--	1.3 (0.17)		1.4

[a] Number in parentheses is CV (std dev/sample mean) of two cores from the center of the stream channel.

[b] Samples not analyzed.

TABLE VI

URANIUM ANALYSIS RESULTS ON SPLIT AND DUPLICATE SOIL CORES FROM POTRILLO CANYON

Sampling Station (m)	Sample Depth (cm)	Split Samples Mean (μg/g)	CV	Duplicate Samples Mean (μg/g)	CV
200 BKG	0- 2.5	11	0.18	--	--
0	10-15	650	0.06	--	--
50	0- 2.5	1800	0.08	1700	0.12
100	2.5- 5.0	3850	0.02	2705	0.73
150	5.0-10	70	0.04	480	1.48
200	2.5- 5.0	39	0.07	215	1.42
350	0- 2.5	26	0.11	23	0.22
1400	0- 2.5	4.3	0.18	4.7	0.20
2800	10-15	1.8	0.20	1.3	0.69
5000	5.0-10	2.8	0.23	--	--

200-m) showed slightly elevated uranium levels in the soil. This fact seemed consistent with known variability in the E-F Site wind patterns, which, during testing periods, apparently cause minor deposition of airborne uranium in those areas.

The CV for duplicate samples from the 0- to 250-m stations was 5-148%. Large variations also were noted in previous analyses of E-F Site soils.[1] These variations are attributed partly to the inhomogeneous spatial distribution that results from the relatively large size range of uranium particles in the soil samples and materially affects the analytical results.[1]

Sediments from 350 m and beyond suggested a more homogeneous distribution of smaller particles with depth in the alluvium and distance from E-F Site. This difference was reflected by the smaller (6-73%) CVs between duplicate soil cores.

Analytical results from the split replicate samples are presented in Table VI, along with the results of duplicate core samples from each station. The split sample results indicated that the variation due to aliquoting only part of the sample contributed only a small error compared to the variation due to the spatial distribution of uranium. In split samples with mean uranium concentrations of about 2-3850 μg/g, the variation was only 2-23%, whereas the duplicate cores taken 10 cm apart and having mean uranium concentrations of about 1-2700 μg/g had CVs of 12-148%. Thus, the between-sample variability was substantially greater than the within-sample variability, which further supports confidence in the analytical procedure developed early in this investigation.

2. *Uranium Inventory.* The parameters used to calculate the uranium inventory in Potrillo Canyon area soils are presented in Table VII, along with the results at 12 distances from E-F Site. Most (57%) of the uranium is at 0-125 m on the mesa top, where the first evidence of a drainage channel appears approximately 25 m beyond the detonation point and provides a focal sampling site. Just under 19% of the estimated uranium in the E-F drainage channels is in the 125- to 300-m segment of the tributary canyon. Thus we accounted for 76% of the uranium estimate before reaching Potrillo Canyon.

The amount of uranium estimated to lie in the E-F Site drainage as far as 9000 m down Potrillo Canyon is 58 kg. Although seemingly large, this amount is <0.1% of the uranium that M-4 expended during 1943-1973 and it indicates that only minor amounts have moved appreciably.

TABLE VII

URANIUM INVENTORY IN POTRILLO CANYON

Distance (m)	Ave U Conc (mg/g Weighted Mean 0-15 cm)	L(m)	W(m)	D(m)	$S(g/m^3)$	Total mg U/Segment	Total U (kg)	% Estimated U Inventory in Segment
0-25	3.02	25	1.0	0.15	1.4×10^6	1.58×10^7	15.8	27.2
25-75	0.44	50	1.0	0.15	1.4×10^6	4.62×10^6	4.62	7.9
75-125	1.23	50	1.0	0.15	1.4×10^6	1.29×10^7	12.9	22.2
125-175	0.34	50	1.0	0.15	1.6×10^6	4.04×10^6	4.04	6.9
175-225	0.46	50	1.0	0.15	1.6×10^6	5.57×10^6	5.57	9.7
225-300	0.07	75	1.0	0.15	1.6×10^6	1.24×10^6	1.24	2.1
300-525	0.04	225	1.5	0.15	1.6×10^6	3.24×10^6	3.24	5.5
525-1050	0.013	525	1.5	0.15	1.6×10^6	2.46×10^6	2.46	4.3
1050-2100	0.006	1050	1.5	0.15	1.6×10^6	2.27×10^6	2.27	4.0
2100-3900	0.003	1800	1.5	0.15	1.6×10^6	1.94×10^6	1.94	3.3
3900-7000	0.002	3100	2.0	0.15	1.6×10^6	2.98×10^6	2.98	5.2
7000-9000	0.001	2000	2.0	0.15	1.6×10^6	0.96×10^6	0.96	1.7
TOTAL							58	100.0

TABLE VIII

STORM RUNOFF FROM E-F SITE ON SEPTEMBER 5, 1975

Sampling Location	Estimated Flow Rate (ℓ/s)	Sediment Suspended (g/ℓ)
Detonation Area	Standing H_2O	0.15
20 m SW of Detonation Area	Standing H_2O	0.89
100 m SW of Detonation Area (on mesa top)	6-7	2.79
250 m SW of Detonation Area (canyon stream channel)	30-35	0.56

E. Storm Runoff Transport of Uranium at LASL

The characteristics of the September 1975 storm runoff at E-F Site are presented in Table VIII. Estimated flow rates were slow on the mesa top, but about 5 times greater in the canyon owing to increased drainage area and slope. However, the suspended sediment load was greater on the mesa top than in the canyon.

Highest total concentrations (Table IX) were found in the standing water from

TABLE IX

URANIUM CONCENTRATIONS IN STANDING WATER AND RUNOFF

FROM E-F SITE ON SEPTEMBER 5, 1975, AND SEPTEMBER 17, 1976

Sample	Date	Uranium in Water (μg U/ℓ)	Uranium in Suspended Sediments (μg U/ℓ)	Total Uranium (μg U/ℓ)	Uranium in Solution (%)
Standing water	1975	$86 \times 10^3 \pm 2 \times 10^3$	590 ± 30	86.6×10^3	99
Detonation Point	1976	$235 \times 10^3 \pm 5 \times 10^3$	$47 \times 10^3 \pm 4 \times 10^3$	282×10^3	83
Standing Water 20 m SW	1975	63 ± 6	$1.25 \times 10^3 \pm 0.2 \times 10^3$	1.3×10^3	5
Detonation Area	1976	240 ± 20	890 ± 30	1.1×10^3	21
Runoff 100 m SW of Detonation	1975	52 ± 5	100 ± 8	152	34
Point (mesa top drainage)	1976	--	--	--	--
Runoff 250 m SW of Detonation	1975	37 ± 2	54 ± 5	91	41
Point (canyon stream channel)	1976	125 ± 9	410 ± 20	535	23

the detonation crater, 86.6 mg/ℓ in 1975 and 282 mg/ℓ in 1976, with nearly all of the uranium in solution. The higher uranium values in 1976 probably resulted from the heavier rain which carried more sediment containing higher uranium concentrations, although the runoff parameters were not estimated. Concentration in the suspended sediments in 1975 was 3900 µg/g, comparable to average surface concentrations in that area. Standing water 20 m SW of the detonation point contained much less uranium, only 60 and 240 µg/ℓ, with 5% in solution in 1975 and 21% in solution in 1976. Field observations of these two sites substantiated that these differences were real; large chunks of depleted uranium around the detonation area are visibly corroding and, presumably, the uranium is being leached from them.

Uranium in the runoff water decreased with distance to 52 and 37 µg/ℓ at 100 and 250 m, respectively, in 1975. Urnaium in the suspended sediment also decreased to 100 and 54 µg/ℓ, respectively. The percentage of uranium in solution was about the same in these two samples (34 and 41%). Uranium concentrations in both the water and suspended sediment were higher in 1976, but the percentage of uranium in solution was lower, at 23%.

These preliminary results implicate storm runoff as an important vector in transporting uranium from E-F Site. Samples will be taken to verify these results and to determine the chemical state of the uranium involved. These preliminary results indicate that the solubility, and hence movement, of uranium through the ecosystem may be greater than anticipated.[8]

V. MACROFAUNA OF SOIL AND LITTER AT LASL STUDY SITES

Studies of litter- and soil-inhabiting invertebrates at LASL study sites continued, and analyses were completed for July and August 1975 (summer), November 1975 (fall), January 1976 (winter), mid-March 1976 (late winter--early spring), and May 1976 (mid-spring). Invertebrates were extracted from the 100-cm^2 soil cores, by use of the Tulgren funnel technique, into a 70% alcohol solution.[9] They were then sorted, identified, and counted under a dissecting microscope.

Soil cores were obtained from E-F and Lower Slobovia (LS) Sites and nearby control sites, with careful consideration given to the soil, vegetation, and topography of each experimental and control area. The organisms' distributions were characterized and compared to ascertain possible differences that might be due to ecological changes caused by the presence of uranium.

Cores extracted in July-August were from 0- to 2- and 2- to 6-cm depths. However, the analyses indicated no apparent distribution difference at the two depths, so subsequent extractions were combined to give a 600-cm^3 core. Soil cores in the other sampling periods were 500 cm^3.

A. Populations and Characteristics

More than 9800 specimens, representing 100-110 species, were isolated from 217 samples. Table X is a complete phylogenetic listing of the groups, with estimates of the numbers of species represented in each. Species of Acarina (ticks and mites) were most abundant, with a relative density (RD = per cent of total animals) of 78% and a frequency (F = per cent of occurrence in samples) of 93%. There were over 40 species of ticks and mites, of which about 10 are considered common. Four families of 1 to 3 species each were identified in the 850 Collembola (springtails) collected with an RD of 9% and an F of 54%. Two families, each represented by a single species, of Thysanoptera (thrips) were common with respective RDs and Fs of 4 and 37%.

The mean number of animals per sample (Table XI) was 10-90, only one value being outside that range. The mean numbers of animals per sample from all sites combined

TABLE X

MACROFAUNA RECOVERED AT LASL STUDY SITES

Phylum	Class	Order	Family	No. of Species
Nematomorpha	Gordioidea			1
Arthropoda	Chilopoda		Lithobiidae	1
	Symphyla			1
	Pauropoda			1
	Arachnida	Acarina	15 Families	> 40
		Araneida	Clubionidae	1
			Gnaphosidae	1-2
			Linyphiidae	1-2
			Theridiidae	1-2
	Insecta	Protura		1
		Diplura	Campodeidae	1
			Japygidae	1
			Anajapygidae	1
		Collembola	Entomobryiidae	3-4
			Isotomidae	1
			Poduridae	1
			Sminthuridae	2
		Isoptera	Rhinotermitidae	1
		Psocoptera		1-2
		Thysanoptera	Phloeothripidae	1-2
			Thripidae	1
		Hemiptera		
		Suborder-Heteroptera	Coreidae	2
			Lygaeidae	2
			Miridae	2
			Miscellaneous nymphs	3
		Suborder-Homoptera	Aphididae	1-2
			Cicadellidae	1-2
			Delphacidae	2
			Miscellaneous nymphs	2
		Coleoptera	Carabidae	2
			Staphylinidae	2
			Larvae	2
		Lepidoptera	Microlepidoptera	1
			Miscellaneous larvae	2-3
		Diptera	Cecidomyiidae	3
			Chironomidae	1
			Mycetophilidae	2
			Psychodidae	1
			Miscellaneous	3
		Hymenoptera	Braconidae	1
			Chalcidoidae	2
			Cynipoidae	1
			Formicidae	4-5

TABLE XI

MEAN NUMBER OF INVERTEBRATES PER SOIL CORE AT LASL URANIUM-FIRING SITES
(July 1975-May 1976)

Sampling Period[a]	No. of Cores	Mean Number of Animals per Soil Core: Test Areas: E-F	Test Areas: Lower Slobovia	Control Areas: E-F	Control Areas: Control Site	Range
July-Aug	24	12	36	59	23	12-59
November	9	47	167	57	64	47-167
January	12	10	28	68	16	10-68
March	4	90	65	--	55	55-90
May	6	90	29	70	33	29-90
	Range	10-90	28-167	57-70	16-64	

[a]July-August soil cores were 600 cm^3; all others were 500 cm^3.

were highest in November, March, and May (84, 70, and 55 per sample, respectively), whereas the July-August and January means were only about half as large (30 and 33 per sample, respectively).

B. Abundance of Various Species and Groups in Test and Control Areas

1. E-F Experimental and Control Sites. The total number of species and the number of species per sample were greater at the control site in all instances in which comparable collections were made at the E-F sites. For all sampling periods combined, there was a mean of about seven species per sample at E-F experimental site compared to nine at the control site. Total numbers of species per sampling period were also greater at the control site (mean of 31, range 24-35) than at the E-F firing site (mean of 23, range 10-31). These differences are not statistically significant because of large variations in the E-F data and the small number of samples.

The numbers of individuals per sample, as well as the frequencies with which given orders occurred (Table XII), were also greater at the control site, although the data were not consistent for all sampling periods.

2. Lower Slobovia Experimental and Control Sites. Results from the Lower Slobovia experimental and control sites are the inverse of those from the E-F sites. The mean number of individuals per sample is higher at the Lower Slobovia experimental site (mean of 65) than at the control site (mean of 38), in all sampling periods except May. The experimental site yielded about 10 species per soil core and an average of 33 species in all cores combined during each sampling period. The control site gave about 8 species per core and 25 species per sampling period. Frequency of occurrence of the major orders (Table XIII) also was consistently higher at the firing site.

C. Distributions of the Major Orders

1. Acarina (Ticks and Mites). This order occurred most often in all sampling areas (Tables XII and XIII), only 22 of the 217 samples being without any representatives. This is a frequency of over 90% for all sampling periods, much higher than that of any other invertebrate order. The relative densities were very high; fall and winter densities were 87 and 85%, respectively. In the spring, the relative densities had decreased to 82 and 67%, and the summer figure was 68%.

TABLE XII

FREQUENCY OF OCCURRENCE (F) AND DENSITIES (D) OF MAJOR SOIL INVERTEBRATE GROUPS AT E-F EXPERIMENTAL AND CONTROL SITES (JULY-AUGUST 1975 to MAY 1976)

		Sampling Period									
		July-August		November		January		March		May	
Taxon		E-F	Control	E-F	Control	E-F	Control	E-F	Control	E-F	Control
Acarina	F	75	92	78	100	58	92	100	--	100	100
(Mites and Ticks	D	7.2	46	40	50	7	60	74	--	48	51
Collembola	F	29	96	56	56	25	67	25	--	33	67
(Springtails)	D	0.7	9.1	0.9	2.4	2.1	7.1	1.3	--	0.7	2
Homoptera and Hemiptera	F	33	31	56	33	8	17	50	--	33	100
(Bugs)	D	0.4	0.5	2.1	0.3	0.1	0.2	1.3	--	0.3	3.2
Diptera	F	54	54	44	56	0	8	0	--	0	17
(Flies)	D	0.9	1.0	0.6	2.7	0.8	0.1	0	--	0	0.2
Thysanoptera	F	17	8	44	0	0	0	100	--	100	50
(Thrips)	D	1.8	0.1	1.9	0	0	0	12.5		25	1.8
Hymenoptera	F	12	42	22	33	17	0	50	--	20	67
(Ants)	D	0.4	1.5	0.2	0.3	0	0	0.8		115	9.2
Araneida	F	0	0	0	0	8	0	0	--	0	0
(Spiders)	D	0	0	0	0	0	0	0		0	0
Coleoptera	F	25	12	22	0	0	0	0	--	50	0
(Beetles)	D	0.3	0.2	0.8	0	0	0	0		0.5	
Lepidoptera	F	0	0	0	22	0	18	0	--	17	0
	D	0	0	0	0	0	0	0		0	0
Psocoptera	F	0	0	0	2	0	8	0	--	0	0
	D	0	0	0	0.6		0.1	0		0	
Miscellaneous	F										
	D	0.1	0.9	0.1	0.3	0	0.2	0		0.2	6

The Acarina densities (mean number of individuals per sample) were significantly greater at the E-F control site than at the experimental site (t = [-2.3], 6 d.f., $P \leq 0.10$), as measured using Student's t test. Differences ranged from only three individuals per sample in May to more than eight times that many in January. The LS sites showed the inverse, Acarina densities generally being greater at the experimental site than at the control site; however, these differences were not significant.

All but one of the 15 Acarina families so far identified are predators. This fact may warrant further investigation because of predators' importance as indicators of overall ecosystem stability.

2. Collembola (Springtails). The Collembola are well represented in most samples (Tables XII and XIII), being about 9% of the sample total. Four families, Entomobryiidae, Isotomidae, Poduridae, and Sminthuridae, are represented. The entomobryiids are represented by three or four species, the sminthurids by at least two, and the podurids and isotomids by one each.

The per cent of catch ranged from <1 (at E-F site in May and at LS control in November) to 21 at E-F in January and 30 at LS in summer. Again, the densities at the E-F control site were significantly greater (t = [2.27], 6 d.f., $P \leq 0.10$) than at the experimental site. Population density differences between the experimental and control sites ranged from more than ninefold in July-August to about twofold in May.

The LS sites again showed the inverse of the E-F results; however, the Collembola density was significantly greater (t = [2.49], 8 d.f., $P \leq 0.10$) at the LS experimental site than at its control, except in May. These differences ranged from a factor of about 11 (Experimental:Control) in July-August to twice as many individuals in

TABLE XIII

FREQUENCY OF OCCURRENCE (F) AND DENSITIES (D) OF MAJOR SOIL INVERTEBRATE GROUPS AT LOWER SLOBOVIA EXPERIMENTAL AND CONTROL SITES

		Sampling Period									
		July-August		November		January		March		May	
Taxon		LS	Control	LS	Control	LS	Control	LS	Control	LS	Control
Acarina	F	100	96	100	100	83	83	100	100	100	100
	D	20	19	132	62	24	16	47	49	19	24
Collembola	F	83	61	44	22	50	33	100	100	50	67
	D	11	0.7	9	0.3	2.8	0.4	6.5	2.5	0.5	1.3
Homoptera and Hemiptera	F	17	7	89	33	33	8	75	75	67	67
	D	0.3	0.3	20	0.4	0.4	0.1	3	2.5	2.8	3
Diptera	F	88	52	78	56	17	0	0	25	0	50
	D	1.1	0.9	2.2	0.7	0.3	0	0	0.3	0	0.5
Thysanoptera	F	17	30	33	33	0	0	25	0	0	0
	D	0.9	1.9	0.4	0.3	0	0	0.3	0	0	
Hymenoptera	F	33	17	22	11	0	0	25	0	83	50
	D	2.1	0.4	0.9	0.1	0	0	7.5	0	4.7	2.7
Araneida	F	0.1	0.1	33	0	0	0	0	0	0	0
	D	0	0.1	0.3	0	0	0	0	0	0	0
Coleoptera	F	21	30	33	11	17	0	25	0	17	17
	D	0.2	0.3	0.7	0	0.2	0	0.3	0	0.7	0.3
Lepidoptera	F	0	0	33	0	8	0	0	0	0	33
	D	0	0	0	0	0	0	0	0	0	0.8
Psocoptera	F	0.1	0	11	22	17	0	0	25	0	33
	D	0.1	0	0.1	0.2	0.2	0	0	0.5	0	0.5
Miscellaneous	F										
	D	0.6	0	1.3		0.2	0	0.3	0	1	0

March. The control site May collections had twice as many Collembola per sample as the experimental site collections.

Collembola were most abundant in summer; >60% of the specimens occurred then, yielding an RD of 13.5%. Winter showed the next greatest abundance, with 17% of the specimens and an RD of 11%. All other collections showed low values, with RDs of 2.4%, 3.0%, and 5.3%. Despite rather low RDs, the Collembola are a very regular part of the fauna. About 50% of the samples contained Collembola, although the numbers of individuals were often quite small. As a group, they may well deserve more study, because their numbers are adequate and they occur consistently.

3. Hymenoptera (Ants and Wasps). The ants and wasps rank third in overall RD, with a mean of about 4.4%, mainly due to high spring and summer ant densities. Four or five species of ants constitute as much as 16% of the catch at the E-F and LS sites in May. The November and January densities were low, <1% of the individuals in these samples. The ants seem to revel in the disturbances at the firing sites as their densities there were greater, although the E-F experimental site results were not consistent. The ants' preference for experimental sites may correlate with an exploitative role; they can avoid the rigors of the soil surface in a disturbed area and take advantage of the greater food variety available there.

4. Thysanoptera (Thrips). This order, consisting of no more than two or three species, somewhat strangely showed a >3% RD, which is low but ranks them fourth in abundance. Thrips parallel the ants in seasonal abundance; populations were low in winter, not much higher in early spring and autumn, and greatest in late spring and summer. They yielded confusing data on firing versus control sites. At the E-F mesa top sites, the thrips were more common

at the firing site, though not significantly so. Populations at the LS sites did not differ consistently.

5. Homoptera and Hemiptera (Bugs). These two orders (considered together because most are herbivorous, sucking insects) have about the same 3% average RD as the thrips. However, they remain active and appear throughout the year. Although somewhat low in winter, their F averages 50% for all seasons, despite low densities. Their seasonal distribution is not well-defined; their winter, early spring, and summer RDs are low. In summer they move up onto the vegetation, which may cause their scarcity in soil samples. Their distribution at experimental and control sites also is inconsistent although they are more common at the LS experimental site than at the control site.

6. Diptera (Flies). Flies are not common in soil samples, as only slightly >1% of the specimens belong to this group. They were most abundant in summer and fall. Samples from experimental and control sites show no consistent similarities or differences.

7. Coleoptera (Beetles). The beetles also show no preference for experimental versus control or canyon versus mesa sites. They constitute <1% of all animals found in soil samples and probably, like the flies, occur largely accidentally in soil. They are probably collected as they pass from one preferred habitat to another, rather than because they are actual residents.

8. Miscellaneous Other Animals. The remaining animals, Psocoptera, Protura, Diplura, Pauropoda, Symphyla, Chilopoda, Araneida, and Lepidoptera, together constitute <1% of the catch and also appear to be merely transient members of the community.

D. Population Responses to Uranium

Analyses of the soil invertebrate community reflect earlier results of the vegetative community analysis in areas of high and low uranium concentrations.[1] E-F Site, an area of relatively high concentrations, had fewer species and individuals per sample than did its comparable control site. Similar results have been found in soil anthropod communities following such disturbances as burning and chronic gamma irradiation.[10,11] Acarina species were found to increase after burning and also to be one of the most radioresistant groups. In the present study, although the Acarina showed consistently greater RDs and Fs at both the control sites, with some exceptions at the LS sites, they are undoubtedly one of the more important species at the firing sites.

Edwards[11] found that the more active, surface-dwelling Collembola, specifically the Entomobryidae and Sminthuridae (both present in LASL collections), were among the most radiosensitive invertebrates. Our studies showed significantly lower Collembola densities at both experimental sites than at their respective control sites.

Except for the Collembola and to some extent the Acarina, the LS experimental site generally had the greater densities of most animal groups. This fact probably can be attributed to the greater diversity of its understory vegetation, a consequence of overstory elimination in fires started by pyrophoric depleted uranium. However, the soil uranium concentrations are also significantly lower than those at the E-F firing site because of the different nature and amount of uranium expended at the sites.

Future studies will focus on populations of surface-dwelling invertebrates collected in pitfalls and by sweeping.

VI. SUMMARY AND CONCLUSIONS

Studies of the long-term consequences of exposing terrestrial ecosystems to natural and depleted uranium dispersed during chemical explosives tests at LASL and test firing of depleted uranium penetrators at EAFB continued. Major accomplishments were (1) description of uranium concentrations in 51 soil samples collected from EAFB Range TA C-74 L before and after firing of seventy-two 30-mm depleted uranium penetrators against armour plate targets; (2) determination and initial interpretation of uranium concentrations in about half of 444 soil samples collected on a polar coordinate grid around LASL E-F Site firing point; (3) description of uranium transport from E-F Site by surface water runoff and of the resultant inventory in Potrillo Canyon by analysis of about 90 alluvium samples collected at up to 9000 m from E-F Site; and (4) extraction and interpretation of soil and litter macrofauna of soil cores from two experimental and two control sites during five seasonal periods to evaluate their possible responses to uranium chemical toxicity.

Uranium concentrations in EAFB samples were highest at sampling points designated 8, 9, and 10. Soil 0-5 cm deep usually contained higher concentrations than soil 5-10 cm deep. No significant concentration changes were apparent in samples taken after test firing of 72 rounds of depleted uranium penetrators. CVs were 10% in sample leachates and 13-42% in duplicate soil aliquots. These data indicated high reproducibility in chemical analyses of EAFB soil samples that contained 1-12 000 μg/g (= ppm) of uranium.

About 70 000 kg of natural and depleted uranium was estimated to have been expended at LASL's E-F Site during its 33-yr use. Soil samples from this site showed highest surface (0- to 2.5-cm) uranium concentrations at 0 and 10 m from the detonation point; they averaged 4500 ppm. Surface concentrations at 50-200 m were usually <15% of that value. Three-dimensional plots of surface soil uranium concentrations showed clusters of highest values west, south, and northeast of the detonation point. Uranium in soil column increments to 30-cm depths at 0, 10, 20, 30, 40, and 50 m from the detonation point showed significant penetration into the soil, and at 50 m the concentration at 20- to 30-cm depth was about 50 times greater than background (0.6-1.2 ppm) for that area.

Surface water transport of uranium from E-F Site into Potrillo Canyon was evaluated by determining uranium concentrations in stream channel sediments and sampling storm runoff water. Surface (0- to 2.5-cm) alluvium 250 m beyond the detonation area contained 300 ppm, or about 10% of the uranium concentration measured at the detonation point, and samples at 2800 m contained twice background levels. Concentrations within 200 m of E-F Site were highly variable to depths of 15 cm, but concentrations were homogeneous to depths of at least 20 cm throughout the 350- to 5000-m segment of the canyon stream bed below E-F Site. There was an estimated 58 kg of uranium in the top 15 cm of alluvium in the canyon below E-F Site, 76% being within 300 m of the source and the rest distributed down the canyon to 9000 m. The 58 kg is <0.1% of the estimated total uranium expended at E-F Site in 1943-1973, indicating only minor amounts of the material have moved any appreciable distance. Initial measurements showed more soluble uranium in storm runoff water than had been anticipated, especially in light of nearly 80-100% solubility of uranium in standing water at the detonation point that contained 86 mg/ℓ in 1975 runoff samples and 235 mg/ℓ in 1976 samples. Concentration in suspended sediments in 1975 was 3900 μg/g, comparable to average surface uranium concentrations in that area.

Soil and litter macrofauna populations and species diversities were apparently reduced at the high-uranium study area compared to their control area counterparts. Collembola populations were significantly lower at both E-F and LS experimental sites than at their respective control sites. Future studies will concentrate on definition of this possible community response to uranium chemical toxicity by a major herbivore species, a major carnivore species, and surface-dwelling arthropods.

Study results confirmed last year's observations that both large fragments and fine particulates from uranium explosives tests corrode readily and move into the soil at variable rates. This mobility will undoubtedly be of greater importance in the more humid environment and porous soils of EAFB.

ACKNOWLEDGMENTS

Environmental Studies Group personnel who deserve recognition include K. V. Bostick for supervising sample processing; P. E. Baldwin, A. Esparsen, M. Maes, J. L. Martinez, and G. Trujillo for technical assistance; and P. Jose, J. Owens, and D. Knab for conducting uranium analyses.

Donald C. Lowrie separated, identified, and summarized soil macrofauna; William D. Purtymun assisted in interpretation of uranium transport data; W. John Smith helped generate computerized graphics; and L. L. Eberhardt of Pacific Northwest Laboratories consulted on sampling design and techniques. We heartily appreciate their efforts.

L. M. Baggett and J. E. Travis of LASL's Dynamic Testing Division provided study site use histories and characterizations.

REFERENCES

1. W. C. Hanson and F. R. Miera, Jr., "Long-Term Ecological Effects of Exposure to Uranium," Los Alamos Scientific Laboratory report LA-6269 (1976).
2. R. L. Griggs, "Geology and Ground Water Resources of the Los Alamos Area New Mexico," Geological Survey Water-Supply paper 1753, U. S. Government Printing Office, Washington, D.C. (1964). (1964).
3. W. D. Purtymun, "Geohydrology of Pajarito Plateau with References to Quality of Water, 1949-1972," Los Alamos Scientific Laboratory report, in preparation.
4. J. W. Owens, "Fluorometric Determination of Uranium in Environmental Materials," Los Alamos Scientific Laboratory report LA-6338-MS (1976).
5. W. D. Purtymun, "Storm Runoff and Transport of Radionuclides in DP Canyon, Los Alamos County, New Mexico," Los Alamos Scientific Laboratory report LA-5744 (1974).
6. T. E. Hakonson, J. W. Nyhan, and W. D. Purtymun, "Accumulation and Transport of Soil Plutonium in Liquid Waste Discharge Areas at Los Alamos," in Transuranium Nuclides in the Environment, IAEA-SM-199/99, pp. 175-189 (1976).
7. L. J. Johnson, "Los Alamos Land Areas Environmental Radiation Survey 1972," Los Alamos Scientific Laboratory report LA-5097-MS (1972).
8. W. C. Hanson, "Ecological Considerations of Depleted Uranium Munitions," Los Alamos Scientific Laboratory report LA-5559 (1974).
9. A. MacFadyn, "Notes on Methods for the Extraction of Small Soil Arthropods," J. Animal Ecol. 22, 65-77 (1953).
10. J. Lassenhop, "Soil Arthropod Response to Prairie Burning," Ecology 57, 88-98 (1976).
11. C. A. Edwards, "Effects of Gamma Irradiation on Populations of Soil Invertebrates," in Symposium on Radioecology, D. J. Nelson and F. C. Evans, Eds., U. S. AEC report CONF-670503 (1963).