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DISTRIBUTION OF PLUTONIUM IN TRINITY SOILS AFTER 28 YEARS[1]

J. W. Nyhan, F. R. Miera, Jr., and R. E. Neher[2]

ABSTRACT

The soils of four intensive study areas located along the fallout pathway of Trinity, the first nuclear detonation, were sampled to determine soil plutonium concentrations as a function of distance from Ground Zero and soil depth.

About half of the $^{239,240}Pu$ in Trinity Site soils was found at the 5-20 cm depth in 1973 compared to total plutonium inventories found only in the upper 5 cm of soil about 20 years ago. Soil plutonium concentrations of samples collected at the same depth of each study area generally exhibited coefficients of variation greater than 1.2. Maximum penetration depths of $^{239,240}Pu$ into Trinity Site soils were related to the presence of subsoil horizons containing carbonate accumulations and the maximum extent of rainwater penetration into these soil profiles.

Increased amounts of plutonium were associated with <100 μm fractions as distance from Ground Zero and soil depth increased. The

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[1]Research funded under contract No. W-7405-Eng. 36 between the U. S. Energy Research and Development Administration and the Los Alamos Scientific Laboratory.

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<100 μm fraction contained 1.2 and 89% of the plutonium in the topsoil at the study areas located 1.6 and 44 km from Ground Zero, respectively. Total amounts of $^{239,240}Pu$ in the <100 μm soil size fractions also generally increased with depth; at 1.6 km from Ground Zero, this size fraction contained 1.2% and 13% of the $^{239,240}Pu$ found at the 0-2.5 and 5.0-10 cm depths, respectively.

The soil plutonium data collected at Trinity Site is discussed relative to the sizes of Trinity fallout particles: setting meaningful health standards for plutonium in soils and the distribution of plutonium in the biota of Trinity Site ecosystems.

Additional Index Words: $^{239,240}Pu$, radioactive fallout, radionuclide distributions in soil, sampling variation, soil size fractions, temporal behavior of radionuclides, terrestrial ecosystems.

The annual production rate of plutonium has been projected to increase from about 20,000 kg from 1970-1980 to about 80,000 kg in the period 1990-2000 (Langham, 1971), reflecting the increasing national power needs over the next three decades.

Despite the national importance of plutonium and the observation that soils contain the largest portion of the plutonium added to most ecosystems, the distribution and long-term environmental behavior of plutonium in soils has been only partially documented. The vertical and fractional distribution of $^{239,240}Pu$ in terrestrial soils was studied at nuclear safety event sites at the Nevada Test Site (Essington et al., 1976[3]; Perry et al., 1966; Tamura, 1974 and 1975), in contaminated areas at Rocky Flats (Little et al., 1973) and in areas receiving world-wide fallout plutonium throughout the Great Plains (Michels, 1973). Soils investigations of plutonium in the fallout pathway of Trinity, the first nuclear detonation, were initiated more than 20 years ago (Larson et al., 1951b and 1951c; Olafson et al., 1957; Olafson and Larson, 1961) and continued in 1972 (Hakonson and Johnson, 1974). Few of the above-mentioned studies have involved either measurements of the natural variation or long-term behavior of plutonium in soils.

The objective of this research was to determine the distribution of $^{239,240}Pu$ in whole soil samples and soil size fractions collected along the fallout pathway of the Trinity detonation as a function of

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[3]Essington, E. H., R. O. Gilbert, L. L. Eberhardt, and E. B. Fowler. 1976. Plutonium, americium and uranium concentrations in Nevada Test Site soil profiles. Submitted to Proc. USERDA/IAEA International Symposium on Transuranium Nuclides in the Environment, IAEA-SM-199/76.

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soil depth and distance from Ground Zero. The horizontal and vertical variation of plutonium in these soils was also determined by replicated sampling of soils from each study area. Soil radionuclide data from this study were compared with similar data collected at the Trinity Site nearly 20 years ago and with soil physical-chemical properties influencing the distribution of plutonium in these soils.

MATERIALS AND METHODS

Site Descriptions

Trinity Site, a fenced area immediately around Ground Zero, is located in a semiarid region of central New Mexico on the White Sands Missile Range. Intensive study areas were established outside of and within the reported fallout pathway of the nuclear debris from the detonation (Fig. 1), based on radiological survey data collected in 1948 (Bellamy *et al.*, 1949). A control site was located 4.8 km south of Ground Zero, outside of the fallout pathway, and sampling locations were also established 1.6, 16 and 44 km northeast of Ground Zero within the fallout pathway.

The climate, physiography, geology and biota of the Trinity environs were previously reported (Bellamy *et al.*, 1949; Blair, 1943; Hakonson and Johnson, 1974; Larson *et al.*, 1951a, 1951b, and 1951c; Shields, 1956). Although a few soil profiles were described by Bellamy *et al.* in 1949, a comprehensive inventory of the soils of the entire White Sands Missile Range was recently assembled using updated taxonomic procedures (Neher and Bailey, 1976). The specific soils found at each study area were also described and classified (Fig. 2, Table 1).

Sampling and Analytical Methods

A total of 12 soil cores were collected to a depth of 50 cm at each

of the four intensive study areas (Fig. 1) in October, 1973. Two soil cores were collected 30 cm apart at each corner of a hectare-sized site and four cores were collected 2 m apart in the center of each site. Each soil core was collected with a polyvinylchloride coring tube (2.4-cm i.d.) with a sharpened end, which was placed in a plastic bag, frozen, and cut up into segments corresponding to 0-2.5, 2.5-5.0, 5.0-10, 10-15, 15-20, 20-25, 25-33, 33-40, and 40-50 cm soil depths. A partial core section was obtained when the coring tube could not be driven any further into the soil, and its length also measured. Soil samples were mechaniclaly separated into six size fractions using a Model L3P sonic sifter (ATM Corporation, Milwaukee, WI): <53 μm, 53-100 μm, 100-500 μm, 500-1000 μm, 1-2 mm and 2-23 mm. Small soil particles were blown off of the larger soil separates with an air hose during the soil separations to minimize contamination of large soil particles with smaller particles.

Soil from the 0-2.5 cm depths of the four cores collected in the center of each plot was composited and particle size fractions from these composites were assayed for their $^{239,240}Pu$ (henceforth referred to as ^{239}Pu) content as previously described (Nyhan et al., 1976). Soil collected from the other depths of the cores from the center of the site was composited, fractionated and analyzed similarly. Individual core segments of samples collected at the corners of each site were also analyzed for plutonium. About 10% of all of the soil samples submitted for plutonium analysis were analyzed as split samples in order to determine variation in soil plutonium levels due to aliquoting and analytical procedures.

RESULTS AND DISCUSSION

Plutonium in Unfractionated Soils

Soil ^{239}Pu concentrations are presented as a function of depth for the control site and the sampling locations at 1.6, 16 and 44 km from Ground Zero in Figures 3-6.

The soils sampled within the fallout pathway (Fig. 3-5) generally had higher levels of plutonium than the soils outside of the fallout pathway at the control site (Fig. 6). The average soil ^{239}Pu levels found at the 0-2.5 cm depth of the three sites within the fallout pathway was 85 times higher than the average concentration of 9.8 femtocuries per gram (fCi/g) measured at the control site. In addition, the total amounts of ^{239}Pu found within the soil profiles sampled inside of the fallout pathway was greater than the amounts of plutonium found in the soils of the control site.

Plutonium concentrations within the soil profiles exhibited considerable variation at all of the intensive study areas. Coefficients of variation (C.V. equals the standard deviation divided by the mean) of soil plutonium levels varied from 0.48 to 1.9, but were generally greater than 1.2 (Table 2). No significant differences were found between the plutonium concentrations found in the core segments collected 30 cm apart and the samples collected 100 m apart within each study area (Two-way analysis of variance, $P<0.10$). In contrast, variation due to aliquoting and analytical procedures generally resulted in C.V.'s of plutonium levels which were less than 0.35 and samples were counted for sufficiently long periods of time such that C.V.'s due to counting were usually less than 0.15. Thus, since most of the samples had C.V.'s >1.2, the largest component of the variation in soil plutonium levels

was generally attributed to natural spatial variation within the soils of each intensive site.

The vertical distribution of ^{239}Pu in Trinity Site soils collected in 1973 (Figs. 3-5) can be compared with similar data collected nearly 20 years ago (Olafson et al., 1957; Olafson and Larson, 1961). The 1973 inventory of ^{239}Pu in each depth increment of individual soil cores was calculated by multiplying the plutonium concentration by the weight of soil in each depth segment and expressing this quantity as a percentage of the total plutonium in the soil profile. Whereas the plutonium in the soils along the fallout pathway was only detected in the upper 5 cm of soil nearly 20 years ago, only 42% and 57% of the ^{239}Pu inventory was found at this depth in 1973 at the 1.6 and 44 km sites, respectively, reflecting considerable downward migration of plutonium into the soil in the intervening 20 years. In contrast, the soils at the 16 km site still contained 78% of their ^{239}Pu in the upper 5 cm of the profile 28 years after the detonation. The total amount of ^{239}Pu measured in the 1.6 and 44 km soil profiles was greater than the inventory found in the profiles at the 16 km site, suggesting that appreciable downward movement of plutonium could only be detected in field locations which were initially relatively highly contaminated (Fig. 1). A similar observation was made relative to the downward movement of fission products into these soils in 1949 and 1950 (Larson et al., 1951a and 1951b).

The soil plutonium data were compared with the morphology (Fig. 2) and classification (Table 1) of the Aridisols at the 1.6 and 16 km sites and the Entisols located at the 44 km site on the Chupadera Mesa to further elucidate the vertical distribution of ^{239}Pu in Trinity Site

soils. Plutonium was not detected in either the B_{3ca} horizon of the Dona Ana sandy loam at the 1.6 km site or the B_{2ca} horizon of the La Fonda sandy loam at the 16 km site. These horizons represent the first strongly calcareous horizons encountered in the subsoil in these areas (Fig. 2). The observed relationship between the vertical distribution of ^{239}Pu and soil horizonation would be expected since the zone of calcium carbonate accumulation is closely related to amounts of rainfall (Jenny and Leanord, 1934) and the average maximum extent of water (and potential plutonium) penetration into the solum. However, increased variation in ^{239}Pu levels was generally observed deeper in the soil profiles, reflecting a differential migration of plutonium into the profiles at various locations within each hectare-sized study area (Table 2), irrespective of these morphological soil properties.

The downward migration of ^{239}Pu was greater in the Rance loam profiles at the 44 km site than in the sandy loam soils at the other study areas. This observation was not initially expected since the 44 km site contained a heavy-textured soil, a factor which would seem to inhibit the vertical migration of plutonium into the soils at this site compared with the sandier soils at the other sampling locations. However, this site receives about 20% more rainfall (5 cm) than the other intensive sites (Bellamy et al., 1949), which could result in enhanced leaching of plutonium into the subsoil at the 44 km site. In addition, the Rance loam profile contains gypsum, which could result in (1) enhanced displacement of ^{239}Pu from soil binding sites by high concentrations of soluble calcium ions as reported by Fried et al. (1974) and (2) enhanced water and potential plutonium movement through the topsoil due to flocculation of soil clays by the calcium ions (Fuller, 1975). Another

explanation was provided by the soil cores from the southwest corner of the 44 km site which had significantly larger amounts of ^{239}Pu from 10-20 cm than the soils from the other corners of this site (Fig. 5; One-way analysis of variance, $P<0.10$). This was probably due to soil disturbances caused by the increased digging activities of badgers, pocket gophers and other ground-dwelling small mammals observed at this location.

Plutonium in Soil Size Fractions

The soil cores collected in the center of each intensive site were cut up into segments and fractionated to determine the distribution of ^{239}Pu in various size fractions of the Trinity Site soils. The plutonium concentration data for the 0-2.5 cm depth of the soil samples collected at each intensive site are presented in Table 3.

The distribution pattern of ^{239}Pu in the soil size fractions varied considerably between sampling locations. At the 44 km site, the highest plutonium concentrations were found in the <53 μm size fraction, while at the 1.6 and 16 km sites, the highest ^{239}Pu levels occurred in the 1.0-2.0 mm and 100-500 μm fractions, respectively (Table 3). The lowest ^{239}Pu concentrations were found in the 2-23 mm size fraction in all samples collected in the fallout pathway; this separate contained from 0.2 to 5% of the maximum ^{239}Pu levels found in smaller size fractions. The ^{239}Pu levels found in the 2-23 mm size fraction at the 1.6 and 16 km sites were generally similar to the plutonium concentrations found in this size fraction at the control site, reflecting the overall low potential reactivity of this size fraction with fallout plutonium.

The fractional distribution of plutonium in the soil separates was considered as a function of distance from Ground Zero. The portion of the total ^{239}Pu in each size fraction of each soil sample was

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calculated from the ^{239}Pu concentration (Table 3) and the mass of soil in each size fraction. Only 1.2% of the ^{239}Pu at the 1.6 km site was found in the <100 μm fractions, which accounted for 20% of the soil mass. The <100 μm size fractions from the 16 km site contained 14% of the ^{239}Pu inventory and 29% of the soil mass, whereas this fraction contained 89% of the total ^{239}Pu and 54% of the soil mass 44 km from Ground Zero. Thus, relatively large amounts and high concentrations of plutonium were associated with relatively small soil particles as distance from Ground Zero increased.

The plutonium data presented in Table 4 for fractionated Trinity samples from the 5.0-10 cm depth can be compared with similar data from the 0-2.5 cm depth (Table 3). The soils at all of the sampling locations generally contained larger amounts of ^{239}Pu in small size fractions with increased depth. For example, whereas only 1.2% of the total ^{239}Pu inventory at the 1.6 km site was found in <100 μm soil size fractions at the 0-2.5 cm depth, this fraction accounted for about 13% of the soil plutonium at the 5.0-10 cm depth. This vertical distribution pattern may reflect possible dissolution of ^{239}Pu originally deposited in the topsoil, which was subsequently leached by rainfall into the soil profile and adsorbed on small soil particles with large surface areas found deep in the soil profile. An exception to this pattern was found at the 44 km site, where the <53 μm fractions contained a larger percentage of the plutonium inventory at the 0-2.5 cm depth than at the 5-10 cm depth. Although the latter fractional distribution of plutonium can be partially explained by the decreased soil mass of < 53 μm particles at the 5-10 cm depth, other causal factors cannot be ruled out at this time.

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The distribution of ^{239}Pu in the soil size fractions is better understood by considering the estimated sizes of radioactive fallout particles originating from the Trinity detonation. Although the physical characteristics of Trinity fallout particles have not been characterized (Olafson et al., 1957), the maximum potential size of one fallout particle can be estimated from the plutonium levels found in the soils (Sill, 1971). Assuming that (1) all of the ^{239}Pu activity (5300 fCi/g) in the 1.0-2.0 mm soil size fraction from the 1.6 km site (Table 3) was found in one spherical fallout particle of pure $^{239}PuO_2$ and (2) a 10-g soil sample was analyzed for plutonium, the diameter of the fallout particle can be calculated to be 3.2 μm. Thus, if all of the plutonium activity was associated with one $^{239}PuO_2$ particle, there would be one 3.2 μm fallout particle in this soil size fraction. Consequently, data presented in Tables 3 and 4 represent the distribution pattern of submicron plutonium fallout particles superimposed upon the distribution pattern of relatively large soil particles. The relatively low variation of ^{239}Pu concentrations in split size fraction samples (C.V. <0.35) lends support to this idea.

SUMMARY AND IMPLICATIONS

The soils of four intensive study areas located along the fallout pathway of Trinity were sampled to determine plutonium distributional relationships. Concentrations of ^{239}Pu were determined for fractionated and unfractionated soil samples as a function of soil depth and distance from Ground Zero, as well as the horizontal and vertical variation of soil plutonium levels. These data were compared to similar data collected at the Trinity Site nearly 20 years ago and with soil morphological properties.

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The total plutonium inventories in Trinity Site soils were generally found in the upper 5 cm of the soil about 20 years ago whereas only 42-57% of the total ^{239}Pu was found at this depth in 1973. Thus, about half of the ^{239}Pu inventory found in the top 5 cm of soil about 20 years ago has subsequently migrated to the 5-20 cm depth in these soil profiles. The maximum depth of penetration of ^{239}Pu into the Trinity Site soils was related to the start of the upper zone of carbonate accumulation and with the average maximum rainwater penetration into these soil profiles. Soil chemical and hydrologic properties such as these will gain increased importance in understanding the universal distribution of plutonium in soils.

The horizontal, vertical and fractional variation in the distribution of plutonium in soils is also an important consideration in setting meaningful health standards for plutonium in soils. Although C.V.'s of ^{239}Pu levels due to radionuclide counting and aliquoting samples were generally less than 0.15 and 0.35, respectively, spatial variation in ^{239}Pu levels commonly resulted in C.V.'s greater than 1.2. This observation, if universally true of soil plutonium, would imply that a practical health standard should encompass a wide range of values (C.V. >1.2) around an average maximum soil plutonium concentration. Although one proposed interim standard for plutonium in soils is related to plutonium levels in the <100 μm soil size fraction (Healy, 1974), this fraction contained from 1.2 to 89% of the ^{239}Pu in Trinity Site topsoils (Table 3). Thus, the highest plutonium concentrations and inventories in soils are not necessarily found in the smallest size fractions, and this relationship varied considerably as a function of distance from Ground Zero and soil depth in Trinity Site soils.

Much additional work is needed before the distribution of environmental plutonium is thoroughly understood. The physical transport processes important in redistributing plutonium-contaminated soil particles must be evaluated, as well as the influence of hydrologic, physical-chemical, and genetic soil characteristics on solution transport of soil plutonium. The digging activities of small and large mammals should be further evaluated relative to vertical transport of plutonium in soils. The distribution of plutonium in soil size fractions should be studied relative to plutonium concentrations in small mammal tissues and to plutonium levels observed in and on plant parts. Comparisons of the distribution and behavior of plutonium will eventually have to be made across different ecosystems, soil types, and source terms before environmental pathways to man can be knowledgeably interpreted and predicted.

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Figure 1. Location of intensive study areas at Trinity Site relative to areas involved in the 1948 intensive radiological survey (Bellamy et al., 1949).

Figure 2. Soil profile and physiography descriptions of Trinity soils as a function of distance from Ground Zero (GZ).

Figure 3. Distribution of soil $^{239,240}Pu$ as a function of depth 1.6 km from Ground Zero. Plutonium concentrations at each depth represent the average of 2 core segments.

Figure 4. Distribution of soil $^{239,240}Pu$ as a function of depth 16 km from Ground Zero. Plutonium concentrations at each depth represent the average of 2 core segments.

Figure 5. Distribution of soil $^{239,240}Pu$ as a function of depth 44 km from Ground Zero. Plutonium concentrations at each depth represent the average of 2 core segments.

Figure 6. Distribution of soil $^{239,240}Pu$ as a function of depth at the control site. Plutonium concentrations at each depth represent the average of 2 core segments.

Figure 1. Location of intensive study areas at Trinity Site relative to areas involved in the 1948 intensive radiological survey (Bellamy *et al.*, 1949).

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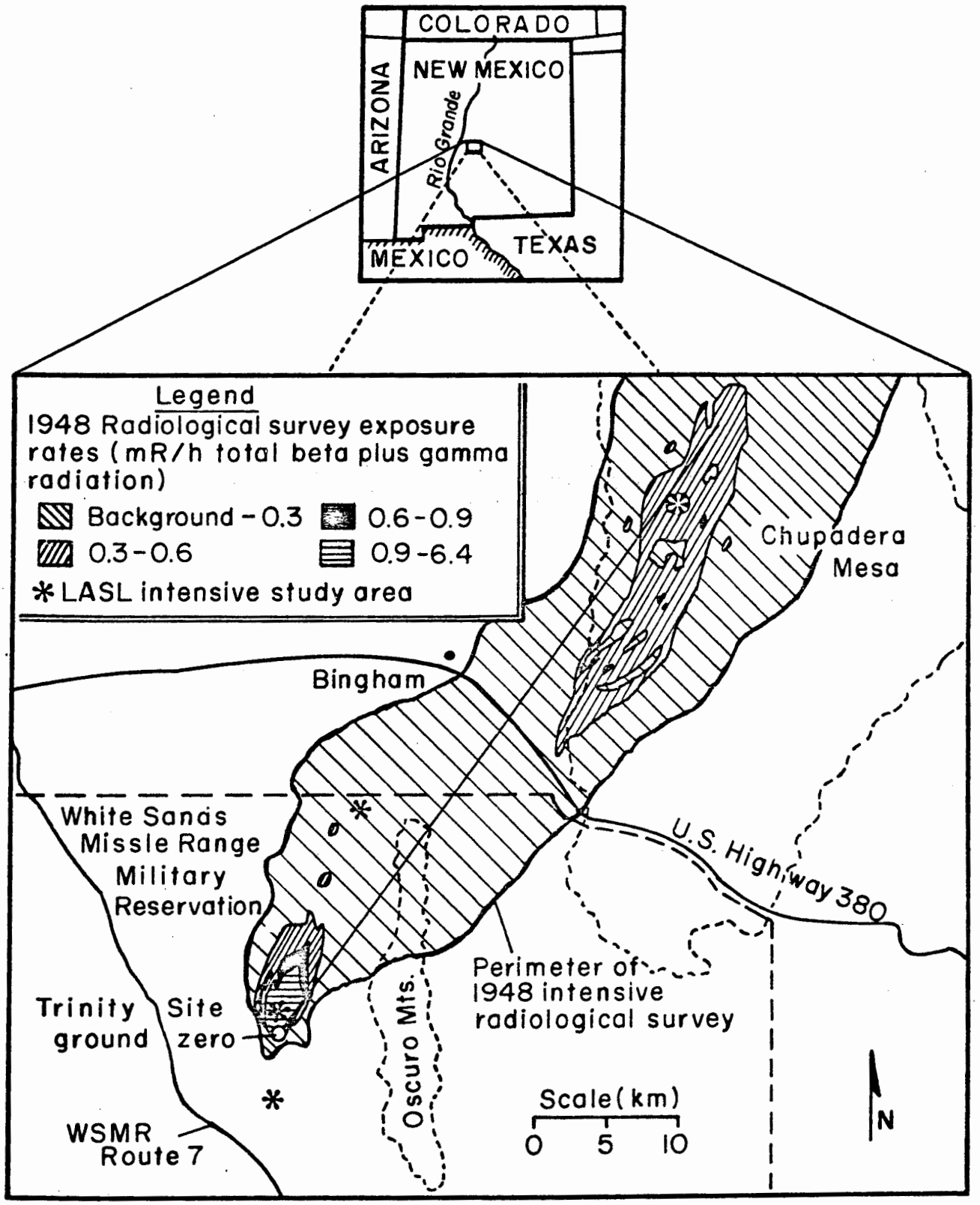

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Figure 2. Soil profile and physiography descriptions of Trinity soils as a function of distance from Ground Zero (GZ).

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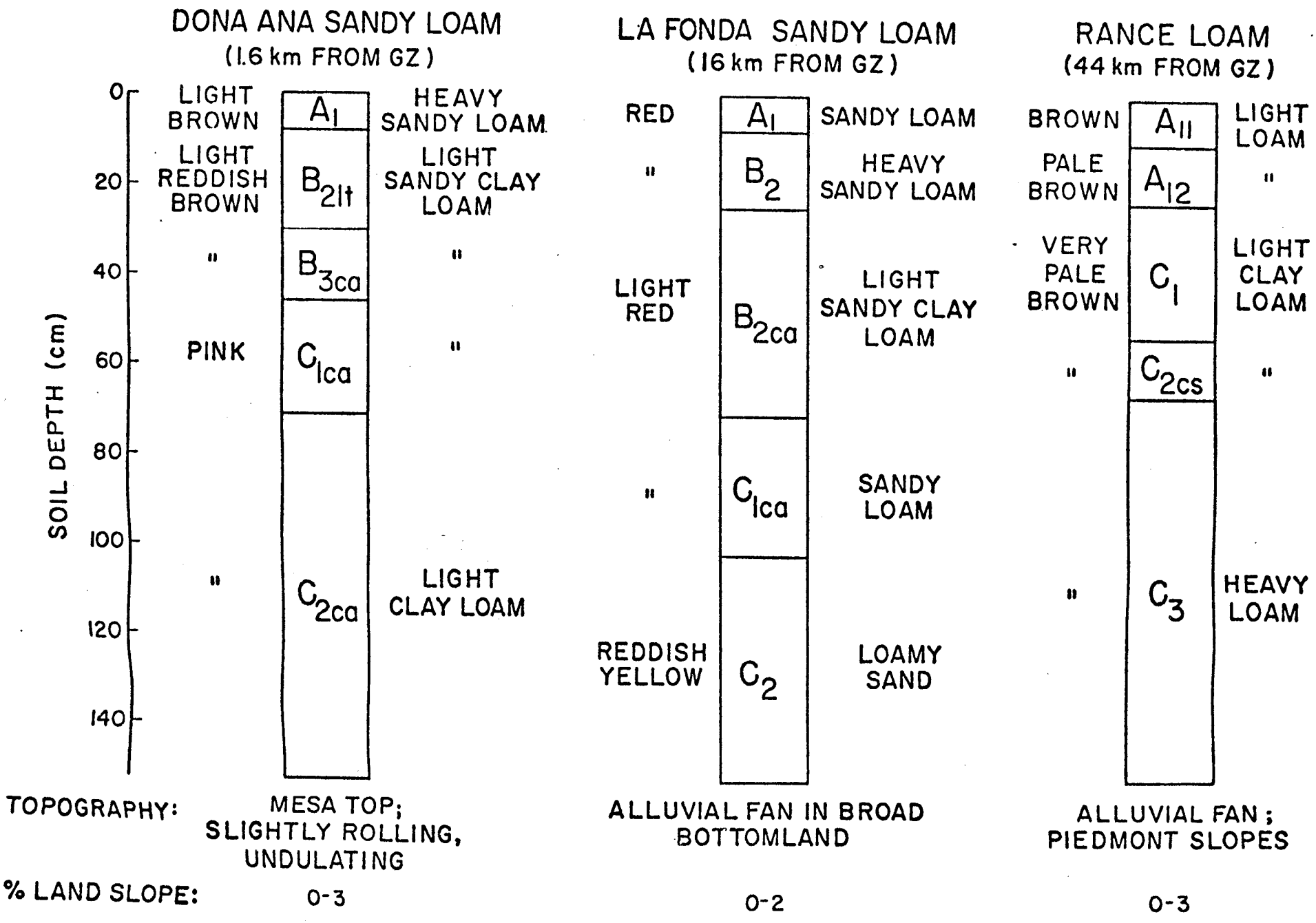
DONA ANA SANDY LOAM
(1.6 km FROM GZ)
LA FONDA SANDY LOAM
(16 km FROM GZ)
RANCE LOAM
(44 km FROM GZ)
SOIL DEPTH (cm)
0
20
40
60
80
100
120
140
LIGHT BROWN
A1
HEAVY SANDY LOAM
LIGHT REDDISH BROWN
B21t
LIGHT SANDY CLAY LOAM
"
B3ca
"
PINK
C1ca
"
"
C2ca
LIGHT CLAY LOAM
RED
A1
SANDY LOAM
"
B2
HEAVY SANDY LOAM
LIGHT RED
B2ca
LIGHT SANDY CLAY LOAM
"
C1ca
SANDY LOAM
REDDISH YELLOW
C2
LOAMY SAND
BROWN
A11
LIGHT LOAM
PALE BROWN
A12
"
VERY PALE BROWN
C1
LIGHT CLAY LOAM
"
C2cs
"
"
C3
HEAVY LOAM
TOPOGRAPHY:
MESA TOP; SLIGHTLY ROLLING, UNDULATING
ALLUVIAL FAN IN BROAD BOTTOMLAND
ALLUVIAL FAN; PIEDMONT SLOPES
% LAND SLOPE:
0-3
0-2
0-3

Figure 3. Distribution of soil $^{239,240}Pu$ as a function of depth 1.6 km from Ground Zero. Plutonium concentrations at each depth represent the average of 2 core segments.

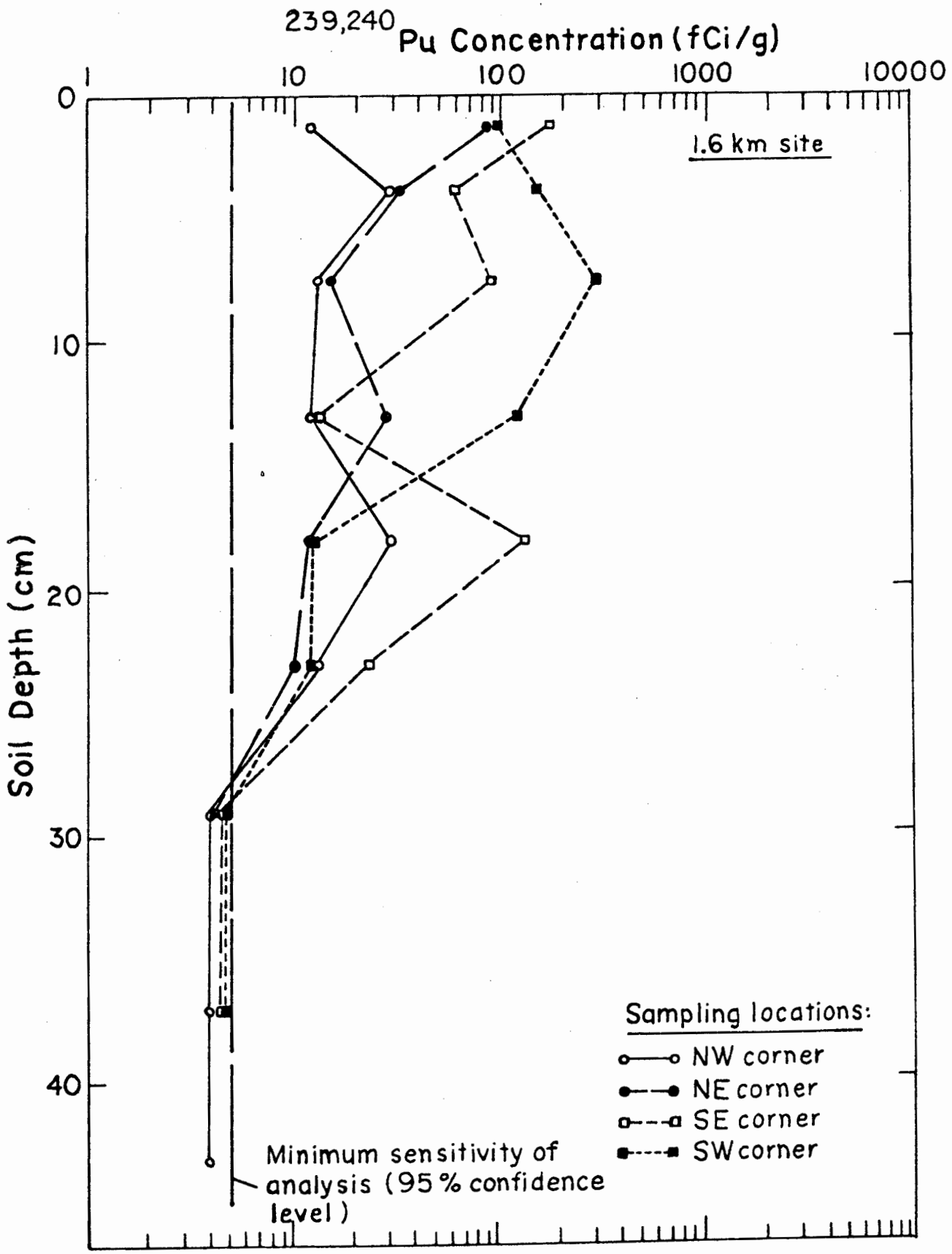
239,240 Pu Concentration (fCi/g)
1
10
100
1000
10000
0
10
20
30
40
Soil Depth (cm)
1.6 km site
Sampling locations:
NW corner
NE corner
SE corner
SW corner
Minimum sensitivity of analysis (95% confidence level)

Figure 4. Distribution of soil $^{239,240}Pu$ as a function of depth 16 km from Ground Zero. Plutontium concentrations at each depth represent the average of 2 core segments.

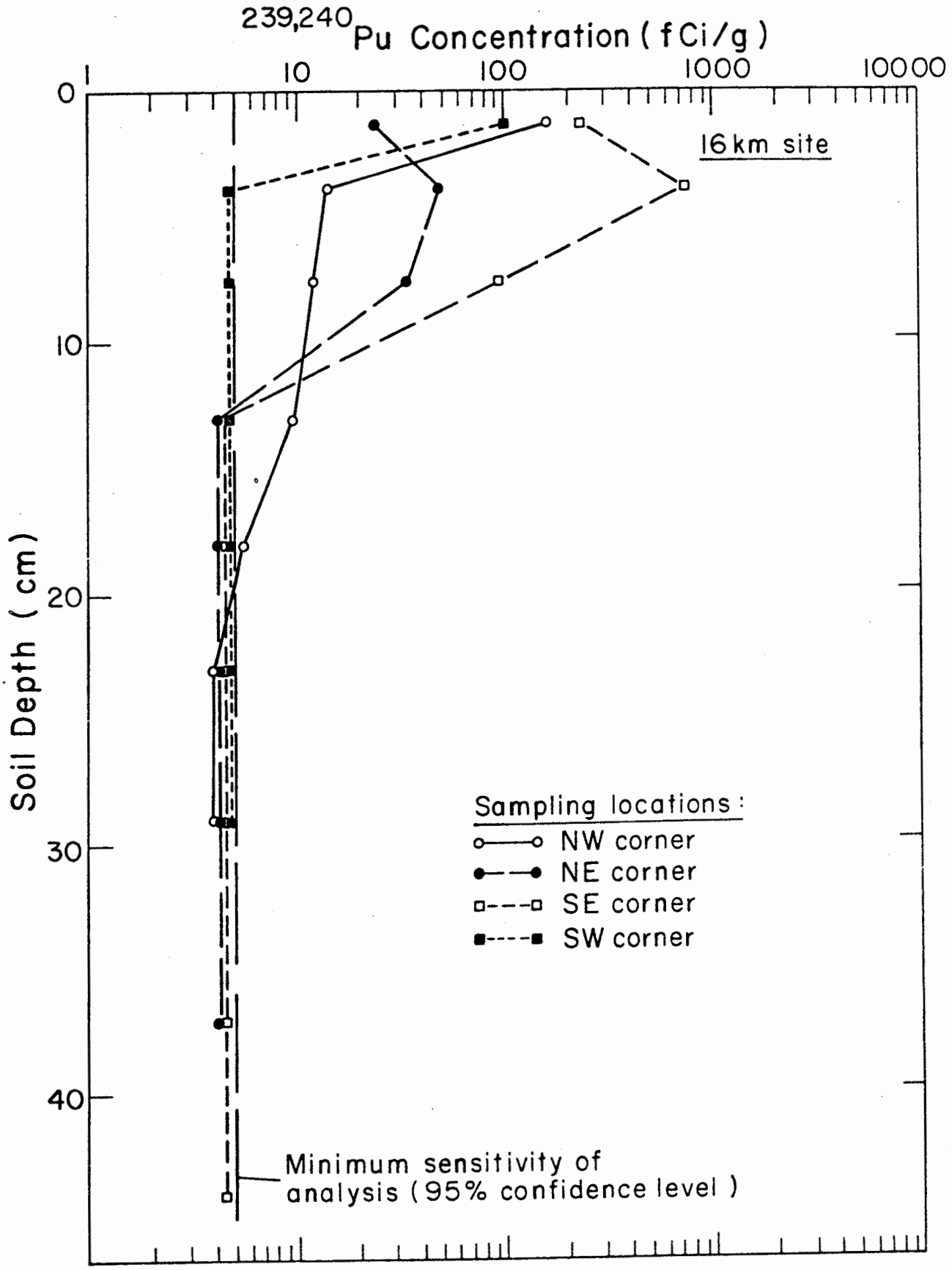
239,240Pu Concentration (fCi/g)
1
10
100
1000
10000
0
10
20
30
40
Soil Depth (cm)
16 km site
Sampling locations:
NW corner
NE corner
SE corner
SW corner
Minimum sensitivity of analysis (95% confidence level)

Figure 5. Distribution of soil $^{239,240}Pu$ as a function of depth 44 km from Ground Zero. Plutonium concentrations at each depth represent the average of 2 core segments.

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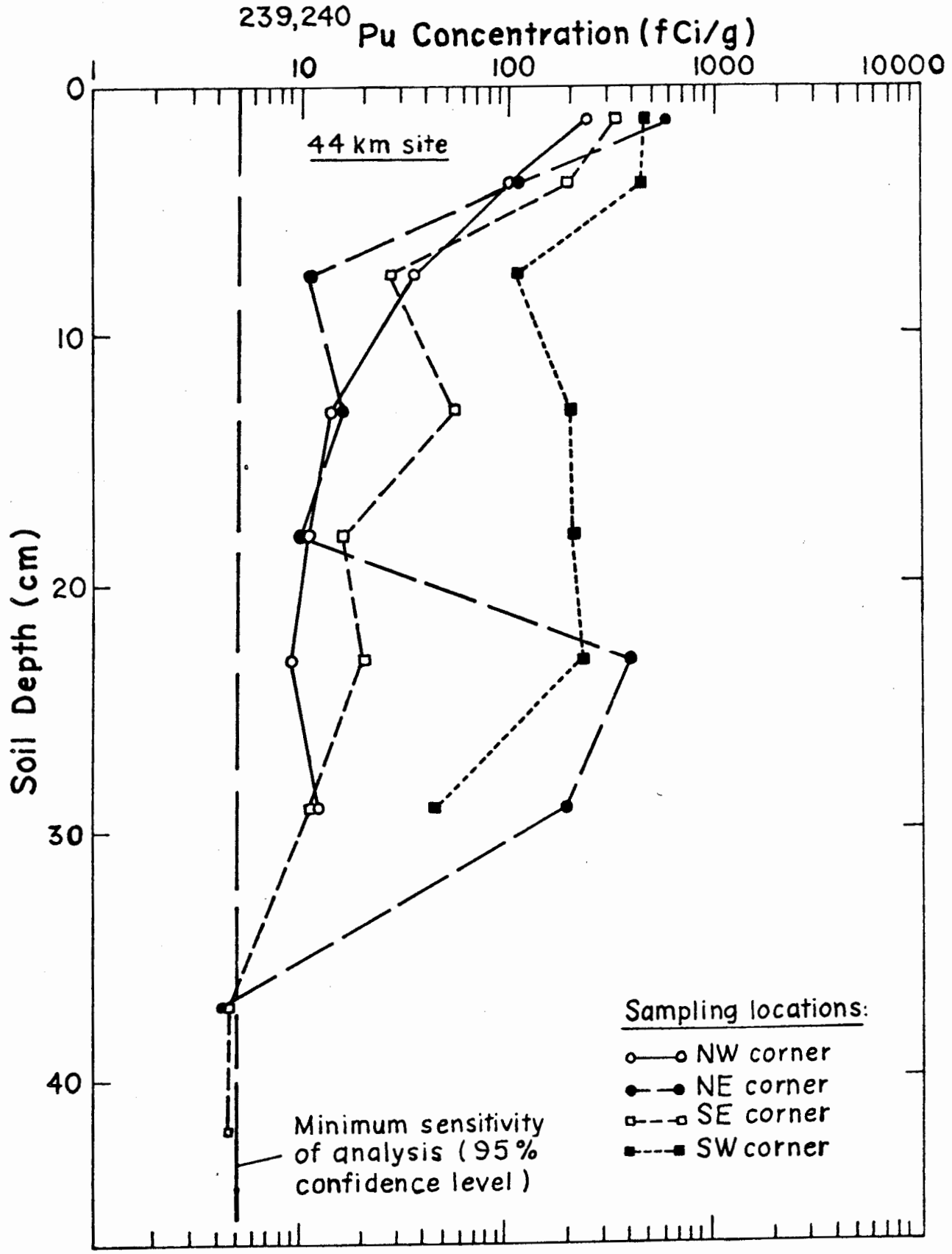
239,240 Pu Concentration (fCi/g)
1
10
100
1000
10000
0
10
20
30
40
Soil Depth (cm)
44 km site
Minimum sensitivity of analysis (95% confidence level)
Sampling locations:
NW corner
NE corner
SE corner
SW corner

Figure 6. Distribution of soil $^{239,240}Pu$ as a function of depth at the control site. Plutonium concentrations at each depth represent the average of 2 core segments.

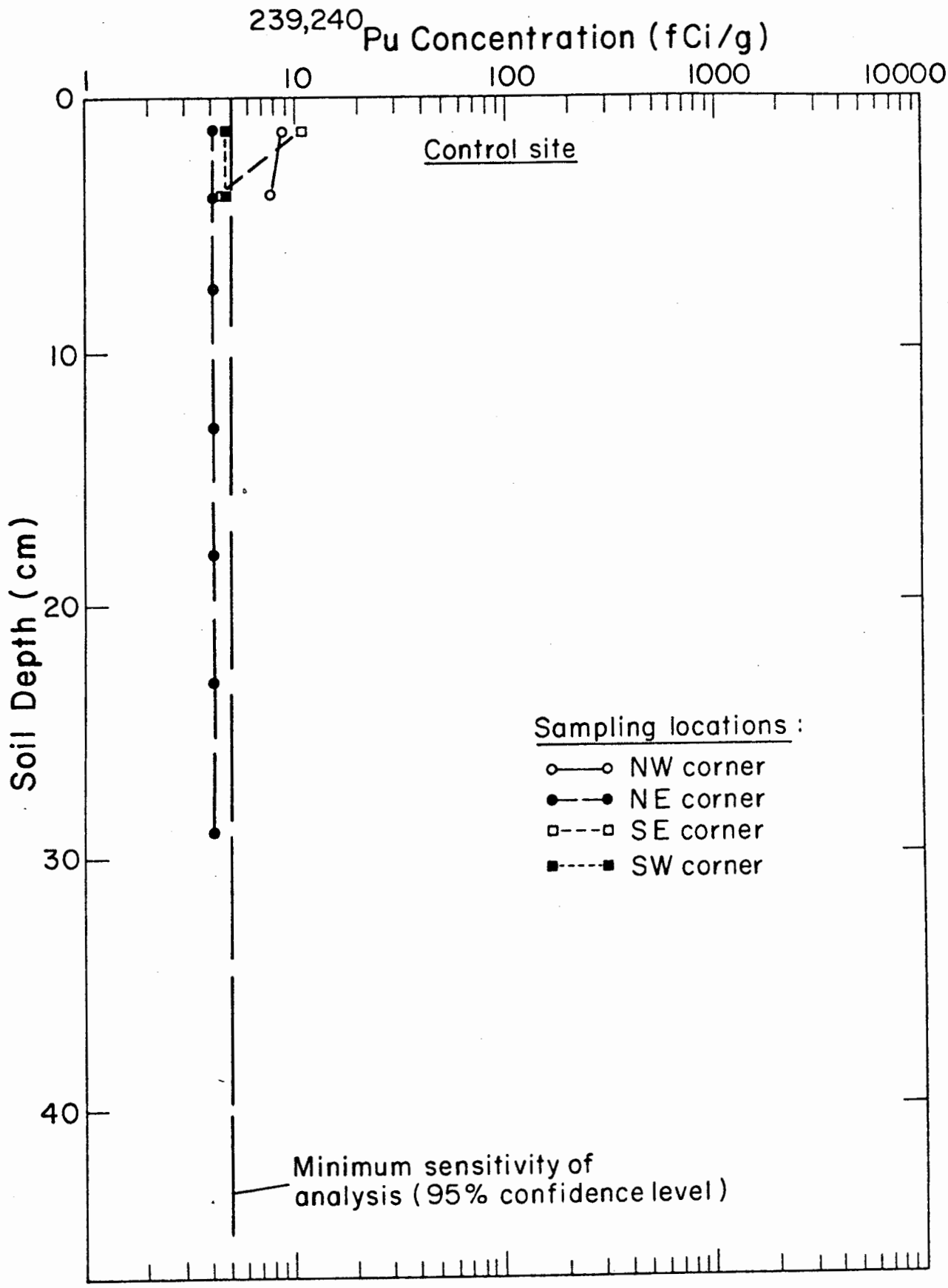
239,240Pu Concentration (fCi/g)
1
10
100
1000
10000
0
10
20
30
40
Soil Depth (cm)
Control site
Sampling locations :
NW corner
NE corner
SE corner
SW corner
Minimum sensitivity of analysis (95% confidence level)

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Table 1. Classification of Trinity Site soils.

Distance from Ground Zero (km)	Soil type	Soil classification
1.6	Dona Ana sandy loam	Typic Haplargid, fine-loamy, mixed, thermic family
16	La Fonda sandy loam	Ustollic Camborthid, fine-loamy, mixed, mesic family
44	Rance loam	Ustic Torriorthent, fine-silty, gypic, mesic family

Table 2. Mean concentrations and coefficients of variation of $^{239,240}Pu$ levels in intensive site soils.

Soil depth (cm)	Mean soil $^{239,240}Pu$ concentrations (fCi/g)*	Coefficient of variation of $^{239,240}Pu$ concentrations†	Number of samples
	1.6 km Site		
0 - 2.5	440	0.82	8
2.5 - 5.0	340	1.0	8
5.0 - 10	510	1.5	8
10 - 15	220	1.7	8
15 - 20	220	1.8	8
20 - 25	200	1.8	7
	16 km Site		
0 - 2.5	130	1.2	8
2.5 - 5.0	380	1.9	4
5.0 - 10	56	1.4	5
	44 km Site		
0 - 2.5	2000	0.48	8
2.5 - 5.0	1000	0.96	8
5.0 - 10	220	1.4	8
10 - 15	340	1.3	8
15 - 20	310	1.5	8
20 - 25	820	1.7	8
25 - 33	350	1.8	7
	Control Site		
0 - 2.5	9.8	1.0	6

*Samples containing nondetectable levels of soil plutonium (< 5.0 femtocuries/g [fCi/g], 95% confidence level) were not included in the calculation of mean concentration.

†Represents standard deviation divided by mean soil plutonium concentration.

Table 3. Distribution of plutonium in soil size fractions of Trinity Site soils at the 0-2.5 cm depth.

Parameter studied	Soil Size fraction					
	<53 μm	53-100 μm	100-500 μm	0.5-1.0 mm	1.0-2.0 mm	2.0-23 mm
			1.6 km from Ground Zero			
$^{239,240}Pu$ concentration (fCi/g)	70	50	920	2100	5300	8.9
Weight % soil	8.9	11	49	23	6.1	2.0
% $^{239,240}Pu$ in fraction	0.78	0.43	36	38	25	0.01
			16 km from Ground Zero			
$^{239,240}Pu$ concentration (fCi/g)	660	98	790	140	67	20
Weight % soil	10	19	65	4.0	0.42	1.6
% $^{239,240}Pu$ in fraction	11	3.0	85	0.92	0.05	0.03
			44 km from Ground Zero			
$^{239,240}Pu$ concentration (fCi/g)	3800	1700	420	640	1600	230
Weight % soil	36	18	25	4.2	2.9	14
% $^{239,240}Pu$ in fraction	73	16	5.5	1.4	2.4	1.8
			Control Site			
$^{239,240}Pu$ concentration (fCi/g)	20	25	7.3	56	ND*	20
Weight % soil	13	17	49	13	4.1	4.4
% $^{239,240}Pu$ in fraction	14	23	19	39	0.0	4.9

*Less than minimum sensitivity of analysis (95% confidence level) of 5.0 fCi $^{239,240}Pu$/g soil.

Table 4. Distribution of plutonium in soil size fractions of Trinity Site soils at the 5.0-10 cm depth.

Parameter studied	Soil Size fraction					
	<53 μm	53-100 μm	100-500 μm	0.5-1.0 mm	1.0-2.0 mm	2.0-23 mm
			1.6 km from Ground Zero			
$^{239,240}Pu$ concentration (fCi/g)	11	37	72	27	10	ND*
Weight % soil	10	12	41	21	9.4	6.6
% $^{239,240}Pu$ in fraction	2.7	10	71	14	2.3	0.0
			16 km from Ground Zero			
$^{239,240}Pu$ concentration (fCi/g)	320	76	42	17	ND	ND
Weight % soil	12	16	58	11	0.55	2.5
% $^{239,240}Pu$ in fraction	49	17	32	2.0	0.0	0.0
			44 km from Ground Zero			
$^{239,240}Pu$ concentration (fCi/g)	270	240	89	33	ND	ND
Weight % soil	28	19	30	8.8	2.2	12
% $^{239,240}Pu$ in fraction	50	30	18	2.0	0.0	0.0

*Less than minimum sensitivity of analysis (95% confidence level) of 5.0 fCi $^{239,240}Pu$/g soil.