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Inorganic and Radionuclide Background Data for Soils, Canyon Sediments, and Bandelier Tuff at Los Alamos National Laboratory

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Abstract

This report summarizes the background data collected for soils, canyon sediments, and Bandelier Tuff in the area of Los Alamos National Laboratory. These data are used in the Resource Conservation and Recovery Act corrective action process to distinguish between contaminated and uncontaminated media and to establish cleanup levels for sites scheduled for remediation. This report ~~describes~~ summarizes the sample locations; the techniques used for sample collection, preparation, and analysis; and the summary statistics, including the upper tolerance limit for each analyte. The BVs are summarized in tables at the end of the document, and the complete background data are presented in graphs in Appendix A.

Explode?

Background values (BVs) are used as simple threshold numbers to identify potentially contaminated site sample results as greater than background. BVs are either upper tolerance of background sample results or detection limits.

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1.0 INTRODUCTION

Los Alamos National Laboratory (LANL or "the Laboratory") has been in operation for over 55 years. To determine the impact of Laboratory operations on surface water, groundwater, soil, sediment, and bedrock, it is necessary to understand the background chemistry of the area's geological and hydrological media. The Resource Conservation and Recovery Act (RCRA) *Risk-Based Decision Tree* developed by the New Mexico Environment Department (NMED) requires that accurate natural background levels be developed (NMED 1998, ER ID 57761). Accurate natural background levels are necessary to (1) distinguish between contaminated and uncontaminated media, (2) establish cleanup levels for sites scheduled for remediation, (3) develop sampling and remediation strategies, and (4) understand the processes controlling contaminant transport. Background levels are defined as the naturally occurring concentrations of inorganic chemicals (including naturally occurring radionuclides) in the area upgradient or upwind from a site (that is, background levels are the concentrations that occurred prior to industrial or hazardous waste operations) (NMED 1998, ER ID 57761). For anthropogenic radionuclides, fallout values derived from sources unrelated to facility activities are considered baseline levels (NMED 1998, ER ID 57761). These background levels and fallout values are ~~the basis for the statistical analysis used to~~ used in the data review that support risk management decisions in the Laboratory's Environmental Restoration (ER) Project.

During the past five years, the Laboratory has conducted extensive analyses to address the nature and variability of background levels of inorganic chemicals and radionuclides for a variety of soil profiles, sediment types, and identified geological subdivisions of the Bandelier Tuff. This report summarizes the results from these studies. Background levels for soils are addressed in "Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles" (Longmire et al. 1995, ER ID 52227); "Natural Background Geochemistry, Geomorphology, and Pedogenesis of Selected Soil Profiles and Bandelier Tuff" (Longmire et al. 1996, ER ID 55115); and "Baseline Data for Fallout Radionuclides at LANL" (Campbell 1998, ER ID 57858). Section 3.0 of this report summarizes these studies, including (1) sample locations and descriptions; (2) the analytical methods used to determine background analyte distributions; (3) the relationship among trace-element background levels, soil chemistry, and the degree of soil development (pedogenesis); and (4) statistical data summaries. The background geochemistry of canyon sediments is presented in "Geochemistry of Background Sediment Samples at Technical Area 39" (Reneau et al. 1995, ER ID 52227) and "Natural Background Geochemistry of Sediments" (McDonald et al. 1997, ER ID 55532). Section 4.0 of this report summarizes these studies, including (1) sampling locations, (2) analytical methods, (3) differences in background levels among various canyons,

2.0 STATISTICAL DATA TREATMENT

Several data preparation steps are needed before statistical calculations can be performed on the background data. First, the data must be inspected for suspect values that are exceptionally high or low relative to the rest of the data. Second, the data must be evaluated to determine whether the background data for each medium, or medium subunit, are derived from a single population. This can be demonstrated by fitting the background data to a standard statistical distribution (e.g., normal, square-root normal, or lognormal). Appendix A shows the fit of the background data to a normal statistical distribution. For further information on data transformations used for statistical distribution analysis, refer to *An Analysis of Transformations* (Box and Cox 1964, ER ID 57572) or Appendix C of *Introduction to Variance Estimation* (Wolter 1985, ER ID 57573).

For inorganic chemicals and some radionuclides, some data were reported as nondetected values. Nondetected values were typically reported as less than ("<") the method detection limit for that chemical. Values that were reported as nondetected by the laboratory were replaced by one-half of the detection limit value to calculate summary statistics. This replacement method is recommended by the Environmental Protection Agency (EPA) when the frequency of nondetected values is relatively low (EPA 1992, ER ID 54947).

The upper tolerance limit (UTL) is a simple measure of the upper end of the background distribution. UTL values for the background data are calculated in one of four ways based on the statistical distribution of the data. These four calculations are described below.

For analytes that are normally distributed without any data transformation, UTL values are calculated using Equation 2.0-1. The k-factor is dependent on the number of background samples with k-factor values increasing as sample size decreases (Gilbert 1987, ER ID 56179; EPA 1989, ER ID 54946).

$$\mathrm{UTL}_{0.95,0.95} = \text{mean} + \text{standard deviation} \times k_{0.95,0.95} \qquad \textbf{(Equation 2.0-1)}$$

For analytes that are normally distributed after a square root transformation, the mean and standard deviation of the square-root transformed data are used in Equation 2.0-2:

$$\mathrm{UTL}_{0.95,0.95} = \left(\text{mean} + \text{standard deviation} \times k_{0.95,0.95}\right)^2 \qquad \textbf{(Equation 2.0-2)}$$

The UTL values for lognormally distributed elements are estimated by a first-order Monte Carlo simulation process (Longmire et al. 1995, ER ID 52227; Longmire et al. 1996, ER ID 55115). This simulation process uses the lognormal distribution function in the S-plus statistical programming

concentrations using two types of sample digestion techniques as described below in Section 3.1.2.

3.1.1 Sample Locations

Twenty-one soil profiles distributed across the Pajarito Plateau were described in the field and were sampled for inorganic chemical analyses (see Table 3.1-1 and Figure 3.1-1). These samples provide information about the varied soils and geomorphic settings that occur on the Pajarito Plateau, allowing for an evaluation of the variability in soil characteristics and chemistry within several of the soil series previously described by Nyhan et al. (1978, ER ID 05702). Most sampled soils were collected from mesa tops. Other geomorphic settings sampled include hillslopes and canyon bottoms (Table 3.1-1).

Soils were described using standard terminology and techniques (see Soil Conservation Survey 1981, ER ID XXXXX). The depths of the individual soil horizons sampled varied among soils, but all soils were continuously sampled from the surface to the base of the profile (depths varied from 25 cm to 394 cm below ground surface).

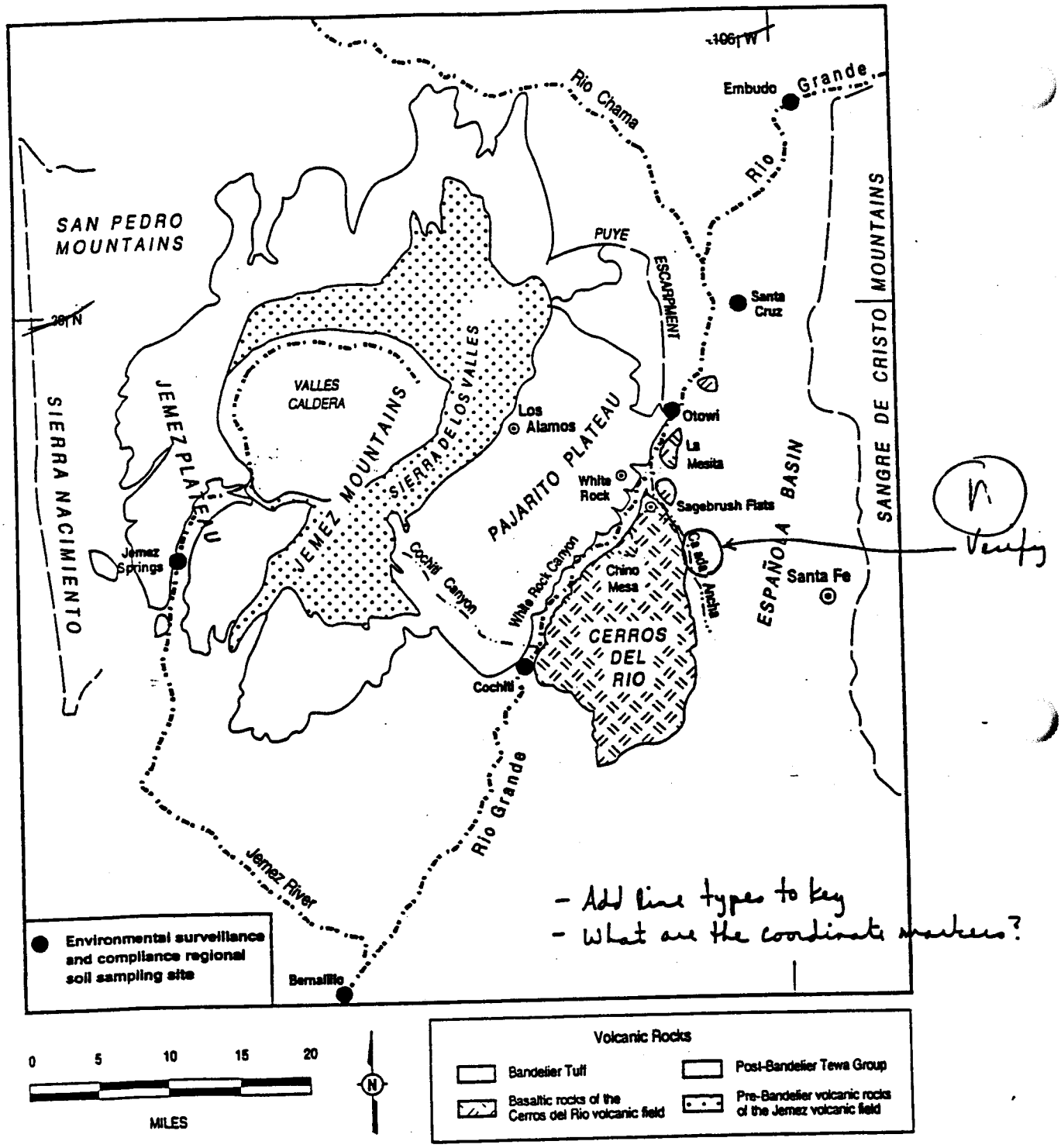

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Figure 3.3-1 Regional Environmental Surveillance Program sample locations.

UTL

used for antimony; only the ICPMS data are used to calculate the soil BV for antimony because they provide a lower detection limit.

TABLE 3.1-2
SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL TECHNIQUES FOR INORGANIC CHEMICALS IN SOIL

Analyte	Sample Preparation Technique	Analytical Technique
Aluminum	3050A[a]	ICPES[b]
Antimony	3050A	ICPES/ICPMS[c]
Arsenic	3050A	GFAA[d]
Barium	3050A	ICPES
Beryllium	3050A	ICPES
Cadmium	3050A	ICPES
Calcium	3050A	ICPES
Chloride	Leach[e]	IC[f]
Chromium	3050A	ICPES
Cobalt	3050A	ICPES
Copper	3050A	ICPES
Iron	3050A	ICPES
Lead	3050A	ICPES
Magnesium	3050A	ICPES
Manganese	3050A	ICPES
Mercury	7471[g]	CVAA[h]
Nickel	3050A	ICPES
Potassium	3050A	ICPES
Selenium	3050A	GFAA
Sodium	3050A	ICPES
Sulfate	Leach	IC
Tantalum	3050A	ICPMS
Thallium	3050A	ICPMS
Thorium	3050A	ICPMS
Uranium	3050A	ICPMS
Vanadium	3050A	ICPES
Zinc	3050A	ICPES

a. 3050A = EPA SW-846 Method 3050A.
b. ICPES = Inductively coupled plasma emission spectroscopy.
c. ICPMS = Inductively coupled plasma mass spectrometry.
d. GFAA = Graphite furnace atomic absorption spectroscopy.
e. Leach = Deionized water leach.
f. IC = Ion chromatography.
g. 7471 = EPA SW-846 Method 7471.
h. CVAA = Cold vapor atomic absorption spectroscopy.

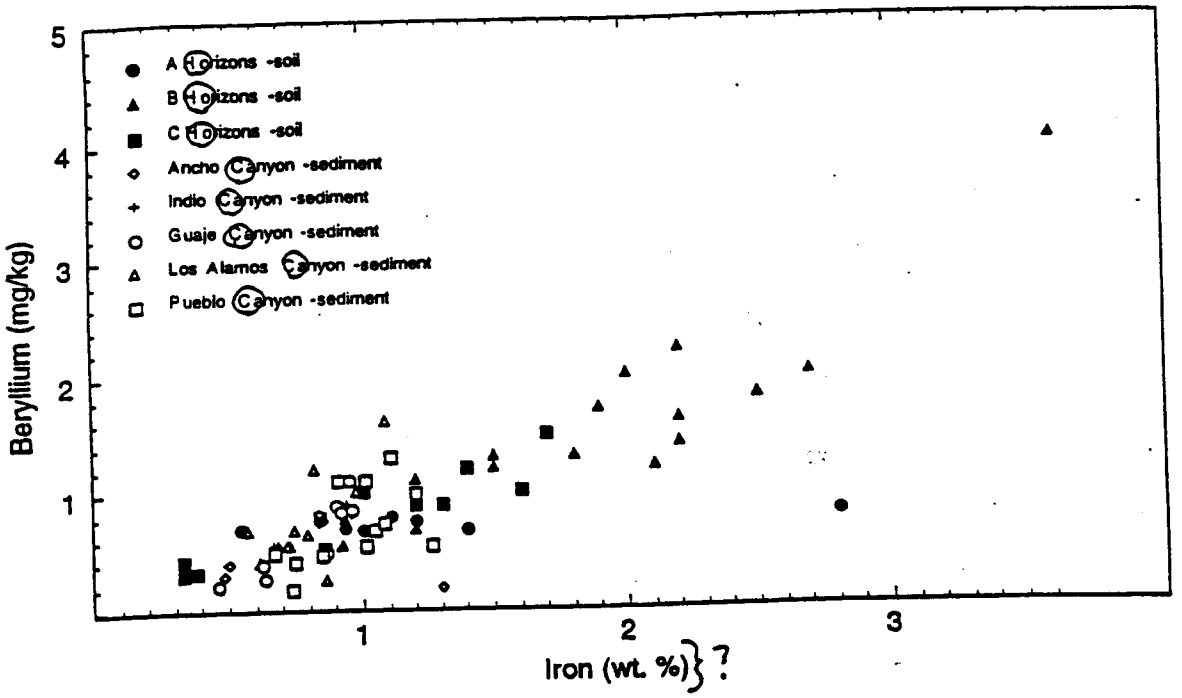


Fig. 3.1-2 **HNO_3 extractable iron concentrations versus HNO_3 extractable beryllium concentrations in background soils in Los Alamos, New Mexico.**

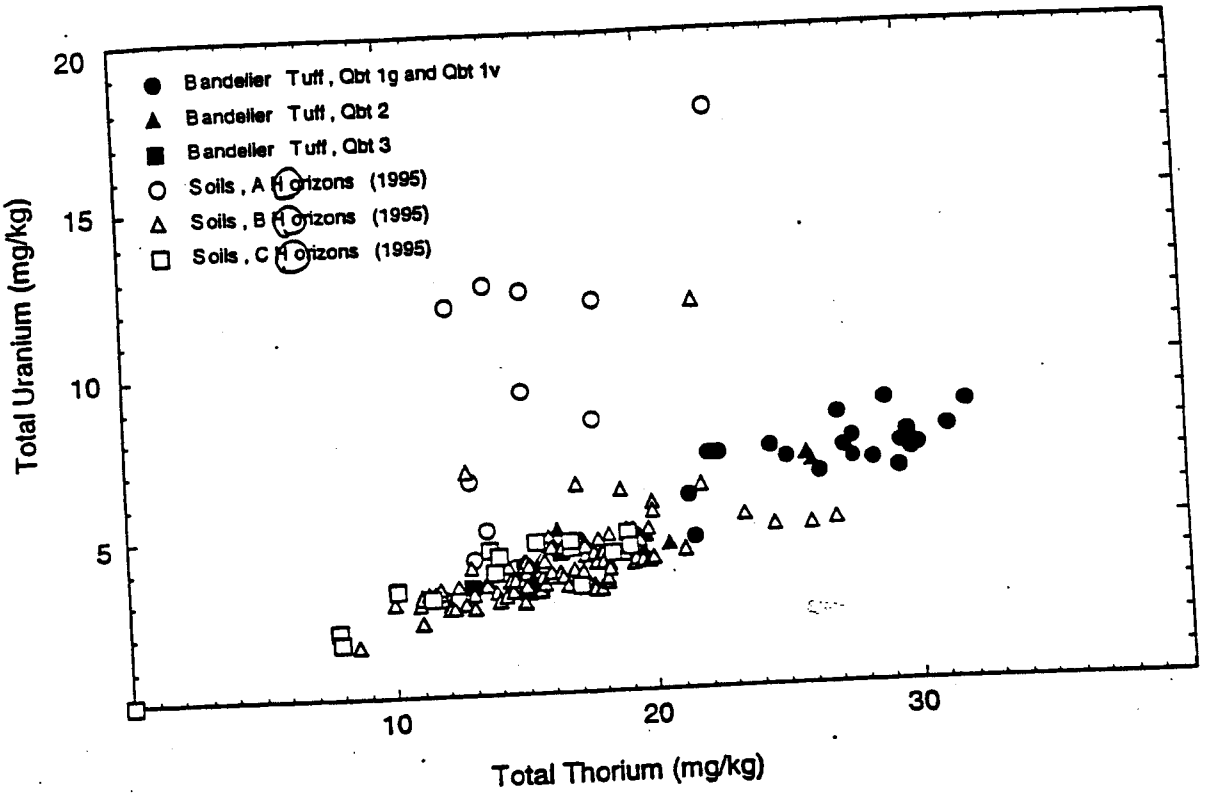


Fig. 3.1-3 Total (HF-extractable) thorium concentrations versus total uranium concentrations in Bandelier Tuff and background soils in Los Alamos New Mexico.

Add to figure: "Anomalous high val of uranium in some A or B horizo samples were excluded from the background data."

3.2 Naturally Occurring Radionuclides

UTL values are provided for total thorium and total uranium in Table 3.2-1 to provide a metric of the mass concentration of the naturally occurring radionuclides. It is important to note that total thorium and total uranium have unique analyte names to distinguish these measurements from the standard thorium and uranium results reported in Table 3.1-3.

There were no isotopic data collected for the soil samples discussed in Section 3.1. Isotopic activity could be estimated from total thorium and total uranium mass (concentration in mg/kg) data. However, less uncertainty is introduced into the assessment of potential radionuclide releases by using the sediment isotopic data as surrogate data for the soils. The rationale for using the sediment data is the similar mineralogy and chemical composition of the A and C soil horizons compared to the canyon sediments. This concept is discussed more completely in Section 4.0.

TABLE 3.2-1
SUMMARY STATISTICS FOR
NATURALLY OCCURRING RADIONUCLIDES IN SOIL[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Total Thorium	171	171	7.8	16	27.15	16.1	3.21	22.4
Total Uranium	160	160	1.7	3.7	6.728	3.80	0.818	5.40

a. Units are mg/kg.

3.3 Fallout Radionuclides

Campbell (1998, ER ID 57858) provides information on the activities of six radionuclides associated with atmospheric fallout (tritium, strontium-90, cesium-137, plutonium-238, plutonium-239,240, and americium-241). These data are collected annually by the Laboratory's Environmental Surveillance Program (ESP) to monitor environmental conditions associated with Laboratory operations.

3.3.1 Sample Locations

Sample locations for fallout radionuclides fall into three categories. First are locations near active Laboratory operations. Because of their proximity to Laboratory operations, these locations are excluded from the data set. Second are locations at the perimeter of the current and historic

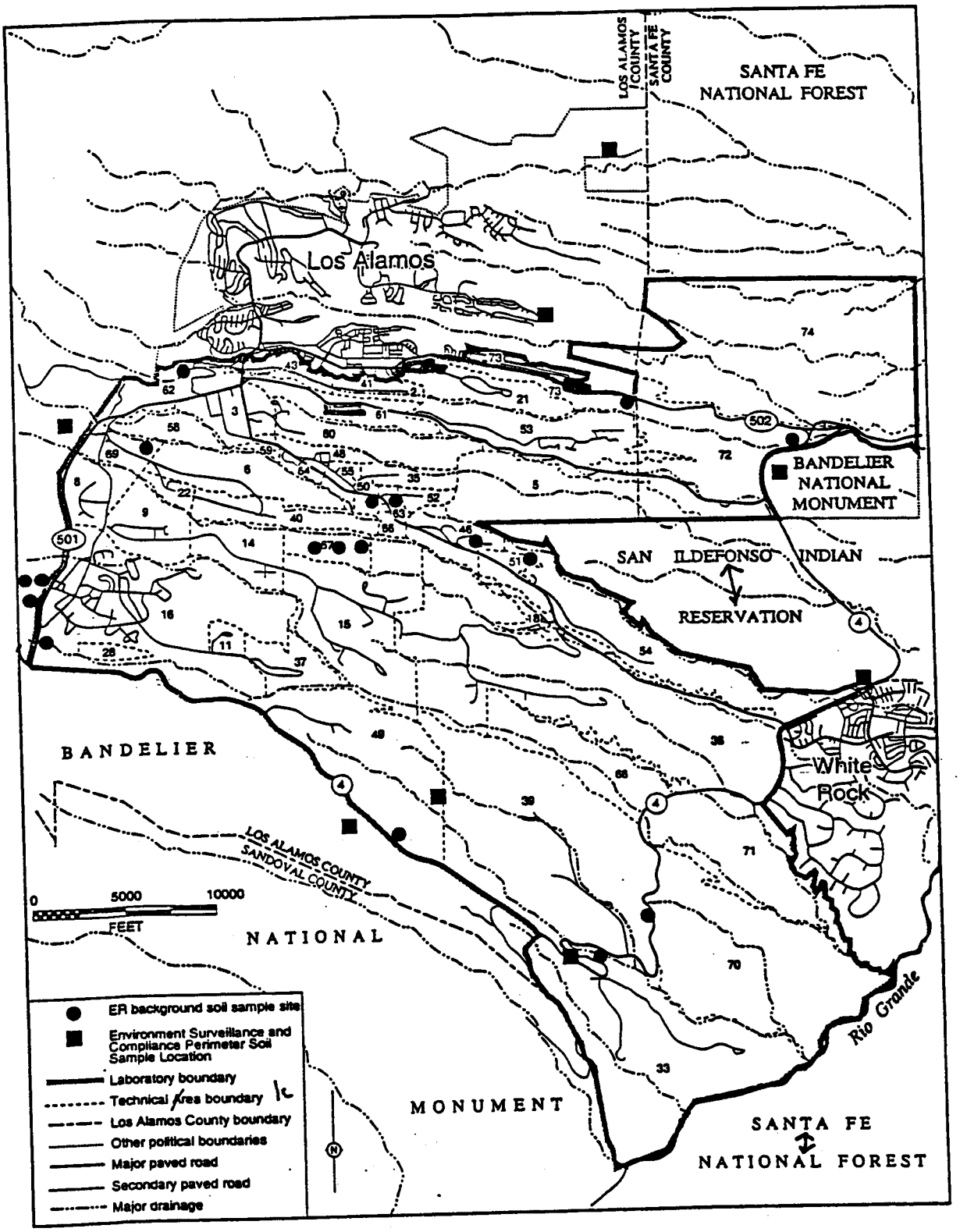


Figure 3.1-1 Distribution of soil sample sites and Environmental Surveillance Program perimeter sample locations at Los Alamos National Laboratory.

TABLE 3.3-2
SUMMARY STATISTICS FOR FALLOUT RADIONUCLIDES IN SURFACE SOIL[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Americium-241	27	27	0.001	0.007	0.013	0.0064	0.0031	0.013
Cesium-137	56	54	0.03	0.3	1.7	0.42	0.41	1.65
Plutonium-238	56	52	0.001	0.004	0.037	0.0054	0.0060	0.023
Plutonium-239,240	56	56	0.001	0.012	0.055	0.015	0.013	0.054
Strontium-90	42	39	0.1	0.3	1.1	0.36	0.30	1.31
Tritium (pCi/mL)	51	35	0.1	0.1	0.9	0.185	0.189	0.766

a. Units are pCi/g unless noted otherwise.

4.0 CANYON SEDIMENT BACKGROUND

This section presents the background data for inorganic chemicals and radionuclides in canyon sediments. For simplicity, the term "sediment" in this report refers to young alluvium in or near stream channels, although in actuality these sediments are a type of soil that has experienced relatively little soil development. The sampled sediments would generally be considered as C or A horizons in soil nomenclature. The master C horizon is a soil horizon that includes primary parent material, and thus, by definition, includes young sediment that has not been subjected to soil-forming processes (Birkeland 1984, ER ID 44019). It also includes material subject to only small degrees of post-depositional weathering and pedogenic alteration. The master A horizon is characterized by the accumulation of humified organic matter mixed with mineral fraction, with the latter being dominant (Birkeland 1984, ER ID 44019). By definition, the master A horizon thus includes young sediments which have been colonized by plants and subjected to the addition of organic matter (humified material). The master C horizon contains less than a 50% volume of humified material (Birkeland 1984, ER ID 44019). The master C horizon is a subsurface horizon different from an A horizon and includes materials in various stages of weathering (Birkeland 1984, ER ID 44019). A bivariate plot of iron versus beryllium (Figure 3.1-2) shows that the background sediments and the A and C horizons are chemically similar and distinct from B horizons that contain higher contents of clay minerals and ferric oxyhydroxides.

Sediment background information and data for inorganic chemicals and radionuclides is derived from two sources. First, "Geochemistry of Background Sediment Samples at Technical Area 39" (Reneau et al. 1995, ER ID 52227) addresses samples collected from Indio and Ancho Canyons.

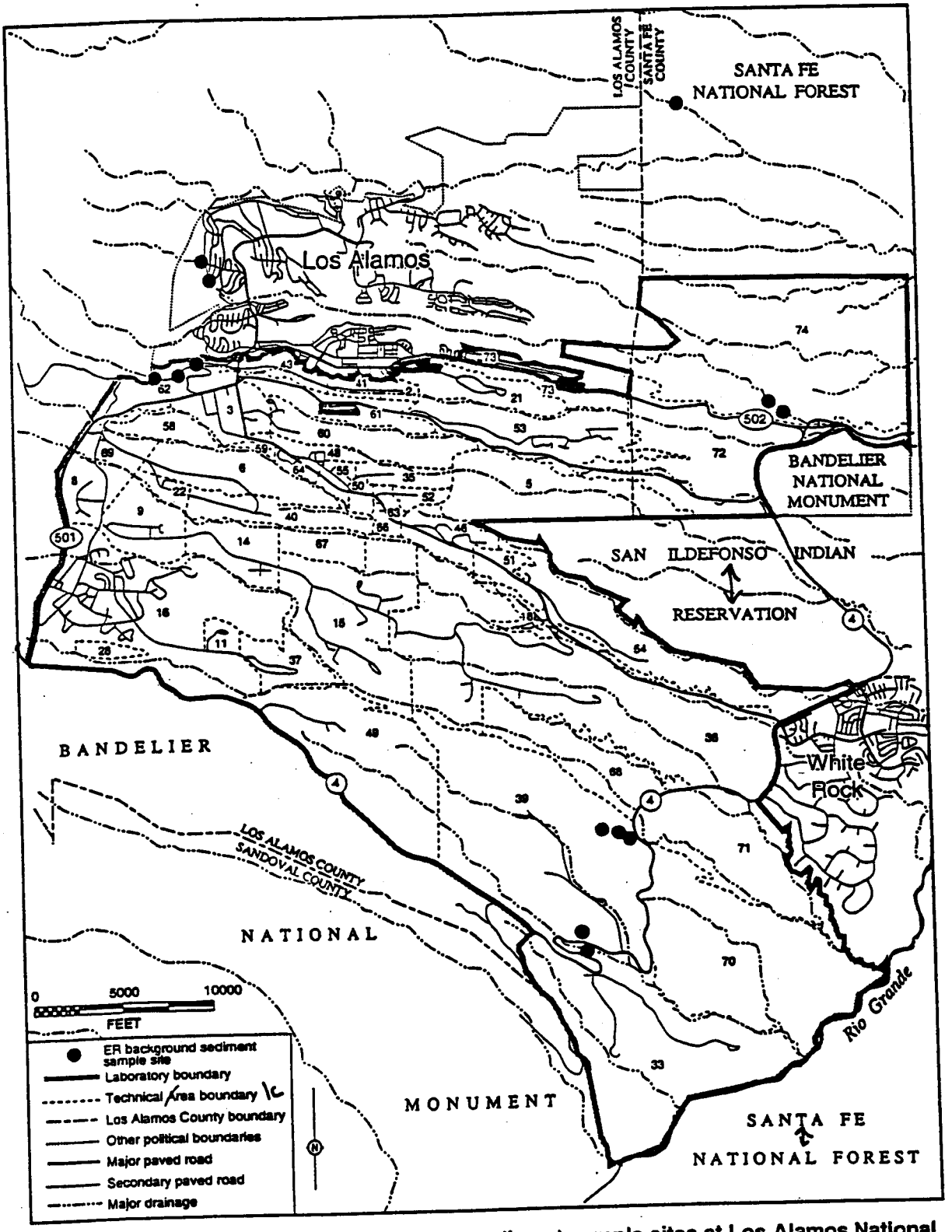


Figure 4.1-1 Distribution of background sediment sample sites at Los Alamos National Laboratory.

TABLE 4.2-1
SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL TECHNIQUES FOR INORGANIC CHEMICALS IN CANYON SEDIMENTS

Analyte	Sample Preparation Technique	Analytical Technique
Aluminum	3050A[a]	ICPES[b]
Antimony	3050A	ICPES
Arsenic	3050A	GFAA[c]/ICPES
Barium	3050A	ICPES
Beryllium	3050A	ICPES
Cadmium	3050A	ICPES
Calcium	3050A	ICPES
Chloride	Leach[d]	IC[e]
Chromium	3050A	ICPES
Cobalt	3050A	ICPES
Copper	3050A	ICPES
Cyanide	9012[f]	Colorimetric
Iron	3050A	ICPES
Lead	3050A	ICPES
Magnesium	3050A	ICPES
Manganese	3050A	ICPES
Mercury	7471[g]	CVAA[h]
Nickel	3050A	ICPES
Potassium	3050A	ICPES
Silver	3050A	ICPES
Selenium	3050A	ICPES
Sodium	3050A	ICPES
Sulfate	Leach	IC
Tantalum	3050A	ICPMS[i]
Thallium	3050A	ICPMS/ICPES
Thorium	3050A	ICPMS
Uranium	3050A	ICPMS
Vanadium	3050A	ICPES
Zinc	3050A	ICPES

a. 3050A = EPA SW-846 Method 3050A.
b. ICPES = Inductively coupled plasma emission spectroscopy.
c. GFAA = Graphite furnace atomic absorption spectroscopy.
d. Leach = Deionized water leach.
e. IC = Ion chromatography.
f. 9012 = EPA SW-846 Method 9012.
g. 7471 = EPA SW-846 Method 7471.
h. CVAA = Cold vapor atomic absorption spectroscopy.
i. ICPMS = Inductively coupled plasma mass spectrometry.

TABLE 4.3-1
SUMMARY STATISTICS FOR INORGANIC CHEMICALS IN CANYON SEDIMENT[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Aluminum	25	25	740	5,510	13,300	5,840	3,240	15,400
Antimony[b]	NA[c]	NA	NA	NA	NA	NA	NA	0.83
Arsenic	31	29	0.25	1.8	3.6	1.84	0.967	3.98
Barium	31	31	8	64.6	127	60.4	30.1	127
Beryllium	31	29	0.04	0.545	1.3	0.590	0.324	1.31
Cadmium	24	6	0.05	0.1	0.18	0.093	0.037	NC[d] (0.4)
Calcium	31	31	180	1,640	4,240	1,680	980	4,420
Chloride	7	2	1.25	1.25	10.3	3.56	3.99	17.1
Chromium	31	31	0.8	5.4	9.2	5.62	2.20	10.5
Cobalt	31	31	0.6	2.2	4.2	2.35	1.08	4.73
Copper	31	31	0.77	4.3	12	4.57	2.45	11.2
Cyanide	24	20	0.075	0.25	0.63	0.295	0.186	0.82
Iron	31	31	1,400	8,400	13,000	8,030	2,610	13,800
Lead	31	30	2	8.9	25.6	9.25	4.72	19.7
Magnesium	31	31	170	826	2,370	977	521	2,370
Manganese	31	31	46	302	517	290	115	543
Mercury	24	3	0.01	0.01	0.03	0.012	0.005	NC (0.1)
Nickel	31	29	1	4.6	8.9	4.98	1.99	9.38
Potassium	31	31	180	1,120	2,600	1,300	628	2,690
Selenium	24	0	0.1	0.1	0.1	0.1	0	NC (0.3)
Silver	18	2	0.05	0.05	0.28	0.066	0.055	NC (1)
Sodium	31	31	34	458	1,970	551	414	1,470
Sulfate	7	2	2.5	2.5	35	10.6	14.0	58.2
Tantalum	7	0	0.15	0.15	0.15	0.15	0	NC (0.3)
Thallium[b]	NA	NA	NA	NA	NA	NA	NA	0.73
Thorium	7	7	0.9	5.5	7	4.20	2.60	S[e] (14.6)
Uranium	31	28	0.14	0.66	2	0.685	0.423	2.22
Vanadium	31	31	1	10	20	10.4	4.19	19.7
Zinc	31	31	9	34	56.2	33.9	11.9	60.2

a. Units are mg/kg.

b. The UTL from LANL soil background data was used because a less sensitive analytical method was used for sediment samples.

c. NA = Not applicable.

d. NC = A UTL was not calculated. The detection limit, noted parenthetically, is used as a BV.

e. S = A UTL was not calculated for thorium because of the small number of samples. The soil UTL is used as a surrogate value for this analyte.

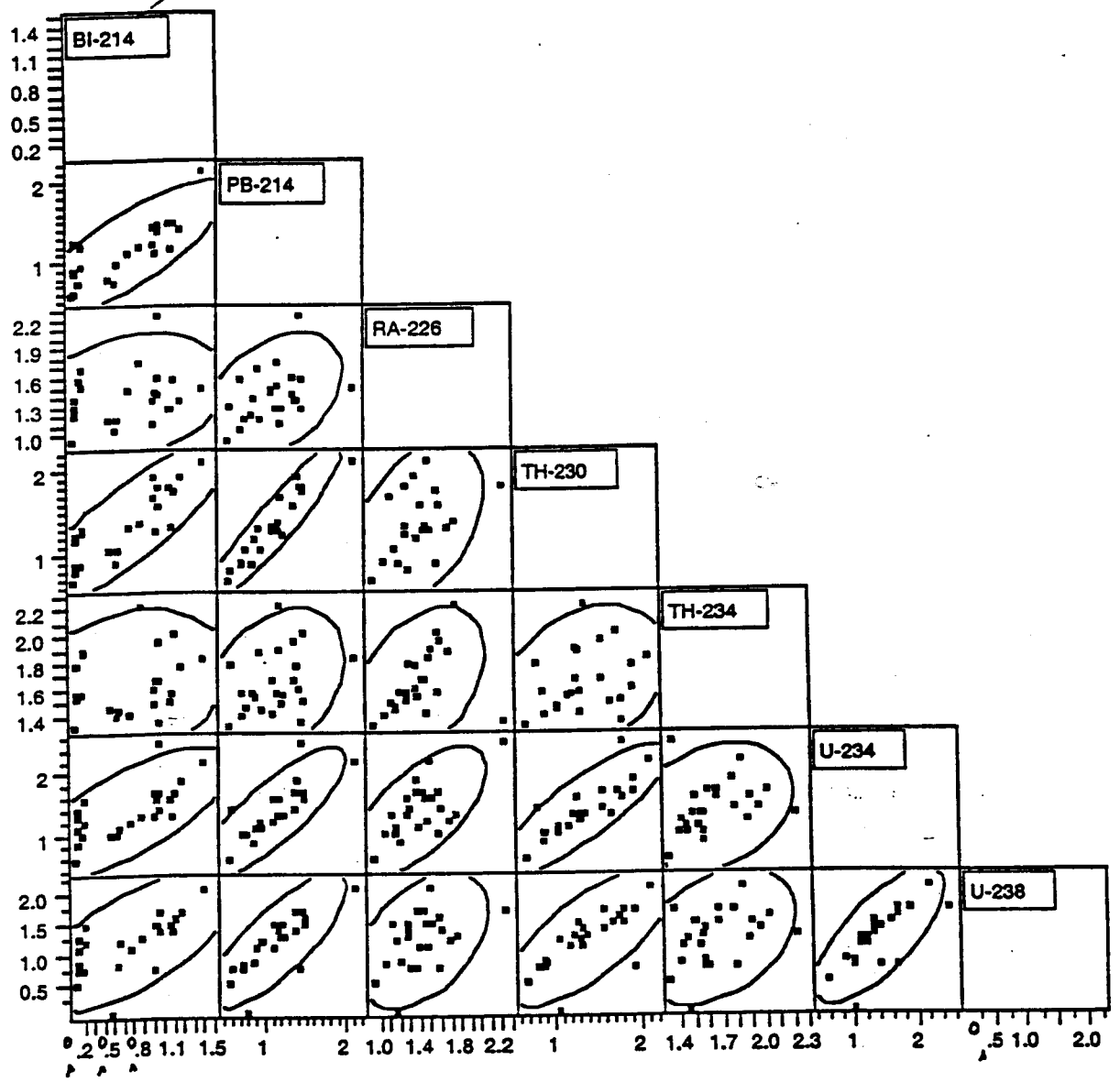
and total thorium consist of only seven samples, UTL values were not calculated for thorium or total thorium in sediment. The soil BVs for thorium and total thorium were used as surrogate BVs in sediments. As discussed in Section 4.0, the basis for using soil background as a surrogate is the similar mineralogy and concentrations of inorganic chemicals in sediment compared to either A- or C- horizon soils.

TABLE 4.3-2
SUMMARY OF NATURALLY OCCURRING URANIUM AND THORIUM ISOTOPES AND PROGENY DETECTED IN SEDIMENT SAMPLES

Decay Series	Radionuclide	Half-life[a]
Thorium series	Thorium-232[b]	14,000,000,000 years
	Thorium-228[b]	1.9 years
	Actinium-228	6.2 hours
	Lead-212	11 hours
	Thallium-208	3.1 minutes
Actinium series	Uranium-235[b]	700,000,000 years
Uranium series	Uranium-238[b]	4,500,000,000 years
	Uranium-234[b]	250,000 years
	Thorium-234	24 days
	Thorium-230[b]	75,000 years
	Radium-226[b]	1,600 years
	Lead-214	27 minutes
	Bismuth-214	20 minutes

[a] Values are rounded to two significant figures from information presented in *Nuclides and Isotopes, Chart of the Nuclides*, fifteenth edition (Parrington et al. 1996, ER ID 58682).

[b] Radionuclides of interest for risk or dose assessment purposes (half-life is greater than 30 days).



The correlation coefficients (r) of daughter radionuclides with uranium-238, the numbers of samples (n), and the statistical significance values (p) for each analyte are as follows:

Bismuth-214 (BI-214):	r = 0.65,	n = 24,	p = <0.001
Lead-214 (PB-214):	r = 0.80,	n = 24,	p = <0.001
Radium-226 (RA-226):	r = 0.45,	n = 24,	p = 0.028
Thorium-230 (TH-230):	r = 0.72,	n = 24,	p = <0.001
Thorium-234 (TH-234):	r = 0.38,	n = 24,	p = 0.071
Uranium-234 (U-234):	r = 0.74,	n = 24,	p = <0.001

Figure 4.3-1 Cross-correlation between radionuclides in the uranium decay series.

TABLE 4.3-4
SUMMARY STATISTICS FOR FALLOUT RADIONUCLIDES IN CANYON SEDIMENTS[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Americium-241	24	24	0.009	0.0185	0.038	0.026	0.025	0.040
Cesium-137	24	7	0.03	0.06	1.28	0.211	0.307	0.90
Plutonium-238	24	20	0	0.002	0.006	0.0021	0.0016	0.006
Plutonium-239,240	24	24	0.002	0.0115	0.065	0.025	0.040	0.068
Potassium-40	24	24	24.21	30.12	35.1	29.8	3.03	36.8
Radium-226[b]	NA[c]	NA	NA	NA	NA	NA	NA	2.59
Radium-228[d]	NA	NA	NA	NA	NA	NA	NA	2.33
Strontium-90	24	11	0.05	0.45	1	0.481	0.355	1.30
Thorium-228	24	24	0.7	1.395	2.12	1.44	0.365	2.28
Thorium-230	24	24	0.69	1.325	2.12	1.37	0.396	2.29
Thorium-232	24	24	0.66	1.395	2.03	1.43	0.390	2.33
Tritium	23	23	0.003	0.018	0.0856	0.024	0.019	0.093
Uranium-234	24	24	0.59	1.3	2.5	1.40	0.429	2.59
Uranium-235	24	15	0.03	0.105	0.16	0.087	0.050	0.20
Uranium-238	24	22	0.03	1.3	2.1	1.22	0.461	2.29

a. Units are pCi/g.
b. The UTL was estimated from uranium-234 instead of using the gamma spectroscopy results for this radionuclide.
c. NA = Not applicable.
d. This analyte was not measured; the UTL was estimated from thorium-232.

5.0 TUFF BACKGROUND

This section presents the background data for inorganic chemicals and radionuclides in the Tshirege Member of the Bandelier Tuff. The Tshirege Member is the most widespread rock unit on the Pajarito Plateau and underlies the majority of the Laboratory's PRSs. Additional background data are presented for tephras of the Cerro Toledo interval and the upper part of the Otowi Member of the Bandelier Tuff. The sampled rock sections represent unweathered tuff, which is typical of the rock underlying mesa-top PRSs. This is significant because tuff sampled in canyon bottom settings may have different geochemistry because these environments have more abundant water, which leads to chemical weathering of the tuff.

The stratigraphic nomenclature for the Bandelier Tuff used in this report follows the usage of Broxton and Reneau (1995, ER ID 49726). Figure 5.0-1 shows the stratigraphic relationships of the units discussed.

5.1 Sample Locations

A total of 113 tuff samples were collected from rock units across the Pajarito Plateau at sites not impacted by PRSs. Details about sample collection, as well as other relevant information about the geologic setting of the samples, are provided by Broxton et al. (1995, ER ID 50121; 1995, ER ID 52227; 1995, ER ID 54709; 1996, ER ID 54948; in review, ER ID 57571). Sample locations included the north wall of Los Alamos Canyon near TA-21, the north and south walls of Mesita del Buey, the north wall of Threemile Canyon near Pajarito Mesa, the north wall of Canon de Valle near MDA P, and the north wall of Frijoles Canyon (Figure 5.1-1).

5.2 Sample Collection, Preparation and Analytical Methods

In general, field work was performed using LANL ER Standard Operating Procedure (SOP) 3.07, "Characterization of Lithologic Variations within the Rock Outcrops of a Volcanic Field" (LANL 1991, 21556). Typically, samples were collected in vertical stratigraphic sections at a nominal vertical spacing of 5 m or at major changes in lithology. Metal tags were installed to mark sample sites in the field. Vertical control was maintained using a Jacob staff and an Abney level in the field, and locations and elevations were estimated from maps or were surveyed by a professional surveying company.

Two types of inorganic analytical data are presented for the bedrock tuff units: leachable element concentrations and total element concentrations. Leachable element concentrations (from HNO_3 acid digestion) are the primary focus of this compilation because they provide a basis for comparison between samples collected during RCRA facility investigations and background concentrations. Risk-based decisions resulting from RCRA facility investigations are based on leachable element concentrations in solid media which indicate the bioavailability of potential contaminants to human or ecological receptors. Leachable element concentrations were determined by leaching the loosely bound inorganic constituents of the rocks in a water or acid solution and analyzing the leachate. Total element concentrations for potassium, thorium, and uranium were also determined and used to calculate the activities of naturally occurring potassium, thorium, and uranium isotopes in the tuffs. The factors developed to convert the mass of these elements to the activities of the naturally occurring isotopes are presented in Table 5.2-1. The activity ratios suggested by these conversion factors are consistent with the measured values of the principal naturally occurring radionuclides in the sediment background samples. In addition, the similarity of measured concentrations of thorium and uranium isotopes in sediment is consistent with the assumption of secular equilibrium used to estimate the abundance of some naturally occurring isotopes in the tuff samples (see the discussion of secular equilibrium in Section 4.3.2).

Inorganic chemicals were analyzed using EPA SW-846 methods, and specific analytical techniques are summarized in Table 5.2-2. All Bandelier Tuff samples were analyzed by the Laboratory's Chemical Science and Technology Division Inorganic Trace Analysis Group (CST-9), except for Material Disposal Area (MDA) P samples, which were analyzed at Rust Geotech of Grand Junction, Colorado. The methods for Bandelier Tuff analyses are identical to those used for the soil background investigation. Analytical methods included ICPMS, ICPES, and GFAA. EPA sample preparation method 3050A (where aliquots of crushed rock powders were treated with a solution of concentrated HNO_3 [pH<1]) was used, and the leachates were analyzed by ICPMS and ICPES. Separate aliquots of crushed rock powders were treated with de-ionized water and the leachate was analyzed for chloride and sulfate by IC.

Radionuclides were analyzed by the methods summarized in Table 5.2-3. Thirteen untreated samples were analyzed at CST-9 for radium-226 activities by gamma-ray spectroscopy. These data are not presented in this document because the minimum detectable activity for radium-226 by gamma spectroscopy is high. Instead, radium-226 parent radionuclide activity (uranium-234) was used to estimate the activity of radium-226. Radionuclide background activities for naturally occurring potassium, thorium, and uranium isotopes were calculated for 52 samples of Bandelier Tuff collected at stratigraphic sections in Frijoles Canyon and near MDA P. Total potassium and

TABLE 5.2-1
SUMMARY OF CONVERSION FACTORS USED TO ESTIMATE THE ACTIVITY OF NATURALLY OCCURRING RADIONUCLIDES

Isotope	Half-life[a] (years)	Specific Activity[a] (pCi/g)	Natural Abundance[a]	Conversion Factor[b]
Potassium-40	1.28E+09	6.98E+06	0.0117%	0.000817
Thorium-232	1.40E+10	1.10E+05	100%	0.110
Uranium-234	2.46E+05	6.21E+09	0.0055%	0.342
Uranium-235	7.04E+08	2.16E+06	0.72%	0.0156
Uranium-238	4.47E+09	3.36E+05	99.2745%	0.334

a. From *Nuclides and Isotopes, Chart of the Nuclides*, fifteenth edition (Parrington et al. 1996, ER ID 58682).

b. Value is the conversion factor for converting mass concentration (mg/kg) to activity (pCi/g). The conversion factor is calculated using the following equation:

$$(\text{Specific activity (pCi/g)} \times \text{natural abundance (\%)})10^{-8}$$

TABLE 5.2-3
SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL TECHNIQUES FOR RADIONUCLIDES AND TOTAL METALS IN TUFF

Analyte	Sample Preparation	Analytical Technique
Total Potassium	Grinding	INAA[a]
Total Thorium	Grinding	INAA/ICPMS[b]
Total Uranium	Grinding	DNAA[c]/ICPMS

a. INAA = Instrumental neutron activation analysis.
b. ICPMS = Inductively coupled plasma mass spectrometry.
c. DNAA = Delayed neutron activation analysis.

5.3 Statistical Summary

The Bandelier Tuff background data are divided into three data groups: upper Bandelier Tuff (Qbt 2, 3, 4); middle Bandelier Tuff (Qbt 1v); and lower Bandelier Tuff (Qbt 1g, Qct, Qbo). All of the tuff samples were collected from unweathered sections, and it is likely that tuff samples collected from shallow, weathered sections will have chemical properties more similar to soil and canyon sediments. The upper Bandelier Tuff background will be relevant for making background comparisons for samples from shallow boreholes (less than 50 ft) into the Bandelier Tuff from mesa-top locations. The other Bandelier Tuff background data will be relevant for deeper borehole investigations or studies that assess certain canyon settings. It is recommended that deep investigations into the tuff or investigations requiring canyon drilling should consider more detailed background comparisons than a simple UTL or BV assessment. Such detailed comparisons should include stratigraphic profiles that compare PRS data to background data. These stratigraphic profiles are also useful for evaluating contaminant transport from potential sources. A graphical presentation of the tuff background data is provided in Appendix A.

5.3.1 Inorganic Chemicals

Tables 5.3-1, 5.3-2, and 5.3-3 provide summary statistics for background data from the upper Bandelier Tuff (Qbt 2, 3, 4), the Bandelier Tuff unit 1v (Qbt 1v), and the lower Bandelier Tuff (Qbt 1g, Qct, Qbo), respectively. The nominal detection limits were used as BVs for certain analytes in each of these strata as follows:

In the upper Bandelier Tuff (Qbt 2, 3, 4) background data, the frequency of detection for antimony, selenium, and silver was too low to permit calculation of a UTL value for these chemicals. Thus, the nominal detection limits are used as BVs for antimony (0.5 mg/kg), selenium (0.3 mg/kg), and silver (1 mg/kg).

TABLE 5.3-2
SUMMARY STATISTICS FOR
INORGANIC CHEMICALS IN BANDELIER TUFF UNIT 1v (Qbt 1v)[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Aluminum	23	23	490	2,700	7,900	2,950	1,720	8,170
Antimony	23	2	0.1	0.1	0.3	0.124	0.047	NC[b] (0.5)
Arsenic	23	14	0.25	0.6	2	0.607	0.415	1.81
Barium	23	23	2.4	11	25	12.3	6.08	26.5
Beryllium	23	20	0.07	0.68	1.5	0.734	0.414	1.70
Cadmium	0	no detects ~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	NC (0.4)
Calcium	23	23	200	960	2,800	1,110	679	3,700
Chloride	23	23	9.6	41	802	118	226	446
Chromium	23	12	0.25	0.6	1.7	0.733	0.451	2.24
Copper	23	13	0.25	1	2.6	1.02	0.724	3.26
Iron	23	23	360	5,700	7,300	4,640	2,260	9,900
Lead	23	23	0.6	9.6	18.3	9.85	3.69	18.4
Magnesium	23	23	78	230	910	291	191	780
Manganese	23	23	52	250	370	238	73.2	408
Nickel	23	1	1	1	2	1.04	0.209	NC (2)
Potassium	23	23	390	1,600	5,400	1,870	1,260	6,670
Selenium	0	no detects ~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	NC (0.3)
Silver	23	0	0.5	0.5	1	0.565	0.172	NC (1)
Sodium	23	23	210	1,400	5,100	1,580	1,120	6,330
Sulfate	23	23	1.5	17.6	199	31.7	47.3	142
Tantalum	23	10	0.1	0.15	0.5	0.189	0.119	0.86
Thallium	23	6	0.1	0.1	1.7	0.259	0.358	1.24
Thorium	23	23	6.2	10.7	19.1	11.7	4.00	22.5
Uranium	23	23	1	2.3	4.8	2.47	1.27	6.22
Vanadium	23	21	0.7	1.6	4.6	1.87	0.930	4.48
Zinc	23	23	12	57	74	53.8	13.3	84.6

a. Units are mg/kg.
b. NC = A UTL was not calculated. The detection limit, noted parenthetically, is used as a BV.

5.3.2 Naturally Occurring Radionuclides

Tables 5.3-4, 5.3-5, and 5.3-6 provide summary statistics for the upper Bandelier Tuff (Qbt 2, 3, 4), Bandelier Tuff unit 1v (Qbt 1v), and lower Bandelier Tuff (Qbt 1g, Qct, Qbo) background data. UTL values for total potassium, total thorium, and total uranium are provided because measurement of total thorium and total uranium is typically done to investigate potential radionuclide releases. These total BVs also allow estimation of the abundances of naturally occurring radionuclides (potassium-40, thorium-232 and progeny, and uranium isotopes and progeny). It is important to note that total potassium, total thorium, and total uranium have unique analyte codes to distinguish these measurements from the standard potassium, thorium, and uranium results reported in Tables 5.3-1, 5.3-2 and 5.3-3.

TABLE 5.3-4
SUMMARY STATISTICS FOR NATURALLY OCCURRING RADIONUCLIDES IN THE UPPER BANDELIER TUFF (Qbt 2, 3, 4)[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Total Potassium	11	11	35,400	38,130	41,360	38,100	1,990	43,700
Total Thorium	26	26	9.2	12.5	25.93	13.9	3.97	22.9
Total Uranium	26	26	2.3	3	7.123	3.36	1.07	5.79

a. Units are mg/kg.

TABLE 5.3-5
SUMMARY STATISTICS FOR NATURALLY OCCURRING RADIONUCLIDES IN BANDELIER TUFF UNIT 1v (Qbt 1v)[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Total Potassium	15	15	36,140	37,410	40,470	37,800	1,440	41,500
Total Thorium	15	15	19.14	26.09	30.08	25.5	3.36	34.1
Total Uranium	15	15	4.71	7.26	7.59	6.86	0.886	9.14

a. Units are mg/kg.

TABLE 5.3-6
SUMMARY STATISTICS FOR NATURALLY OCCURRING RADIONUCLIDES IN THE LOWER BANDELIER TUFF (Qbt 1g, Qct, Qbo)[a]

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Total Potassium	11	11	28,760	40,150	47,920	38,400	5,730	54,500
Total Thorium	11	11	15.62	28.99	37.06	27.4	6.11	44.5
Total Uranium	11	11	5.078	7.746	10.13	7.42	1.53	11.7

a. Units are mg/kg.

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APPENDIX A STATISTICAL PLOTS

This Appendix presents statistical probability plots for all of the Los Alamos National Laboratory ("the Laboratory" or LANL) Environmental Restoration (ER) Project background data by media. The probability plots show each background analytical result ordered from lowest to highest. Detected values are shown as solid circles, and nondetected values, plotted as one-half of the detection limit, are shown as open circles. The *x*-axis is the standard normal quantile scale. The units of the standard normal quantile are in standard deviations, where 1 represents one sigma or standard deviation. The *y*-axis of the probability plot is the concentration of inorganic chemicals (in mg/kg) or the activity of radionuclides (in pCi/g). The purpose of these plots is two-fold. First, they are a succinct way to present all of the data for each analyte. Second, they are way to assess the statistical distribution of each analyte. Specifically, if the data for an analyte follow a straight line when plotted on a standard normal scale, these data are considered to follow a normal statistical distribution. One can assess the fit to other statistical distributions by transforming the *y*-axis to another scale. For example, chemical data frequently follow a lognormal distribution, and the fit to a lognormal distribution is assessed by transforming the *y*-axis into a logarithmic scale.

To facilitate review of these probability plots, several statistics are shown. First, the 5th percentile, 50th percentile (or median), and the 95th percentile of the distribution are shown by three sets of dashed lines. The solid, sloped line represents the estimated normal distribution of the data (where the intercept of this line is the estimated mean and the slope is the standard deviation). If the data fall off of the line this suggests that the data did not originate from a normal statistical distribution. Second, the calculated upper tolerance limit (UTL) value for the distribution is plotted as a dotted line that intersects the *y*-axis.

The title for each plot includes the analyte name and the calculated UTL value ("NC" indicates that a UTL was not calculated). In addition, a parenthetical code shows what kind of statistical distribution was used to calculate the UTL as follows: "(1)" indicates that a normal distribution was used, "(2)" indicates that a square-root normal distribution was used, "(3)" indicates that a lognormal distribution was used, and "(4)" indicates that nonparametric methods were used.

TABLE 6.0-1
SUMMARY OF BACKGROUND VALUES BY MEDIA FOR INORGANIC CHEMICALS[a]

Analyte	Soil	Canyon Sediment	Qbt 2,3,4[b]	Qbt 1v[b]	Qbt 1g, Qct, Qbo[b]
Aluminum	29,200	15,400	7,340	8,170	3,560
Antimony	0.83	0.83	0.5	0.5	0.5
Arsenic	8.17	3.98	2.79	1.81	0.56
Barium	295	127	46	26.5	25.7
Beryllium	1.83	1.31	1.21	1.70	1.44
Cadmium	0.4	0.4	1.63	0.4	0.4
Calcium	6,120	4,420	2,200	3,700	1,900
Chloride	231	17.1	94.6	446	474
Chromium	19.3	10.5	7.14	2.24	2.60
Cobalt[c]	8.64	4.73	3.14	1.78	8.89
Copper	14.7	11.2	4.66	3.26	3.96
Cyanide	0.5	0.82	0.5	0.5	0.5
Iron	21,500	13,800	14,500	9,900	3,700
Lead	22.3	19.7	11.2	18.4	13.5
Magnesium	4,610	2,370	1,690	780	739
Manganese	671	543	482	408	189
Mercury	0.1	0.1	0.1	0.1	0.1
Nickel	15.4	9.38	6.58	2	2
Potassium	3,460	2,690	3,500	6,670	2,390
Selenium	1.52	0.3	0.3	0.3	0.3
Silver	1	1	1	1	1
Sodium	915	1,470	2,770	6,330	4,350
Sulfate	293	58.2	157	142	1,120
Tantalum	0.3	0.3	1.16	0.86	0.95
Thallium	0.73	0.73	1.10	1.24	1.22
Thorium	14.6	14.6	10.8	22.5	4.51
Uranium	1.82	2.22	2.40	6.22	0.72
Vanadium	39.6	19.7	17	4.48	4.59
Zinc	48.8	60.2	63.5	84.6	40.0

a. Units are mg/kg.
b. Value represents background for unweathered tuff.
c. Maximum value from neutron activation analysis is reported for rock background.