NM.4-4

United States
Environmental Protection
Agency

Office of Radiation Programs
Las Vegas Facility
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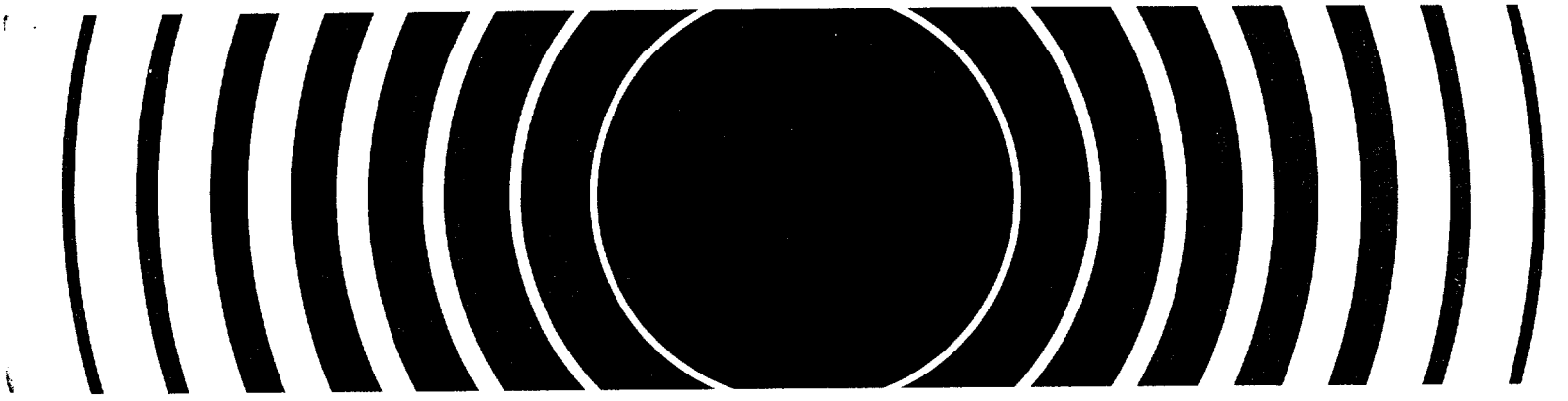
Technical Note
ORP/LV-78-3
October 1978

Radiation

EPA

Levels and Distribution of Environmental Plutonium Around the Trinity Site



Technical Note
ORP/LV-78-3

LEVELS AND DISTRIBUTION OF ENVIRONMENTAL PLUTONIUM AROUND THE TRINITY SITE

Richard L. Douglas

October 1978

OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
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FOREWORD

The Office of Radiation Programs (ORP) of the U.S. Environmental Protection Agency (U.S. EPA) carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation, and to promote the controls necessary to protect the public health and safety. The purpose of this report is to present the results of a survey of plutonium levels in the environs of the Trinity atomic bomb test site in central New Mexico.

Readers of this report are encouraged to inform the authors of any omissions or errors. Comments or requests for further information are also invited.

Donald W. Hendricks

Donald W. Hendricks
Director, Office of
Radiation Programs, LVF

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ACKNOWLEDGMENTS

The author gratefully acknowledges the contributions of the following people to this study:

Mr. John Rodgers, formerly with the New Mexico Environmental Improvement Agency, for his efforts in obtaining land ownership maps, contacting landowners and residents, obtaining permission for us to sample, and helping collect the samples.

Messrs. William Moore, Frank Jakobowski, Daniel Wait, and Thomas Horton, now or formerly at EPA - Las Vegas, for their assistance during the two field surveys.

Mr. Charles Rosenberry and his staff of the Reynolds Electrical and Engineering Company at the Nevada Test Site, for their assistance in weighing, drying, and grinding the soil samples.

Mr. Brian Zamora, formerly with the New Mexico Environmental Improvement Agency in Socorro, and Mr. Matt Williams, formerly foreman at the Monte Prieto Ranch, for their faithful and conscientious operation of the air samplers at these two locations.

Special thanks are due to Dr. Wes Efurd at the McClellan Central Laboratory for his efforts in analyzing the samples, and his technical discussions, particularly in regard to the use and significance of the Pu-240/Pu-239 ratios.

Mrs. Edith Boyd, for her patient and uncompromising efforts in typing this report.

INTRODUCTION

The world's first atomic bomb, called Trinity, was detonated on July 16, 1945. The detonation took place about 60 miles north-northwest of Alamagordo, New Mexico at a location which is now part of the U.S. Army's White Sands Missile Range (WSMR). The plutonium nuclear weapon had a nominal explosive yield of 20 kilotons. The fallout cloud from the test was carried to the northeast by prevailing winds. The approximate fallout pattern on the ground was established in the first few weeks after the test by surveys of the intensity of beta-gamma radiation from fission product deposition.

Since 1945, studies have been made of the distribution and environmental behaviour of the Trinity fallout material (Larson et al, 1951a; Larson et al, 1951b; Olafson et al, 1957; Romney et al, 1969, and Warren, 1949). However, these contained relatively little specific information on the plutonium component of the fallout. When the U.S. Environmental Protection Agency's Office of Radiation Programs (ORP) began work to establish federal guidance for environmental plutonium contamination, it was recognized, on the basis of the little data available, that the deposition from the Trinity fallout cloud constituted one of the significant plutonium-contaminated areas in the United States, both in terms of quantity of plutonium deposited and areal extent. To provide documentation of the Trinity plutonium, a study was initiated in 1973 by the Las Vegas Facility of the Office of Radiation Programs (ORP-LVF). The purpose of this study was to document the current levels and extent of the Trinity plutonium deposition, particularly in regard to those areas outside the controlled area of the WSMR.

STUDY METHODS AND RESULTS

It was decided that sampling surface soil was the most sensitive and efficient way to meet the general objective of the study. Based on fallout deposition data and maps published by Warren (1949), a plan for an initial screening survey was worked out. Basically, this consisted of collecting soil samples at periodic intervals along highways and major unpaved roads over an area which was expected to encompass the total residual fallout area. Since the EPA's primary interest was in the unrestricted areas, no samples were to be collected on the restricted area of the WSMR at this stage. Particular emphasis was given to the Chupadera Mesa, an area beginning about 30 miles northeast of the detonation point (ground zero, or GZ). From earlier measurements, this topographically elevated area was known to have received higher radioactivity deposition than surrounding areas due to rainout of material from the fallout cloud when it passed over the mesa.

1973 SAMPLE COLLECTION

This plan was implemented in November 1973 when two two-man teams spent five days collecting samples in the designated area. A total of 37 surface samples and 7 profile samples were collected.

Samples were collected using the method described by Bliss (1976). Primarily, surface samples (5-cm depth) were collected, although a few profile samples, using 5-cm horizons, were collected to evaluate penetration of the plutonium into the soil profile. The surface samples were collected using a scoop, open on the top and one end, which had dimensions of 100 cm by 100 cm by 5 cm deep. A small hole, having one vertical face and a depth somewhat greater than 5 cm, was dug, and the scoop was placed in the hole. The open end of the scoop was then pushed into the vertical face

until the scoop was full. Ten such scoops of soil were composited to form a sample representing a total area of 1000 square centimeters. The ten scoops were typically collected over an area of a few square meters. Profile samples were collected by digging a hole to the desired depth, taking care to maintain one vertical face. The 5-cm scoop was then pushed into this face, taking a descending series of samples at 5-cm depth increments (horizons). One scoop of soil was collected for each horizon.

After collection, the total sample was weighed at field moisture content. After mixing, an aliquot of the sample (usually 1.5 kg) was weighed, oven dried at 105° C, and re-weighed to determine moisture content. The moisture content was used to correct the field weight of the total sample to dry weight. The aliquot was then ball-milled and sent to the laboratory for radiochemical analysis. The samples were analyzed at the EPA's Environmental Monitoring and Support Laboratory (EMSL-Las Vegas), using the methods described by Johns (1975) and Talvitie (1971 and 1972). Basically, the analytical procedure consisted of complete dissolution of one gram of sample in hydrofluoric and nitric acids. Following ion exchange separation, the plutonium was electrodeposited on a stainless steel planchet for alpha spectrometic determination. The plutonium recovery was determined by use of plutonium-236 as an internal tracer. Cesium-137 was also determined by gamma spectroscopy, using a separate aliquot of the sample. After the plutonium results were available, selected samples having higher plutonium levels were analyzed for americium-241.

After the plutonium concentration (pCi/gram) in the sample was determined, the plutonium deposition (nCi/m^2)* was calculated

* Numerically equal to mCi/km^2, a unit frequently used in references on environmental plutonium. The unit of nCi/m^2 is used in this report because it is felt that an individual sample result is more representative of plutonium deposition for one square meter than for a square kilometer.

by multiplying the concentration by the dry weight of the total sample, dividing by the sample area, and applying the appropriate conversion factors.

1974 SAMPLE COLLECTION

The results of the 1973 survey provided a somewhat clearer picture of the deposition pattern of the Trinity plutonium. It was then possible to select locations for further sampling in order to fill in the gaps and provide more detailed information on the levels and extent of the deposition. To meet this end, a second sampling trip, again using two field sampling teams, was conducted in December 1974. A total of 39 surface and five profile samples was collected. During this survey, access was gained to the WSMR, and 12 samples were collected within the restricted area between ground zero and the northern range boundary.

The sample collection and preparation procedures for these samples were essentially the same as those used for the 1973 samples. One exception was that 2.5-cm horizons were used for the profile samples instead of 5-cm horizons and a few 2.5-cm depth surface samples were collected. In addition, the 1974 samples were analyzed under contract by the U.S. Air Force McClellan Central Laboratory (MCL). The plutonium analytical techniques used by MCL were similar to those used by EMSL, except that a 10-gram aliquot of the soil was taken for dissolution, rather than a one-gram aliquot. The samples were also analyzed by mass spectroscopy as well as alpha spectroscopy in order to obtain the ratio of plutonium-240 to plutonium-239.

During the December 1974 survey, arrangements were made to start an air sampling program to measure airborne plutonium levels. Two sampling stations were established using Gelman Tempest samplers. These samplers operate continuously and draw approximately 10 cubic feet of air per minute through a 4-inch

diameter glass fiber filter. The filters were changed weekly. One station was at the Monte Prieto Ranch on Chupadera Mesa, an area which the 1973 survey (and previous survey reports) had shown to have elevated plutonium deposition levels. The other station was at the State Health Department building in Socorro, which is a background area relative to Trinity plutonium. Sampling was begun in February 1975 and continued into December of that year. Several laboratories were involved in analyzing the air filters. Some were analyzed by the EPA's EMSL-LV laboratory; others were sent to MCL, Eberline Instrument Corporation, or Mound Laboratory for partial or total analysis under contract.

SAMPLE RESULTS

As a point of reference, Figure 1 shows the location within the state of New Mexico of the approximate area covered by the combined 1973 and 1974 soil sampling programs. Tables A-1 and A-2 show the coordinates of the sampling locations for the 1973 and 1974 surveys, respectively. Tables A-3 and A-4 show the soil sampling results for the two surveys. The sample identification number in the left column of Tables A-3 and A-4 is coded as follows:

Table A-3	Table A-4	Explanation
First two digits	First three digits	Sample location number (hereafter referred to as "sample number")
Third digit	Fourth digit	Type of sample: 1 = surface 2 = profile
Fourth digit	Fifth digit	Sampling depth increment(s): For surface samples: 6 = 2.5 cm 7 = 5 cm For profile samples: A, etc. = 2.5 cm N, etc. = 5 cm

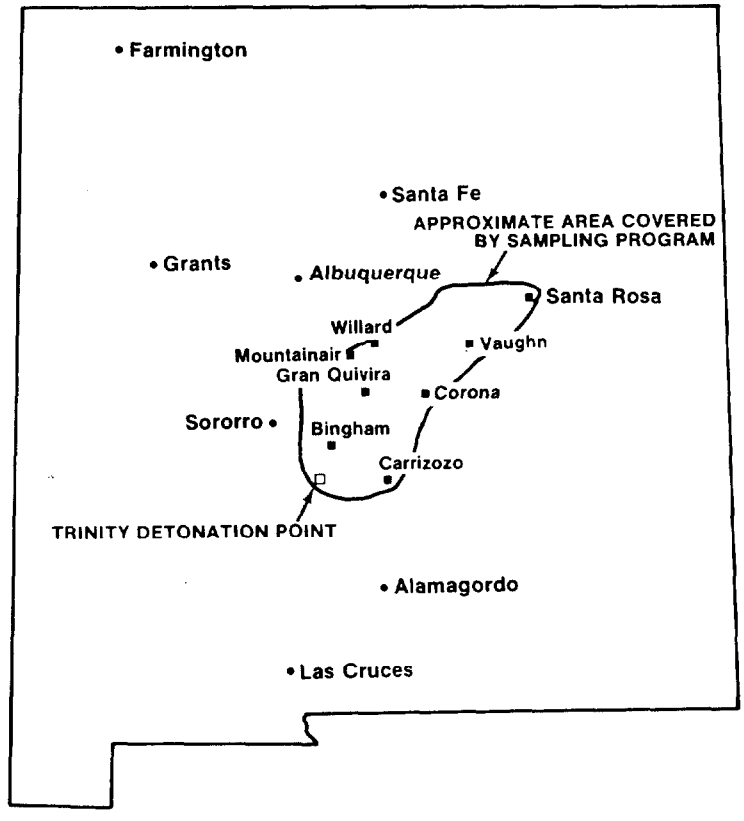

Figure 1. Location Within the State of New Mexico of the Approximate Area Covered by Soil Sampling Program

Table A-3 shows the plutonium-239, 240 concentration (pCi/g) and deposition (nCi/m^2), and the plutonium-238, americium-241, and cesium-137 concentrations for the 1973 samples. These samples were analyzed at the EPA's EMSL-LV laboratory. The results of the soil samples collected in 1974, analyzed by the McClellan Central Laboratory, are shown in Table A-4. This table shows the plutonium-239, 240 concentrations as measured both by alpha spectroscopy and mass spectroscopy, the plutonium-239, 240 deposition, the atom ratio of plutonium-240 to plutonium-239, and the plutonium-238 concentration.

The combined results of the 1973 and 1974 soil sampling surveys are shown in Figure 2. This map shows major roads,

communities, and landmarks in the area covered by the surveys. Each sampling location is shown, and the calculated plutonium-239, 240 deposition, in nCi/m^2, is shown. The error term shown for each deposition number is that calculated from the two-sigma counting error of the concentration in the same manner that the deposition number was calculated from the concentration. The atom ratio (Pu-240/Pu-239) is shown in parenthesis below the deposition number for those samples where the atom ratio was calculated.

The results of the profile samples are shown in Figures A-1 through A-6. Only those profile samples which had plutonium concentrations above the minimum detectable level in at least the top two horizons are plotted, and the results are only plotted to the lowest horizon at which detectable plutonium concentrations were found. In these Figures, the plutonium concentration value for each horizon is plotted at the midpoint of the depth increment on the vertical (depth) scale. The zero value on the vertical scale represents the ground surface.

The analytical results for the air filters collected at Socorro are tabulated in Table A-5 and plotted as a function of time in Figure 3. The same data for the air sampling station at the Monte Prieto Ranch are presented in Table A-6 and Figure 4. Tables A-5 and A-6 show, for each sample, the starting and ending dates of each sampling period, the plutonium-239, 240 and plutonium-238 concentrations in aCi/m^3*, and a code number which indicates which laboratory performed the analysis. The samples collected during August from both stations were lost during the analytical procedure, so no results can be reported for these samples. No result for plutonium-238 was obtained on the nine filters analyzed by MCL, since their analysis on these filters was by mass spectroscopy for Pu-239, 240 only.

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* aCi = attocurie = 10^{-18} curie

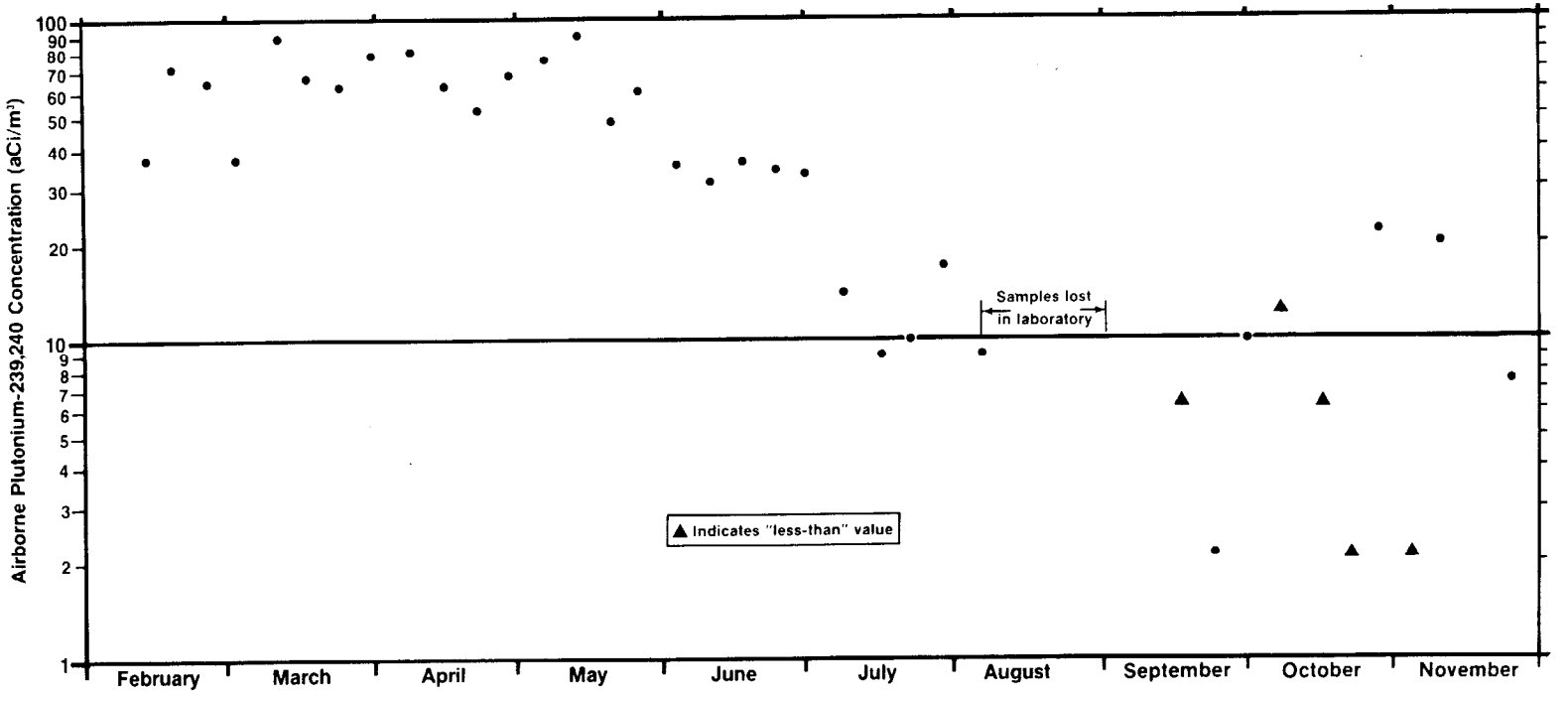

Figure 3. Airborne Plutonium Concentrations at Socorro During 1975

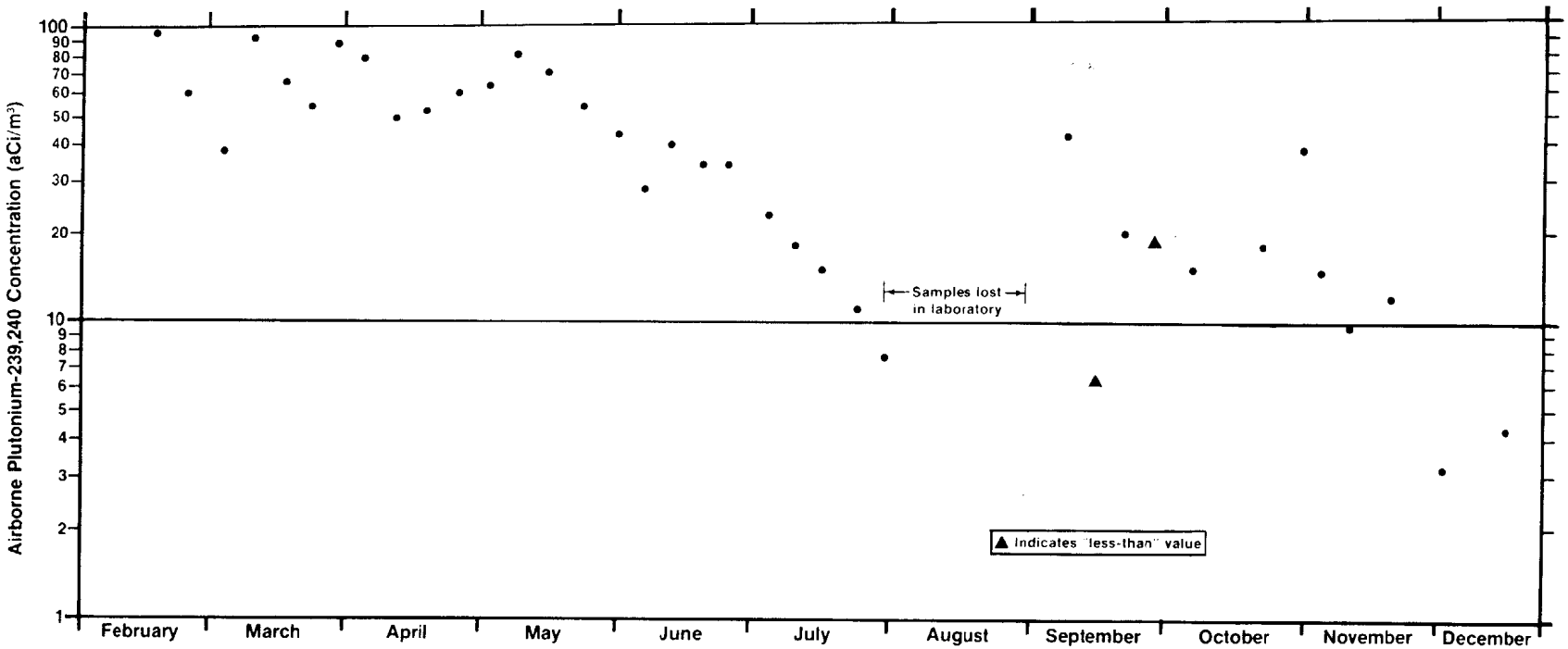

Figure 4. Airborne Plutonium Concentrations at Monte Prieto Ranch During 1975

In Figures 3 and 4, only the plutonium-239, 240 results are plotted, since many of the plutonium-238 results were below the minimum detectable level. In these figures, the "less-than" results for plutonium-239, 240 were not plotted, nor was the sample collected at Socorro on September 2-9, since the extremely high result for this sample (230 ± 200 aCi/m^3) relative to the other data appears to be an analytical error.

An attempt was made to determine the atom ratio (Pu-240/Pu-239) on the filters analyzed by MCL using mass spectroscopy. Unfortunately, the levels were so low that valid results were obtained on only five of the nine filters. These results are shown in Table 1.

TABLE 1. ATOM RATIOS (Pu-240/Pu-239) OF AIRBORNE PLUTONIUM SAMPLES

Location	Date Collected	Atom Ratio Pu-240/Pu-239
Monte Prieto Ranch	Oct 31 - Nov 4	0.107 ± 0.028
Monte Prieto Ranch	Nov 4 - Nov 11	0.099 ± 0.026
Monte Prieto Ranch	Nov 11 - Nov 20	---
Monte Prieto Ranch	Nov 20 - Dec 2	0.100 ± 0.022
Monte Prieto Ranch	Dec 2 - Dec 15	0.097 ± 0.023
Socorro - Health Bldg	Sep 16 - Sep 23	0.181 ± 0.047

Ten of the soil samples collected in 1973, which had previously been analyzed by EMSL-LV, were sent to MCL for analysis by mass spectroscopy in order to determine the atom ratios of the plutonium. The results of these MCL analyses, with the corresponding EMSL analytical results, are shown in Table 2. Because the mass spectroscopic analyses were felt to be more sensitive and more accurate than the EMSL alpha spectroscopic analyses, new deposition values (nCi/m^2) were calculated from the mass spectroscopic analyses and have been used in Figure 2 and in the following discussion.

TABLE 2. RESULTS OF McCLELLAN CENTRAL LABORATORY ANALYSIS OF SELECTED 1973 SOIL SAMPLES

Sample Number	Plutonium-239,240 (pCi/gm) Alpha Spect.	Mass Spect.	EMSL*	Atom Ratio Pu-240/Pu-239	Calculated Deposition of Pu-239,240** (nCi/m^2)
0517	0.008 ± 0.0022	0.009 ± 0.0005	<0.015	0.189 ± 0.014	0.47 ± 0.026
1517	0.012 ± 0.0016	0.015 ± 0.0015	0.024 ± 0.009	0.250 ± 0.050	0.79 ± 0.079
1617	0.009 ± 0.0013	0.012 ± 0.0009	0.018 ± 0.008	0.190 ± 0.030	0.76 ± 0.057
1717	0.013 ± 0.0025	0.014 ± 0.0004	0.017 ± 0.008	0.162 ± 0.009	0.82 ± 0.023
1917	0.043 ± 0.0031	0.043 ± 0.0005	0.071 ± 0.021	0.043 ± 0.002	2.4 ± 0.028
2317	<0.005	0.011 ± 0.0017	<0.015	0.263 ± 0.066	0.60 ± 0.093
2817	0.075 ± 0.0044	0.076 ± 0.0008	0.031 ± 0.010	0.069 ± 0.003	3.6 ± 0.038
3817	0.030 ± 0.0042	0.025 ± 0.0028	0.073 ± 0.020	0.087 ± 0.017	1.3 ± 0.14
4217	0.073 ± 0.0088	0.076 ± 0.0033	0.051 ± 0.011	0.048 ± 0.012	4.3 ± 0.19
4417	0.044 ± 0.0053	0.051 ± 0.0009	0.025 ± 0.009	0.071 ± 0.003	2.7 ± 0.047

* Repeated from Table A-3 for comparison (measurement by alpha spectroscopy).

** Using the MCL mass spectroscopy concentration values.

DISCUSSION OF RESULTS

EVALUATION OF SAMPLING AND ANALYTICAL METHODS

A total of 88 soil samples were collected and analyzed for plutonium-239, 240. Excluding three samples which were intended to be "background" samples (Nos. 4, 16, and 25), this sampling array covered an area of roughly 4500 square miles, and the furthest sample from the Trinity detonation point was about 135 miles to the northeast. Obviously, any conclusions drawn from data based on a sample density averaging one sample per 50 square miles must be treated with caution. The variability of the deposition data was so great, and the data points were so widespread in most areas, that any attempt to estimate an inventory of Trinity plutonium over the large area involved was considered fruitless.

It was recognized from the beginning of the study that soil sampling has several limitations for determining the amount of plutonium present from a specific point source such as Trinity. The first of these is the variability of the initial deposition. For example, as previously mentioned, it is well known that the Chupadera Mesa, about 30 miles northeast of ground zero, received heavier initial fallout than did the surrounding areas due to "rainout" from the Trinity cloud as it passed over this area.

The second variable is redistribution of the plutonium due to wind and water erosion, movement into the soil profile due to various processes, and human activities. The net effect of all these processes during the nearly 30 years between detonation and this study could be expected to be considerable.

A third factor is the variability inherent in the sample collection and analysis procedures. Considerable variability,

for instance, can arise in the sample collection process alone. Some obvious sources of variation are in the measurement of the depth and area of soil collected, weighing errors, and the difficulties of obtaining a representative aliquot of the total sample for analysis. For example, the oven-dry weight of a typical 5-cm depth surface sample was 5 to 6 kilograms. From this mass of soil, typically 1.5 kg were taken for ball milling. From this, a one-gram aliquot (by EMSL) or ten-gram aliquot (by MCL) was actually analyzed. Analytical errors include weighing and pipetting errors, errors in tracer calibration, instrument calibration and gain shift, and random variability in tracer, background, and sample counts. All these errors and variables are, of course, compounded through the sampling and analytical processes to arrive at the final result (Bernhardt, 1976).

Replicate sample collection and analysis to determine the magnitude of these errors and sources of variability becomes very expensive. Because of the survey nature of this study, and the relatively limited resources available for it, no replicate sample collection was done. However, because difficulties with the "hot particle" problems had been encountered by EPA and others during plutonium studies at the Nevada Test Site (Bliss, personal communication) an attempt was made to evaluate this problem for the Trinity study.

This was done by analyzing ten replicate aliquots from each of three different soil samples, selected to represent high (sample #31), medium (#22), and low (#39) plutonium concentrations. The samples were analyzed by MCL using both alpha spectroscopy and mass spectroscopy. The results are shown in Table 3.

Both log-probability and arithmetic probability plots were made of these data. In all cases, the arithmetic probability plots produced a better approximation of a straight line, indicating that the data are approximately normally distributed. The

TABLE 3. RESULTS OF REPLICATE ANALYSES OF THREE TRINITY SOIL SAMPLES

SAMPLE #3117			SAMPLE #2217			SAMPLE #3917		
Pu-239,240 (pCi/gm)		Ratio	Pu-239, 240 (pCi/gm)		Ratio	Pu-239, 240 (pCi/gm)		Ratio
Alpha Spect.	Mass Spect.	Pu-240/239	Alpha Spect.	Mass Spect.	Pu-240/239	Alpha Spect.	Mass Spect.	Pu-240/239
1.8 ± .16	1.7 ± .062	.023 ± .0041	.099 ± .017	.16 ± .0070	.059 ± .0097	.035 ± .0077	.051 ± .0061	--
1.4 ± .082	1.5 ± .024	.025 ± .00090	.099 ± .020	.12 ± .0058	.033 ± .0059	.026 ± .0057	Limit	--
1.3 ± .13	.96 ± .012	.024 ± .00072	.096 ± .021	.089 ± .0050	.041 ± .0059	.023 ± .0046	.013 ± .00018	.084 ± .0027
1.3 ± .79	.96 ± .017	.025 ± .0011	.085 ± .020	.075 ± .0036	.055 ± .015	.017 ± .0041	Limit	--
1.3 ± .28	1.3 ± .018	.030 ± .0017	.084 ± .0059	.084 ± .0067	.13 ± .065	.017 ± .0044	.014 ± .00084	.082 ± .014
1.1 ± .070	1.0 ± .014	.025 ± .0013	.078 ± .010	.046 ± .022	.043 ± .050	.016 ± .0038	Limit	--
1.0 ± .051	1.2 ± .028	.026 ± .00083	.068 ± .022	.074 ± .0034	.030 ± .0060	.014 ± .0024	Limit	--
.92± .071	.94 ± .034	.023 ± .0033	.067 ± .0094	.14 ± .0036	.066 ± .0070	.013 ± .011	.013 ± .0011	.083 ± .027
.91± .096	.86 ± .0086	.025 ± .0012	.061 ± .016	.060 ± .0079	Limit	.013 ± .0065	Limit	--
.44± .065	.47 ± .013	.028 ± .0038	.017 ± .0034	.019 ± .00053	.11 ± .0076	.012 ± .0079	Limit	--
$\bar{X}\pm\sigma$: 1.15 ± .364	1.09 ± .349		.0754± .0246	.0867± .0429		.0186± .0073		

Notes: 1. Error terms are one-sigma counting error.

2. "Limit" indicates activity was below the limit of detection.

coefficients of variation (standard deviation as a percentage of the mean) for these data sets are shown below.

Sample Number	Type of Analysis	Mean (pCi/gram)	Coefficient of Variation
31	Alpha spectrometry	1.15	32%
	Mass spectrometry	1.09	32%
22	Alpha spectrometry	0.0754	33%
	Mass spectrometry	0.0867	49%
39	Alpha spectrometry	0.0186	39%

The coefficients of variation show that, at the 95 percent confidence level (based on 9 degrees of freedom and a t-value of 2.26), one could expect (using alpha spectrometric analyses) a given analytical result to be within 72 to 88 percent of the "true" value for that sample. This variation is not greatly affected by the plutonium concentration over the approximately two orders of magnitude involved here, although there is an apparent slight increase in the coefficient of variation with decreasing concentration. These data provide an estimate of the variation to be expected from the analytical process itself, beginning with a ball-milled sample aliquot. It should be recognized that ball milling is a homogenizing process, and undoubtedly removes much of the variation which would exist had the aliquots been taken from an unprocessed sample.

Note that the data do not provide any estimate of "sampling error", i.e., the variation to be expected if replicate samples were to be collected at the same sampling location. One estimate of this sampling variation (including the effects of natural and man-made redistribution) can be obtained from the series of samples collected at the Monte Prieto Ranch. After it was decided to establish an air sampling station at the ranch, four 2.5-cm depth surface samples (Nos. 164, 166, 167, and 169) were collected within a radius of approximately 300 meters, with the intention

of characterizing the plutonium deposition of this (relatively) small area in more detail. The plutonium deposition results for these four samples were respectively 28, 8, 86, and 42 nCi/m^2. While plutonium redistribution around the ranch headquarters is undoubtedly greater, due to more intensive human and agricultural activity, than in most other similar-sized areas monitored, this order-of-magnitude variation is probably not excessive. It should be noted that the Pu-240/Pu-239 atom ratio is relatively constant for all four samples, varying from 0.025 to 0.032 (the four values are not statistically different, considering the counting errors), indicating that all four samples contained essentially the same fraction (about 95 percent) of Trinity plutonium.

DISTRIBUTION OF TRINITY PLUTONIUM

Another problem encountered when using soil sampling to measure deposited material is in determining the contribution of Trinity plutonium in the presence of global fallout plutonium. Near ground zero, the contribution of global fallout is insignificant compared to the levels of Trinity plutonium. But at increasing distance from ground zero, as the levels of Trinity plutonium approach the levels of global fallout, it becomes increasingly difficult to distinguish between the two.

One useful technique for evaluating this problem is through the use of the Pu-240/Pu-239 atom ratio. This ratio has been shown to be a useful tool for identifying the contribution of a local source of plutonium to global fallout plutonium, provided that the atom ratios for the two sources are sufficiently different (Krey et al., 1976; Krey and Krajewski, 1972; Hardy, 1972; Efurd, 1975; Krey, 1976). As pointed out by these authors, the 240/239 atom ratio varies according to the conditions under which the plutonium was formed. Consequently, if the atom ratio of plutonium in a sample containing two distinct sources of plutonium is measured, and the atom ratios of the respective sources are known, measured, or assumed, then a straight-forward calculation

yields the contribution of the two sources to the mixture. The equation is:

$$f_T = \frac{R_M - R_F}{R_T - R_F}$$

where f is the fraction due to a given source, R is the 240/239 atom ratio, and the subscripts T, F, and M respectively indicate Trinity, global fallout, and the mixture, or sample.

For the present case, the atom ratio of Trinity plutonium (R_T in the above equation) is assumed to be 0.023, since this is the lowest value measured (sample number 121, about 9 kilometers north of the Trinity GZ). The atom ratio of global fallout (R_F) is somewhat more difficult to ascertain. Krey and Krajewski (1972) indicate a 240/239 ratio of 0.1801 ± 0.24 percent (one-sigma) for global fallout plutonium, based on a sample collected at Brookhaven National Laboratory. The atom ratio varies somewhat with geographical location, and Krey (1976) used a value of 0.163 for studies at the Rocky Flats plant near Denver. Merrill et al. (1977) in their comment on Krey's paper, suggested that a value of 0.169 would be a more appropriate value for the Rocky Flats area. However, since the Trinity area covered by this study has presumably had very little, if any, localized effect from the Nevada Test Site, the value quoted by Krey et al. (1976) of 0.176 has been used here as the atom ratio for global fallout.

The 240/239 atom ratios were reported for 53 soil samples by MCL for this study. Of these, only five were higher than the 0.176 value. These values were:

Sample No.	Atom Ratio, 240/239
103	0.177 ± 0.039
05	0.189 ± 0.014
16	0.190 ± 0.030
15	0.250 ± 0.050
23	0.263 ± 0.066

Considering the counting errors, the first three atom ratios listed above are not significantly different from the 0.176 value. Sample numbers 15 and 23 were both reported by the analyst to have ran quite poorly during the mass spectroscopic analysis (de Jonckheere, 1976; Efurd, 1978). Consequently, it appears that the value of 0.176 for the 240/239 ratio in global fallout is applicable to this study area.

Using these two values (R_T = 0.023 and R_F = 0.176), Figure 5 is a graphical presentation of the equation for calculating the fraction of plutonium due to Trinity in a soil sample having a given value of R_M.

In order to evaluate the contribution of Trinity plutonium, it is helpful to know the "background" level of global fallout plutonium on which the Trinity plutonium is superimposed. A generally accepted level of background plutonium is on the order of 1 nCi/m^2, although this varies widely with geographical location. Three samples were collected during the November 1973 sampling mission which were intended to evaluate background. The results of these samples are summarized below.

Sample No.	Pu-239 Deposition (nCi/m^2)	Atom Ratio Pu-240/239	Type of Analysis
04	<0.57	Not measured	EMSL-alpha spect.
16	0.76 ± 0.057	0.190 ± 0.030	MCL - mass spect.
25	1.1 ± 0.97	Not measured	EMSL-alpha spect.

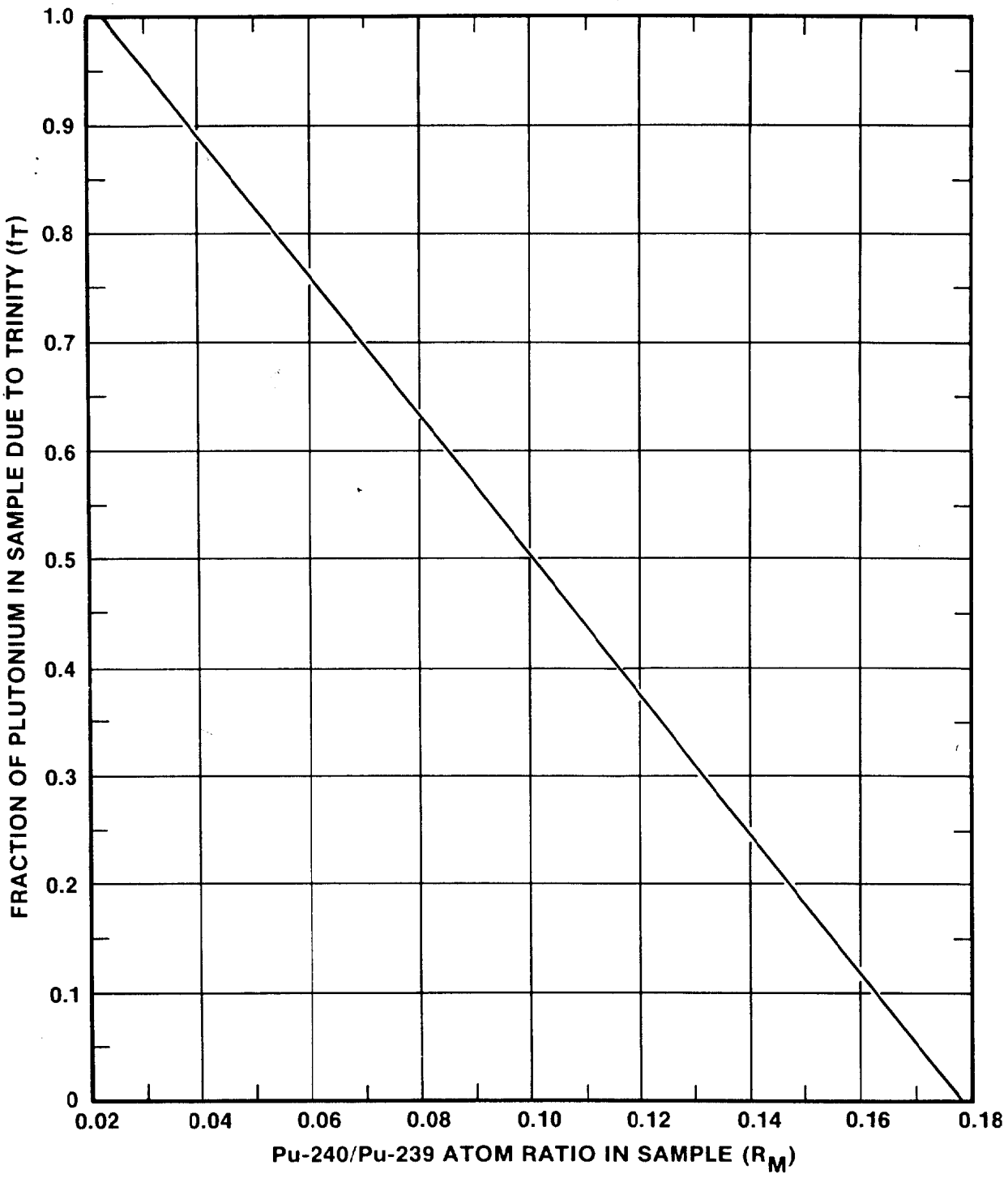

Figure 5. Fraction of Plutonium in Soil Sample Due to Trinity as a Function of Pu-240/Pu-239 Ratio in the Sample

As discussed above, the atom ratio of sample #16 is not significantly different from the 0.176 value which is considered to be due to global fallout. Since this sample presumably contains no Trinity plutonium, the deposition value of 0.76 nCi/m^2 appears to be one valid point for estimating the background plutonium deposition for the Trinity area.

The results of several other samples also appear applicable to this problem, although these samples were not specifically intended to be "background" samples. These samples were selected and evaluated as follows. First, the deposition values for all samples having concentrations (and consequently, deposition values) greater than the minimum detectable activity were plotted on log probability paper. The result was a fairly straight line, indicating that the entire data set was fairly well characterized by a log-normal distribution. However, a fairly pronounced break appeared in the curve at deposition values of about 1.0 to 1.3 nCi/m^2, indicating that the portion of the plot below these values might be represented by a different distribution. Consequently, a separate log-normal plot was made of these deposition values $\leq$ 1.0 nCi/m^2 (15 values). The result was a curved line, indicating that this portion of the data set was not well represented by a log-normal distribution. However, an arithmetic probability plot of the data resulted in a straight line (the "goodness of fit", r^2, of a linear regression line on these data was 0.97). This strongly suggested that these data are normally distributed, and that the mean and standard deviation (0.70 $\pm$ 0.22 nCi/m^2) are the appropriate parameters to describe this distribution. Whether fortituous or not, this is a good agreement with the background value of 0.76 nCi/m^2 discussed above.

These samples are listed in Table 4, in order of increasing deposition value, along with their atom ratio and calculated f_T (when available).

TABLE 4. DEPOSITION AND f_T VALUES FOR BACKGROUND SAMPLES

Sample No.	Atom Ratio	f_T	Deposition (nCi/m^2)
120	0.165 ± 0.043	.072	0.31 ± 0.20
103	0.177 ± 0.039	0	0.42 ± 0.043
05	0.189 ± 0.014	0	0.47 ± 0.026
100	Not measured	-	0.56 ± 0.010
104	Not measured	-	0.56 ± 0.12
23	0.263 ± 0.006	0	0.60 ± 0.093
102	0.175 ± 0.12	0	0.61 ± 0.23
16	0.190 ± 0.030	0	0.76 ± 0.057
15	0.250 ± 0.050	0	0.79 ± 0.079
39	Not measured	-	0.80 ± 0.73
17	0.162 ± 0.009	0.092	0.82 ± 0.023
112	Not measured	-	0.91 ± 0.51
101	Not measured	-	0.93 ± 0.65
09	Not measured	-	1.0 ± 0.88
109	Not measured	-	1.0 ± 0.15

The data in Table 4 are not strictly compatible, since some of the results are by alpha spectrometric analysis by EMSL, while others are by mass spectrometric analysis from MCL. Atom ratios for the four samples having the highest deposition values are not available, so there could be an undetermined contribution of Trinity plutonium to these samples. The 9 percent Trinity contribution to sample #17 and the 7 percent contribution to #120 may not be statistically significant, since the atom ratios and their counting errors are not significantly different from the 0.176 global fallout value at the 95 percent confidence level.

On the basis of the above discussion, several observations may be made about the areal extent of the Trinity plutonium deposition. (Refer to Figure 2 for the following discussion.) Sample #05, the eastern-most sample collected along U.S. 380, definitely appears to be out of the fallout pattern. Proceeding west along this highway, samples #06, #07, and #29 appear to have

little contribution from Trinity, based on the "less-than" deposition numbers. Since these samples were not analyzed by MCL, the atom ratios are not available to confirm this. It appears that the eastern edge of the fallout pattern in this area is somewhat east of sample #28, which definitely has a contribution of Trinity plutonium.

Sample #17, about 6 miles east of Corona on N.M. 42, may have a small contribution of Trinity plutonium, although this may not be statistically significant, as discussed above. Consequently, the eastern edge of the fallout pattern is probably east of this point. This sample was originally analyzed by EMSL, and the deposition figure of 0.98 nCi/m^2 indicated that it was approximately at background, in terms of the data which were available prior to access to the MCL analytical data. Consequently, no further sampling was done in this area in 1974. Only after the sample was re-analyzed by MCL in 1975 did it become apparent that more samples should have been collected to better define and confirm the eastern edge of the pattern in this area.

The same situation prevails along I-40 to the north. Although it was suspected, on the basis of deposition values calculated from the 1973 sampling, that the northeastern limits of the fallout pattern had probably not been reached by the 1973 sampling, no further sampling was done in this direction in 1974 because of resource limitations on the study. However, when three of the eight samples were re-analyzed by MCL, the atom ratios indicated a definite Trinity contribution (60 - 80 percent) along this arc, and it appears certain that Trinity plutonium could be found further to the northeast.

All the samples on the arc along U.S. 60 from Willard to Vaughn were collected in 1974. Again, the eastern edge of the pattern was obviously not reached in this area. Sample #113, about five miles southeast of Vaughn, contains about 87 percent Trinity plutonium as calculated by the atom ratio.

The western edge of the pattern is also not well defined. Sample #103, five miles east of Willard, appears to be at background on the basis of both atom ratio and deposition level, as shown in Table 4. Sample#104, five miles further east, also appears to be background on the basis of the deposition value of 0.56 nCi/m^2, although the atom ratio data are not available to confirm this. However, sample #24, just south of Willard and west of both of these samples definitely appears to have Trinity plutonium with a deposition value of 2.9 nCi/m^2, although again, the atom ratio is not available. This is a good illustration of the areal inconsistency of the observed Trinity plutonium deposition. As discussed previously, this inconsistency could be accounted for by one or a combination of three major factors - sampling and analytical variability, natural and human redistribution, and initial deposition. For example, most of the samples were collected along roads. Although every effort was made to select an "undisturbed" sampling location, it was difficult in practice to be sure that the site was truly undisturbed over the past 30 years. Grading and earth-moving activities associated with road maintenance and construction can be disguised over a period of time by vegetative growth and minor wind and water erosion so that the area looks natural. It is possible that samples #103 and #104 were collected at spots where the topsoil has been removed since 1945. Consequently, these results could be due to "sampling error" which resulted in sampling relatively clean topsoil while Trinity plutonium may have been buried or removed.

Continuing the discussion of the western edge of the pattern, the atom ratios of the two samples collected at Gran Quivira National Monument (#162 and #163) indicate 85 - 95 percent Trinity plutonium at this location. The deposition values for samples #36 (2.4 nCi/m^2) and #30 (2.6 nCi/m^2) suggest that these are not background values, and that the fallout pattern extends west of these locations. Samples #16 (on U.S. 60) and #100, #101, and #102 (on U.S. 380), as shown in Table 4, appear to be

background on the basis of their atom ratios and/or deposition levels. Therefore, the western edge of the deposition pattern lies somewhere west of a line trending northeast through Bingham on U.S. 380, Gran Quivira, and Willard on U.S. 60.

Because the allowed access time for the sampling teams onto the WSMR was limited to one day, relatively few samples were collected on the Range. This was not considered to be a significant shortcoming, however, since the primary objective of the study was to evaluate plutonium deposition in the off-site (unrestricted) area. Not surprisingly, the highest plutonium deposition levels found during the study were from samples on the Range. No samples were collected inside the fenced area surrounding the GZ. A sample collected about one mile south of GZ showed a relatively low deposition value of 1.1 nCi/m^2 and contained about 32 percent Trinity plutonium. Sampling to the east on the WSMR was limited by the physical barrier of the Oscura Mountains.

In summary, the above discussion of the data from samples around the edge of the sampling array indicates that the edges of the deposition pattern are somewhat outside the edges of the sampling array on the east and north, and possibly somewhat to the south. The only area in which the edges of the deposition pattern are relatively well defined is along U.S. 380. Since this area is closer to GZ, the original fallout pattern was narrow at this point and better defined than it was further downwind as the fallout cloud dispersed.

As mentioned previously, the Chapadera Mesa area was of particular interest to the study since higher deposition levels were known to have occurred there. These were confirmed by this study. The highest deposition value found off the WSMR, 86 nCi/m^2, was at the Monte Prieto Ranch. As shown on Figure 2, several samples having elevated plutonium deposition values, many in the tens of nCi/m^2, were collected in this area.

SOIL PROFILES

A total of 12 soil profiles were sampled to determine the penetration of plutonium into the soil. Seven of the profiles, collected in 1973, consisted of 5-cm depth increments, or horizons, and ranged in total depth from 20 to 35 cm. Five profiles were collected in 1974 using 2.5-cm horizons, and ranged in total depth from 10 to 25 cm. The total sampling depth was determined by soil conditions at each sampling site, but an attempt was made to collect at least five horizons.

The results are presented graphically in Figures A-1 through A-6 for the six samples which had plutonium concentrations above the minimum detectable activity in at least the top two horizons. The remaining six profiles were not plotted because "less-than" concentration values were found in the top horizons.

The six profiles which are plotted generally show a constant or decreasing plutonium concentration with depth to the depth sampled. In those profiles which apparently contained significant amounts of Trinity plutonium, the concentration decreased rapidly with depth to about the 10- to 15-cm depth. Sample #115 was anomalous in that the concentration in the second horizon was less than the minimum detectable activity, while lower horizons had definitely detectable plutonium. This result does not appear real, and may be due to a sample processing or analytical error.

AIR SAMPLING

The results of the air sampling at Socorro and at Monte Prieto Ranch are shown in Tables A-5 and A-6 and in Figures 3 and 4, respectively. The mean and standard deviation of the results (excluding less-than values and the outlier at Socorro) are 43 ± 27 for Socorro ($n = 31$ samples) and 41 ± 27 aCi/m^3 for the Monte Prieto Ranch ($n = 35$).

Using the Pu-240/Pu-239 atom ratio technique described previously, and the data shown in Table 1, the contribution of

Trinity plutonium to the Monte Prieto samples can be calculated. If values of R_F = 0.181 (as measured in Socorro, and not statistically different from the 0.176 value assumed for global fallout in soil) and R_T = 0.023 (as assumed previously) are used, the four air filters collected at Monte Prieto which were successfully analyzed by mass spectroscopy were found to contain an average of about 50 percent Trinity plutonium.

These air sampling data pose an interesting question. The average concentrations at the two locations are not statistically different, even though plutonium deposition on the ground at the Monte Prieto Ranch is considerably higher than that at Socorro. Furthermore, resuspension was definitely occurring at the ranch, since about 50 percent of the plutonium collected on the air filters was due to Trinity. On the surface, the conclusion might be drawn that global fallout at the ranch was half that in Socorro. This is highly unlikely, since the two locations are only about 40 miles apart.

A possible explanation of this apparent anomaly might lie in the fact that the concentration data for both locations are averaged over a period of about 10 months, whereas the atom ratio data at Monte Prieto are based on four filters collected in November and early December. Consequently, the 50-percent Trinity contribution may not be representative of the airborne plutonium composition at Monte Prieto on an annual average basis.

SUMMARY AND CONCLUSIONS

Soil samples were collected from an area in central New Mexico to evaluate the extent and distribution of plutonium resulting from the detonation of the Trinity device in 1945. A total of 88 samples were analyzed, covering an area of roughly 4500 square miles. Emphasis was on sampling in areas accessible to the public, although some samples were collected on the restricted area of the White Sands Missile Range, where the Trinity ground zero is located. The results indicate that most of the area sampled contains detectable amounts of Trinity plutonium in the surface 5 cm of soil. The highest levels off the Missile Range were on the Chupadera Mesa, approximately 30 miles northeast of the ground zero, and were on the order of 20 - 90 nCi/m^2.

Air samples were collected during 1975 at a location on the Chupadera Mesa and at Socorro, which is west of the deposition pattern. The average concentrations at these locations were 41 ± 27 and 43 ± 27 aCi/m^3, respectively.

Federal Radiation Protection Guidance currently being promulgated by the Environmental Protection Agency (FR, 1977) suggests a "screening level" of 200 nCi (of transuranium elements) per square meter for soil contamination, in the top 1 cm of soil. The maximum soil contamination level measured in this study (in an unrestricted area) was 86 nCi of Pu-239,240 per square meter, or less than half the proposed screening level. The values reported from this study are for the top 5 cm of soil, and consequently are higher than the value for the top 1 cm. While higher plutonium levels could no doubt be found by additional sampling, the sampling density on the Chupadera Mesa makes it unlikely that grossly higher values are present in this area.

The EPA also derives a recommended air concentration of 1000 aCi/m^3 based on an activity median aerodynamic particle diameter of 0.1 μm or less. The measured 10-month average air concentration at the Monte Prieto Ranch, located on the Chupadera Mesa, was a factor of 25 below this concentration. (This measurement included all particles collected.) Furthermore, this average concentration was not statistically different from the average concentration during the same time period at Socorro, although some of the filters collected at the Monte Prieto Ranch were shown to contain Trinity plutonium.

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APPENDIX A

TABLE A-1. COORDINATES OF NOVEMBER 1973 SOIL SAMPLING LOCATIONS

Sample Code	North Latitude	West Longitude
01	33° 52' 30"	106° 28' 15"
02	33° 53' 00"	106° 25' 15"
03	33° 53' 15"	106° 22' 30"
04	33° 31' 15"	106° 02' 00"
05	33° 45' 00"	106° 03' 00"
06	33° 45' 30"	106° 07' 00"
07	33° 46' 45"	106° 09' 30"
08	33° 58' 15"	106° 15' 30"
09	33° 56' 45"	106° 04' 00"
10	34° 00' 00"	106° 06' 00"
11	34° 02' 00"	106° 04' 00"
12	34° 01' 00"	106° 01' 00"
13	33° 59' 00"	106° 00' 00"
14	33° 57' 45"	106° 00' 00"
15	33° 57' 00"	105° 54' 30"
16	34° 25' 00"	106° 38' 00"
17	34° 11' 45"	105° 32' 00"
18	34° 16' 30"	105° 35' 00"
19	34° 18' 00"	105° 38' 00"
20	34° 22' 30"	105° 42' 00"
21	34° 25' 30"	105° 47' 00"
22	34° 28' 30"	105° 52' 00"
23	34° 30' 30"	105° 57' 45"
24	34° 34' 45"	106° 01' 15"
25	Approx. 17 miles east of Holbrook, AZ on I-40	
26	33° 52' 45"	106° 19' 30"
27	33° 50' 45"	106° 17' 30"
28	33° 49' 00"	106° 15' 00"
29	33° 48' 00"	106° 12' 15"
30	33° 57' 45"	106° 18' 00"
31	33° 59' 15"	106° 13' 00"
32	33° 59' 45"	106° 09' 30"
33	34° 03' 45"	106° 07' 00"
34	34° 06' 00"	106° 11' 00"
35	34° 07' 45"	106° 14' 15"
36	34° 07' 15"	106° 16' 45"
37	34° 56' 45"	104° 42' 15"
38	34° 58' 15"	104° 47' 45"
39	34° 58' 30"	104° 52' 45"
40	34° 58' 30"	104° 48' 00"
41	34° 59' 00"	105° 01' 00"
42	34° 59' 15"	105° 10' 00"
43	34° 59' 30"	105° 15' 45"
44	34° 59' 45"	105° 21' 15"

TABLE A-2. COORDINATES OF DECEMBER 1974 SOIL SAMPLING LOCATIONS

Sample Code	North Latitude	West Longitude
100	34° 52' 50"	105° 31' 20"
101	34° 53' 00"	106° 34' 40"
102	34° 53' 10"	106° 37' 50"
103	34° 35' 10"	105° 56' 30"
104	34° 37' 30"	105° 52' 20"
105	34° 40' 10"	105° 48' 20'
106	34° 41' 00"	105° 43' 20"
107	34° 40' 30"	105° 37' 40"
108	34° 40' 10"	105° 32' 50"
109	34° 42' 50"	105° 29' 00"
110	34° 38' 30"	105° 26' 30"
111	34° 36' 30"	105° 22' 20"
112	34° 35' 10"	105° 17' 30"
113	34° 34' 00"	105° 16' 50"
114	34° 3' 00"	106° 3' 40"
115	34° 6' 00"	106° 2' 50"
116	34° 4' 20"	105° 58' 50"
117	34° 1' 30"	105° 57' 40"
118	34° 12' 10"	105° 59' 50"
119	34° 41' 10"	106° 28' 40"
120	34° 43' 20"	106° 29' 50"
121	34° 44' 50"	106° 28' 20"
122	34° 47' 30"	106° 29' 30"
123	34° 48' 00"	106° 29' 00"
124	34° 47' 30"	106° 32' 30"
150	34° 8' 30"	106° 6' 50"
151	34° 8' 25"	106° 2' 40"
152	34° 7' 40"	105° 59' 50"
153	34° 39' 50"	106° 29' 00"
154	34° 44' 30"	106° 26' 40"
155	34° 43' 55"	106° 24' 10"
156	34° 47' 00"	106° 24' 30"
157	34° 49' 00"	106° 24' 00"
158	34° 49' 20"	106° 25' 30"
159	34° 54' 40"	106° 21' 30"
160	34° 55' 30"	106° 15' 50"
161	34° 01' 20"	106° 6' 50"
162 - 163	34° 15' 20"	106° 5' 40"
164 & 166-169	34° 6' 00"	106° 7' 10"
165	34° 15' 40"	105° 53' 00"

TABLE A-3. RADIONUCLIDE CONCENTRATIONS IN TRINITY SOIL SAMPLES COLLECTED DURING NOVEMBER 1973

Sample Number	PLUTONIUM-239, 240 Concentration (pCi/g)	PLUTONIUM-239, 240 Deposition (nCi/m^2)	Plutonium-238 Concentration (pCi/g)	Americium-241 Concentration (pCi/g)	Cesium-137 Concentration (pCi/g)
	Surface Samples - See text for coding description				
0117	0.041 ± 0.022	2.9 ± 1.5	0.021 ± 0.017	<0.0052	0.38
0217	0.026 ± 0.019	1.8 ± 1.3	0.020 ± 0.017	<0.0041	0.47
0517	<0.015	<0.79	<0.015	NA	0.69
0617	<0.015	<0.84	0.019 ± 0.018	NA	0.24
0717	<0.014	<0.71	0.035 ± 0.021	NA	0.56
0817	0.054 ± 0.025	3.0 ± 1.4	<0.016	NA	0.21
0917	0.018 ± 0.016	1.0 ± 0.88	0.018 ± 0.016	<0.0050	0.71
1217	0.082 ± 0.031	4.9 ± 1.8	0.021 ± 0.018	NA	0.44
1317	0.033 ± 0.021	1.5 ± 0.99	0.021 ± 0.018	NA	0.94
1417	0.069 ± 0.036	4.1 ± 2.1	<0.021	NA	0.34
1517	0.024 ± 0.018	1.3 ± 0.97	<0.021	NA	0.39
1617	0.018 ± 0.017	1.1 ± 1.1	<0.017	NA	0.19
1717	0.017 ± 0.016	0.98 ± 0.93	<0.013	NA	0.76
1817	0.035 ± 0.021	1.8 ± 1.1	0.020 ± 0.017	NA	0.82
1917	0.071 ± 0.041	4.0 ± 2.3	<0.032	NA	0.47
2117	0.037 ± 0.018	2.5 ± 1.2	<0.018	NA	0.55
2217	0.086 ± 0.048	4.7 ± 2.7	<0.035	NA	0.45
2317	<0.015	<0.82	<0.026	NA	0.29
2417	0.045 ± 0.022	2.9 ± 1.5	<0.023	<0.0022	0.27
2517	0.016 ± 0.015	1.1 ± 0.97	<0.026	NA	0.12
2617	0.033 ± 0.020	2.0 ± 1.2	<0.022	NA	0.28
2817	0.031 ± 0.020	1.5 ± 0.96	0.017 ± 0.017	<0.0034	1.3
2917	<0.013	<0.63	<0.012	NA	0.72
3017	0.047 ± 0.022	2.6 ± 1.2	0.022 ± 0.016	NA	0.32
3117	0.91 ± 0.11	52 ± 6.4	0.076 ± 0.029	NA	1.4
3317	1.2 ± 0.15	68 ± 8.3	0.11 ± 0.041	NA	2.5
3417	0.065 ± 0.026	3.6 ± 1.4	<0.025	NA	0.57
3517	<0.032	<1.9	<0.035	NA	0.66
3617	0.040 ± 0.033	2.4 ± 1.9	<0.035	NA	0.59
3717	<0.034	<2.2	<0.034	NA	0.58
3817	0.073 ± 0.040	3.8 ± 2.1	<0.040	NA	0.73
3917	0.015 ± 0.013	0.80 ± 0.73	<0.021	<0.0022	0.35
4017	0.031 ± 0.019	1.8 ± 1.1	<0.021	<0.0037	0.31
4117	0.039 ± 0.020	1.8 ± 0.90	<0.020	<0.0024	1.1
4217	0.051 ± 0.022	2.9 ± 1.3	<0.023	0.0054 ± 0.0027	0.56
4317	0.049 ± 0.022	2.6 ± 1.2	<0.023	0.0055 ± 0.0033	0.91
4417	0.025 ± 0.018	1.3 ± 0.94	<0.020	<0.0038	1.2

TABLE A-3. RADIONUCLIDE CONCENTRATIONS IN TRINITY SOIL SAMPLES COLLECTED DURING NOVEMBER 1973 (Continued)

Sample Number	PLUTONIUM-239, 240 Concentration (pCi/g)	PLUTONIUM-239, 240 Deposition (nCi/m^2)	Plutonium-238 Concentration (pCi/g)	Americium-241 Concentration (pCi/g)	Cesium-137 Concentration (pCi/g)
		Profile Samples - See text for coding description			
032N	0.12 ± 0.051	8.5 ± 3.5	<0.026	NA	0.34
032Ø	<0.0094	<0.54	<0.024	NA	0.14
032P	0.12 ± 0.039	6.7 ± 2.1	0.025 ± 0.021	NA	ND
032Q	<0.034	<2.0	<0.050	NA	ND
032R	<0.021	<1.4	<0.019	NA	ND
042N	<0.011	<0.57	<0.024	NA	ND
042Ø	<0.014	<0.98	<0.025	NA	ND
042P	<0.008	<0.58	<0.027	NA	ND
042Q	<0.0074	<0.31	<0.023	NA	ND
102N	<0.0081	<0.40	<0.022	NA	0.25
102Ø	0.057 ± 0.036	2.8 ± 1.8	<0.031	NA	ND
102P	0.034 ± 0.033	1.7 ± 1.7	<0.036	NA	0.072
102Q	<0.012	<0.51	<0.028	NA	0.14
102R	<0.034	<1.7	<0.031	NA	ND
112N	<0.0086	<0.54	<0.025	NA	0.13
112Ø	<0.010	<0.66	<0.021	NA	ND
112P	<0.034	<2.1	<0.049	NA	ND
112Q	<0.013	<0.78	<0.021	NA	0.077
202N	0.30 ± 0.057	21 ± 4.0	0.033 ± 0.020	NA	0.73
202Ø	0.19 ± 0.044	13 ± 3.0	0.025 ± 0.018	NA	0.54
202P	0.079 ± 0.030	5.1 ± 1.9	0.027 ± 0.020	NA	0.080
202Q	0.029 ± 0.020	2.1 ± 1.4	0.020 ± 0.018	NA	0.065
202R	0.030 ± 0.020	2.0 ± 1.3	0.017 ± 0.016	<0.0041	0.064
202S	0.029 ± 0.020	2.2 ± 1.5	<0.016	NA	ND
272N	0.050 ± 0.029	2.8 ± 1.6	0.027 ± 0.023	NA	0.66
272Ø	0.018 ± 0.016	1.0 ± 0.88	0.016 ± 0.015	NA	ND
272P	0.027 ± 0.018	0.98 ± 0.67	0.020 ± 0.017	NA	0.08
272Q	0.051 ± 0.024	1.7 ± 0.79	0.029 ± 0.019	NA	ND
272R	0.054 ± 0.024	1.3 ± 0.57	0.032 ± 0.020	NA	ND
272S	0.024 ± 0.018	0.58 ± 0.44	0.044 ± 0.022	NA	0.095
272T	0.035 ± 0.021	2.0 ± 1.2	0.020 ± 0.017	NA	ND
322N	0.83 ± 0.11	47 ± 6.1	0.056 ± 0.026	NA	2.7
322Ø	0.11 ± 0.033	6.0 ± 1.8	0.017 ± 0.016	NA	0.30
322P	0.035 ± 0.020	2.1 ± 1.2	0.016 ± 0.015	<0.0029	ND
322Q	<0.014	<0.66	<0.014	NA	ND

Notes:
1. Error terms are two-sigma counting error.
2. "<" indicates concentration is less than the stated value.
3. NA indicates no analysis.
4. ND indicates activity was non-detectable.

TABLE A-4. RADIONUCLIDE CONCENTRATIONS IN TRINITY SOIL SAMPLES COLLECTED DURING DECEMBER 1974 (Continued)

Sample Number	PLUTONIUM 239, 240 Concentration (pCi/g) Alpha Spectroscopy	Mass Spectroscopy	Deposition (nCi/m^2)	Atom Ratio Pu-240/Pu-239	Plutonium-238 Concentration (pCi/gm)
	Profile Samples - See text for coding description				
1092A	0.036 ± 0.0036	0.034 ± 0.0044	1.5 ± 0.15	0.070 ± 0.039	Limit
1092B	0.014 ± 0.0016	0.015 ± 0.0014	0.53 ± 0.060	0.104 ± 0.021	0.002 ± 0.0009
1092C	<0.039	<0.001	-	Limit	Limit
1092D	<0.025	<0.0008	-	Limit	Limit
1092E	<0.038	Limit	-	Limit	Limit
1092F	<0.015	<0.023	-	Limit	Limit
1092G	<0.003	Limit	-	Limit	Limit
1092H	<0.009	<0.0003	-	Limit	Limit
1092I	<0.030	<0.002	-	Limit	Limit
1092J	<0.021	<0.002	-	Limit	Limit
1102A	0.010 ± 0.0062	0.0090 ± 0.00095	0.27 ± 0.17	0.084 ± 0.024	Limit
1102B	<0.0090	0.0020 ± 0.00015	0.053± 0.0039		Limit
1152A	1.3 ± 0.11	1.4 ± 0.014	36 ± 3.0	0.025 ± 0.00060	0.072 ± 0.0060
1152B	<0.0050	0.0050 ± 0.00094	0.17 ± 0.031		Limit
1152C	0.255 ± 0.0714	0.268 ± 0.0038	-	0.026 ± 0.0011	Limit
1152D	0.120 ± 0.0432	0.141 ± 0.0107	-	0.029 ± 0.0052	Limit
1152E	0.064 ± 0.0218	0.060 ± 0.0008	-	0.029 ± 0.0017	Limit
1152F	<0.042	<0.018	-		Limit
1152G	0.013 ± 0.0055	<0.016	-		Limit
1152H	<0.006	<0.003	-		Limit
1152I	<0.014	<0.001	-		Limit
1152J	<0.012	<0.007	-		Limit
1182A	0.088 ± 0.015	0.093 ± 0.0032	2.1 ± 0.36	0.035 ± 0.0070	Limit
1182B	0.075 ± 0.0065	0.080 ± 0.0034	2.0 ± 0.17	0.039 ± 0.0086	0.0050± 0.0017
1182C	0.086 ± 0.0138	<0.100	-		Limit
1182D	0.066 ± 0.0172	<0.081	-		Limit
1182E	<0.010	<0.002	-		Limit
1182F	<0.010	Limit	-		Limit
1182G	<0.017	Limit	-		Limit
1182H	<0.013	Limit	-		Limit
1182I	<0.027	Limit	-		Limit
1182J	<0.008	Limit	-		Limit
1522A	0.0070± 0.0031	0.0090 ± 0.00067	0.19 ± 0.083	0.119 ± 0.021	Limit
1522B	1.2 ± 0.11	1.3 ± 0.015	39 ± 3.6	0.025 ± 0.00065	0.073 ± 0.0085
1522C	<0.019	Limit	-		Limit
1522D	<0.012	Limit	-		Limit
1522E	<0.024	Limit	-		Limit
1522F	<0.015	Limit	-		Limit
1522G	<0.007	Limit	-		Limit
1522H	<0.005	Limit	-		Limit
1522I	<0.006	Limit	-		Limit

Analysis Codes:
1. Error terms are two-sigma counting error.
2. "Limit" indicates activity was below limit of detection.
3. "<" indicates concentration is less than the stated value.

TABLE A-4. RADIONUCLIDE CONCENTRATIONS IN TRINITY SOIL SAMPLES COLLECTED DURING DECEMBER 1974

Sample Number	PLUTONIUM 239, 240 Concentration (pCi/g) Alpha Spectroscopy	PLUTONIUM 239, 240 Concentration (pCi/g) Mass Spectroscopy	PLUTONIUM 239, 240 Deposition (nCi/m^2)	Atom Ratio Pu-240/Pu-239	Plutonium-238 Concentration (pCi/g)
	Surface Samples - See text for coding description				
10017	<0.023	0.007 ± 0.0013	0.56 ± 0.10	Limit	Limit
10117	0.011 ± 0.0077	Limit	0.93 ± 0.65	Limit	Limit
10217	<0.034	0.008 ± 0.003	0.61 ± 0.23	0.175 ± 0.12	Limit
10317	<0.021	0.008 ± 0.00082	0.42 ± 0.043	0.177 ± 0.039	Limit
10417	<0.056	0.009 ± 0.002	0.56 ± 0.12	Limit	Limit
10517	<0.021	0.025 ± 0.013	1.9 ± 0.93	Limit	Limit
10617	0.015 ± 0.0060	0.011 ± 0.00055	1.1 ± 0.44	0.135 ± 0.015	Limit
10717	0.077 ± 0.0099	0.084 ± 0.0024	4.6 ± 0.59	0.053 ± 0.0046	Limit
10817	<0.012	Limit	<0.76		Limit
11117	0.096 ± 0.050	0.095 ± 0.0072	6.1 ± 3.2	0.076 ± 0.018	Limit
11217	0.013 ± 0.0073	0.019 ± 0.014	0.91 ± 0.51	Limit	Limit
11317	0.15 ± 0.016	0.15 ± 0.0034	9.1 ± 0.93	0.043 ± 0.0032	Limit
11417	0.53 ± 0.038	0.53 ± 0.013	28 ± 2.0	0.028 ± 0.0024	0.028 ± 0.0032
11617	0.38 ± 0.047	0.44 ± 0.016	29 ± 3.5	0.036 ± 0.0086	0.049 ± 0.015
11717	0.068 ± 0.0082	0.074 ± 0.0066	4.5 ± 0.27	0.047 ± 0.021	Limit
11917	14 ± 1.8	15 ± 0.22	1100 ±130	0.025 ± 0.00030	0.80 ± 0.11
12017	0.004 ± 0.0026	0.0060± 0.00067	0.31 ± 0.20	0.165 ± 0.043	Limit
12117	1.3 ± 0.21	1.4 ± 0.019	110 ±17	0.023 ± 0.0012	0.079 ± 0.019
12217	0.022 ± 0.011	Limit	1.8 ± 0.87	Limit	Limit
12317	0.015 ± 0.0030	0.017 ± 0.0095	1.2 ± 0.24	0.153 ± 0.077	0.005 ± 0.0027
12417	0.013 ± 0.0057	0.014 ± 0.00070	1.1 ± 0.48	0.133 ± 0.015	Limit
15017	0.52 ± 0.071	0.47 ± 0.013	32 ± 4.3	0.026 ± 0.0028	0.027 ± 0.0070
15117	0.24 ± 0.023	0.23 ± 0.0046	17 ± 1.6	0.032 ± 0.0021	0.025 ± 0.0055
15317	0.017 ± 0.0095	0.021 ± 0.0011	1.1 ± 0.62	0.127 ± 0.018	Limit
15417	0.38 ± 0.092	0.34 ± 0.020	27 ± 6.5	0.042 ± 0.0081	Limit
15517	0.022 ± 0.0048	0.029 ± 0.0015	1.7 ± 0.38	0.114 ± 0.015	Limit
15617	0.29 ± 0.071	0.29 ± 0.0047	25 ± 5.9	0.038 ± 0.0024	Limit
15717	0.17 ± 0.030	0.18 ± 0.014	12 ± 2.1	0.049 ± 0.0094	Limit
15817	0.14 ± 0.020	0.19 ± 0.015	10 ± 1.4	0.075 ± 0.024	Limit
15917	0.18 ± 0.035	0.16 ± 0.0065	12 ± 2.4	0.031 ± 0.0062	Limit
16017	0.60 ± 0.16	0.52 ± 0.010	48 ±12	0.028 ± 0.0015	0.034 ± 0.016
16117	0.10 ± 0.022	0.12 ± 0.0097	6.1 ± 1.3	0.027 ± 0.014	Limit
16217	0.25 ± 0.081	0.24 ± 0.019	20 ± 6.3	0.048 ± 0.014	0.072 ± 0.035
16317	0.11 ± 0.012	0.12 ± 0.0030	8.6 ± 0.96	0.031 ± 0.0045	0.0070± 0.0025
16416	0.63 ± 0.33	1.0 ± 0.010	28 ±15	0.027 ± 0.00043	Limit
16516	1.2 ± 0.42	1.3 ± 0.038	45 ±15	0.037 ± 0.0033	Limit
16616	0.30 ± 0.065	0.29 ± 0.0059	8.0 ± 1.8	0.027 ± 0.0015	Limit
16716	2.8 ± 0.73	3.2 ± 0.038	86 ±22	0.025 ± 0.0011	0.16 ± 0.062
16916	1.5 ± 0.26	1.6 ± 0.054	42 ± 7.2	0.032 ± 0.0062	0.098 ± 0.033

TABLE A-5. AIRBORNE PLUTONIUM CONCENTRATIONS AT SOCORRO DURING 1975

Date On	Date Off	Plutonium-239,240 (aCi/m^3)	Plutonium-238 (aCi/m^3)	Analysis Code
Feb 4	Feb 12	37 ± 8.2	<5.0	1
Feb 12	Feb 18	71 ± 11	<6.3	1
Feb 18	Feb 25	64 ± 19	<14	1
Feb 25	Mar 3	37 ± 3.7	1.9 ± 0.84	2
Mar 3	Mar 11	88 ± 5.3	2.3 ± 0.86	2
Mar 11	Mar 17	66 ± 4.9	3.9 ± 1.2	2
Mar 17	Mar 24	62 ± 4.4	2.9 ± 0.96	2
Mar 24	Apr 1	78 ± 5.1	3.7 ± 1.1	2
Apr 1	Apr 8	80 ± 5.3	ND	2
Apr 8	Apr 15	62 ± 4.3	1.6 ± 0.67	2
Apr 15	Apr 22	52 ± 4.1	2.5 ± 0.90	2
Apr 22	Apr 29	67 ± 4.8	ND	2
Apr 29	May 6	75 ± 6.4	2.3 ± 1.1	2
May 6	May 13	89 ± 7.5	1.5 ± 0.96	2
May 13	May 20	48 ± 5.2	1.9 ± 1.0	2
May 20	May 26	60 ± 6.1	ND	2
May 26	Jun 3	35 ± 3.2	1.3 ± 0.61	2
Jun 3	Jun 10	32 ± 3.2	ND	2
Jun 10	Jun 17	36 ± 3.3	2.1 ± 0.81	2
Jun 17	Jun 24	34 ± 4.1	3.4 ± 1.3	2
Jun 24	Jun 30	33 ± 4.2	1.1 ± 0.77	2
Jun 30	Jul 8	14 ± 2.5	15 ± 2.5	2
Jul 8	Jul 16	8.7± 2.1	ND	2
Jul 16	Jul 22	10 ± 1.9	0.70± 0.50	2
Jul 22	Jul 29	17 ± 2.3	0.62± 0.44	2
Jul 29	Aug 5	8.8± 1.7	1.1 ± 0.60	2
Aug 5	Aug 12	NA	NA	1
Aug 12	Aug 19	NA	NA	1
Aug 19	Aug 26	NA	NA	1
Aug 26	Sep 2	NA	NA	1
Sep 2	Sep 9	230 ±200	160 ± 94	1
Sep 9	Sep 16	<6.0	<2.0	3
Sep 16	Sep 23	2.14± 0.317	NA	4
Sep 23	Sep 30	10 ± 7.0	<2.0	3
Sep 30	Oct 7	<14	25 ± 12	3
Oct 7	Oct 16	< 6.0	<2.0	3
Oct 16	Oct 22	< 2.0	<2.0	3
Oct 22	Oct 28	22 ± 10	9.0 ± 6.0	3
Oct 28	Nov 4	< 2.0	<2.0	3
Nov 4	Nov 10	20 ± 15	26 ± 18	3
Nov 10	Nov 18	ND	NA	4
Nov 18	Nov 25	7.40 ± 2.07	NA	4
Nov 25	Dec 2	ND	NA	4

Analysis Codes:
1. Total analysis by EMSL-LV
2. Chemistry and electroplating by EMSL-LV; alpha spectroscopy by Mound Laboratory
3. Total analysis by Eberline Instrument Corporation
4. Total analysis by McClellan Central Laboratory using mass spectroscopy

NA = no analysis
ND = non-detectable

TABLE A-6. AIRBORNE PLUTONIUM CONCENTRATIONS AT MONTE PRIETO RANCH DURING 1975

Date On	Date Off	Plutonium-239,240 (aCi/m^3)	Plutonium-238 (aCi/m^3)	Analysis Code
Feb 11	Feb 17	96 ± 21	<13	1
Feb 17	Feb 24	60 ± 4.3	3.3 ± 1.0	2
Feb 24	Mar 3	38 ± 3.6	12 ± 2.0	2
Mar 3	Mar 10	92 ± 5.6	7.3 ± 1.6	2
Mar 10	Mar 17	65 ± 4.7	2.2 ± 0.86	2
Mar 17	Mar 23	54 ± 4.4	4.7 ± 1.3	2
Mar 23	Mar 29	88 ± 5.8	2.5 ± 0.97	2
Mar 29	Apr 4	78 ± 5.0	3.5 ± 1.1	2
Apr 4	Apr 11	49 ± 3.8	3.8 ± 1.1	2
Apr 11	Apr 18	51 ± 4.0	0.62 ± 0.44	2
Apr 18	Apr 25	60 ± 4.2	2.5 ± 0.85	2
Apr 25	May 2	63 ± 5.9	2.5 ± 1.2	2
May 2	May 8	81 ± 7.2	ND	2
May 8	May 15	70 ± 6.4	22 ± 3.5	2
May 15	May 23	54 ± 3.6	1.8 ± 0.67	2
May 23	May 31	43 ± 3.5	0.94 ± 0.51	2
May 31	Jun 6	28 ± 2.9	0.95 ± 0.54	2
Jun 6	Jun 12	40 ± 3.8	1.5 ± 0.73	2
Jun 12	Jun 19	34 ± 3.2	1.5 ± 0.68	2
Jun 19	Jun 25	34 ± 4.4	ND	2
Jun 25	Jul 4	23 ± 3.0	3.2 ± 1.1	2
Jul 4	Jul 10	18 ± 3.3	1.5 ± 0.95	2
Jul 10	Jul 16	15 ± 2.4	0.69 ± 0.51	2
Jul 16	Jul 24	11 ± 1.7	ND	2
Jul 24	Jul 30	7.6± 1.6	ND	2
Jul 30	Aug 5	NA	NA	1
Aug 5	Aug 12	NA	NA	1
Aug 12	Aug 18	NA	NA	1
Aug 18	Aug 25	NA	NA	1
Aug 25	Aug 31	NA	NA	1
Aug 31	Sep 8	42 ± 18	<2.0	3
Sep 8	Sep 15	<6.0	<2.0	3
Sep 15	Sep 21	20 ± 14	<2.0	3
Sep 21	Sep 28	<18	<2.0	3
Sep 28	Oct 6	15 ± 8.0	<4.0	3
Oct 6	Oct 15	No sample due to broken sampler		
Oct 15	Oct 22	18 ± 13	<2.0	3
Oct 22	Oct 31	38 ± 16	<4.0	3
Oct 31	Nov 4	14.7± 1.29	NA	4
Nov 4	Nov 11	9.11± 1.02	NA	4
Nov 11	Nov 20	12.1± 2.66	NA	4
Nov 20	Dec 2	3.35± 0.30	NA	4
Dec 2	Dec 15	4.25± 0.38	NA	4

Analysis Codes:
1. Total analysis EMSL-LV
2. Chemistry and electroplating by EMSL-LV; alpha spectroscopy by Mound Laboratory
3. Total analysis by Eberline Instrument Corporation
4. Total analysis by McClellan Central Laboratory using mass spectroscopy

NA = no analysis
ND = non-detectable

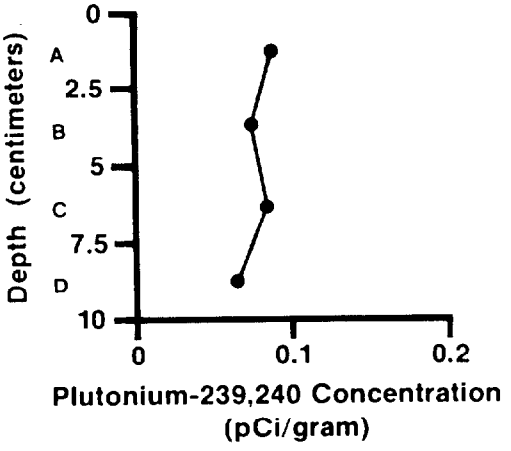

Figure A-1. Depth Profile for Sample #118

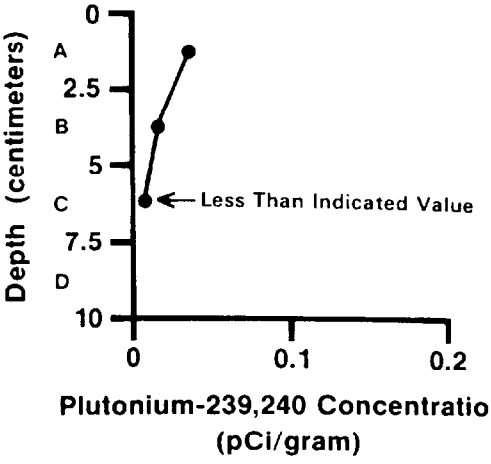

Figure A-2. Depth Profile for Sample #109

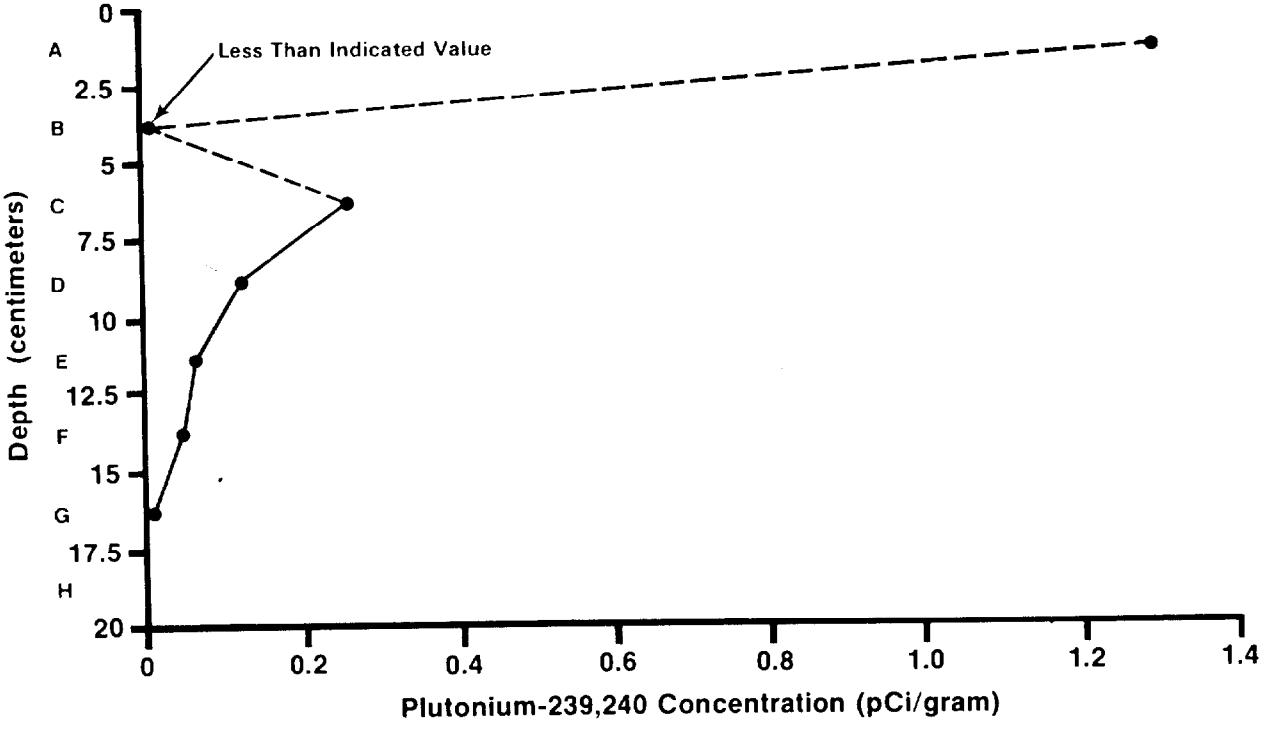

Figure A-3. Depth Profile for Sample #115

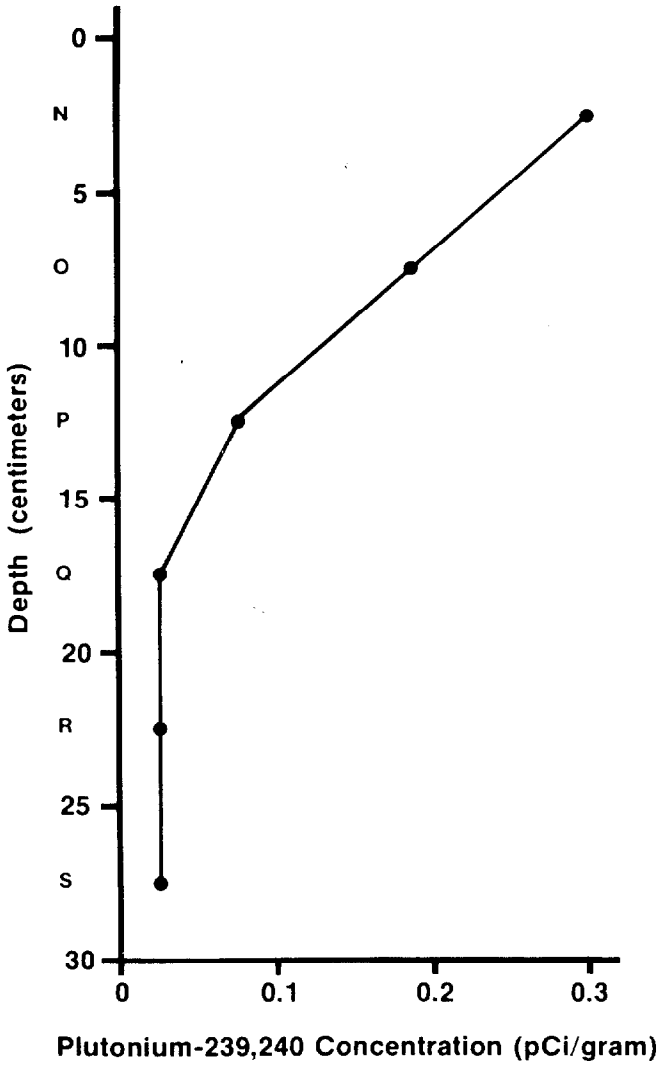

Figure A-4. Depth Profile for Sample #20

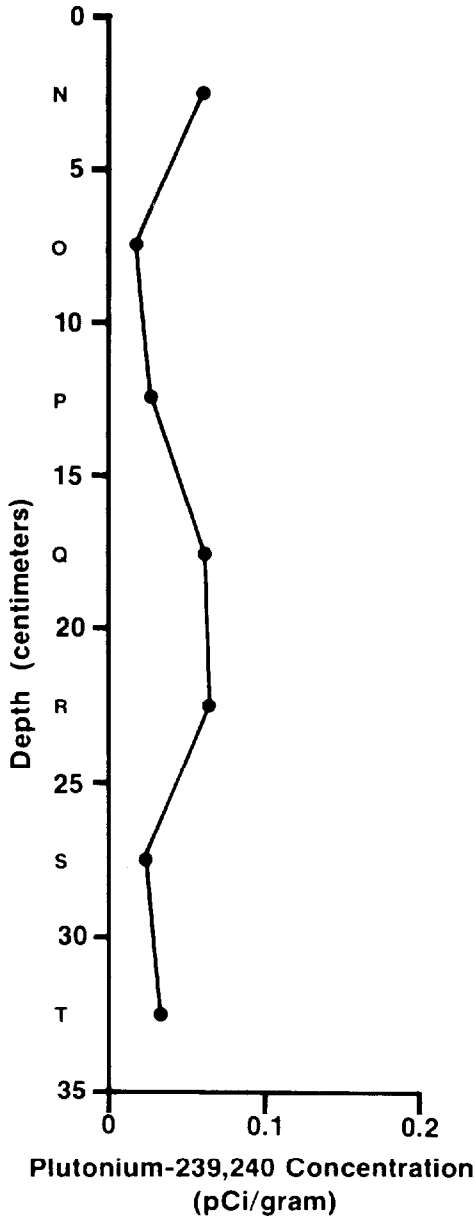

Figure A-5. Depth Profile for Sample #27

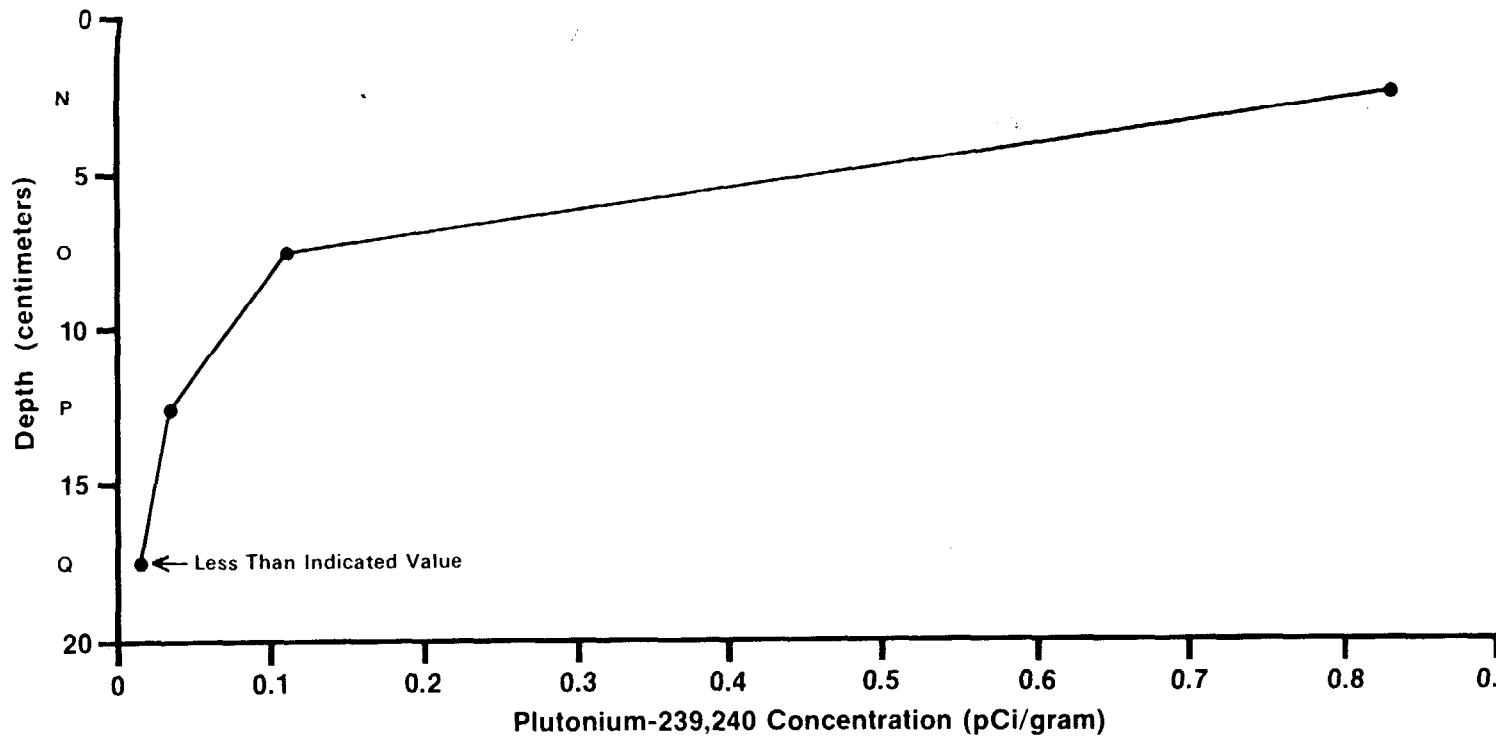

Figure A-6. Depth Profile for Sample #32

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
ORP/LV-78-3		

4. TITLE AND SUBTITLE	5. REPORT DATE
Levels and Distribution of Environmental Plutonium Around the Trinity Site	October 1978
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Richard L. Douglas	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
U.S. Environmental Protection Agency Office of Radiation Programs-Las Vegas Facility P. O. Box 15027 Las Vegas, NV 89114	11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Same as above	Final
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A study was conducted in central New Mexico to evaluate the levels and distribution of plutonium resulting from the detonation of the Trinity device in 1945. A total of 88 soil samples were collected, covering an area of roughly 4500 square miles. Air samples were collected during 1975 at a location within the Trinity fallout pattern, and at another site outside the pattern. All samples were analyzed for plutonium-239,240 by alpha spectroscopy, and some were analyzed by mass spectroscopy for both nuclides. Trinity plutonium can be distinguished from global fallout plutonium by the ratio of the two plutonium nuclides. The results indicate that most of the area sampled contains detectable amounts of Trinity plutonium in the surface 5 cm of soil. The highest levels of plutonium-239,240 deposition in soil (in unrestricted areas) were on the order of 90 nCi/m^2. The air samples at the site within the fallout pattern contained about 50 percent Trinity plutonium, but the average concentration of airborne plutonium at the two locations was the same.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Plutonium	Trinity	0702
Plutonium-239	Environmental plutonium	1802

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to public	Unclassified	51
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	