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Subjects: ACTIVITY LEVELS -- CORRELATIONS; URANIUM -- RADIONUCLIDE MIGRATION; URANIUM -- ACTIVITY LEVELS; RODENTS -- RADIONUCLIDE KINETICS; PLANTS -- RADIONUCLIDE KINETICS; DEPTH -- CORRELATIONS; LASL; TERRESTRIAL ECOSYSTEMS; SOILS; VERTEBRATES; US ORGANIZATIONS; US ERDA; US DOE; US AEC; NATIONAL ORGANIZATIONS; METALS; MASS TRANSFER; MAMMALS; ENVIRONMENTAL TRANSPORT; ELEMENTS; ECOSYSTEMS; DIMENSIONS; ANIMALS; ACTINIDES

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Mobility of Elevated Levels of Uranium in the Environment

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ABSTRACT

Studies of the long-term consequences of exposing terrestrial ecosystems to aged deposits of natural and depleted uranium at Los Alamos Scientific Laboratory (LASL) have been conducted over the past 3 years. The E-F explosive testing site at LASL was selected for intensive study of uranium redistribution during its 24-year use. The highest surface-soil (0 to 2.5 cm) uranium concentrations occurred 0 to 10 m from the detonation point and averaged 1500 μg/g. Concentrations in surface soil 50 and 200 m from the detonation point were generally less than 15% of that value. The uranium distribution to 30-cm depths for the 0- to 50-m distant sampling locations and to 10-cm depths at 50- to 200-m sampling distances showed significant penetration into the soil profile. Alluvium collected 250 m from the E-F detonation area indicated that surface (0 to 2.5 cm) uranium concentrations were about 10% of those at the detonation point, and at 2.8 km they were twice background, averaging 5 μg/g.

Ratios of plant/soil uranium concentrations varied from 0.05 to 0.08. Internal tissues from two species of small mammals had tissue/soil ratios of 10^{-3} and 10^{-4}, although gastrointestinal contents of these mammals had mean uranium levels greater than 10% of soil concentrations.

The importance of nuclear facilities as viable alternatives to fossil-fuel power plants is not certain at present. However, the need for appreciable production of uranium to feed nuclear facilities has prompted intensive hydrogeochemical survey programs to locate subsurface ore bodies in several countries. The mining and processing of uranium have resulted in contamination of the environment with uranium as well as other undesirable chemical wastes. In addition, decontamination of areas in which radioactive materials have been stored or discharged usually involves uranium. Despite the impor-

tance of uranium, its ecological behavior in the environment is poorly documented (Hanson, 1974; Essington et al., 1976). Natural uranium ores are of concern because of associated radioactivity. During milling and refining processes, most of the decay-chain products that are of principal radioactive concern are removed; thus the primary concern for uranium to terrestrial ecosystems is its chemical toxicity.

During the past 3 years, we have been studying the fate of some 70,000 kg of natural and depleted ($^{235}U/^{238}U$, < 0.0072) uranium dispersed during dynamic tests at the Los Alamos Scientific Laboratory (LASL) environs of north-central New Mexico. The objectives of the present study were to evaluate the horizontal distribution of uranium from the detonation point and its vertical distribution into the soil profile on the mesa where the tests were conducted as well as the adjacent drainage area and to determine uranium concentrations in selected biota.

METHODS AND MATERIALS

The LASL Study Area

The LASL reservation consists of 113 km^2 in north-central New Mexico on the Pajarito Plateau, which is situated on the eastern slopes of the Jemez Mountains west of the Rio Grande (Fig. 1). The plateau, which has a pronounced elevational gradient in the east-west direction, was formed by successive ash flows from a volcanic area 32 km to the west. The soils of the area have recently been characterized in detail (Nyhan et al., 1978). The climate is semiarid, with approximately 46 cm of annual precipitation. Nearly 75% of this occurs during intense May—October thundershowers, and the runoff generated accounts for much of the canyon erosion in the area.

The E-F testing site, located in the west-central portion of LASL on a mesa top at an elevation of 2190 m, has been since mid-1949 the most continuously used LASL site for the expenditure of uranium. No cleanup operations of potentially hazardous gamma emissions have been reported to date (Hanson and Miera, 1977). The fact that the overstory vegetation surrounding the site has been burned and is now in successional recovery stages exhibits evidences of both the pyrophoric properties of depleted uranium and the properties of the resultant chemical explosives. The biotic inventory of the area is discussed elsewhere (Hanson and Miera, 1976).

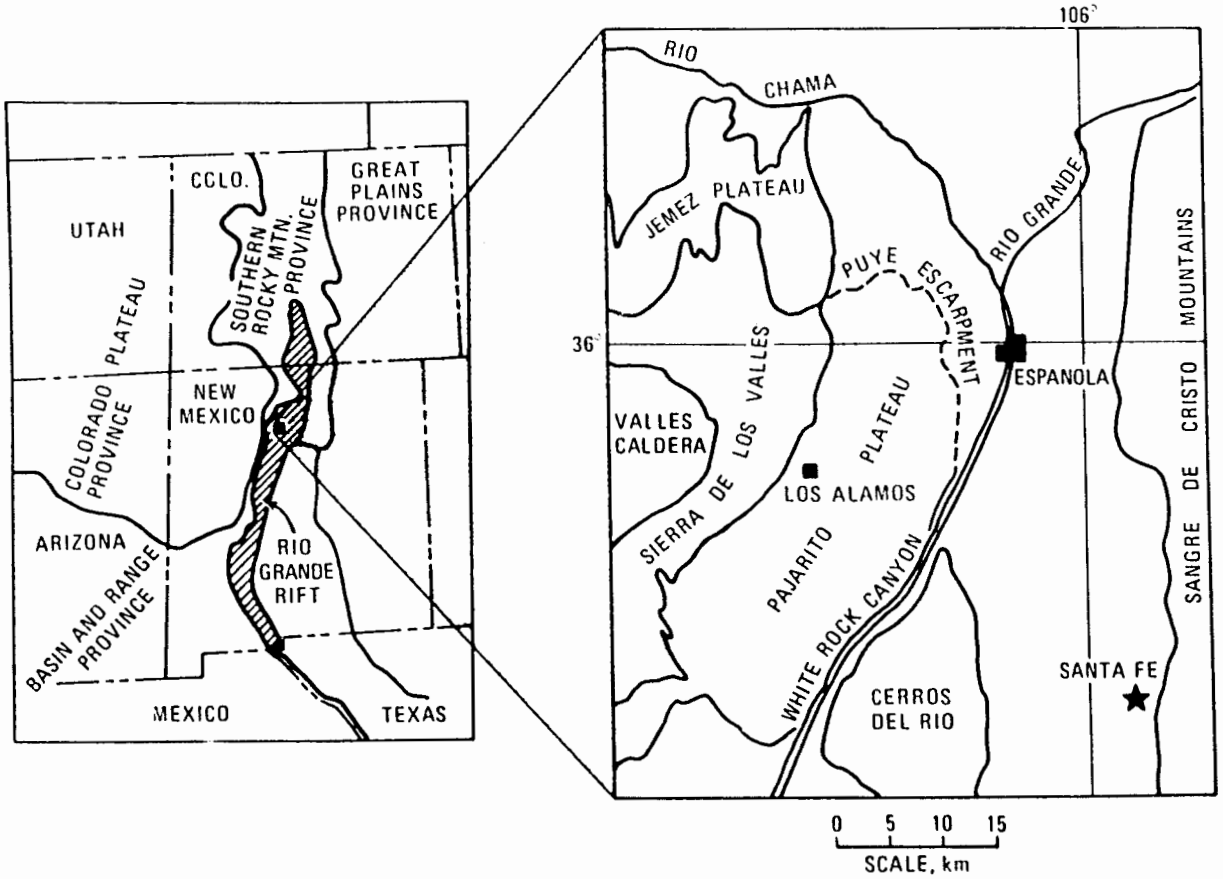

Fig. 1 Location of the Los Alamos Scientific Laboratory in north-central New Mexico.

We have assumed that the uranium inventory is mostly available for surface transport, mainly by storm runoff in the Potrillo Canyon drainage. The contributions from other sites in this drainage area, other than the E-F site, are considered negligible (Hanson and Miera, 1977). The head of Potrillo Canyon is slightly more than 1 km west of the E-F detonation site at about 2250 m elevation. The canyon extends due east for about 10 km, dropping rapidly in elevation to about 1650 m where it enters the Rio Grande. 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 east of the E-F site, the canyon broadens and sediment depths increase to about 1 to 2 m (Griggs, 1964; Purtymun, 1978). There is no continuous surface water flow in Potrillo Canyon. As in most intermittent streams of the area, appreciable water flow after heavy rains carries sediments downstream.

Sample Collection

A polar coordinate sampling scheme was devised to determine the soil distribution of uranium in the study area. Soil cores were collected at the intersection 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 polyvinyl chloride coring tube (2.5 cm, inside diameter) with a sharpened end was used to collect two 30-cm-deep soil cores spaced 0.5 m apart at each sampling location. The maximum sampling depth and the amount of compaction for each core were recorded. Prior to processing the percent compaction was distributed evenly over the sampling depth.

One core from each location 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 to examine depth distribution patterns. Thirty percent of the duplicate cores collected along the NE, SE, SW, and NW radii were randomly selected and similarly processed to define the spatial variability of uranium with distance from the detonation point and with depth into the soil profile.

Forty soil samples representing duplicate 0- to 5-cm- and 5- to 10-cm-depth cores collected along the N, E, S, and W radii at distances of 10, 20, 50, 100, 150, and 200 m from the detonation point were processed for soil particle size analysis. These samples were mechanically separated with a sonic sifter into six size fractions: $< 53\ \mu m$, 53 to 105 μm, 105 to 500 μm, 500 to 1000 μm, 1 to 2 mm, and 2 to 23 mm in diameter.

A sampling network was also 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 located on the mesa top. The remainder of the sampling stations were at distances of 150, 200, and 250 m from the detonation point in a tributary canyon that drains into Potrillo Canyon and at 350, 700, 1400, 2800, 5600, and 9000 m within Potrillo Canyon. Duplicate cores were extracted 10 cm apart from the center of the stream channel by using the same coring technique and were segmented into similar depth increments as previously mentioned. Some sampling depths in the upper parts of the canyon were less than 30 cm owing to shallow sediments, but a partial core was obtained in all cases. Samples that were collected in the top 15 cm (the maximum sampling depth for two of the stations) were used to estimate the Potrillo Canyon uranium inventory as a function of distance from the E-F site. Calculations for the inventory estimate are presented in detail elsewhere (Hanson and Miera, 1977).

Vegetation samples were collected from 1-m^2 plots adjacent to small mammal trapping stations. All standing vegetation within each plot was clipped at ground level, and all species were composited as one sample. Particulates were not removed from the exterior of the plant surfaces before uranium analyses. An attempt was also made to evaluate the uranium content within plant roots of the dominant grass species *Sitanion hystrix* (bottlebrush squirreltail) in the study area. Plots that were 1 dm^2 were established 1 m from the 1-m^2 vegetation sampling plots, and the vegetation was collected as above. The intact soil was then removed to a depth of 10 cm, yielding a 1-dm^3 sample with plant roots in place. This material was then passed through a 2-mm sieve to separate the soil from the roots. The soil was treated as previously described; the roots were washed in a sonic bath of distilled water for 2 to 3 min, rinsed with distilled water, microscopically examined for adhering particulates, and then analyzed as vegetation samples.

Two sympatric small-mammal species, *Peromyscus maniculatus* (deer mouse) and *Thomomys bottae* (valley pocket gopher), were trapped at the E-F site. Deer mice were collected along a trapline consisting of 20 stations centered approximately 10 m south of the detonation point and running east to west. Pocket gophers were selectively trapped where there were mounds of freshly excavated dirt within a radius of 100 m from the detonation point. All animals were carefully dissected to minimize cross contamination of internal organs and tissues by soil particles that had adhered to the fur. Samples analyzed separately included the pelt, gastrointestinal (GI) contents, lungs, liver, kidneys, and carcass (skeleton and muscle).

Sample Analyses

Soil samples were oven-dried at 100°C for 24 hr, and the samples (except for those samples to be used in particle sizing) were passed through a 6-mm sieve to remove large pieces of rock and uranium. The <6-mm material was ground to less than 100 mesh in a pulverizer and was thoroughly blended to provide a homogeneous sample. Aliquots ranging from 2 to 5 g were used for analyses; replicates were submitted for about 10% of the samples. Vegetation and rodent samples were oven-dried at 100°C for 24 hr, or until a constant dry weight was observed, and then ashed in a muffle furnace at 450°C until a white ash was obtained. In most cases the entire ash was analyzed.

All soil and rodent samples reported in this paper were analyzed for uranium by instrumental epithermal neutron activation analysis (IENAA) (Steinnes, 1971; Gladney, Hensley, and Minor, 1978). The analyses of vegetations were conducted prior to development of the IENAA technique by a standard fluorometric procedure (Owens, 1976) which requires complete sample dissolution, a step not necessary for IENAA analyses. A comparison of the two techniques has recently been reported to show good agreement with similar detection limits (Gladney, Hensley, and Minor, 1978).

In the IENAA analyses samples were first irradiated with epithermal neutrons (energy range ≈280 to 1000 eV) for 2 min. After decay for 2 to 4 days, each sample was counted for 5 min on a large Ge(Li) detector [full width at half maximum (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 analyses. Neptunium-239 is the daughter of uranium-239, which is produced by epithermal neutron irradiation. The spectra of gamma rays were accumulated on 4000-channel analyzers, the regions of interest punched on paper tape, and the data reduced by electronic computer programs.

Soil samples were leached for the fluorometric analysis method in a hydrofluoric and nitric acid solution. Small volumes of the dissolved sample were pipetted onto 50-mg NaF/LiF pellets and fused for 2 min at approximately 1200°C with a burner as described by Price, Ferretti, and Schwartz (1953). The pellets were allowed to cool for 15 min, and then the fluorescence at 245 nm was determined on a fluorometer. The resulting data were reduced by computer to obtain final concentrations. International Atomic Energy Agency (IAEA) soils with certified uranium concentrations were used as standards for the two methods of analyses.

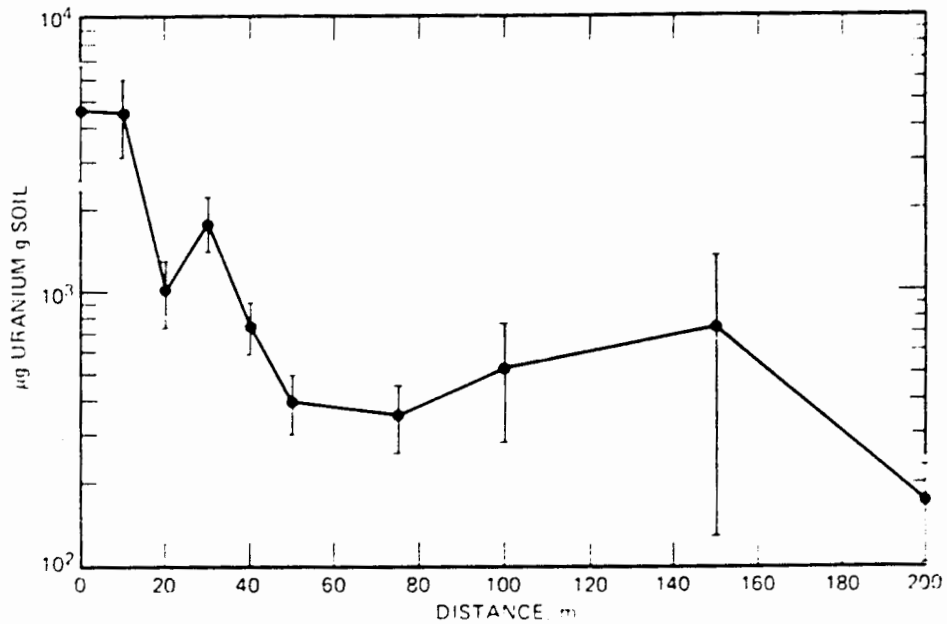

Fig. 2 Mean surface (0- to 2.5-cm depth) uranium concentrations (±1 standard error) in soil at the E-F site.

RESULTS AND DISCUSSION

Uranium Concentrations and Distribution in the E-F Site Soils

The results to date indicate significant migration of uranium into the soil profile at the E-F testing site and also that transport of uranium from the mesa top into the adjacent drainage of Potrillo Canyon has occurred. The highest mean concentrations in surface soils (0- to 2.5-cm depth) were found within 10 m of the detonation point, averaging 4500 μg uranium/g soil, and decreased exponentially with distance from the detonation point (Fig. 2). Uranium concentrations in surface soils beyond 50 m from the detonation point were generally less than 15% of those within 10 m.

Surface-soil uranium concentrations varied greatly with sampling location. The coefficients of variations (CV's) (standard deviation/mean x 100) for soils collected 0.5 m apart at individual sampling locations ranged from 18 to 96%, averaging 57% for all distances. For samples collected along annuli, CV's averaged 55 to 90% within 75 m of the detonation point but increased markedly at 100 m and beyond to as high as 230%. These data suggest that the results from the soil sampling activities are strongly influenced by the variable

deposition of uranium debris in the form of fragments from past explosive tests. This is further illustrated in Fig. 3, which depicts estimated isopleths of uranium concentrations in the 0- to 5-cm soil horizon at the E-F site. The isopleths were obtained by transforming each data point to log values and then converting the polar coordinate sampling array values to Cartesian coordinate values. The plane surface was generated by an electronic data-processing program that interpolated between data points. Areas of highest soil concentrations were at the detonation point and 150 m to the west with

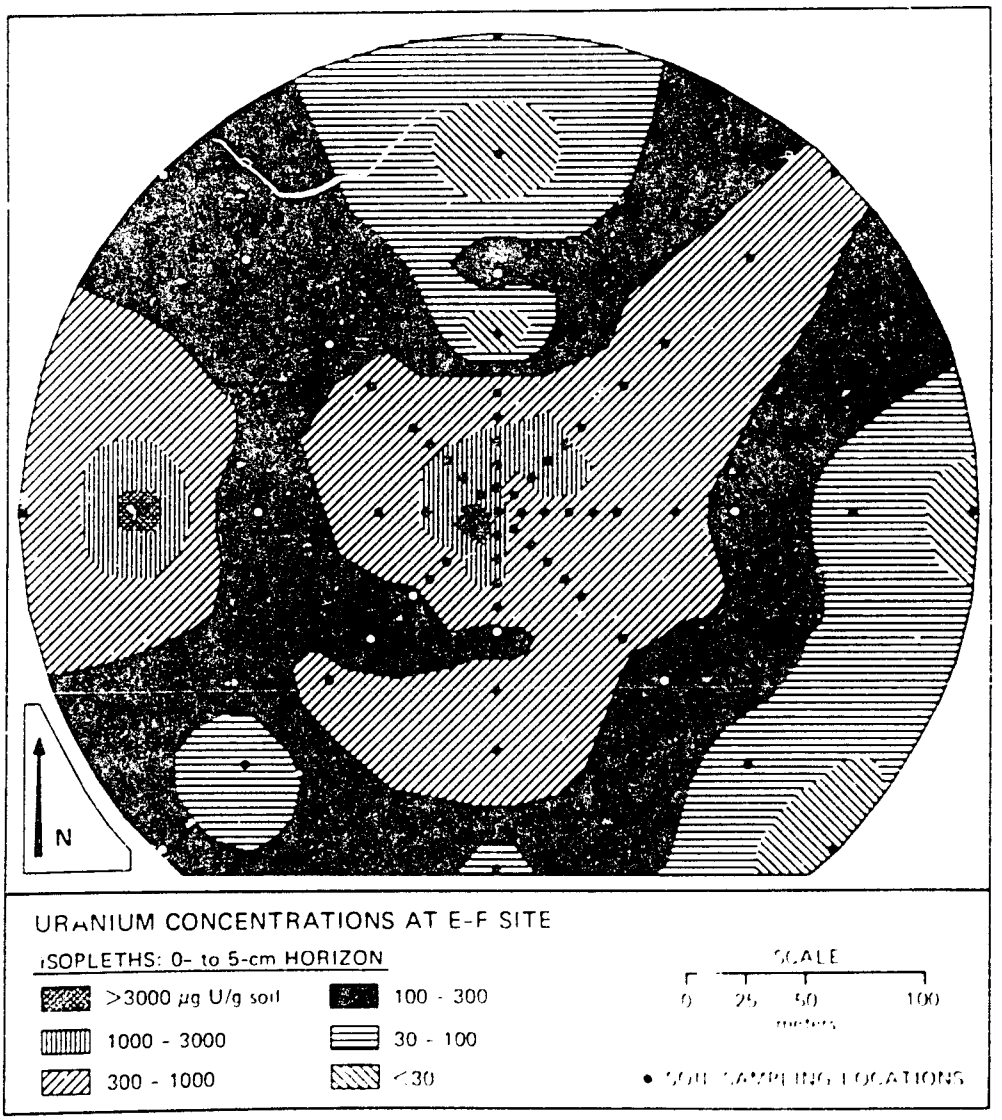

Fig. 3 Estimated isopleths of uranium concentrations in the 0- to 5-cm horizon at the E-F site.

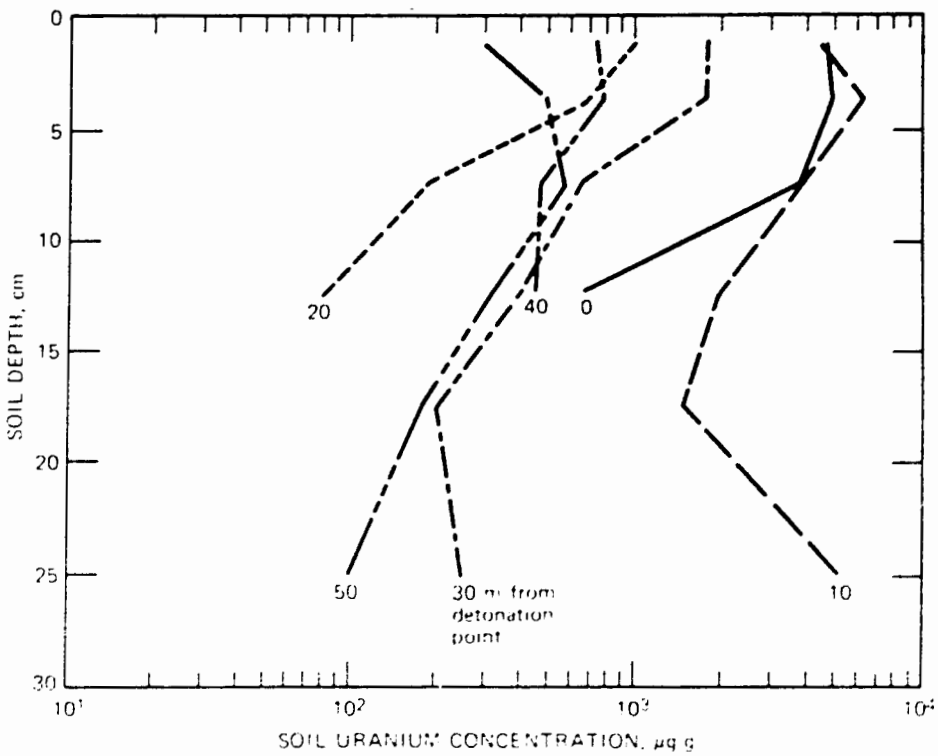

Fig. 4 Uranium concentration vs. soil depth and distance from the E-F site. Concentrations are mean radial values obtained using a polar coordinate sampling system.

uranium levels of more than 3000 μg/g soil. Surface soils to the south and northeast of the detonation point also exhibited high uranium concentrations ranging from 300 to 1000 μg/g of soil.

Analyses of soil samples collected to depths of 30 cm within 50 m of the detonation point and also to a depth of 10 cm out to the 200-m sampling distance indicate significant uranium migration into the soil profile to the maximum sampling depths. The vertical distribution of uranium at various distances from the detonation area is shown in Fig. 4. Values in the upper 0- to 2.5- and 2.5- to 5-cm soil horizons varied more than those at greater depths; below the 5-cm depth, uranium concentrations generally decreased with depth. Mean concentrations of 100 μg/g for the 50-m sampling locations and 17 μg/g for the 5- to 10-cm depth at the 200-m sampling locations are about 50 and 10 times as great as, respectively, background uranium levels in soils for the area, which range from 0.2 to 1.2 μg/g (Johnson, 1972). These data emphasize the mobility of uranium in the soil and also that uranium has penetrated to greater depths than these sampled.

The vertical partitioning of the uranium inventory in depth profiles was determined by multiplying the concentration by the weight of soil in each depth segment and by expressing this quantity as a percentage of the total uranium in the soil profile to the maximum sampling depth. At the 0- to 10-m sampling distances, 68 and 48% of the total uranium in the columns, respectively, were in the top 5 cm of soil. Locations within 10 m of the detonation area were also likely influenced by mechanical disturbances and fragment projectile penetration from the explosive tests. The uranium in the top 5 cm at 20, 30, 40, and 50 m was 86, 71, 62, and 43%, respectively, of the total. However, at the greater sampling distances of 100, 150, and 200 m, the percentage uranium in the top 5 cm increased with distance from the detonation point to 64, 70, and 91%, respectively. The regular decrease in the percent uranium associated with the 0- to 5-cm horizon at distances of 20 to 50 m is probably related to uranium particle size and dispersion patterns; smaller particles are dispersed farther and result in optimization for vertical mixing—migration of uranium. Beyond 50 m surface contamination is apparently less affected by shot dispersion of uranium but more by redistribution mechanisms, such as surface-water transport.

So that the potential for redistribution of uranium that might be adsorbed to soil particles could be evaluated, the particle size composition and uranium content of soil separates at the E-F site were determined. Uranium concentrations in six soil size separates from the 0- to 5-cm and 5- to 10-cm depths are shown in Figs. 5 and 6. Generally, an exponential decrease of uranium concentration with distance was observed for each size fraction, although with appreciable variation in values as a function of both distance from the detonation point and depth in the soil profile. The highest concentrations of uranium were found at the 10-m distance in the < 53-μm size fraction for both soil column increments; however, at 20- to 50-m distances, the highest concentrations were generally associated with the larger particle sizes (1 to 2 mm). For sampling locations 100 to 200 m from the detonation point, the highest concentrations were again associated with the smaller soil particle sizes (< 500 μm).

The fractional distribution of uranium in the soil separates was also evaluated as a function of distance from the detonation point. The portion of the total uranium in each size fraction was calculated by multiplying the concentration by the soil mass of each fraction. The distribution of uranium for all sampling locations in the six soil size fractions for the 0- to 5- and 5- to 10-cm depths indicated that about 70% of the total uranium and 60% of the soil mass were

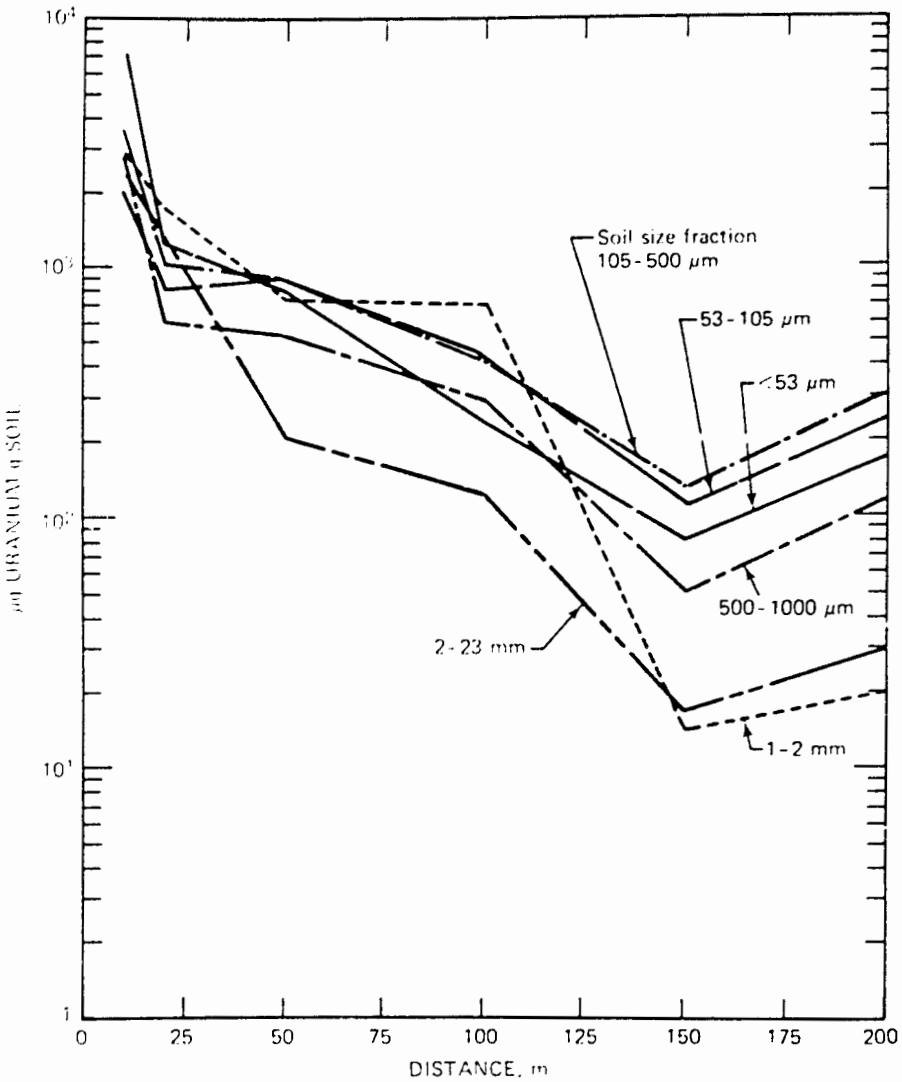

Fig. 5 Uranium concentrations in soil size fractions as a function of distance in the 0- to 5-cm horizon at the E-F site.

associated with < 500-μm soil particles. For the 0- to 5-cm depth, the percent uranium associated with the < 500-μm size fractions increased from 50% at the 10-m sampling locations to nearly 90% at the 200-m sampling locations. Soil masses for the respective sampling locations in the < 500-μm fractions (classified as silt, clay, and sand fractions) were 40 and 70%. The ratio of the total uranium in the < 53-μm fraction to that in the 2- to 23-mm fraction for the 0- to 5- and 5- to 10-cm depths increased from 1.1 and 2.5 at 10 m to 18 and 21 at the 200-m sampling locations, respectively. These distribution

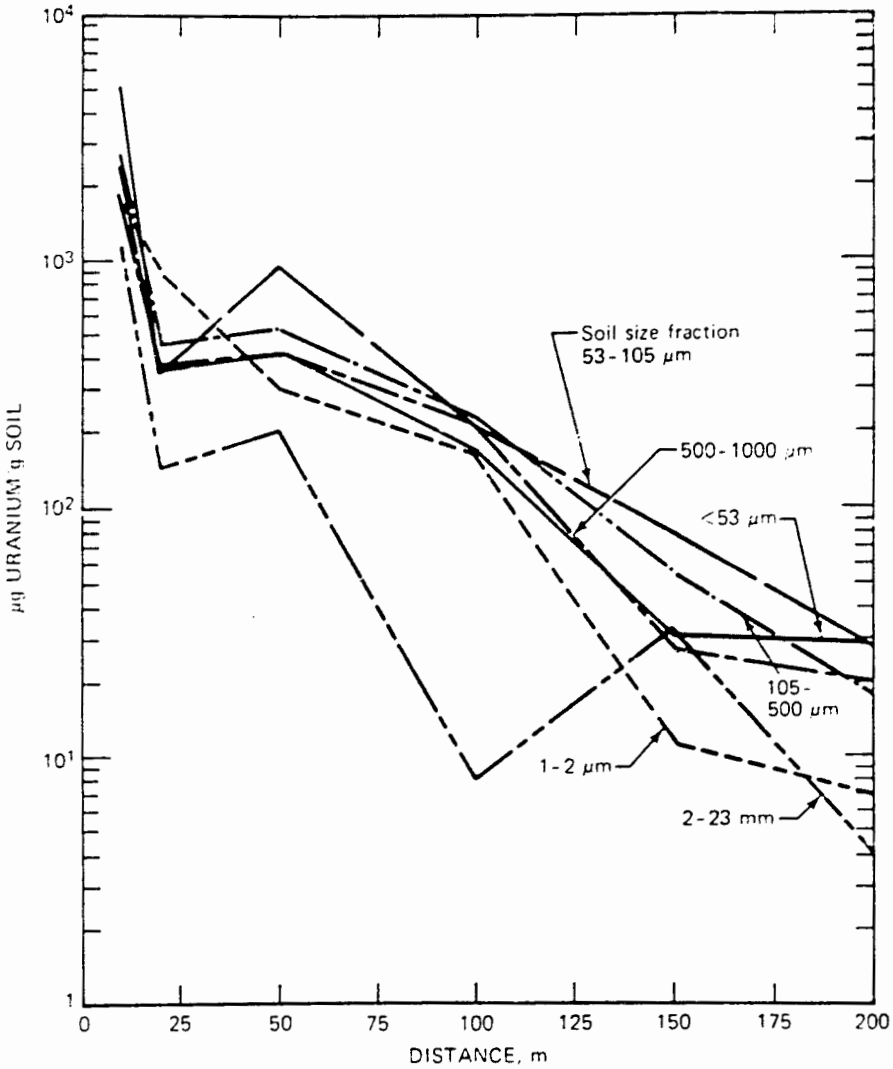

Fig. 6 Uranium concentrations in soil size fractions as a function of distance in the 5- to 10-cm horizon at the E-F site.

patterns suggest that mobilization and physical transport, i.e., by surface water and wind, of uranium associated with smaller soil particles are occurring with time at this time.

Surface-Water Transport of Uranium into Potrillo Canyon

Surface-water transport of uranium from the E-F site into Potrillo Canyon was evaluated by determining concentrations in stream channel sediments. Uranium concentrations in alluvium from

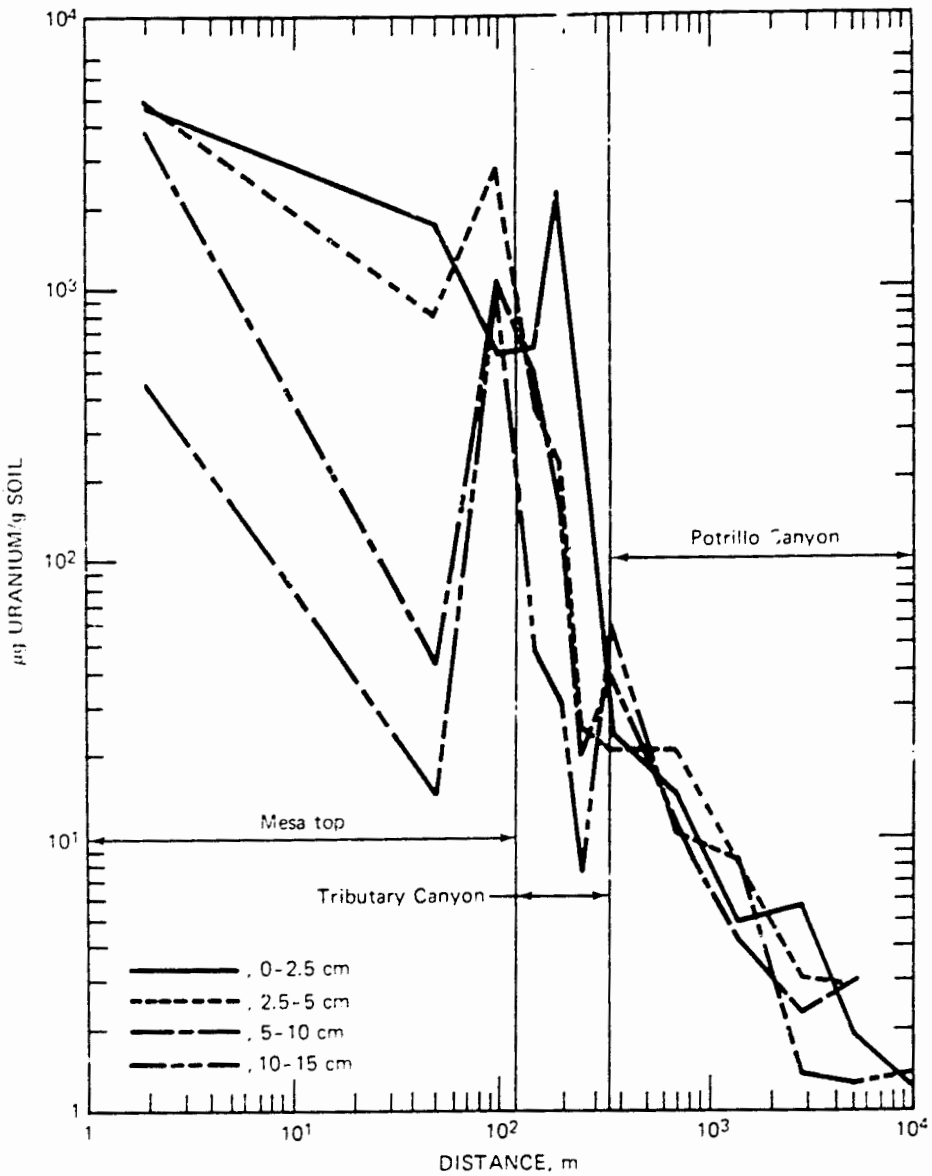

Fig. 7 Distribution of uranium from the E-F site into Potrillo Canyon as a function of distance and soil depth.

the mesa top (0, 50, and 100 m from the E-F site detonation point) and in Potrillo Canyon sediments are shown in Fig. 7. Uranium levels were greatest (4850 μg/g) at the detonation point and decreased rapidly to 300 μg/g at a distance of 250 m beyond the detonation area. Samples collected (for the 0- to 2.5-cm depth) at the 2800-m distance contained uranium levels that were twice background levels.

TABLE 1

Estimated Uranium Inventory in Potrillo Canyon

Distance, m	Weighted mean uranium concentration (0 to 15 cm), mg/g	Total uranium, kg	Estimated uranium inventory in segment, %
0—25	3.02	15.8	27.2
25—75	0.44	4.62	7.9
75—125	1.23	12.9	22.2
125—175	0.34	4.04	6.9
175—225	0.46	5.57	9.7
225—300	0.07	1.24	2.1
300—525	0.04	3.24	5.5
525—1050	0.013	2.46	4.3
1050—2100	0.006	2.27	4.0
2100—3900	0.003	1.94	3.3
3900—7000	0.002	2.98	5.2
7000—9000	0.001	0.96	1.7
Total		58	100

Uranium concentrations in soil samples from the mesa top drainage area showed variability with distance from the detonation point and depth similar to that reported earlier in this paper for samples obtained by the polar coordinate sampling scheme. Samples from the tributary canyon (150 to 250 m) had highest concentrations in the 0- to 2.5-cm horizon with concentrations decreasing with depth. Concentrations were considerably diluted and more homogeneously distributed, to depths of at least 20 cm, from the 250- to 5000-m locations, as reflected by the smaller CV's between duplicate soil cores (6 to 73%). Uranium concentrations at the 350-m sampling distance (23 μg uranium/g soil) were less than 1% of those at the detonation point. Uranium levels in alluvial samples taken at 5000 m and beyond were near background levels of 0.2 to 1.2 μg/g.

The drainage area uranium inventory for the E-F site from the detonation point to the 9000-m distance was estimated to be 58 kg. The estimated uranium inventory for each of the 12 segments shown in Table 1 indicates that most (57%) of the uranium is within 125 m of the detonation point on the mesa top. About 75% of the estimate had been accounted for in the proximal 300 m. Although the 58-kg inventory is seemingly large, this amount is less than 0.1% of the uranium expended at this site during 1949—1973, and it indicates that only minor amounts have moved appreciably.

Uranium Concentrations in Biota

Vegetation from the E-F site sampled in the late fall of 1974 consisted of standing dead vegetation that had been growing in uranium-contaminated soil for at least 6 months. During the late spring of 1975, principally green plant material that had been only briefly exposed to external uranium deposition or uptake was sampled. Late fall vegetation averaged 320 μg uranium/g dry vegetation, and the late spring samples averaged 125 μg uranium/g vegetation. These differences were probably due to (1) greater external deposition over considerable time; (2) different species of plants available at the sampling times; and (3) greater amounts of fresh growth in spring samples, which resulted in dilution. Observed concentration ratios (plant uranium/soil uranium) were 0.08 for fall vegetation and 0.05 for spring samples.

Root/soil uranium ratios for the 1-dm^2 subplots averaged 0.28, and the grass/soil ratios were 0.07. At least part of this variability was caused by small particles of soil and, presumably, uranium adhering to roots; the particles were observed by microscopic examination. It can be further speculated that uranium colloids may have been sorbed on the root surface. This further complicates the differentiation of "in" vs. "on" uranium components in plant roots. However, our plant/soil ratios are consistent with those of Cannon (1952), whose uranium "indicator" plants had ratios of 0.1 to 1.0.

Concentrations for small mammals are given in Table 2; both mean and median uranium values are reported for the two sympatric species. These results indicate that there were differences in uranium concentrations in several tissue types and that deer mice generally contained higher mean concentrations in their tissues than did pocket gophers. As evidenced by the range of minimum to maximum values, the concentration distribution is very broad and positively skewed, with most values occurring below the mean. Thus, for samples with high uranium concentrations, such as pelts and GI contents, a mean value is biased toward the large values with the median value probably providing a more realistic estimate. Kidney and liver samples contained about 5 to 10% of pelt values, whereas lungs and carcass samples contained concentrations that were slightly above soil uranium background levels. Internal tissues, such as carcass, kidneys, and livers, had concentration factors (tissue/soil) of 10^{-3} to 10^{-4}, although GI contents of these mammals had mean uranium levels greater than 10% of soil concentrations.

Several environmental and physiological parameters, which may also be substantially affected by seasonal variations, may account for the difference observed in uranium concentrations between deer

TABLE 2

Uranium Concentrations in Tissue Samples from Two Sympatric Species of Small Mammals at LASL's E-F Site (April—May 1977)

Species	Sample	Uranium concentration, μg/g				CV	n
		Mean	Median	Minimum	Maximum		
Peromyscus	GI	900	380	140	3600	1.49	6*
Thomomys		220	75	<0.5†	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

**Peromyscus* were pooled—two animals per sample.
†Minimum detectable limit.

mice and pocket gopher tissues. Soil moisture varies strongly with climatic features 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 pelt samples of the more surface-active deer mouse (mean 500, median 300 μg uranium/g) and those of the subterranean-dwelling pocket gopher (mean 200, median 120 μg uranium/g). Food habits of the small mammals also vary appreciably (Martin, Zim, and Nelson, 1951). The pocket gopher is a vegetarian, and therefore it is heavily dependent on plant roots and other vegetative parts. The diet of the deer mouse 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 (68%) plant foods during summer. The food habits would presumably influence the concentrations of uranium in internal organs, although appreciable amounts of soil and uranium are ingested by small mammals during their normal grooming habits. The apparent low fraction of uranium transferred from the GI tract to blood presumably accounts for the modest concentrations found in internal organs and mitigates the consequences of ingestion of uranium. The amounts of uranium in lung samples of deer mice and pocket gophers collected during the spring of 1977 were similar to one another and to carcass values, which argues against appreciable inhalation of resuspended particles.

The uranium concentration values for tissue samples shown in Table 2 illustrate that the range of values was extremely large, often positively skewed, and highly variable. Such characteristics are indicated by CV's almost consistently greater than 1.0, which complicates the strict interpretation of the data and suggests that a much greater sample size would be necessary to provide conclusive results. These conditions apparently result from the particulate nature of uranium, its density and mobility in the environment, and the variable habits of the animals.

SUMMARY AND CONCLUSIONS

During the past 3 years, we have been studying the fate of some 70,000 kg of natural and depleted uranium dispersed in the LASL environs during conventional explosives tests that occurred from 1949 to 1973. The initial objectives of our studies have been to determine the concentrations, distribution, and transport of uranium in soils and concentrations of uranium in selected biota.

Concentrations in surface soils (0- to 2.5-cm depth) at 10 m from the detonation point averaged 4500 μg/g; concentrations in surface soil at 50 to 200 m from the firing point were generally less than 15% of that value. Concentrations at a depth of 20 to 30 cm at the 50-m radius from the detonation point averaged 100 μg/g and for the 5- to 10-cm depth at 200 m averaged 17 μg/g. These values are about 50 and 10 times as great as, respectively, the background uranium levels in area soils, which range from 0.2 to 1.2 μg/g; this emphasizes the mobility of uranium into the soil profile. The spatial variation, as determined by computing the CV for duplicate soil cores taken 0.5 m apart, was found generally to increase with distance from the detonation point and with depth into the soil profile.

The distribution of uranium for all sampling locations in the six soil size fractions for the 0- to 5- and 5- to 10-cm depths indicated that about 70% of the total uranium and 60% of the soil mass were associated with soil particles that were less than 500 μm. For the 0- to 5-cm depth, the uranium associated with the < 500-μm size fractions increased from 50% at the 10-m sampling locations to nearly 90% at the 200-m sampling stations. The ratio of the total uranium in the smallest size fraction (< 53 μm) to those in the largest size fraction (2 to 23 mm) sampled for the two depths increased from 1.1 and 2.5 at 10 m to 18 and 21 at the 200-m sampling locations, respectively. These distribution patterns suggest that mobilization and physical transport, via surface water and wind mechanisms, of uranium associated with small soil particles is occurring at this site.

Alluvium collected 250 m from the detonation point in the adjacent Potrillo Canyon drainage area had surface concentrations (0- to 2.5-cm depth) that averaged 330 μg uranium/g, and, at a distance of 2.8 km, they were twice background levels. Uranium concentrations were considerably diluted and homogeneously distributed to sediment depths of 20 cm for sampling locations located 350 to 5000 m beyond the detonation point.

Ratios of plant/soil uranium concentrations ranged from 0.05 to 0.08. Internal tissues of small mammals sampled from the study area had concentration factors (tissue/soil) of 10^{-3} to 10^{-4}, although GI contents of these mammals had uranium levels greater than 10% of soil concentrations.

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