

5075

# DRAFT

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

R. T. Rytli, P. A. Longmire, D. E. Broxton, S. L. Reneau, and E. V. McDonald

prepared for the  
Los Alamos National Laboratory  
Environmental Restoration Project

July 31, 1998

### 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 <sup>summarizes</sup> describes 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.

Expend?

Background values <sup>(BVs)</sup> 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.



3513

1.0	Introduction .....	1
2.0	Statistical Data Treatment.....	3
3.0	Soil Background .....	4
3.1	Inorganic Chemicals.....	4
3.1.1	Sample Locations .....	5
3.1.2	Sample Collection, Preparation, and Analytical Techniques.....	8
3.1.3	Geochemical Correlations.....	10
3.1.3.1	Beryllium and Iron Correlation.....	10
3.1.3.2	Thorium and Uranium Correlation.....	12
3.1.4	Statistical Summary.....	12
3.2	Naturally Occurring Radionuclides .....	15
3.3	Fallout Radionuclides .....	15
3.3.1	Sample Locations .....	15
3.3.2	Sample Collection, Preparation, and Analytical Techniques.....	16
3.3.3	Summary.....	18
4.0	Canyon Sediment Background .....	19
4.1	Sample Locations .....	20
4.2	Sample Collection, Preparation, and Analytical Techniques .....	20
4.3	Statistical Summary.....	22
4.3.1	Inorganic Chemicals .....	22
4.3.2	Naturally Occurring Radionuclides and Discussion of Secular Equilibrium.....	26
4.3.3	Fallout Radionuclides .....	30
5.0	Tuff Background .....	31

July 31, 1998

5.1	Sample Locations.....	33
5.2	Sample Collection, Preparation and Analytical Methods.....	33
5.3	Statistical Summary.....	39
5.3.1	Inorganic Chemicals.....	39
5.3.2	Naturally Occurring Radionuclides.....	43
5.3.3	Fallout Radionuclides.....	44
6.0	Summary.....	44
7.0	Acknowledgments.....	46
8.0	References.....	47
Appendix A	Statistical Plots.....	51

## LIST OF FIGURES

	<i>Location</i> Figure 3.1-1 Distribution of soil sample sites and Environmental Surveillance Program perimeter sample locations at Los Alamos National Laboratory. 7	
	Figure 3.1-2 HNO <sub>3</sub> extractable iron concentrations versus HNO <sub>3</sub> extractable beryllium concentrations in background soils in Los Alamos, New Mexico. ....11	
	Figure 3.1-3 Total (HF-extractable) thorium concentrations versus total uranium concentrations in Bandelier Tuff and background soils in Los Alamos, New Mexico.....13	
	Figure 3.3-1 Regional Environmental Surveillance Program sample locations.....17	
✓	Figure 4.1-1 <i>Location</i> Distribution of background sediment sample sites at Los Alamos National Laboratory. <u>21</u> →	
	Figure 4.3-1 Cross-correlation between radionuclides in the thorium decay series.....28	
✓	Figure 4.3-1 <sup>2</sup> Cross-correlation between radionuclides in the uranium decay series. ....29	
	Figure 5.0-1 Schematic stratigraphic section showing rock units sampled for background chemistry (modified from Broxton and Reneau 1995, ER ID 49726). ....32	
	Figure 5.1-1 <i>Location</i> Distribution of background tuff sample sites. .... <i>at Los Alamos National Lab.</i> 34	
	Figure A-1 Standard normal probability plots for inorganic chemicals in soil. ....53	
	Figure A-2 Standard normal probability plots for fallout radionuclides. ....53	
	Figure A-3 Standard normal probability plots for the inorganic chemicals in sediment. ....53	
	Figure A-4 Standard normal probability plots for the radionuclides in sediment. ....53	
	Figure A-5 Standard normal probability plots for the inorganic chemicals in upper Bandelier Tuff (Qbt 2,3,4). ....53	
	Figure A-6 Standard normal probability plots for the inorganic chemicals in Bandelier Tuff unit 1v (Qbt 1v). ....53	

Figure A-7 Standard normal probability plots for the inorganic chemicals in lower Bandelier  
Tuff (Qbt 1g, Qct, Qbo).....53

## LIST OF TABLES

Table 1.0-1 Summary of Sources Used to Establish Background and Fallout Values .....	2
Table 3.1-1 Background Soil Sample Locations and Environmental Settings.....	6
Table 3.1-2 Summary of Sample Preparation and Analytical Techniques for Inorganic Chemicals in Soil .....	9
Table 3.1-3 Summary Statistics for Inorganic Chemicals in Soil <sup>a</sup> .....	14
Table 3.2-1 Summary Statistics for Naturally Occurring Radionuclides in Soil <sup>a</sup> .....	15
Table 3.3-1 Summary of Sample Preparation and Analytical Techniques for Radionuclides and Total Metals in Soil.....	18
Table 3.3-2 Summary Statistics for Fallout Radionuclides in Surface Soil <sup>a</sup> .....	19
Table 4.2-1 Summary of Sample Preparation and Analytical Techniques for Inorganic Chemicals in Canyon Sediments.....	23
Table 4.2-2 Summary of Sample Preparation and Analytical Techniques for Radionuclides and Total Metals in Canyon Sediments.....	24
Table 4.3-1 Summary Statistics for Inorganic Chemicals in Canyon Sediments <sup>a</sup> .....	25
Table 4.3-2 Summary of Naturally Occurring Uranium and Thorium Isotopes and Progeny Detected in Sediment Samples .....	27
Table 4.3-3 Summary Statistics for Naturally Occurring Radionuclides in Canyon Sediments <sup>a</sup> .....	30
Table 4.3-4 Summary Statistics for Fallout Radionuclides in Canyon Sediments <sup>a</sup> .....	31
Table 5.2-1 Summary of Conversion Factors Used to Estimate the Activity of Naturally Occurring Radionuclides .....	37
Table 5.2-2 Summary of Sample Preparation and Analytical Techniques for Inorganic Chemicals in Tuff.....	38
Table 5.2-3 Summary of Sample Preparation and Analytical Techniques for Radionuclides and Total Metals in Tuff.....	39

Table 5.3-1 Summary Statistics for Inorganic Chemicals in the Upper Bandelier Tuff (Qbt 2, 3, 4)<sup>a</sup>.....40

Table 5.3-2 Summary Statistics for Inorganic Chemicals in Bandelier Tuff Unit 1v (Qbt 1v)<sup>a</sup>.....41

Table 5.3-3 Summary Statistics for Inorganic Chemicals in the Lower Bandelier Tuff (Qbt 1g, Qct, Qbo)<sup>a</sup>.....42

Table 5.3-4 Summary statistics for Naturally Occurring radionuclides in the upper Bandelier Tuff (Qbt 2, 3, 4)<sup>a</sup>.....43

Table 5.3-5 Summary statistics for Naturally Occurring radionuclides in Bandelier Tuff unit 1v (Qbt 1v)<sup>a</sup>.....43

Table 5.3-6 Summary statistics for Naturally Occurring radionuclides in the lower Bandelier Tuff (Qbt 1g, Qct, Qbo)<sup>a</sup>.....43

Table 6.0-1 Summary of background values by media for inorganic Chemicals<sup>a</sup>.....45

Table 6.0-2 Summary of Background Values by media for radionuclides<sup>a</sup>.....46

## 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~~ <sup>used in the data review</sup> ~~statistical analysis used to support~~ <sup>that</sup> 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,

and (4) differences in background levels among various geomorphic units and sample grain sizes. Lastly, the background analyte chemistry for the Bandelier Tuff is presented in "Natural Background Geochemistry of the Bandelier Tuff and Other Rock Units" (Broxton et al. 1995, ER ID 52227) and "Natural Background Geochemistry of the Bandelier Tuff at MDA P" (Broxton et al. 1996, ER ID 54948). Section 5.0 of this report summarizes these studies, including (1) sample locations, (2) sample collection and analytical methods, and (3) statistical data summaries.

To facilitate review of this document, Table 1.0-1 summarizes how the background studies described above established the background values (BVs) for inorganic chemicals and naturally occurring radionuclides, and the fallout values for radionuclides. Section 6.0 of this report provides summary tables of the background values for inorganic chemicals and radionuclides in all media.

**TABLE 1.0-1  
SUMMARY OF SOURCES USED  
TO ESTABLISH BACKGROUND AND FALLOUT VALUES**

Chemical Group	Soil	Sediment	Tuff
Inorganic chemicals	Directly measured in samples collected from several soil profiles in uncontaminated locations in Los Alamos County (except silver, for which the detection limit is used as background)	Directly measured in samples collected from five canyons in Los Alamos County (except antimony and thallium, for which soil data are used as surrogate background)	Directly measured in samples collected from several tuff profiles in uncontaminated locations in Los Alamos County (except mercury, for which the detection limit is used as background)
Naturally occurring radionuclides	Not measured; sediment data are used as surrogate background	Directly measured in samples collected from three canyons in Los Alamos County	Used total elemental abundance (mass) of thorium and uranium to estimate the activity of isotopes
Fallout radionuclides	Used Laboratory Environmental Surveillance data for 1992 through 1995	Directly measured in samples collected from three canyons in Los Alamos County	Not measured; fallout radionuclides are not expected in subsurface samples and detection limits are used as background

## 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).

$$UTL_{0.95,0.95} = \text{mean} + \text{standard deviation} \times k_{0.95,0.95} \quad (\text{Equation 2.0-1})$$

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:

$$UTL_{0.95,0.95} = \left( \text{mean} + \text{standard deviation} \times k_{0.95,0.95} \right)^2 \quad (\text{Equation 2.0-2})$$

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

language. Inputs to this function are the lognormal mean (E) and the lognormal standard deviation (V). Definitions of E and V, as well as methods for calculating these statistics, can be found on page 164 of *Statistical Methods for Environmental Pollution Monitoring* (Gilbert 1987, ER ID 56179).

For analytes where a statistical distribution could not be estimated, a nonparametric approach was used to calculate UTL values (see Equation 11.12 on page 141 of Gilbert 1987, ER ID 56179). The nonparametric UTL calculation is based on an order statistic of the analyte. The order statistic of the UTL is calculated from Equation 2.0-3. Typically, the result of Equation 2.0-3 is a noninteger order statistic value, which means that the estimated UTL value will be linearly interpolated between the appropriate nearest-integer order statistics.

$$\text{Rank(UTL)} = 0.95 \times (n + 1) + 0.427 \times n^{0.5} \quad \text{(Equation 2.0-3)}$$

The UTL can be used as a BV, and analytes for which all potential release site (PRS) sample values are less than the UTL can be eliminated from further assessment. In cases where a UTL cannot be calculated, either the detection limit or maximum reported value is used as a BV.

### 3.0 SOIL BACKGROUND

This section presents the background data for inorganic chemicals and radionuclides in soil. In this report, the term "soil" refers to material overlying intact bedrock that has been subject to soil-forming processes such as the addition of organic matter, the vertical translocation of clay-sized particles, or the development of ferric oxyhydroxides. Thus, soils are the typical surficial material on mesa tops and hillslopes, and are widespread in canyon bottoms. At sites where potentially contaminated surface material represents imported fill or a combination of soil and fill, soil is considered to be the most appropriate background comparison material.

#### 3.1 Inorganic Chemicals

Information on the concentrations of 26 inorganic chemicals relevant to the Laboratory's ER Project are presented for a variety of soils and geomorphic settings across the Pajarito Plateau in two studies: "Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles" (Longmire et al. 1995, ER ID 52227) and "Natural Background Geochemistry, Geomorphology, and Pedogenesis of Selected Soil Profiles and Bandelier Tuff" (Longmire et al. 1996, ER ID 55115). These studies include analysis of 175 soil samples for background-elemental

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).

**TABLE 3.1-1  
BACKGROUND SOIL SAMPLE LOCATIONS AND ENVIRONMENTAL SETTINGS**

Sample Site <sup>a</sup>	Soil Classification	Vegetation	Setting	Topographic Surficial Material
TA-16, S-1	Udic Paleustalf	Ponderosa pine	Alluvial fan	Pleistocene alluvium
TA-16, S-2	Typic Haplustalf	Ponderosa pine	Base of scarp	Holocene colluvium
TA-16, Water Tanks Trench	Calcic Haploxeralf	Ponderosa pine	Base of scarp	Holocene colluvium
TA-16, WT-1	Udic Paleustalf	Ponderosa pine	Base of scarp	Pre-El Cajete colluvium
TA-33, AC-1	Andic Dystrochrept	Ponderosa pine	Canyon bottom	Holocene alluvium
TA-39, Ancho Canyon Mesa	Calcic Haploxeralf	Piñon-juniper	Mesa top	Pre-El Cajete soil
TA-46, Fracture Fill	No soil	Piñon-juniper	Mesa top	Pre-El Cajete soil
TA-49, Frijoles Mesa	Typic Dystrandept	Ponderosa pine	Mesa top	El Cajete pumice
TA-51	Lithic Ustochrept	Piñon-juniper	Mesa top	Pre-post El Cajete soil
TA-63, TA-63-1	Typic Haplustalf	Grass	Mesa top	Pre-post El Cajete soil
TA-63, TA-63-2	Typic Haplustalf	Grass	Mesa top	Pre-post El Cajete soil
TA-63, TA-63-3	Lithic Ustochrept	Grass	Mesa top	Post El Cajete sediment
TA-63, TA-63-4	Udic Ustochrept	Grass	Mesa top	Post El Cajete sediment
TA-67, TA-67-67-E1	Typic Haplustalf	Piñon-juniper	Mesa top	Pre-post El Cajete soil
TA-67, TA-67-67-E3	Typic Haplustalf	Piñon-juniper	Mesa top	Pre-post El Cajete soil
TA-67, TA-67-67-W1	Typic Haplustalf	Piñon-juniper	Mesa top	Pre-post El Cajete soil
TA-67, TA-67-67-W5	Typic Haplustalf	Piñon-juniper	Mesa top	Pre-post El Cajete soil
TA-69, Twomile Mesa	Typic Haplustalf	Ponderosa pine	Mesa top	Pleistocene alluvium
TA-72, Lower Los Alamos Canyon	Typic Ustipsamment	Piñon-juniper	Canyon bottom	Holocene alluvium
TA-72, Upper Los Alamos Canyon	Cumulic Haploxeroll	Fir	Canyon bottom	Holocene colluvium
TA-73, EG&G Gully	Udic Ustochrept	Piñon-juniper	Mesa-top gully	Holocene colluvium

a. For detailed descriptions of sample locations, see "Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles" (Longmire et al. 1995, ER ID 52227) and "Natural Background Geochemistry, Geomorphology, and Pedogenesis of Selected Soil Profiles and Bandelier Tuff" (Longmire et al. 1996, ER ID 55115).

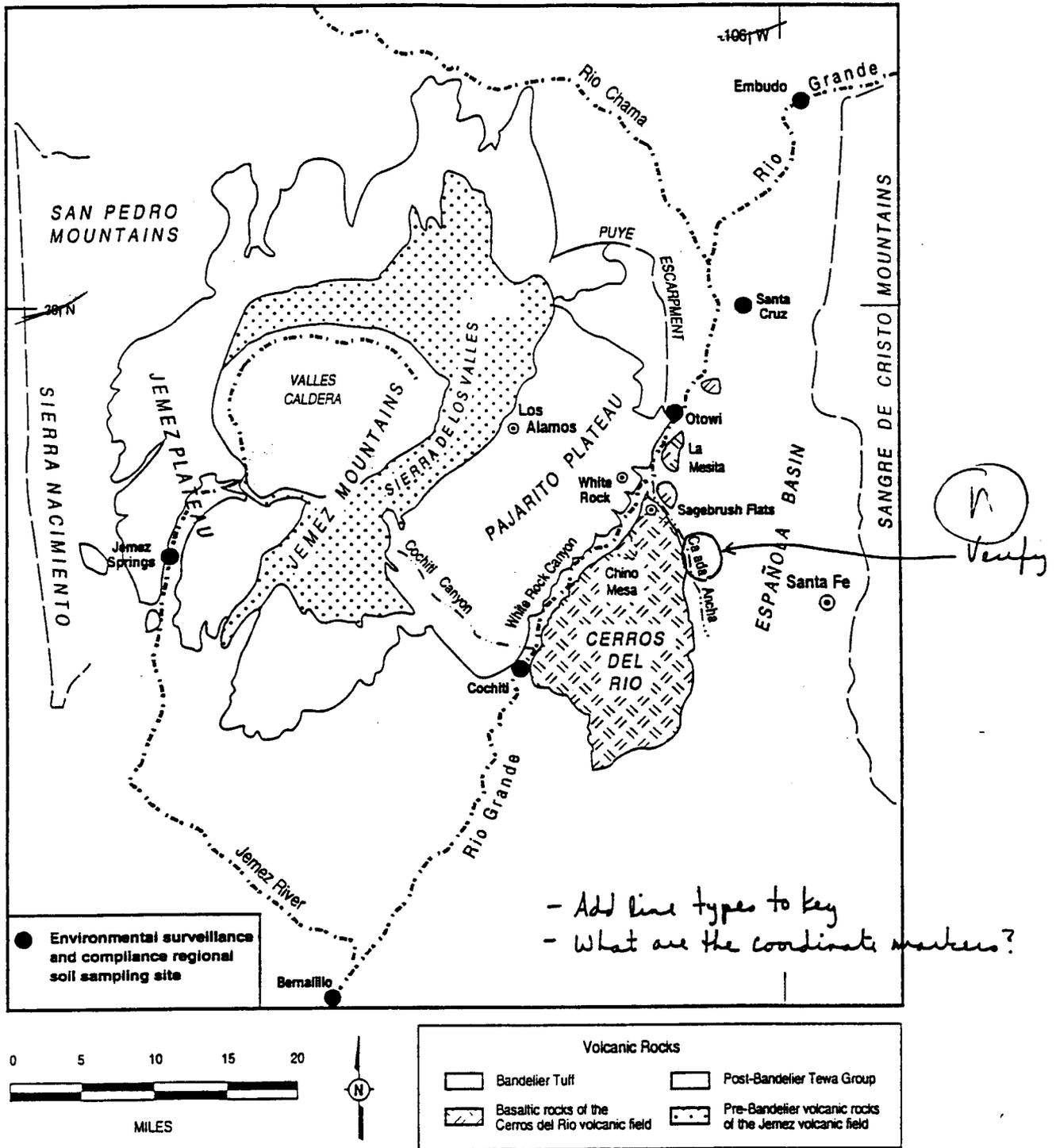


Figure 3.3-1 Regional Environmental Surveillance Program sample locations.

### 3.1.2 Sample Collection, Preparation, and Analytical Techniques

Soil samples were passed through a 2-mm sieve to remove pebbles and roots. Samples were then either air-dried or dried in a forced-air circulation oven at 105°C for 24 hours before performing chemical analyses. All samples were split into two representative fractions with one fraction for soil characterization and the other for trace element chemistry. All equipment used in sample preparation was cleaned after each sample.

The sample preparation and analytical techniques used for these soil samples are presented in Table 3.1-2. Concentrations of trace elements were analyzed using two sample digestion methods: (1) total element concentrations extracted from the complete digestion of soil material using concentrated hydrofluoric acid (HF), and (2) partial analyte concentrations extracted from partial digestion of soil material using concentrated nitric acid (HNO<sub>3</sub>) (EPA Method 3050A) (EPA 1997, ER ID 57589). The data from the latter method are used to calculate most of the summary statistics (including UTL values) and are the primary data used for evaluating chemical releases at PRSs. Two exceptions are uranium and thorium concentrations. For these constituents, it is necessary to evaluate whether the sample preparation method produces a total element concentration or a "leachable" element concentration as described above. Trace element measurements were conducted in accordance with EPA SW-846 analytical techniques, which are described in detail in several documents (see EPA 1997, ER ID 57589; LANL 1993, ER ID 31794).

Quality assurance (QA) was provided by concurrent analysis of different National Institute of Standards and Technology (NIST), EPA, and United States Geological Survey (USGS) sample reference materials described in Volume IV of "Health and Environmental Chemistry: Analytical Techniques, Data Management, and Quality Assurance" (LANL 1993, ER ID 31796). Quality control (QC) samples, including laboratory duplicates and spiked samples, were analyzed at frequencies specified by the EPA (EPA 1997, ER ID 57589). The lowest reported detection limits for specific elements were 0.08 mg/kg for beryllium using inductively coupled plasma emission spectroscopy (ICPES), 0.12 mg/kg for tantalum using inductively coupled plasma mass spectrometry (ICPMS), 12 mg/kg for sulfate using ion chromatography (IC), 0.1 mg/kg for mercury using cold vapor atomic absorption (CVAA), and 0.3 mg/kg for arsenic using graphite furnace atomic absorption spectroscopy (GFAA). (Note that GFAA is equivalent to electrothermal vapor atomic absorption spectroscopy [ETVAA].) It was noted during data assessment that the first year's cobalt data were elevated because cobalt was introduced during sample preparation. These cobalt data were excluded from the soil background data. Both ICPES and ICPMS were

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 <sup>a</sup>	ICPES <sup>b</sup>
Antimony	3050A	ICPES/ICPMS <sup>c</sup>
Arsenic	3050A	GFAA <sup>d</sup>
Barium	3050A	ICPES
Beryllium	3050A	ICPES
Cadmium	3050A	ICPES
Calcium	3050A	ICPES
Chloride	Leach <sup>e</sup>	IC <sup>f</sup>
Chromium	3050A	ICPES
Cobalt	3050A	ICPES
Copper	3050A	ICPES
Iron	3050A	ICPES
Lead	3050A	ICPES
Magnesium	3050A	ICPES
Manganese	3050A	ICPES
Mercury	7471 <sup>g</sup>	CVAA <sup>h</sup>
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.

### 3.1.3 Geochemical Correlations

aeolian?  
Selected trace elements, including beryllium, iron, thorium, and uranium, can systematically co-vary as a function of soil age, soil and parent-material mineralogy, the amount and composition of aeolian dust and other forms of aerosols, the degree of chemical weathering, and pore water chemistry (McDonald et al. 1996, ER ID 58235). Because the distribution of beryllium, iron, thorium, and uranium illustrates the spatial variability of natural background levels and because these elements are important with respect to determining potential release sites of contaminants, the distribution of these elements within Laboratory soils is discussed in more detail below in Sections 3.1.3.1 and 3.1.3.2. More detailed discussions of the geochemical characteristics of these trace elements are provided by Longmire et al. (1995, ER ID 52227; 1996, ER ID 55115).

#### 3.1.3.1 Beryllium and Iron Correlation

Bivariate plots of iron versus beryllium for A, B, and C soil horizons and sediment samples indicate a strong correlation between increases in iron and increases in beryllium (see Figure 3.1-2). Concentrations of beryllium are also generally higher in B horizons than in C or A horizons. Furthermore, the concentration of beryllium generally increases with the relative development of the B horizon, with higher concentrations occurring in well-developed Bt horizons relative to the more weakly-developed Bw horizons. These two relationships suggest that enrichment of beryllium in soils on the Pajarito Plateau correlates with increasing soil development, specifically the formation of B horizons containing ferric oxyhydroxides and clay minerals. Many studies have shown that the abundance of ferric oxyhydroxides and clay minerals increases as B-horizon development increases (Birkeland 1984, ER ID 44019; Sposito 1989, ER ID 58685). These geochemically reactive minerals usually have large surface areas and are characterized by a net-negative surface charge at neutral to alkaline pH values. This net-negative surface charge enhances the adsorption of cationic trace elements in soil environments (Sposito 1984, ER ID 58684; Sposito 1989, ER ID 58685). In addition to beryllium, other trace elements, including arsenic, chromium, manganese, and nickel, correlate well with iron or aluminum concentrations in background soils (Longmire et al. 1995, ER ID 52227; Longmire et al. 1996, ER ID 55115). These bivariate plots represent a valuable tool for evaluating PRS data. Plotting the relationship between beryllium and iron for PRS and background data allows observation of whether the PRS has elevated concentrations of beryllium relative to the range of iron concentrations. This graphical background comparison approach is discussed in more detail by Ryti et al. (1996, ER ID 53953).

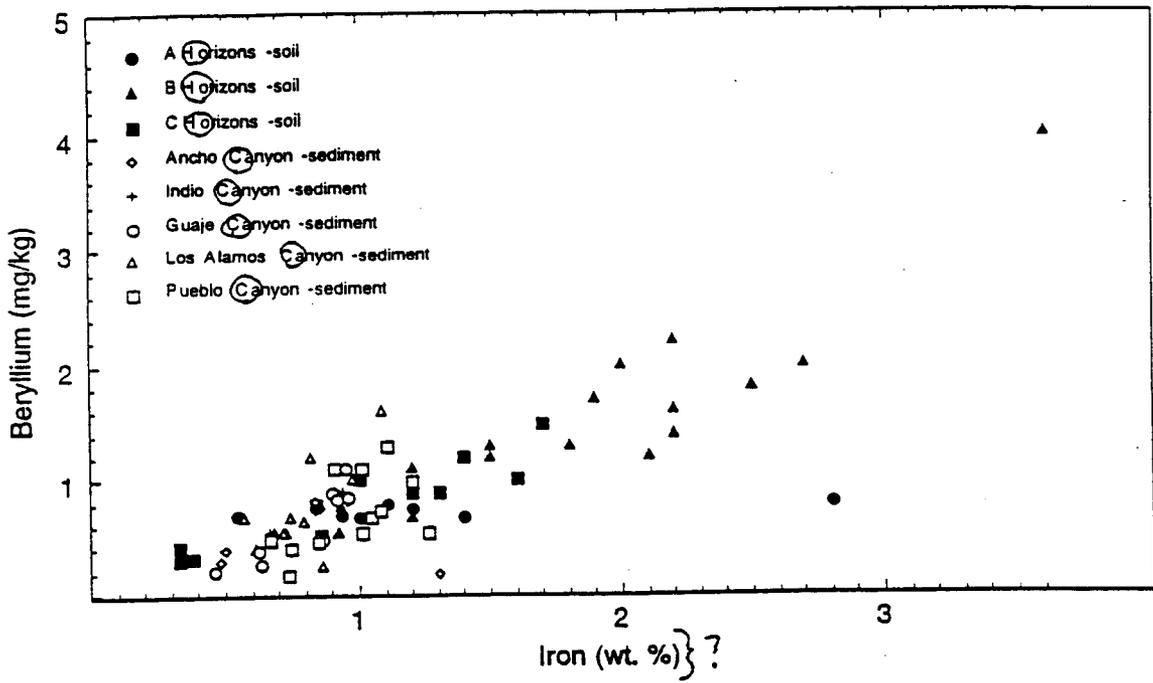


Fig. 3.1-2 HNO<sub>3</sub> extractable iron concentrations versus HNO<sub>3</sub> extractable beryllium concentrations in background soils in Los Alamos, New Mexico.

### 3.1.3.2 Thorium and Uranium Correlation

Thorium and uranium are actinide elements that occur naturally in the Bandelier Tuff and in soils forming on the Pajarito Plateau. These elements may also occur above background concentrations as a result of Laboratory activities. An understanding of background elemental distributions of thorium and uranium provides information on the distribution, fate, and transport of anthropogenic actinide elements through different geochemical evaluations.

Total (nonisotopic) thorium and total uranium concentrations from soil and tuff samples are positively correlated (see Figure 3.1-3). Total thorium and total uranium concentrations in soil samples collected from the B and C horizons generally fall within the background distribution for the Tshirege Member of the Bandelier Tuff, where tuff units Qbt 1g and 1v have the highest concentrations of thorium and uranium, followed by units Qbt2 and Qbt3 (Broxton et al. 1995, ER ID 52227; Longmire et al. 1995, ER ID 52227). However, several soil samples collected from A and transitional B horizons at mesa top sites (Technical Area [TA] 63 and TA-67, Table 3.1-1) contain elevated concentrations of uranium, which may represent aerosol dispersion of anthropogenic uranium from nearby firing sites used for testing and development of high explosives and weapons (Figure 3.1-3). These suspect high uranium values were excluded from the soils background data (Longmire et al. 1995, ER ID 52227).

### 3.1.4 Statistical Summary

The soil background data were evaluated for suspect values through a weight-of-evidence approach. This approach used information on the geochemical correlations, soil horizon designation, and significance of the suspect value relative to risk-based screening levels (NMED 1998, 57761). This evaluation led to the statistical distribution analysis, which was needed to calculate summary statistics, including UTL values. To facilitate comparisons between PRS data and soil background data, data from all soil types and horizons were used to calculate the UTL values. A graphical presentation of the soil background data is provided in Appendix A.

Table 3.1-3 presents summary statistics for inorganic chemicals, including the calculated UTL values. Frequency of detection for cadmium, mercury, and tantalum was too low to permit calculation of UTL values for these chemicals. Thus, the reported method detection limits will be used as BVs for cadmium (0.4 mg/kg), mercury (0.1 mg/kg), and tantalum (0.3 mg/kg). Because silver was not included in the analyte list for the background soil samples, silver's nominal method detection limit (1 mg/kg based on ICPES) will be used as a BV.

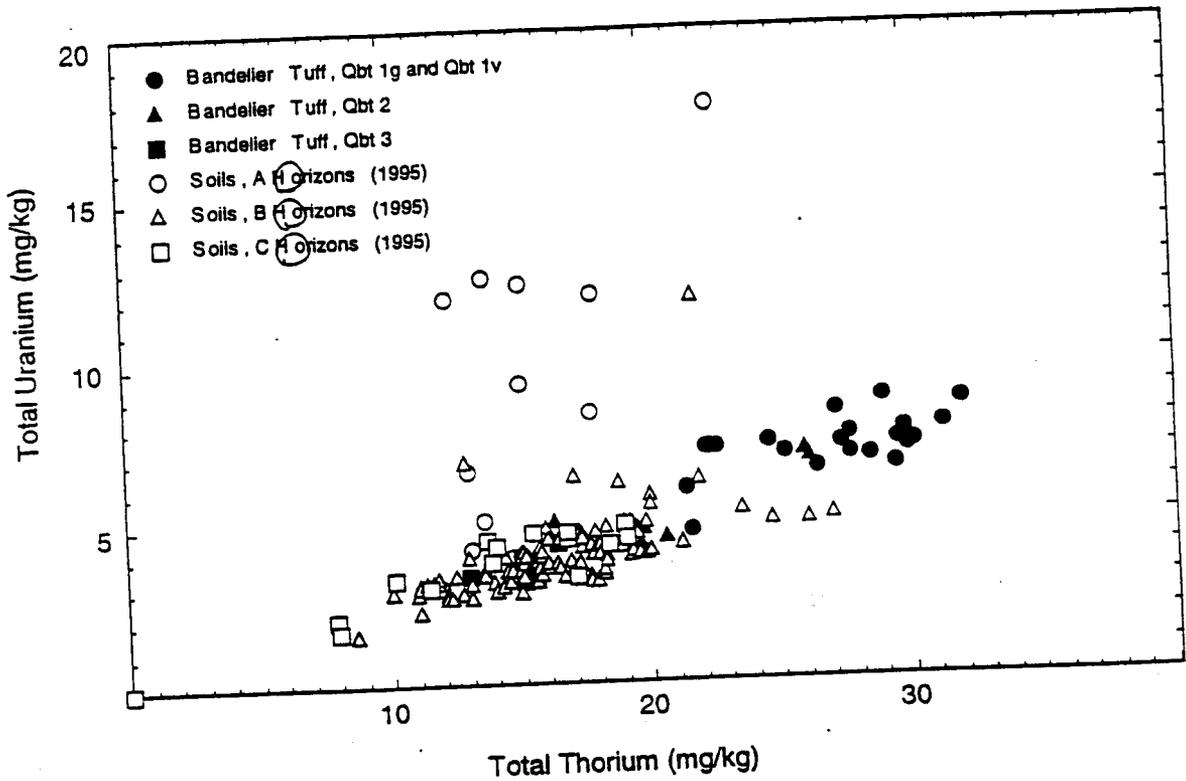


Fig. 3.1-3 Total (HF-extractable) thorium concentrations versus total uranium concentrations in Bandelier Tuff and background soils in Los Alamos, New Mexico.

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

**TABLE 3.1-3  
SUMMARY STATISTICS FOR INORGANIC CHEMICALS IN SOIL<sup>a</sup>**

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Aluminum	174	174	900	10,000	61,500	11,680	8,810	29,200
Antimony <sup>b</sup>	135	18	0.1	0.5	1	0.505	0.181	0.83
Arsenic	150	150	0.3	4	9.3	3.95	1.92	8.17
Barium	173	173	21	130	410	143	74.1	295
Beryllium	174	172	0.04	0.895	3.95	0.911	0.447	1.83
Cadmium	39	3	0.2	0.2	2.6	0.364	0.465	NC <sup>c</sup> (0.4)
Calcium	173	173	500	2,100	14,000	2,640	1,770	6,120
Chloride	174	174	8	14.45	303	28.1	42.6	231
Chromium	173	173	1.9	8.6	36.5	9.04	4.36	19.3
Cobalt <sup>d</sup>	131	131	1	5.3	9.5	5.16	1.85	8.64
Copper	174	172	0.25	5.75	16	6.06	2.59	14.7
Iron	174	174	3,300	12,000	36,000	12,150	4,260	21,500
Lead	173	164	2	12	28	12.7	5.25	22.3
Magnesium	174	174	420	1,975	10,000	2,160	1,150	4,610
Manganese	173	173	76	320	1,100	340	166	671
Mercury	39	2	0.05	0.05	0.1	0.053	0.011	NC (0.1)
Nickel	174	160	1	7	29	7.07	4.01	15.4
Potassium	174	174	410	1,600	6,850	1,750	786	3,460
Selenium	39	21	0.1	0.3	1.7	0.447	0.417	1.52
Sodium	174	174	58	225	1,800	304	292	915
Sulfate	174	173	6	28.5	1,200	62.5	126	293
Tantalum	174	0	0.06	0.1	0.45	0.182	0.132	NC (0.3)
Thallium	173	105	0.063	0.2	1	0.276	0.186	0.73
Thorium	174	174	2	8.2	21.6	8.59	2.98	14.6
Uranium	162	162	0.2	0.9	3.6	0.985	0.436	1.82
Vanadium	174	174	4	21	56.5	21.3	8.92	39.6
Zinc	172	172	14	30.75	75.5	31.5	9.00	48.8

a. Units are mg/kg.

b. Excludes ICPEs results, which were all reported as "<5 mg/kg."

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

d. Excludes first year of data because cobalt was introduced in sample preparation.

### 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<sup>a</sup>**

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

Laboratory operations area (see Figure 3.1-1 for locations). Third are locations that are farther from Los Alamos, which are sampled to provide estimates of the regional activity of fallout radionuclides (see Figure 3.3-1 for locations). Fallout values for radionuclides presented in this report are calculated from the perimeter and regional stations, with the exception of tritium. Tritium data from the TA-33 sampling station were excluded because of the proximity of this station to the TA-33 Tritium Facility, which was in operation until 1991.

### **3.3.2 Sample Collection, Preparation, and Analytical Techniques**

The Laboratory's annual environmental surveillance reports provide procedures for soil sample collection, QA/QC protocols, and data handling, validation, and tabulation (see, for example, Environmental Surveillance and Compliance Programs 1997, ER ID 56684). Briefly, sample collection involves laying out the four corners and center point of a 10-m square, collecting a 2-cm-deep core at each of these five locations, and compositing all five samples into a single sample for laboratory analysis. Analytical techniques are summarized in Table 3.3-1. The analytical methods are described in Volume II of "Health and Environmental Chemistry: Analytical Techniques, Data Management, and Quality Assurance" (LANL 1993, ER ID 31794). Tritium is measured by a distillation and liquid scintillation counting procedure (LANL Method ER210). Strontium-90 is measured by gas-flow proportional beta counting (LANL Method ER190). Cesium-137 is measured by gamma spectroscopy (LANL Method ER130). Plutonium-238, plutonium-239,240 (unresolved isotopes), and americium-241 are measured by chemical separation and alpha spectroscopy (LANL Method ER160 for plutonium isotopes and LANL Methods ER110 or ER160 for the americium isotope).

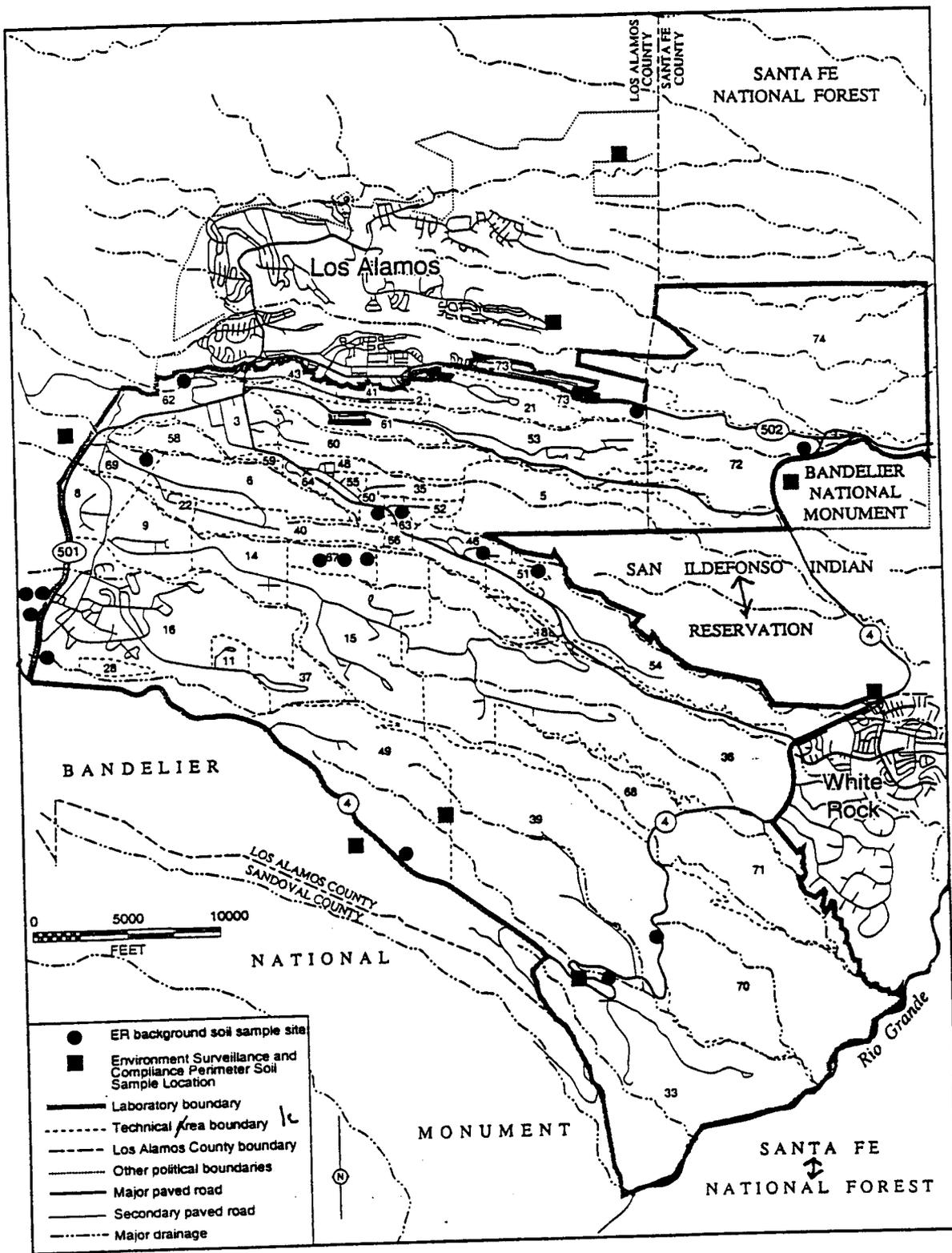


Figure 3.1-1 Distribution of soil sample sites and Environmental Surveillance Program perimeter sample locations at Los Alamos National Laboratory.

**TABLE 3.3-1**  
**SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL**  
**TECHNIQUES FOR RADIONUCLIDES AND TOTAL METALS IN SOIL**

Analyte	Sample Preparation Technique	Analytical Technique
Total Thorium	HF <sup>a</sup>	ICPMS <sup>b</sup>
Total Uranium	HF	ICPMS
Americium-241	Complete digest	α-spec <sup>c</sup>
Cesium-137	None	γ-spec <sup>d</sup>
Plutonium-238	Complete digest	α-spec
Plutonium-239,240	Complete digest	α-spec
Strontium-90	HNO <sub>3</sub> <sup>e</sup>	GPC <sup>f</sup>
Tritium	Distillation	LSC <sup>g</sup>
a. HF = Hydrofluoric acid digestion. b. ICPMS = Inductively coupled plasma mass spectrometry. c. α-spec = Alpha spectroscopy. d. γ-spec = Gamma spectroscopy. e. HNO <sub>3</sub> = Partial digestion using nitric acid. f. GPC = Gas proportional counting. g. LSC = Liquid scintillation counting.		

*Statistical*

**3.3.3 Summary**

Fallout radionuclide data apply to surface soil samples only (0- to 6-in. sample depth) because of the atmospheric deposition mechanism of these radionuclides. A graphical presentation of the fallout radionuclide data is provided in Appendix A.

Table 3.3-2 provides summary statistics for the soil fallout radionuclide data. These data represent samples collected and analyzed from 1991 to 1995. Data from the 1970s to 1980s were excluded, primarily because of a decreasing trend in the activity of the short-lived fallout radionuclides (tritium [half-life is 12.3 years], cesium-137 [half-life is 30.1 years], and strontium-90 [half-life is 28.8 years]). Suspect values in the remaining data were removed from the data, and UTLs were calculated based on either a lognormal or normal statistical distribution. There was no overall spatial pattern in the values excluded as outliers, and thus no way to ascribe a particular spatial effect of Laboratory operations on these fallout values. Detailed information on the data analysis and statistical methods used to calculate these values are presented by Campbell (1998, ER ID 57858).

**TABLE 3.3-2**  
**SUMMARY STATISTICS FOR FALLOUT RADIONUCLIDES IN SURFACE SOIL<sup>a</sup>**

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.

Second, "Natural Background Geochemistry of Sediments, Los Alamos National Laboratory" (McDonald et al. 1997, ER ID 55532) summarizes additional sediment samples collected from Los Alamos, Pueblo, and Guaje Canyons. McDonald et al. (1997, ER ID 55532) include the data from Indio and Ancho Canyons in their geochemical and statistical evaluation of sediment background.

#### **4.1 Sample Locations**

Figure 4.1-1 shows the sample locations for the sediment background investigations. Locations were selected to represent areas that are upstream of known Laboratory contaminant sources or from stratigraphic sections derived from uncontaminated, pre-Laboratory (pre-1942) sediments. The locations were also selected to obtain material from both channel and floodplain geomorphic settings. One sample was collected from an unusual sediment layer dominated by black magnetite sands. Because of the unique mineralogy of this sample, it was excluded from the sediment background data.

#### **4.2 Sample Collection, Preparation, and Analytical Techniques**

Samples were collected from surface deposits and bank exposures using methods similar to those employed for the background soils investigation (see Sections 3.1.2 and 3.3.2). To examine the relationship between sample grain size and concentration of inorganic chemicals and activity of radionuclides, several samples were field-sieved into two size fractions (the <2-mm size fraction and the <0.0625-mm size fraction). Reneau et al. (1995, ER ID 52227) used a slightly different sieve size, 0.075 mm, to represent the fine sediment fraction.

Inorganic chemicals were analyzed using EPA SW-846 methods or equivalent methods. Specific analytical techniques are summarized in Table 4.2-1. The techniques used were identical to the soil background investigation (see Table 3.1-2) except for the techniques used for antimony and thallium. Antimony and thallium in sediment samples were primarily or exclusively analyzed by ICPES, which is less sensitive than the ICPMS or GFAA techniques that were used for these elements in the soils investigation.

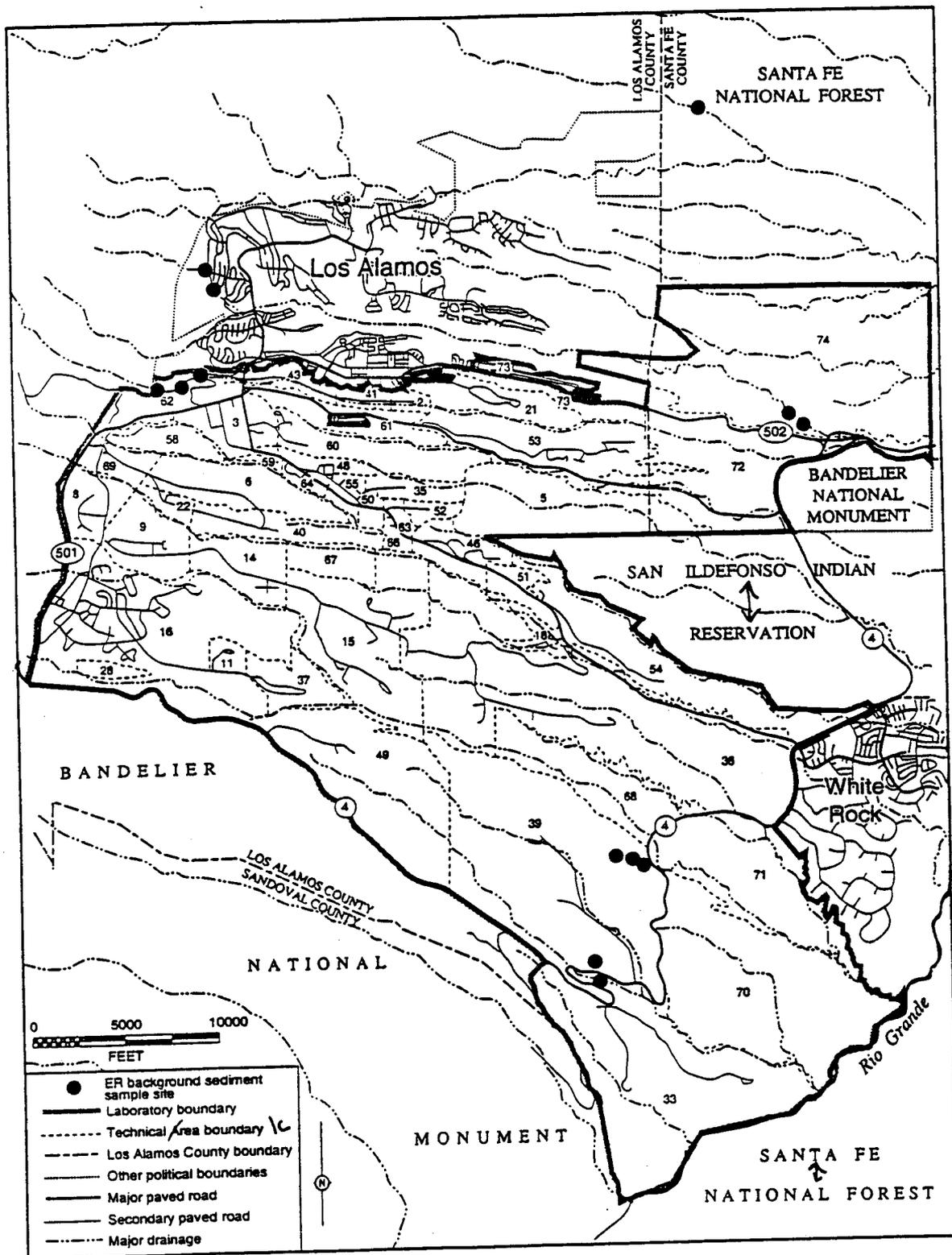


Figure 4.1-1 Distribution of background sediment sample sites at Los Alamos National Laboratory.

Radionuclides and total metals were analyzed by the methods summarized in Table 4.2-2. The radionuclide suite for sediments includes several analytes that are not included in the soils fallout radionuclide suite (see Table 3.3-1). The radionuclides include thorium isotopes, which were measured by alpha spectroscopy, and potassium-40 and radium-226, which were measured by gamma spectroscopy. Because of the relatively high minimum detectable activity for radium-226 by gamma spectroscopy, the radium-226 parent radionuclide activity (uranium-234) was used to estimate the activity of radium-226 (secular equilibrium suggests that the activity of radium-226 is equal to its parent radionuclide). In addition, the activity of radium-228 was estimated from its parent radionuclide (thorium-232) by assuming secular equilibrium between these radionuclides (see the discussion of secular equilibrium below in Section 4.3.2).

### 4.3 Statistical Summary

#### 4.3.1 Inorganic Chemicals

The canyon sediment background data include data from five canyons where samples included both channel and floodplain geomorphic units. A graphical presentation of the sediment background data is provided in Appendix A. The statistical evaluation of the canyon sediment data showed that the major source of variability was sample grain size. The fine fraction had higher concentrations of most analytes compared to the <2-mm size fraction, which is the result of a larger surface-area-to-mass ratio for the fine-fraction particles. The floodplain samples showed few differences from the channel samples, and the differences between samples from different canyons were also small.

Table 4.3-1 provides summary statistics for the canyon sediment background data for inorganic chemicals. Frequency of detection for cadmium, mercury, selenium, silver, and tantalum was too low to permit calculation of a UTL value for these chemicals. Thus, the reported detection limit will be used as a BV for cadmium (0.4 mg/kg), mercury (0.1 mg/kg), selenium (0.3 mg/kg), silver (1 mg/kg), and tantalum (0.3 mg/kg). For antimony and thallium, a less sensitive analytical method (ICPES) with a higher detection limit was used for the sediment background data than for the soils background data. Because a more sensitive method (ICPMS) was used for the soil background investigation, the soil UTL will be used as a <sup>surrogate</sup> BV for these chemicals. 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 4.2-1**  
**SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL**  
**TECHNIQUES FOR INORGANIC CHEMICALS IN CANYON SEDIMENTS**

Analyte	Sample Preparation Technique	Analytical Technique
Aluminum	3050A <sup>a</sup>	ICPES <sup>b</sup>
Antimony	3050A	ICPES
Arsenic	3050A	GFAA <sup>c</sup> /ICPES
Barium	3050A	ICPES
Beryllium	3050A	ICPES
Cadmium	3050A	ICPES
Calcium	3050A	ICPES
Chloride	Leach <sup>d</sup>	IC <sup>e</sup>
Chromium	3050A	ICPES
Cobalt	3050A	ICPES
Copper	3050A	ICPES
Cyanide	9012 <sup>f</sup>	Colorimetric
Iron	3050A	ICPES
Lead	3050A	ICPES
Magnesium	3050A	ICPES
Manganese	3050A	ICPES
Mercury	7471 <sup>g</sup>	CVAA <sup>h</sup>
Nickel	3050A	ICPES
Potassium	3050A	ICPES
Silver	3050A	ICPES
Selenium	3050A	ICPES
Sodium	3050A	ICPES
Sulfate	Leach	IC
Tantalum	3050A	ICPMS <sup>i</sup>
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 4.2-2**  
**SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL**  
**TECHNIQUES FOR RADIONUCLIDES AND TOTAL METALS IN CANYON SEDIMENTS**

Analyte	Sample Preparation Technique	Analytical Technique
Total Thorium	HF <sup>a</sup>	ICPMS <sup>b</sup>
Total Uranium	HF	ICPMS
Americium-241	Complete digest	$\alpha$ -spec <sup>c</sup>
Cesium-137	None	$\gamma$ -spec <sup>d</sup>
Plutonium-238	Complete digest	$\alpha$ -spec
Plutonium-239,240	Complete digest	$\alpha$ -spec
Potassium-40	None	$\gamma$ -spec
Radium-226	None	$\gamma$ -spec
Strontium-90	HNO <sub>3</sub> <sup>e</sup>	GPC <sup>f</sup>
Thorium-228	Complete digest	$\alpha$ -spec
Thorium-230	Complete digest	$\alpha$ -spec
Thorium-232	Complete digest	$\alpha$ -spec
Tritium	Distillation	LSC <sup>g</sup>
Uranium-234	Complete digest	ICPMS
Uranium-235	Complete digest	ICPMS
Uranium-238	Complete digest	ICPMS

a. HF = Hydrofluoric acid digestion.  
 b. ICPMS = Inductively coupled plasma mass spectrometry.  
 c.  $\alpha$ -spec = Alpha spectroscopy.  
 d.  $\gamma$ -spec = Gamma spectroscopy.  
 e. HNO<sub>3</sub> = Partial digestion using nitric acid.  
 f. GPC = Gas proportional counting.  
 g. LSC = Liquid scintillation counting.

**TABLE 4.3-1  
SUMMARY STATISTICS FOR INORGANIC CHEMICALS IN CANYON SEDIMENT<sup>a</sup>**

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 <sup>b</sup>	NA <sup>c</sup>	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 <sup>d</sup> (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 <sup>b</sup>	NA	NA	NA	NA	NA	NA	NA	0.73
Thorium	7	7	0.9	5.5	7	4.20	2.60	S <sup>e</sup> (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.

#### 4.3.2 Naturally Occurring Radionuclides and Discussion of Secular Equilibrium

✓ The naturally occurring radionuclides include uranium and thorium isotopes and their progeny (Table 4.3-2). Because of the short half-life associated with many of the naturally occurring isotopes, they are <sup>not</sup> of interest for risk or dose assessment purposes. The naturally occurring radioactive decay series resulting from uranium-238, uranium-235, and thorium-232 are examples in which the half lives of the parent nuclides are much longer than those of their respective progeny (Faure 1977, ER ID 58686) (Table 4.3-2). Therefore, the number of parent atoms remains constant for several half lives of the progeny. This universal condition in which the rate of decay of the progeny is equal to that of its parent is known as secular equilibrium (Faure 1977, ER ID 58686).

When secular equilibrium is established in a uranium- or thorium- bearing mineral, the decay rates of the intermediate progeny are equal to those of their respective parents (Faure 1977, ER ID 58686). The half-lives of uranium-238 and thorium-232 are very much longer than those of their respective progeny (Faure 1977, ER ID 58686). Therefore these decay series satisfy the prerequisite condition for the establishment of secular equilibrium. Over time, the activity of the radionuclides in the chain reaches a steady-state equilibrium. Thus, secular equilibrium would suggest that the activity of thorium-232 would be equal to the activity of thorium-228 if the mineral(s) containing the radionuclides is a closed system. Background media at LANL have not been assessed to determine whether they represent open or closed systems with respect to uranium and thorium isotopes. Because of the large concentration differences in nitric-acid-digested uranium and total uranium, however, it is likely that little natural uranium has been leached from soils, sediments, and Bandelier Tuff, supporting the concept of secular equilibrium (Longmire et al. 1995, ER ID 52227). Figures 4.3-1 and 4.3-2 show a strong correlation between radionuclides in the thorium and uranium decay series. In the thorium decay series, actinium-228 exhibits a relatively low correlation with the other radionuclides, which is a result of the imprecision associated with quantifying actinium-228 activity by gamma spectroscopy. A similar phenomenon can be observed in the uranium decay chain, where bismuth-214, radium-226, and thorium-234 are poorly quantified by gamma spectroscopy.

Table 4.3-3 provides summary statistics for the canyon sediment background data for radionuclides. UTL values for total thorium and uranium have been provided because measurement of total thorium and total uranium is typically done to investigate potential radionuclide releases. 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 for inorganic chemicals in Table 4.3-1. Because sediment background data for thorium

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 <sup>a</sup>
Thorium series	Thorium-232 <sup>b</sup>	14,000,000,000 years
	Thorium-228 <sup>b</sup>	1.9 years
	Actinium-228	6.2 hours
	Lead-212	11 hours
	Thallium-208	3.1 minutes
Actinium series	Uranium-235 <sup>b</sup>	700,000,000 years
Uranium series	Uranium-238 <sup>b</sup>	4,500,000,000 years
	Uranium-234 <sup>b</sup>	250,000 years
	Thorium-234	24 days
	Thorium-230 <sup>b</sup>	75,000 years
	Radium-226 <sup>b</sup>	1,600 years
	Lead-214	27 minutes
	Bismuth-214	20 minutes

<sup>a</sup> 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).

<sup>b</sup> Radionuclides of interest for risk or dose assessment purposes (half-life is greater than 30 days).

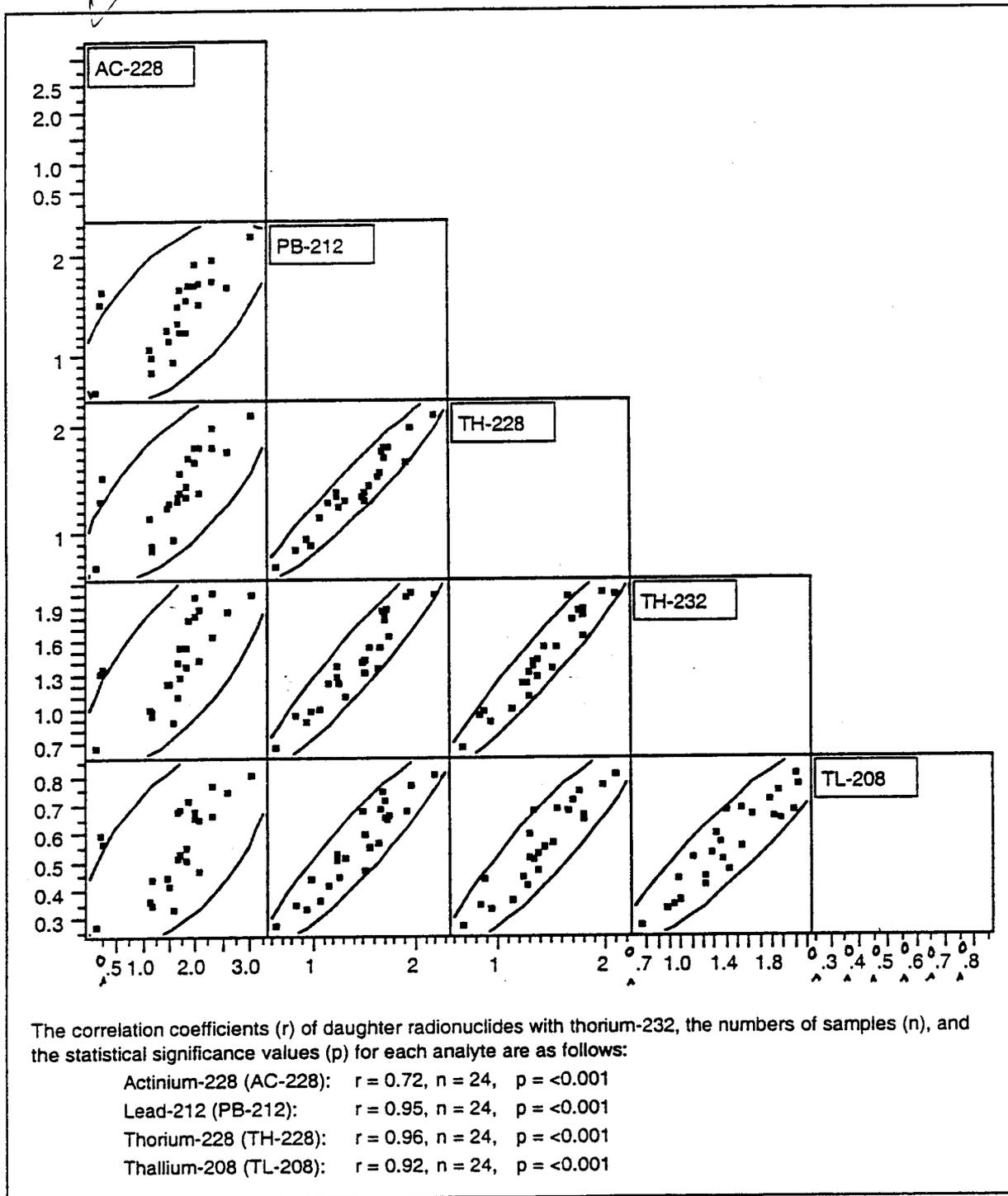


Figure 4.3-1 Cross-correlation between radionuclides in the thorium decay series.

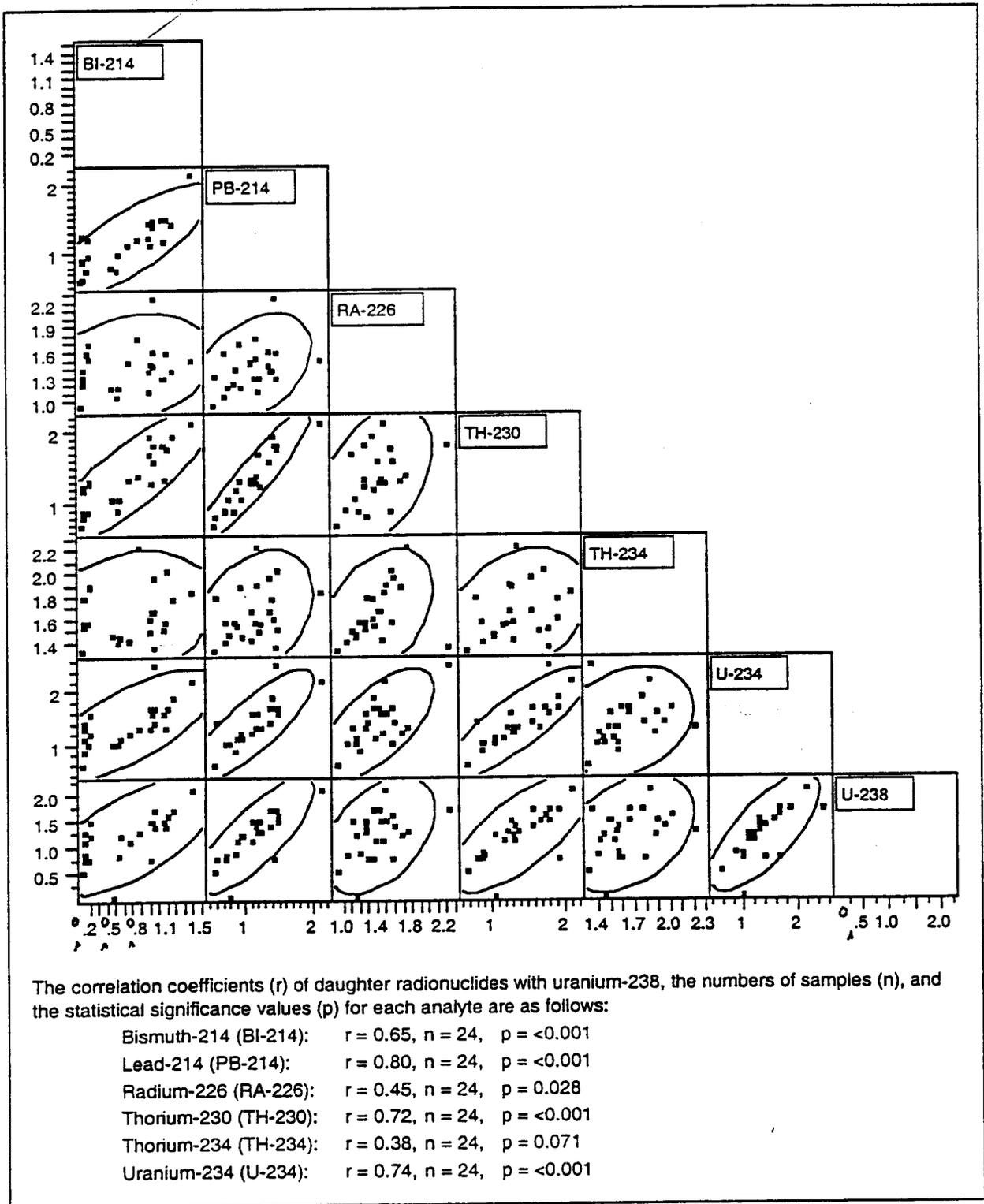


Figure 4.3-1 Cross-correlation between radionuclides in the uranium decay series.

**TABLE 4.3-3  
SUMMARY STATISTICS FOR NATURALLY  
OCCURRING RADIONUCLIDES IN CANYON SEDIMENTS<sup>a</sup>**

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Total Thorium	7	7	3.3	13	18	11.1	5.73	S <sup>b</sup> (22.4)
Total Uranium	31	31	0.7	4	7.2	3.76	1.46	6.99

a. Units are mg/kg.  
b. 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.

### 4.3.3 Fallout Radionuclides

The canyon sediment background data include data from three canyons where samples included both channel and floodplain geomorphic units. A graphical presentation of the sediment background data is provided in Appendix A. Fallout radionuclides include cesium-137, strontium-90, tritium, plutonium-238, and plutonium-239,240. The statistical evaluation of the canyon sediment data showed that the major source of variability for these radionuclides was sample grain size. The fine fraction had higher activities of most analytes compared to the <2-mm size fraction, which is the result of a larger surface-area-to-mass ratio for the fine fraction particles. The floodplain samples showed few differences from the channel samples, and the differences between samples from different canyons were also small.

Table 4.3-4 provides summary statistics for the canyon sediment background data for fallout radionuclides. Results for americium-241 and plutonium-239,240 were elevated in one sample. Because this sample did not seem to be drawn from the same statistical distribution as the other data, it was omitted to calculate summary statistics and UTL values for these radionuclides. There were no other suspect values for this sample, which was collected near the reservoir in Los Alamos Canyon and was located upstream of Laboratory activities. Activities of tritium (0.0856 pCi/g), cesium-137 (<0.12 pCi/g), plutonium-238 (0.003 pCi/g), and strontium-90 (1 pCi/g) are close to or less than the detection limits of liquid scintillation, gamma spectroscopy, alpha spectrometry, and gas-proportional counting, respectively. The activities of uranium-234, uranium-235, and uranium-238 in this sample are 1.6, 0.14, and 1.5 pCi/g, respectively. The concentrations of total and nitric-acid-digested uranium in this sample are 4.4 and 0.75 mg/kg, respectively, using ICPMS as the analytical method.

**TABLE 4.3-4  
SUMMARY STATISTICS FOR FALLOUT RADIONUCLIDES IN CANYON SEDIMENTS<sup>a</sup>**

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 <sup>b</sup>	NA <sup>c</sup>	NA	NA	NA	NA	NA	NA	2.59
Radium-228 <sup>d</sup>	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 tephra 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.

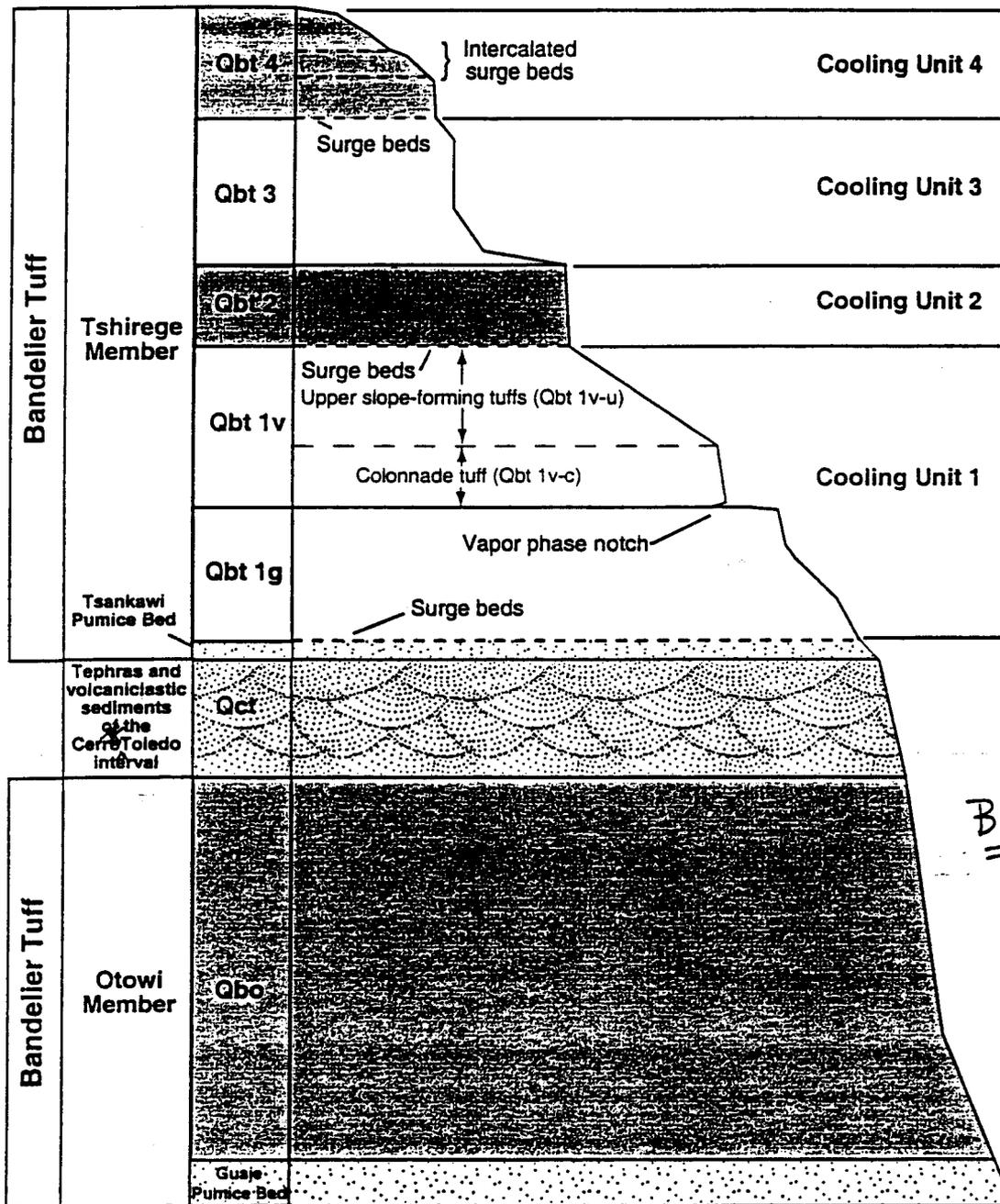


Figure 5.0-1 Schematic stratigraphic section showing rock units sampled for background chemistry (modified from Broxton and Reneau 1995, ER ID 49726).

## **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.

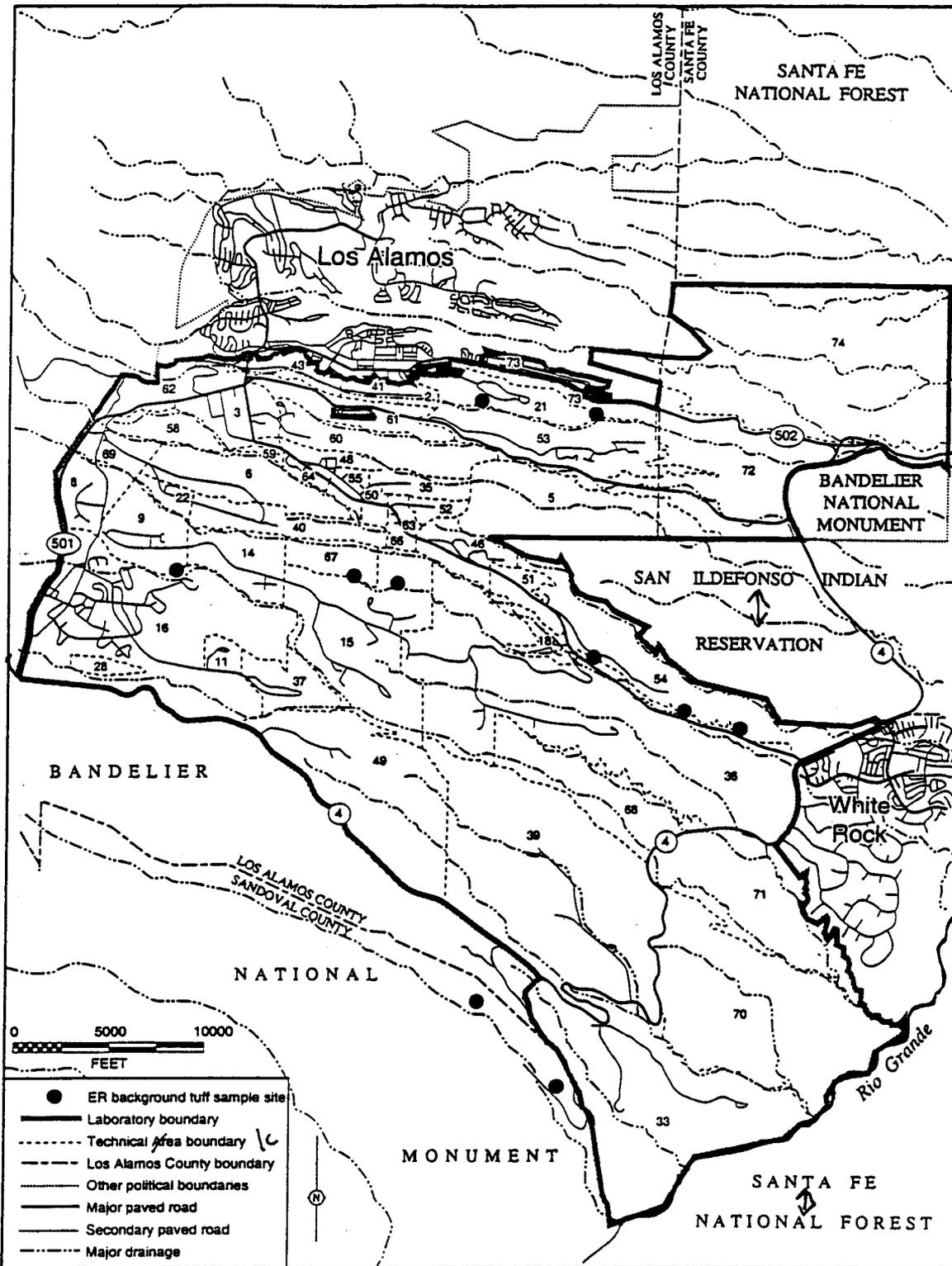


Figure 5.1-1 Distribution of background tuff sample sites.

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<sub>3</sub> 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 <sup>human or ecological</sup> 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<sub>3</sub> [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

thorium concentrations were determined by instrumental neutron activation analysis (INAA) and total uranium was determined by delayed neutron activation analysis (DNAA) at the Laboratory's Omega West reactor facility for the Frijoles Canyon data. Minor et al. (1982, ER ID 58683) and Garcia et al. (1982, ER ID XXXXX) provide additional information about analytical uncertainties, conditions of analysis, and detection limits for elements analyzed by INAA. Total thorium and total uranium were determined by ICPMS for the MDA P data. Activities of naturally occurring isotopes were calculated using total elemental concentrations and assuming secular isotopic equilibrium in the tuffs (see Section 4.3.2 for a discussion of the concept of secular equilibrium). Isotopic activities were calculated by multiplying the total element BV by the percent natural abundance of the isotope of interest and the specific activity of that isotope. Several progeny radionuclides were estimated from the parent radionuclide by assuming secular equilibrium (see Table 5.2-3).

Isotopic abundances are determined using mass spectrometry and these abundances are known with high precision (ranging from one thousandth to one ten-thousandth of one percent). The uncertainty in the last figure for isotopic abundance values is generally less than 5. For example, the isotopic abundances of uranium-234, uranium-235, and uranium-238 are reported as 0.0055%, 0.720%, and 99.2745%, respectively (Parrington et al. 1996, ER ID 58682). Samples have been observed, however, for which there is natural variation in isotopic abundances, especially for lithium-6 and boron-10 (Parrington et al. 1996, ER ID 58682). Natural variation in boron from 19.1% to 20.3% has been measured. Another example is potassium-40, which is naturally occurring. The isotopic abundance for potassium-40 is 0.0117%. The isotopic composition of potassium in natural samples is generally constant, even though fractionation of potassium isotopes has been observed on a small scale across contacts of igneous intrusions (Faure 1977, 58686).

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

Isotope	Half-life <sup>a</sup> (years)	Specific Activity <sup>a</sup> (pCi/g)	Natural Abundance <sup>a</sup>	Conversion Factor <sup>b</sup>
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 5.2-2  
SUMMARY OF SAMPLE PREPARATION AND  
ANALYTICAL TECHNIQUES FOR INORGANIC CHEMICALS IN TUFF**

Analyte	Sample Preparation Technique	Analytical Technique
Aluminum	3050A <sup>a</sup>	ICPES <sup>b</sup>
Antimony	3050A	ICPMS <sup>c</sup>
Arsenic	3050A	GFAA <sup>d</sup>
Barium	3050A	ICPES
Beryllium	3050A	ICPES
Cadmium	3050A	ICPES
Calcium	3050A	ICPES
Chloride	Leach <sup>e</sup>	IC <sup>f</sup>
Chromium	3050A	ICPES
Cobalt	Grinding	INAA <sup>g</sup>
Copper	3050A	ICPES
Iron	3050A	ICPES
Lead	3050A	ICPES
Magnesium	3050A	ICPES
Manganese	3050A	ICPES
Mercury	7471 <sup>h</sup>	CVAA <sup>i</sup>
Nickel	3050A	ICPES
Potassium	3050A	ICPES
Silver	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. INAA = Instrumental neutron activation analysis.  
h. 7471 = EPA SW-846 Method 7471.  
i. CVAA = Cold vapor atomic absorption spectroscopy.

**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 <sup>a</sup>
Total Thorium	Grinding	INAA/ICPMS <sup>b</sup>
Total Uranium	Grinding	DNAA <sup>c</sup> /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).

In the Bandelier Tuff unit 1v (Qbt 1v) and the lower Bandelier Tuff (Qbt 1g, Qct, Qbo) background data, the frequency of detection for antimony, cadmium, nickel, and silver was too low to permit calculation of UTL values for these chemicals. Thus, the nominal detection limits are used as BVs for antimony (0.5 mg/kg), cadmium (0.4 mg/kg), nickel (2 mg/kg), and silver (1 mg/kg). Selenium analysis was not conducted; therefore a nominal detection limit of 0.3 mg/kg is used as a BV.

**TABLE 5.3-1  
SUMMARY STATISTICS FOR  
INORGANIC CHEMICALS IN THE UPPER BANDELIER TUFF (Qbt 2, 3, 4)<sup>a</sup>**

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Aluminum	63	63	350	1,900	8,370	2,520	2,020	7,340
Antimony	64	6	0.05	0.15	0.4	0.125	0.065	NC <sup>b</sup> (0.5)
Arsenic	64	46	0.25	0.7	5	0.881	0.833	2.79
Barium	63	63	1.4	19	51.6	20.9	12.5	46.0
Beryllium	64	59	0.04	0.555	1.8	0.557	0.324	1.21
Cadmium	15	14	0.1	0.83	1.5	0.797	0.324	1.63
Calcium	64	64	200	595	2,230	759	520	2,200
Chloride	64	64	4.2	14.45	465	33.3	69.9	94.6
Chromium	64	48	0.25	1.35	13	1.98	2.13	7.14
Copper	64	34	0.25	0.665	6.2	1.36	1.40	4.66
Iron	64	64	190	5,225	19,500	5,880	4,310	14,500
Lead	63	63	1.6	4.4	15.5	5.31	2.92	11.2
Magnesium	64	64	39	225	2,820	489	575	1,690
Manganese	64	64	22	210	752	223	129	482
Nickel	63	16	0.5	1	7	1.87	1.71	6.58
Potassium	64	64	250	480	4,720	1,040	943	3,500
Selenium	15	0	0.1	0.1	0.105	0.101	0.002	NC (0.3)
Silver	64	1	0.2	0.5	1.9	0.452	0.224	NC (1)
Sodium	64	64	130	305	7,700	775	1,080	2,770
Sulfate	64	64	1.6	11.65	1,430	60.3	200	157
Tantalum	49	7	0.1	0.15	2	0.203	0.288	1.16
Thallium	64	14	0.05	0.15	1.7	0.233	0.331	1.10
Thorium	49	49	1.9	5.6	10.4	5.91	1.88	10.8
Uranium	49	49	0.2	0.8	5	0.951	0.738	2.40
Vanadium	64	59	0.25	2.6	21	3.93	4.03	17.0
Zinc	64	64	5.5	36.5	65.6	33.5	14.9	63.5

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

**TABLE 5.3-2**  
**SUMMARY STATISTICS FOR**  
**INORGANIC CHEMICALS IN BANDELIER TUFF UNIT 1v (Qbt 1v)<sup>a</sup>**

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 <sup>b</sup> (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	<i>no data</i> 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	<i>no data</i> 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.

**TABLE 5.3-3**  
**SUMMARY STATISTICS FOR INORGANIC**  
**CHEMICALS IN THE LOWER BANDELIER TUFF (Qbt 1g, Qct, Qbo)<sup>a</sup>**

Analyte	Count	Count of Detects	Minimum	Median	Maximum	Mean	Standard Deviation	UTL
Aluminum	26	26	490	1,450	3,400	1,510	751	3,560
Antimony	26	1	0.1	0.1	0.2	0.125	0.029	NC <sup>b</sup> (0.5)
Arsenic	25	5	0.25	0.25	0.7	0.308	0.124	0.56
Barium	26	26	3.6	11	23	12.5	5.82	25.7
Beryllium	26	24	0.07	0.395	1.4	0.514	0.406	1.44
Cadmium	0	no data	0	0	0	0	0	NC (0.4)
Calcium	25	25	210	590	2,300	694	463	1,900
Chloride	26	26	3.65	16.2	384	82.1	120	474
Chromium	26	19	0.25	0.81	2.3	0.900	0.523	2.60
Copper	26	19	0.25	2.1	2.6	1.74	0.672	3.96
Iron	26	26	730	1,550	3,700	1,730	865	3,700
Lead	26	26	2	4.05	20	5.04	3.70	13.5
Magnesium	26	26	69	240	690	282	165	739
Manganese	26	26	38	73.5	210	91.0	42.9	189
Nickel	26	2	1	1	2.8	1.11	0.397	NC (2)
Potassium	26	26	440	1,030	2,500	1,100	464	2,390
Selenium	0	no data	0	0	0	0	0	NC (0.3)
Silver	26	0	0.5	0.5	1	0.596	0.201	NC (1)
Sodium	26	26	450	1,600	3,500	1,640	784	4,350
Sulfate	26	26	1.64	23.8	815	148	214	1,120
Tantalum	26	3	0.1	0.125	0.9	0.165	0.159	0.95
Thallium	26	9	0.1	0.15	0.9	0.235	0.208	1.22
Thorium	26	26	0.9	1.5	8.8	1.92	1.57	4.51
Uranium	26	14	0.1	0.2	1.6	0.258	0.292	0.72
Vanadium	26	18	0.2	1.1	3.8	1.21	0.914	4.59
Zinc	26	26	5.3	11	46	15.5	10.8	40.0

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)<sup>a</sup>**

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)<sup>a</sup>**

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)<sup>a</sup>**

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.								

### **5.3.3 Fallout Radionuclides**

There are no background data for fallout radionuclides in tuff because background tuff samples were collected from mostly unweathered locations where the tuff would not be expected to be exposed to anthropogenic fallout. Thus, the minimum detectable activities should be used as fallout values for americium-241 (0.05 pCi/g using alpha spectroscopy), cesium-137 (0.1 pCi/g using gamma spectroscopy), plutonium-238 (0.05 pCi/g using alpha spectroscopy), plutonium-239,240 (0.05 pCi/g using alpha spectroscopy), strontium-90 (1 pCi/g using gas proportional counting), and tritium in tuff (0.3 pCi/mL using liquid scintillation counting).

## **6.0 SUMMARY**

The BVs developed for making initial comparisons between PFS and background data are summarized by media in Tables 6.0-1 and 6.0-2. Table 6.0-1 presents the background data for inorganic chemicals by media. The rationale for these values was presented in Sections 3.1.4, 4.3.1, and 5.3.1. Table 6.0-2 presents the background for radionuclides by media, and the rationale for these values was presented in Sections 3.2, 3.3.3, 4.3.2, 4.3.3, 5.3.2, and 5.3.3.

## 8.0 REFERENCES

Birkeland, P. W., 1984. *Soils and Geomorphology*, Oxford University Press, New York, New York. (Birkeland 1984, ER ID 44019)

Box, G. E. P., and D. R. Cox, 1964. "An Analysis of Transformations," *Journal of the Royal Statistical Society, Series B*, Vol. 26, pp. 211–243. (Box and Cox 1964, ER ID 57572)

Broxton, D. E., and S. L. Reneau, August 1995. "Stratigraphic Nomenclature of the Bandelier Tuff for the Environmental Restoration Project at Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-13010-MS, Los Alamos, New Mexico. (Broxton and Reneau 1995, ER ID 49726)

Broxton, D. E., C. LaDelfe, S. J. Chipera, and E. C. Kluk, in review. "Stratigraphy, Mineralogy, and Chemistry of Bedrock Tuffs at Mesita del Buey, Los Alamos National Laboratory, New Mexico," Los Alamos National Laboratory report, Los Alamos, New Mexico. (Broxton et al. in review, ER ID 57571)

Broxton, D. E., D. Vaniman, S. J. Chipera, E. C. Kluk, and R. G. Warren, December 1, 1995. "Stratigraphy, Mineralogy and Chemistry of Tuffs at Pajarito Mesa," *Geological Site Characterization for the Proposed Mixed Waste Disposal Facility, Los Alamos National Laboratory*, Los Alamos National Laboratory Report LA-13089-MS, Los Alamos, New Mexico, pp. 5–30. (Broxton et al. 1995, ER ID 54709)

Broxton, D. E., G. H. Heiken, S. J. Chipera, and F. M. Byers, Jr., June 1995. "Stratigraphy, Petrography, and Mineralogy of Bandelier Tuff and Cerro Toledo Deposits," in *Earth Science Investigation for Environmental Restoration—Los Alamos National Laboratory Technical Area 21*, Los Alamos National Laboratory Report LA-12934-MS, Los Alamos, New Mexico, pp. 33–63. (Broxton et al. 1995, ER ID 50121)

Broxton, D. E., R. T. Rytty, D. Carlson, R. G. Warren, E. Kluk, and S. Chipera, March 20, 1996. "Natural Background Geochemistry of the Bandelier Tuff at MDA P, Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-UR-96-1151, Los Alamos, New Mexico. (Broxton et al. 1996, ER ID 54948)

Broxton, D. E., R. T. Ryti, S. L. Reneau, C. Duffy, and P. A. Longmire, October 1, 1995. "Natural Background Geochemistry of the Bandelier Tuff and Other Rock Units, Los Alamos, New Mexico," in *Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles, Sediments, and Bandelier Tuff, Los Alamos, New Mexico*, Los Alamos National Laboratory Report LA-UR-95-3468, Los Alamos, New Mexico. (Broxton et al. 1995, ER ID 52227)

Campbell, K., February 1998. "Baseline Data for Fallout Radionuclides at LANL," Los Alamos National Laboratory Report LA-UR-98-958, Los Alamos, New Mexico. (Campbell 1998, ER ID 57858)

Environmental Surveillance and Compliance Programs, September 1997. "Environmental Surveillance and Compliance at Los Alamos during 1996," Los Alamos National Laboratory Report LA-13343-ENV, Los Alamos, New Mexico. (Environmental Surveillance and Compliance Programs 1997, ER ID 56684)

EPA (US Environmental Protection Agency), May 1987. "Test Methods for Evaluating Solid Waste, Laboratory Manual, Physical/Chemical Methods," SW-846, Third Edition, Update III, Washington, DC. (EPA 1997, ER ID 57589)

EPA (US Environmental Protection Agency), April 1, 1989, "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities," Interim final guidance, Office of Solid Waste, Waste Management Division, Washington, DC. (EPA 1989, ER ID 54946)

EPA (US Environmental Protection Agency), April 1, 1992, "Guidance for Data Usability in Risk Assessment (Part A)," Publication 9285.7-09A, Office of Emergency Remedial Response, Washington, DC. (EPA 1992, ER ID 54947)

Faure, G., 1977. *Principles of Isotope Geology*, John Wiley & Sons, Inc., New York, New York. (Faure 1977, ER ID 58686)

Garcia, S. R., W. K. Hensley, M. M. Minor, M. Denton, and M. A. Fuka, Month 1982. "An Automated Multidetector System for Instrumental Neutron Activation Analysis of Geologic and Environmental Materials," in *Atomic and Nuclear Methods in Fossil Energy Research*, Plenum, New York, New York, pp. 133-140. (Garcia et al. 1982, ER ID XXXXX)

Gilbert, R. O., 1987. *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, New York. (Gilbert 1987, ER ID 56179)

LANL (Los Alamos National Laboratory), May 1991. "Environmental Restoration Standard Operating Procedures," Vol. I-II, Los Alamos, New Mexico. (LANL 1991, ER ID 21556)

LANL (Los Alamos National Laboratory), July 1993. "Health and Environmental Chemistry: Analytical Techniques, Data Management, and Quality Assurance," Los Alamos National Laboratory Report LA-10300-M, Vol. II, Los Alamos, New Mexico. (LANL 1993, ER ID 31794)

LANL (Los Alamos National Laboratory), July 1993. "Health and Environmental Chemistry: Analytical Techniques, Data Management, and Quality Assurance," Los Alamos National Laboratory Report LA-10300-M, Vol. IV, Los Alamos, New Mexico. (LANL 1993, ER ID 31796)

Longmire, P., S. Reneau, P. Watt, L. McFadden, J. Gardner, C. Duffy, and R. Rytı, May 1, 1996. "Natural Background Geochemistry, Geomorphology, and Pedogenesis of Selected Soil Profiles and Bandelier Tuff, Los Alamos, New Mexico," Los Alamos National Laboratory Report LA-12913-MS, Los Alamos, New Mexico. (Longmire et al. 1996, ER ID 55115)

Longmire, P. A., E. V. McDonald, R. T. Rytı, S. L. Reneau, and P. M. Watt, October 1, 1995. "Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles, Los Alamos, New Mexico," *Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles, Sediments, And Bandelier Tuff, Los Alamos, New Mexico*, Los Alamos National Laboratory Report LA-UR-95-3468, Los Alamos, New Mexico. (Longmire et al. 1995, ER ID 52227)

McDonald, E., R. T. Rytı, S. L. Reneau, D. Carlson, and J. Harris, September 1997. "Natural Background Geochemistry of Sediments, Los Alamos National Laboratory," (draft), Los Alamos National Laboratory report, Los Alamos, New Mexico. (McDonald et al. 1997, ER ID 55532)

McDonald, E. V., P. A. Longmire, P. M. Watt, R. T. Rytı, and S. L. Reneau, September 1996. "Natural Major and Trace Element Background Geochemistry of Selected Soil Profiles, Los Alamos, New Mexico," *New Mexico Geological Society Guidebook*, 47th Field Conference, Jemez Mountains Region, pp. 375-382. (McDonald et al. 1996, ER ID 58235)

Minor, M. M., W. K. Hensley, M. M. Denton, and S. R. Garcia, 1982. "An Automated Activation Analysis System," *Journal of Radioanalytical Chemistry*, Vol. 70, No. 1-2, pp. 459-471. (Minor et al. 1982, ER ID 58683)

NMED (New Mexico Environment Department), March 3, 1998. *Risk-Based Decision Tree*, Santa Fe, New Mexico. (NMED 1998, ER ID 57761)

Nyhan, J. W., L. W. Hacker, T. E. Calhoun, and D. L. Young, June 1978. "Soil Survey of Los Alamos County, New Mexico," Los Alamos Scientific Laboratory Report LA-6779-MS, Los Alamos, New Mexico. (Nyhan et al. 1978, ER ID 05702)

Parrington, Josef R., H. D. Knox, S. L. Breneman, E. M. Baum, and F. Feiner, 1996. *Nuclides and Isotopes, Chart of the Nuclides*, fifteenth edition, General Electric Co. and KAPL, Inc., San Jose, California. (Parrington et al. 1996, ER ID 58682)

Reneau, S. L., P. A. Longmire, K. Campbell, and E. V. McDonald, October 1, 1995. "Geochemistry of Background Sediment Samples at Technical Area 39," *Natural Background Geochemistry and Statistical Analysis of Selected Soil Profiles, Sediments, and Bandelier Tuff, Los Alamos, New Mexico*, Los Alamos National Laboratory Report LA-UR-95-3468, Los Alamos, New Mexico. (Reneau et al. 1995, ER ID 52227)

Ryti, R., P. Longmire, and E. McDonald, March 29, 1996. "Application of LANL Background Data to ER Project Decision-Making, Part I: Inorganics in Soils, Sediments, and Tuff," Los Alamos National Laboratory Report LA-UR-96-1534, Los Alamos, New Mexico. (Ryti et al. 1996, ER ID 53953)

Soil Conservation Survey, Month 1981. "Examination and Description of Soils in the Field," *Soil Survey Manual*, (USDA-ARS), Washington, D.C. (Soil Conservation Survey 1981, ER ID XXXXX)

Sposito, G., 1984. *The Surface Chemistry of Soils*, Oxford University Press, New York, New York. (Sposito 1984, ER ID 58684)

Sposito, G., 1989. *The Chemistry of Soils*, Oxford University Press, New York, New York. (Sposito 1989, ER ID 58685)

Wolter, K. M., 1985. *Introduction to Variance Estimation*, Springer-Verlag, New York, New York. (Wolter 1985, ER ID 57573)

## 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.

The following figures are included in this appendix:

- Figure A-1 presents the standard normal probability plots for the inorganic chemicals in soil data.
- Figure A-2 presents the standard normal probability plots for the fallout radionuclides in soils data.
- Figure A-3 presents the standard normal probability plots for the inorganic chemicals in sediment data.
- Figure A-4 presents the standard normal probability plots for the radionuclides in sediment data.
- Figure A-5 presents the standard normal probability plots for the inorganic chemicals in upper Bandelier Tuff (Qbt 2,3,4) data.
- Figure A-6 presents the standard normal probability plots for the inorganic chemicals in Bandelier Tuff unit 1v (Qbt 1v) data.
- Figure A-7 presents the standard normal probability plots for the inorganic chemicals in lower Bandelier Tuff (Qbt 1g, Qct, Qbo) data.

**TABLE 6.0-1  
SUMMARY OF BACKGROUND VALUES BY MEDIA FOR INORGANIC CHEMICALS<sup>a</sup>**

Analyte	Soil	Canyon Sediment	Qbt 2,3,4 <sup>b</sup>	Qbt 1v <sup>b</sup>	Qbt 1g, Qct, Qbo <sup>b</sup>
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 <sup>c</sup>	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.

**TABLE 6.0-2  
SUMMARY OF BACKGROUND VALUES BY MEDIA FOR RADIONUCLIDES<sup>a</sup>**

Analyte	Soil	Canyon Sediment	Qbt 2,3,4 <sup>b</sup>	Qbt 1v <sup>b</sup>	Qbt 1g, Qct, Qbo <sup>b</sup>
Total Thorium <sup>c</sup>	22.4	22.4	22.9	34.1	44.5
Total Uranium	5.40	6.99	5.79	9.14	11.7
Americium-241	0.013 <sup>d</sup>	0.040	0.05 <sup>e</sup>	0.05 <sup>e</sup>	0.05 <sup>e</sup>
Cesium-137	1.65 <sup>d</sup>	0.90	0.1 <sup>e</sup>	0.1 <sup>e</sup>	0.1 <sup>e</sup>
Plutonium-238	0.023 <sup>d</sup>	0.006	0.05 <sup>e</sup>	0.05 <sup>e</sup>	0.05 <sup>e</sup>
Plutonium-239 <sup>f</sup>	0.054 <sup>d</sup>	0.068	0.05 <sup>e</sup>	0.05 <sup>e</sup>	0.05 <sup>e</sup>
Potassium-40	36.8	36.8	35.7	33.9	44.5
Radium-226	2.59	2.59	1.98	3.12	4.00
Radium-228	2.33	2.33	2.52	3.75	4.90
Strontium-90	1.31 <sup>d</sup>	1.30	1 <sup>e</sup>	1 <sup>e</sup>	1 <sup>e</sup>
Thorium-228	2.28	2.28	2.52	3.75	4.90
Thorium-230	2.29	2.29	1.98	3.12	4.00
Thorium-232	2.33	2.33	2.52	3.75	4.90
Tritium	0.76 <sup>d,g</sup>	0.093	0.3 <sup>e,g</sup>	0.3 <sup>e,g</sup>	0.3 <sup>e,g</sup>
Uranium-234	2.59	2.59	1.98	3.12	4.00
Uranium-235	0.20	0.20	0.09	0.14	0.18
Uranium-238	2.29	2.29	1.93	3.05	3.90

a. Units are pCi/g, unless noted otherwise.  
 b. Represents background for unweathered tuff.  
 c. Whole sample result was determined by total HF digest or neutron activation analysis, where units are mg/kg.  
 d. Value applies to samples collected from 0-6 in. only.  
 e. Nominal minimum detectable activity.  
 f. Sometimes also reported with analyte name of plutonium-239/240.  
 g. Units are pCi/mL soil moisture. To convert to pCi/g, use the following equation:  

$$BV(\text{per unit mass}) = BV(\text{per unit moisture}) \times m / (100 - m)$$
 where  $m$  = percent soil moisture of sample.

## 7.0 ACKNOWLEDGMENTS

This work was conducted as part of the Laboratory's ER Project, supported by the Earth Science Technical Team (Framework Studies), the Earth Science Technical Council, the Decision Support Council, Field Unit 4, and the MDA P Closure Program. The authors thank Deb Carlson for statistical programming support.