Carlsbad Environmental *Monitoring & Research Center*

2005/2006

Report

2005/2006 Report
Carlsbad Environmental Monitoring & Research Center

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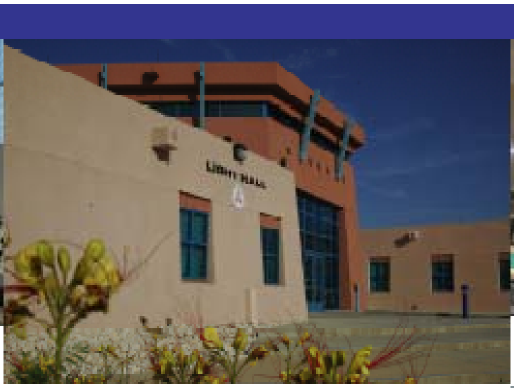
Acronyms and Abbreviations

μBq	microBecquerel
μm	micrometer
AA, AAS	atomic absorption, atomic absorption spectrometry
Ag	silver
Al	aluminum
Am	americium
As	arsenic
ASTM	American Society for Testing and Materials
Ba	barium
Be	beryllium
Bq	Becquerel
C	centigrade
Ca	calcium
Cd	cadmium
Ce	cerium
CEMRC	Carlsbad Environmental Monitoring & Research Center
CEMRP	Carlsbad Environmental Monitoring & Research Program
CFR	Code of Federal Regulations
Ci	Curie
CLP	Contract Laboratory Program
cm	centimeter
Cm	curium
Co	cobalt
Cr	chromium
CRDL	Contract Required Detection Limit
CRM	certified reference materials
Cs	cesium
Cu	copper
DL	detection limit
DOE	U.S. Department of Energy
Dy	dysprosium
EM	Environmental Monitoring
EML	Environmental Monitoring Laboratory
EPA	U.S. Environmental Protection Agency
Er	erbium
ERA	Environmental Research Associates
Eu	europium
F	fluoride
Fe	iron
FY	fiscal year
g	gram
Gd	gadolinium
Ge	germanium
GPS	global positioning satellite
HCl	hydrochloric acid
$HClO_4$	perchloric acid
HF	hydrofluoric acid
Hg	mercury

HNO_3	nitric acid
H_2O_2	hydrogen peroxide
hr	hour
IC	ion chromatography
ICP-MS	inductively coupled plasma-mass spectrometry
K	potassium
km	kilometer
L	liter
La	lanthanum
LaF_3	lanthanum fluoride
lb	pound
LDBC	"Lie Down and Be Counted"
LFB	Laboratory Fortified Blank
LFM	Laboratory Fortified Matrix
Li	lithium
LRB	Laboratory Reagent Blanks
m	meter
mb	millibar
MBL	mobile bioassay laboratory
mBq	milliBecquerel
MDC	minimum detectable concentration
Mg	magnesium
min	minute
MJ	megajoule
mL	milliliter
mm	millimeter
Mn	manganese
Mo	molybdenum
Na	sodium
NaOH	sodium hydroxide
Nd	neodymium
Ni	nickel
NIST	National Institute of Standards and Technology
nm	nanometer
NMSU	New Mexico State University
Np	neptunium
ORNL	Oak Ridge National Laboratory
p	probability
Pa	protactinium
Pb	lead
pH	scale indicating acidity or alkalinity of a substance
PM_{10}	particulate matter smaller than 10 micrometers in aerodynamic diameter
$PM_{2.5}$	particulate matter smaller than 2.5 micrometers in aerodynamic diameter
Pr	praseodymium
PRB	Program Review Board
Pu	plutonium
QA	quality assurance
QAP	quality assurance program
QC	quality control
RIP	Radiochemistry Intercomparison Program
Ru	ruthenium
SAB	Science Advisory Board

Sb	antimony
Sc	scandium
SD	standard deviation
Se	selenium
SE	standard error
sec	second
Sm	samarium
Sn	tin
Sr	strontium
$T_{1/2}$	half-life
Th	thorium
Ti	titanium
TIMS	thermal ionization mass spectrometry
Tl	thallium
TSP	total suspended particulates
U	uranium
UVB	Ultra-Violet B
V	vanadium
W	watt
WERC	Waste-management Education & Research Consortium
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WTS	Westinghouse TRU Solutions


New VOC GC-MS Laboratory



Light Hall – Home of CEMRC

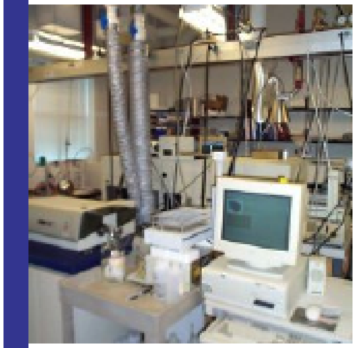

Plutonium-Glove Box in New Radiochemistry Laboratory

FOREWORD

This report was written, edited and produced collaboratively by the staff of the Carlsbad Environmental Monitoring & Research Center (CEMRC), who are hereby acknowledged for their contributions to the report and the project activities described herein. The first Section is an overview of the current program activities, structure, resources and quality assurance. The second section consists of data summaries as specific chapters containing methods and descriptions of results of studies in the WIPP Environmental Monitoring project and other activities at CEMRC during 2005/2006.

Production of this report is supported as part of the Carlsbad Environmental Monitoring and Research Center, a grant from the U.S. Department of Energy to New Mexico State University (DE-FG04-91-AL74167). The issuance of this report and other publications fulfills a CEMRC mission in making the results of CEMRC research available for public access.

This year's cover photograph is of the entrance to the CEMRC facility. The Foreword shows various equipment and laboratories used by scientists at CEMRC.


Inductively Coupled Plasma-Mass Spectrometer


Oxford/Canberra Oasis Alpha Spectrometer


GC-MS for Head Space Gas


Hivol air samplers near WIPP


Lung Counter


Student Training in Radiological Issues


A citizen getting a whole body count

OVERVIEW

Current Program Status

HISTORY

The Carlsbad Environmental Monitoring and Research Center (CEMRC) was established in 1991 with a grant from the U.S. Department of Energy (DOE). The primary goals of the CEMRC are to:

- Establish a permanent center of excellence to anticipate and respond to emerging health and environmental needs, and
- Develop and implement an independent health and environmental monitoring program in the vicinity of the DOE Waste Isolation Pilot Plant (WIPP), and make the results easily accessible to all interested parties.

CEMRC is a division of the College of Engineering at New Mexico State University (NMSU). Under the terms of the grant from DOE, the design and conduct of research for environmental monitoring at the WIPP are carried out independently of the DOE, and the production and release of resulting reports do not require DOE review or approval. A brief history of the CEMRC is presented in Appendix A.

The CEMRC is operated as a research institute within NMSU, supported through grants and service contracts. The CEMRC's primary objectives are to:

- Provide for objective, independent health and environmental monitoring;
- Conduct research on environmental phenomena, with particular emphasis on natural and anthropogenic radionuclide chemistry;
- Provide advanced training and educational opportunities;
- Develop improved measurement methods, procedures and sensors; and
- Establish a health and environmental database accessible to all sectors.

Over the last three years, about 60% of CEMRC funding has come from more direct contract support of WIPP by providing facility and scientific support to entities such as Los Alamos National Laboratory (LANL) and Washington TRU Solutions (WTS), such that the monitoring mission dropped from 100% of the Center's activities to about 40%.

KEY ACTIVITIES

The following is a summary of several key activities that are necessary to achieve the goal of establishing and developing CEMRC. Activities to achieve the goal of monitoring in the vicinity of the WIPP are presented in the following section (WIPP Environmental Monitoring Project).

1. **Assemble a team of highly qualified research scientists and support staff capable of carrying out current and future projects.**

At the end of FY2006, the CEMRC employed 27 personnel (Table 2). Two positions were in recruitment.

2. **Create state-of-the-art laboratory facilities capable of supporting advanced studies in areas of scientific specialization.**

In January 1997, the CEMRC was relocated to Light Hall, a new 26,000 ft^2

laboratory and office facility constructed adjacent to the NMSU-Carlsbad branch campus. In 2005 and 2006, three significant facility upgrades occurred. The first was a radiochemistry laboratory designed for investigating the chemistry of plutonium, uranium and other actinides, particularly for performance assessment studies for the WIPP site by LANL Carlsbad Operations. 600 ft^2 of laboratory space was separated from the surrounding labs, and new fume hoods and glove boxes feeding into a new HEPA-filtered isolated ventilation system were installed along with new benchwork. Funding for this upgrade was obtained from the City of Carlsbad with additional funds from NMSU CEMRC and LANL.

The second was the construction of an 800 ft^2 organic chemistry laboratory dedicated to the measurement of volatile organic compounds (VOCs). Over 100 linear feet of benchwork was installed, and a bank of gas chromatograph – mass spectrometers (GC-MS), were set up to measure constituents such as methylene chloride, benzene, carbon tetrachloride, hydrogen, and methane, in WIPP underground air and waste drum head space gas. Funding for this upgrade was obtained from DOE through WTS with additional funds from NMSU CEMRC.

Third, a new ventilation system specifically designed to handle high acid volumes was installed in the primary laboratory wing to accommodate WTS radiochemical operations. Funding for this upgrade was provided by DOE through WTS.

During these 2005/2006 construction activities, the WIPP Environmental Monitoring project at CEMRC was shut down for about 8 months.

The CEMRC's scientific activities are organized into major areas of specialization, with corresponding assignment of staff roles and responsibilities. Although some of the CEMRC's projects involve only one or two of the program areas, all of the program areas collaborate in carrying out the WIPP Environmental Monitoring project. The five scientific program areas include (1) radiochemistry, (2) environmental chemistry, (3) informatics and modeling, (4) internal dosimetry, and (5) field programs. Detailed descriptions of each program area and associated facilities and instrumentation are on the CEMRC web site at http://www.cemrc.org.

3. **Establish grants and contracts to replace the original grant.**

Table 1 gives a summary of CEMRC's budget over the last several years, including 2007. The following is a list of grants and contracts generated during FY2005 and 2006.

DOE CBFO

- 2005 - $1.2 million for WIPP Environmental Monitoring
- 2006 - $1.2 million for WIPP Environmental Monitoring

Washington TRU Solutions

- 2005 - $1.0 million for Technical Services to WTS
- 2006 - $350,000 for VOC analyses
- 2006 - $432,000 for construction and equipping a new VOC laboratory
- 2006 - $85,000 for Whole Body Counting of selected WTS employees
- 2006 - $225,000 certification for Head Space Gas Analyses under DOE's PDP

Los Alamos National Laboratory
- 2005 - $910,000 for Actinide Chemistry scientific support
- 2006 - $801,000 for Actinide Chemistry scientific support

Sandia National Laboratory
- 2005 - $90,000 for Performance Assessment Scientific Support
- 2006 - $89,000 for Performance Assessment Scientific Support

City of Carlsbad
- 2005 - $350,000

OCUP
- 2006 - $137,899

Rodent
- 2005 - $50,000

PuDust
- 2005 - $101,000
- 2006 - $101,000

Waste Control Specialists
- 2005 - $47,250
- 2006 - $52,500

Other
- 2005/2006 - $35,000

4. **Establish effective liaisons with leading research groups and laboratories to facilitate shared services and collaborative research.**

In response to the need for expanding the CEMRC research role, the Center has developed a partnership with LANL to conduct actinide chemistry research for WIPP recertification, and with WTS radiochemistry group to support compliance activities such as radiobioassay and WIPP permit-required environmental monitoring. Agreements and partnerships were also developed with New Mexico Tech in Socorro, the New Mexico Military Institute in Roswell, and the National Guard 64th Civil Support Team and Rio Rancho, to develop emergency radiological response training.

5. **Publish research results and create a database management system to provide access to information generated by the CEMRC.**

CEMRC staff authored or co-authored many presentations at international, national and regional scientific meetings and 18 papers were published in peer-reviewed scientific journals and books during 2005/2006 (Appendix C). A cumulative list of publications by CEMRC staff since 1996 can be obtained by request, as can previous CEMRC annual reports and other CEMRC information.

6. **Establish regional, national and international outreach and collaboration.**

During 2005/2006, the CEMRC hosted various colloquia presented by visiting scientists, was involved in other outreach activities including presentations for local civic and professional groups and exhibits for various school, and community events some of which are listed in Appendix D. As described in a later section, over 1000 volunteers from the local community have participated in the “Lie Down and Be Counted” project.

7. **Implement programs to offer visiting scientists training in specialized research techniques and methodologies and to involve CEMRC resources and personnel in providing educational opportunities for students nationwide.**

During 2005/2006, five undergraduate students worked in laboratory aide positions at the CEMRC; these positions provided training and basic skills development relevant to the position assignments. Visiting scientists on sabbatical leave also worked at CEMRC in support of various research projects (Appendix B).

Table 1: CEMRC Budget Changes Since FY2002 (in $thousands)

Funding	2002	2003	2004	2005	2006	2007
DOE	$2,461	$2,450	$698	$1,200	$1,200	$1,200
LANL	0	0	175	910	801	848
WTS	0	0	1,100	1,000	1,092	1,115
Carlsbad	0	0	0	350	0	0
SNL	0	0	184	90	89	268
Other	200	148	229	346	179	192
TOTAL	**$2,661**	**$2,598**	**$2,386**	**$3,896**	**$3,361**	**$3,623**

Table 2: Listing of CEMRC Staff as of September 30, 2006

Name	Position
Arimoto, Richard	Senior Scientist
Ballard, Sally	Environmental Scientist
Brown, Becky	Administrative Services Manager
Bill Brown	Facilities Manager
Conca, James	Director
Ganaway, David	Environmental Scientist
Garrett, Fran	Secretary
Greene, Chris	Physicist Scientist
Hudston, Lisa	Environmental Scientist
Khaing, Hnin	Environmental Scientist
Kirchner, Thomas	Computer & Information Systems Manager
Kirchner, Vicki	Technology Specialist
Marple, Julia	Chemical Technician
McCauley, Sharyl	Quality Assurance Manager
Monk, James	Environmental Scientist
Najera, Angela	Secretary
Nesbit, Curtis	Environmental Scientist
Pennock, Karl	Environmental Scientist
Porter, Ruthie	Records Technician
Sage, Sondra	Physical Scientist
Schoep, David	Radiation Safety Training Specialist
Sneller, Michele	Chemical Technician
Spruiell, Roy	Network/Computer Systems Administrator
Stewart, Barry	Physical Scientist
Sullivan, Tina	Network/Computer Systems Administrator
Ui Chearnaigh, Kim	Environmental Scientist
York, Larry	Biological Technician

WIPP Environmental Monitoring Project

PROJECT CONCEPT

As defined in the original grant, the purpose of the WIPP EM project is to establish and maintain independent environmental research and monitoring in the vicinity of the WIPP and to make the results easily accessible to all interested parties. This project was implemented during the WIPP pre-disposal phase, and is now continuing during the operational (disposal) phase. The WIPP EM project is organized and carried out independent of direct oversight by DOE, and the project does not provide data to any regulatory body to meet the compliance demonstration requirements applicable to the WIPP. Analytical results and interpretations from the WIPP EM are published by CEMRC to inform the public and particularly the environmental science community.

A detailed description of the WIPP EM concepts, sampling design and baseline studies is presented on the CEMRC web page. The following is a summary of 2005/2006 activities for each major environmental medium in the WIPP EM. It is important to note that nuclear waste first began being received at WIPP on March 26, 1999. Mixed waste was first received by the WIPP on September 9, 2000, and higher-activity waste (called remote handled or RH waste) was first received at the beginning of 2007. Results summarized in this report cover samples collected through December 2006.

Based on the radiological analyses of monitoring phase samples (collected since March 26, 1999) completed to date for area residents and for selected aerosols, soils, drinking water and surface water, there is no evidence of increases in radiological contaminants in the region of the WIPP that could be attributed to releases from the WIPP. Levels of radiological and non-radiological analytes measured in 2005 and 2006 were within the range of baseline levels measured previously by CEMRC for the targeted analytes, and are within the ranges measured by other entities at the State and local levels since well before disposal phase operations began in 1999.

In the summer of 2001, the Carlsbad Field Office (CBFO) of DOE requested CEMRC to investigate whether the Center's direction could become more closely aligned with scientific and analytical activities foreseen by the CBFO to support the safe and efficient operation of the WIPP. To further develop the CEMRC program, during 2005/2006 the Center has been working with the CBFO management to define research and analytical tasks that will address such needs. This redirection permits CEMRC to pursue new research avenues aggressively in partnership with (versus independent of) the DOE community.

The tasks requested to be performed by the CEMRC during 2005/2006 included:

- Analytical and scientific support for the LANL Actinide Chemistry and Repository Science Program including construction of a new actinide chemistry laboratory during 2005 and 2006 that is focused on research with Pu and other actinide elements under WIPP conditions
- Identification and quantification of Gnome-derived radionuclides

- Environmental safety and health support for WIPP operations including providing WTS scientists with radio-chemical laboratory space, office space and safety support for environmental compliance and monitoring activities; measurement of VOCs in WIPP underground air for permit compliance, and development and certification of the capability to measure head space gas constituents in WIPP waste drums, including construction of an 800 ft^2 organics laboratory during 2006. A summary of the progress made on these tasks is also provided in this report.

ORGANIZATION OF THE MONITORING PROGRAM

The scheduling and management of sample analyses collected in the WIPP EM project are based on (1) priorities for providing information to the public, (2) relative risks of human exposure to contaminants among the various media sampled, (3) needs for data validation and verification prior to release, (4) time constraints resulting from sample preparation and analysis procedures, (5) funding changes, and (6) time and resource coordination among the other programs in the facility.

During 2003/2004, the elements of the monitoring project were reviewed and evaluated as part of the strategic planning for CEMRC activities over the next few years. A re-definition of the scope of the monitoring program has been driven by two factors - (1) the diminishing resources available for the monitoring work, and (2) the increased emphasis at CEMRC on direct research and technical support of WIPP operations. The challenge that has faced CEMRC during 2005/2006 has been to restructure and optimize the WIPP EM in order to maintain a long-term environmental monitoring program that will contribute to the public's confidence in the safe operation of the WIPP, and identify missing elements in our understanding of the WIPP environment that are not addressed by the ongoing and proposed long-term monitoring studies.

A major reduction in the resources devoted to the WIPP EM was proposed by CEMRC through a cut back in the frequency of sampling of the various media and by reducing the number of target analytes. The justification for this reduction is based on the fact that, to date, there has been no evidence for any perturbation to drinking water, soils, surface water or sediments caused by the WIPP operations. Studies of airborne particulate matter (aerosols) will continue to be the major focus of the CEMRC's monitoring efforts because, in the event that radioactive or chemical contaminants are released from WIPP, these materials could be rapidly dispersed through the atmosphere and spread throughout the environment. In addition, monitoring of the public through the Lie Down and Be Counted program is of the utmost importance as humans are the most important target whatever will be the transmission vector for contaminants.

Past public surveys indicated that air monitoring and direct monitoring of people (whole body counting), followed by monitoring of drinking water, were the areas of greatest public interest. While it is highly unlikely that any chemical impacts of the WIPP will be detected through analyses of media other than air and people, CEMRC considers there is value in continued monitoring of soils, water and sediments, and vegetation and biota in some form and frequency. Thus, a program has been recommended, and will be revised yearly with input from various stakeholders, in which one of the media other than air and people are sampled each year on a rotating basis.

The continuation of the WIPP EM and new WIPP-related projects reflect the Center's commitment to ensuring that the public, workers, and the environment are protected from exposure to contaminants. It is likely that additional adjustments to the WIPP EM will be needed as the Center's capabilities continue to evolve and the other programs supporting the WIPP also move in new directions.

AEROSOLS

Aerosol particle sampling is conducted at four locations, with samplers operating continuously at each location. The locations include a port inside the WIPP exhaust shaft (Station A, FAS samples), a site approximately 0.1 km northwest (downwind) of the WIPP exhaust shaft (On Site station), a site approximately 1 km northwest (downwind) of the WIPP (Near Field station), and a site approximately 19 km southeast (upwind) of the WIPP (Cactus Flats station). In November 2006, CEMRC began collecting samples at a point inside the WIPP exhaust but after the filtration system (Station B). The schedule for analysis of these samples will be decided based upon discussions with stakeholders.

Continuous sampling of aerosol particles was conducted through December 2006. Analyses of all particle samples collected through December 2005 for both radiological and non-radiological constituents have been completed and are reported herein. All FAS samples from 2006 have been analyzed with respect to gross alpha and beta and are reported herein, while 2006 samples from the other aerosol sites along with spectroscopy on the 2006 FAS samples are still being analyzed.

SOILS

Soil samples were collected during 2005, and measurements were made for ^{137}Cs, ^{208}Tl, ^{212}Pb, ^{212}Bi, ^{214}Bi, ^{214}Pb, ^{228}Ac, and ^{40}K. The analyses for ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, ^{228}Th, ^{239,240}Pu, ^{241}Am are not reported because of low yields. Soil samples were collected during 2006 and have been archived for future analysis to be based upon programmatic decisions.

SURFACE WATER AND SEDIMENTS

Surface waters and sediments were collected during 2005 from three regional reservoirs situated on the Pecos River - Brantley Lake, Red Bluff and Lake Carlsbad. Surface waters were analyzed for inorganic constituents.

DRINKING WATER

The WIPP EM studies of ground water focus on the major drinking water supplies used by communities in the WIPP region because these are often perceived by the public as a potential route for contaminants to reach humans. Five community supplies of drinking water (representing three major regional aquifers) are included in routine sampling, including Carlsbad, Loving/Malaga, Otis, Hobbs and a secondary source for Carlsbad. One private water well (representing a fourth aquifer) that is located within 16 km of the WIPP is also sampled. During 2005, drinking water samples were collected in the spring at five of the six drinking water supplies (the sixth was dry), and results of radiological and non-radiological analyses are reported herein for 2005.

BIOTA

During 2005/2006, no vegetation samples were collected or analyzed.

HUMAN POPULATION

The *Lie Down and Be Counted* (LDBC) project serves as a component of the WIPP EM that directly addresses the general concern about personal exposure to contaminants shared by residents who live near DOE sites. As in other aspects of the WIPP EM, *in vivo* bioassay testing was used to establish a baseline profile of internally-deposited radionuclides in a sample of local residents before disposal phase operations began, and has continued into the disposal phase to the present. The sampling design includes solicitation of volunteers from all segments of the community, with sample sizes sufficient to meet or exceed a 15% range in margin of error for comparisons between major population ethnicity and gender categories as identified in the 1990 census. Radiobioassays of the original volunteer cohort have been ongoing since July 1999. New volunteers will continue to be recruited each year to establish new study cohorts and replace volunteer attrition. Results of the LDBC project through December 2006 are reported herein.

RADIOCHEMICAL AND ACTIVITY UNITS

The primary unit of activity, or radioactivity, used in this report is the becquerel (Bq) which is equal to one disintegration of a nucleus per second. This disintegration gives rise to ejection of a particle or ray of ionizing radiation, either an alpha, beta, neutron, or gamma.

Quality Assurance

The CEMRC is subject to the policies, procedures and guidelines adopted by NMSU, as well as state and federal laws and regulations that govern the operation of the University. The management of CEMRC is committed to conducting a well-defined quality assurance program, incorporating good professional practice and focusing on the quality of its testing and calibration in research and service to sponsors. CEMRC technical programmatic areas in 2005-2006 included: Environmental Chemistry, Organic Chemistry, Radiochemistry, Field Programs, Informatics and Modeling and Internal Dosimetry. The development and implementation of an independent health and environmental monitoring program has been CEMRC's primary activity since establishment.

PROJECT REPORTING REQUIREMENTS

Since its inception, CEMRC's WIPP Environmental Monitoring Program (WIPP-EM) has been conducted as a scientific investigation, that is, without any compliance, regulatory, or oversight responsibilities. As such, there are no specific requirements for reporting data other than good scientific practices. An example of reporting decisions made by CEMRC for this program is whether to correct or not correct data for blanks. The decision to subtract blanks from the monitoring data was made by the senior staff in the mid-1990s because the consensus opinion was that this procedure provided the best means for determining the analytes' true concentrations, i.e. bias-free estimates of the values. The practice of correcting environmental data for blanks is well established, as described by the International Union of Pure and Applied Chemistry (IUPAC) and The International Organization for Standardization (ISO). See also http://epa.gov/waterscience/methods/det/faca/mtg20051208/blank.html

QUALITY ASSURANCE PROGRAM

Beginning in early 2002, a significant effort was devoted to refining CEMRC's quality system to meet applicable requirements of the U.S. DOE Carlsbad Field Office (CBFO) Quality Assurance Program Document (QAPD, CAO-94-1012). This effort was in response to the CBFO's request for a change in CEMRC's direction to allow it to become more closely aligned with scientific and analytical activities seen by CBFO to support the safe and efficient operation of WIPP. As a result, CEMRC produced a center-wide Quality Assurance Plan (QAP) CP-QAP-004, which was subsequently submitted to and approved by DOE.

Internal surveillances were performed during 2005/2006 on the following programmatic areas: Environmental Chemistry, Field Programs, Informatics and Modeling, Internal Dosimetry Organic Chemistry and Radiochemistry. In addition, internal surveillances were performed in the Administrative, Quality Assurance areas as well as on Document Control and maintenance of Scientific Notebooks. A summary of 2005/2006 audits is reported in Appendix E.

QUALITY ASSURANCE/ QUALITY CONTROL FOR ORGANIC CHEMISTRY

The following audits were conducted on the Organic Chemistry group:

- A VOCs Confirmatory Monitoring Audit, by WTS QA, February 2005 and February 2006. Both audits were passed. These audits were routine yearly program audits conducted in compliance with contract requirements.
- CEMRC QA audits were conducted on the OC group July 9-11, 2005, and June 13-14, 2006. Both audits were passed and were conducted in compliance with the Center's QAP.

QUALITY ASSURANCE/QUALITY CONTROL FOR RADIOANALYSES

Routine quality assurance/quality control activities conducted for radioanalyses include tracking and verification of analytical instrument performance, use of American Chemical Society certified reagents, use of National Institute of Standards and Technology (NIST) traceable radionuclide solutions and verification testing of radionuclide concentrations for tracers not purchased directly from NIST or Eckert and Ziegler Analytics. When making laboratory solutions, volumes and lot numbers of stock chemicals are recorded. Prior to weighing radionuclide tracers and samples, the balance being used is checked using NIST traceable weights.

Control checks were performed on all nuclear counting instrumentation each day or prior to counting a new sample. The type of instrument and methods used for performance checks were as follows: for the Protean 9604 gas-flow α/β proportional counter used for the FAS program, efficiency control charting was performed using ^{239}Pu and ^{90}Sr check sources along with ensuring that α/β cross-talk was within limits. Sixty-minute background counts were recorded daily. Two blanks per week for the FAS program were counted for 20 hours and were used as a background history for calculating results.

Routine background determinations were made on the HPGe detector systems by counting blank samples, and the data was used to blank correct the sample concentrations.

For the Oxford Oasis alpha spectrometer, efficiency, resolution and centroid control charting was performed using ^{148}Gd check sources on a regular basis. Before each sample count, pulser checks were performed to ensure acceptable detector resolution and centroid. Blanks counted for 5 days were used as a background history for calculating results.

During 2004 - 2006, CEMRC participated in the NIST Radiochemistry Intercomparison Program (NIST-RIP) and the Mixed-Analyte Performance Evaluation Program (MAPEP-05) for soil, air filter and water analysis. In NRIP, there were a variety of matrices to analyze. Isotopes of interest in the NRIP studies were ^{234}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{230}Th, ^{241}Am, and ^{90}Sr. In the 2005 study, CEMRC performed consistently well when analyzing ^{234}U, ^{238}U, ^{238}Pu, ^{239}Pu and ^{241}Am, with the experimental values nearly matching the NRIP reported values. The other two isotopes, ^{230}Th and ^{90}Sr performed less well, with some experimental values exceeding the lower limit of acceptability. However, replicate samples of these analytes were within the acceptable range.

For MAPEP, the matrices selected were air filters, soils, and water and the isotopes were $^{233/234}$U, ^{238}U, ^{238}Pu, $^{239/240}$Pu, ^{241}Am, and ^{90}Sr. The analyses were carried out using CEMRC's actinide and separation procedures, and were treated as a regular sample set to test regular performance. CEMRC's results were consistently close to the known value, with only two "Not Acceptable" results on strontium analysis.

Results for NRIP and MAPEP are given in Appendix E.

QUALITY ASSURANCE/QUALITY CONTROL FOR ENVIRONMENTAL CHEMISTRY INORGANIC ANALYSES

The analytical methods employed for inorganic analyses in the environmental chemistry program at CEMRC are based, when applicable, on various standard procedures (EPA/600/4-79-020, 1983; EPA/SW-846, 1997; American Public Health Association, 1981). For some matrix/analyte combinations, appropriate external standard procedures do not exist, and for those cases, specialized procedures have been developed to meet the needs of the WIPP EM and other research projects.

INSTRUMENTATION

A DIONEX 500 ion chromatography (IC) system is used to determine the concentrations of a suite of anions, including nitrate, nitrite, sulfate, chloride, fluoride, and phosphate in water samples and aqueous extracts of aerosol samples, soils, and sediments. Configured differently, the same instrumentation can be used to determine the concentrations of several cations (calcium, magnesium, sodium, ammonium and potassium). The anion analyses are performed with the use of AS11 and AS14 anion exchange columns and AG11 and AG14 guard columns, with chemical suppression and conductivity detection. The cations are determined using a CG12A guard column and a CS12A analytical column, with the same type of chemical suppression and conductivity detection.

Inorganic analyses were performed using Perkin-Elmer Elan 6000 and 6100 inductively-coupled plasma mass spectrometers (ICP-MS). Regular QC verifications and batch QC provide records of sample performance data. For all environmental chemistry analyses, QC samples are analyzed with each sample batch as an indicator of the reliability of the data produced. The types, frequencies of analysis, and limits for these QC samples have been established in a set of standard operating procedures. Extraction QC samples include Laboratory Reagent Blanks, or LRBs (for aerosol and FAS samples, unused cellulose ester filters were used as LRB samples), Laboratory Fortified Blanks, or LFBs (a cellulose ester CRM, "Trace Metals on Filter Media" from High Purity Standards in Charleston, South Carolina, was used for QC of aerosol sample metals analyses), duplicates and Laboratory Fortified Matrix (LFM) samples. In cases where duplicate aliquots from the original sample were not feasible (such as aerosol filters), separate aliquots of the sample extract were analyzed for the duplicate and LFM analyses. The digestion QC parameters used for the evaluation of constituents in water, soils, and sediments were based on concepts in EPA Contract Laboratory Program (EPA 540/R-94013, 1994); and SW-846 methods (EPA/SW-846, 1997). No comparable control parameters presently exist for aerosol samples. All constituents values were reported relative to the method detection limit as determined by the method outlined in 40 CFR 136, Appendix B.

For each ICP-MS analysis, the QC requirements are as follows: 1) A spiked blank (LFB, or laboratory fortified blank) is prepared identically to a sample for every batch (ten samples) and its percent recovery must be within 15%. 2) A batch blank (LRB, or laboratory reagent blank) is prepared and analyzed for every ten samples, and its value must be lower than the method detection limit (MDL). If the value is higher than the MDL, the entire batch is reanalyzed up to 3 times. If the value consistently falls above the MDL, blank subtraction may be performed on the samples in that batch, or the data for the analyte(s) in question are flagged or not reported, at the discretion of the lead scientist. 3) One duplicate sample for every ten samples is either collected in the field or two aliquots from a single field sample are prepared and analyzed identically. The percent difference between duplicates must be within 20%. 4) One laboratory fortified sample matrix (LFSM) is prepared for each batch of 10 samples by spiking a sample with a known amount of standard. The percent recovery for the spike must fall within 15% of the expected value. 5) After calibration, an initial calibration verification (ICV) standard from a different lot number and/or manufacturer of the calibration standards is analyzed, and the value must fall within 10% of the expected value. If one or more analytes falls outside of the expected range, recalibration is performed or the analyte(s) in question are either flagged as having a greater uncertainty or are not reported. 6) A mid-range calibration standard is reanalyzed every ten samples and the percent recovery must be within 15% of the true value. 7) The calibration blank is reanalyzed immediately after calibration and then every ten samples thereafter (including batch blanks and batch spiked blanks) and must be less than 3 times the instrument detection limit. 8) The relative percent difference between the 3 replicate sweeps of the instrument for each analyte must be less than 20%. 9) The correlation coefficient for the linear regression of the calibration curve must be greater than 0.995. 10) All samples and standards are spiked with an internal standard (usually indium), and the percent recovery of the internal standard must lie between 60% and 125% of the value measured in the calibration blank.

Independent quality assurance samples are obtained and analyzed to verify the performance of the instrumentation and the proficiency of the analyst. Reference samples (obtained from an outside source or prepared internally, with true values known at the time of analysis) are the primary method used to perform this function at CEMRC. Occasionally, blind samples (obtained from an outside source, with true values not known at the time of analysis) are used. However, since blind samples are usually diluted many times, the instrument is not optimized for any one or group of elements, and the instrument measures such a large number of analytes at one time at near their MDCs, several analytes often exceed the acceptable range by several percent, in particular aluminum, beryllium, cobalt, iron, chlorine and fluorine. This increases the overall uncertainty of the analyses. Examples of results from a reference sample and a blind sample (from the Environmental Resource Associates [ERA] WatR^{TM} Supply Proficiency Testing Study) for 2005 are given in Appendix E. Table E-4 shows that, of the analytes run, Al, Be, Co and Fe were not within the acceptable range of approximately ±10% in 2005 and Br, and Cl were not within the acceptable range in 2006. Instead, these analytes were between ±10% and ±20%. In this report, assume that these analytes have a ±20% uncertainty associated with their values. In 2006, F had an uncertainty of 25%, therefore, for this report assume F has a ±25% uncertainty associated with it values. Table E-6 gives an example of the daily performance tests for ICP-MS.

QUALITY ASSURANCE/QUALITY CONTROL FOR FIELD SAMPLING

For the collection of most WIPP EM samples, no external standard procedures are considered completely appropriate for the objectives of the studies. In these cases, customized plans are developed and documented. After the activity is completed, the plan is revised to reflect any departures from the original plan, and documented to file. For most environmental media, the sampling plans combine selected standard procedures with specific adaptations to address scientific objectives of interest. For example, procedures for collection and preservation of samples for compliance with Safe Drinking Water Act requirements are applied to the collection of drinking water and surface water samples, but the locations of sample collection are selected on the basis of other criteria. Likewise, high-volume air samplers are operated to meet an EPA standard of 1.13 m^3min^{-1}, but the frequency of filter replacement is based on optimal loading for radioanalysis.

Logbooks are maintained by technical staff in field operations to record locations and other specifics of sample collection, and data on instrument identification, performance, calibration and maintenance. Data generated from field sampling equipment are error-checked by using routine cross checks, control charts and graphical summaries. Most data collected in written form are also entered in electronic files, and electronic copies are crosschecked against the original data forms. All electronic files are backed up daily.

Calibration and maintenance of equipment and analytical instruments are carried out on predetermined schedules coinciding with manufacturer's specifications or modified to special project needs. Calibrations are either carried out by equipment vendors or by CEMRC personnel using certified calibration standards.

QUALITY ASSURANCE/QUALITY CONTROL FOR INTERNAL DOSIMETRY

The *in vivo* bioassay program at CEMRC participates in the Department of Energy's *In Vivo* Laboratory Accreditation Program (DOELAP) via WIPP, and is currently accredited as a service laboratory to perform the following direct bioassays:

- Transuranrium elements via L x-ray in lungs
- 241Am in lungs
- 234Th in lungs
- 235U in lungs
- Fission and activation products in lungs including 54Mn, 58Co, 60Co and 144Ce
- Fission and activation products in total body including 134Cs and 137Cs

Under DOELAP, the *in vivo* bioassay program is subject to the performance and quality assurance requirements specified in *Department of Energy Laboratory Accreditation Program for Radiobioassay* (DOE-STD-1112-98) and *Performance Criteria for Radiobioassay* (ANSI-N13.30). A DOELAP testing cycle was completed in 2005-2006 that included counting phantoms representative of each of the categories listed above.

To evaluate system performance, quality control data were routinely collected throughout the year in order to verify that the lung and whole body counting system was operating as it was at the time the system was calibrated. Quality control parameters that track both overall system performance and individual detector performance were measured. Quality control parameters tracked to evaluate individual detector performance, included:

- Net peak area, peak centroid and peak resolution (FWHM) across the energy range of the spectrum,
- Detector background

Quality control parameters tracked to assess overall system performance included:

- Mean weighted activity of a standard source
- Summed detector background

In addition, calibration verification counts were routinely performed using NIST-traceable standards and phantoms.

The Internal Dosimetry program also participated in an intercomparison study program for whole body counting administered by Oak Ridge National Laboratory (ORNL). Under this program bottle phantoms containing unknown amounts of ^{137}Cs, ^{60}Co, ^{57}Co, ^{88}Y and ^{133}Ba are sent to CEMRC, quarterly. The phantoms were counted on the lung and whole body counting system and the measured activities were reported back to ORNL and compared against the known activities. An example of results for one quarter is shown in Appendix E. For all years since CEMRC has participated in the ORNL program, CEMRC has consistently out-performed all other laboratories in this area.

INDEPENDENT REVIEWS

Periodically, CEMRC has had independent review panels and scientific advisory boards that have addressed scientific and programmatic issues and questions, and have provided guidance and recommendations. In 2007, a review panel made up of chemistry professors from the main campus of NMSU (Prof. Gary

Eiceman, Department of Chemistry and Biochemistry, Prof. Gary Rayson, Department of Chemistry and Biochemistry, and Dr. F. William (Bill) Boyle, of the SWAT - Soil, Water, and Air Testing laboratory) performed a scientific review centering on two primary QA questions concerning data generated in 2005/2006: 1) should instrument blanks be subtracted or corrected for in the final values of data from analyses such as ICP-MS, and 2) what constitutes valid resolution of failures for certain analytes on external performance tests and what impact should this have on reported data for research projects.

The panel commended the staff at CEMRC for having developed and followed criteria for quality assurance and quality control during the acquisition of sample analyses.

The consensus of the panel was that every effort should be made in the reporting of analysis results to provide sufficient information for any reader to arrive at an interpretation of those results. Regarding the use of blank subtraction in data processing, it was recommended that measurements arising from reagent blanks not be systematically subtracted from all subsequent sample measurements, but that those values be included in any reports to enable the most accurate interpretation of the results. Although blank subtraction is a common data analysis procedure, the often extremely low concentrations that can be encountered with samples analyzed at CEMRC necessitates a post-calibration processing of blank measurements with the requisite statistical evaluations. In response to this panel recommendation the ICP-MS results tabulated in this report include a column showing the blank values for each analysis.

The panel felt that the inability of any laboratory to agree with “acceptable” external values for a concentration of targeted analytes within performance evaluation samples should not be considered as an indictment of their abilities to generate accurate results. It should, however, be interpreted as an opportunity to re-evaluate the QA/QC protocols and criteria for acceptable performance. Results generated follow-ing a “failed” performance evaluation sample should be reported with an indication of that non-agreement with “known” samples and a discussion of the causes of such results including efforts made to address any concerns revealed during post-PE sample internal evaluations. Simply stated, it is the opinion of the panel that full disclosure of all results, both positive and “negative,” should be provided in any and all reports, a practice that CEMRC has always followed. As a result, the performance tests in 2005 and 2006 are presented in Appendix E with all results, including those several analytes that were outside the acceptable ranges as discussed above.

CEMRC thanks the panel members for their time and effort. CEMRC intends to continue these types of periodic reviews in the future.

CHAPTER 1

Ambient Aerosol Studies for the WIPP-EM

INTRODUCTION

The CEMRC ambient aerosol monitoring studies focus on both man-made and naturally-occurring radionuclides, but special emphasis is given to the members of the actinide series that are major components of the wastes emplaced at the WIPP. The main objective for the aerosol studies presented here, and for the WIPP Environmental Monitoring (WIPP-EM) Program in general, has been to determine whether the nuclear waste handling and storage operations at the WIPP have released radionuclides into the environment around the WIPP. The aerosol program also has included investigations of several non-radioactive, inorganic chemical species because the data for those substances have been found to be useful for interpreting the results of the actinide studies. Summaries of the WIPP-EM aerosol studies have been included in prior Annual Reports from the Center starting in 1997, and two papers specifically based on the WIPP-EM aerosol research have been published in peer-reviewed journals (Arimoto et al. 2002 and 2006).

One element of particular interest for the WIPP-EM is plutonium (Pu, element 94), which has been dispersed throughout the global environment mainly by nuclear weapons tests. When quantified by alpha spectrometry ^{239}Pu typically is determined together with ^{240}Pu, because isotopes are difficult to separate chemically, and they are represented as ^{239,240}Pu (^{239}Pu half-life, $t_{1/2}$ = 24,110 yr and ^{240}Pu $t_{1/2}$ = 6563 yr). ^{239}Pu and ^{240}Pu also have similar alpha particle energies, about 5.25 MeV. Another actinide of interest is ^{241}Am ($t_{1/2}$ = 432 yr), which is not directly produced in significant quantities during the detonation of thermonuclear weapons but rather is a daughter of bomb-produced ^{241}Pu ($t_{1/2}$ = 14.3 yr).

An important finding of the earlier studies was that the activity of Pu and the concentration of Al in aerosols were correlated and this was driven by the resuspension of dust particles contaminated with radioactive fallout from past nuclear weapons tests. Similar results were found for ^{241}Am and Al. Related studies of soils collected on and near the WIPP site have shown that correlations exist among Al and both naturally-occurring and bomb-derived radionuclides including ^{239,240}Pu (Kirchner et al., 2002).

Here we briefly review the methods used for the ambient aerosol studies and then summarize some recent results, highlighting the continuing efforts to evaluate potential releases from the WIPP. In addition to the environmental aerosol studies, aerosol particles also have been and continue to be collected using a fixed air sampler (FAS) in the WIPP exhaust shaft. Results of the FAS studies are presented in the following chapter.

METHODS

The sampling design for the ambient aerosol studies has changed over the course of the project, and detailed information regarding the sampling design has been presented in prior CEMRC reports starting in 1998. Samples for the aerosol/radionuclide studies have been collected using high-volume samplers ("hivols," flow rate ~1.13 m^3 min^{-1}) since the WIPP-EM program began in 1996. Three long-term aerosol sampling stations have been established; these are On Site, Near Field and Cactus Flats, and each supports a hivol sampler for collecting total suspended particulate (TSP) matter (see Figure 2-1). The Near Field and Cactus Flats stations also supported a second hivol sampler for a time, and those were used for studies of PM_{10}, particulate matter less than 10 µm aerodynamic equivalent diameter. A fourth set of samples was collected at Hobbs over a period of approximately a year and a half, but the sampling there was discontinued in April 2002.

Until the end of March 2002, both low-volume samplers ("lovols," 10 L min^{-1}) and Graseby-Anderson dichotomous samplers (dichots) were used for collection of aerosols for the studies of non-radioactive, inorganic constituents, specifically trace elements and selected water soluble ions. The WIPP-EM underwent major restructuring in FY 2002, and afterwards sampling for the non-radiological aerosol analytes was done using dichots exclusively. In November 2004, the collection of aerosols by dichots was discontinued.

In brief, the sampling strategy for the aerosol/radionuclide studies has been to collect as much particulate material as reasonably practical so as to maximize the chances of detecting the radionuclides of interest. Individual samples typically have been collected over periods of 3 to 5 weeks depending on the rate at which the sample filters become loaded. For these studies, high-volume samples were collected on 20 x 25 cm Gelman A/E™ glass fiber filters. Gravimetric measurements of the glass fiber filters were made to determine the mass of aerosol material that accumulated over the sampling interval.

The high-volume samples were analyzed for selected radionuclides, including ^{238}Pu, ^{239,240}Pu and ^{241}Am following 4 hr of heating in a muffle furnace at 500° C, which drives off organics; dissolution of the material on the filters using strong acids (HF, HCl and $HClO_4$,); and multiple precipitation, co-precipitation, and ion-exchange and/or extraction chromatography steps. The nuclides of interest were precipitated with LaF_3, deposited onto filters, mounted on planchettes, and counted using an Oxford Oasis alpha spectroscopy system.

The radionuclide data are reported in the following two ways. First, the *activity concentration* is calculated as the nuclide's activity per unit volume of air sampled (Bq m^{-3}). Second, *activity density* is calculated as the nuclide's activity per unit aerosol mass collected (Bq g^{-1}).

RESULTS AND DISCUSSION

Summary Statistics

Summary data reported for high volume aerosol samples (hi-vols) are presented in Table 1-1. ^{238}Pu was infrequently detected, with activity concentrations slightly above minimum detectable levels in only six of the 208 samples. ^{239,240}Pu was above detection limits in 205 of the 208 samples. As in prior years, the ^{239,240}Pu activity concentrations showed a strong annual cycle with activities greatest in the spring (Figure 1.1).

During most years studied, the peak ^{239,240}Pu activities generally occur in the March to June timeframe, which is when strong and gusty winds in the area frequently give rise to blowing dust. Some samples taken at Cactus Flats in 1999 and

2000, and at On Site in 2004, exhibited slightly higher ^{239,240}Pu activity concentrations (Figure 1.1) than surrounding data points. The points correspond with higher activity densities as well (Figure 1.2). However, insufficient auxiliary data is available for attributing a cause to this result.

Methods for determining the activity of ^{241}Am were developed by the CEMRC radiochemistry group over a period of years, and the available ambient aerosol data for this nuclide are presented here. The activity concentrations of ^{241}Am (Figure 1.3) in the high-volume samples closely tracked those of ^{239,240}Pu as shown in Figure 1.1. Most notably, strong springtime peaks in ^{241}Am activity concentrations were evident in the samples from 2001 through 2002, and 2004 through 2005. Data from 2003 do not exhibit these springtime peaks. A time series plot for ^{241}Am activity density is presented in Figure 1.4.

In contrast to the actinide data, the aerosol mass loadings at On Site were generally the highest of the three stations with comparable data sets (Table 1-1 and Figures 1.6, 1.7, and 1.8). A timeseries plot (Figure 1.5) shows that the aerosol mass loadings at all stations tend to track one another remarkably well, but that during several extended periods, most noticeably January 1999 to July 2000 and July 2001 to January 2002, the mass loadings at On Site were consistently higher than at the other sites.

As a consequence of the similar ^{239,240}Pu activity concentrations at all stations and the higher mass loadings at On Site, the activity densities at On Site tended to be lower than at Cactus Flats or Near Field (Table 1-1 and Figure 1.6). The combination of ^{239,240}Pu and gravimetrics data thus suggest that activities at the WIPP may in fact generate detectable levels of aerosol particles, but those particles actually contain less ^{239,240}Pu than typical ambient aerosols. These are most probably particles from construction dusts or salt from the underground operations.

NEW DIRECTIONS FOR THE AEROSOL PROGRAM

Operational aspects of the ambient aerosol component of the WIPP EM have changed since the 2003 Annual Report. Whatman 41 sampling began on 1/4/07. 8” X 10” filters are being used on Hi-Q Hi-Vol HVP-3800AFC samplers. These samplers are located at sites 107 and 108 and are directly across from the Hi-Vol glass fiber sampler. The samplers are set at 20 SCFM and are changed approximately every 2 weeks and in conjunction with the glass fiber filers. No gravimetric data is collected from the Whatman 41 filters. It is anticipated that these filters may be used to more directly compare trace and major elemental concentrations to actinide and mass concentrations collected at the same locations. A summary of the latest ambient aerosol sampling program is given in Table 1-2.

SUMMARY STATEMENTS

The results presented here demonstrate that actinide concentrations have not changed significantly since the WIPP began receiving waste. Ambient aerosol samples continue to be collected on a regular basis and will be analyzed and the data reported as time permits.

Table 1-1: Summary Statistics for Aerosol Mass Loadings and Actinide Activities in High-Volume Aerosol Samples

Station		Cactus Flats	Near Field	On Site
Type of Sample		**TSP**	**TSP**	**TSP**
Number of Samples		70	69	69
Aerosol Mass, micrograms per cubic meter	[a]N	70	69	69
	Mean	1.37	1.33	1.65
	StdDev	0.57	0.50	0.59
^{241}Am Activity Concentration, Bq m^{-3}	N	33	30	35
	Mean	5.4E-09	4.2E-09	4.4E-09
	StdDev	3.2E-09	2.0E-09	2.2E-09
^{241}Am Activity Density, Bq g^{-1}	N	32	29	35
	Mean	1.9E-04	1.6E-04	1.4E-04
	StdDev	4.5E-05	5.7E-05	5.2E-05
^{238}Pu Activity Concentration, Bq m^{-3}	N	4	1	4
	Mean	3.1E-09	1.5E-09	2.8E-09
	StdDev	2.8E-09		2.0E-09
^{238}Pu Activity Density, Bq g^{-1}	N	4	1	4
	Mean	9.0E-05	3.4E-05	7.1E-05
	StdDev	4.8E-05		2.8E-05
^{239,240}Pu Activity Concentration, Bq m^{-3}	N	70	68	67
	Mean	1.6E-08	1.2E-08	1.3E-08
	StdDev	1.2E-08	7.7E-09	8.2E-09
^{239,240}Pu Activity Density, Bq g^{-1}	N	69	68	68
	Mean	5.3E-04	4.5E-04	4.0E+00
	StdDev	2.1E-04	1.4E-04	2.1E-04

[a]N stands for number of samples with masses or activities above detection limits.

Table 1-2: Aerosol Sampling Status for WIPP EM (January 2007)

Site	[a]Sampler	Analyses	Frequency	Comments
Station A (Exhaust Shaft)	PM_{10}-Shrouded Probe	Mass, Gross Alpha and Beta Activities, Trace Elements, Gamma Emitters, Actinides	Daily	Monthly Composites
Station B (Post Filtration)		Gross Alpha and Beta Activities, Actinides	Weekly	Monthly Composites
Cactus Flats Near Field On Site	TSP-HI VOL Glass Fiber Filter	Mass & Radionuclides	[b]Variable	Continuous
	[c]TSP-HI VOL Whatman 41 Filter	Elemental	Variable	Continuous

[a] Sampler types are as follows: PM_{10}-Shrouded Probe = particles greater than 10 μm diameter (50% cut-size), TSP-HI VOL = high volume total suspended particles.
[b] Samples are changed when the flow drops to 90% of original for the 2-stage pumps.
[c] TSP-HI VOL Whatman 41 Filters are collected at Cactus Flats and Near Field.

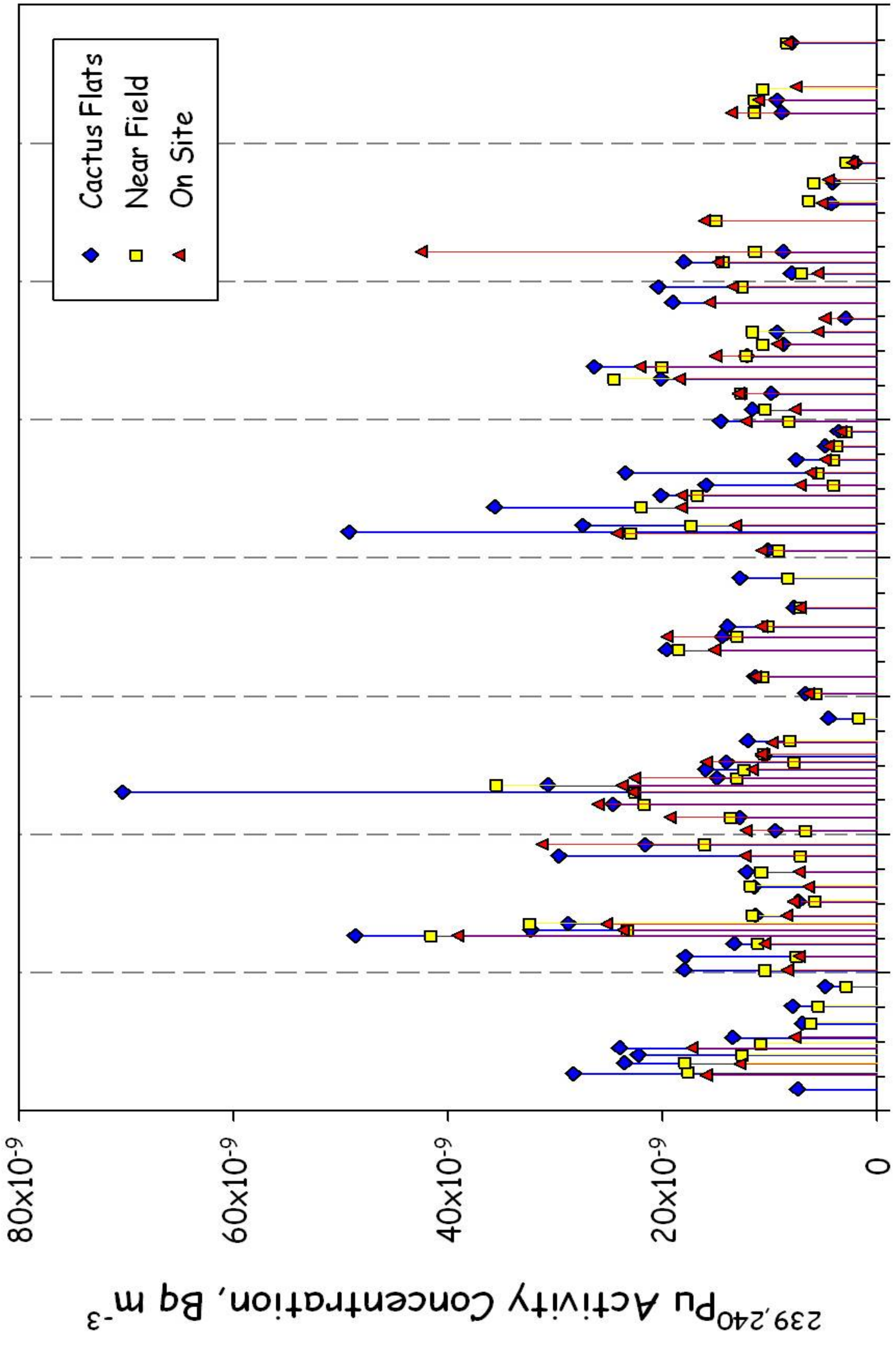

Cactus Flats
Near Field
On Site
1998
1999
2000
2001
2002
2003
2004
2005
80x10-9
60x10-9
40x10-9
20x10-9
0
239,240Pu Activity Concentration, Bq m-3

Figure 1.1: High Volume Ambient Aerosol ^{239,240}Pu Activity Concentration

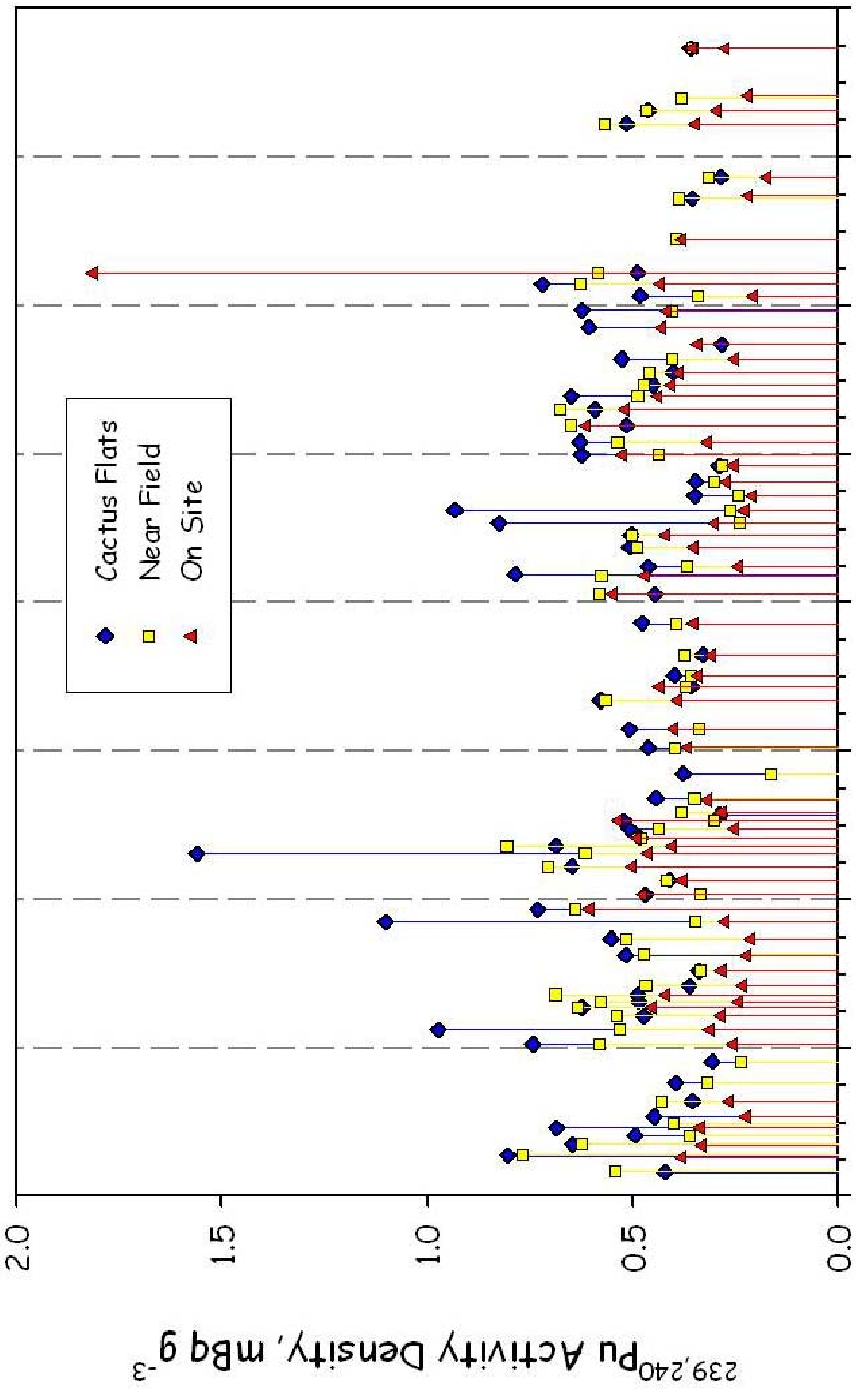

Cactus Flats
Near Field
On Site
2.0
1.5
1.0
0.5
0.0
1998
1999
2000
2001
2002
2003
2004
2005
239,240Pu Activity Density, mBq g-3

Figure 1.2: High Volume Ambient Aerosol ^{239,240}Pu Activity Density

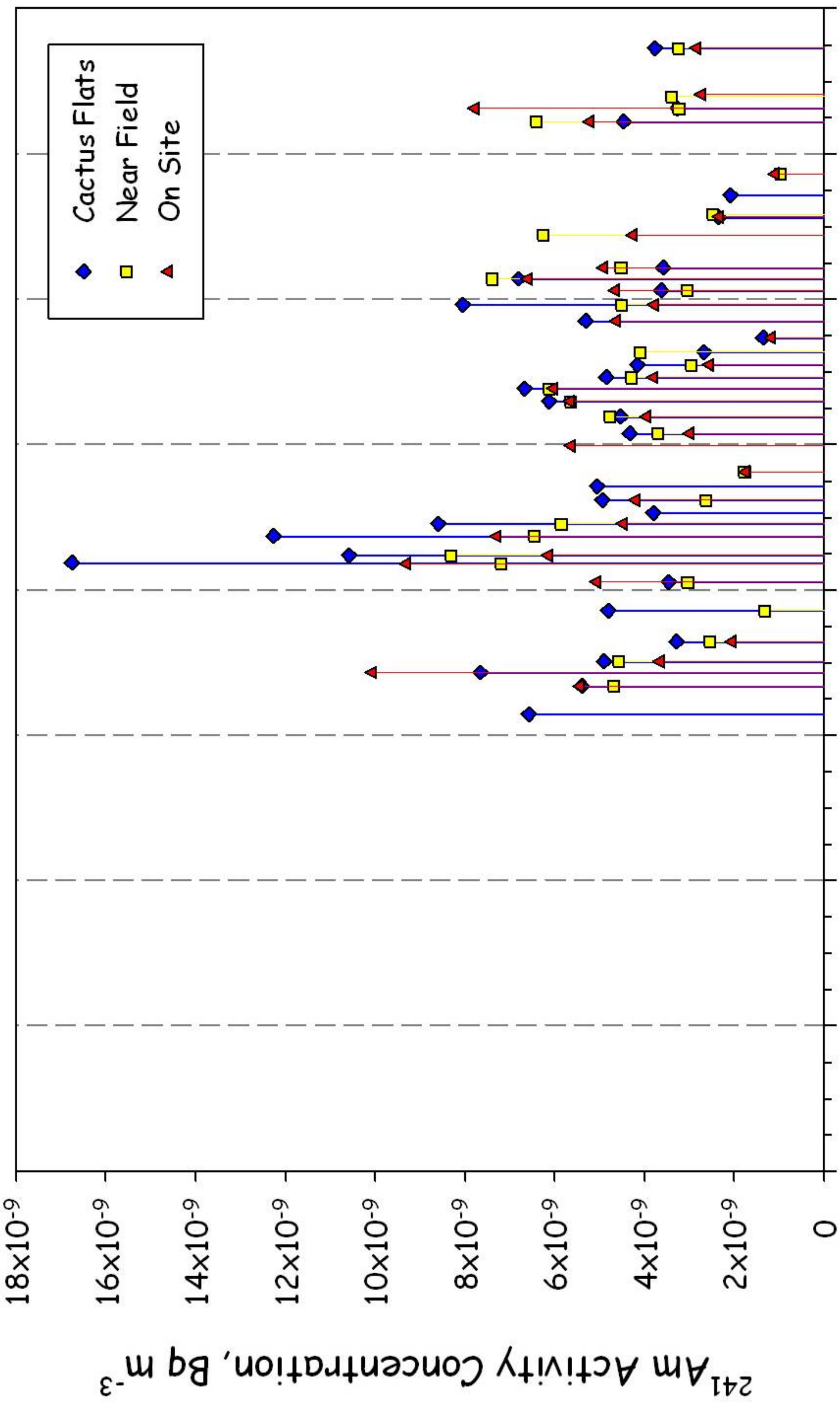

Cactus Flats
Near Field
On Site
18x10-9
16x10-9
14x10-9
12x10-9
10x10-9
8x10-9
6x10-9
4x10-9
2x10-9
0
1998
1999
2000
2001
2002
2003
2004
2005
241Am Activity Concentration, Bq m-3

Figure 1.3: High Volume Ambient Aerosol ^{241}Am Activity Concentration

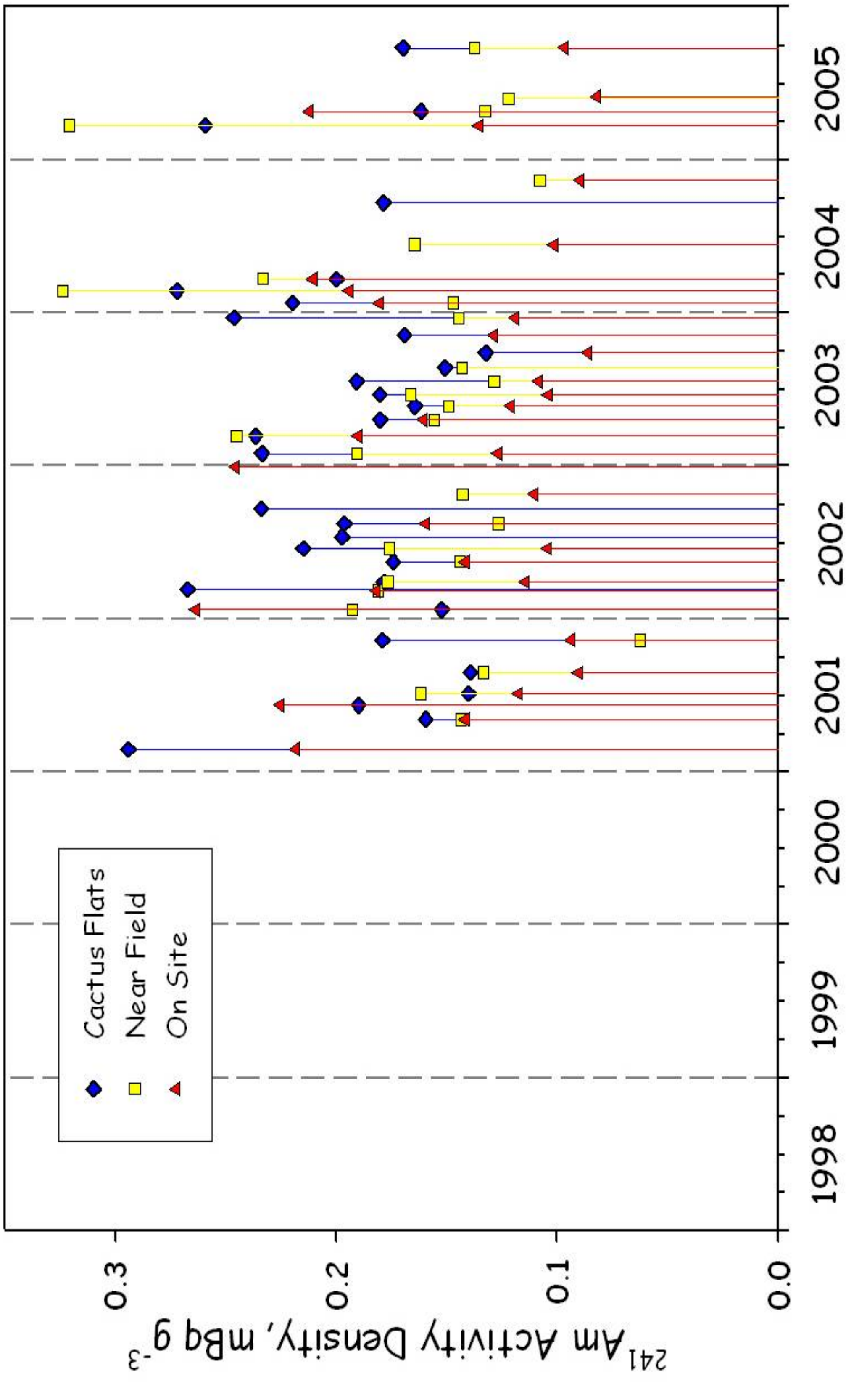


Figure 1.4: High Volume Ambient Aerosol ^{241}Am Activity Density

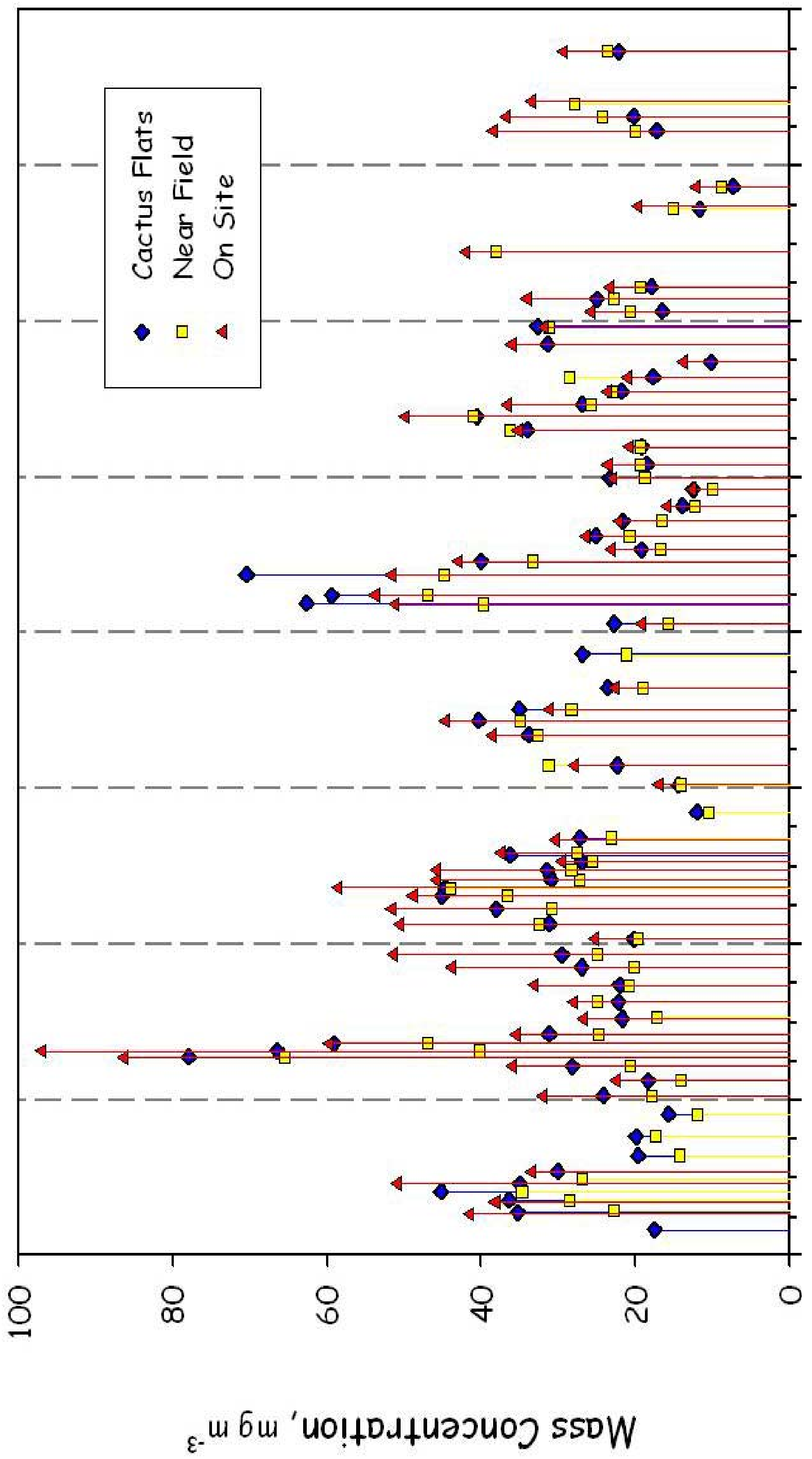


Figure 1.5: High Volume Ambient Aerosol Mass Concentrations

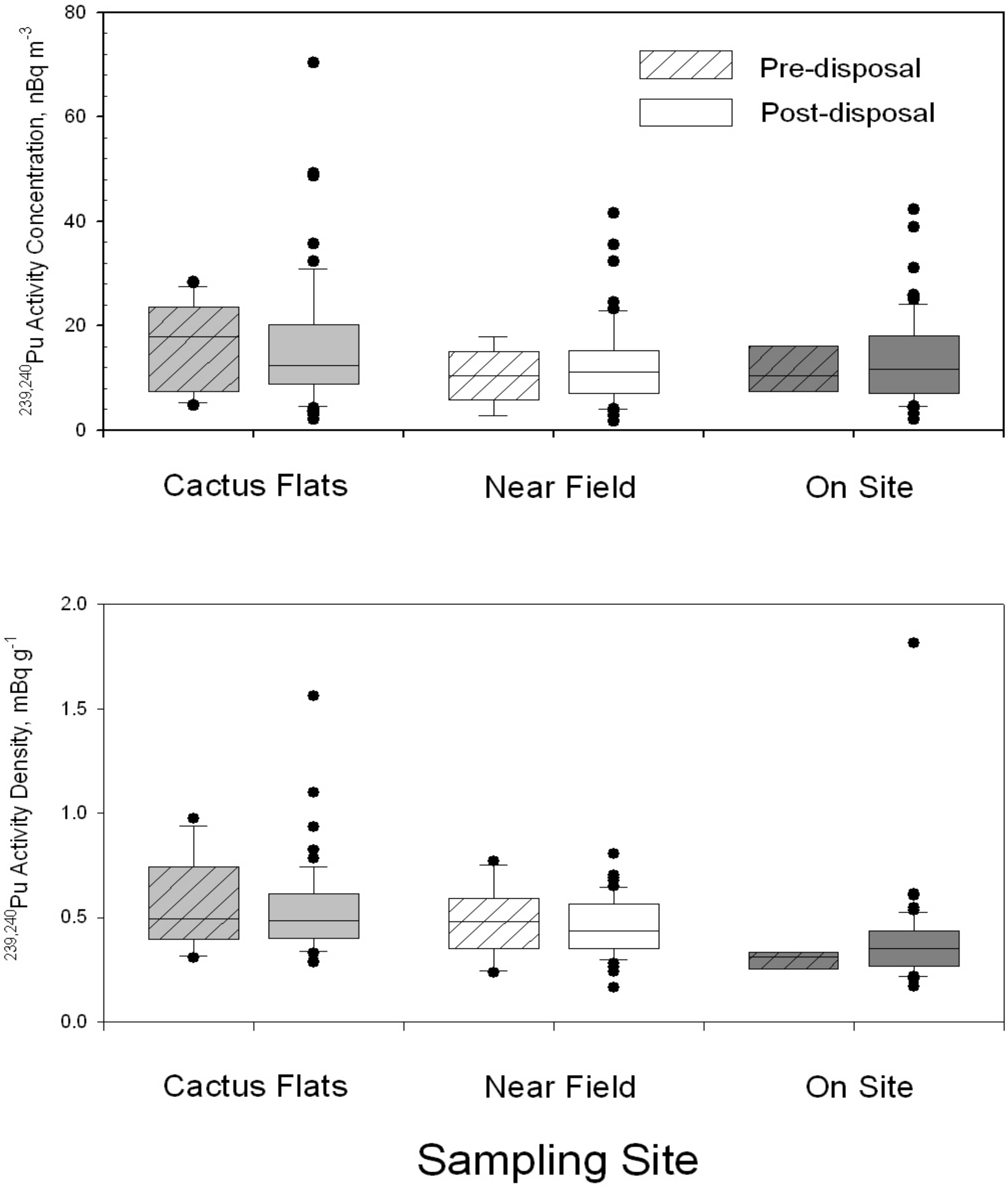


Figure 1.6: Whisker Plots Showing High Volume Ambient Aerosol ^{239,240}Pu Activity Concentrations and Densities

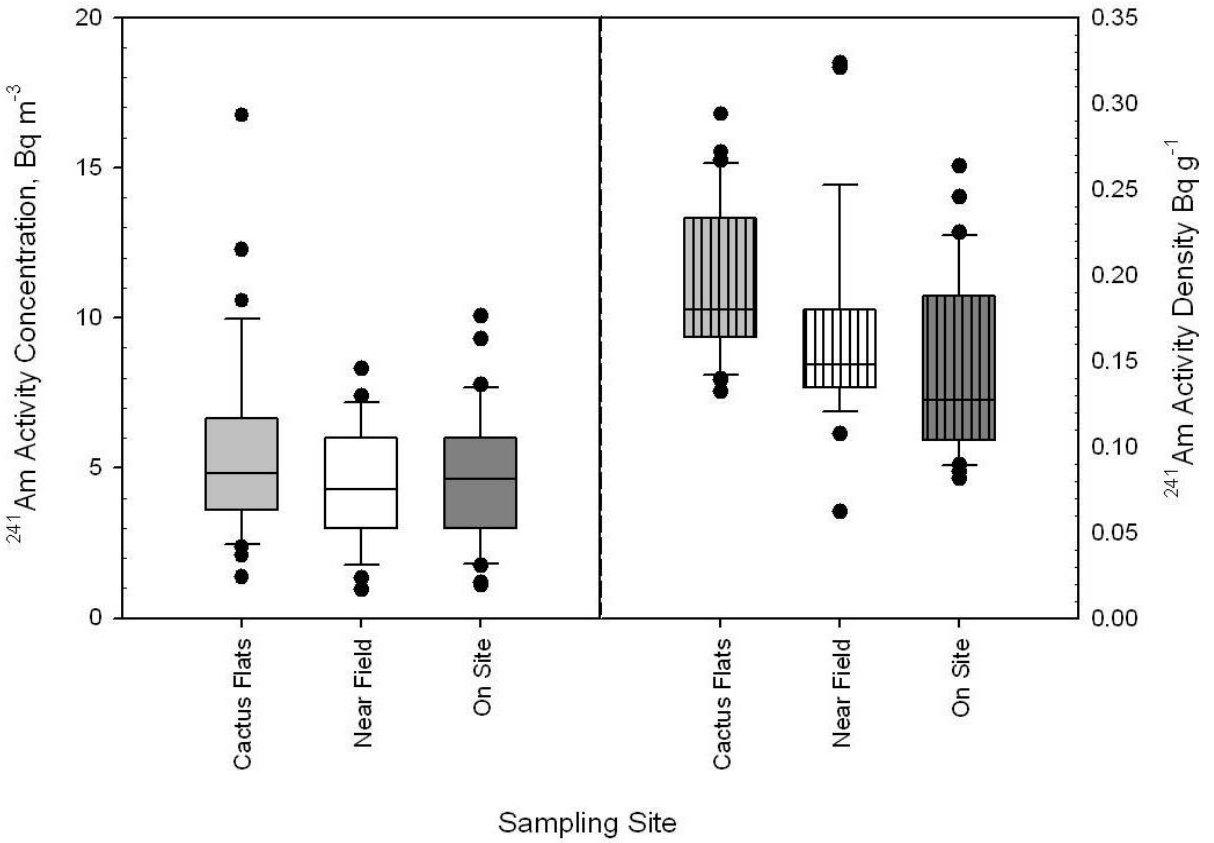


Figure 1.7: Whisker Plots Showing High Volume Ambient Aerosol ^{241}Am Activity Concentrations and Densities

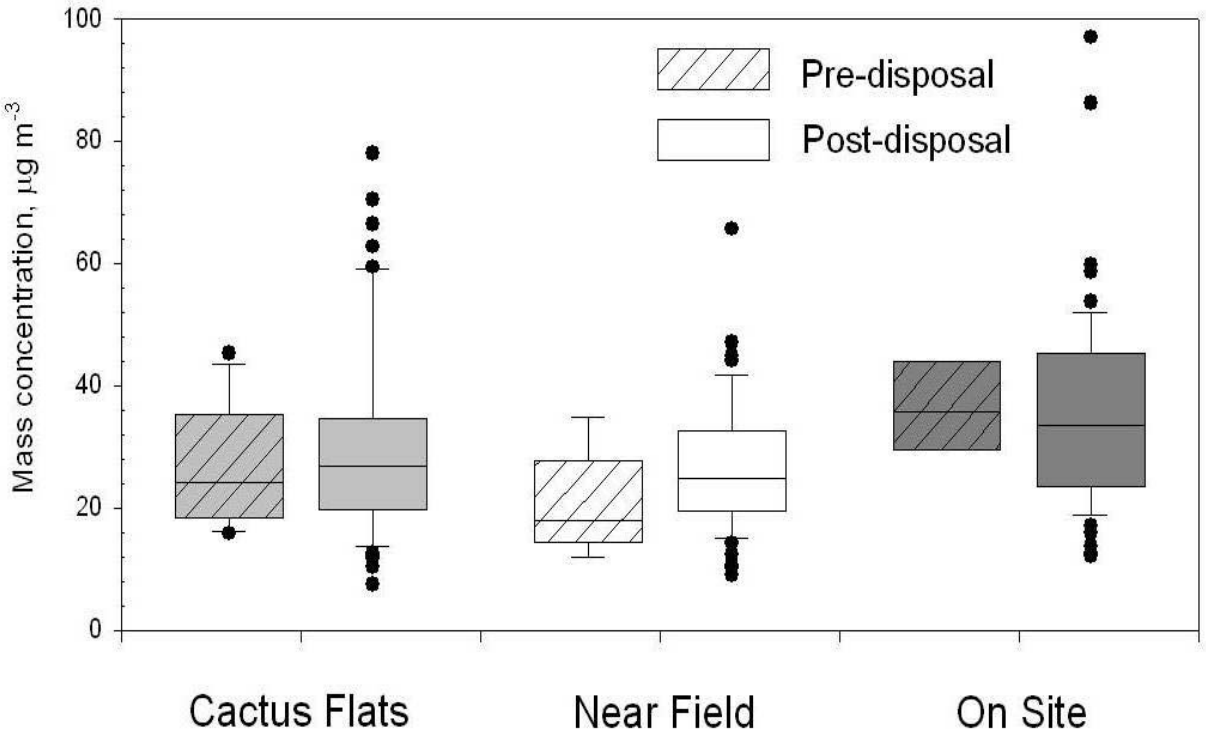


Figure 1.8: Whisker Plots Showing High Volume Ambient Aerosol Mass Concentrations

CHAPTER 2

Radionuclides and Inorganics in WIPP Exhaust Air

INTRODUCTION

The aerosol studies at Station A are a major component of CEMRC's WIPP environmental monitoring (WIPP EM) program. Station A is an above-ground air sampling platform shared with several other groups, and sampling operations there provide a way to monitor for releases of radionuclides and other substances in the exhaust air from the WIPP. In addition, if radioactive materials were to be released from the facility, the Station A data also would be invaluable for reconstructing exposure scenarios.

From a practical standpoint, Station A is located where radioactive or hazardous materials would most likely first be detected in the event of a release. Therefore, CEMRC has developed procedures and methods to provide a "quick look" (i.e., weeks where possible) at radioactive materials in the exhaust air. This addresses a strategic need for the monitoring program because most of the other WIPP EM analyses require several months or more to complete. That is, the data from Station A provide a preliminary look at the monitoring results; and, while these results are less specific and less detailed than those from the other studies, the data can be used to trigger more detailed investigations when appropriate.

Indeed, the sensitivity of the monitoring program at Station A was dramatically demonstrated in January 2001 when the CEMRC found elevated gross beta radioactivity in the FAS sample filters. Follow-up investigations eventually traced the source of the beta emitter(s) to the discharge of a fire extinguisher underground, but the incident was more notable because it demonstrated for the first time the ability of the monitoring system to detect a non-routine event. A second, more significant incident occurred when scientists from CEMRC reported that they had detected a small quantity of Pu in a composite aerosol sample from the second calendar quarter of 2003. This discovery was later corroborated by both EEG and WTS through the analyses of samples that were independently collected and analyzed. The detection of Pu in the exhaust air led to the issuance of a CEMRC report to the U.S. Department of Energy and a briefing presented to the New Mexico Environment Department. The activity was extremely low and well-within historic background, but indicated the ability of the monitoring program to detect radionuclides of interest at any level above the MDC.

METHODS

CEMRC commenced sampling of the WIPP exhaust air at Station A on 12 December 1998. Detailed descriptions of the sampling and analytical methods have been included in prior CEMRC Annual Reports. In brief, the samples are collected on 47 mm diameter membrane filters with the use of a shrouded probe, commonly referred to as a fixed air sampler or FAS. The airflow through the FAS is approximately 170 liters per minute.

There are actually three shrouded-probe aerosol samplers at Station A; these are located on three separate sampling skids denoted A1, A2 and A3 (Figure 2.1; see also Figures 11.1 and 11.2). The airstream sampled by each skid is split among three legs such that three concurrent samples can be collected from each skid. On 15

January 2000, the CEMRC sampling operations were moved from the original sampling point at Skid A2 (west), leg 1 to Skid A1 (east skid), leg 2 to facilitate more direct data comparisons among the three organizations sampling the effluent air. Since that time all groups, CEMRC plus Washington TRU Solutions (WTS) and the Environmental Evaluation Group (EEG) and later the New Mexico Environment Department (NMED), have sampled from the same skid. In April 2001, primary sampling operations were transferred from Skid A1 to A3 (south skid) to reduce problems associated with water infiltration into the exhaust shaft.

A summary flow diagram illustrating the handling and analysis of the aerosol sample filters is presented in Figure 2.2. The FAS sample filters are normally changed daily except on holidays when a filter will run for multiple days. The aerosol sampling operations at Station A have at times been hampered by filter clogging, and during one interval (24 January 2000 to 28 November 2001) CEMRC and the other organizations changed filters twice daily Monday through Friday. Daily sampling resumed when the mass concentrations decreased and flow rates improved. However, occasionally more than one sample per day is still collected, that is, if the flow rate on any of the sampler legs drops below 1.8 cfm, a low-flow alarm on the sampler is activated and the filters are changed. See Chapter 11 for a discussion of clogging and occlusion.

All the analyses of the FAS filters are performed according to methods detailed in CEMRC document-controlled, standard operating procedures. After the samples are returned to the laboratory, the individual filters are first weighed to determine mass loadings, and after allowing for the decay of short-lived radon daughters, they are counted for gross alpha/beta activities for 1200 minutes using a low-background gas proportional counter (LB4100, Canberra and more recently starting in April 2006, a Protean MPC9604). During a study to investigate fouling of the sample probes (see Chapter 11), the count times were reduced to 480 minutes to accommodate additional samples from the experimental unit used in some studies of probe-fouling. In preparation for that study, data from the back-up FAS sampler were collected to determine whether gravimetric and gross alpha/beta data were comparable to the data obtained with the sampler of record.

The gross alpha and beta activities are expressed in the following two ways. First, the *activity concentration* is calculated as the activity per unit volume of air sampled (mBq m^{-3}). Second, *activity density* is calculated as the activity per unit aerosol mass collected (Bq g^{-1}). The minimum detectable activity concentrations and densities for the gross alpha emitters were ≈ 0.1 mBq m^{-3}) and ≈ 0.7 Bq g^{-1}, respectively, while for gross beta emitters the corresponding values were ≈ 0.2 mBq $m^{-3}$and ≈ 1.7 Bq g^{-1}

Elemental and gamma-ray analyses are conducted on weekly composites of the filters. Quarterly composites were initially used for the determination of actinide activities, but monthly compositing was implemented in July of 2004. Individual FAS filters are digested using a mixture of strong acids in a microwave digestion unit, and weekly composites were prepared from the digestates of the individual filters. The weekly composites are then analyzed for a suite of trace elements with the use of a Perkin-Elmer Elan inductively coupled plasma-mass spectrometry (ICP-MS). The ICP-MS methods can provide data for up to ~35 elements, but in practice the concentrations of some elements, including As, Be, Cd, Er, Eu, Sc, Se, Sm, Tl and V are often below detectable or quantifiable levels, and a second set of elements (notably Ag, Li and Sn) has variable concentrations in blank filters which makes their quantification difficult. Analyses of gamma emitters are performed on the same weekly composites as used for the elemental studies; the gamma analyses are done using a low-background, high-purity Ge well detector and a count time of 24 hours. For FAS weekly composites collected prior to October 2004, a 10 mL aliquot was gamma counted. For those collected on or after October 1, 2004, the entire FAS weekly composite was gamma counted.

Finally, quarterly, or more recently, monthly composites are prepared from the weekly composites, and these are used for the determination of actinide activities. Only one half of the composite sample is normally used for the determination of the actinide activities. The remaining aliquot is archived. The composite sample is evaporated to dryness, and the residue is digested in perchloric acid to destroy the black residue, which consists mostly of diesel exhaust particulates. This process ensures that fluorine is completely removed and all traces of organic filter residue have been oxidized. The actinides are then separated as a group by co-precipitation on $Fe(OH)_3$. After dissolution, Pu, U, and Am are separated by anion exchange and extraction chromatography, and the sample planchettes are finally prepared for alpha spectrometry using rare-earth micro-coprecipitation.

RESULTS AND DISCUSSION

The essence of the strategic design for the WIPP EM, including the studies at Station A, has been to compare pre- vs. post-disposal data. The first radioactive waste shipments were received at the WIPP on March 26, 1999, and this is considered the cut-off date separating the pre-disposal phase from the post-disposal or operational phase. The WIPP first received mixed waste on September 9, 2000, and therefore data for samples collected prior to that date compose a pre-mixed waste baseline for the elemental data while those collected afterwards are considered operational.

In Figures 2.3 through 2.7 discussed below, data points are distinguished by color, with red being pre-disposal, blue being operational, black being Station A backup results, and green being filters collected as part of the probe fouling study.

GROSS ALPHA AND BETA ACTIVITIES AND AEROSOL MASS LOADINGS

The gross alpha and beta activities in the samples collected prior to the receipt of the first waste shipment represent the pre-disposal background, and the bulk of the activity in those samples was due to naturally occurring radioactive materials, specifically radon daughters. As shown in Table 2-1, the pre-operational gross alpha activity densities and concentrations were both high compared with the annual mean values for the next five years. This is in large measure due to the fact that the gross alpha activities exhibit clear seasonal variability with peaks occurring in winter (Figure 2.3), and the pre-disposal samples were collected at that time of year. An especially pronounced annual cycle in alpha activity concentrations, with high values in December and January and low values mid-year is seen in 2004 to 2005. After 2005, activities appear to have gone back up to pre-operational levels.

Generally similar trends in gross beta data can be seen in Figure 2.4. One entry that stands out in Table 2-1 is the maximum beta activity concentration of 58.4 Bq m^{-3} observed in 2001. This sample and another collected around the same time (Figure 2.4) are the ones that were contaminated by the material released from the underground fire extinguisher as mentioned above.

While the activities of the alpha and beta emitters have not changed greatly since the inception of the studies, the gross alpha activities appeared to decrease slightly after the WIPP became operational and then in 2003 began to increase again to levels approaching or slightly exceeding the pre-disposal values. The reported gross alpha and beta activities are normalized by dividing the measured activities by the mass loadings on the sample filters or by the amount of air sampled. Therefore trends in the former, that is the activity densities, could either be due to changes in the amount of radioactivity in the sample or the aerosol mass in the samples (the volumes of air sampled, which are not shown, have changed little during the course of the program and so there should be little or no effect on the activity concentrations). A timeseries plot of the aerosol mass loadings (Fig. 2-5) shows a trend towards lower sample masses beginning in 2004 and also less scatter in the gravimetric data. The latter point is also evident in Table 2-3, which shows that the relative standard error, i.e,. the standard error divided by the arithmetic mean and expressed as a percentage was ≤ 6.3% in the last four years of the study compared with 10% to 20% in the three of the first four years of the program. This decrease in aerosol mass loadings would directly contribute to the high alpha and beta activity densities observed in the most recent years of the WIPP-EM.

A direct x-y plot of the matched beta vs. alpha activities per filter (Figure 2-6) suggests two end-member mixing, with one of the end members having a alpha/beta activity ratio of ~0.06 and the other with a ratio of ~0.33. Studies are underway to determine the source of each end-member but it is anticipated that the end-member having an alpha/ beta ratio of 0.06 is Salado salt and the other is ordinary dust with bomb-pulse signatures. These two plots coupled with the change in aerosol mass loadings mentioned above suggest that the composition of the WIPP exhaust air may have changed over time, but it is also important to determine whether any changes in the analytical methods or equipment could be responsible for the apparent trends in the data. Additional studies are needed to resolve this issue.

ELEMENTAL DATA

Prior studies at Station A have shown that the concentrations of hazardous metals and various trace elements can be highly variable over time; this was true even in the samples collected prior to receipt of the mixed waste in September 2000. In timeseries plots of selected trace element data (Figures 2-7 and 2-8), the baseline samples are represented as open symbols while the operational samples are shown as filled symbols. There is some data missing from the elemental data plots due to a sample holding time issue. This occurred from September through December 2004.

No marked differences are evident in the baseline vs. operational samples, but seasonal cycles are clear, especially for Na, the most abundant of the elements plotted. The data for Na are of particular interest because panel excavation and other operations in the WIPP underground generate salt dusts, and the temporal peaks at the beginning of each new calendar year presumably reflect those activities taking place in the repository. The longer term trend in Na concentrations appears to be downward, especially after the beginning of 2003. This is most evident when comparing the seasonal peaks in Na for 2003/2004, 2004/2005 and 2005/2006 with those in the preceding years. It is also worth noting that the general decreasing trend in Na and other elements is consistent with the changes in aerosol mass loadings discussed above.

Another non-radiogenic constituent of interest is aluminum; this interest is due to relationships observed between the Al concentrations in ambient aerosols and the activities of ^{239,240}Pu and ^{241}Am (Arimoto et al., 2002 and 2006). Windblown dust is the main source for Al and many other elements (Fe, Mn, Sc, and the rare earth elements) and also represents a source for U and some other naturally occurring radionuclides. Kirchner et al. (2002) have also shown relationships between Al and various radionuclides, both artificial and naturally occurring, in soils. Studies are currently underway under separate funding to investigate the nature of the relationship between Pu and iron oxides in mineral matter (Tatro et al., 2006).

Several potentially toxic elements (i.e., Pb, Cd, U, Th) that are components of the WIPP mixed waste were already present in measurable amounts in the WIPP aerosol effluent prior to the receipt of mixed waste. The concentrations of these elements, too, change with season and over the course of the monitoring program. Most important, there is no evidence for a long-term increase in the concentrations of any of these elements that can be linked to the WIPP operations in any way.

Table 2-1: Summary Statistics for Gross Alpha Analyses of Daily FAS Filters

		Activity Density (Bq g^{-1})				Activity Concentration (mBq m^{-3})			
Group	**[a]N**	**% < [b]MDA**	**[c]Mean**	**[d]SE**	**[e]Max**	**% < [b]MDA**	**Mean**	**SE**	**Max**
Pre-Disposal	70	0%	3.6	0.59	36.7	0%	0.315	0.031	1.49
1999[f]	185	1%	1.9	0.33	61.4	1%	0.110	0.005	0.37
2000	465	67%	1.0	0.07	3.8	67%	0.112	0.005	0.39
2001	428	65%	1.3	0.12	9.6	65%	0.082	0.004	0.42
2002	382	33%	1.0	0.13	21.5	34%	0.081	0.002	0.26
2003	345	35%	2.1	0.61	135.4	35%	0.104	0.005	0.40
2004	370	17%	2.4	0.18	26.6	17%	0.144	0.008	1.29
2005	361	4%	5.6	1.07	327.8	4%	0.223	0.006	0.71
2006	264	3%	3.1	0.21	35.4	3%	0.166	0.007	1.43

[a] N represents the number of samples

[b] Percentage of samples less than the MDC (minimum detectable activity)

[c] Arithmetic mean

[d] SE stands for standard error

[e] Max is the maximum observed value

[f] From 26 March to 31 December 1999

Table 2-2: Summary Statistics for Gross Beta Analyses of Daily FAS Filters

		Activity Density (Bq g^{-1})				Activity Concentration(mBq m^{-3})			
Group	[a]N	% < [b]MDC	[c]Mean	[d]SE	[e]Max	% < [b]MDC	Mean	SE	Max
Pre-Disposal	70	0%	14.0	1.90	120	0%	1.14	0.09	4.94
1999	189	0%	20.0	2.20	350	0%	0.99	0.03	3.25
2000	461	6%	7.7	0.54	76	6%	0.98	0.02	2.73
2001	429	3%	12.0	1.00	190	3%	1.14	0.16	58.41
2002	382	2%	12.0	0.99	200	2%	0.90	0.02	1.97
2003	345	1%	20.0	6.30	2100	1%	0.79	0.02	4.77
2004	369	4%	16.0	1.50	460	4%	0.81	0.02	4.85
2005	361	1%	20.0	3.90	1300	1%	0.78	0.02	2.07
2006	324	1%	9.8	0.57	93	1%	0.61	0.02	2.10

[a]N represents the number of samples
[b]Percentage of samples less than the MDC (minimum detectable activity)
[c]Arithmetic mean
[d]SE stands for standard error
[e]Max is the maximum observed value
[f]From 26 March to 31 December 1999

Table 2-3: Summary Statistics for Aerosol Mass Loadings (micrograms per filter) on FAS Filters

Group	[a]N	[b]Mean	[c]SE	[d]RSE
Pre-Disposal	70	125.0	12.2	9.8%
1999[e]	189	171.2	17.1	10.0%
2000	461	396.5	20.7	5.2%
2001	429	285.4	29.4	10.3%
2002	382	274.7	55.5	20.2%
2003	345	204.3	12.7	6.2%
2004	369	95.7	6.0	6.3%
2005	361	90.2	3.9	4.3%
2006	324	84.8	3.0	3.5%

[a]N represents the number of samples
[b]Arithmetic mean
[c]SE stands for standard error
[d]RSE is the relative standard error expressed as a percentage (the Standard Error divided by the Mean)
[e]From 26 March to 31 December 1999

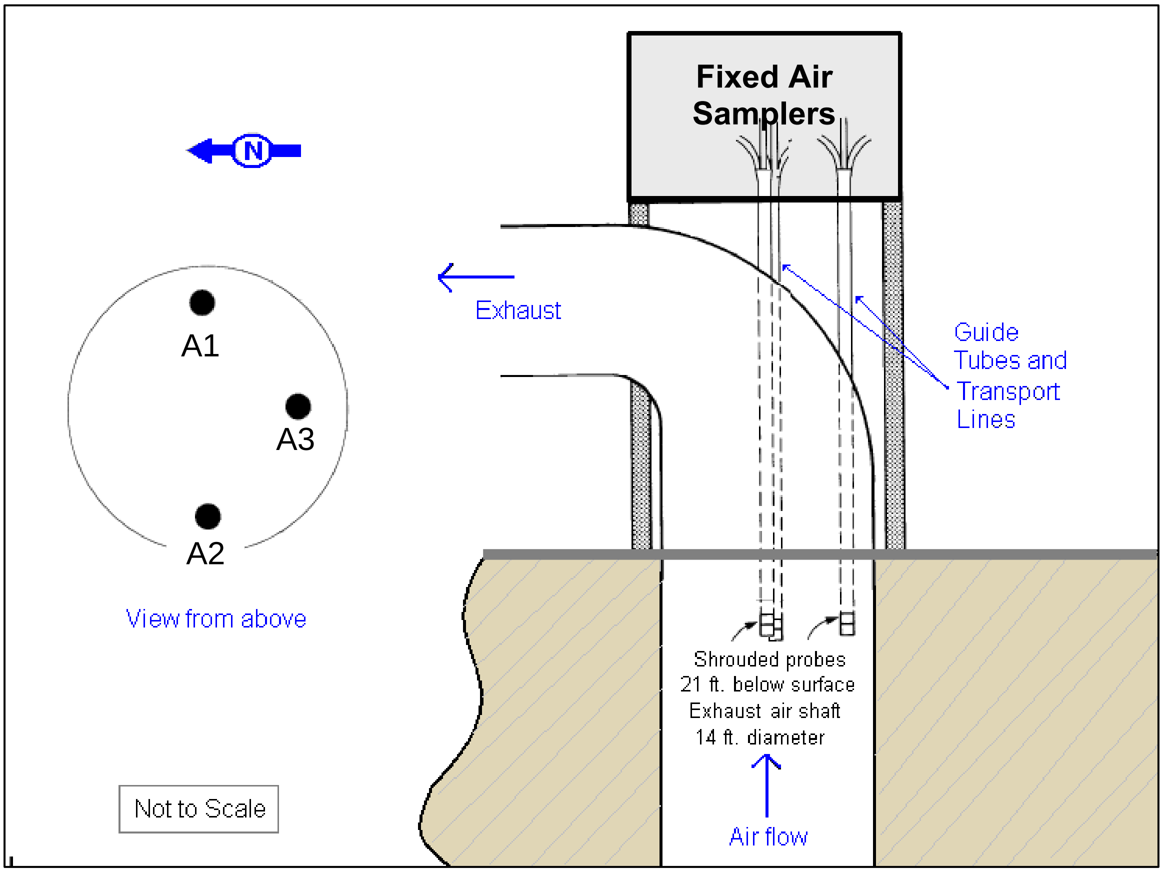


Figure 2.1: Fixed Air Samplers at Station A

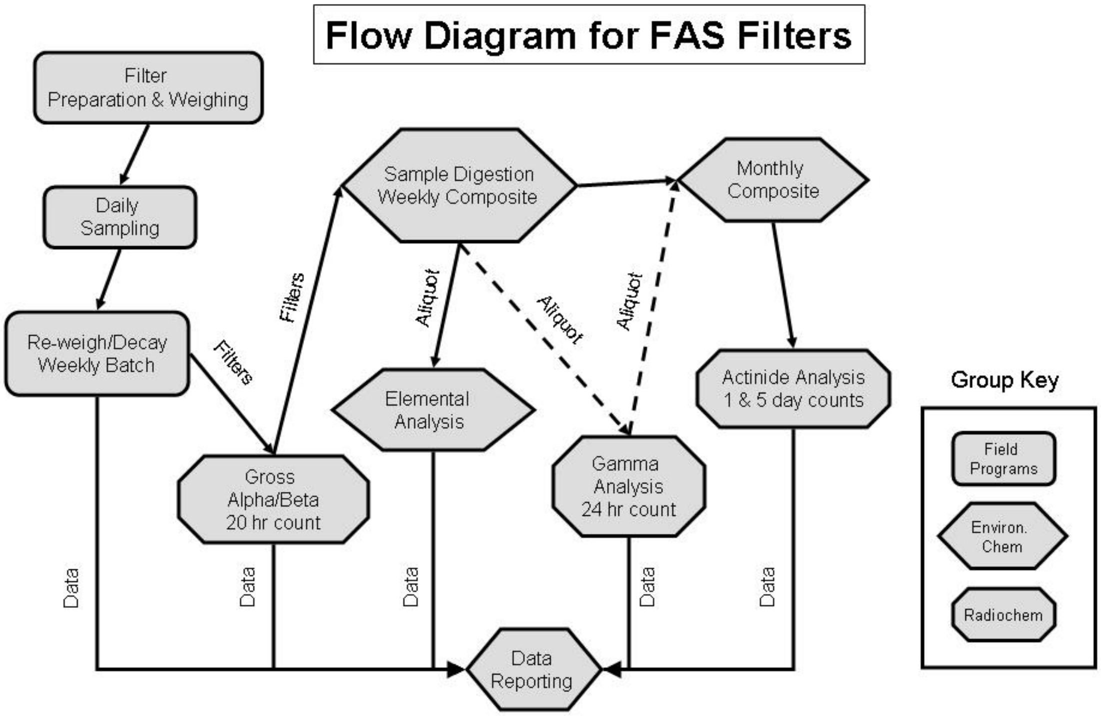


Figure 2.2: Flow diagram showing the handling and analysis of the aerosol sample filters from Station A

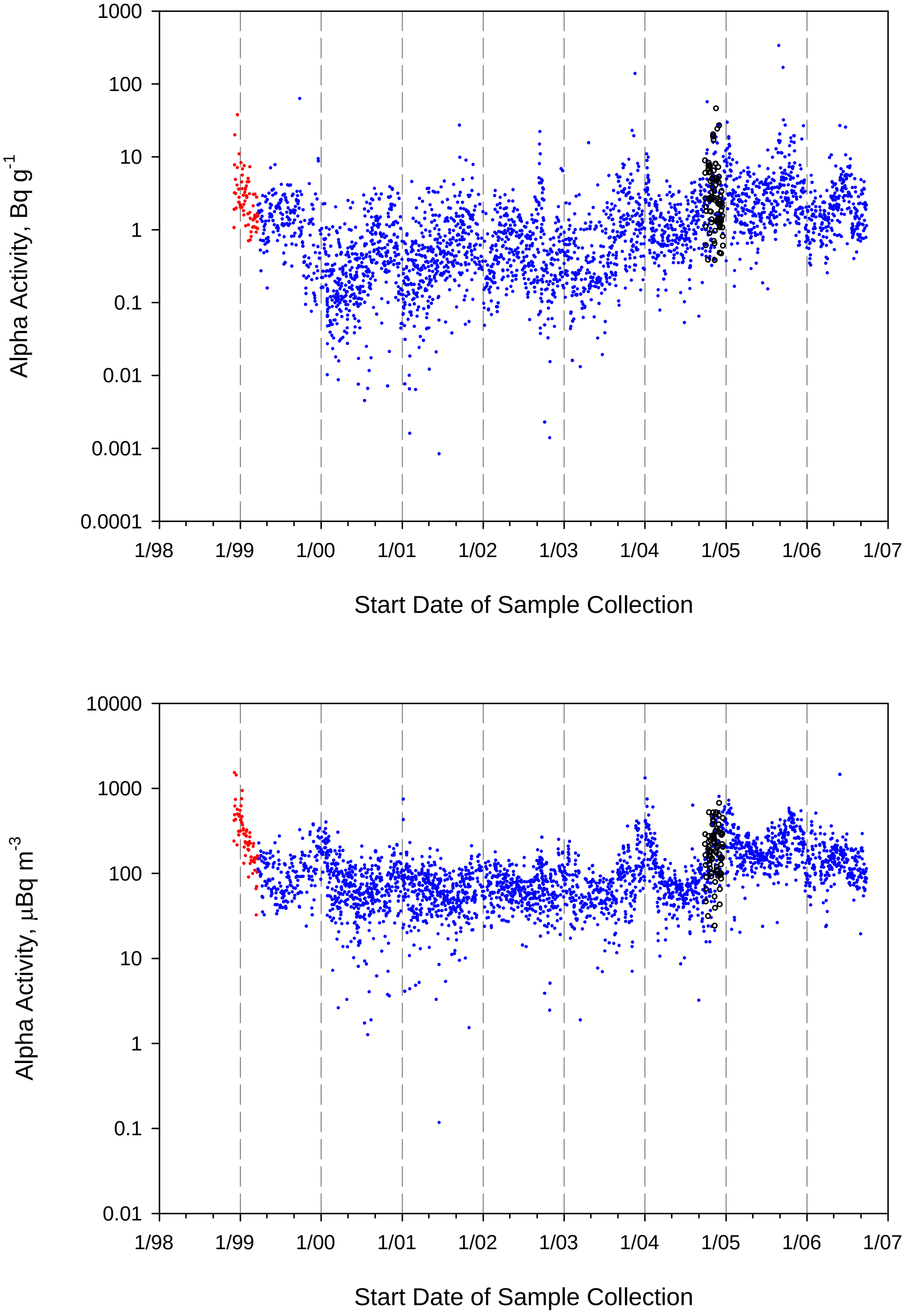


Figure 2.3: Timeseries plots of gross alpha activity densities (upper panel) and activity concentrations (lower panel). Red points denote pre-disposal samples, blue points are for operational samples and black points are for samples collected with the back-up sampler.

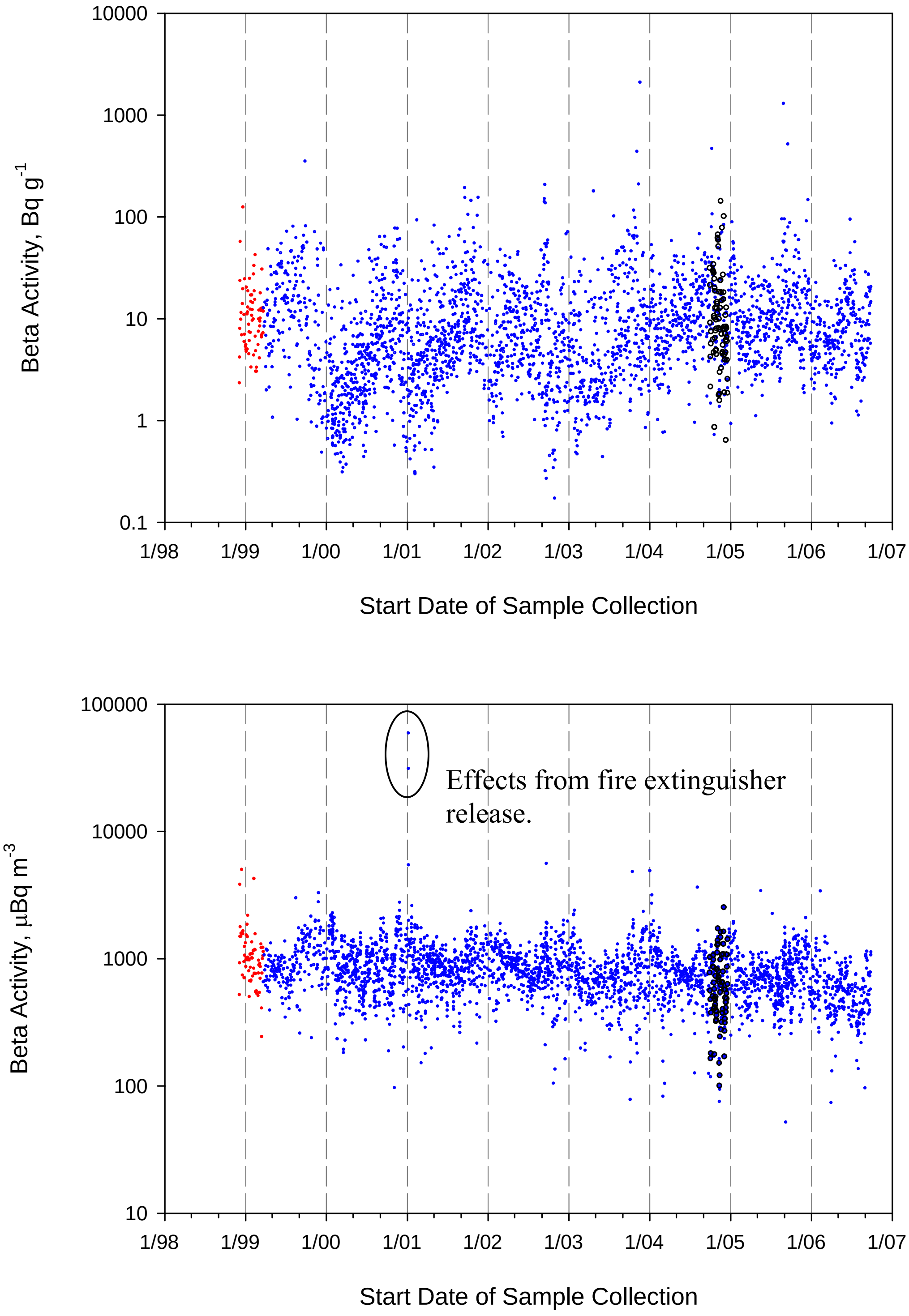


Figure 2.4: Timeseries plots of gross beta activity densities (upper panel) and activity concentrations (lower panel). Red points denote pre-disposal samples, blue points are for operational samples and black points are for samples collected with the back-up sampler.

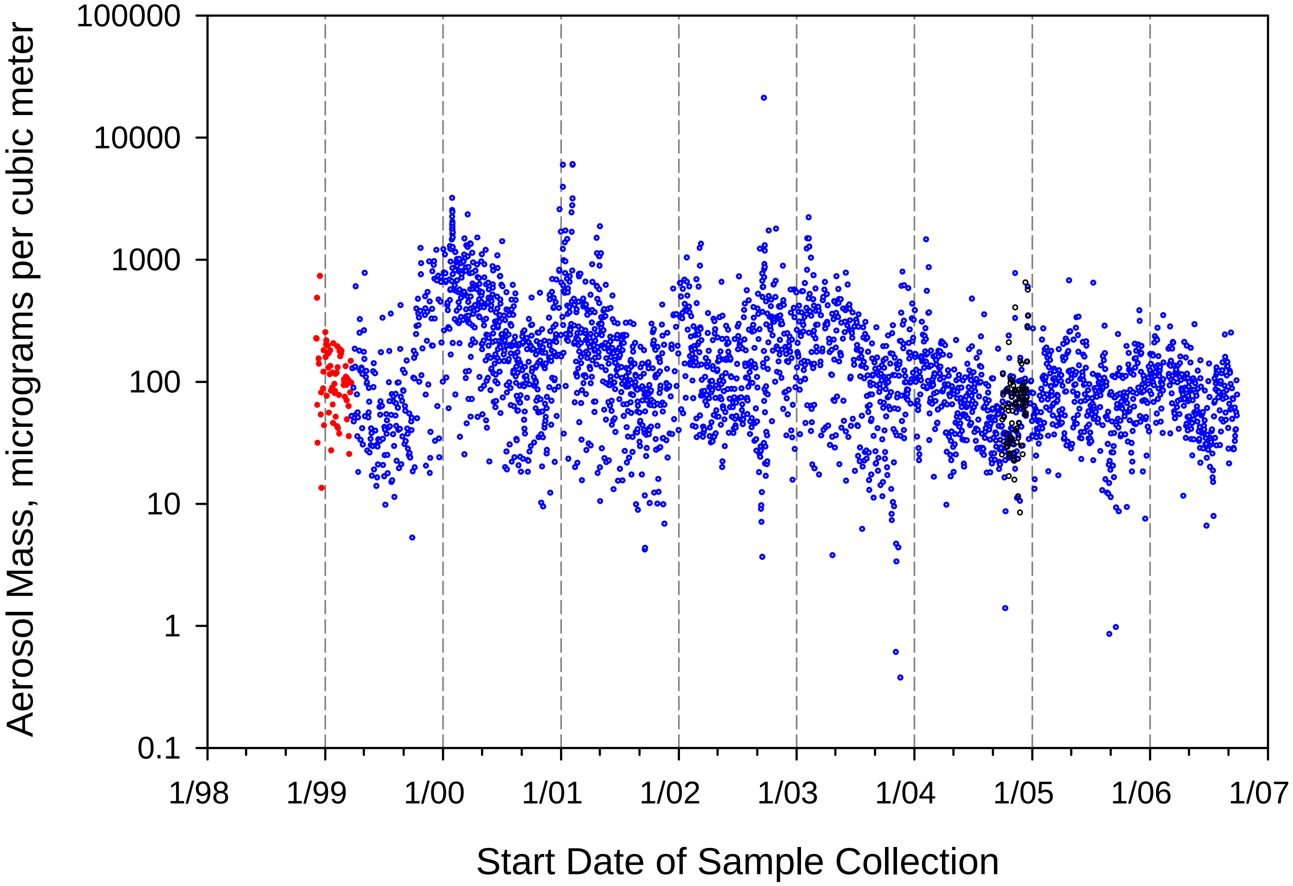


Figure 2.5: Timeseries plot of aerosol mass loadings. Red points denote pre-disposal samples, blue points are for operational samples and black points are for samples collected with the back-up sampler.

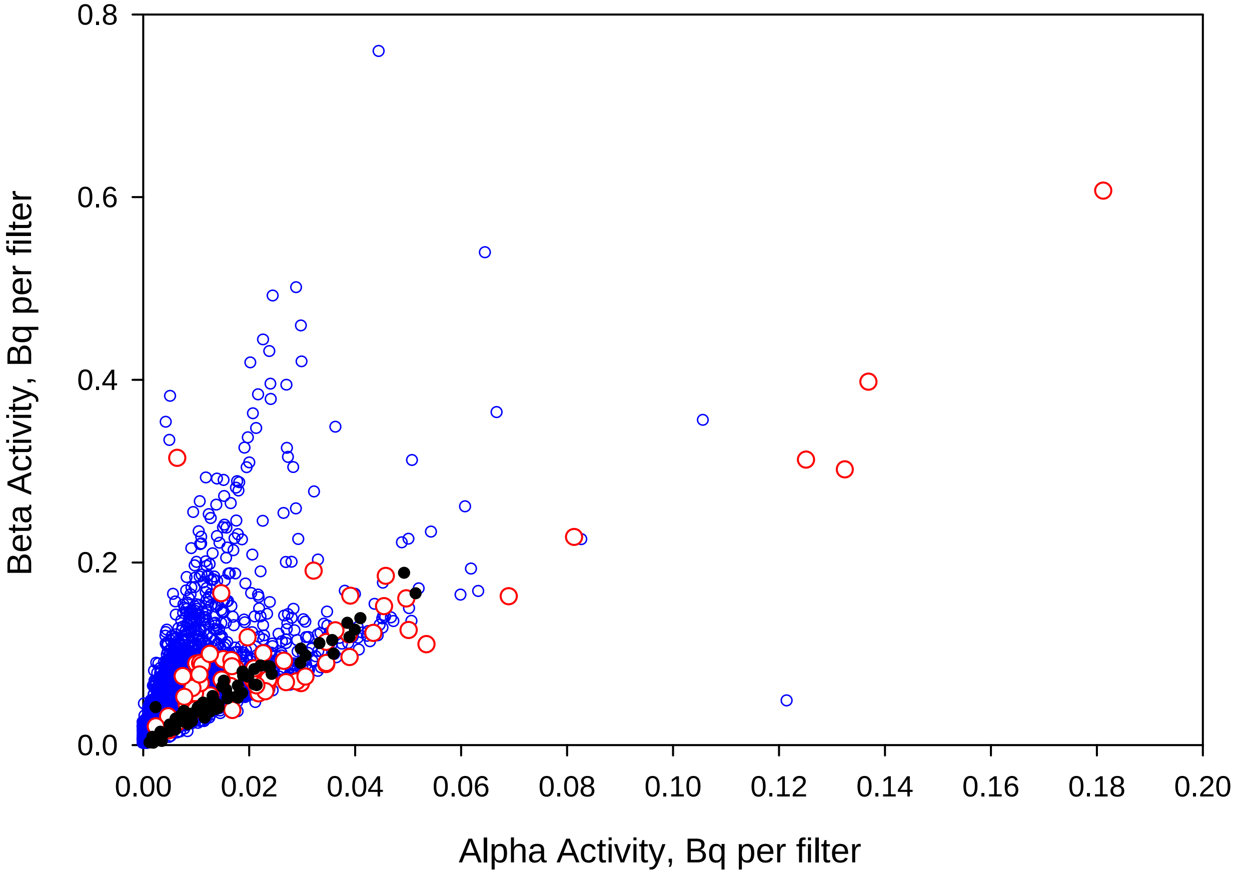


Figure 2.6: Beta activity vs. alpha activity in fixed air samples from Station A. Red points denote pre-disposal samples, blue points are for operational samples and black points are for samples collected with the back-up sampler.

Figure 2.7: Concentration of Selected Elements (Al, Mg, Na) in WIPP Exhaust Air

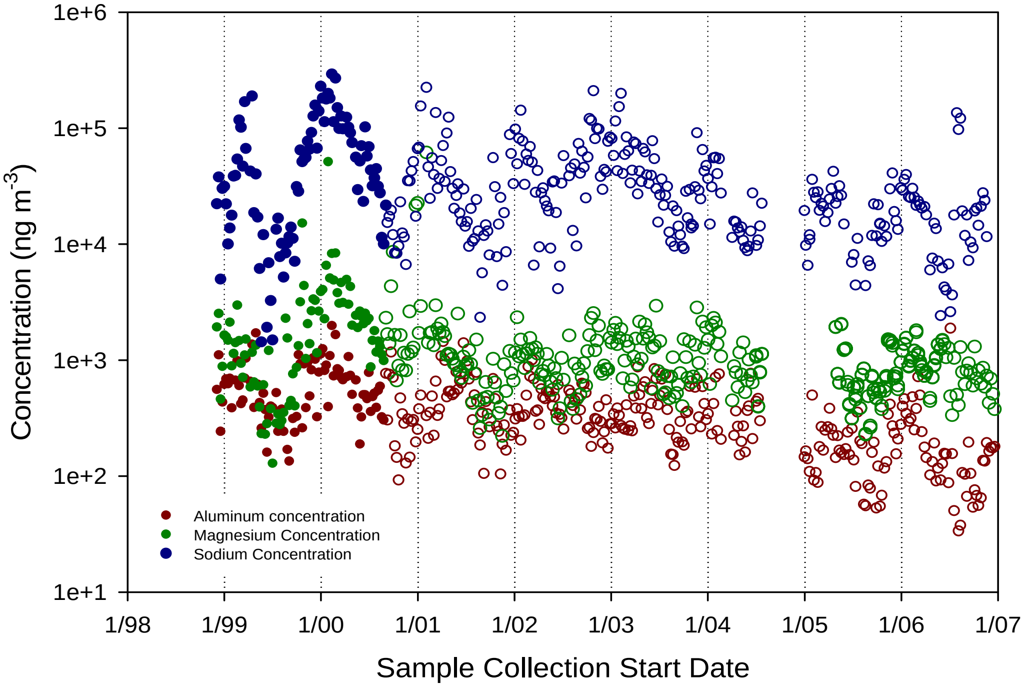
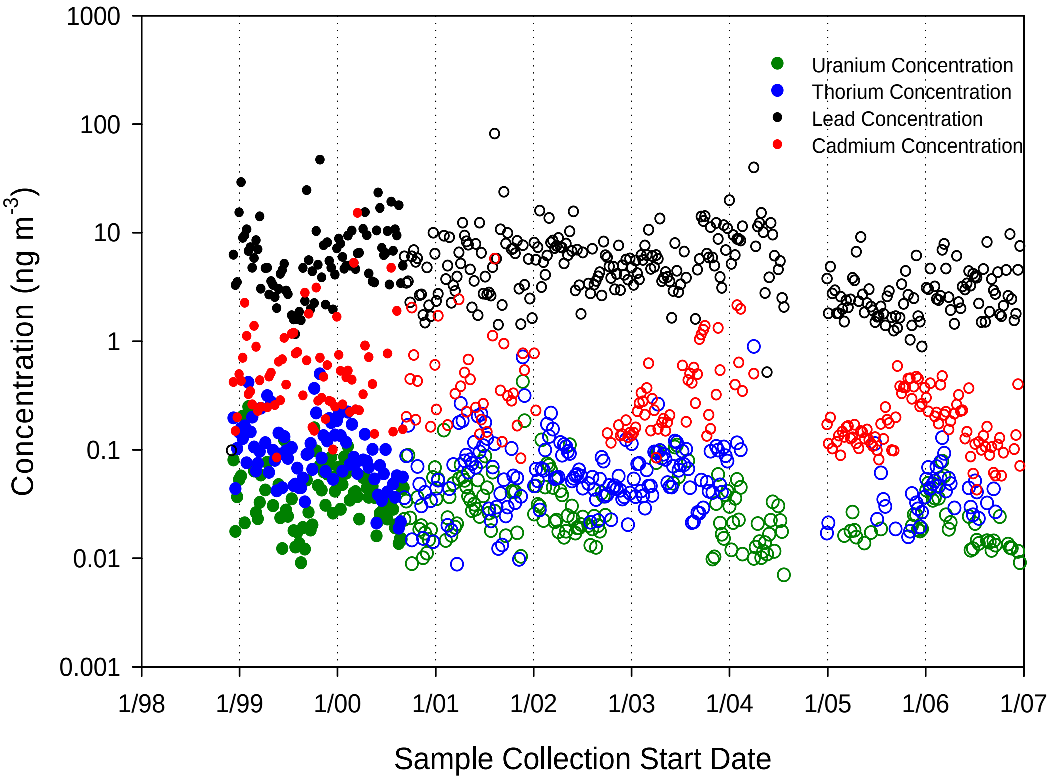


Figure 2.8: Concentration of Selected Elements (U, Th, Pb, Cd) in WIPP Exhaust Air



Filled circles represent pre-operational data. Open circles represent data since WIPP began accepting mixed waste.

CHAPTER 3

Surface Soil Radionuclides

INTRODUCTION

Results reported herein are from soil samples collected during 2005 from a grid of 16 locations surrounding the WIPP site (the Near Field grid). Also reported are summary statistics for the 1998-2001 data for the Near Field grid and for a grid of 16 locations approximately 12 miles southeast of the WIPP (the Cactus Flats grid, Figure 3.1). The 2005 soil samples were collected after the arrival of the first mixed waste shipments at WIPP. Thus, the data for the radioactive and hazardous waste constituents are results from the monitoring phase. Measurements were made by CEMRC on the 2005 surface soil samples for ^{137}Cs, ^{208}Tl, ^{212}Pb, ^{212}Bi, ^{214}Bi, ^{214}Pb, ^{228}Ac, and ^{40}K. The analyses for ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, ^{228}Th, ^{239,240}Pu, ^{241}Am have not yet been completed. The natural radionuclides ^{208}Tl, ^{212}Bi, ^{214}Pb and ^{212}Pb are measured after allowing for ingrowth to equilibrium and their concentrations do not represent natural levels in the environment. The activity of ^{214}Pb was used to estimate the original environmental concentration of ^{226}Ra. The activity of ^{208}Tl, ^{212}Bi and ^{212}Pb can be used to estimate activities of other members of the thorium series.

METHODS

The 16 sampling locations constituting each grid are distributed over approximately 16,580 hectares. In both 1998 and 1999 at each of the 32 locations (grid nodes), soil was collected from three randomly selected sites within a 50-m radius of the selected reference point. In 2000, one sample was collected at each of the 32 grid nodes. In 2001, two samples were collected at each of the 32 grid nodes. One of each pair of the 2001 samples was analyzed and the other was archived. In 2005 one sample was collected at each of the 16 grid nodes, but these samples were collected in an annulus between 20 and 40 meters from the grid node in order to reduce the chance of re-sampling an area. Two field duplicates were collected at randomly selected reference points each year within each grid sampled. Individual sampling sites were selected on the basis of relatively flat topography, minimum surface erosion and minimum surface disturbance by human or livestock activity. Approximately 4 L of soil were collected from within the sampling areas to a depth of approximately 2-cm for radionuclide analyses. Soil samples were excavated using a trowel and placed in plastic bags for transport and storage. Sampling equipment was cleaned between samples.

Initial preparation of the samples for radiological analyses consisted of passing the soil through a 2-mm sieve to remove rocks, roots and other materials. Samples were then dried at 105˚C for 12 hours and ground using a jar mill. Approximately 300-mL aliquots were used for gamma spectroscopy analysis. The samples for gamma analysis were sealed in a ~ 300-mL can and stored for at least 21 days to allow radon progeny to reach equilibrium with parent radionuclides.

Gamma spectroscopy analysis was conducted using high purity Ge (HPGe) detector systems. A set of soil matrix standards was prepared using NIST traceable solutions and used to establish matrix-specific calibration and counting efficiencies. A summary of QA/QC for radioanalyses is presented in Appendix E.

Reported concentrations are blank-corrected. Negative concentrations of analytes can result when both the sample and the blank have concentrations above the MDL, and are hence regarded as detectable quantities, with the blank concentration exceeding the sample concentration. Thus negative values are invariably small and represent values very close to the blank concentrations.

Quality Control

Reproducibility of the measurements of radionuclides was determined by comparing measurements from a set of laboratory duplicates. Relative Error Ratios (RERs) were computed for all measurements for which concentrations were greater than the MDC. RER is computed as

$$RER = \frac{|c_1 - c_2|}{\sqrt{s_1^2 + s_2^2}}$$

where c_i is the concentration of the i^{th} duplicate and s_i is the estimated standard deviation of the i^{th} concentration. The standard deviation incorporates counting uncertainty and uncertainties associated with other aspects of the instrument measurements. Relative error ratios are used in addition to RPDs when comparing duplicate samples of radionuclides because they take into account counting and other uncertainties that are associated with activity measurements. RERs were computed for ^{228}Ac, ^{241}Am, ^{212}Bi, ^{214}Bi, ^{137}Cs, ^{40}K, ^{212}Pb, ^{214}Pb, ^{239}Pu, ^{228}Th, ^{230}Th, ^{232}Th, ^{208}Tl, ^{234}U, ^{235}U, and ^{238}U.

RESULTS AND DISCUSSION

Reproducibility of Measurements

The measurements of radionuclides in laboratory duplicates were generally in good agreement. RPDs ranged between 0.3% and 6.1%. RPDs hold meaning only when the RERs are relatively low, i.e. when the differences do not fall within the range of analytical uncertainty. The maximum RER was 1.04 for the radionuclides measured by gamma analysis (Table 3-1). These RERs are comparable to the RERs for soil radionuclide measurements reported in the DOE/WIPP Site Environmental Report (DOE/WIPP 2006, hereafter DOE/WIPP SER). The duplicate soil analyses reported in the DOE/WIPP SER were limited to ^{234}U, ^{235}U, ^{238}U, ^{40}K and ^{137}Cs. The maximum RER reported in the DOE/WIPP SER was 1.69.

Comparison to Other Studies

The activity concentrations of ^{137}Cs and ^{40}K in CEMRC 2005 samples were similar to those reported in the DOE/WIPP SER. The mean concentrations of the gamma-emitting radionuclides (Table 3-2) were also comparable to the concentrations observed in previous years (Figure 3.2). The data in comparison to the mean of previous years by grid node is presented in Table 3-3.

Table 3-1: RPDs and RERs for Soil Gamma Duplicate Measurements

SID	Nuclide1	RPD	RER
18293	^{137}Cs	0.91%	0.18
18293	^{208}Tl	3.51%	0.68
18293	^{212}Bi	5.03%	0.27
18293	^{212}Pb	4.45%	0.96
18293	^{214}Bi	3.09%	0.80
18293	^{214}Pb	2.08%	0.68
18293	^{228}Ac	6.16%	1.04
18293	^{40}K	0.31%	0.13

Table 3-2: Summary Statistics for Radionuclides in Soil Samples Collected in 2005

Analyte	Unit	Near Field		
		^{a}N	^{b}Mean	Range
^{137}Cs	Bq kg^{-1}	18	3.35E+00	5.41E-01 - 6.24E+00
^{208}Tl	Bq kg^{-1}	19	3.00E+00	1.78E+00 - 4.61E+00
^{212}Bi	Bq kg^{-1}	19	1.04E+01	6.29E+00 - 1.73E+01
^{212}Pb	Bq kg^{-1}	19	7.46E+00	4.91E+00 - 1.06E+01
^{214}Bi	Bq kg^{-1}	19	8.83E+00	4.49E+00 - 1.26E+01
^{214}Pb	Bq kg^{-1}	19	9.51E+00	6.47E+00 - 1.32E+01
^{228}Ac	Bq kg^{-1}	19	8.92E+00	2.61E+00 - 1.43E+01
^{40}K	Bq kg^{-1}	19	2.43E+02	1.61E+02 - 3.66E+02

[a] N = number of samples > MDC
[b] Mean = arithmetic mean
[c] Based on ^{214}Pb at equilibrium

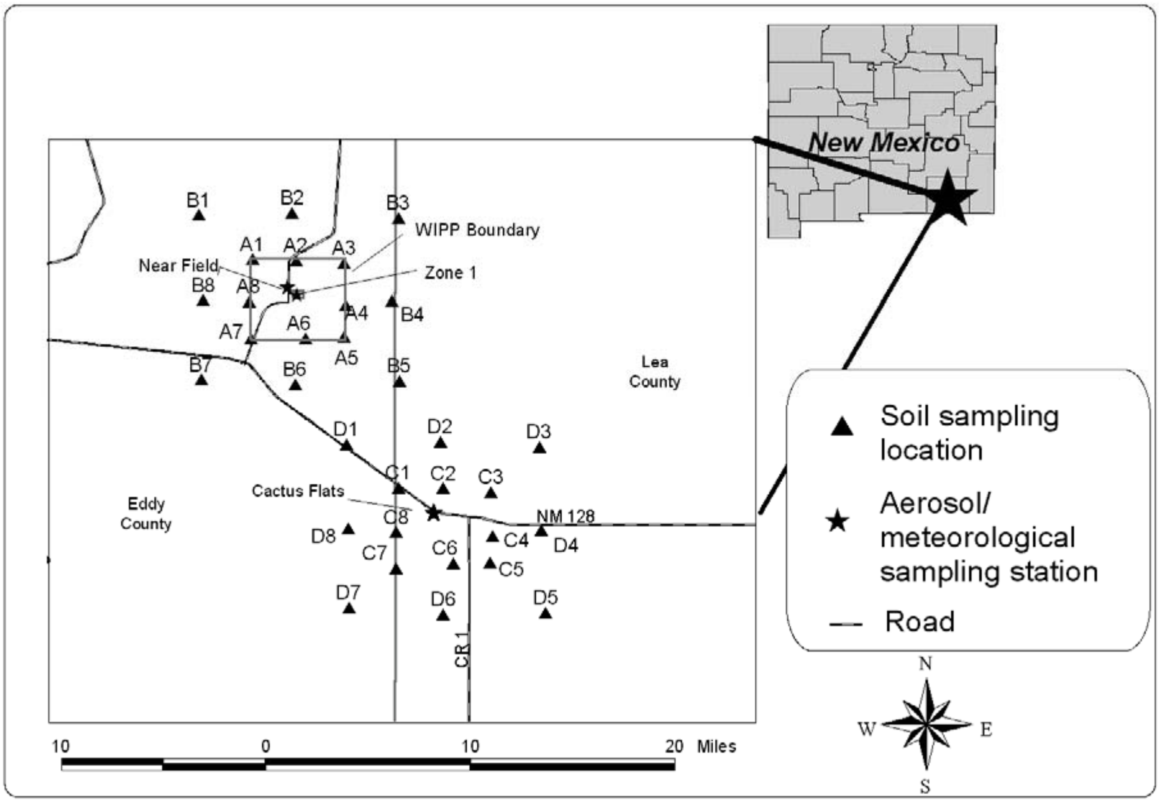


Figure 3.1: Soil Sampling Locations in the Vicinity of the WIPP

Also shown are aerosol sampling and meteorological monitoring sites at Near Field and Cactus Flats.

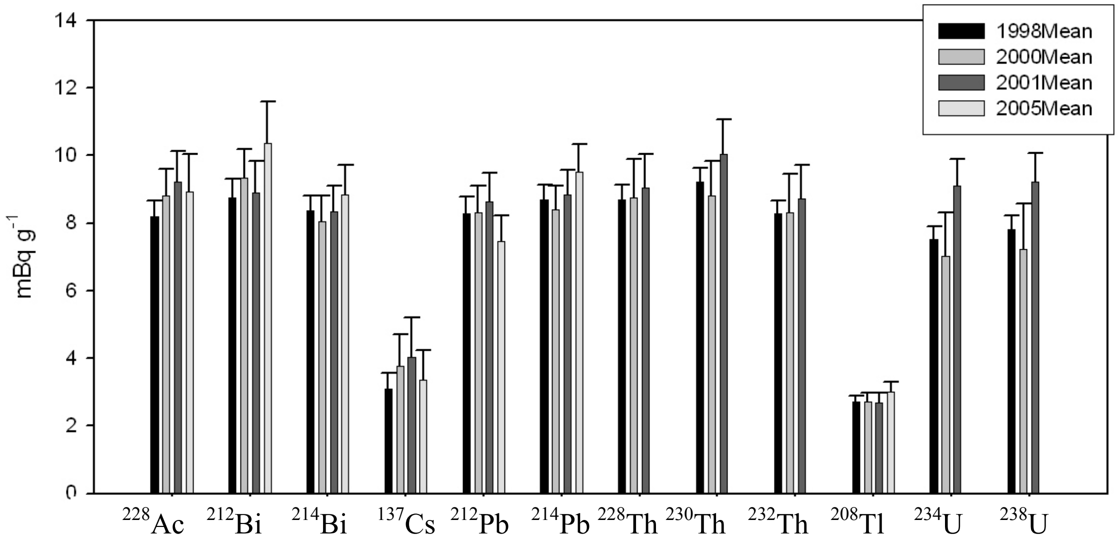


Figure 3.2: Mean Concentrations of Radionuclides in Soil Samples from Near Field Grid Collected during 1998 – 2001 Compared to 2005

Error bars show upper 95% confidence intervals for concentrations.

Table 3-3: Concentrations of Radionuclides in Soil by Grid Node for 2005 in Comparison to the Means of Concentrations from Previous Years

		1998-2001					2005				
Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)	Activity (Bq/kg)	Uncertainty (Bq/kg)	MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
A1	Ac228	9.73E+00	3.89E-01	1.12E+00	8.51E+00	1.07E+01	1.06E+01	3.29E-01	1.06E+00		
A1	Am241	5.56E-02	1.13E-02	1.80E-02	1.43E-02	9.37E-02					
A1	Bi212	9.50E+00	1.22E+00	3.82E+00	8.03E+00	1.18E+01	1.23E+01	1.42E+00	4.38E+00		
A1	Bi214	9.55E+00	2.84E-01	7.04E-01	9.01E+00	1.01E+01	9.92E+00	2.68E-01	6.04E-01		
A1	Cs137	3.98E+00	1.25E-01	2.11E-01	1.79E+00	6.88E+00	4.81E+00	1.08E-01	2.13E-01		
A1	K40	2.46E+02	4.20E+00	3.59E+00	2.13E+02	2.83E+02	2.78E+02	4.88E+00	2.93E+00		
A1	Pb212	9.47E+00	3.08E-01	4.28E-01	8.76E+00	9.87E+00	1.06E+01	2.00E-01	3.59E-01		
A1	Pb214	9.89E+00	2.65E-01	7.37E-01	9.13E+00	1.03E+01	1.06E+01	2.36E-01	6.69E-01		
A1	Pu238	1.62E-02	6.93E-03	1.22E-02	1.62E-02	1.62E-02					
A1	Pu239	1.39E-01	1.68E-02	2.40E-02	6.64E-02	3.89E-01					
A1	Th228	9.31E+00	2.31E-01	7.61E-02	9.06E+00	9.60E+00					
A1	Th230	9.71E+00	2.38E-01	7.94E-02	8.64E+00	1.06E+01					
A1	Th232	8.95E+00	2.23E-01	2.92E-02	8.53E+00	9.49E+00					
A1	Tl208	3.03E+00	1.29E-01	3.54E-01	2.85E+00	3.29E+00	3.21E+00	1.08E-01	2.42E-01		
A1	U234	9.50E+00	2.76E-01	5.39E-02	9.05E+00	1.04E+01					
A1	U235	5.12E-01	5.72E-02	5.20E-02	4.81E-01	5.75E-01					
A1	U238	9.83E+00	2.84E-01	5.65E-02	9.53E+00	1.03E+01					
A2	Ac228	7.61E+00	3.22E-01	1.01E+00	6.17E+00	8.72E+00	8.08E+00	2.78E-01	9.29E-01		
A2	Am241	3.71E-02	9.53E-03	1.87E-02	2.94E-02	4.28E-02					
A2	Bi212	7.16E+00	1.02E+00	3.18E+00	5.67E+00	8.17E+00	9.82E+00	1.36E+00	4.27E+00		
A2	Bi214	7.31E+00	2.48E-01	6.18E-01	6.30E+00	7.85E+00	7.68E+00	2.28E-01	5.47E-01		
A2	Cs137	2.48E+00	6.75E-02	1.93E-01	9.69E-01	4.00E+00	9.46E-01	5.22E-02	1.73E-01		
A2	K40	2.00E+02	3.61E+00	3.39E+00	1.80E+02	2.27E+02	1.98E+02	3.70E+00	3.53E+00		
A2	Pb212	7.44E+00	2.04E-01	3.84E-01	6.35E+00	8.15E+00	7.82E+00	1.57E-01	3.10E-01		
A2	Pb214	7.55E+00	2.06E-01	6.01E-01	6.07E+00	8.18E+00	8.00E+00	1.81E-01	4.37E-01		
A2	Pu239	9.63E-02	1.23E-02	1.59E-02	5.21E-02	1.41E-01					
A2	Th228	7.78E+00	2.05E-01	6.17E-02	6.49E+00	8.66E+00					
A2	Th230	8.27E+00	2.14E-01	7.45E-02	7.19E+00	9.22E+00					
A2	Th232	7.44E+00	1.98E-01	3.57E-02	6.49E+00	8.38E+00					
A2	Tl208	2.40E+00	1.05E-01	2.85E-01	2.12E+00	2.58E+00	2.61E+00	1.06E-01	2.73E-01		
A2	U234	6.89E+00	1.98E-01	4.10E-02	5.05E+00	8.22E+00					
A2	U235	3.49E-01	4.28E-02	4.44E-02	2.58E-01	4.49E-01					
A2	U238	7.25E+00	2.04E-01	4.58E-02	5.25E+00	9.19E+00					
A3	Ac228	6.49E+00	3.34E-01	1.01E+00	5.83E+00	7.39E+00	7.47E+00	3.39E-01	9.13E-01		
A3	Am241	4.12E-02	9.75E-03	1.79E-02	2.31E-02	5.30E-02					
A3	Bi212	7.12E+00	1.07E+00	3.33E+00	6.50E+00	8.14E+00	8.55E+00	1.21E+00	3.76E+00		
A3	Bi214	6.01E+00	2.33E-01	6.33E-01	5.47E+00	6.57E+00	6.94E+00	2.35E-01	6.03E-01		
A3	Cs137	3.46E+00	3.71E-01	1.89E-01	2.13E+00	4.39E+00	3.15E+00	1.33E-01	3.63E-01		
A3	K40	1.78E+02	3.30E+00	3.24E+00	1.73E+02	1.83E+02	1.91E+02	3.59E+00	2.74E+00		
A3	Pb212	6.12E+00	4.50E-01	3.90E-01	5.83E+00	6.53E+00	9.47E+00	2.69E-01	6.98E-01		
A3	Pb214	6.47E+00	2.13E-01	6.35E-01	6.25E+00	6.86E+00	7.33E+00	1.84E-01	5.53E-01		
A3	Pu239	1.29E-01	1.46E-02	1.46E-02	7.19E-02	1.92E-01					
A3	Sr90	5.04E-01	1.25E-01	4.58E-01	5.04E-01	5.04E-01					
A3	Th228	7.04E+00	1.98E-01	6.82E-02	6.40E+00	7.42E+00					
A3	Th230	7.32E+00	2.02E-01	7.47E-02	6.65E+00	7.80E+00					

		1998-2001					2005				
Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)	Activity (Bq/kg)	Uncertainty (Bq/kg)	MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
A3	Th232	6.56E+00	1.87E-01	3.66E-02	5.83E+00	7.18E+00					
A3	Tl208	2.03E+00	1.02E-01	2.73E-01	1.83E+00	2.36E+00	2.23E+00	8.80E-02	2.05E-01		
A3	U234	6.28E+00	1.85E-01	4.31E-02	5.31E+00	7.27E+00					
A3	U235	3.01E-01	3.87E-02	4.41E-02	2.05E-01	3.80E-01					
A3	U238	6.29E+00	1.86E-01	4.23E-02	5.36E+00	7.01E+00					
A4	Ac228	7.93E+00	3.31E-01	1.07E+00	7.56E+00	8.49E+00	7.96E+00	3.53E-01	1.02E+00		
A4	Am241	3.74E-02	8.30E-03	1.52E-02	2.28E-02	5.04E-02					
A4	Bi212	8.29E+00	1.02E+00	3.12E+00	6.76E+00	9.63E+00	9.18E+00	1.24E+00	3.86E+00		
A4	Bi214	7.80E+00	2.48E-01	6.35E-01	6.70E+00	8.98E+00	7.16E+00	2.29E-01	5.72E-01		
A4	Cs137	2.69E+00	7.15E-02	1.77E-01	4.29E-01	3.98E+00	1.99E+00	1.03E-01	2.80E-01		
A4	K40	2.00E+02	3.55E+00	3.40E+00	1.94E+02	2.08E+02	2.30E+02	4.13E+00	2.40E+00		
A4	Pb212	7.77E+00	2.13E-01	3.84E-01	7.12E+00	8.84E+00	6.20E+00	2.10E-01	5.62E-01		
A4	Pb214	8.20E+00	2.21E-01	5.99E-01	7.33E+00	9.32E+00	8.48E+00	1.93E-01	4.82E-01		
A4	Pu239	7.31E-02	1.07E-02	1.53E-02	1.45E-02	9.84E-02					
A4	Th228	7.93E+00	2.28E-01	1.02E-01	7.22E+00	8.59E+00					
A4	Th230	8.33E+00	2.36E-01	9.65E-02	7.44E+00	9.29E+00					
A4	Th232	7.55E+00	2.18E-01	6.67E-02	7.05E+00	8.11E+00					
A4	Tl208	2.59E+00	1.06E-01	2.70E-01	2.08E+00	3.05E+00	2.62E+00	1.05E-01	2.62E-01		
A4	U234	7.42E+00	2.03E-01	3.43E-02	6.84E+00	7.82E+00					
A4	U235	3.80E-01	4.29E-02	4.17E-02	3.08E-01	4.24E-01					
A4	U238	7.44E+00	2.03E-01	4.01E-02	7.23E+00	7.85E+00					
A5	Ac228	6.87E+00	3.09E-01	1.10E+00	5.59E+00	8.25E+00	4.99E+00	3.42E-01	1.10E+00	2.61E+00	7.37E+00
A5	Am241	4.35E-02	9.23E-03	1.59E-02	2.20E-02	5.89E-02					
A5	Bi212	7.24E+00	1.13E+00	3.57E+00	6.12E+00	8.13E+00	6.85E+00	1.20E+00	3.78E+00	6.29E+00	7.41E+00
A5	Bi214	6.99E+00	2.55E-01	7.89E-01	6.10E+00	7.93E+00	6.01E+00	2.17E-01	5.40E-01	4.49E+00	7.52E+00
A5	Cs137	3.05E+00	8.36E-02	2.01E-01	2.37E+00	3.55E+00	6.23E-01	8.59E-02	2.67E-01	5.41E-01	7.04E-01
A5	K40	1.88E+02	3.44E+00	3.48E+00	1.70E+02	2.04E+02	1.81E+02	3.43E+00	2.83E+00	1.61E+02	2.00E+02
A5	Pb212	6.61E+00	1.87E-01	4.33E-01	5.71E+00	7.86E+00	5.43E+00	1.90E-01	5.04E-01	4.91E+00	5.95E+00
A5	Pb214	7.34E+00	2.14E-01	6.94E-01	6.53E+00	8.40E+00	7.28E+00	1.77E-01	4.73E-01	6.47E+00	8.08E+00
A5	Pu239	9.92E-02	1.36E-02	1.78E-02	7.33E-02	1.31E-01					
A5	Th228	7.45E+00	1.94E-01	5.53E-02	6.21E+00	8.49E+00					
A5	Th230	8.09E+00	2.06E-01	6.78E-02	7.10E+00	9.04E+00					
A5	Th232	7.02E+00	1.84E-01	3.21E-02	5.71E+00	8.04E+00					
A5	Tl208	2.22E+00	1.12E-01	3.65E-01	1.88E+00	2.72E+00	2.11E+00	9.94E-02	2.63E-01	1.78E+00	2.44E+00
A5	U234	6.16E+00	1.64E-01	4.36E-02	4.99E+00	7.94E+00					
A5	U235	3.71E-01	4.12E-02	3.85E-02	2.90E-01	4.67E-01					
A5	U238	6.60E+00	1.72E-01	4.42E-02	5.43E+00	8.28E+00					
A6	Ac228	7.98E+00	3.32E-01	1.06E+00	7.58E+00	8.52E+00	7.94E+00	3.47E-01	9.92E-01		
A6	Am241	3.67E-02	1.07E-02	2.09E-02	3.67E-02	3.67E-02					
A6	Bi212	7.59E+00	1.11E+00	3.44E+00	6.48E+00	9.46E+00	7.43E+00	1.25E+00	3.95E+00		
A6	Bi214	7.99E+00	2.53E-01	5.92E-01	7.41E+00	8.60E+00	8.01E+00	2.27E-01	5.08E-01		
A6	Cs137	7.19E-01	1.40E-01	1.99E-01	2.97E-01	1.10E+00					
A6	K40	1.92E+02	3.55E+00	3.54E+00	1.85E+02	2.05E+02	2.06E+02	3.76E+00	2.26E+00		
A6	Pb212	7.94E+00	2.46E-01	4.20E-01	7.15E+00	8.74E+00	6.14E+00	2.08E-01	5.57E-01		
A6	Pb214	8.39E+00	2.37E-01	6.69E-01	7.59E+00	9.15E+00	8.30E+00	1.90E-01	4.95E-01		
A6	Pu239	4.37E-02	9.02E-03	1.34E-02	3.70E-02	5.23E-02					
A6	Th228	8.36E+00	2.14E-01	5.52E-02	7.67E+00	9.03E+00					
A6	Th230	8.98E+00	2.27E-01	7.74E-02	7.94E+00	9.75E+00					
A6	Th232	7.76E+00	2.02E-01	4.15E-02	7.29E+00	8.08E+00					
A6	Tl208	2.49E+00	1.20E-01	3.27E-01	2.22E+00	2.79E+00	2.69E+00	1.03E-01	2.53E-01		

		1998-2001					2005				
Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)	Activity (Bq/kg)	Uncertainty (Bq/kg)	MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
A6	U234	7.76E+00	2.41E-01	5.20E-02	5.69E+00	9.25E+00					
A6	U235	4.53E-01	5.64E-02	4.99E-02	2.94E-01	6.22E-01					
A6	U238	7.55E+00	2.38E-01	4.47E-02	5.71E+00	8.47E+00					
A7	Ac228	7.45E+00	3.26E-01	1.10E+00	5.87E+00	8.16E+00	9.07E+00	3.74E-01	1.03E+00		
A7	Am241	3.05E-02	7.20E-03	1.37E-02	2.20E-02	4.48E-02					
A7	Be7	3.62E+00	9.75E-01	3.14E+00	3.62E+00	3.62E+00					
A7	Bi212	8.02E+00	1.22E+00	3.88E+00	6.87E+00	8.71E+00	1.25E+01	1.29E+00	3.92E+00		
A7	Bi214	7.53E+00	2.44E-01	6.61E-01	6.29E+00	8.66E+00	9.31E+00	2.53E-01	5.63E-01		
A7	Cs137	2.28E+00	9.57E-02	2.07E-01	6.11E-01	3.32E+00	3.00E+00	1.18E-01	3.05E-01		
A7	K40	2.01E+02	3.65E+00	3.48E+00	1.89E+02	2.15E+02	2.50E+02	4.43E+00	2.42E+00		
A7	Pb212	7.33E+00	2.28E-01	4.16E-01	6.54E+00	8.04E+00	7.28E+00	2.28E-01	6.01E-01		
A7	Pb214	7.90E+00	2.28E-01	6.09E-01	6.93E+00	9.47E+00	1.02E+01	2.14E-01	5.29E-01		
A7	Pu239	6.27E-02	1.01E-02	1.78E-02	1.86E-02	1.10E-01					
A7	Th228	7.70E+00	2.03E-01	6.97E-02	6.41E+00	8.36E+00					
A7	Th230	8.42E+00	2.17E-01	8.59E-02	6.86E+00	9.67E+00					
A7	Th232	7.27E+00	1.94E-01	3.87E-02	6.12E+00	7.80E+00					
A7	Tl208	2.35E+00	1.19E-01	3.39E-01	2.15E+00	2.82E+00	2.95E+00	1.11E-01	2.74E-01		
A7	U234	6.91E+00	2.06E-01	6.06E-02	5.36E+00	8.45E+00					
A7	U235	3.68E-01	4.90E-02	5.36E-02	2.18E-01	5.47E-01					
A7	U238	7.09E+00	2.09E-01	5.43E-02	5.62E+00	8.50E+00					
A8	Ac228	1.06E+01	3.98E-01	1.21E+00	8.74E+00	1.21E+01	1.43E+01	4.63E-01	1.17E+00		
A8	Am241	6.05E-02	1.09E-02	1.78E-02	4.12E-02	8.45E-02					
A8	Bi212	1.08E+01	1.35E+00	4.21E+00	6.83E+00	1.49E+01	1.73E+01	1.43E+00	4.29E+00		
A8	Bi214	9.93E+00	3.03E-01	7.48E-01	8.23E+00	1.09E+01	1.26E+01	2.93E-01	6.01E-01		
A8	Cs137	5.27E+00	1.25E-01	2.29E-01	3.17E+00	7.49E+00	5.37E+00	1.46E-01	3.39E-01		
A8	K40	2.67E+02	4.61E+00	4.02E+00	2.27E+02	2.83E+02	3.66E+02	6.13E+00	2.74E+00		
A8	Pb212	1.05E+01	4.21E-01	4.38E-01	8.35E+00	1.16E+01	1.05E+01	2.76E-01	6.90E-01		
A8	Pb214	1.03E+01	2.87E-01	7.73E-01	8.39E+00	1.10E+01	1.32E+01	2.47E-01	5.89E-01		
A8	Pu238	1.60E-02	6.91E-03	1.44E-02	1.55E-02	1.65E-02					
A8	Pu239	1.85E-01	1.62E-02	1.47E-02	7.18E-02	2.59E-01					
A8	Th228	1.14E+01	3.06E-01	1.02E-01	8.65E+00	1.45E+01					
A8	Th230	1.18E+01	3.11E-01	1.01E-01	9.77E+00	1.34E+01					
A8	Th232	1.09E+01	2.94E-01	5.52E-02	8.50E+00	1.36E+01					
A8	Tl208	3.38E+00	1.33E-01	3.33E-01	2.65E+00	3.84E+00	4.61E+00	1.35E-01	3.04E-01		
A8	U234	8.79E+00	2.86E-01	4.64E-02	6.89E+00	1.05E+01					
A8	U235	5.20E-01	5.78E-02	4.96E-02	3.56E-01	7.33E-01					
A8	U238	9.24E+00	2.99E-01	5.48E-02	7.39E+00	1.07E+01					
B1	Ac228	1.10E+01	4.13E-01	1.21E+00	9.89E+00	1.37E+01	9.51E+00	3.93E-01	1.08E+00	9.13E+00	9.71E+00
B1	Am241	4.53E-02	8.56E-03	1.62E-02	3.29E-02	5.97E-02					
B1	Bi212	1.12E+01	1.29E+00	4.01E+00	9.78E+00	1.41E+01	1.05E+01	1.35E+00	4.19E+00	1.01E+01	1.08E+01
B1	Bi214	1.06E+01	2.98E-01	7.08E-01	9.45E+00	1.22E+01	9.46E+00	2.56E-01	5.67E-01	9.28E+00	9.57E+00
B1	Cs137	4.34E+00	9.66E-02	2.15E-01	3.39E+00	5.25E+00	2.91E+00	1.18E-01	3.05E-01	1.63E+00	3.57E+00
B1	K40	2.74E+02	4.70E+00	3.68E+00	2.47E+02	3.21E+02	2.66E+02	4.68E+00	2.35E+00	2.51E+02	2.75E+02
B1	Pb212	1.07E+01	2.84E-01	4.54E-01	9.75E+00	1.26E+01	7.24E+00	2.34E-01	6.24E-01	7.02E+00	7.35E+00
B1	Pb214	1.09E+01	2.78E-01	7.18E-01	9.57E+00	1.27E+01	1.01E+01	2.15E-01	5.51E-01	9.88E+00	1.02E+01
B1	Pu239	1.42E-01	1.59E-02	1.89E-02	1.10E-01	1.67E-01					
B1	Th228	1.08E+01	2.94E-01	8.71E-02	9.59E+00	1.31E+01					
B1	Th230	1.13E+01	3.01E-01	1.06E-01	9.01E+00	1.39E+01					
B1	Th232	1.04E+01	2.85E-01	5.57E-02	8.82E+00	1.24E+01					
B1	Tl208	3.49E+00	1.32E-01	3.04E-01	2.87E+00	4.13E+00	3.23E+00	1.16E-01	2.81E-01	3.14E+00	3.31E+00

		1998-2001					2005				
Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)	Activity (Bq/kg)	Uncertainty (Bq/kg)	MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
B1	U234	9.81E+00	2.97E-01	5.52E-02	7.41E+00	1.26E+01					
B1	U235	4.97E-01	5.49E-02	5.62E-02	3.33E-01	7.56E-01					
B1	U238	1.02E+01	3.06E-01	4.72E-02	7.80E+00	1.30E+01					
B2	Ac228	8.95E+00	4.15E-01	1.22E+00	7.55E+00	1.14E+01	9.82E+00	3.94E-01	1.10E+00		
B2	Am241	4.26E-02	1.02E-02	1.91E-02	2.64E-02	6.44E-02					
B2	Bi212	1.02E+01	1.36E+00	4.23E+00	8.67E+00	1.20E+01	1.06E+01	1.30E+00	4.01E+00		
B2	Bi214	8.70E+00	2.95E-01	7.80E-01	7.18E+00	1.11E+01	9.93E+00	2.63E-01	5.78E-01		
B2	Cs137	4.11E+00	1.22E-01	2.34E-01	1.88E+00	5.96E+00	5.29E+00	1.37E-01	2.98E-01		
B2	K40	2.38E+02	4.19E+00	3.61E+00	1.95E+02	2.82E+02	2.97E+02	5.12E+00	2.42E+00		
B2	Pb212	9.00E+00	2.70E-01	4.68E-01	7.36E+00	1.09E+01	7.30E+00	2.37E-01	6.36E-01		
B2	Pb214	8.97E+00	2.56E-01	7.99E-01	7.60E+00	1.06E+01	1.10E+01	2.23E-01	5.57E-01		
B2	Pu238	1.84E-02	7.30E-03	1.52E-02	1.84E-02	1.84E-02					
B2	Pu239	1.27E-01	1.43E-02	1.43E-02	5.45E-02	1.60E-01					
B2	Th228	9.90E+00	2.59E-01	7.14E-02	7.77E+00	1.20E+01					
B2	Th230	1.11E+01	2.82E-01	9.88E-02	8.34E+00	1.32E+01					
B2	Th232	9.51E+00	2.49E-01	3.50E-02	7.56E+00	1.12E+01					
B2	Tl208	2.88E+00	1.23E-01	3.53E-01	2.26E+00	3.43E+00	3.13E+00	1.16E-01	2.88E-01		
B2	U234	8.71E+00	3.08E-01	5.54E-02	7.92E+00	1.00E+01					
B2	U235	4.74E-01	5.66E-02	4.69E-02	3.31E-01	5.71E-01					
B2	U238	9.11E+00	3.18E-01	5.13E-02	8.10E+00	1.06E+01					
B3	Ac228	9.77E+00	3.71E-01	1.19E+00	8.74E+00	1.13E+01	1.08E+01	3.92E-01	1.03E+00		
B3	Am241	6.33E-02	1.07E-02	1.60E-02	4.37E-02	9.73E-02					
B3	Bi212	1.04E+01	1.32E+00	4.13E+00	9.85E+00	1.10E+01	1.16E+01	1.33E+00	4.09E+00		
B3	Bi214	9.63E+00	2.90E-01	6.59E-01	9.16E+00	1.03E+01	1.02E+01	2.59E-01	5.63E-01		
B3	Cs137	5.71E+00	1.14E-01	2.08E-01	4.28E+00	8.83E+00	6.24E+00	1.45E-01	2.96E-01		
B3	K40	2.48E+02	4.30E+00	3.73E+00	2.32E+02	2.61E+02	2.71E+02	4.71E+00	2.34E+00		
B3	Pb212	9.93E+00	2.56E-01	4.07E-01	8.71E+00	1.13E+01	7.90E+00	2.39E-01	6.28E-01		
B3	Pb214	1.01E+01	2.65E-01	7.38E-01	9.36E+00	1.05E+01	1.07E+01	2.19E-01	5.50E-01		
B3	Pu239	1.76E-01	1.77E-02	1.81E-02	1.42E-01	3.14E-01					
B3	Th228	9.99E+00	2.54E-01	7.63E-02	9.05E+00	1.17E+01					
B3	Th230	9.98E+00	2.52E-01	6.78E-02	8.99E+00	1.27E+01					
B3	Th232	9.20E+00	2.37E-01	3.57E-02	8.14E+00	1.10E+01					
B3	Tl208	3.26E+00	1.26E-01	2.82E-01	2.92E+00	3.63E+00	3.42E+00	1.18E-01	2.85E-01		
B3	U234	7.70E+00	2.08E-01	3.99E-02	5.23E+00	9.86E+00					
B3	U235	4.35E-01	4.40E-02	4.27E-02	2.78E-01	7.36E-01					
B3	U238	7.93E+00	2.12E-01	3.84E-02	5.38E+00	1.04E+01					
B4	Ac228	1.03E+01	3.59E-01	9.61E-01	7.56E+00	1.22E+01	1.01E+01	3.87E-01	1.01E+00		
B4	Am241	5.67E-02	8.98E-03	1.46E-02	1.94E-02	1.02E-01					
B4	Bi212	1.09E+01	1.18E+00	3.61E+00	7.31E+00	1.37E+01	1.24E+01	1.29E+00	3.94E+00		
B4	Bi214	9.24E+00	2.73E-01	6.10E-01	7.35E+00	1.04E+01	9.55E+00	2.50E-01	5.49E-01		
B4	Cs137	4.83E+00	9.71E-02	2.02E-01	2.67E+00	8.45E+00	3.80E+00	1.22E-01	2.94E-01		
B4	K40	2.35E+02	4.08E+00	3.33E+00	2.05E+02	2.64E+02	2.50E+02	4.41E+00	2.32E+00		
B4	Pb212	9.92E+00	2.57E-01	4.10E-01	7.58E+00	1.13E+01	8.23E+00	2.36E-01	6.06E-01		
B4	Pb214	9.63E+00	2.50E-01	6.91E-01	8.26E+00	1.08E+01	9.87E+00	2.09E-01	5.36E-01		
B4	Pu239	1.54E-01	1.60E-02	1.89E-02	1.08E-01	2.52E-01					
B4	Th228	1.02E+01	2.58E-01	9.54E-02	7.47E+00	1.24E+01					
B4	Th230	1.01E+01	2.55E-01	7.41E-02	7.50E+00	1.26E+01					
B4	Th232	9.86E+00	2.50E-01	4.20E-02	7.41E+00	1.20E+01					
B4	Tl208	3.14E+00	1.18E-01	2.67E-01	2.52E+00	3.54E+00	3.55E+00	1.15E-01	2.65E-01		
B4	U234	8.26E+00	2.58E-01	4.69E-02	7.00E+00	1.05E+01					

		1998-2001					2005				
Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)	Activity (Bq/kg)	Uncertainty (Bq/kg)	MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
B4	U235	4.38E-01	5.42E-02	4.65E-02	3.20E-01	6.29E-01					
B4	U238	8.67E+00	2.67E-01	3.96E-02	7.28E+00	1.10E+01					
B5	Ac228	6.92E+00	3.15E-01	9.84E-01	6.53E+00	7.81E+00	7.71E+00	3.54E-01	9.83E-01		
B5	Am241	6.32E-02	1.13E-02	1.84E-02	1.29E-02	1.27E-01					
B5	Be7	2.80E+00	7.51E-01	2.41E+00	2.80E+00	2.80E+00					
B5	Bi212	7.36E+00	1.20E+00	3.79E+00	5.71E+00	8.26E+00	7.80E+00	1.28E+00	4.02E+00		
B5	Bi214	6.61E+00	2.37E-01	5.90E-01	6.22E+00	6.94E+00	9.16E+00	2.40E-01	5.06E-01		
B5	Cs137	3.30E+00	6.88E-02	2.06E-01	2.29E+00	4.88E+00	4.61E+00	1.33E-01	3.07E-01		
B5	K40	1.57E+02	3.07E+00	3.61E+00	1.41E+02	1.68E+02	1.97E+02	3.64E+00	2.43E+00		
B5	Pb212	6.80E+00	3.59E-01	4.07E-01	6.34E+00	7.19E+00	6.08E+00	2.11E-01	5.73E-01		
B5	Pb214	7.17E+00	2.30E-01	6.41E-01	6.59E+00	7.58E+00	9.57E+00	2.04E-01	5.05E-01		
B5	Pu239	9.93E-02	1.27E-02	1.79E-02	6.43E-02	1.38E-01					
B5	Th228	7.11E+00	2.17E-01	1.24E-01	6.84E+00	7.53E+00					
B5	Th230	7.83E+00	2.30E-01	1.02E-01	7.24E+00	8.84E+00					
B5	Th232	6.67E+00	2.05E-01	6.29E-02	6.48E+00	7.01E+00					
B5	Tl208	2.14E+00	1.11E-01	2.91E-01	1.91E+00	2.29E+00	2.60E+00	1.05E-01	2.64E-01		
B5	U234	6.52E+00	1.87E-01	3.94E-02	5.62E+00	8.14E+00					
B5	U235	3.61E-01	4.48E-02	4.77E-02	2.89E-01	5.03E-01					
B5	U238	6.71E+00	1.90E-01	3.97E-02	5.57E+00	8.39E+00					
B6	Ac228	6.88E+00	3.27E-01	1.14E+00	5.62E+00	8.06E+00	6.45E+00	3.35E-01	1.02E+00		
B6	Am241	2.53E-02	6.36E-03	1.24E-02	1.54E-02	3.51E-02					
B6	Bi212	7.73E+00	1.34E+00	4.30E+00	5.22E+00	9.75E+00	8.39E+00	1.17E+00	3.64E+00		
B6	Bi214	6.60E+00	2.45E-01	6.98E-01	5.68E+00	8.04E+00	6.41E+00	2.14E-01	5.34E-01		
B6	Cs137	1.67E+00	5.78E-01	2.12E-01	3.13E-01	5.22E+00	4.91E+00	1.28E-01	2.74E-01		
B6	K40	1.66E+02	3.17E+00	3.53E+00	1.45E+02	1.86E+02	1.88E+02	3.47E+00	2.12E+00		
B6	Pb212	6.29E+00	3.42E-01	4.17E-01	5.43E+00	7.23E+00	4.99E+00	1.91E-01	5.27E-01		
B6	Pb214	6.95E+00	2.26E-01	6.73E-01	6.06E+00	8.82E+00	7.08E+00	1.76E-01	4.78E-01		
B6	Pu239	5.54E-02	8.66E-03	1.19E-02	1.94E-02	1.54E-01					
B6	Th228	6.81E+00	1.86E-01	7.31E-02	5.97E+00	7.34E+00					
B6	Th230	7.25E+00	1.93E-01	7.66E-02	6.29E+00	7.96E+00					
B6	Th232	6.52E+00	1.78E-01	3.59E-02	5.78E+00	6.98E+00					
B6	Tl208	2.17E+00	1.15E-01	2.96E-01	1.71E+00	2.72E+00	2.36E+00	9.68E-02	2.41E-01		
B6	U234	6.56E+00	2.29E-01	4.89E-02	5.13E+00	7.60E+00					
B6	U235	3.88E-01	4.69E-02	4.38E-02	2.66E-01	5.13E-01					
B6	U238	6.65E+00	2.31E-01	5.31E-02	5.47E+00	7.28E+00					
B7	Ac228	8.96E+00	3.33E-01	1.05E+00	6.80E+00	1.03E+01	9.73E+00	3.83E-01	1.03E+00		
B7	Am241	3.80E-02	7.90E-03	1.49E-02	1.70E-02	6.37E-02					
B7	Be7	3.72E+00	9.62E-01	3.10E+00	3.08E+00	4.35E+00					
B7	Bi212	8.73E+00	1.11E+00	3.45E+00	7.29E+00	1.02E+01	1.24E+01	1.28E+00	3.87E+00		
B7	Bi214	8.64E+00	2.56E-01	6.35E-01	7.19E+00	9.45E+00	9.40E+00	2.47E-01	5.37E-01		
B7	Cs137	2.97E+00	7.94E-02	1.92E-01	7.96E-01	5.82E+00	1.48E+00	9.81E-02	2.82E-01		
B7	K40	2.02E+02	3.64E+00	3.23E+00	1.62E+02	2.23E+02	2.34E+02	4.18E+00	2.38E+00		
B7	Pb212	8.57E+00	2.40E-01	4.01E-01	6.70E+00	9.72E+00	7.86E+00	2.34E-01	6.09E-01		
B7	Pb214	8.88E+00	2.37E-01	5.83E-01	7.70E+00	9.72E+00	9.94E+00	2.09E-01	5.18E-01		
B7	Pu239	7.61E-02	1.08E-02	1.64E-02	3.72E-02	1.46E-01					
B7	Th228	9.02E+00	2.29E-01	8.94E-02	7.52E+00	1.05E+01					
B7	Th230	1.04E+01	2.53E-01	7.61E-02	8.44E+00	1.16E+01					
B7	Th232	8.85E+00	2.24E-01	3.97E-02	7.11E+00	1.04E+01					
B7	Tl208	2.78E+00	1.12E-01	2.94E-01	2.27E+00	3.16E+00	3.29E+00	1.12E-01	2.63E-01		
B7	U234	8.52E+00	2.26E-01	4.83E-02	7.22E+00	9.98E+00					

		1998-2001					2005				
Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)	Activity (Bq/kg)	Uncertainty (Bq/kg)	MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
B7	U235	4.44E-01	4.90E-02	4.15E-02	3.52E-01	6.58E-01					
B7	U238	8.62E+00	2.27E-01	4.66E-02	7.40E+00	9.81E+00					
B8	Ac228	9.03E+00	4.24E-01	1.20E+00	7.96E+00	9.83E+00	1.10E+01	4.18E-01	1.10E+00		
B8	Am241	5.13E-02	1.00E-02	1.72E-02	3.32E-02	6.90E-02					
B8	Bi212	9.76E+00	1.20E+00	3.73E+00	8.54E+00	1.03E+01	1.12E+01	1.35E+00	4.17E+00		
B8	Bi214	8.98E+00	2.83E-01	7.04E-01	8.38E+00	9.86E+00	1.11E+01	2.71E-01	5.68E-01		
B8	Cs137	4.53E+00	1.27E-01	2.17E-01	2.90E+00	5.95E+00	4.78E+00	1.36E-01	3.14E-01		
B8	K40	2.25E+02	4.00E+00	3.61E+00	1.98E+02	2.44E+02	2.94E+02	5.06E+00	2.50E+00		
B8	Pb212	8.97E+00	2.75E-01	4.10E-01	8.36E+00	9.78E+00	8.77E+00	2.51E-01	6.47E-01		
B8	Pb214	9.31E+00	2.49E-01	7.10E-01	8.57E+00	1.04E+01	1.18E+01	2.29E-01	5.37E-01		
B8	Pu238	6.26E-02	1.35E-02	1.91E-02	6.26E-02	6.26E-02					
B8	Pu239	1.56E-01	1.57E-02	1.73E-02	1.03E-01	2.26E-01					
B8	Th228	9.02E+00	2.58E-01	6.31E-02	8.59E+00	9.69E+00					
B8	Th230	9.21E+00	2.59E-01	1.04E-01	8.21E+00	1.07E+01					
B8	Th232	8.68E+00	2.49E-01	4.98E-02	7.91E+00	9.42E+00					
B8	Tl208	2.89E+00	1.19E-01	2.99E-01	2.55E+00	3.34E+00	3.73E+00	1.21E-01	2.84E-01		
B8	U234	9.03E+00	2.73E-01	4.11E-02	8.00E+00	1.04E+01					
B8	U235	4.72E-01	5.40E-02	4.73E-02	4.29E-01	5.47E-01					
B8	U238	9.50E+00	2.83E-01	4.98E-02	8.74E+00	1.07E+01					

CHAPTER 4

The Identification and Quantification of Gnome-Derived Radionuclides in WIPP Environmental Samples

INTRODUCTION

The Gnome Site lies about 9 km southwest of the WIPP boundary and was contaminated by fission radionuclides in 1961 when an underground test of a 3-kiloton ^{239}Pu device vented to the surface (USAEC 1973). The venting continued for about 24 h. The fallout plume was determined to extend to the northwest. Because there are elevated levels of radionuclides in the soil near the Gnome Site, there is a potential for contamination of WIPP environmental samples with soil from that location. CEMRC conducted a study to determine whether Gnome-contaminated soil can be reliably identified using isotopic ratios of plutonium, the ratios of other fission products, or ratios of non-radioactive metals. Results reported herein are from soil samples collected during 2001 from nine locations near the Gnome Site. Gnome-contaminated soils and soils collected near the WIPP site were analyzed for their concentrations of radionuclides and metals. Ratios of various radionuclides and metals in the soils from the two sites were compared in an attempt to identify a reliable "fingerprint" or "signature" for Gnome contamination. Two such ratios, the mean ratio of ^{240}Pu to ^{239}Pu and the mean ratio of ^{137}Cs to ^{239,240}Pu, were found to be significantly different between the two sites.

HISTORY OF DECONTAMINATION ACTIVITIES AND SOIL SAMPLING NEAR THE GNOME SITE

Decontamination of the Gnome Site was conducted in 1968-69 with the goal of removing all material exhibiting radiation levels greater that 0.1 mR h^{-1} as measured with a Geiger-Muller survey meter (Faller 1994). The contaminated soil was either disposed of in the Gnome shaft and drift tunnels or buried on site. All surface facilities were removed and the boreholes plugged except for those used for hydrological monitoring (US AEC 1973, Faller 1994). Starting in 1978 a second cleanup of the site was initiated. Erosion had exposed some of the contaminated material in the salvage yard and the waste dump to the northeast of the access shaft. The goal for the second remediation was to remove soil having alpha plus beta radiation exceeding 20 pCi g^{-1} (0.74 Bq/g).

The Gnome shaft and the nearby Coach shaft were both used for disposal of contaminated material, including a large mass of salt muck. The Coach shaft was excavated for another Plowshare program detonation that was subsequently cancelled. Materials that could not be placed in these shafts were transported to the Nevada Test Site for burial as low-level waste.

In 1992 another survey of surface activity was conducted at the Gnome Site as part of a program to assess in-situ gamma exposure rates for those tests conducted outside of the Nevada Test Site (Faller

1994). Survey sites were selected based on the locations of waste disposal sites, operational facilities and shafts. Maps from previous surveillance reports were used to select sites of potential contamination and reference sites having only background levels of radiation. Twenty-two in situ measurements were collected at a 1-m height using a high purity germanium detector over a 45-minute interval and with a pressurized ion chamber over periods of 15 minutes. In addition, 11 soil cores were collected. The soil cores underwent gamma detection and 2 of the samples underwent chemical separation of ^{90}Sr for beta counting. Dose rates for ^{40}K, ^{232}Th, ^{238}U, ^{7}Be, and ^{137}Cs were reported. No determinations of actinide levels were performed. The greatest level of ^{137}Cs was measured at the site of the decontamination pad and was reported to be about 10- kBqm^{-2}. The ^{90}Sr/^{137}Cs ratio was reported to be about 0.03, which was consistent with such measurements made during the 1978 cleanup operations. It was noted that this ratio was considerably smaller than the ratio found in the water taken from a U. S. Geological Survey well (Faller 1994). This well was part of a tracer study conducted by the USGS that injected ^{90}Sr and ^{137}Cs into the Culebra Dolomite aquifer.

The Environmental Evaluation Group (EEG) and its subcontractor, the Chemrad Tennessee Corporation (CTC) conducted another survey of the area around the Gnome Site over a seven-month interval in 1994-1995 (Kenny et al 1995). Gamma surveys were conducted by EEG using a sodium iodide detector positioned at 10 cm above the surface. CTC made measurements of beta, gamma and dose rates. In addition, soil samples to a depth of 2.5 cm were collected for analysis using a Canberra high purity germanium detector. Aliquots of the soil underwent separation and purification in preparation for alpha spectroscopy. The four samples reported for the Gnome area sampling ranged from 0.6 mBq g^{-1} to 48,000 mBq g^{-1}of ^{239,240}Pu. Of 9 soil samples collected from around the WIPP site at the same time, six ^{239,240}Pu values reported as 0 (i.e. < minimum detection levels) while the remaining three ^{239,240}Pu values ranged from 0.37mBq g^{-1} to 0.74 mBq g^{-1}. Thus, in spite of the earlier remediation efforts at the Gnome Site, there are some areas where levels of radionuclide contamination remain elevated relative to the levels in the testing area.

METHODS

Sample Collection

IT Corporation conducted the most recent survey of the Gnome Site for the Nevada Operations Office starting in February 2002. IT cooperated with CEMRC by collecting soils for our analyses. Soil was collected using IT's standard methodology at three locations: an area along the road to the dump site, near the vent, and along the path of the plume. Nine samples of approximately 1.5 kg each were collected to a depth of about 2.5 cm using a plastic scoop and stainless steel containers. The soil samples were assigned Sample Identification Numbers using the SID Database system (CP-PROC-003). Locations of the samples were identified using GPS and recorded. Chain of custody forms were completed on site and turned over to CEMRC with the samples. Preliminary screening showed that there are elevated levels of radioactivity in all of the samples as compared to the WIPP baseline data, but no samples showed levels where radiation safety would be a significant issue. The WIPP soil aliquots were selected from eight samples collected previously as part of the CEMRC Environmental Monitoring program (Kirchner et al. 2002).

Measurement of Radionuclides

Initial preparation of the samples for radiological analyses consisted of passing the soil through a 2 mm sieve to remove rocks, roots and other materials. Approximately 300 mL (500 g) aliquots were used for gamma spectroscopy analysis. Gamma spectroscopy analysis was conducted using high purity Ge (HPGe) detector systems for 1-2 days. A set of soil matrix standards was prepared using NIST traceable solutions and used to establish matrix-specific calibration and counting efficiencies.

A 2 g aliquot was used for analyses of each of the soil samples for ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, and ^{228}Th. A 10-g aliquot was used for analysis of ^{241}Am and ^{239,240}Pu for eight of the nine soil samples. The remaining sample was determined to have elevated ^{241}Am levels, hence it was deemed likely to have an elevated ^{239,240}Pu concentration. Three 1 g aliquots of this sample were analyzed for ^{241}Am and ^{239,240}Pu. The aliquots were taken from the 500 g sample used for gamma spectroscopy analysis. The aliquots were heated in a muffle furnace at 500 °C to combust organic material and spiked with a radioactive tracer to allow determination of the efficiency of extraction. The aliquots used to determine ^{241}Am and ^{239,240}Pu then underwent dissolution with HNO_3, HF and HCl followed by digestion with perchloric acid to remove silica. These samples were then dissolved in dilute HNO_3 and boric acid. The aliquots used to determine U and Th were spiked with radioactive tracers and then underwent NaOH fusion. The fused sample was dissolved in HCl and treated with HF and perchloric acid to remove silica.

Multiple precipitation, co-precipitation and ion-exchange and/or extraction chromatography procedures were then used to separate and purify the desired elements from each of aliquots. The elements of interest from each were then precipitated with NdF_3, deposited onto filters, mounted and counted on an alpha spectroscopy system.

Effects of Sieving

Some of the Gnome samples were sieved in preparation for gamma counting prior to removing an aliquot for inorganic analysis. In the procedures used for analyzing the WIPP EM soils for metals, a separate aliquot is collected in the field and this aliquot is never sieved. To determine the impact of sieving soils on the inorganic analyses, an experiment was conducted to determine whether or not sieving of soils would significantly increase the concentrations of metals in the soils. Two aliquots were taken from each of three samples of Gnome soil. A duplicate of one of the three un-sieved soil aliquots was also analyzed. One of the aliquots from each sample was then sieved to remove twigs, leaves and other non-soil objects. All six aliquots were then analyzed for their inorganic constituents. Relative percent differences were then computed for the results paired by sample.

Measurement of Inorganic Analytes

Soil sample aliquots of 0.25 g were analyzed for the inorganic analytes. Aliquots were extracted from the samples prepared for gamma analysis. Four additional aliquots were analyzed for use in the sieving study microwave digestion, based on EPA Method 3052, to prepare samples for ICP-MS. Concentrations of Ag, Al, As, Ba, Be, Ca, Cd, Ce, Co, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hg, K, La, Li, Mg, Mn, Mo, Na, Nd, Ni, Pb, Pr, Sb, Sc, Si, Sm, Sr, Th, Ti, Tl, U, V and Zn were determined using a method derived from

EPA Method 200.8. Levels of Cr could not be reported due to an analytical problem. The lower detection limits are in the low parts per billion range. The mean concentrations of these analytes reported herein for soils include only those values that are above detection levels. Thus, some estimates of the mean may be biased toward larger values.

Reported concentrations are blank-corrected. Negative concentrations of analytes can result when both the sample and the blank have concentrations above the MDL, and are hence regarded as detectable quantities, with the blank concentration exceeding the sample concentration. Thus negative values are invariably small and represent values very near the blank concentrations.

Determination of Isotopic Ratios of ^{239}Pu and ^{240}Pu

Isotopic ^{240}Pu:^{239}Pu ratios can be determined using accelerator mass spectrometry (AMS) (McAninch 2000). Dr. Terry Hamilton of Lawrence Livermore National Laboratory (LLNL) conducted a preliminary analysis to help evaluate the detection level for the ^{240}Pu:^{239}Pu ratio in Gnome soil using the LLNL AMS. An aliquot of one of the nine samples of soil collected from the vicinity of the Gnome site was prepared for analysis at CEMRC. The sample selected had the highest gamma activity of the nine samples (Sample Location 5 in Table 4-1). Three dilutions of this aliquot (using 1%, 5% and 10% of the leachate) were prepared in order to evaluate the detection level of the AMS methodology. Subsequently, the ^{240}Pu:^{239}Pu ratios for nine samples of Gnome soils and eight soil samples from the WIPP site were measured.

RESULTS AND DISCUSSION

Radionuclide Concentrations

All of the Gnome soil samples show elevated concentrations of ^{137}Cs as compared to the across-year maximum concentrations for the Near Field and Cactus Flats sites (Table 4-1). The data for the Cactus Flats and Near Field sites, referred to collectively as the WIPP data, are shown separately because the samples of the Cactus Flats site generally have higher concentrations of radionuclides and non-radioactive metals than does the Near Field site. The maximum observed concentration of ^{137}Cs for the Gnome samples, 2.98E+03 Bq kg^{-1}, was more than 100 times larger than the largest concentration seen previously in the WIPP surface soil samples. Variability among the ^{137}Cs concentrations of the Gnome samples was high. The Gnome concentrations for ^{228}Ac and ^{40}K fell within the range of values previously measured for the WIPP soils locations except for sample 9, which shows somewhat elevated levels of both of these radionuclides. Sample 9 was collected on the path of the plume and had a noticeably greater content of clay and silt than typical for surface soils in that area. Because ^{40}K is a naturally occurring radionuclide, its elevated concentration may simply be due to differences in soil texture (Kirchner et al. 2002). Concentrations of ^{238}Pu, ^{239,240}Pu and ^{241}Am for one of the Gnome samples were more than to 650 times greater than the maximum concentrations observed in WIPP soils. However, the remaining samples showed at most only moderately higher actinide activity concentrations and many of these samples fell within the range of concentrations previously observed in WIPP soils. The ^{239,240}Pu concentration was 0.158±0.012 Bq kg^{-1} in the CEMRC aliquot of the sample selected for the preliminary AMS analysis, whereas the concentration was measured as 0.39±0.02 Bq kg^{-1} using AMS.

The mean ratio of ^{137}Cs to ^{239,240}Pu from Gnome samples is significantly greater than the mean ratio from WIPP samples (Table 4-2). The within-aliquot variability is very great in the Gnome samples. The mean ratio of ^{238}Pu to ^{239,240}Pu from the Gnome sample is not significantly different that the mean ratio for the WIPP samples. However, the mean ratio for the WIPP samples (0.13) is dominated by two of the 21 samples for which ^{238}Pu concentrations were above the minimum detection levels. Excluding these two values reduces the WIPP mean ratio to 0.094. In either case the ^{238}Pu:^{239,240}Pu ratios for both Gnome and WIPP exceed the global fallout mean ratio for latitudes of 30-40ºN of 0.061 (Mitchell et al, 1997).

Effects of Sieving

Soils are sieved as part of the sample preparation for gamma analyses in order to remove twigs, leaves and other non-soil objects. However, sieving has the potential for contamination the soil with metals from the sieve. The results of the inorganic analyses for the sieved and un-sieved soils were paired by sample and relative percent differences (RPDs) by analyte were computed (Table 4-3). In computing RPDs the absolute value of the difference is usually used because the sign of the difference is usually not important. However, in computing the RPDs for this comparison the absolute value was not taken because the sign can be used to determine whether the concentration of a metal was higher or lower in the sieved versus un-sieved aliquot. Positive RPDs result when the sieved soil had a greater concentration of an analyte than an un-sieved soil. These paired results do not show any obvious impacts of screening on the metal concentrations. In addition, given the variability in metal concentrations, the screened soils do not shown any marked differences when compared to the unscreened soils (Figure 4.1).

Concentrations of Inorganic Analytes

The mean concentrations of the inorganic analytes in the Gnome soils were elevated compared to the mean concentrations found in the WIPP surface soils (Table 4-4). The greatest differences are for Ca and Hg. Excluding these two analytes the average of the ratios across analytes shows the Gnome samples to have about three times the concentration of the metals than found in the WIPP surface soil. As discussed elsewhere (Kirchner et al 2002), soil texture can have a significant impact on the concentrations of radionuclides and metals. In general, there is a positive correlation between the proportion of fine particles and the concentration of radionuclides, Al and other metals. Normalizing the Near Field, Cactus Flats and Gnome results by dividing by their respective mean concentration of Al helps correct for the potential effect of soil texture differences (Table 4-5). The RPDs of most of these normalized analyte values are similar in magnitude to the RPDs from duplicate analyses within a location. Besides the elevated levels of Ca and Hg, discussed above, these results indicate that Pb may be elevated in the Gnome samples. The cleanup activities at the site could be responsible for elevation Pb concentrations in the soils. In any case Pb is likely to be too common in other sources of contamination to be used as a reliable fingerprint of Gnome contamination.

^{240}Pu/^{239}Pu Atom Ratios

The preliminary analysis of three dilutions (1%, 5% and 10%) of one Gnome sample yielded ^{240}Pu: ^{239}Pu atom-ratios ($\pm \sigma$) of 0.075±0.008, 0.077±0.004 and 0.073±0.003, respectively. The mean atom-ratio was 0.075±0.003. Dilution by a factor of 10 to 100 appears to have little impact on the measurement of the isotopic ratios by AMS. Hence it was concluded that the AMS system would have no difficulty in determining the ^{240}Pu:^{239}Pu ratios for either the remaining Gnome samples or the WIPP EM samples.

On average, the Gnome samples had lower ^{240}Pu:^{239}Pu ratios than those of the WIPP samples (Figure 4.2). The mean and 95% confidence interval for the ^{240}Pu:^{239}Pu atom-ratio of the Gnome soils was $0.085 \leq 0.114 \leq 0.143$, and that for the WIPP soils was $0.162 \leq 0.175 \leq 0.187$. These ratios are significantly ($p<0.05$) different. The Gnome sample having the greatest activity concentration (743 Bq/kg) had a ^{240}Pu:^{239}Pu atom-ratio of 0.074±0.003. This value is probably a good estimate of the ^{240}Pu:^{239}Pu atom-ratio of Gnome fallout. Three of the Gnome samples had ^{240}Pu:^{239}Pu atom-ratios within the range of the ratios measured for the WIPP samples (Figure 4.2). The activity concentrations of these three samples also fall within the range of the WIPP samples. Two of these samples were collected along the line of the original fallout plume and one from the side of a road used to haul contaminated materials during cleanup of the site. Given the cleanup of the site, it would not be surprising if the plutonium in these samples came from global fallout. Although these samples had relatively low activity concentrations of ^{239}Pu, activity concentration alone is not a good predictor of ^{240}Pu:^{239}Pu atom-ratio. Three of the remaining Gnome samples fall within or below the range of activity concentrations observed in the WIPP samples. Nevertheless, these samples show ^{240}Pu:^{239}Pu atom-ratios that are consistent with the Gnome samples having higher ^{239}Pu activity concentrations than those seen in the WIPP samples (Figure 4.2).

Variability in the isotopic ratio was also evident within a Gnome sample. The plutonium extracted from another 50 g aliquot of the same sample sent for preliminary analysis (sample 105855 in Table 4-6) was prepared and measured as one of the nine Gnome samples and eight WIPP samples subsequently analyzed by AMS. In the second analysis the ^{240}Pu:^{239}Pu ratio was measured as 0.100±0.008. The difference in these ratios is probably due to heterogeneity in the distribution of radioactive particles in the Gnome soil samples.

The Gnome device was a relatively low-yield device similar to those detonated at the Nevada Test Site (NTS). The smaller yield tests conducted at the NTS typically injected radioactivity only into the troposphere and produced fallout largely within the southwestern United States. The NTS attempted to conduct tests only when the winds would carry fallout north over largely unpopulated areas, although some fallout plumes did extend to New Mexico. The atom-ratios for 99 test events conducted at the NTS ranged from 1.5×10^{-4} to 0.082. Three of the nine samples fall within this range, but the mean ratio for the Gnome samples exceeds this range. In contrast, ^{240}Pu:^{239}Pu atom ratios for thermonuclear devices tended to be larger than the NTS ratios due to the larger neutron fluxes prevalent in thermonuclear events (Krey et al, 1990). For example, the atom-ratio for the MIKE shot of October, 1952 was 0.35 (Perkins and Thomas 1980). These large thermonuclear devices were capable of injecting radioactivity into the stratosphere where it circled the globe and became the primary source of global fallout. Measurements of the ratio in soils collected from around the world typically show values of about 0.19. The exceptions in the northern hemisphere are associated with soils collected in the southwestern United States, where fallout from the NTS events was also deposited (Perkins and Thomas 1980).

Fallout in the vicinity of the WIPP is undoubtedly a mixture of global fallout from thermonuclear devices and tests conducted at the NTS. Thus the mean ^{240}Pu:^{239}Pu atom-ratio observed in the WIPP samples (0.175) is consistent with the source being largely global fallout.

SUMMARY AND CONCLUSIONS

CEMRC conducted a study to determine whether Gnome-contaminated soil can be reliably identified using isotopic ratios of plutonium, the ratios of other fission products, or ratios of non-radioactive metals. Soil samples from nine locations near the Gnome Site were collected and analyzed to determine the concentrations of metals and radionuclides. These concentrations and various ratios of concentrations were subsequently compared to equivalent data from soils collected near the WIPP site as part of CEMRC's Environmental Management program. In addition, aliquots of the nine Gnome soils and eight WIPP soils were prepared and sent to LLNL for determination of their ^{240}Pu:^{239}Pu ratios using accelerator mass spectroscopy. Two ratios, the mean ratio of ^{240}Pu to ^{239}Pu and the mean ratio of ^{137}Cs to ^{239,240}Pu, were found to be significantly different between the two sites. The mean ^{240}Pu:^{239}Pu ratio for the Gnome samples was significantly less that the mean ratio for the WIPP soils. The Gnome sample having the largest ^{239,240}Pu soil activity concentration had a ^{240}Pu:^{239}Pu ratio (0.074) that fell within the range of those observed at the Nevada Test Site. Because of the large variability in ^{137}Cs:^{239,240}Pu ratios, the ^{240}Pu:^{239}Pu ratio represents the most reliable "fingerprint" for identifying Gnome-contaminated soil.

Table 4-2: Mean Concentrations in Bq kg^{-1} of Radionuclides for Each of Nine Gnome Sample Locations and Across-sample Statistics in Comparison to the Concentrations in Surface Soils Collected from Two Areas Near the WIPP Site

Site	Sample Location	^{137}Cs	^{228}Ac	^{40}K	^{60}Co	^{238}Pu	^{239,240}Pu	^{241}Pu	^{241}Am
Gnome	1	1.98E+03	1.22E+01	3.24E+02	6.58E-01	1.05E+02	7.44E+02	7.82E+02	1.68E+02
Gnome	2	5.10E+02	1.04E+01	2.02E+02	<MDC	3.20E-02	2.42E-01	<MDC	8.21E-02
Gnome	3	4.69E+01	7.74E+00	1.77E+02	<MDC	1.36E-01	4.67E-01	<MDC	2.16E-01
Gnome	4	4.10E+02	9.10E+00	1.84E+02	<MDC	4.63E-02	1.66E-01	<MDC	6.17E-02
Gnome	5	2.98E+03	9.93E+00	1.93E+02	<MDC	3.09E-02	1.58E-01	<MDC	4.81E-02
Gnome	6	9.47E+02	9.34E+00	2.01E+02	<MDC	1.61E-02	2.90E-01	<MDC	9.26E-02
Gnome	7	1.79E+03	1.12E+01	2.38E+02	<MDC	<MDC	2.61E-01	<MDC	9.45E-02
Gnome	8	9.35E+02	9.95E+00	2.34E+02	<MDC	3.95E-02	3.90E-01	<MDC	1.01E-01
Gnome	9	3.08E+02	1.94E+01	3.40E+02	<MDC	6.56E-02	7.43E-01	<MDC	2.23E-01
Gnome	Mean	8.40E+02	1.03E+01	2.18E+02	6.58E-01	2.88E+01	1.49E+02	7.82E+02	3.61E+01
Gnome	Minimum	4.59E+01	7.62E+00	1.75E+02	6.58E-01	1.61E-02	7.28E-02	2.59E+02	4.28E-02
Gnome	Maximum	2.98E+03	1.94E+01	3.40E+02	6.58E-01	2.19E+02	1.55E+03	1.63E+03	3.46E+02
Gnome	Standard Error	2.47E+02	8.434E-01	1.51E+01		2.00E+01	1.05E+02	4.30E+02	2.52E+01
Gnome	n	13	13	13	1	11	15	3	14
Cactus Flats	Mean	5.63E+00	1.13E+01	2.24E+02	NA	2.27E-02	2.04E-01	NA	6.96E-02
Cactus Flats	Minimum	6.93E-01	6.67E+00	1.42E+02	NA	1.13E-02	1.35E-02	NA	2.10E-02
Cactus Flats	Maximum	1.48E+01	1.58E+01	3.24E+02	NA	4.23E-02	5.07E-01	NA	2.57E-01
Cactus Flats	Standard Error	3.34E-01	2.31E-01	437E+00	NA	2.19E-03	1.11E-02	NA	4.16E-03
Cactus Flats	n	86	86	86	NA	17	111	NA	86
Near Field	Mean	3.46E+00	8.56E+00	2.14E+02	NA	2.59E-02	1.19E-01	NA	4.74E-02
Near Field	Minimum	2.97E-01	5.59E+00	1.42E+02	NA	1.55E-02	1.45E-02	NA	1.29E-02
Near Field	Maximum	8.83E+00	1.37E+01	3.21E+02	NA	6.26E-02	3.89E-01	NA	1.27E-01
Near Field	Standard Error	2.06E-01	1.87E-01	4.18E00	NA	9.20E-03	6.80E-03	NA	2.88E-03
Near Field	n	85	86	86	NA	5	90	NA	66

Table 4-3: Ratios of ^{137}Cs and ^{238}Pu to ^{239,240}Pu in Gnome Samples in Comparison to Mean Values for WIPP Soils

Sample Identifier	Aliquot Identifier	^{137}Cs/^{239,240}Pu	^{238}Pu/^{239,240}Pu
102837	102899	2.66	0.14
102838	102900	2106.22	0.13
102839	102901	55.05	0.16
102839	103029	629.97	NA
102840	102902	2541.06	0.28
102840	103030	2370.86	NA
102841	102903	18853.69	0.20
102842	102904	3261.37	0.06
102843	102905	6874.66	<MDC
102844	102906	2393.92	0.10
102845	102907	414.45	0.09
Gnome	Mean	3591.26	0.14
	Standard Error	1635.70	0.025
	n	11	8
WIPP	Mean	29.33	0.13
	Standard Error	0.42	0.027
	n	162	21

Table 4-4: Relative Percent Differences Between Sieved and Unsieved Soils Paired by Sample

Only results greater than the minimum detectable concentration are reported.

Analyte	RPD	Analyte	RPD	Analyte	RPD
Al	-8.54%	Ga	-64.33%	Pb	-4.66%
Al	-4.79%	Ga	-21.17%	Pr	3.47%
Al	32.40%	Ga	-29.09%	Pr	-27.14%
Al	-17.75%	Gd	-10.35%	Pr	43.78%
As	-54.51%	Gd	16.09%	Pr	-11.16%
Ba	-6.03%	Gd	41.47%	Sc	-2.67%
Ba	3.96%	Gd	-6.93%	Sc	-3.00%
Ba	45.66%	K	14.42%	Sc	31.61%
Ba	-7.65%	K	11.18%	Sc	-29.29%
Be	34.24%	K	44.54%	Si	-14.83%
Be	28.19%	K	-11.45%	Si	-22.05%
Be	57.81%	La	-37.08%	Si	7.68%
Be	-4.61%	La	-2.87%	Si	-94.33%
Ca	15.01%	La	40.57%	Sm	-18.43%
Ca	13.52%	La	-15.36%	Sm	9.59%
Ca	29.81%	Li	38.44%	Sm	42.75%
Ca	5.04%	Li	31.59%	Sm	-9.71%
Ce	-1.98%	Li	63.80%	Sr	-31.73%
Ce	-33.46%	Li	8.43%	Sr	-28.14%
Ce	42.48%	Mg	20.79%	Sr	34.02%
Ce	-13.17%	Mg	21.43%	Sr	-8.87%
Co	19.97%	Mg	46.70%	Th	39.09%
Co	25.37%	Mg	4.80%	Th	-4.16%
Co	30.60%	Mn	2.40%	Th	47.91%
Co	-25.64%	Mn	3.34%	Th	3.36%
Cu	-12.79%	Mn	32.99%	Ti	-55.51%
Dy	-1.97%	Mn	-5.93%	Ti	-50.87%
Dy	17.27%	Mo	-18.25%	Ti	20.31%
Dy	34.48%	Mo	-44.17%	Ti	-72.89%
Dy	-8.38%	Mo	36.47%	Tl	-53.04%
Er	18.66%	Mo	-59.67%	U	21.58%
Er	5.09%	Nd	6.38%	U	-1.54%
Er	37.30%	Nd	-21.12%	U	46.45%
Er	-9.49%	Nd	45.49%	U	-8.27%
Eu	-16.33%	Nd	-6.36%	V	-13.90%
Eu	4.15%	Ni	16.07%	V	-11.64%
Eu	-13.21%	Ni	13.78%	V	28.99%

Fe	-4.26%	Ni	44.64%	V	-29.14%
Fe	0.89%	Ni	-2.90%	Zn	1.62%
Fe	31.72%	Pb	8.62%	Zn	-0.14%
Fe	-13.01%	Pb	11.72%	Zn	24.24%
Ga	-63.35%	Pb	31.22%	Zn	-16.24%

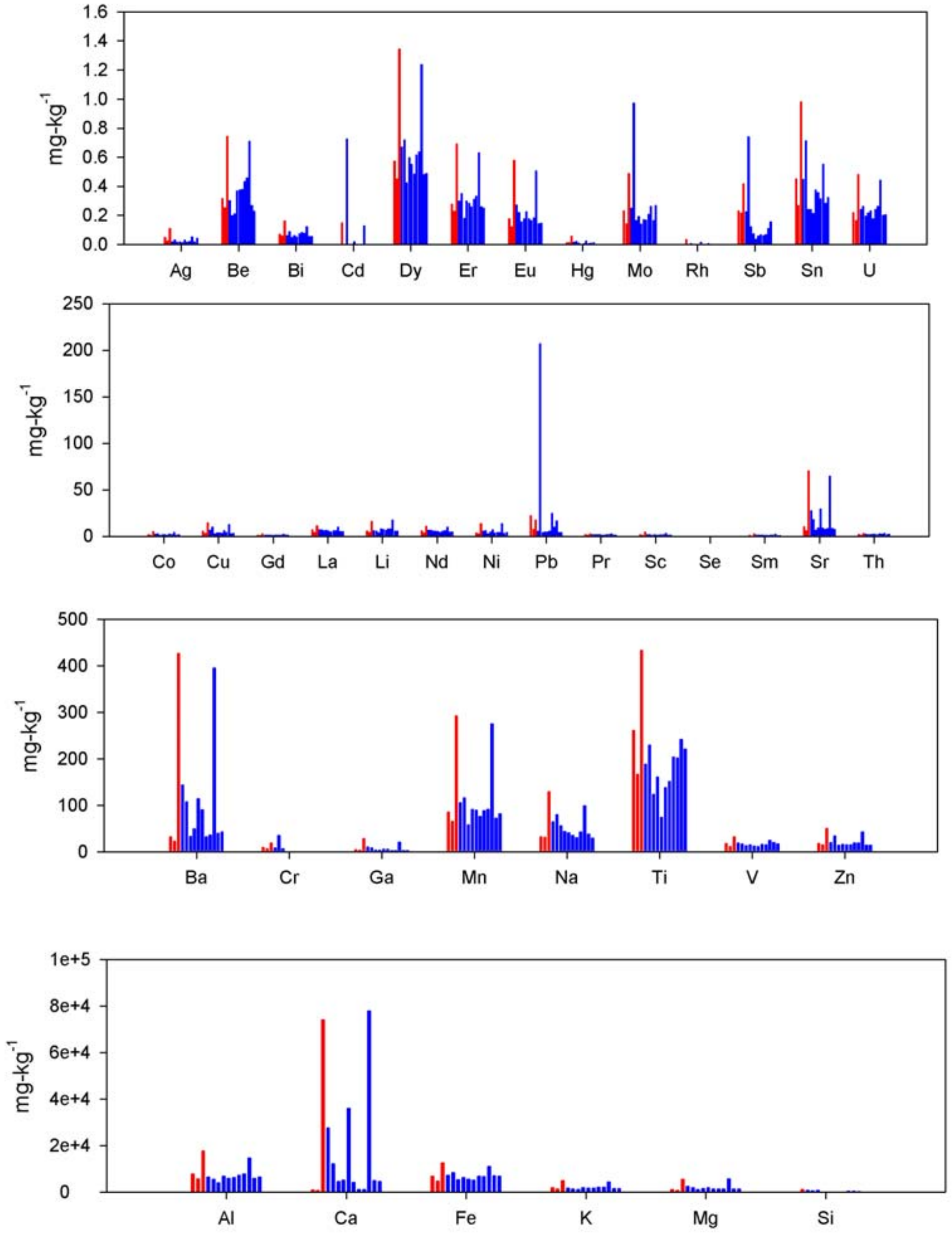


Figure 4.1: Concentrations of Metals in Gnome Soils

Screened soils are shown in blue, unscreened soils in red.

Table 4-5: Ratio of Concentration of Metals in Sieved Gnome Soils to Those in WIPP Soils

Analyte	WIPP Location	Ratio Gnome/WIP	Analyte	WIPP Location	Ratio Gnome/WIP
Ag	Cactus	6.08	Li	Near	3.00
Ag	Near Field	9.49	Mg	Cactus	3.70
Al	Cactus	2.69	Mg	Near	4.28
Al	Near Field	3.50	Mn	Cactus	2.34
As	Cactus	1.42	Mn	Near	3.09
As	Near Field	1.92	Mo	Cactus	2.21
Ba	Cactus	4.52	Mo	Near	3.04
Ba	Near Field	6.06	Na	Cactus	3.54
Be	Cactus	2.52	Na	Near	3.37
Be	Near Field	3.26	Nd	Cactus	1.68
Ca	Cactus	27.23	Nd	Near	2.14
Ca	Near Field	27.72	Ni	Cactus	2.69
Ce	Cactus	1.99	Ni	Near	2.86
Ce	Near Field	2.36	Pb	Cactus	4.43
Co	Cactus	2.50	Pb	Near	6.11
Co	Near Field	3.19	Pr	Cactus	1.70
Cu	Cactus	6.30	Pr	Near	2.18
Cu	Near Field	8.09	Sb	Cactus	3.82
Dy	Cactus	1.99	Sb	Near	4.51
Dy	Near Field	2.66	Sc	Cactus	2.64
Er	Cactus	2.10	Sc	Near	3.38
Er	Near Field	2.84	Si	Cactus	1.96
Eu	Cactus	2.62	Si	Near	0.78
Eu	Near Field	3.37	Sm	Cactus	1.86
Fe	Cactus	1.64	Sm	Near	2.36
Fe	Near Field	2.11	Sr	Cactus	5.24
Gd	Cactus	2.01	Sr	Near	6.49
Gd	Near Field	2.61	Th	Cactus	1.43
Hg	Cactus	21.39	Th	Near	1.84
Hg	Cactus	11.51	Ti	Cactus	3.82
Hg	Near Field	25.45	Ti	Near	4.51
Hg	Near Field	18.12	Tl	Cactus	3.99
K	Cactus	2.75	Tl	Near	3.87
K	Near Field	3.63	U	Cactus	2.16
La	Cactus	1.72	U	Near	2.62
La	Near Field	2.23	V	Cactus	3.39
Li	Cactus	2.52	V	Near	3.62

Table 4-6: Relative Percent Differences Between the Gnome and WIPP Normalized Analyte Concentration

Normalization involved dividing the analyte concentrations by their respective mean Al concentration to help correct for soil texture differences.

Analyte	GridID	RPD Of Ratios	Analyte	GridID	RPD Of Ratios
As	Cactus Flats	44.51%	Mg	Near Field	38.58%
As	Near Field	40.85%	Mn	Cactus Flats	8.32%
Ba	Cactus Flats	43.60%	Mn	Near Field	6.81%
Ba	Near Field	46.33%	Mo	Cactus Flats	18.86%
Be	Cactus Flats	12.96%	Mo	Near Field	24.52%
Be	Near Field	12.44%	Nd	Cactus Flats	22.55%
Ca	Cactus Flats	163.14%	Nd	Near Field	24.67%
Ca	Near Field	154.06%	Ni	Cactus Flats	19.10%
Ce	Cactus Flats	11.30%	Ni	Near Field	1.08%
Ce	Near Field	20.21%	Pb	Cactus Flats	116.46%
Co	Cactus Flats	4.33%	Pb	Near Field	120.16%
Co	Near Field	2.24%	Pr	Cactus Flats	24.30%
Cu	Cactus Flats	57.07%	Pr	Near Field	25.55%
Cu	Near Field	55.88%	Sb	Cactus Flats	73.32%
Dy	Cactus Flats	12.07%	Sb	Near Field	64.66%
Dy	Near Field	9.41%	Sc	Cactus Flats	0.63%
Er	Cactus Flats	7.72%	Sc	Near Field	0.89%
Er	Near Field	3.86%	Si	Cactus Flats	1.00%
Eu	Cactus Flats	7.48%	Si	Near Field	105.52%
Eu	Near Field	8.53%	Sm	Cactus Flats	15.64%
Fe	Cactus Flats	24.48%	Sm	Near Field	18.12%
Fe	Near Field	25.52%	Sr	Cactus Flats	55.03%
Gd	Cactus Flats	3.19%	Sr	Near Field	50.41%
Gd	Near Field	3.50%	Th	Cactus Flats	32.55%
Hg	Cactus Flats	94.38%	Th	Near Field	33.60%
Hg	Cactus Flats	135.27%	Ti	Cactus Flats	26.21%
Hg	Near Field	130.28%	Ti	Near Field	16.62%
Hg	Near Field	108.53%	Tl	Cactus Flats	10.71%
K	Cactus Flats	7.90%	Tl	Near Field	39.60%
K	Near Field	9.15%	U	Cactus Flats	2.15%
La	Cactus Flats	25.32%	U	Near Field	4.80%
La	Near Field	25.51%	V	Cactus Flats	39.69%
Li	Cactus Flats	17.54%	V	Near Field	20.60%
Li	Near Field	8.74%	Zn	Cactus Flats	17.96%
Mg	Cactus Flats	49.70%	Zn	Near Field	27.74%

Table 4-7: ^{240}Pu/^{239}Pu Isotopic Ratios and Activity Concentrations for Gnome and WIPP Samples

Site	Sample Identifier	^{240}Pu /^{239}Pu atom	Measurement Uncertainty(1 σ)	Activity Concentration (Bq/kg)
GNOME	105851	0.074	0.003	743.6
	105852	0.075	0.006	0.2423
	105853	0.07	0.002	0.4670
	105854	0.113	0.009	0.1660
	105855[1]	0.1	0.008	0.6976
	105856	0.156	0.01	0.2902
	105857	0.154	0.011	0.2606
	105858	0.168	0.008	0.3904
	105859	0.118	0.006	0.7429
	Mean	**0.114**		**82.99**
	Standard Error	**0.013**		**82.58**
WIPP EM	105860	0.177	0.009	0.4106
	105861	0.193	0.01	0.4326
	105862	0.186	0.008	0.5070
	105863	0.172	0.011	0.3889
	105864	0.173	0.008	0.4016
	105865	0.146	0.012	0.2585
	105866	0.164	0.009	0.255
	105876	0.188	0.013	0.314
	Mean	**0.175**		**0.3611**
	Standard Error	**0.005**		**0.0294**

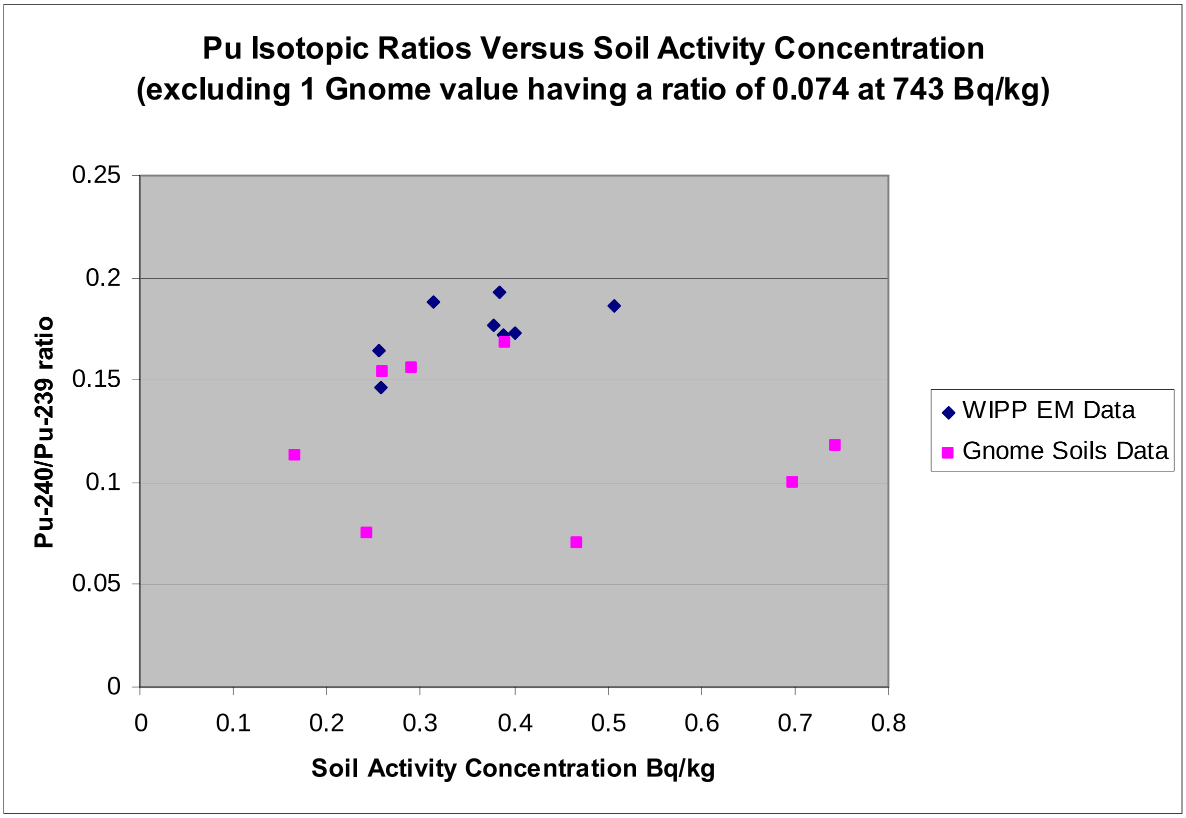


Figure 4.2: Isotopic Ratios Versus Activity Concentrations for Gnome and WIPP Samples

CHAPTER 5

Vertical Distribution of ^{137}Cs, ^{241}Am and ^{239,240}Pu in the Vicinity of the Waste Isolation Pilot Plant

The distribution of ^{137}Cs, ^{239,240}Pu and ^{241}Am activities with depth in soil profiles is utilized in this study to evaluate the importance of transport mechanisms affecting the fate of radionuclides in the arid environment of the northern extremity of the Chihuahuan desert where the WIPP site is located (Figure 3.1). The ^{137}Cs results were reported in the CEMRC Annual Report of 2002. This present report reiterates the analyses of the ^{137}Cs data and adds to them the results of analyses of ^{239,240}Pu and ^{241}Am from the upper layers of the profile. Fallout from aboveground nuclear testing was the primary source of ^{137}Cs in soils (Ritchie, 1990), although a potential source in the near vicinity of the WIPP site is the Gnome test site, about 8.8 km southwest of the WIPP site. This test involved a 3.1 kiloton yield nuclear underground detonation in 1961 from which venting to the atmosphere occurred (Faller, 1994). ^{239,240}Pu in WIPP soil is all derived from the detonation of nuclear devices and primarily from global fallout from weapons tests. Although contamination of WIPP soil from the Gnome test remains a possibility, ^{240}Pu/^{239}Pu isotopic ratios obtained from a selection of WIPP soils were consistent with that expected for global fallout whereas soil samples collected near the Gnome site showed isotopic ratios similar to those found at the Nevada Test Site (Chapter 4, this report).

Kirchner et al. (2002) utilized surface soil data (2 cm depth) collected using a grid scheme to characterize radionuclide concentrations in soils near the WIPP. The activity concentrations of ^{239,240}Pu, excluding one value that was less than the minimum detection level (MDL), ranged from 0.015 to 0.51 Bq kg^{-1}. The ^{137}Cs activity concentrations for the surface soils, also excluding one value <MDL, ranged from 0.31 to 15 Bq kg^{-1}, a range of more than an order of magnitude. The excluded values were associated with the same sample. The mean ^{137}Cs and ^{239,240}Pu activity concentrations from soils collected in the near vicinity of the WIPP were 3.1 (S.E. = 0.23) and 0.1 (S.E. = 0.007) Bq kg^{-1}, respectively and were slightly higher for soils at a reference site approximately 20 km SE of the WIPP site, where mean activity concentrations were 6.2 (S.E. = 0.52) and 0.22 (S.E. = 0.018) Bq kg^{-1}, respectively. Variability in surface soil concentrations reported in this study was attributed to redistribution of contaminated soil particles via resuspension and erosion, and perhaps from variation in rates of vertical transport.

The variability in ^{137}Cs activity concentrations reported by Kirchner et al. (2002) in surface soil points to the dynamic complexity of the soil landscape. The landscape surrounding WIPP is dominated by sandy soils on undulating plains and low hills. The soils developed in noncalcareous, wind-worked sandy deposits are highly susceptible to wind and water erosion (Chugg et al., 1971). Understanding the relative role of redistribution of soil within a system, and how that redistribution depends on episodic events, is directly relevant to addressing the general issue of contaminant transport in semiarid ecosystems (Whicker et al., 2002).

The objective of this investigation was to evaluate whether some of the variability in surface concentrations of radionuclides could be explained by spatial variability in vertical transport and soil erosion processes, and whether a sufficient change in surface concentrations due to erosion could occur as to be misinterpreted as an indication of a release of contaminants from the WIPP site.

^{239,240}Pu are the isotopes of most concern in terms of a potential release from the WIPP. Pu is generally considered to have low mobility in the environment because it tends to have low solubility. However, the vertical distribution of ^{137}Cs is also of interest because 1) the activity concentrations of ^{137}Cs in soils from fallout are considerably greater than those for ^{239,240}Pu and 2) ^{137}Cs is a gamma-emitter and it requires little effort to prepare samples for analysis. Although chemically quite different, ^{137}Cs is expected to behave similarly to ^{239,240}Pu in dry soils because it adheres tightly to cation-exchange surfaces (Coppinger et al., 1991). ^{137}Cs has been accepted as a reliable analog for estimating both horizontal and vertical transport of Pu (EPA 1999, Hulse et al., 1996, Hodge et al., 1996, White et al., 1981). Bunzl et al. (1995) showed that the residence half-times (i.e. rates of vertical transport) of ^{137}Cs, ^{239,240}Pu, ^{237}Np and ^{241}Am showed only small differences in grassland soil near Munich, Germany.

^{137}Cs from fallout has frequently been used to characterize soil particle transport (Schimmack et al., 2002; Pimentel et al., 1995). Cesium can adsorb to organic matter as well as soil mineral particles. However, cesium adsorption on clay minerals is strongly specific, whereas adsorption on organic matter is considered to be non-specific (Staunton and Levacic, 1999). Therefore, even when organic matter is responsible for a large proportion of soil cation exchange capacity trace amounts of radiocesium will be preferentially adsorbed on clay minerals. Nevertheless, organic matter can play a role in the mobility of cesium in the soil. There is a growing amount of evidence that Cs bioavailability increases as organic matter content increases.

Assuming that deposition of fallout onto a landscape was uniform, then the current distribution of radionuclides in the soil reflects the integrated effects of water, wind, soil properties, vegetation, and topography on erosion and deposition during the 35 to 45 years after the major deposition period (Walling and Quine, 1991). The horizontal movement of ^{137}Cs in soils by biological and chemical processes is small in comparison with movement of ^{137}Cs by physical processes (water and wind) that transport soil particles across the landscape (Ritchie and McHenry, 1990). The same can undoubtedly be said for ^{239,240}Pu and other relatively insoluble radionuclides. Coppinger et al. (1991) examined patterns and assessed transport mechanisms of soil erosion and deposition in a native sagebrush steppe landscape in south central Wyoming using ^{137}Cs. Results showed that wind was the major factor responsible for small-scale (0.5-10 m) transport of soils in this landscape and that there was little or no intermediate-scale (approximately 100 m) transport occurring.

Downward migration of Cs and Pu is dependent on numerous factors: sorption and desorption processes in soil, soil mineral composition, soil moisture and precipitation, particle size and specific surface area, soil type, pH, organic matter content, cation competitive effects, etc. (Barisic et al., 1999). Increased concentrations of competing ions such as

Na, K and H slightly decrease ^{137}Cs adsorption (Ritchie and McHenry, 1990). Adsorption of ^{137}Cs on soil particles is considered to be rapid, yielding a distribution in undisturbed soil profiles that shows an approximately exponential decrease with soil depth (Ritchie and McHenry 1990; Barisic et al., 1999). ^{239,240}Pu has been shown to have a vertical profile similar to that for ^{137}Cs (e.g. Komosa 1999, Turner et al., 2003). However, the peak concentration of both of these radionuclides can lie below the soil surface (e.g. Boulyga et al., 2003, Kochan and Shuktomova 1995, Komosa 1999, Gaca et al. 2006, Breban et al., 2003).

Vertical migration of contaminants in soil will generally depend on the relatively rapid movement of the contaminants in solution, and hence be affected by soil-water partitioning (Kd), and by the slower movement of the insoluble or absorbed component. In turf-podzol soil Boulyga et al. found that 80-95 % of actinide activity is associated with slow migration. Isaksson et al. (2000) examined the depth distribution of ^{137}Cs in labeled soils annually over a six-year period in southern Sweden. They found great similarities between years, indicating that once deposited, ^{137}Cs migrated into the topsoil, and thereafter showed a slow migration. A study of vertical migration in columns constructed using WIPP soil and subjected to irrigation showed very low rates of the vertical migration of ^{134}Cs (CEMRC 2002). In a related experiment, Whicker (2005) showed that cycles of wetting-drying can accelerate the vertical migration of ^{134}Cs in columns of intact WIPP and Rocky Flats soils as compared to irrigation without drying. The vertical migration rate for Pu in soil is also slow, ranging from 0.1 to 1 cm-yr^{-1} (Clark et al., 1996).

This study examines the vertical distribution of ^{137}Cs, ^{239,240}Pu and ^{241}Am and the characterization of four soil profiles in the vicinity of the WIPP site. These distributions can provide insight into the dynamics of transport of these radionuclides over the last four decades in a desert environment.

METHODS

Field Site Profiles

Four soil profiles were sampled in the spring of 2001 for the purpose of defining the distribution of ^{137}Cs, ^{239,240}Pu and ^{241}Am as a function of depth. Individual profiles (Figure 5.1) were sampled using the depth increments listed in Table 5-1. When an indurated layer was encountered at a depth shallower than 150 cm, sampling was terminated within the last unconsolidated layer at the assigned sampling thickness.

Sampling site locations were determined by the nature of the surface (minimal disturbance, absence of brush vegetation, etc.) and within a 50-m square centered on a designated grid node marker. Two sites were located within a grid surrounding the WIPP site and two sites were located within a reference grid approximately 20 km SE of the WIPP site (Kirchner et al., 2002), (Figure 3.1).

All sampling equipment (buckets, scoops, etc.) was non-metallic with the exception of excavation equipment (shovels, chipping bars, hammers). The vertical profile face was scraped clean with a plastic trowel after excavation. Samples were collected by depth increment by removing a 0.25 m^2 area beginning at the profile face and working back into the undisturbed profile (Figure 5.2). A 25 cm alley was removed from around the sampled area to the depth sampled before the next depth increment was collected. Soil samples were sealed in plastic containers for transport to the lab.

Soil samples were air-dried in the laboratory and sieved through a 2 mm sieve. Particle-size distribution was determined using the pipette method described by Gee and Bauder (Gee and Bauder, 1986). Specific conductivity and pH were determined on 1:2 (soil: deionized water) suspensions. Activity concentrations of ^{137}Cs in the soil samples were measured with gamma-spectroscopy. Multiple precipitation, co-precipitation and ion-exchange and/or extraction chromatography procedures were then used to separate and purify ^{239,240}Pu and ^{241}Am from aliquots of the soil. These radionuclides were then precipitated with NdF_3, deposited onto filters, mounted and counted on an alpha spectroscopy system.

Because of the expense of using alpha spectroscopy to measure actinides, only the top 10 cm of soil have thus far been analyzed for ^{239,240}Pu, and only a few of the upper layers have been analyzed for ^{241}Am.

Soil Profiles

Profiles 1, 2, and 3 have similar ^{137}Cs activity distributions (Table 5-2 Figure 5.3). The maximum activity in each of these profiles occurs in either the third or fourth cm below the soil surface ranging from 7.12 to 8.66 Bq kg^{-1}, and concentration declines approximately exponentially below the peak. The activities drop off sharply within 10 cm of the soil surface and are at or below minimum detectable concentrations (MDC) within 20 cm below the soil surface. There is no indication that radionuclides have mobilized to any substantial degree within these profiles. It is possible that the increase in ^{137}Cs activities with a slight increase in depth could be the result of leaching. However, it is also possible that the immediate surface is characteristic of a "mixing zone" in which the sandy surface could be depositional, erosional, or both.

The ^{137}Cs distribution in profile 4 appears to be quite different from the other three profiles (Table 5-2, Figure 5.3). An initial interpretation of the profile might be that a pulse of ^{137}Cs activity has moved to a depth of 20 cm. However, a profile inventory of the profile would suggest otherwise. Using an estimated soil bulk density of 1.4 g/cm^3, the total ^{137}Cs activity in the first three profiles ranged from 503 (±10.0) to 797 (±8.0) Bq/m^2, two to four time higher than the profile inventory reported by Collins et al. (2001) for soils located in more equatorial latitudes. The total inventory of ^{137}Cs activity in the fourth profile is almost three times higher than the other three profiles with an activity concentration of 2,263 (±30.1) Bq/m^2 (Table 5-3).

The distribution of ^{239,240}Pu in the soil profiles was more irregular, in terms of overall trends, than those for ^{137}Cs (Figure 5.4). Profile 1 exhibited the highest concentration of ^{239,240}Pu in the surface layer, but did show a secondary peak in the layer from 3-4 cm deep. The highest concentrations of ^{239,240}Pu for profiles 2 and 4 were also found in this same 3-4 cm layer. Profile 3 showed a peak concentration of ^{239,240}Pu between 1 and 2 cm of depth, although this peak was only slightly higher than the concentration found in the surface layer. There was a significant ($p=0.0009$) correlation between ^{239,240}Pu and ^{137}Cs, although the R^2 value was only 0.35 because the slope was close to zero (Figure 5.5). Profile 4 exhibited little if any correlation, whereas profile 1 had two relatively large deviations from the regression line.

The soil inventories for ^{239,240}Pu through the first 10 cm of depth range from 4.3 to 10.9 Bq/m^2 (Table 5.3). The data do not extend deep enough to determine whether the inventory for Profile 4 will significantly exceed that for the other profiles.

Although there are relatively few ^{241}Am results (Figure 5.7), there are two observations that can be made: 1) the highest concentrations in all four profiles occurred in between 2 and 3 cm depth and 2) the concentrations of ^{241}Am showed no correlation with ^{239,240}Pu concentrations (R^2 = .002). Neither of these observations should be considered conclusive because for two profiles samples were analyzed only to the 2-3 cm layer, and the remaining two profiles were analyzed for ^{241}Am only to a depth of 4 cm.

Pedogenically, three of the four profiles were quite similar. Profiles 1, 2, and 3 had relatively thick sandy surfaces underlain by weakly developed subsoil horizons that are distinguished from the surface by a distinct increase in clay (loamy, mixed, thermic Arenic Ustalfic Haplargid). The clay percentages presented in Table 5-2 ranged from approximately 2 to 5 % in the upper 6 cm of the profiles. Clay maxima in the underlying subsoil horizons ranged from approximate 12 to 15 %. Profile 4 was unique in that the clay increase in the subsoil was absent (siliceous, thermic Typic Torripsamment). The clay content observed in Table 5-2 for Profile 4 reflects a uniform distribution of approximately 2 % clay, increasingly only slightly (<1 %) with depth. Because the WIPP soils are dominated by sand and because Cs and Pu have affinities for binding to clay particles, the distribution of clay in the soil could be a factor affecting the distribution of ^{137}Cs and ^{239,240}Pu in the soil. However, there appears to be no relationship between the percentage of clay in a soil layer and the concentration of ^{137}Cs in that layer (Figure 5.6).

The salinity of these sandy soils is relatively low as illustrated by the low specific conductivity values in Table 5-1, given the occurrence of saline and gypsiferous outcrops in the vicinity (Chugg et al., 1971). Specific conductivity values in the profiles are generally <70 µS in the upper 40 cm of the soil profiles, with the exception of the immediate surface (upper 2 cm). The concentration of salts at the soil surface reflects the capillary rise and evaporation of moisture in the soil profile. Substantial increases in salinity occur at depths below 50 cm with specific conductivity values exceeding 100 µS, and are indicative of the effective leaching depth in these profiles. The maximum value was observed in the deepest sample collected from Profile 1, having a specific conductivity value of 190 µS. To put things into perspective, a soil is not considered saline until the specific conductivity of a saturated paste exceeds 4,000 µS (USDA, 1961).

The pH values observed in each of the profiles are uniform throughout for the most part, with pH values generally falling between 6.5 and 7.5. The majority of pH values in Profiles 2, 3, and 4, occur in the pH range of 6.5 to 7.0, while pH values in Profile 1 are dominantly between 7.0 and 7.5. The extremes observed included a low pH value of 6.26 in the second cm-increment of Profile 3 and a high pH value of 7.55 in the deepest horizon sampled in Profile 1.

The distribution of ^{137}Cs seen in profiles 1, 2 and 3 is similar to that reported by Owens et al. (1996) on field and laboratory experiments in Devon, UK. These experiments were carried out to provide empirical information on the fate of ^{137}Cs applied to different soil types over a 10-month period in order to simulate transport of fallout during individual storm events. The results suggested that most of the ^{137}Cs was contained in the top few millimeters of the soil profile, with activity concentrations declining approximately exponentially with depth. The longer-term net effect of ^{137}Cs sorption and movement within the soil profile since fallout began in the 1950's was investigated by examining contemporary soil profiles collected from stable non-eroding locations. Unlike experimentally leached columns, which represent the fate of applied radiocesium after shorter periods of time, the peak in ^{137}Cs concentration was not located at the soil surface, but a few cm below (1.5 to 3.0 cm). The location of the peak below the surface is considered to reflect the interaction of internal soil processes (such as diffusion, translocation and bioturbation) operating within the soil profile since the initiation of ^{137}Cs fallout inputs in the early 1950's, and the fact that the input of ^{137}Cs to the soil surface has declined through time since the mid-1960s.

The most likely explanation for the distribution of ^{137}Cs in Profile 4 is deposition and burial of the original profile after it received nuclear fallout during the 1950's and early 1960's. This is not to be unexpected in a landscape dominated by sand dunes. If the ^{137}Cs pulse is bisected at the maximum (assuming a similar profile distribution to the first three profiles), and only the underlying ^{137}Cs activities considered, the total ^{137}Cs is 855 (±17.9) Bq/m^2, which is much more in line with the other three profiles (Table 5.3). The presence of a buried peak in ^{137}Cs activity was also interpreted as a former surface in studies of an area in southern Zambia reported by Collins et al. (2001). Unfortunately, the ^{239,240}Pu data currently available do not provide support for this conjecture, due to the irregularity in their profiles and the restricted depth covered by the current analyses.

The activities of ^{137}Cs in profile 4 between the surface and a depth of 15 cm range from 2.419 to 3.309 Bq kg^{-1}. This would suggest that the source of deposition is from eroded surface soil higher in ^{137}Cs relative to deeper, subsoil activity concentrations which are generally less than 1.0 Bq kg^{-1}, but somewhat lower than the maximum concentrations observed in the near surface environments of profiles 1, 2 and 3. It would be expected that the depositional material would be a combination of material relatively high in ^{137}Cs with materials lower in activity depending on the severity of the erosion from which the depositional sand originated.

The maximum depth at which ^{137}Cs could be detected further supports the argument that the original surface of profile 4 receiving radionuclide fallout has been buried. Profiles 1, 2 and 3 had detectable concentrations of ^{137}Cs down to 20 cm. Profile 4 had detectable ^{137}Cs activity down to 40 cm. If the ^{137}Cs activity peak in profile 4 that begins at a depth of 20 cm is assumed to be the original surface, this profile would have received 20 cm of erosional sand. Accounting for this burial, the depth to which ^{137}Cs has penetrated the buried profile falls in line with the other three profiles at 20 cm.

Discontinuities in the vertical distribution of properties that affect the mobilization of ^{137}Cs, such as pH and salinity, could result in the concentration of ^{137}Cs near the discontinuity. The relative uniformity in pH and salinity in the subsurface soil does not offer an explanation for the occurrence of sub-surface maxima in ^{137}Cs concentrations. In addition, the high level of conductivity in the surface layer is indicative of vertical movement of water through evaporation and capillary flow, which would be expected to work in opposition to a downward diffusion of ^{137}Cs.

CONCLUSIONS

Based on this investigation of in situ soil profiles and on the soil column experiments reported in the 2002 Annual Report, it is apparent that leaching and colloidal transport are not major factors in affecting the vertical movement of ^{137}Cs or ^{239,240}Pu in the soils found in the vicinity of WIPP. The lateral movement of soil by wind erosion is, by far, more responsible for the redistribution of the radionuclides in this ecosystem. The maximum ^{137}Cs activity concentrations observed in the soil profiles, ranging from 6.73 to 8.66 Bq kg^{-1}, were slightly higher than the mean values reported by Kirchner et al. (2002) of 3.1 and 6.2 Bq kg^{-1} (Near Field and Cactus Flats, respectively) for soil samples sampled to a depth of 2.5 cm. However, the values were well within the range of activity concentrations reported, 0.31 to 15 Bq kg^{-1}. ^{239,240}Pu concentrations ranged from 6.3E-2 to 2.2E-1 as compared to the mean concentrations in surface soils of 2.2E-1 and 1.0E-1 Bq kg^{-1} on the Cactus Flats and Near Field grids, respectively. This analysis indicates that erosional conditions could expose soils having higher concentrations of ^{137}Cs, and perhaps of ^{239,240}Pu and other radionuclides, than the concentrations currently present in surface soils.

Soil surface concentrations of radionuclides can also affect aerosol concentrations. Arimoto et al. (2002) reported that ^{239,240}Pu activity concentrations in total suspended particle (TSP) samples varied strongly with season (12 to 16 nBq/m^3), with the highest values generally occurring in spring (March through May, a period commonly typified by frequent dust storms). The source for the plutonium was hypothesized to be from resuspended soil. The authors offered that the results of their study demonstrated that processes affecting the resuspension of $^{239/240}$Pu and possibly other substances of concern are of great importance and must be known and quantified if any impacts of WIPP operations are to be properly evaluated. Thus the detection of increased concentrations of radionuclides in the WIPP soils or aerosols should not be automatically attributed to releases from the WIPP.

Table 5-1: Specific Conductivity and pH Data as a Function of Depth for the Four Soil Profiles

Lower depth (cm)	Specific Conductivity(µS)				pH			
	Profile 1	**Profile 2**	**Profile 3**	**Profile 4**	**Profile 1**	**Profile 2**	**Profile 3**	**Profile 4**
1	128	200	60	128	7.20	6.58	6.53	6.59
2	71	169	48	89	7.11	6.51	6.26	6.64
3	55	66	47	73	7.12	6.74	6.43	6.73
4	63	53	39	60	6.76	6.71	6.61	6.61
6	55	55	48	50	7.28	6.76	6.58	6.79
8	64	55	45	48	7.25	6.85	6.58	6.94
10	64	50	49	39	6.76	6.78	6.51	6.94
15	56	37	50	39	6.99	6.71	6.68	6.91
20	62	31	54	39	7.19	6.75	6.52	6.88
30	54	41	49	30	7.63	6.62	6.66	6.96
40	54	43	52	30	6.83	6.64	6.67	7.05
50	73	32	62	61	7.39	6.94	6.79	6.84
75	87	33	123	72	7.19	6.90	6.59	7.08
100	125	76		137	7.44	6.74		6.70
125	190			59	7.55			6.94
150				67				6.85

Table 5-2: Distribution of Clay, ^{137}Cs and ^{239,240}Pu as a Function of Depth in the Four Soil Profiles

Lower Depth (cm)	Clay (%)				^{137}Cs (Bq kg-1)				^{239,240}Pu (Bq kg-1)			
	Profile				Profile				Profile			
	1	2	3	4	1	2	3	4	1	2	3	4
1	3.6	2.0	3.2	1.9	5.261	5.030	6.321	2.419	0.221	0.059	0.071	0.023
2	4.1	2.0	4.1	2.0	6.730	6.439	6.983	2.472	0.077	0.091	0.075	0.032
3	4.3	3.0	4.4	2.1	7.399	8.296	7.124	2.923	0.088	0.075	0.037	0.040
4	3.9	2.9	4.6	2.0	6.722	8.661	5.104	2.612	0.169	0.101	0.040	0.074
6	3.9	3.4	5.0	2.0	5.932	6.864	2.126	2.816	0.062	0.054	0.025	0.056
8	4.1	3.0	5.4	2.2	2.951	3.029	1.080	2.911	0.036	0.025	0.006	0.020
10	4.7	3.7	4.9	2.1	1.378	1.658	0.408	3.052	0.013	0.017	0.010	0.031
15	4.7	3.7	5.5	1.9	0.634	0.846	0.437	3.309	NA[2]	NA	NA	NA
20	5.1	3.8	5.6	1.7	0.400	0.240	0.191	4.489	NA	NA	NA	NA
30	5.9	3.9	5.9	2.1	<MDC[1]	<MDC	<MDC	6.727	NA	NA	NA	NA
40	6.8	4.1	6.8	2.2	<MDC	<MDC	<MDC	2.741	NA	NA	NA	NA
50	8.3	4.2	9.0	2.3	<MDC	<MDC	<MDC	<MDC	NA	NA	NA	NA
75	9.3	5.0	12.0	2.5	<MDC	<MDC	<MDC	<MDC	NA	NA	NA	NA
100	10.4	13.0		2.8	<MDC	<MDC		<MDC	NA	NA	NA	NA
125	15.1			2.8	<MDC			<MDC	NA	NA	NA	NA
150				2.8				<MDC	NA	NA	NA	NA

[1] <MDC = less than minimum detectable concentration
[2] NA = Not Analyzed

Table 5-3: Profile Inventories for ^{137}Cs and ^{239,240}Pu

Profile	Inventory ^{137}Cs (Bq/m^2)	Inventory[2] ^{239,240}Pu (Bq/m^2)
1	725	10.9
2	797	7.3
3	503	4.3
4	2263	5.4
[1]4	855	NA[3]

[1] Below the sample having the maximum concentration
[2] Inventory in the top 10 cm only
[3] Not applicable

Figure 5.1: Soil Profile 3 before sampling

Figure 5.2: Soil Profile 4 after sampling

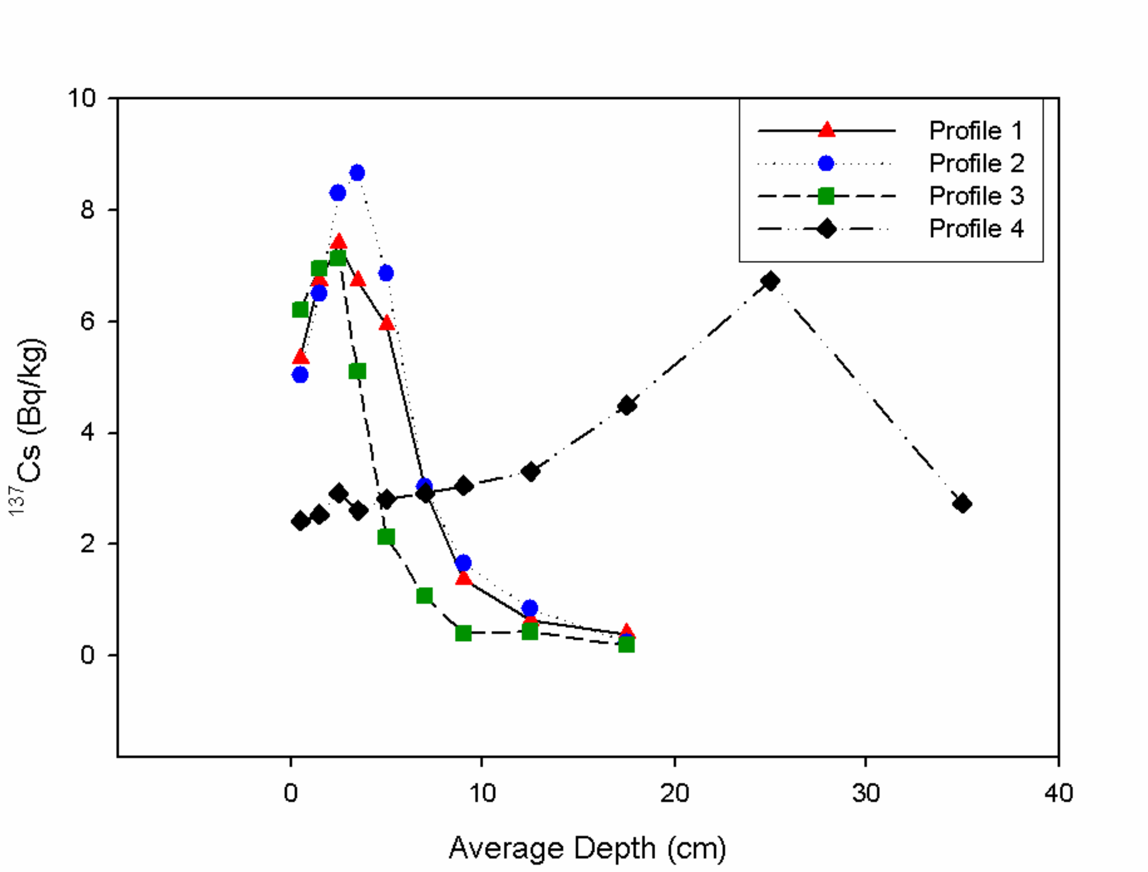


Figure 5.3: Distribution of ^{137}Cs Expressed as a Function of Depth in Four Profiles

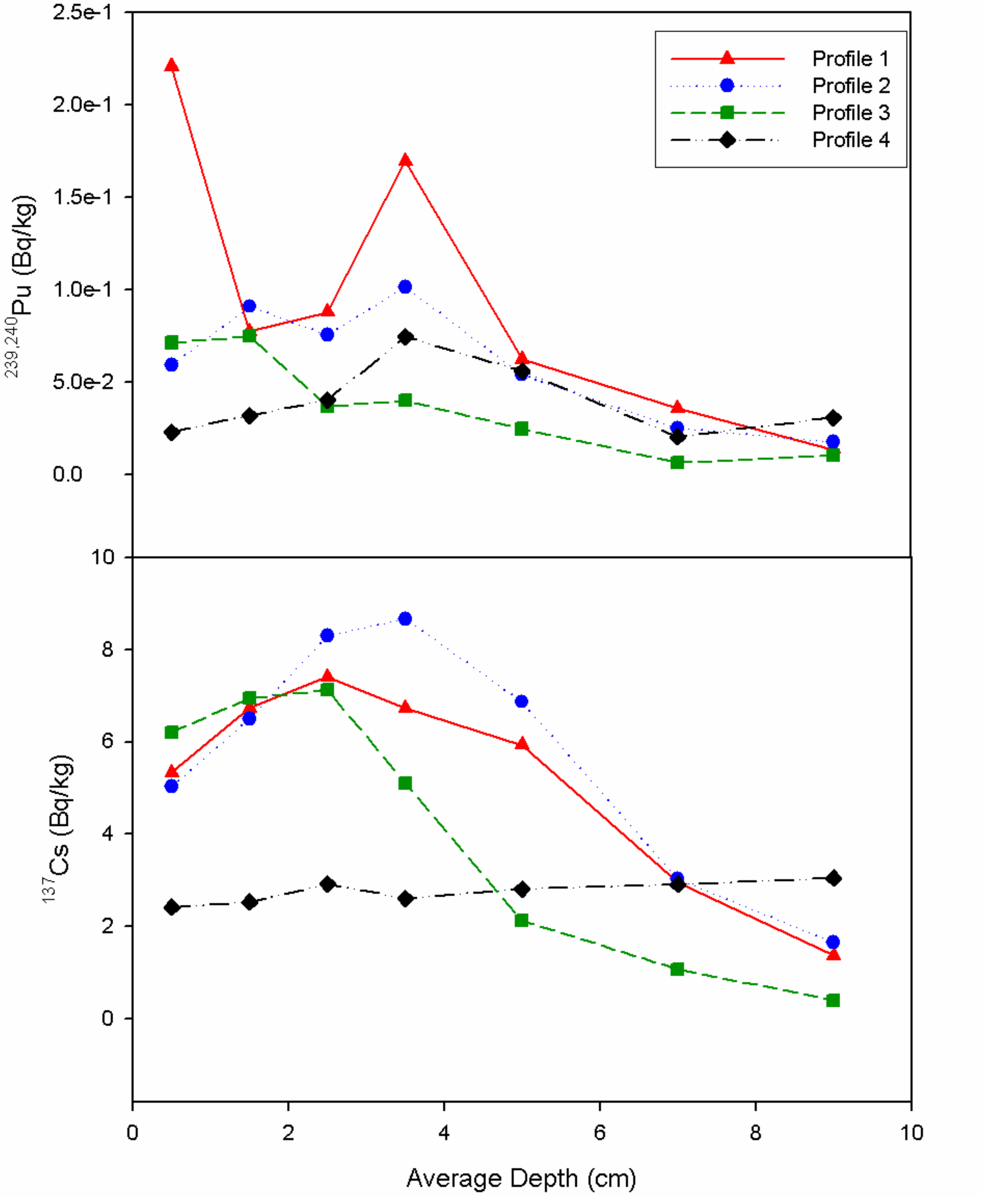


Figure 5.4: Distributions of ^{137}Cs and ^{239,240}Pu Expressed as a Function of Depth in the Top 10 cm of Soil

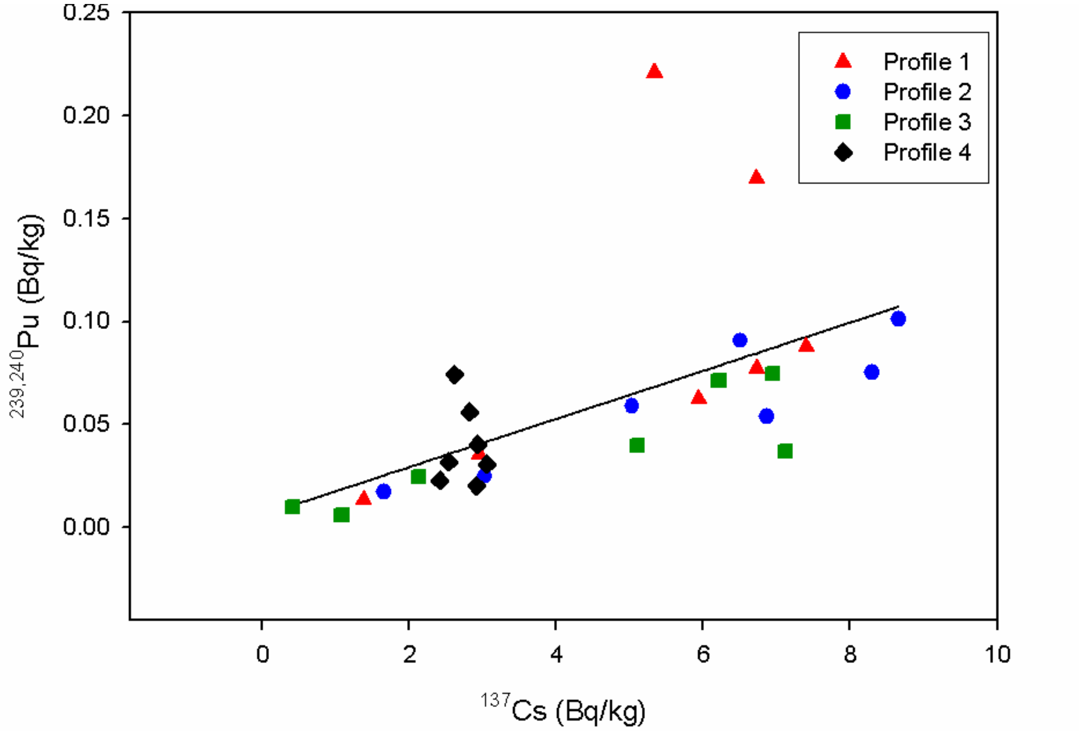


Figure 5.5: Correlation Between ^{239,240}Pu and ^{137}Cs

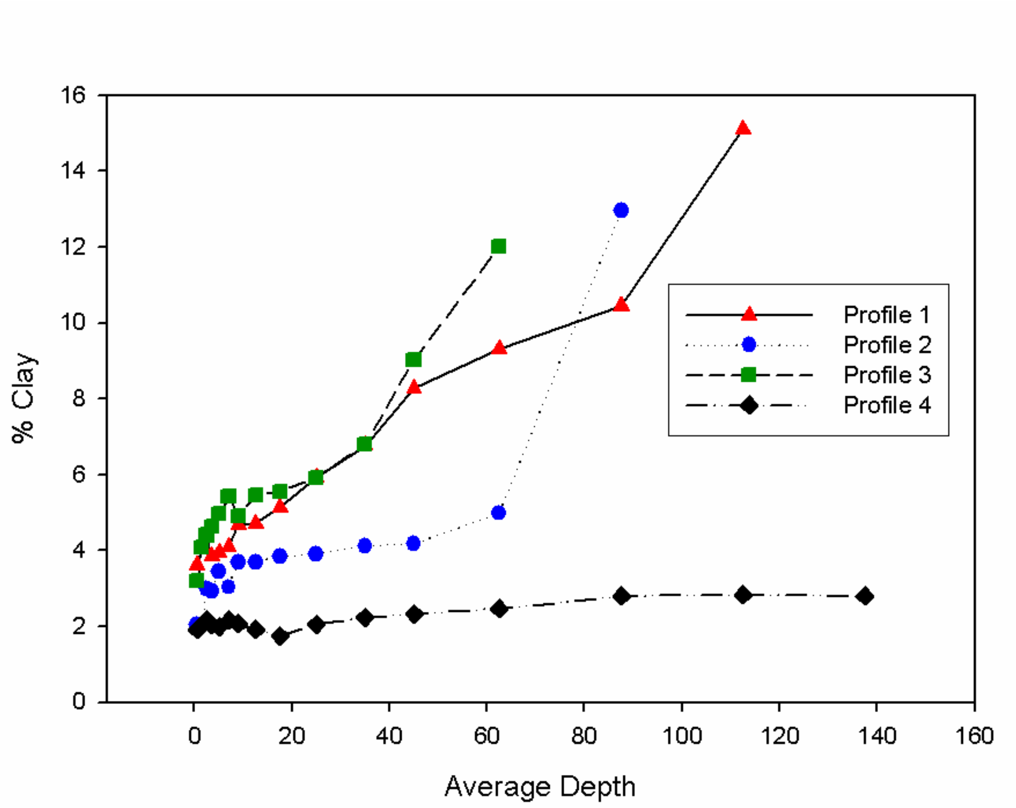


Figure 5.6: Distribution of Clay Content Expressed as a Function of Depth in Four Profiles

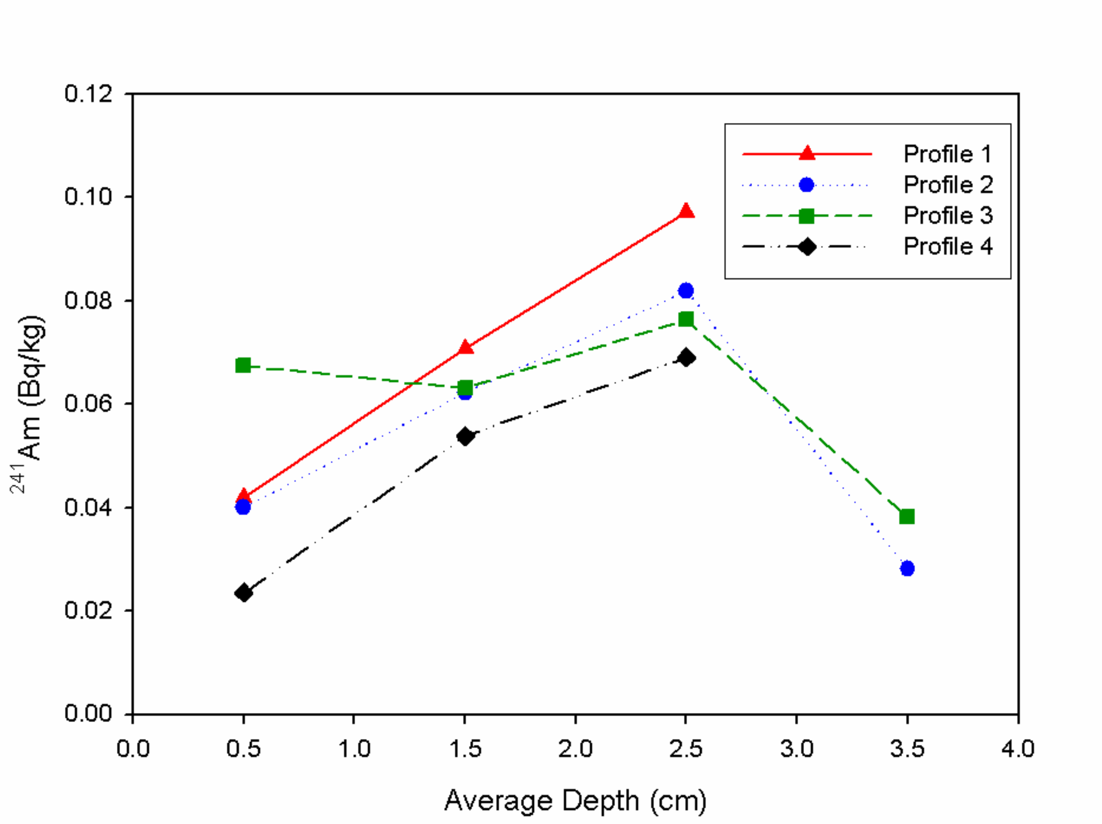


Figure 5.7: Distribution of ^{241}Am Expressed as a Function of Depth in the Top 4 cm of Soil

CHAPTER 6

Radionuclides and Inorganics in Selected Water Sources

INTRODUCTION

During 2005, water samples were collected for CEMRC environmental monitoring studies from eight sources in the region of the WIPP, five drinking water sources and three surface water sources. The drinking water wells in the vicinity of the WIPP site provide water primarily for livestock, industrial usage by oil and gas production operations, and monitoring studies conducted by various groups. The sources included the community water supplies of Carlsbad, Loving, Otis, and Hobbs, and the water supply for the WIPP site (Double Eagle). An additional source in the past, a private well, has been dry for the last few years.

Aquifers in the region surrounding the WIPP include Dewey Lake, Culebra-Magenta, Ogalalla, Dockum, Pecos River alluvium and Capitan Reef. The main Carlsbad water supply is the Sheep Draw well field whose primary source is the Capitan Reef aquifer. The Hobbs and WIPP-Double Eagle water supplies are drawn from the Ogalalla aquifer, while the Loving/Malaga and Otis supply wells draw from deposits that are hydraulically linked to the flow of the Pecos River. The source for the private well sampling site is a well seven miles southwest of the WIPP; this water is drawn from the Culebra aquifer when it is not dry.

CEMRC began collecting drinking water samples in 1997, and summaries of methods, data and results from previous sampling were reported in previous CEMRC reports (available at http://www.cemrc.org). Present results as well as the results of previous analyses of drinking water were generally consistent for each source across sampling periods, with few organic contaminants detected and inorganic substances mostly below levels specified under the Safe Drinking Water Act.

As part of the WIPP EM project, surface waters are routinely sampled from three regional reservoirs situated on the Pecos River, Brantley Lake and Red Bluff Reservoir. These were selected for sampling because they are impoundments located “upstream” and “downstream”, respectively, relative to surface and ground water flows from the area immediately surrounding the WIPP site. Both reservoirs support a warm-water fishery and are used for irrigation, livestock watering, wildlife habitat and recreation. Lake Carlsbad is an impounded section of the Pecos River within the city of Carlsbad that is used extensively by the local population for recreational warm-water fishing, boating and swimming. Overviews of these surface water sites are illustrated in Figures 6.1 through 6.3.

Analyses reported herein are for 2005 for all sources. Surface water samples were analyzed for inorganic constituents, and drinking water samples for both inorganics and radionuclides.

METHODS

Alpha-emitting radionuclides analyzed in water samples included ^{241}Am, ^{238}Pu, ^{239,240}Pu, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U. Gamma-emitting radionuclides included ^{228}Ac, ^{241}Am, ^{7}Be, ^{212}Bi, ^{213}Bi, ^{214}Bi, ^{144}Ce, ^{249}Cf, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{152}Eu,

^{154}Eu, ^{40}K, ^{233}Pa, ^{234m}Pa, ^{212}Pb, ^{214}Pb, ^{106}Rh, ^{125}Sb, and ^{208}Tl.

Inorganic analytes include those listed in Tables 6-2 and 6-3.

All drinking water samples were collected according to CEMRC protocols for the collection, handling and preservation of drinking water as follows: (1) 4 L for radiological analyses, (2) 1 L for elemental analyses and (3) 1 L for anion tests. None of the samples were filtered before analysis, but a portion of the 4 L sample was transferred to a 3 L Marinelli beaker for gamma spectroscopy analyses.

CEMRC performed non-radiological analyses of drinking water samples using ICP-MS. Radiological analyses were carried out at CEMRC by first counting the samples in Marinelli beakers using a coaxial, high purity Ge detector system to determine gamma-emitting radionuclide activity concentrations. Radiochemistry was then applied to each sample for actinide separation and purification using multiple precipitation, co-precipitation and ion-exchange and/or extraction chromatography. Once the actinides were separated elementally, they were co-precipitated with LaF_3 and deposited onto filters, which were then counted on an alpha spectroscopy system.

In the laboratory, surface water samples collected were vacuum-filtered to 0.2 μm and acidified with HNO_3 to a $pH < 2$. A 3 L aliquot was removed for analysis of alpha and gamma-emitting radionuclides. A 1 L aliquot of the surface water samples was removed for elemental analyses. Aliquots were blank-corrected after application of dilution factors. In cases where blank corrections lowered solution concentrations below MDC values, concentrations greater than zero are reported; negative concentrations are reported as less than MDC.

RESULTS AND DISCUSSION

Radiological Drinking Water

No radionuclides were measured above MDC in 2005 samples as measured by gamma spectroscopy targeting 11 naturally occurring and 12 anthropogenic gamma-emitters. Four naturally occurring actinides (^{234}U, ^{235}U, ^{238}U, and ^{228}Th) were detected via alpha spectroscopy in all of the samples from each location. However, measured levels of ^{228}Th are considered largely an artifact of the use of ^{232}U as a tracer during the radioanalytical process. (^{232}U decays to ^{228}Th, resulting in a positive bias in ^{228}Th measurements).

For the 2005 drinking water samples, three naturally occurring uranium isotopes (^{234}U, ^{235}U and ^{238}U) were detected in all drinking water samples as is the case for most waters in New Mexico. These results are listed in Table 6-1. Calculated values for samples collected during 2005 from Carlsbad were 27.5 ± 0.82 mBqL^{-1} for ^{234}U, 1.51 ± 0.14 mBqL^{-1} for ^{235}U, and 11.1 ± 0.39 mBqL^{-1} for ^{238}U. These levels are similar to values measured for the last eight years, and are within about a factor of two of the 1998 baseline levels, with the 2005 ^{234}U and ^{238}U slightly lower than 1998 and ^{235}U slightly higher. These levels and ratios of uranium are typical of natural variations in ground water (Cothern, C.R. and W.L. Lappenbusch, 1983; Luo et al., 2000) and agree well with the few directly comparable values reported from studies in the region. The federal and state action level for gross alpha emitters, which includes isotopes of Pu and U, is 15 pCi/L (0.56 Bq/L). This is over 10,000 times the levels measured by CEMRC in any drinking water sample over the last 8 years.

Across all years, the highest levels of all three uranium isotopes were measured in samples from Private Well #2 (which has been dry since 2001), with Otis and Hobbs second. The lowest levels were measured in samples from Carlsbad. The ranges and ratios of all three uranium isotopes measured during 2005 were similar to values from 1992 samples from Carlsbad, Double Eagle and Loving reported by EEG (Kenny, J.W., 1994).

Since 1998, neither ^{239,240}Pu or ^{238}Pu have been measured above the MDC in any samples, an example of which is given in Figure 6.4 for ^{239,240}Pu in Carlsbad drinking water. Figures 6.5 and 6.6 show the historic values for ^{239,240}Pu and ^{238}Pu at all sites. All are below the MDC.

Non-Radiological Results Drinking Water

Measurements of inorganic analytes by CEMRC from the five drinking water sources showed little variation between years for each source. Differences of a factor of two or three between one set of successive years is common.

The 2005 measurements exhibit a high level of consistency with past results that provides a useful characterization of each source (Table 6-2). Pb levels in all sources have been between 0.1 and 8 μg L^{-1} (ppb). Hg was detected only in samples from Hobbs (0.009-0.014 μg L^{-1}). Arsenic (As) levels were highest in samples from Hobbs (4.5-7.4 μg L^{-1}) and Double Eagle (4.3-7.8 μg L^{-1}), and these measurements suggest that these drinking water sources may exceed any As standard $\leq$ 5.0 μg L^{-1} as has been recently adopted by EPA but not yet enforced for many small municipalities. Arsenic in Carlsbad drinking water has consistently been between 0.3 – 0.7 μg L^{-1}.

As per the grant requirements and the fact that CEMRC does not use EPA compliance procedures, these results are not appropriate for use in assessing regulatory compliance. However, CEMRC results for drinking water collected during 2005 agreed well with, and were generally below, measurements for the same elements published in 2005 by the City of Carlsbad Municipal Water System (*2005 Annual Consumer Report on the Quality of Your Drinking Water (www.cityofcarlsbadnm .com/documents/CCR2005.pdf).*

Non-Radiological Surface Water

Surface water samples have been analyzed for a suite of inorganic compounds shown in Table 6-3. 2005 results are consistent with previous years 1999-2003 and the baseline year of 1998 (Table 6-3). The majority of analytes were detected in each of the samples collected from each sampling period. No nitrates were detected in any of the lakes sampled.

Table 6-4 shows the comparison between deep and shallow samples from the same location. Shallow samples are collected from 0.5 meters below the water's surface and deep samples are collected from 1.0 meter above the lake bottom. No significant trends or effects are seen.

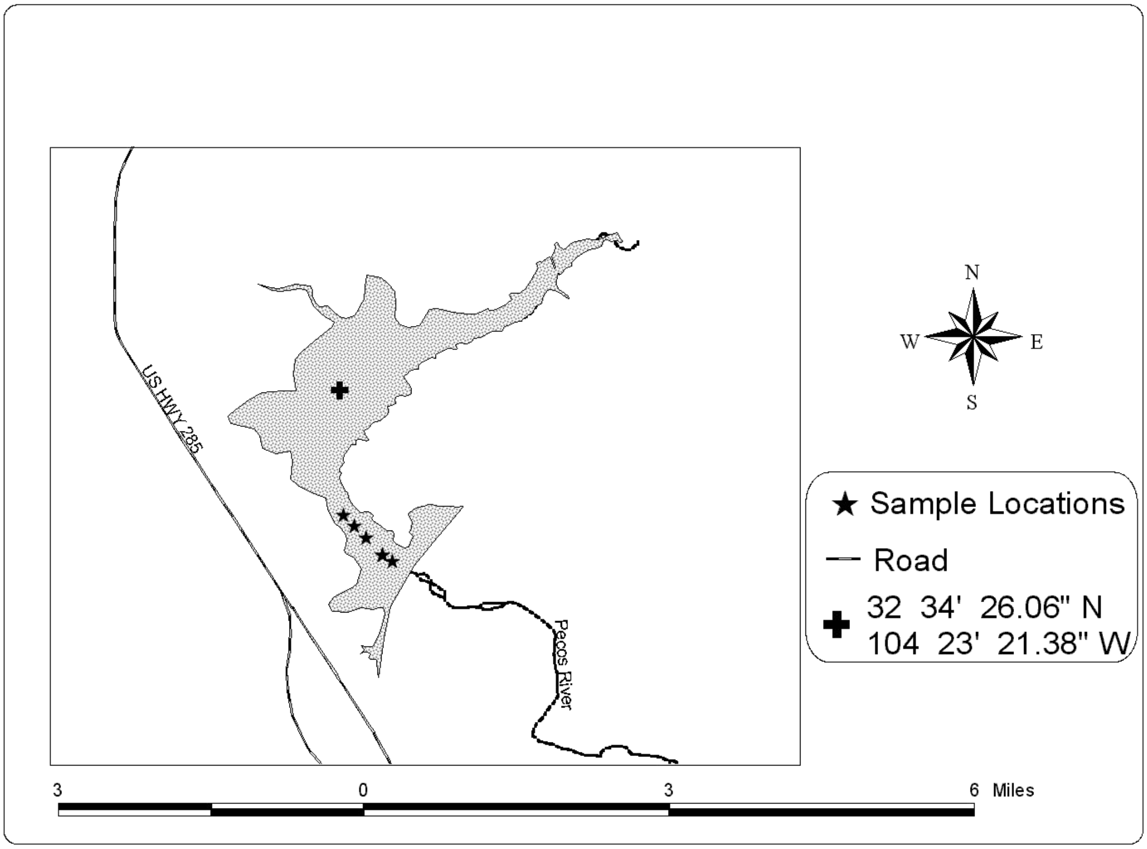


Figure 6.1: Surface Water and Sediment Sampling Locations at Brantley Lake

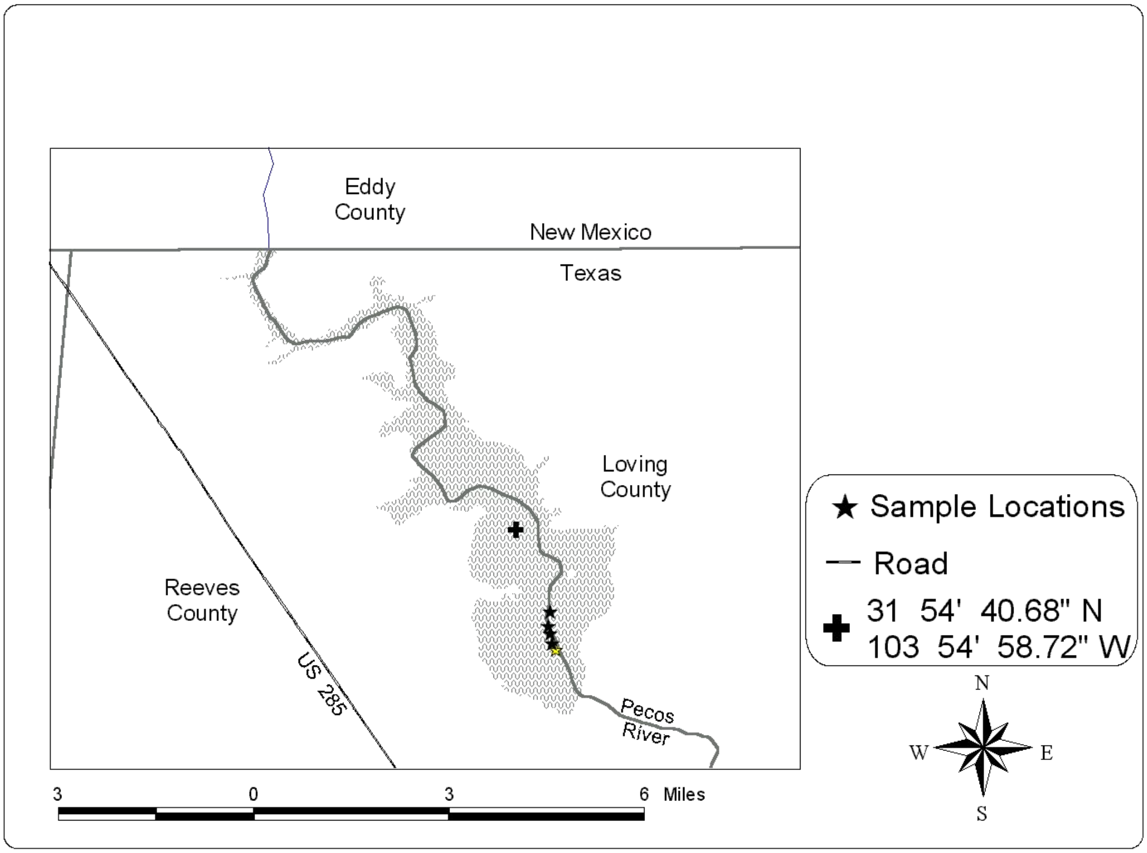


Figure 6.2: Surface Water and Sediment Sampling Locations at Red Bluff Reservoir

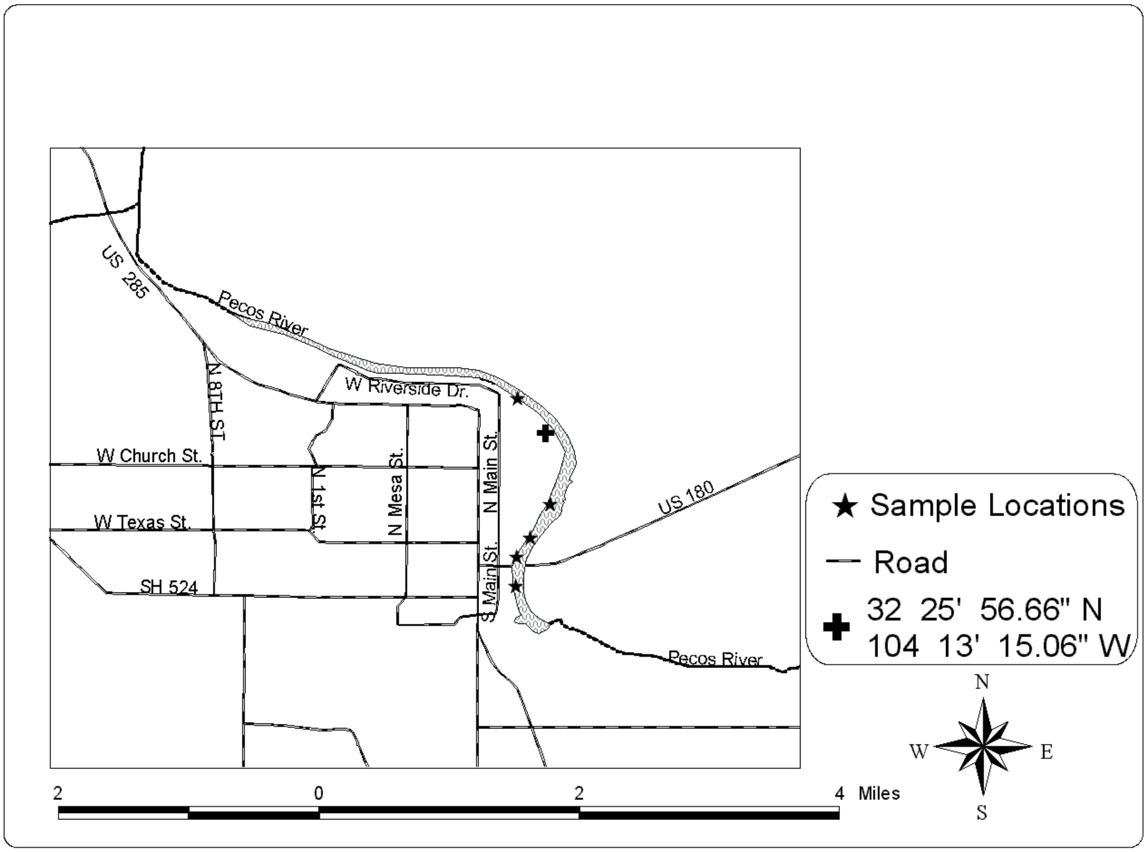


Figure 6.3: Surface Water and Sediment Sampling Locations at Lake Carlsbad

Table 6-1: Range of Activity Concentrations for Uranium Isotopes Measured in Drinking Water During 2005 and Comparisons with 1998/1999 Baseline

Location	Analyte	2005 Activity Concentration (Bq L^{-1})		[a]RPC from baseline (%)	
		Activity	Uncertainty	2005:1998	2005:1999
Carlsbad	^{234}U	2.75E-02	8.16E-04	-17.7	-6.5
	^{235}U	1.51E-03	1.41E-04	100.8	116.0
	^{238}U	1.11E-02	3.91E-04	-17.8	-2.6
Double Eagle	^{234}U	5.83E-02	1.60E-03	5.2	-5.8
	^{235}U	1.54E-03	1.43E-04	42.6	40.0
	^{238}U	2.48E-02	7.46E-04	22.2	6.9
Hobbs	^{234}U	9.82E-02	2.61E-03	11.1	15.0
	^{235}U	2.68E-03	2.11E-04	20.2	8.9
	^{238}U	4.27E-02	1.20E-03	11.5	10.6
Loving	^{234}U	8.11E-02	2.17E-03	-0.5	-4.3
	^{235}U	1.74E-03	1.55E-04	4.8	15.2
	^{238}U	2.63E-02	7.82E-04	8.7	0.0
Otis	^{234}U	1.17E-01	3.09E-03	-9.3	-22.0
	^{235}U	2.60E-03	2.07E-04	-4.8	-8.8
	^{238}U	4.36E-02	1.23E-03	-6.6	-17.7

[a] RPC = relative percent change; for 2005:1998 = ((2005 concentration –1998 concentration) / 1998 concentration) * 100%; for 2005:1999 = ((2005 concentration –1999 concentration) / 1999 concentration) * 100%

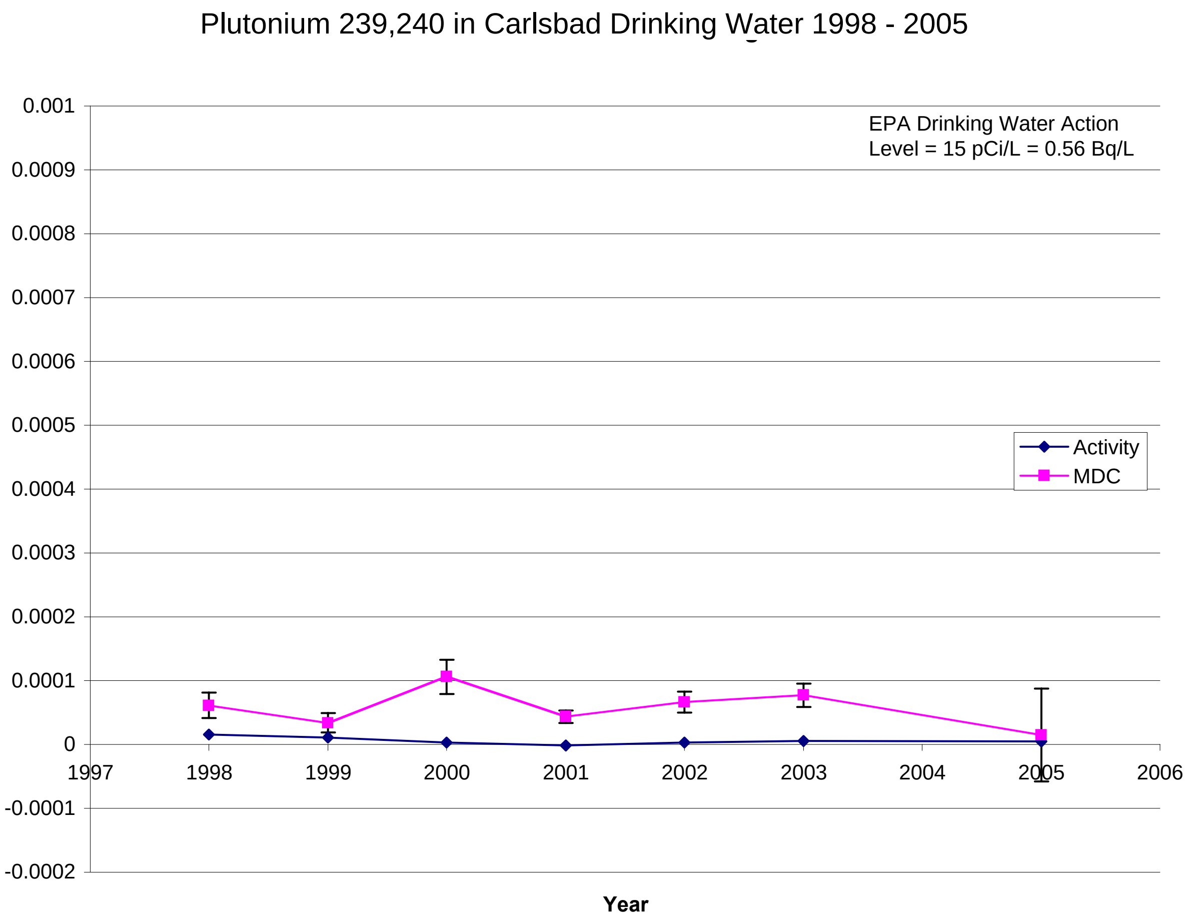


Figure 6.4: ^{239,240}Pu in Carlsbad drinking water from 1998 to 2005. MDC is the minimum detection concentration, and all samples are below this lower limit. EPA Action levels are for all alpha-emitters, including U+Pu.

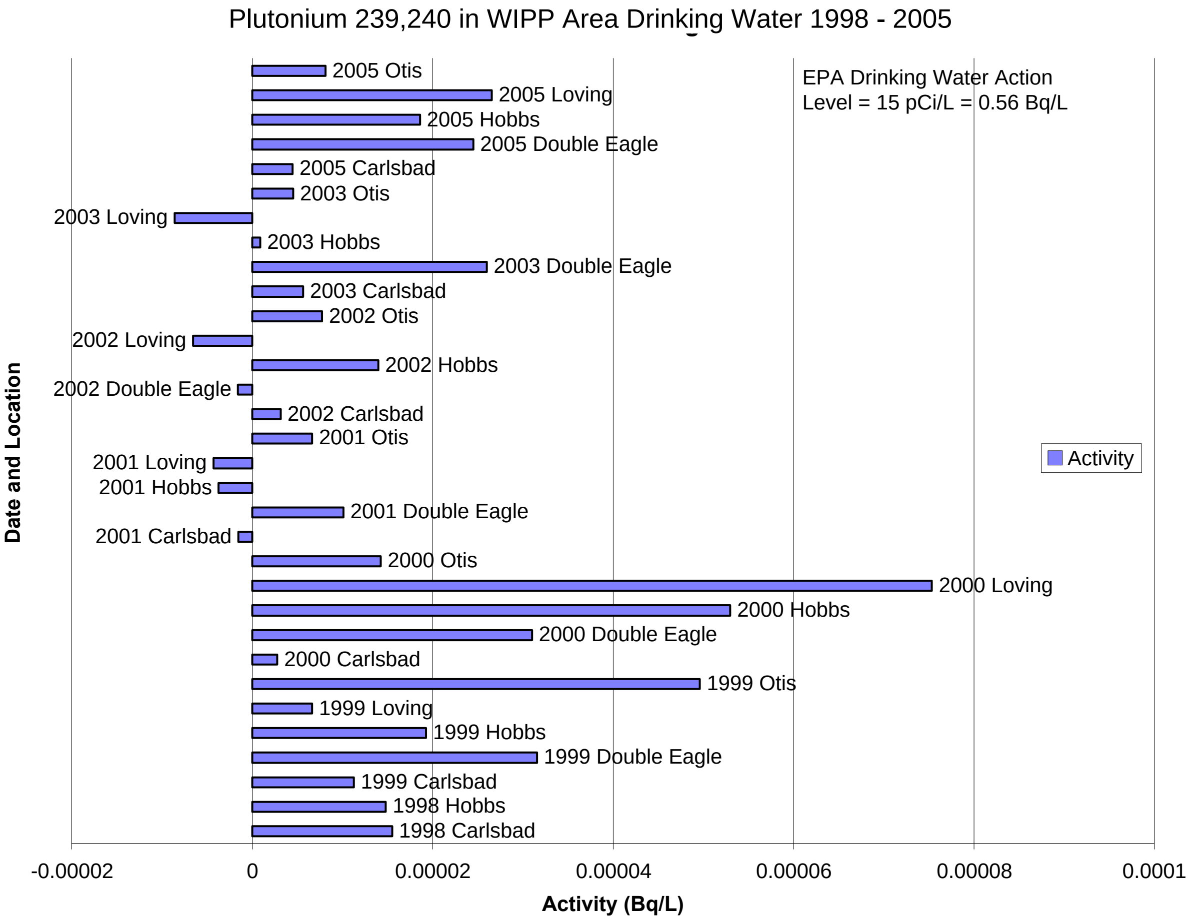


Figure 6.5: ^{239,240}Pu in regional drinking water from 1998 to 2005. EPA Action levels are for all alpha-emitters, including U+Pu.

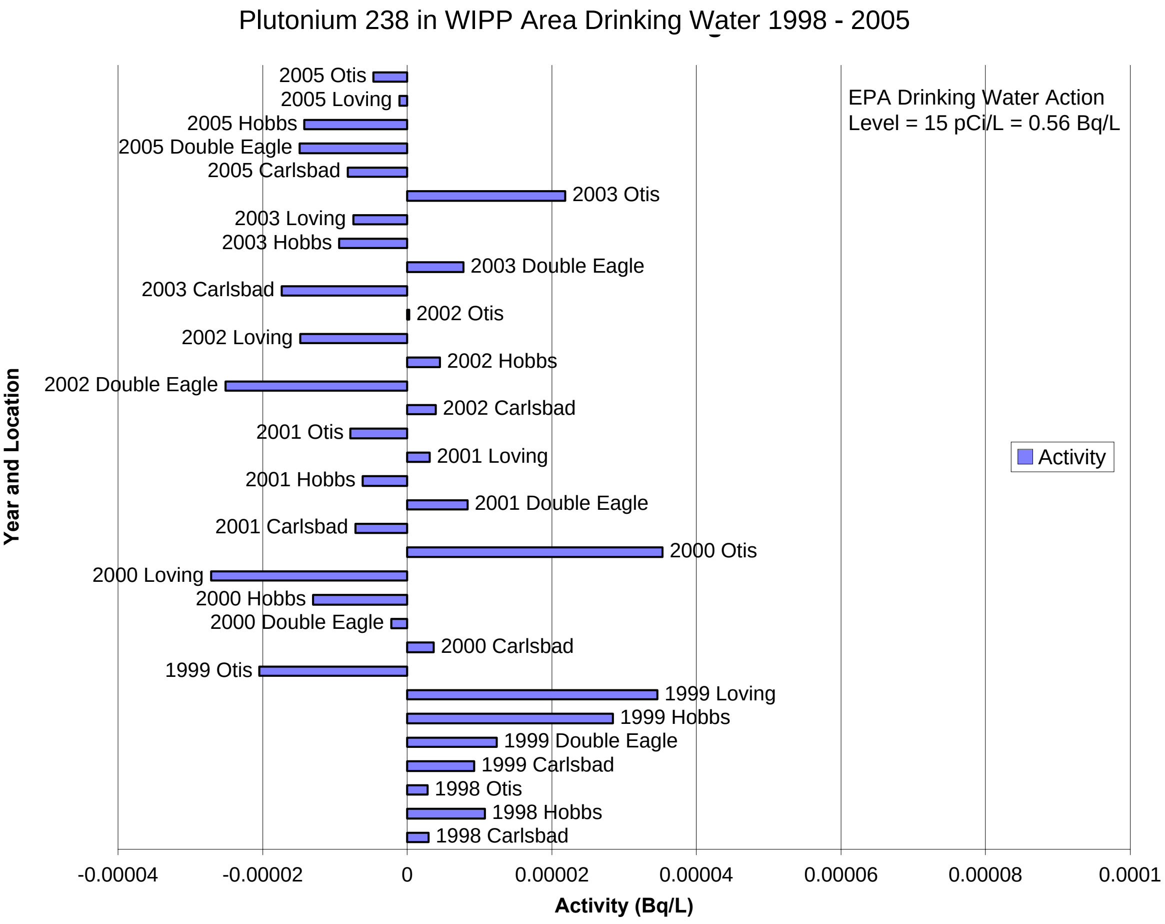


Figure 6.6: ^{238}Pu in regional drinking water from 1998 to 2005. EPA Action levels are for all alpha-emitters, including U+Pu.

Table 6-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2005 at Five Locations

Carlsbad												
	1998-2005				2003				2005			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)
Ag	8	2	1.23E-02	1.75E-02	3.00E-02	-1.36E-03	<MDC	<MDC	2.30E-02	1.11E-01	<MDC	<MDC
Al	9	4	2.34E+00	3.17E+01	2.20E+00	-9.12E-01	<MDC	<MDC	1.49E+01	-2.80E+01	<MDC	<MDC
As	9	6	3.45E-01	6.82E-01	1.80E+00	-3.04E-01	<MDC	<MDC	2.01E+00	3.19E+01	<MDC	<MDC
B	1	1	3.07E+01	3.07E+01	3.40E+00	-1.23E+00	3.07E+01	3.07E+01	N/A[6]	N/A	N/A	N/A
Ba	9	9	6.64E+01	7.62E+01	1.40E-01	-1.63E-02	6.77E+01	6.77E+01	1.24E-01	-5.63E+00	7.62E+01	7.62E+01
Be	8	0	N/A	N/A	8.00E-01	1.02E-02	<MDC	<MDC	N/A	N/A	N/A	N/A
Ca	8	8	6.54E+04	8.06E+04	2.40E+03	-1.47E+00	6.54E+04	6.54E+04	N/A	N/A	N/A	N/A
Cd	8	0	N/A	N/A	3.20E-02	-1.51E-02	<MDC	<MDC	6.73E-02	1.91E+00	<MDC	<MDC
Ce	7	0	N/A	N/A	1.20E-02	1.35E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Co	8	6	8.80E-02	3.41E-01	5.00E-02	-3.07E-04	<MDC	<MDC	7.21E-01	8.25E-01	<MDC	<MDC
Cr	9	7	2.68E+00	7.15E+00	5.60E-02	-8.89E-02	3.31E+00	3.22E+00	7.82E+00	9.24E+01	<MDC	<MDC
Cu	9	8	1.23E+00	1.67E+01	3.10E-01	4.75E-02	2.11E+00	2.11E+00	8.98E-02	3.68E+01	1.67E+01	1.67E+01
Dy	8	0	N/A	N/A	3.50E-02	3.30E-03	<MDC	<MDC	2.79E-02	-1.77E-01	<MDC	<MDC
Er	8	0	N/A	N/A	2.70E-02	-1.40E-03	<MDC	<MDC	1.21E-02	-5.61E-02	<MDC	<MDC
Eu	8	6	1.35E-02	2.43E-02	2.30E-02	-9.25E-04	<MDC	<MDC	1.64E-02	-1.04E-01	<MDC	<MDC
Fe	9	3	2.14E+01	3.85E+01	7.60E+00	-1.51E+01	3.85E+01	2.34E+01	2.94E+02	3.66E+03	<MDC	<MDC
Ga	2	2	3.24E+00	3.25E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gd	6	0	N/A	N/A	3.40E-02	-5.68E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
Hg	7	0	N/A	N/A	1.21E-02	9.60E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
K	8	8	1.04E+03	3.56E+03	4.40E+01	-1.16E+01	1.29E+03	1.29E+03	N/A	N/A	N/A	N/A
La	8	5	1.41E-02	4.48E-02	1.50E-02	-5.90E-04	<MDC	<MDC	1.36E-02	1.00E-01	<MDC	<MDC
Li	7	7	6.09E+00	7.87E+00	4.00E-01	-1.12E-02	6.14E+00	6.14E+00	N/A	N/A	N/A	N/A
Mg	8	8	3.14E+04	3.47E+04	1.20E+01	2.01E-01	3.20E+04	3.20E+04	5.97E+00	-8.94E+01	3.47E+04	3.47E+04
Mn	9	8	5.50E-02	9.40E-01	1.66E-01	1.65E-02	5.31E-01	5.31E-01	1.60E+00	1.97E+01	<MDC	<MDC
Mo	9	8	7.03E-01	1.26E+00	1.10E-01	-9.78E-04	1.20E+00	1.20E+00	1.35E+00	-3.05E+01	<MDC	<MDC
Na	8	8	1.28E+04	9.94E+04	1.12E+03	-3.13E+00	2.09E+04	2.09E+04	N/A	N/A	N/A	N/A
Nd	8	0	N/A	N/A	3.40E-02	5.32E-03	<MDC	<MDC	1.65E-02	3.60E-01	<MDC	<MDC
Ni	8	7	1.01E+00	2.89E+00	1.90E-01	-9.44E-03	1.01E+00	1.01E+00	1.74E+00	1.14E+01	<MDC	<MDC
P	1	0	N/A	N/A	N/A	N/A	N/A	N/A	2.27E+01	-2.59E+02	<MDC	<MDC
Pb	8	8	1.63E-01	8.53E+00	3.50E-02	1.11E-02	6.02E-01	6.02E-01	3.16E-02	-7.17E+00	8.53E+00	1.36E+00
Pr	8	0	N/A	N/A	1.20E-02	6.91E-04	<MDC	<MDC	1.29E-02	-1.81E-01	<MDC	<MDC
Rh	2	1	1.10E-02	1.10E-02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sb	9	4	3.00E-02	1.99E-01	2.50E-02	-1.86E-04	3.00E-02	3.00E-02	1.02E-01	1.96E-01	<MDC	<MDC
Sc	6	6	1.72E+00	3.11E+00	8.20E-01	-2.93E-01	1.90E+00	1.90E+00	N/A	N/A	N/A	N/A
Se	8	3	9.25E-02	1.75E+00	1.90E+00	6.50E-01	<MDC	<MDC	N/A	N/A	N/A	N/A
Si	4	4	5.31E+03	1.68E+04	1.00E+03	-1.29E-01	5.31E+03	5.31E+03	7.32E+01	-1.01E+04	1.68E+04	6.77E+03
Sm	8	7	2.34E-02	3.64E-02	3.00E-02	-3.80E-03	3.24E-02	3.24E-02	1.62E-02	-2.01E-01	<MDC	<MDC
Sn	5	1	5.97E-02	5.97E-02	5.50E-02	-3.96E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Sr	9	9	3.23E+02	4.59E+02	1.80E-01	2.11E-02	3.54E+02	3.54E+02	2.51E-01	-1.19E-01	3.48E+02	3.48E+02
Th	8	1	1.98E-02	1.98E-02	5.40E-03	-6.30E-05	<MDC	<MDC	1.49E-02	6.30E-03	<MDC	<MDC
Ti	4	3	3.64E-01	4.22E+00	2.60E+00	-1.00E-01	4.22E+00	4.22E+00	N/A	N/A	N/A	N/A
Tl	8	8	9.97E-02	1.54E-01	1.20E-02	-2.21E-04	1.47E-01	1.47E-01	1.07E-02	2.05E-02	9.97E-02	9.97E-02
U	8	8	8.21E-01	8.79E-01	8.60E-03	-5.83E-04	8.79E-01	8.79E-01	7.76E-03	-9.50E-04	8.60E-01	8.60E-01
V	9	9	3.82E+00	5.90E+00	2.80E+00	3.16E-01	4.91E+00	4.91E+00	2.75E+00	-2.71E+00	4.53E+00	4.53E+00
Zn	9	9	2.36E+00	1.52E+01	7.40E-01	7.85E-02	2.36E+00	2.36E+00	7.92E-01	-3.37E+01	3.32E+00	3.32E+00

[1] El = Element analyzed;
[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3] Min = the lowest value measured above MDC; Max = the highest value measured;
[4] MDC = Minimum detectable concentration;
[5] Average sample values with and without subtraction of the blank value; when blank subtraction is performed, it is only done when the blank value falls outside of the range (–MDC < blank < +MDC)
[6] N/A = Not Applicable

Table 6-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2005 at Five Locations – continued

Double Eagle												
	1998-2005				2003				2005			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)
Ag	8	1	3.62E-03	3.62E-03	3.00E-02	-1.36E-03	<MDC	<MDC	2.30E-02	1.11E-01	<MDC	<MDC
Al	8	5	2.57E+00	7.22E+01	2.20E+00	-9.12E-01	<MDC	<MDC	1.49E+01	-2.80E+01	<MDC	<MDC
As	8	8	4.26E+00	7.80E+00	1.80E+00	-3.04E-01	4.43E+00	4.43E+00	2.01E+00	3.19E+01	7.80E+00	7.80E+00
B	1	1	7.00E+01	7.00E+01	3.40E+00	-1.23E+00	7.00E+01	7.00E+01	N/A	N/A	N/A	N/A
Ba	7	7	7.93E+01	1.26E+02	1.40E-01	-1.63E-02	8.30E+01	8.30E+01	1.24E-01	-5.63E+00	7.93E+01	7.93E+01
Be	7	1	3.63E-02	3.63E-02	8.00E-01	1.02E-02	<MDC	<MDC	N/A	N/A	N/A	N/A
Ca	7	7	5.18E+03	5.83E+04	2.40E+03	-1.47E+00	5.04E+04	5.04E+04	N/A	N/A	N/A	N/A
Cd	8	3	1.87E-02	1.85E-01	3.20E-02	-1.51E-02	<MDC	<MDC	6.73E-02	1.91E+00	<MDC	<MDC
Ce	6	2	3.18E-03	3.63E-03	1.20E-02	1.35E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Co	8	4	9.31E-02	1.12E+00	5.00E-02	-3.07E-04	<MDC	<MDC	7.21E-01	8.25E-01	<MDC	<MDC
Cr	8	8	1.22E+00	3.25E+01	5.60E-02	-8.89E-02	1.75E+00	1.66E+00	7.82E+00	9.24E+01	3.25E+01	3.25E+01
Cu	8	8	8.09E-01	4.84E+00	3.10E-01	4.75E-02	3.96E+00	3.96E+00	8.98E-02	3.68E+01	3.26E+00	3.26E+00
Dy	8	0	N/A	N/A	3.50E-02	3.30E-03	<MDC	<MDC	2.79E-02	-1.77E-01	<MDC	<MDC
Er	8	0	N/A	N/A	2.70E-02	-1.40E-03	<MDC	<MDC	1.21E-02	-5.61E-02	<MDC	<MDC
Eu	8	6	1.68E-02	2.86E-02	2.30E-02	-9.25E-04	<MDC	<MDC	1.64E-02	-1.04E-01	<MDC	<MDC
Fe	8	5	7.93E+01	9.32E+02	7.60E+00	-1.51E+01	8.69E+02	8.54E+02	2.94E+02	3.66E+03	9.32E+02	9.32E+02
Ga	1	1	4.46E+00	4.46E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gd	6	0	N/A	N/A	3.40E-02	-5.68E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
Hg	6	0	N/A	N/A	1.21E-02	9.60E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
K	7	7	2.51E+03	2.94E+04	4.40E+01	-1.16E+01	2.82E+03	2.82E+03	N/A	N/A	N/A	N/A
La	8	5	1.19E-02	6.26E-02	1.50E-02	-5.90E-04	<MDC	<MDC	1.36E-02	1.00E-01	<MDC	<MDC
Li	7	7	1.29E+01	1.90E+01	4.00E-01	-1.12E-02	1.41E+01	1.41E+01	N/A	N/A	N/A	N/A
Mg	7	7	1.09E+03	1.07E+04	1.20E+01	2.01E-01	8.79E+03	8.79E+03	5.97E+00	-8.94E+01	1.01E+04	1.01E+04
Mn	8	8	2.30E-01	6.04E+00	1.66E-01	1.65E-02	6.04E+00	6.04E+00	1.60E+00	1.97E+01	5.89E+00	5.89E+00
Mo	8	8	1.48E+00	6.70E+00	1.10E-01	-9.78E-04	2.13E+00	2.13E+00	1.35E+00	-3.05E+01	6.70E+00	6.70E+00
Na	7	7	3.84E+03	3.25E+04	1.12E+03	-3.13E+00	3.18E+04	3.18E+04	N/A	N/A	N/A	N/A
Nd	8	1	5.37E-03	5.37E-03	3.40E-02	5.32E-03	<MDC	<MDC	1.65E-02	3.60E-01	<MDC	<MDC
Ni	8	8	8.00E-01	4.03E+00	1.90E-01	-9.44E-03	8.00E-01	8.00E-01	1.74E+00	1.14E+01	4.03E+00	4.03E+00
P	1	0	N/A	N/A	N/A	N/A	N/A	N/A	2.27E+01	-2.59E+02	<MDC	<MDC
Pb	8	8	2.56E-01	7.70E+00	3.50E-02	1.11E-02	4.21E+00	4.21E+00	3.16E-02	-7.17E+00	7.70E+00	5.28E-01
Pr	8	1	9.05E-04	9.05E-04	1.20E-02	6.91E-04	<MDC	<MDC	1.29E-02	-1.81E-01	<MDC	<MDC
Rh	1	1	1.56E-02	1.56E-02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sb	8	5	2.41E-02	1.39E-01	2.50E-02	-1.86E-04	3.52E-02	3.52E-02	1.02E-01	1.96E-01	<MDC	<MDC
Sc	6	6	4.61E+00	9.08E+01	8.20E-01	-2.93E-01	6.55E+00	6.55E+00	2.68E-01	-8.94E+01	9.08E+01	1.40E+00
Se	7	4	2.28E+00	3.53E+00	1.90E+00	6.50E-01	3.37E+00	3.37E+00	N/A	N/A	N/A	N/A
Si	3	3	1.53E+04	2.64E+04	1.00E+03	-1.29E-01	1.53E+04	1.53E+04	7.32E+01	-1.01E+04	2.64E+04	1.64E+04
Sm	8	6	2.69E-02	4.26E-02	3.00E-02	-3.80E-03	<MDC	<MDC	1.62E-02	-2.01E-01	<MDC	<MDC
Sn	4	2	9.41E-02	3.36E-01	5.50E-02	-3.96E-03	9.41E-02	9.41E-02	N/A	N/A	N/A	N/A
Sr	8	8	5.06E+01	5.63E+02	1.80E-01	2.11E-02	5.28E+02	5.28E+02	2.51E-01	-1.19E-01	5.28E+02	5.28E+02
Th	8	3	4.32E-03	1.36E-02	5.40E-03	-6.30E-05	1.36E-02	1.36E-02	1.49E-02	6.30E-03	<MDC	<MDC
Ti	4	3	2.62E+00	2.87E+00	2.60E+00	-1.00E-01	2.62E+00	2.62E+00	N/A	N/A	N/A	N/A
Tl	7	2	2.73E-02	4.84E-02	1.20E-02	-2.21E-04	4.84E-02	4.84E-02	1.07E-02	2.05E-02	<MDC	<MDC
U	8	8	1.34E+00	1.99E+00	8.60E-03	-5.83E-04	1.49E+00	1.49E+00	7.76E-03	-9.50E-04	1.99E+00	1.99E+00
V	8	8	2.65E+01	3.26E+01	2.80E+00	3.16E-01	3.16E+01	3.16E+01	2.75E+00	-2.71E+00	3.01E+01	3.01E+01
Zn	8	8	1.80E+00	1.25E+01	7.40E-01	7.85E-02	6.77E+00	6.77E+00	7.92E-01	-3.37E+01	2.72E+00	2.72E+00

[1] El = Element analyzed;

[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;

[3] Min = the lowest value measured above MDC; Max = the highest value measured;

[4] MDC = Minimum detectable concentration;

[5] Average sample values with and without subtraction of the blank value; when blank subtraction is performed, it is only done when the blank value falls outside of the range (–MDC < blank < +MDC)

[6] N/A = Not Applicable

Table 6-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2005 at Five Locations – continued

Hobbs												
	1998-2005				2003				2005			
EL^1	N^2	N$_{DET}$^{2}	Min^3	Max^3	MDC^4 (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt^5 (ug/L)	Avg Conc. w/o Blank Subt^5 (ug/L)	MDC^4 (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt^5 (ug/L)	Avg Conc. w/o Blank Subt^5 (ug/L)
Ag	7	2	3.86E-03	1.04E-01	3.00E-02	-1.36E-03	<MDC	<MDC	2.30E-02	1.11E-01	<MDC	<MDC
Al	7	5	3.03E+00	1.14E+02	2.20E+00	-9.12E-01	6.36E+00	6.36E+00	1.49E+01	-2.80E+01	<MDC	<MDC
As	7	7	4.51E+00	7.37E+00	1.80E+00	-3.04E-01	4.51E+00	4.51E+00	2.01E+00	3.19E+01	6.78E+00	6.78E+00
B	1	1	1.41E+02	1.41E+02	3.40E+00	-1.23E+00	1.41E+02	1.41E+02	N/A	N/A	N/A	N/A
Ba	7	7	5.65E+01	6.06E+01	1.40E-01	-1.63E-02	5.88E+01	5.88E+01	1.24E-01	-5.63E+00	6.06E+01	6.06E+01
Be	6	1	5.39E-02	5.39E-02	8.00E-01	1.02E-02	<MDC	<MDC	N/A	N/A	N/A	N/A
Ca	6	6	8.09E+03	9.06E+04	2.40E+03	-1.47E+00	8.43E+04	8.43E+04	N/A	N/A	N/A	N/A
Cd	7	1	1.57E-01	1.57E-01	3.20E-02	-1.51E-02	<MDC	<MDC	6.73E-02	1.91E+00	<MDC	<MDC
Ce	6	4	5.10E-03	2.23E-02	1.20E-02	1.35E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Co	7	5	9.78E-02	3.61E-01	5.00E-02	-3.07E-04	<MDC	<MDC	7.21E-01	8.25E-01	<MDC	<MDC
Cr	7	7	7.33E-01	1.13E+01	5.60E-02	-8.89E-02	7.33E-01	6.44E-01	7.82E+00	9.24E+01	1.13E+01	1.13E+01
Cu	7	7	1.06E+00	6.93E+00	3.10E-01	4.75E-02	2.85E+00	2.85E+00	8.98E-02	3.68E+01	6.93E+00	6.93E+00
Dy	7	1	4.18E-03	4.18E-03	3.50E-02	3.30E-03	<MDC	<MDC	2.79E-02	-1.77E-01	<MDC	<MDC
Er	7	0	N/A	N/A	2.70E-02	-1.40E-03	<MDC	<MDC	1.21E-02	-5.61E-02	<MDC	<MDC
Eu	7	5	1.31E-02	1.97E-02	2.30E-02	-9.25E-04	<MDC	<MDC	1.64E-02	-1.04E-01	<MDC	<MDC
Fe	6	4	3.64E+01	4.44E+02	N/A	N/A	N/A	N/A	2.94E+02	3.66E+03	4.44E+02	4.44E+02
Ga	1	1	2.56E+00	2.56E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gd	6	0	N/A	N/A	3.40E-02	-5.68E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
Hg	5	2	1.06E-02	1.42E-02	1.21E-02	9.60E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
K	6	6	2.43E+03	2.53E+04	4.40E+01	-1.16E+01	2.43E+03	2.43E+03	N/A	N/A	N/A	N/A
La	7	4	1.51E-02	5.01E-02	1.50E-02	-5.90E-04	<MDC	<MDC	1.36E-02	1.00E-01	<MDC	<MDC
Li	6	6	2.65E+01	3.18E+01	4.00E-01	-1.12E-02	2.97E+01	2.97E+01	N/A	N/A	N/A	N/A
Mg	6	6	2.11E+03	2.08E+04	1.20E+01	2.01E-01	2.02E+04	2.02E+04	5.97E+00	-8.94E+01	2.08E+04	2.08E+04
Mn	7	7	3.79E-01	2.67E+00	1.66E-01	1.65E-02	4.20E-01	4.20E-01	1.60E+00	1.97E+01	2.67E+00	2.67E+00
Mo	7	7	2.60E+00	3.31E+00	1.10E-01	-9.78E-04	3.07E+00	3.07E+00	1.35E+00	-3.05E+01	3.31E+00	3.31E+00
Na	6	6	4.97E+03	4.83E+04	1.12E+03	-3.13E+00	4.29E+04	4.29E+04	N/A	N/A	N/A	N/A
Nd	7	3	3.01E-03	1.28E-02	3.40E-02	5.32E-03	<MDC	<MDC	1.65E-02	3.60E-01	<MDC	<MDC
Ni	7	7	1.08E+00	2.77E+00	1.90E-01	-9.44E-03	1.08E+00	1.08E+00	1.74E+00	1.14E+01	2.01E+00	2.01E+00
P	1	0	N/A	N/A	N/A	N/A	N/A	N/A	2.27E+01	-2.59E+02	<MDC	<MDC
Pb	7	7	9.44E-02	7.72E+00	3.50E-02	1.11E-02	2.45E-01	2.45E-01	3.16E-02	-7.17E+00	7.72E+00	5.50E-01
Pr	7	1	1.57E-03	1.57E-03	1.20E-02	6.91E-04	<MDC	<MDC	1.29E-02	-1.81E-01	<MDC	<MDC
Rh	1	1	2.52E-02	2.52E-02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sb	6	5	3.88E-02	7.02E-02	2.50E-02	-1.86E-04	6.66E-02	6.66E-02	1.02E-01	1.96E-01	<MDC	<MDC
Sc	5	5	7.17E+00	9.25E+01	8.20E-01	-2.93E-01	1.05E+01	1.05E+01	2.68E-01	-8.94E+01	9.25E+01	3.06E+00
Se	5	3	3.50E+00	6.23E+00	1.90E+00	6.50E-01	5.41E+00	5.41E+00	N/A	N/A	N/A	N/A
Si	3	3	2.54E+04	3.59E+04	1.00E+03	-1.29E-01	2.54E+04	2.54E+04	7.32E+01	-1.01E+04	3.59E+04	2.58E+04
Sm	7	6	1.93E-02	3.27E-02	3.00E-02	-3.80E-03	3.27E-02	3.27E-02	1.62E-02	-2.01E-01	<MDC	<MDC
Sn	3	0	N/A	N/A	5.50E-02	-3.96E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Sr	7	7	7.89E+01	1.04E+03	1.80E-01	2.11E-02	9.70E+02	9.70E+02	2.51E-01	-1.19E-01	9.92E+02	9.92E+02
Th	7	2	4.54E-03	4.56E-03	5.40E-03	-6.30E-05	<MDC	<MDC	1.49E-02	6.30E-03	<MDC	<MDC
Ti	3	3	3.14E+00	7.47E+00	2.60E+00	-1.00E-01	7.47E+00	7.47E+00	N/A	N/A	N/A	N/A
Tl	5	2	2.24E-02	2.31E-02	1.20E-02	-2.21E-04	2.31E-02	2.31E-02	1.07E-02	2.05E-02	<MDC	<MDC
U	7	7	2.90E+00	3.43E+00	8.60E-03	-5.83E-04	3.14E+00	3.14E+00	7.76E-03	-9.50E-04	3.43E+00	3.43E+00
V	7	7	3.30E+01	3.71E+01	2.80E+00	3.16E-01	3.45E+01	3.45E+01	2.75E+00	-2.71E+00	3.30E+01	3.30E+01
Zn	7	7	1.47E+00	4.37E+00	7.40E-01	7.85E-02	1.91E+00	1.91E+00	7.92E-01	-3.37E+01	2.31E+00	2.31E+00

[1] El = Element analyzed;

[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;

[3] Min = the lowest value measured above MDC; Max = the highest value measured;

[4] MDC = Minimum detectable concentration;

[5] Average sample values with and without subtraction of the blank value; when blank subtraction is performed, it is only done when the blank value falls outside of the range (–MDC < blank < +MDC)

[6] N/A = Not Applicable

Table 6-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2005 at Five Locations – continued

Loving												
	1998-2005				2003				2005			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)
Ag	9	3	2.55E-03	1.30E-01	1.50E-02	-1.36E-03	<MDC	<MDC	2.30E-02	1.11E-01	<MDC	<MDC
Al	8	2	3.76E+00	5.19E+01	2.20E+00	-9.12E-01	<MDC	<MDC	1.49E+01	-2.80E+01	<MDC	<MDC
As	8	6	1.20E+00	2.16E+00	1.80E+00	-3.04E-01	<MDC	<MDC	2.01E+00	3.19E+01	2.16E+00	2.16E+00
B	1	1	7.55E+01	7.55E+01	3.40E+00	-1.23E+00	7.55E+01	7.55E+01	N/A	N/A	N/A	N/A
Ba	8	8	2.86E+01	3.11E+01	1.40E-01	-1.63E-02	2.86E+01	2.86E+01	1.24E-01	-5.63E+00	3.06E+01	3.06E+01
Be	6	1	9.35E-02	9.35E-02	8.00E-01	1.02E-02	<MDC	<MDC	N/A	N/A	N/A	N/A
Ca	6	6	9.14E+03	1.04E+05	2.40E+03	-1.47E+00	9.08E+04	9.08E+04	N/A	N/A	N/A	N/A
Cd	8	0	N/A	N/A	3.20E-02	-1.51E-02	<MDC	<MDC	6.73E-02	1.91E+00	<MDC	<MDC
Ce	6	1	9.74E-04	9.74E-04	1.20E-02	1.35E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Co	8	5	1.02E-01	4.04E-01	5.00E-02	-3.07E-04	<MDC	<MDC	7.21E-01	8.25E-01	<MDC	<MDC
Cr	8	6	1.21E+00	7.44E+00	5.60E-02	-8.89E-02	1.21E+00	1.12E+00	7.82E+00	9.24E+01	<MDC	<MDC
Cu	8	8	1.71E+00	5.59E+00	3.10E-01	4.75E-02	4.45E+00	4.45E+00	8.98E-02	3.68E+01	1.71E+00	1.71E+00
Dy	8	0	N/A	N/A	3.50E-02	3.30E-03	<MDC	<MDC	2.79E-02	-1.77E-01	<MDC	<MDC
Er	8	0	N/A	N/A	2.70E-02	-1.40E-03	<MDC	<MDC	1.21E-02	-5.61E-02	<MDC	<MDC
Eu	8	5	7.00E-03	1.01E-02	2.30E-02	-9.25E-04	<MDC	<MDC	1.64E-02	-1.04E-01	<MDC	<MDC
Fe	8	3	1.56E+01	2.24E+02	7.60E+00	-1.51E+01	1.56E+01	<MDC	2.94E+02	3.66E+03	<MDC	<MDC
Ga	1	1	1.26E+00	1.26E+00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gd	6	2	2.15E-03	2.26E-03	3.40E-02	-5.68E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
Hg	4	0	N/A	N/A	1.21E-02	9.60E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
K	6	6	1.85E+03	1.98E+04	4.40E+01	-1.16E+01	1.85E+03	1.85E+03	N/A	N/A	N/A	N/A
La	8	4	7.27E-03	2.22E-02	1.50E-02	-5.90E-04	<MDC	<MDC	1.36E-02	1.00E-01	<MDC	<MDC
Li	6	6	1.66E+01	1.96E+01	4.00E-01	-1.12E-02	1.66E+01	1.66E+01	N/A	N/A	N/A	N/A
Mg	7	7	4.04E+03	4.02E+04	1.20E+01	2.01E-01	4.01E+04	4.01E+04	5.97E+00	-8.94E+01	3.53E+04	3.53E+04
Mn	8	6	1.43E-02	1.77E+00	1.66E-01	1.65E-02	<MDC	<MDC	1.60E+00	1.97E+01	1.77E+00	1.77E+00
Mo	8	6	1.41E+00	1.81E+00	1.10E-01	-9.78E-04	1.81E+00	1.81E+00	1.35E+00	-3.05E+01	<MDC	<MDC
Na	6	6	2.33E+03	2.29E+04	1.12E+03	-3.13E+00	2.01E+04	2.01E+04	N/A	N/A	N/A	N/A
Nd	8	1	3.37E-03	3.37E-03	3.40E-02	5.32E-03	<MDC	<MDC	1.65E-02	3.60E-01	<MDC	<MDC
Ni	8	6	1.19E+00	3.43E+00	1.90E-01	-9.44E-03	1.19E+00	1.19E+00	1.74E+00	1.14E+01	<MDC	<MDC
P	2	0	N/A	N/A	N/A	N/A	N/A	N/A	2.27E+01	-2.59E+02	<MDC	<MDC
Pb	8	8	6.33E-01	7.34E+00	3.50E-02	1.11E-02	6.33E-01	6.33E-01	3.16E-02	-7.17E+00	7.34E+00	1.71E-01
Pr	7	0	N/A	N/A	1.20E-02	6.91E-04	<MDC	<MDC	1.29E-02	-1.81E-01	<MDC	<MDC
Rh	1	1	3.07E-02	3.07E-02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sb	7	4	3.51E-02	1.84E-01	2.50E-02	-1.86E-04	5.56E-02	5.56E-02	1.02E-01	1.96E-01	<MDC	<MDC
Sc	6	6	3.22E+00	8.97E+01	8.20E-01	-2.93E-01	3.30E+00	3.30E+00	2.68E-01	-8.94E+01	8.96E+01	<MDC
Se	5	0	N/A	N/A	1.90E+00	6.50E-01	<MDC	<MDC	N/A	N/A	N/A	N/A
Si	4	4	8.54E+03	2.01E+04	1.00E+03	-1.29E-01	8.54E+03	8.54E+03	7.32E+01	-1.01E+04	1.99E+04	9.85E+03
Sm	8	3	8.43E-03	1.30E-02	3.00E-02	-3.80E-03	<MDC	<MDC	1.62E-02	-2.01E-01	<MDC	<MDC
Sn	4	1	4.45E-01	4.45E-01	5.50E-02	-3.96E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Sr	8	8	7.60E+01	9.37E+02	1.80E-01	2.11E-02	8.51E+02	8.51E+02	2.51E-01	-1.19E-01	8.07E+02	8.07E+02
Th	8	2	5.69E-03	9.63E-03	5.40E-03	-6.30E-05	<MDC	<MDC	1.49E-02	6.30E-03	<MDC	<MDC
Ti	3	3	2.68E+00	1.04E+01	2.60E+00	-1.00E-01	1.04E+01	1.04E+01	N/A	N/A	N/A	N/A
Tl	7	1	4.32E-02	4.32E-02	1.20E-02	-2.21E-04	<MDC	<MDC	1.07E-02	2.05E-02	<MDC	<MDC
U	8	8	1.98E+00	2.26E+00	8.60E-03	-5.83E-04	2.15E+00	2.15E+00	7.76E-03	-9.50E-04	2.10E+00	2.10E+00
V	8	8	1.19E+01	1.44E+01	2.80E+00	3.16E-01	1.19E+01	1.19E+01	2.75E+00	-2.71E+00	1.21E+01	1.21E+01
Zn	8	8	4.13E+00	2.09E+01	7.40E-01	7.85E-02	4.13E+00	4.13E+00	7.92E-01	-3.37E+01	2.01E+01	2.01E+01

[1] El = Element analyzed;
[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;
[3] Min = the lowest value measured above MDC; Max = the highest value measured;
[4] MDC = Minimum detectable concentration;
[5] Average sample values with and without subtraction of the blank value; when blank subtraction is performed, it is only done when the blank value falls outside of the range (–MDC < blank < +MDC)
[6] N/A = Not Applicable

Table 6-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2005 at Five Locations – continued

Otis												
	1998-2005				2003				2005			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)	MDC[4] (ug/L)	Blank Conc. (ug/L)	Avg Conc. w/Blank Subt[5] (ug/L)	Avg Conc. w/o Blank Subt[5] (ug/L)
Ag	7	1	2.63E-02	2.63E-02	3.00E-02	-1.36E-03	<MDC	<MDC	2.30E-02	1.11E-01	<MDC	<MDC
Al	7	1	5.74E+00	5.74E+00	2.20E+00	-9.12E-01	<MDC	<MDC	1.49E+01	-2.80E+01	<MDC	<MDC
As	8	4	6.53E-01	1.56E+00	3.60E+00	-3.04E-01	<MDC	<MDC	2.01E+00	3.19E+01	<MDC	<MDC
B	2	2	1.46E+02	1.52E+02	3.40E+00	-1.23E+00	1.46E+02	1.46E+02	N/A	N/A	N/A	N/A
Ba	8	8	1.35E+01	1.75E+01	1.40E-01	-1.63E-02	1.35E+01	1.35E+01	1.24E-01	-5.63E+00	1.44E+01	1.44E+01
Be	6	0	N/A	N/A	8.00E-01	1.02E-02	<MDC	<MDC	N/A	N/A	N/A	N/A
Ca	7	7	2.14E+05	3.83E+05	4.80E+04	-1.47E+00	2.58E+05	2.58E+05	N/A	N/A	N/A	N/A
Cd	7	0	N/A	N/A	3.20E-02	-1.51E-02	<MDC	<MDC	6.73E-02	1.91E+00	<MDC	<MDC
Ce	5	0	N/A	N/A	1.20E-02	1.35E-03	<MDC	<MDC	N/A	N/A	N/A	N/A
Co	7	6	1.19E-01	9.51E-01	5.00E-02	-3.07E-04	1.19E-01	1.19E-01	7.21E-01	8.25E-01	<MDC	<MDC
Cr	8	7	1.11E+00	6.67E+00	5.60E-02	-8.89E-02	1.28E+00	1.19E+00	7.82E+00	9.24E+01	<MDC	<MDC
Cu	8	7	2.43E+00	6.02E+00	3.10E-01	4.75E-02	2.80E+00	2.80E+00	8.98E-02	3.68E+01	2.43E+00	2.43E+00
Dy	7	1	3.39E-03	3.39E-03	3.50E-02	3.30E-03	<MDC	<MDC	2.79E-02	-1.77E-01	<MDC	<MDC
Er	7	0	N/A	N/A	2.70E-02	-1.40E-03	<MDC	<MDC	1.21E-02	-5.61E-02	<MDC	<MDC
Eu	7	3	3.42E-03	9.48E-03	2.30E-02	-9.25E-04	<MDC	<MDC	1.64E-02	-1.04E-01	<MDC	<MDC
Fe	8	8	2.87E+00	8.53E+02	7.60E+00	-1.51E+01	7.53E+01	6.02E+01	2.94E+02	3.66E+03	4.60E+02	4.60E+02
Ga	1	1	6.54E-01	6.54E-01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gd	5	0	N/A	N/A	3.40E-02	-5.68E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
Hg	6	0	N/A	N/A	1.21E-02	9.60E-04	<MDC	<MDC	N/A	N/A	N/A	N/A
K	7	7	2.75E+03	4.01E+03	4.40E+01	-1.16E+01	3.20E+03	3.20E+03	N/A	N/A	N/A	N/A
La	7	2	3.97E-03	6.30E-03	1.50E-02	-5.90E-04	<MDC	<MDC	1.36E-02	1.00E-01	<MDC	<MDC
Li	6	6	4.11E+01	4.85E+01	4.00E-01	-1.12E-02	4.30E+01	4.30E+01	N/A	N/A	N/A	N/A
Mg	7	7	5.16E+04	1.08E+05	1.20E+01	2.01E-01	9.04E+04	9.04E+04	5.97E+00	-8.94E+01	5.16E+04	5.16E+04
Mn	7	6	1.78E-01	2.32E+00	1.66E-01	1.65E-02	7.27E-01	7.27E-01	1.60E+00	1.97E+01	<MDC	<MDC
Mo	7	7	2.39E+00	3.13E+00	1.10E-01	-9.78E-04	2.47E+00	2.47E+00	1.35E+00	-3.05E+01	3.13E+00	3.13E+00
Na	7	7	7.83E+04	1.62E+05	1.12E+03	-3.13E+00	1.21E+05	1.21E+05	N/A	N/A	N/A	N/A
Nd	7	3	4.80E-03	3.97E-02	3.40E-02	5.32E-03	<MDC	<MDC	1.65E-02	3.60E-01	<MDC	<MDC
Ni	7	7	2.45E+00	1.06E+01	1.90E-01	-9.44E-03	2.45E+00	2.45E+00	1.74E+00	1.14E+01	2.62E+00	2.62E+00
P	1	1	4.54E+01	4.54E+01	N/A	N/A	N/A	N/A	2.27E+01	-2.59E+02	4.54E+01	4.54E+01
Pb	7	7	1.08E-01	7.20E+00	3.50E-02	1.11E-02	1.35E-01	1.35E-01	3.16E-02	-7.17E+00	7.20E+00	<MDC
Pr	7	0	N/A	N/A	1.20E-02	6.91E-04	<MDC	<MDC	1.29E-02	-1.81E-01	<MDC	<MDC
Rh	1	1	1.29E-01	1.29E-01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sb	7	5	3.50E-02	4.10E-01	2.50E-02	-1.86E-04	3.50E-02	3.50E-02	1.02E-01	1.96E-01	<MDC	<MDC
Sc	6	6	3.53E+00	8.95E+01	8.20E-01	-2.93E-01	5.12E+00	5.12E+00	2.68E-01	-8.94E+01	8.95E+01	<MDC
Se	7	0	N/A	N/A	3.80E+00	6.50E-01	<MDC	<MDC	N/A	N/A	N/A	N/A
Si	4	4	9.77E+03	1.99E+04	1.00E+03	-1.29E-01	9.77E+03	9.77E+03	7.32E+01	-1.01E+04	1.99E+04	9.83E+03
Sm	7	1	3.56E-03	3.56E-03	3.00E-02	-3.80E-03	<MDC	<MDC	1.62E-02	-2.01E-01	<MDC	<MDC
Sn	4	1	9.71E-02	9.71E-02	5.50E-02	-3.96E-03	9.71E-02	9.71E-02	N/A	N/A	N/A	N/A
Sr	8	8	2.38E+03	3.61E+03	1.80E-01	2.11E-02	3.13E+03	3.13E+03	2.51E-01	-1.19E-01	2.41E+03	2.41E+03
Th	7	2	3.44E-03	2.67E-02	5.40E-03	-6.30E-05	<MDC	<MDC	1.49E-02	6.30E-03	<MDC	<MDC
Ti	4	4	5.68E+00	3.79E+01	2.60E+00	-1.00E-01	3.64E+01	3.64E+01	N/A	N/A	N/A	N/A
Tl	6	0	N/A	N/A	1.20E-02	-2.21E-04	<MDC	<MDC	1.07E-02	2.05E-02	<MDC	<MDC
U	7	7	3.73E+00	5.34E+00	8.60E-03	-5.83E-04	3.86E+00	3.86E+00	7.76E-03	-9.50E-04	3.73E+00	3.73E+00
V	8	8	1.05E+01	1.29E+01	2.80E+00	3.16E-01	1.16E+01	1.16E+01	2.75E+00	-2.71E+00	1.05E+01	1.05E+01
Zn	8	8	1.54E+00	1.64E+01	7.40E-01	7.85E-02	2.05E+00	2.05E+00	7.92E-01	-3.37E+01	1.54E+00	1.54E+00

[1] El = Element analyzed;

[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;

[3] Min = the lowest value measured above MDC; Max = the highest value measured;

[4] MDC = Minimum detectable concentration;

[5] Average sample values with and without subtraction of the blank value; when blank subtraction is performed, it is only done when the blank value falls outside of the range (–MDC < blank < +MDC)

[6] N/A = Not Applicable

Table 6-3: Range of Concentrations for Baseline Inorganic Constituents in Surface Water Collected During 1999 to 2005 from Three Regional Reservoirs

Brantley Lake										
	Baseline[3]				Monitoring[3]				2005	
EL[1]	N[2]	N_{DET}[2]	Minimum Detected (µg/L)	Maximum Detected (µg/L)	N[2]	N_{DET}[2]	Minimum Detected (µg/L)	Maximum Detected (µg/L)	Avg. Sample Conc. (µg/L)	Avg. MDC (µg/L)
Ag	6	1	1.03E-02	1.03E-02	5	0	N/A	N/A	<MDC	2.30E-02
Al	6	6	4.25E+01	1.20E+03	5	4	4.63E+01	4.14E+02	6.91E+01	1.49E+01
As	6	6	1.13E+00	5.21E+00	5	2	2.68E+00	2.71E+00	2.69E+00	2.01E+00
Ba	6	6	4.41E+01	7.45E+01	5	5	4.71E+01	6.44E+01	6.28E+01	1.24E-01
Be	6	3	2.46E-02	6.61E-02	5	2	1.29E-01	1.43E-01	1.36E-01	3.50E-02
Ca	6	6	3.47E+05	6.95E+05	3	3	4.54E+05	5.15E+05	N/A	N/A
Cd	6	3	7.37E-02	7.70E-02	5	0	N/A	N/A	<MDC	6.73E-02
Ce	6	6	8.07E-02	1.15E+00	5	5	5.71E-02	3.46E-01	1.03E-01	1.75E-02
Co	6	6	1.81E+00	8.01E+00	5	3	9.72E-01	2.32E+00	<MDC	7.21E-01
Cr	6	6	3.17E-01	2.41E+00	5	0	N/A	N/A	<MDC	7.82E+00
Cu	6	6	4.69E+00	8.07E+00	5	2	3.10E+00	3.56E+00	3.33E+00	8.98E-01
Dy	6	6	5.79E-03	9.01E-02	5	2	2.88E-02	2.97E-02	<MDC	2.79E-02
Er	6	4	3.52E-03	4.66E-02	5	0	N/A	N/A	<MDC	1.21E-02
Eu	6	6	1.55E-02	4.79E-02	5	1	3.16E-02	3.16E-02	<MDC	1.64E-02
Fe	6	6	5.30E+01	8.56E+02	5	5	2.75E+02	6.71E+02	5.37E+02	2.94E+02
Gd	6	6	7.34E-03	1.37E-01	5	0	N/A	N/A	<MDC	1.91E-02
Hg	6	2	3.60E-03	5.61E-03	3	1	1.77E-01	1.77E-01	N/A	N/A
K	6	6	6.61E+03	1.63E+04	5	5	4.59E+03	6.92E+03	6.84E+03	3.88E+01
La	6	4	5.32E-02	4.80E-01	5	2	3.38E-02	6.49E-02	4.93E-02	1.36E-02
Li	6	6	3.89E+01	8.88E+01	3	3	4.21E+01	6.34E+01	N/A	N/A
Mg	6	6	9.31E+04	2.26E+05	5	5	9.23E+04	1.46E+05	9.48E+04	5.93E+00
Mn	6	5	8.98E+00	9.45E+02	5	5	1.80E+01	6.97E+02	6.80E+01	1.60E+00
Mo	6	6	2.41E+00	3.83E+00	5	5	2.98E+00	3.94E+00	3.65E+00	1.35E+00
Na	6	6	3.68E+05	1.21E+06	3	3	3.50E+05	7.34E+05	N/A	N/A
Nd	6	6	3.73E-02	5.69E-01	5	2	3.34E-02	4.69E-02	4.02E-02	1.65E-02
Ni	6	6	3.65E+00	3.28E+01	5	5	6.92E+00	1.93E+01	7.64E+00	1.74E+00
Pb	6	4	2.88E-01	9.14E-01	5	2	6.76E-01	9.71E-01	8.24E-01	3.16E-02
Pr	6	4	1.08E-02	1.39E-01	5	1	2.30E-02	2.30E-02	1.61E-02	1.29E-02
Sb	6	4	2.01E-01	3.01E-01	5	2	2.64E-01	2.72E-01	2.68E-01	1.02E-01
Se	6	0	N/A	N/A	2	0	N/A	N/A	N/A	N/A
Sm	6	3	2.93E-02	1.69E-01	5	2	2.00E-02	3.82E-02	2.91E-02	1.62E-02
Sr	6	6	5.00E+03	1.15E+04	5	5	6.12E+03	7.55E+03	6.16E+03	2.51E-01
Th	6	5	1.67E-02	1.91E-01	5	2	2.75E-02	7.45E-02	5.10E-02	1.49E-02
Tl	6	1	4.81E-02	4.81E-02	5	0	N/A	N/A	<MDC	1.07E-02
U	6	6	3.42E+00	8.46E+00	5	5	3.61E+00	4.75E+00	4.71E+00	7.76E-03
V	6	6	5.13E+00	7.33E+00	5	5	3.47E+00	5.31E+00	4.93E+00	2.75E+00
Zn	6	6	5.03E+00	1.71E+01	3	0	N/A	N/A	N/A	N/A

[1] El = Element analyzed;

[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;

[3] The baseline period is represented by two sampling events in 1999 and 2000. The monitoring period is represented by two sampling events in 2001 and 2005

Table 6-3: Range of Concentrations for Baseline Inorganic Constituents in Surface Water Collected During 1999 to 2005 from Three Regional Reservoirs – cont.

Lake Carlsbad										
	Baseline[3]				Monitoring[3]				2005	
EL[1]	N[2]	N_{DET}[2]	Minimum Detected (µg/L)	Maximum Detected (µg/L)	N[2]	N_{DET}[2]	Minimum Detected (µg/L)	Maximum Detected (µg/L)	Avg. Sample Conc. (µg/L)	Avg. MDC (µg/L)
Ag	4	0	N/A	N/A	4	0	N/A	N/A	<MDC	2.30E-02
Al	4	4	5.70E+01	2.15E+02	4	4	7.85E+01	5.03E+02	8.14E+01	1.49E+01
As	4	4	1.23E+00	2.37E+00	4	0	N/A	N/A	<MDC	2.01E+00
Ba	4	4	1.86E+01	3.30E+01	4	4	2.08E+01	3.00E+01	2.13E+01	1.24E-01
Be	4	2	3.26E-02	4.90E-02	4	2	8.05E-02	1.47E-01	1.14E-01	3.50E-02
Ca	4	4	3.04E+05	4.19E+05	2	2	3.29E+05	3.32E+05	N/A	N/A
Cd	4	1	1.60E-01	1.60E-01	4	0	N/A	N/A	<MDC	6.73E-02
Ce	4	4	8.08E-02	4.16E-01	4	4	1.15E-01	4.87E-01	1.20E-01	1.75E-02
Co	4	4	1.67E+00	5.22E+00	4	2	9.28E-01	1.00E+00	<MDC	7.21E-01
Cr	4	4	3.02E-01	2.19E+00	4	0	N/A	N/A	<MDC	7.82E+00
Cu	4	4	3.88E+00	1.13E+01	4	2	3.46E+00	3.92E+00	3.69E+00	8.98E-01
Dy	4	3	6.67E-03	3.51E-02	4	1	3.28E-02	3.28E-02	<MDC	2.79E-02
Er	4	4	1.17E-03	1.51E-02	4	0	N/A	N/A	<MDC	1.21E-02
Eu	4	4	6.54E-03	1.81E-02	4	0	N/A	N/A	<MDC	1.64E-02
Fe	4	4	7.60E+01	3.96E+03	4	4	4.07E+02	6.32E+02	5.79E+02	2.94E+02
Gd	4	4	9.10E-03	4.84E-02	4	0	N/A	N/A	<MDC	1.91E-02
Hg	4	0	N/A	N/A	2	1	2.82E-02	2.82E-02	N/A	N/A
K	4	4	5.26E+03	1.24E+04	4	4	4.96E+03	5.82E+03	5.13E+03	3.88E+01
La	4	2	4.29E-02	2.21E-01	4	2	5.29E-02	6.12E-02	5.71E-02	1.36E-02
Li	4	4	4.33E+01	7.75E+01	2	2	5.01E+01	5.03E+01	N/A	N/A
Mg	4	4	1.09E+05	1.51E+05	4	4	1.04E+05	1.23E+05	1.14E+05	5.93E+00
Mn	4	3	1.92E+01	6.65E+01	4	4	8.47E+00	2.97E+01	9.18E+00	1.60E+00
Mo	4	4	2.65E+00	3.37E+00	4	4	2.69E+00	3.64E+00	2.93E+00	1.35E+00
Na	4	4	3.38E+05	5.06E+05	2	2	3.58E+05	3.67E+05	N/A	N/A
Nd	4	4	3.79E-02	2.31E-01	4	2	6.37E-02	8.34E-02	7.35E-02	1.65E-02
Ni	4	4	2.33E+00	2.29E+01	4	4	7.27E+00	1.37E+01	7.77E+00	1.74E+00
Pb	4	3	6.38E-01	2.65E+00	4	3	8.06E-01	2.42E+00	8.42E-01	3.16E-02
Pr	4	2	1.11E-02	5.66E-02	4	2	1.92E-02	5.29E-02	1.38E-02	1.29E-02
Sb	4	0	N/A	N/A	4	1	1.17E-01	1.17E-01	<MDC	1.02E-01
Se	4	1	5.54E-01	5.54E-01	2	0	N/A	N/A	N/A	N/A
Sm	4	2	1.51E-02	5.94E-02	4	1	1.63E-02	1.63E-02	<MDC	1.62E-02
Sr	4	4	4.16E+03	6.15E+03	4	4	4.36E+03	5.37E+03	5.03E+03	2.51E-01
Th	4	4	9.10E-03	5.40E-02	4	3	1.55E-02	5.79E-02	2.37E-02	1.49E-02
Tl	4	2	1.20E-01	1.36E-01	4	2	1.32E-01	1.65E-01	1.49E-01	1.07E-02
U	4	4	3.78E+00	9.17E+00	4	4	4.40E+00	6.06E+00	5.27E+00	7.76E-03
V	4	4	6.13E+00	9.31E+00	4	4	6.19E+00	8.68E+00	6.36E+00	2.75E+00
Zn	4	4	5.93E+00	2.08E+01	2	0	N/A	N/A	N/A	N/A

[1] El = Element analyzed;

[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;

[3] The baseline period is represented by two sampling events in 1999 and 2000. The monitoring period is represented by two sampling events in 2001 and 2005

Table 6-3: Range of Concentrations for Baseline Inorganic Constituents in Surface Water Collected During 1999 to 2005 from Three Regional Reservoirs – cont.

Red Bluff Reservoir										
	Baseline^3				Monitoring^3				2005	
EL^1	N^2	N_{DET}^2	Minimum Detected (µg/L)	Maximum Detected (µg/L)	N^2	N_{DET}^2	Minimum Detected (µg/L)	Maximum Detected (µg/L)	Avg. Sample Conc. (µg/L)	Avg. MDC (µg/L)
Ag	4	0	N/A	N/A	6	0	N/A	N/A	<MDC	2.30E-02
Al	4	3	1.65E+01	6.54E+01	6	6	5.70E+01	3.96E+02	6.84E+01	1.49E+01
As	4	4	1.96E+00	4.97E+00	6	4	4.63E+00	5.00E+00	4.78E+00	2.01E+00
Ba	4	4	6.43E+01	9.58E+01	6	6	6.83E+01	9.82E+01	9.45E+01	1.24E-01
Be	4	3	1.83E-02	5.14E-02	6	4	1.77E-01	2.68E-01	2.04E-01	3.50E-02
Ca	4	4	4.19E+05	6.18E+05	2	2	6.37E+05	6.64E+05	N/A	N/A
Cd	4	1	6.59E-02	6.59E-02	6	2	4.11E-01	1.04E+00	<MDC	6.73E-02
Ce	4	4	3.93E-02	9.78E-02	6	6	8.85E-02	5.71E-01	1.10E-01	1.75E-02
Co	4	4	1.42E+00	6.01E+00	6	6	8.16E-01	2.05E+00	8.30E-01	7.21E-01
Cr	4	3	2.36E-01	2.24E+00	6	1	1.70E+01	1.70E+01	<MDC	7.82E+00
Cu	4	4	6.73E+00	8.70E+00	6	4	7.22E+00	8.87E+00	8.20E+00	8.98E-01
Dy	4	2	2.99E-03	3.50E-03	6	2	3.66E-02	4.24E-02	<MDC	2.79E-02
Er	4	3	2.08E-03	8.34E-03	6	1	1.35E-02	1.35E-02	<MDC	1.21E-02
Eu	4	2	2.36E-02	3.43E-02	6	6	2.53E-02	6.86E-02	3.00E-02	1.64E-02
Fe	4	4	3.38E+01	8.24E+01	6	6	3.31E+02	1.40E+03	1.32E+03	2.94E+02
Gd	4	2	1.44E-02	1.51E-02	6	3	2.03E-02	8.33E-02	<MDC	1.91E-02
Hg	4	2	2.36E-03	2.72E-03	2	0	N/A	N/A	N/A	N/A
K	4	4	1.92E+04	3.63E+04	6	6	3.19E+04	3.57E+04	3.52E+04	3.88E+01
La	4	2	3.51E-02	4.68E-02	6	5	3.95E-02	4.47E-01	6.70E-02	1.36E-02
Li	3	3	6.77E+01	9.48E+01	2	2	1.16E+02	1.23E+02	N/A	N/A
Mg	4	4	1.24E+05	2.25E+05	6	6	1.77E+05	2.49E+05	1.81E+05	5.93E+00
Mn	4	4	3.85E+01	2.97E+02	6	6	5.59E+01	9.84E+01	6.07E+01	1.60E+00
Mo	4	4	3.00E+00	4.92E+00	6	6	3.44E+00	5.82E+00	3.74E+00	1.35E+00
Na	4	4	7.21E+05	1.36E+06	2	2	1.32E+06	1.34E+06	N/A	N/A
Nd	4	2	2.06E-02	3.12E-02	6	4	3.71E-02	6.47E-02	5.46E-02	1.65E-02
Ni	4	4	1.35E+01	2.84E+01	6	6	1.24E+01	2.23E+01	1.48E+01	1.74E+00
Pb	4	3	7.76E-01	1.28E+00	6	4	2.51E-01	5.08E-01	3.58E-01	3.16E-02
Pr	4	2	7.11E-03	8.10E-03	6	4	1.30E-02	7.55E-02	1.44E-02	1.29E-02
Sb	4	4	2.47E-01	4.83E-01	6	6	3.35E-01	4.39E-01	4.05E-01	1.02E-01
Se	4	0	N/A	N/A	2	0	N/A	N/A	N/A	N/A
Sm	4	2	3.11E-02	3.80E-02	6	4	3.94E-02	5.20E-02	4.51E-02	1.62E-02
Sr	4	4	5.76E+03	9.49E+03	6	6	7.23E+03	9.83E+03	7.30E+03	2.51E-01
Th	4	4	4.68E-03	1.72E-02	6	3	2.82E-02	7.90E-02	2.88E-02	1.49E-02
Tl	4	0	N/A	N/A	6	0	N/A	N/A	<MDC	1.07E-02
U	4	4	4.70E+00	9.51E+00	6	6	5.08E+00	8.17E+00	5.14E+00	7.76E-03
V	4	4	2.48E+00	4.91E+00	6	6	3.92E+00	5.27E+00	4.20E+00	2.75E+00
Zn	4	3	6.21E+00	1.09E+01	2	0	N/A	N/A	N/A	N/A

[1] El = Element analyzed;

[2] N = Total number of samples analyzed; N_{det} = number of samples with detectable (above MDC) values;

[3] The baseline period is represented by two sampling events in 1999 and 2000. The monitoring period is represented by two sampling events in 2001 and 2005

Table 6-4: Comparison of Inorganic Analyte Concentrations in Shallow vs. Deep Surface Water from 1998 to 2005

Brantley Lake

	Shallow[1]				Deep[1]				MDC[2]		Significant[3]
EL[1]	Average Conc. µg/L	Conc. Std. Dev.	N[2]	N_{DET}[2]	Average Conc. µg/L	Conc. Std. Dev.	N[2]	N_{DET}[2]	Average ’98-’05 µg/L	MDC Std. Dev.	
Ag	<MDC	N/A	5	0	1.03E-02	N/A	5	1	6.50E-02	7.83E-02	No
Al	1.55E+02	1.36E+02	6	6	3.91E+02	4.84E+02	6	5	4.92E+01	3.81E+01	No
As	1.67E+00	7.11E-01	6	4	3.09E+00	1.46E+00	6	4	1.36E+00	1.41E+00	No
B	2.09E+02	N/A	1	1	2.18E+02	N/A	1	1	1.89E+00	0.00E+00	N/A
Ba	5.15E+01	8.80E+00	6	6	6.81E+01	5.49E+00	6	5	4.25E-01	3.24E-01	No
Be	8.18E-02	5.47E-02	6	3	7.68E-02	7.39E-02	6	2	3.36E-01	5.04E-01	No
Bi	<MDC	N/A	1	0	<MDC	N/A	1	0	9.60E-02	0.00E+00	N/A
Ca	4.19E+05	4.45E+04	5	5	5.83E+05	9.21E+04	4	4	7.26E+03	4.20E+03	Yes
Cd	7.53E-02	2.36E-03	6	2	7.40E-02	N/A	6	1	1.12E-01	7.67E-02	No
Ce	1.39E-01	1.05E-01	6	6	4.26E-01	4.29E-01	6	5	3.36E-02	1.76E-02	No
Co	2.67E+00	1.41E+00	6	5	4.82E+00	3.07E+00	6	4	2.72E-01	2.90E-01	No
Cr	8.76E-01	4.99E-01	6	3	1.91E+00	9.31E-01	6	4	4.39E+00	4.92E+00	No
Cu	5.12E+00	1.63E+00	6	4	6.25E+00	2.11E+00	6	4	3.49E+00	4.62E+00	No
Dy	1.33E-02	1.05E-02	6	4	3.47E-02	3.21E-02	6	5	1.50E-02	1.15E-02	No
Er	3.52E-03	N/A	6	1	2.69E-02	1.76E-02	6	3	1.14E-02	1.05E-02	No
Eu	1.63E-02	1.10E-03	6	3	3.37E-02	1.08E-02	6	4	1.37E-02	9.77E-03	No
Fe	2.06E+02	1.42E+02	6	6	5.04E+02	2.58E+02	6	5	8.00E+01	1.08E+02	No
Gd	1.15E-02	3.59E-03	6	3	7.54E-02	5.44E-02	6	3	1.33E-02	1.03E-02	No
Hg	1.77E-01	N/A	5	1	4.61E-03	1.42E-03	5	2	6.80E-03	4.13E-03	No
K	7.66E+03	3.24E+03	6	6	8.80E+03	6.02E+03	6	6	1.37E+03	1.39E+03	No
La	4.35E-02	1.37E-02	6	2	2.16E-01	1.82E-01	6	4	1.10E-01	1.18E-01	No
Li	4.12E+01	2.06E+00	5	5	7.46E+01	1.11E+01	5	4	5.66E+00	1.10E+01	No
Mg	9.49E+04	4.26E+03	6	6	1.39E+05	8.14E+04	6	6	6.03E+02	5.08E+02	No
Mn	2.27E+01	2.08E+01	6	5	6.25E+02	3.26E+02	6	5	7.36E+00	1.08E+01	Yes
Mo	3.70E+00	2.44E-01	6	6	2.70E+00	1.27E+00	6	6	3.63E-01	4.82E-01	No
Na	3.89E+05	6.52E+04	5	5	7.81E+05	4.73E+05	5	5	4.17E+03	3.24E+03	No
Nd	4.96E-02	1.74E-02	6	4	2.48E-01	2.25E-01	6	4	9.87E-02	1.16E-01	No
Ni	1.38E+01	6.79E+00	6	6	1.91E+01	1.20E+01	6	5	3.64E+00	4.53E+00	No
P	1.48E+02	N/A	1	1	1.27E+02	N/A	1	1	2.27E+01	0.00E+00	N/A
Pb	5.59E-01	3.63E-01	6	3	7.56E-01	1.37E-01	6	3	5.24E-01	4.70E-01	No
Pr	1.08E-02	N/A	6	1	6.43E-02	5.19E-02	6	4	2.81E-02	2.14E-02	No
Sb	2.58E-01	5.13E-02	6	3	2.43E-01	2.82E-02	5	4	1.27E-01	3.85E-02	No
Sc	1.00E+00	9.50E-02	2	2	1.56E+00	N/A	1	1	5.56E-01	0.00E+00	N/A
Se	<MDC	N/A	4	0	<MDC	N/A	5	0	3.55E+00	2.22E+00	No
Si	<MDC	N/A	2	0	3.01E+03	N/A	1	1	2.78E+03	0.00E+00	N/A
Sm	2.47E-02	6.57E-03	6	2	8.79E-02	7.07E-02	6	3	7.25E-02	5.50E-02	No
Sr	6.03E+03	5.18E+02	6	6	7.13E+03	4.01E+03	6	6	4.93E+01	3.95E+01	No
Th	4.05E-02	2.95E-02	6	3	8.04E-02	7.97E-02	6	4	1.24E-02	1.00E-02	No
Ti	<MDC	N/A	2	0	<MDC	N/A	2	0	8.89E+00	4.44E+00	No
Tl	<MDC	N/A	6	0	4.81E-02	N/A	6	1	6.88E-01	1.53E+00	No
U	4.41E+00	8.57E-01	6	6	5.83E+00	2.19E+00	6	5	9.97E-03	1.10E-02	No
V	5.38E+00	4.18E-01	6	6	5.27E+00	1.37E+00	5	5	9.93E-01	1.04E+00	No
Zn	9.69E+00	4.24E+00	5	3	1.29E+01	3.64E+00	4	3	1.23E+01	1.22E+01	No

[1]”Shallow” refers to water collected approximately 0.5m below the surface of the body of water; “Deep” refers to water collected 1.0m above the bottom.

[2]MDC: Minimum Detectable Concentration; determined yearly for each analytical instrument

[3]Significance was determined with Student’s t-test, 95% confidence interval. Instrument-estimated values below the MDC were included.

[4]”N samp” = Number of samples analyzed

[5]”N det” = Number of samples with detectable values (above the MDC)

[6]”Average Conc” = the average concentration for samples *above* the MDC

[7]”N/A” = Not Applicable

Table 6-4: Comparison of Inorganic Analyte Concentrations in Shallow vs. Deep Surface Water from 1998 to 2005 - continued

Lake Carlsbad											
	Shallow[1]				Deep[1]				MDC[2]		Significant[3]
EL[1]	Average Conc. µg/L	Conc. Std. Dev.	N[2]	N_{DET}[2]	Average Conc. µg/L	Conc. Std. Dev.	N[2]	N_{DET}[2]	Average ’98-’05 µg/L	MDC Std. Dev.	
Ag	<MDC	N/A	4	0	<MDC	N/A	2	0	6.98E-02	8.39E-02	No
Al	1.33E+02	8.83E+01	5	5	3.10E+02	1.67E+02	3	3	4.51E+01	4.12E+01	No
As	1.53E+00	4.17E-01	5	2	1.85E+00	7.32E-01	3	2	1.28E+00	1.36E+00	No
B	2.11E+02	2.01E+01	2	2	<MDC	N/A	0	0	1.89E+00	0.00E+00	N/A
Ba	2.29E+01	3.68E+00	5	5	2.98E+01	3.32E+00	3	3	4.09E-01	3.41E-01	Yes
Be	9.23E-02	5.03E-02	5	3	3.26E-02	N/A	3	1	3.17E-01	5.25E-01	No
Bi	<MDC	N/A	2	0	<MDC	N/A	0	0	9.60E-02	0.00E+00	N/A
Ca	3.51E+05	6.08E+04	3	3	3.60E+05	4.64E+04	3	3	6.31E+03	4.95E+03	No
Cd	<MDC	N/A	5	0	1.60E-01	N/A	3	1	1.30E-01	8.00E-02	No
Ce	1.38E-01	5.23E-02	5	5	3.70E-01	1.45E-01	3	3	2.95E-02	1.74E-02	Yes
Co	2.45E+00	1.96E+00	5	3	2.99E+00	2.15E+00	3	3	3.21E-01	3.21E-01	No
Cr	8.09E-01	7.17E-01	5	2	1.63E+00	7.86E-01	3	2	4.85E+00	5.09E+00	No
Cu	4.44E+00	1.40E+00	5	4	9.61E+00	2.43E+00	3	2	3.38E+00	4.77E+00	No
Dy	7.60E-03	1.32E-03	5	2	3.40E-02	1.62E-03	3	2	1.64E-02	1.25E-02	No
Er	5.18E-03	5.68E-03	5	2	1.36E-02	2.09E-03	3	2	1.15E-02	1.09E-02	No
Eu	9.80E-03	4.61E-03	5	2	1.54E-02	3.83E-03	3	2	1.38E-02	1.04E-02	No
Fe	3.55E+02	2.42E+02	5	5	1.53E+03	2.10E+03	3	3	1.04E+02	1.24E+02	No
Gd	1.41E-02	7.06E-03	5	2	3.41E-02	2.02E-02	3	2	1.40E-02	1.08E-02	No
Hg	<MDC	N/A	3	0	2.82E-02	N/A	3	1	7.33E-03	4.13E-03	No
K	6.75E+03	3.19E+03	5	5	7.55E+03	2.71E+03	3	3	1.41E+03	1.46E+03	No
La	5.24E-02	9.18E-03	5	3	2.21E-01	N/A	3	1	1.00E-01	1.27E-01	No
Li	5.22E+01	1.00E+01	3	3	6.26E+01	1.38E+01	3	3	9.20E+00	1.34E+01	No
Mg	1.18E+05	1.68E+04	5	5	1.36E+05	1.99E+04	3	3	5.86E+02	5.02E+02	No
Mn	1.60E+01	8.43E+00	5	4	3.89E+01	2.43E+01	3	3	7.83E+00	1.28E+01	No
Mo	3.05E+00	3.56E-01	5	5	3.22E+00	5.12E-01	3	3	4.61E-01	5.68E-01	No
Na	4.04E+05	8.97E+04	3	3	4.35E+05	7.05E+04	3	3	5.23E+03	3.60E+03	No
Nd	6.89E-02	2.35E-02	5	4	1.64E-01	9.50E-02	3	2	9.14E-02	1.23E-01	No
Ni	1.01E+01	6.35E+00	5	5	1.38E+01	8.66E+00	3	3	3.61E+00	4.65E+00	No
P	8.82E+01	6.61E+00	2	2	<MDC	N/A	0	0	2.27E+01	0.00E+00	N/A
Pb	1.18E+00	8.28E-01	5	4	2.00E+00	9.18E-01	3	2	5.72E-01	5.01E-01	No
Pr	1.52E-02	5.74E-03	5	2	5.48E-02	2.64E-03	3	2	2.44E-02	2.09E-02	Yes
Sb	1.17E-01	N/A	4	1	<MDC	N/A	2	0	1.32E-01	2.45E-02	No
Sc	4.72E+00	N/A	1	1	4.42E+00	N/A	1	1	5.56E-01	0.00E+00	N/A
Se	<MDC	N/A	3	0	5.54E-01	N/A	3	1	2.95E+00	2.39E+00	No
Si	7.15E+03	N/A	1	1	7.68E+03	N/A	1	1	2.78E+03	0.00E+00	N/A
Sm	1.57E-02	8.84E-04	5	2	5.94E-02	N/A	3	1	6.32E-02	5.98E-02	Yes
Sr	4.97E+03	7.96E+02	5	5	5.49E+03	9.84E+02	3	3	4.67E+01	4.10E+01	No
Th	2.09E-02	1.04E-02	5	4	4.93E-02	1.18E-02	3	3	1.29E-02	1.03E-02	Yes
Ti	<MDC	N/A	1	0	1.40E+01	N/A	1	1	1.11E+01	0.00E+00	N/A
Tl	1.39E-01	2.34E-02	5	3	1.36E-01	N/A	3	1	1.02E+00	1.82E+00	No
U	5.28E+00	1.50E+00	5	5	6.94E+00	2.40E+00	3	3	9.96E-03	1.13E-02	No
V	7.29E+00	1.39E+00	5	5	8.54E+00	6.67E-01	3	3	1.15E+00	1.13E+00	No
Zn	9.70E+00	5.33E+00	3	2	1.72E+01	5.05E+00	3	2	1.33E+01	1.19E+01	No

[1]”Shallow” refers to water collected approximately 0.5m below the surface of the body of water; “Deep” refers to water collected 1.0m above the bottom.

[2]MDC: Minimum Detectable Concentration; determined yearly for each analytical instrument

[3]Significance was determined with Student’s t-test, 95% confidence interval. Instrument-estimated values below the MDC were included.

[4]”N samp” = Number of samples analyzed

[5]”N det” = Number of samples with detectable values (above the MDC)

[6]”Average Conc” = the average concentration for samples *above* the MDC

[7]”N/A” = Not Applicable

Table 6-4: Comparison of Inorganic Analyte Concentrations in Shallow vs. Deep Surface Water from 1998 to 2005 - continued

Red Bluff Reservoir

	Shallow[1]				Deep[1]				MDC[2]		Significant[3]
EL[1]	Average Conc. µg/L	Conc. Std. Dev.	N[2]	N_{DET}[2]	Average Conc. µg/L	Conc. Std. Dev.	N[2]	N_{DET}[2]	Average '98-'05 µg/L	MDC Std. Dev.	
Ag	<MDC	N/A	6	0	<MDC	N/A	4	0	5.43E-02	6.59E-02	No
Al	1.29E+02	1.41E+02	6	6	5.77E+01	3.36E+01	4	3	3.91E+01	3.85E+01	No
As	3.57E+00	1.39E+00	5	4	4.36E+00	1.04E+00	4	4	1.25E+00	1.18E+00	No
B	3.71E+02	1.09E+00	2	2	3.75E+02	9.20E-01	2	2	1.89E+00	0.00E+00	No
Ba	7.80E+01	1.13E+01	6	6	8.83E+01	1.61E+01	4	4	3.52E-01	3.24E-01	No
Be	1.29E-01	8.36E-02	6	3	1.33E-01	1.18E-01	4	4	2.60E-01	4.78E-01	No
Bi	<MDC	N/A	2	0	3.38E-01	N/A	2	1	9.60E-02	0.00E+00	No
Ca	5.85E+05	1.12E+05	4	4	5.47E+05	7.15E+04	2	2	8.75E+03	1.35E+03	No
Cd	7.28E-01	4.48E-01	6	2	6.59E-02	N/A	4	1	1.18E-01	7.54E-02	No
Ce	1.94E-01	2.01E-01	6	6	9.78E-02	3.51E-02	4	4	2.71E-02	1.62E-02	No
Co	2.08E+00	1.98E+00	6	6	2.33E+00	2.33E+00	4	4	4.01E-01	3.29E-01	No
Cr	9.61E+00	1.04E+01	6	2	1.05E+00	1.15E+00	4	2	5.45E+00	4.66E+00	No
Cu	7.54E+00	6.99E-01	6	4	8.61E+00	3.25E-01	4	4	2.89E+00	4.34E+00	Yes
Dy	2.73E-02	2.13E-02	6	3	3.50E-03	N/A	4	1	1.87E-02	1.20E-02	No
Er	2.08E-03	N/A	6	1	8.35E-03	5.12E-03	4	3	1.16E-02	9.63E-03	No
Eu	3.88E-02	1.90E-02	5	5	3.31E-02	3.31E-03	3	3	1.77E-02	6.81E-03	No
Fe	5.54E+02	5.64E+02	6	6	7.28E+02	7.52E+02	4	4	1.42E+02	1.35E+02	No
Gd	3.96E-02	3.80E-02	5	3	2.14E-02	9.88E-03	3	2	1.83E-02	7.82E-03	No
Hg	2.36E-03	N/A	4	1	2.72E-03	N/A	2	1	7.33E-03	4.13E-03	No
K	3.17E+04	6.32E+03	6	6	3.34E+04	4.53E+03	4	4	1.13E+03	1.41E+03	No
La	1.41E-01	2.03E-01	6	4	7.70E-02	2.65E-02	4	3	8.28E-02	1.18E-01	No
Li	1.11E+02	1.47E+01	3	3	8.05E+01	1.80E+01	2	2	4.80E-01	3.75E-01	No
Mg	2.01E+05	4.88E+04	6	6	1.91E+05	1.74E+04	4	4	4.70E+02	5.06E+02	No
Mn	6.82E+01	2.30E+01	6	6	1.75E+02	1.27E+02	4	4	7.79E+00	1.15E+01	No
Mo	4.73E+00	8.94E-01	6	6	3.56E+00	5.47E-01	4	4	6.40E-01	6.26E-01	Yes
Na	1.18E+06	3.08E+05	4	4	1.14E+06	1.44E+05	2	2	5.23E+03	3.60E+03	No
Nd	3.84E-02	1.85E-02	6	3	5.16E-02	1.79E-02	4	3	7.65E-02	1.13E-01	No
Ni	1.99E+01	6.01E+00	6	6	1.71E+01	7.48E+00	4	4	3.24E+00	4.17E+00	No
P	1.37E+02	3.63E+00	2	2	1.32E+02	9.03E-01	2	2	2.27E+01	0.00E+00	No
Pb	5.65E-01	1.89E-01	6	3	6.92E-01	5.18E-01	4	4	4.64E-01	4.97E-01	No
Pr	3.18E-02	3.79E-02	6	3	1.36E-02	4.75E-03	4	3	2.21E-02	1.90E-02	No
Sb	3.92E-01	6.42E-02	6	6	3.50E-01	6.92E-02	4	4	1.24E-01	2.21E-02	No
Sc	5.93E-01	N/A	2	1	<MDC	N/A		0	5.56E-01	0.00E+00	N/A
Se	<MDC	N/A	4	0	<MDC	N/A	2	0	2.95E+00	2.39E+00	No
Si	<MDC	N/A	2	0	<MDC	N/A		0	2.78E+03	0.00E+00	N/A
Sm	3.97E-02	1.92E-03	6	3	4.34E-02	1.09E-02	4	3	5.38E-02	5.64E-02	No
Sr	8.22E+03	1.69E+03	6	6	7.87E+03	8.90E+02	4	4	3.74E+01	4.11E+01	No
Th	3.25E-02	3.32E-02	6	4	1.93E-02	8.02E-03	4	3	1.33E-02	9.13E-03	No
Ti	1.30E+01	N/A	2	1	<MDC	N/A		0	1.11E+01	0.00E+00	N/A
Tl	<MDC	N/A	6	0	<MDC	N/A	4	0	8.14E-01	1.66E+00	No
U	6.79E+00	2.02E+00	6	6	6.34E+00	1.91E+00	4	4	9.52E-03	1.00E-02	No
V	4.41E+00	7.59E-01	6	6	4.01E+00	1.06E+00	4	4	1.47E+00	1.20E+00	No
Zn	8.55E+00	3.31E+00	4	2	1.07E+01	N/A	2	1	1.33E+01	1.19E+01	No

[1] "Shallow" refers to water collected approximately 0.5m below the surface of the body of water; "Deep" refers to water collected 1.0m above the bottom.

[2] MDC: Minimum Detectable Concentration; determined yearly for each analytical instrument

[3] Significance was determined with Student's t-test, 95% confidence interval. Instrument-estimated values below the MDC were included.

[4] "N samp" = Number of samples analyzed

[5] "N det" = Number of samples with detectable values (above the MDC)

[6] "Average Conc" = the average concentration for samples *above* the MDC

[7] "N/A" = Not Applicable

CHAPTER 7

Occurrence of Radionuclides in Residents of the Carlsbad, New Mexico Area

INTRODUCTION

Citizen volunteers from the Carlsbad, New Mexico area were monitored for internally deposited radionuclides through a project entitled "Lie Down and Be Counted" (LDBC). This project is provided as an outreach service to the public and to support education about naturally occurring and man-made radioactivity present in people who live in the vicinity of the WIPP. The data collected prior to the opening of the WIPP facility (26 March 1999) serve as a baseline for comparisons with periodic follow-up measurements that are slated to continue throughout the 35-year operational phase of the WIPP. It is important to note that these data represent an interim summary (through 31 December 2006) of an ongoing study.

Participating in the LDBC consists of a lung and whole body count every two years. Volunteers are recruited through presentations to local community groups and businesses. The entire measurement process takes approximately one hour. A detailed description of the measurement protocol, analysis and instrument detection limits is provided in the CEMRC 1998 Report. In addition, the status of the project and results are available on the CEMRC website (http://www.cemrc.org).

BIOASSAY RESULTS

As of 31 December 2006, 783 individuals had participated in the LDBC project. At the time the WIPP opened, 366[1] individuals had been measured using the *in vivo* protocol. This group of 366 measurements constitutes the pre-operational baseline to which subsequent results are compared. Counts performed after the opening of the WIPP are considered to be a part of the operational monitoring phase of the WIPP EM. Recounts began in July 1999, and 249 recount bioassays had been performed through 31 December 2006. In addition, 217 new volunteers have participated in the program since 1 October 2002.

Demographic characteristics (Table 7-1) of the current LDBC cohort are statistically[2] unchanged from those reported in previous CEMRC reports, and are generally consistent with those reported in the 2000 census for citizens living in Carlsbad. The largest deviation between the LDBC cohort and 2000 census is under-sampling of Hispanics. In addition, it is important to note that if the presence of a radionuclide is dependent on a subclass of interest (gender, ethnicity, etc.), valid population estimates can still be made by correcting for the proportion of under- or over-sampling for the particular subclass.

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[1] This number was previously reported at 367 but that number included one test that was not part of the subject population.

[2] The statistics reported for the bioassay program assume that the individuals participating are a random sample of the population. Given that the bioassay program relies on voluntary participation, randomness of the sample cannot be assured and, as is discussed later, sampling appears to be biased by ethnicity.

Baseline monitoring includes only the initial count of individuals made prior to 26 March 1999. Seven people were recounted during the baseline interval but these data are not reported in order to remain consistent with previous reports. Operational monitoring includes the counting of new individuals and the recounting of previously measured participants. Based on the data reported herein, there is no evidence of an increase in the frequency of detection of internally deposited radionuclides for citizens living within the vicinity of the WIPP since the WIPP began receipt of radioactive waste.

As discussed in detail in the CEMRC 1998 Report and elsewhere (Webb and Kirchner, 2000), the criterion, L_C, was used to evaluate whether a result exceeds background, and the use of this criterion will result in a statistically inherent 5% false-positive error rate per pair-wise comparison (5% of all measurements will be determined to be positive when there is no activity present in the person). The radionuclides being investigated and their minimum detectable activities are listed in Table 7-2. For the baseline measurements (N = 366), the percentage of results greater than L_C were consistent with a 5% random false-positive error rate, at the 95% confidence level (1 to 9%), for all radionuclides except ^{232}Th via the decay of ^{212}Pb, ^{235}U / ^{226}Ra, ^{60}Co, ^{137}Cs, ^{40}K, ^{54}Mn, ^{232}Th via the decay of ^{228}Ac (Table 7-2). As discussed in detail in the 1998 report, five of these (^{232}Th via ^{212}Pb, ^{60}Co, ^{40}K, ^{54}Mn (^{228}Ac interference) and ^{232}Th (via ^{228}Ac)) are part of the shield-room background and positive detection is expected at low frequency. ^{40}K is a naturally occurring isotope of an essential biological element, so detection in all individuals is expected. ^{137}Cs and ^{235}U / ^{226}Ra are not components of the shielded room background and were observed at frequencies greater than the 95% confidence interval for the false positive error rate (discussed in more detail later).

For the operational monitoring counts (Table 7-3, N = 690), the percentage of results greater than L_C were consistent with baseline at a 95% confidence level (margin of error), except for ^{60}Co and ^{232}Th (via ^{228}Ac). For these radionuclides, the percentage of results greater than L_C decreased relative to the baseline. This would be expected for ^{60}Co, since the radionuclide has a relatively short half life (5.2 years), and the content within the shield has decreased via decay by approximately 59% since the baseline phase of monitoring. The differences in ^{232}Th (via ^{228}Ac) results between the baseline and operational monitoring phase were also observed in 2001 and 2002 and are likely due to the replacement of aluminum (tends to contain Th and U) in some of the detector cryostat components with those manufactured from low radiation background steel.

^{40}K results were positive for all participants through December 2006 and ranged from 792 to 5558 Bq per person with an overall mean (± SE) of 2526 (± 26) Bq per person. Such results are expected since K is an essential biological element contained primarily in muscle, and a theoretical constant fraction of all naturally occurring K is the radioactive isotope ^{40}K. The mean ^{40}K value for males (± SE), was 3104 (± 30) Bq per person, which was significantly greater ($p < 0.0001$) than that of females, which was 1900 (± 22) Bq per person. This result was expected since, in general, males tend to have larger body sizes and greater muscle content than females.

Detectable ^{137}Cs is present in 23 ± 3% (95% confidence level, baseline and operational monitoring counts) of citizens living in the Carlsbad area. These results are consistent with findings previously reported in CEMRC reports and elsewhere (Webb et al., 2000). Detectable ^{137}Cs body burdens ranged from 4.9 to 77.5 Bq per person with an overall mean (± SE) of 10.6 (± 0.6) Bq per person. The mean ^{137}Cs body burden for males (± SE), was 11.5 (± 0.8) Bq per person, which was significantly greater ($p = 0.002$) than that of females, which was 8.7 (± 0.3) Bq per person. As previously reported (CERMC Reports; Webb et al., 2000) the presence of ^{137}Cs was independent of ethnicity, age, radiation work history, consumption of wild game, nuclear medical treatments and European travel. However, the occurrence of detectable ^{137}Cs was associated with gender where males had higher prevalence of ^{137}Cs relative to females. Furthermore, the presence of ^{137}Cs was associated with smoking. Smokers had a higher prevalence of detectable ^{137}Cs (29.7 %) as compared to non-smokers (24.1 %). It is likely that the association with gender is related to the tendency for larger muscle mass in males than in females, as supported by the ^{40}K results. The association of ^{137}Cs with smoking could be related to the presence of fallout ^{137}Cs in tobacco, decreased pulmonary clearing capability in smokers, or other as yet unidentified factors.

These results, particularly the absence of detectable levels of plutonium, suggest that there have been no significant releases from WIPP.

As reported in previous CEMRC reports, the percentage of results greater than L_C for ^{235}U/^{226}Ra (11 %) are significantly higher than the distribution-free confidence interval for a 5 % random false-positive error rate. These data are not nearly as compelling as those for ^{137}Cs, but the large sample size of the current cohort tends to support the observed pattern. Although ^{235}U and ^{226}Ra cannot be differentiated via gamma spectroscopy, it is likely the signal is the result of ^{226}Ra because the natural abundance of ^{226}Ra is much greater than that of ^{235}U.

Table 7-1: Demographic Characteristics of the "Lie Down and Be Counted" Population Sample through December 31, 2006

Characteristic		2006 Sample Group [a](margin of error)	[b]Census, 2000
Gender	Male	49.9% (46.4 to 53.4%)	48.2 %
	Female	50.1% (46.6 to 53.6%)	51.8 %
Ethnicity	Hispanic	15.2% (12.7 to 17.7%)	36.7 %
	Non-hispanic	83.7% (81.2 to 86.3%)	63.3 %
Age 60 or older		26.9% (24.2 to 29.5%)	24.5 %
Currently or previously classified as a radiation worker		7.4% (5.8 to 8.9%)	[c]NA
Consumption of wild game within 3 months prior to count		21.7% (19.2 to 24.2%)	NA
Medical treatment other than x-rays using radionuclides		7.6% (6.0 to 9.2%)	NA
European travel within 2 years prior to the count		5.6% (4.2 to 6.9%)	NA
Current smoker		13.5% (11.4 to 15.5%)	NA

[a] The margin of error represents the 95% confidence interval of the observed proportion.; under complete replication of this experiment, one would expect the confidence interval to include the true population proportion 95% of the time if the sample was representative of the true population.

[b] http://quickfacts.census.gov. United States Department of Commerce, Economics and Statistics Administration, Bureau of the Census.

[c] NA = not available

Table 7-2: Minimum Detectable Activities

2005-2006 Calibration

Radionuclides Deposited in the Lungs

Radionuclide	Energy (keV)	CWT = 1.6 MDA (nCi)	CWT = 2.22 MDA (nCi)	CWT = 3.01 MDA (nCi)	CWT = 3.33 MDA (nCi)	CWT = 4.18 MDA (nCi)	CWT = 5.10 MDA (nCi)	CWT = 6.0 MDA (nCi)
AM-241	59.50	0.14	0.17	0.23	0.26	0.34	0.47	0.65
CE-144	133.50	0.39	0.47	0.58	0.64	0.81	1.05	1.35
CF-252	19.20	13.07	25.90	61.87	87.99	225.35	623.13	1683.65
CM-244	18.10	13.55	28.84	75.64	111.24	313.69	959.26	2877.79
Co-60	1332.00	0.16	0.18	0.21	0.22	0.25	0.30	0.35
EU-155	105.30	0.22	0.26	0.33	0.37	0.48	0.64	0.84
NP-237	86.50	0.42	0.52	0.67	0.74	0.98	1.32	1.77
Pu-238	17.10	14.13	32.57	94.55	144.92	455.07	1568.21	5264.10
Pu-239	17.10	35.17	81.04	235.24	360.56	1132.24	3901.76	13097.28
Pu-240	17.10	13.82	31.84	92.42	141.65	444.81	1532.84	5145.36
Pu-242	17.10	16.67	38.41	111.49	170.88	536.60	1849.14	6207.10
Ra-226	186.10	1.38	1.59	1.94	2.10	2.59	3.25	4.05
Th-232 Via Pb-212	238.60	0.13	0.15	0.18	0.20	0.24	0.31	0.38
Th-232	59.00	23.30	28.93	38.11	42.60	57.29	79.09	108.16
Th-232 via Th-228)	84.30	4.01	4.90	6.36	7.07	9.34	12.59	16.90
U-233	440.30	0.56	0.65	0.78	0.83	1.01	1.25	1.54
U-235	185.70	0.09	0.10	0.12	0.13	0.16	0.20	0.25
Nat U via Th-234	63.30	1.27	1.58	2.06	2.30	3.09	4.23	5.77

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.67
Ba-140	537	1.31
Ce-141	145	1.18
Co-58	811	0.31
Co-60	1333	0.36
Cr-51	320	3.26
Cs-134	604	0.29
Cs-137	662	0.36
Eu-152	344	1.31
Eu-154	1275	0.85
Eu-155	105	2.69
Fe-59	1099	0.62
I-131	365	0.38
I-133	530	0.37
Ir-192	317	0.40
Mn-54	835	0.44
Ru-103	497	0.32
Ru-106	622	3.02
Sb-125	428	1.02
Th-232 via Ac-228	911	1.18
Y-88	898	0.33
Zn-65	1116	1.05
Zr-95	757	0.51

Table 7-2: Minimum Detectable Activities (continued)

2006-2007 Calibration

Radionuclides Deposited in the Lungs

Radionuclide	Energy (keV)	CWT = 1.6 MDA (nCi)	CWT = 2.22 MDA (nCi)	CWT = 3.01 MDA (nCi)	CWT = 3.33 MDA (nCi)	CWT = 4.18 MDA (nCi)	CWT = 5.10 MDA (nCi)	CWT = 6.0 MDA (nCi)
AM-241	59.50	0.18	0.23	0.29	0.33	0.44	0.60	0.81
CE-144	133.50	0.47	0.56	0.69	0.76	0.95	1.23	1.57
CF-252	19.20	16.41	32.73	78.83	112.79	290.17	808.62	2199.46
CM-244	18.10	15.35	32.95	87.42	129.26	368.87	1145.73	3476.70
EU-155	105.30	0.28	0.34	0.43	0.47	0.61	0.80	1.06
NP-237	86.50	0.50	0.61	0.78	0.86	1.13	1.52	2.02
Pu-238	17.10	16.38	38.20	112.73	174.23	555.50	1952.28	6685.42
Pu-239	17.10	40.75	95.05	280.49	433.48	1382.11	4857.35	16633.59
Pu-240	17.10	16.01	37.34	110.19	170.30	542.97	1908.24	6534.63
Pu-242	17.10	19.31	45.05	132.93	205.44	655.02	2302.01	7883.04
Ra-226	186.10	1.68	1.95	2.35	2.54	3.11	3.88	4.82
Th-232 Via Pb-212	238.60	0.16	0.18	0.22	0.24	0.30	0.37	0.46
Th-232	59.00	33.96	41.87	54.88	61.17	81.63	111.39	151.30
Th-232 via Th-228)	84.30	5.04	6.16	7.93	8.78	11.52	15.46	20.59
U-233	440.30	0.66	0.76	0.91	0.98	1.19	1.48	1.81
U-235	185.70	0.10	0.12	0.15	0.16	0.19	0.24	0.30
Nat U via Th-234	63.30	1.59	2.13	2.54	2.83	3.76	5.12	6.92
AM-241	59.50	0.18	0.23	0.29	0.33	0.44	0.60	0.81

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.76
Ba-140	537	1.45
Ce-141	145	1.70
Co-58	811	0.34
Co-60	1333	0.37
Cr-51	320	4.34
Cs-134	604	0.33
Cs-137	662	0.43
Eu-152	344	1.52
Eu-154	1275	0.92
Eu-155	105	4.00
Fe-59	1099	0.63
I-131	365	0.46
I-133	530	0.41
Ir-192	317	0.56
Mn-54	835	0.45
Ru-103	497	0.38
Ru-106	622	3.19
Sb-125	428	1.29
Th-232 via Ac-228	911	1.15
Y-88	898	0.35
Zn-65	1116	1.08
Zr-95	757	0.57

Table 7-3: "Lie Down and Be Counted" Results through December 31, 2006

Radionuclide	***In Vivo* Count Type**	**Baseline Counts [c](margin of error) (data prior to 27 March 1999) [a]N = 366**	**Operational Monitoring Counts (margin of error) (27 March 1999 – 31 December 2006) N = 690**
		% of Results ≥ [b]L_C	**% of Results ≥ L_C**
^{241}Am	Lung	5.2 (4.0 to 6.4)	4.1 (3.3 to 4.8)
^{144}Ce	Lung	4.6 (3.5 to 5.7)	3.3 (2.6 to 4.0)
^{252}Cf	Lung	4.1 (3.1 to 5.1)	5.8 (4.9 to 6.7)
^{244}Cm	Lung	5.7 (4.5 to 7.0)	4.6 (3.8 to 5.4)
^{155}Eu	Lung	7.1 (5.8 to 8.4)	4.6 (3.8 to 5.4)
^{237}Np	Lung	3.6 (2.6 to 4.5)	4.2 (3.4 to 5.0)
^{210}Pb	Lung	4.4 (3.3 to 5.4)	6.1 (5.2 to 7.0)
Plutonium Isotope	Lung	5.7 (4.5 to 7.0)	5.4 (4.5 to 6.2)
[d] ^{232}Th via ^{212}Pb	Lung	34.2 (31.7 to 36.6)	33.9 (32.1 to 35.7)
^{232}Th	Lung	4.9 (3.8 to 6.0)	5.1 (4.2 to 5.9)
^{232}Th via ^{228}Th	Lung	4.1 (3.1 to 5.1)	5.1 (4.2 to 5.9)
^{233}U	Lung	5.7 (4.5 to 7.0)	9.6 (8.4 to 10.7)
^{235}U/^{226}Ra	Lung	10.7 (9.0 to 12.3)	11.2 (10.0 to 12.4)
Natural Uranium via ^{234}Th	Lung	5.2 (4.0 to 6.4)	6.1 (5.2 to 7.0)
^{133}Ba	Whole Body	3.6 (2.6 to 4.5)	3.0 (2.4 to 3.7)
^{140}Ba	Whole Body	5.2 (4.0 to 6.4)	3.9 (3.2 to 4.7)
^{141}Ce	Whole Body	3.6 (2.6 to 4.5)	4.9 (4.1 to 5.8)
^{58}Co	Whole Body	4.4 (3.3 to 5.4)	2.5 (1.9 to 3.1)
[d] ^{60}Co	Whole Body	54.6 (52.0 to 57.2)	28.6 (26.9 to 30.3)
^{51}Cr	Whole Body	5.7 (4.5 to 7.0)	4.2 (3.4 to 5.0)
^{134}Cs	Whole Body	1.6 (1.0 to 2.3)	2.5 (1.9 to 3.1)
^{137}Cs	Whole Body	28.4 (26.1 to 30.8)	21.2 (19.6 to 22.7)
^{152}Eu	Whole Body	7.4 (6.0 to 8.7)	6.2 (5.3 to 7.2)
^{154}Eu	Whole Body	3.8 (2.8 to 4.8)	2.6 (2.0 to 3.2)
^{155}Eu	Whole Body	3.8 (2.8 to 4.8)	3.8 (3.1 to 4.5)
^{59}Fe	Whole Body	3.8 (2.8 to 4.8)	5.8 (4.9 to 6.7)
^{131}I	Whole Body	5.2 (4.0 to 6.4)	3.9 (3.2 to 4.7)
^{133}I	Whole Body	3.3 (2.3 to 4.2)	4.1 (3.3 to 4.8)
^{193}Ir	Whole Body	4.1 (3.1 to 5.1)	4.2 (3.5 to 5.0)
^{40}K	Whole Body	100.0 (100.0 to 100.0)	100.0 (100.0 to 100.0)
[d] ^{54}Mn	Whole Body	12.3 (10.6 to 14.0)	11.9 (10.7 to 13.1)
^{103}Ru	Whole Body	2.2 (1.4 to 3.0)	1.6 (1.1 to 2.1)
^{106}Ru	Whole Body	4.4 (3.3 to 5.4)	3.9 (3.2 to 4.7)
^{125}Sb	Whole Body	5.2 (4.0 to 6.4)	3.8 (3.0 to 4.5)
^{232}Th via ^{228}Ac	Whole Body	34.7 (32.2 to 37.2)	25.2 (23.5 to 26.8)
^{88}Y	Whole Body	7.7 (6.3 to 9.0)	6.0 (5.1 to 6.9)
^{95}Zr	Whole Body	6.6 (5.3 to 7.9)	4.1 (3.3 to 4.8)

[a] N = number of individuals. **Baseline counts include only the initial counts during this baseline period.**

[b] To determine whether or not activity has been detected in a particular person, the parameter L_C is used; the L_C represents the 95th percentile of a null distribution that results from the differences of repeated, pair-wise background measurements; an individual result is assumed to be statistically greater than background if it is greater than L_C

[c] The margin of error represents the 95% confidence interval of the observed percentage; under replication of this experiment, one would expect 95 % of the confidence intervals to include the true population if the sample was representative of the true population.

[d] These radionuclides are present in the shield background, so they are expected to be detected periodically

CHAPTER 8

Analysis of Volatile Organic Compounds

INTRODUCTION

The WIPP Hazardous Waste Facility Permit, Attachment N, issued by the New Mexico Environment Department under the Resource Conservation and Recovery Act (RCRA), mandates the monitoring of nine volatile organic compounds (VOCs) in the ambient air in the WIPP underground to assure that their respective concentrations of concern are not exceeded. These nine compounds are listed in Table 8-1. Monitoring is conducted in accordance with the "*Confirmatory Volatile Organic Compound Monitoring Plan*", prepared by the WIPP management and operations contractor, Washington TRU Solutions (WTS). Ambient air samples are collected in six liter Summa or equivalent canisters by Washington Regulatory and Environmental Services (WRES) personnel and delivered for analysis to CEMRC in weekly batches.

CEMRC first began analysis of samples for the Confirmatory VOCs Monitoring Plan in April 2004, using analysts from the Environmental Chemistry (EC) Group and following a successful VOCs program audit by the WTS QA group. At that time, CEMRC had one 6890/5973 Hewlett Packard (now Agilent) gas chromatograph/ mass spectrometer (GC/MS) which had previously been used by Los Alamos National Laboratory (LANL). CEMRC purchased an Entech 7100 Preconcentrator for use as the sample concentration and introduction system. In addition, CEMRC purchased an Entech 3100 Canister Cleaning System for cleaning and evacuation of canisters after analysis.

VOCs PROJECT EXPANSION

The original VOCs laboratory was set up in a small room (149) in the science laboratory wing at CEMRC and only included the equipment necessary for Confirmatory VOCs analysis. In late 2003, the Department of Energy (DOE) requested that CEMRC expand its capabilities to prepare for the analysis of headspace gas (HSG) samples collected from waste drums required under the WIPP Permit, Attachment B. In preparation for this expansion of scope, CEMRC visited the HSG group at LANL to determine the equipment required for the process. Thereafter, a turnkey HSG analysis system consisting of a 6890/5973N Agilent GC/MS with a loop injection system and three Entech 7032 Autosamplers installed in series was purchased from Entech Instruments, Inc. Also included in this purchase was an Entech 3100A oven-based canister cleaning system, an Entech 4600 Dynamic Diluter for automatic preparation of VOCs calibration standards, and fifty 400 mL Silonite-coated mini-canisters with Nupro valves and attached pressure gauges.

After a few months of VOCs Confirmatory Analyses, it became critical to expand the laboratory to accommodate the addition of a backup analysis system. This shortcoming was noted by auditors for the next two years. CEMRC did purchase a backup Preconcentrator to minimize system downtime. However, there was no available space in which to set up the backup GC/MS instrument even if it were purchased.

With the addition of headspace gas analysis, it was decided in July 2005 to move the VOCs Confirmatory Analysis and Headspace Gas Analysis programs from the EC group into the newly created Organic Chemistry (OC) Group. The primary management focus for the EC group was research oriented, whereas the functions of the OC group were regulatory in nature and required different QA/QC measures and documentation.

Analyses were originally conducted by manually changing the sample attached to the preconcentrator for each sample. Due to the need to maximize efficiency, an Entech 7016 canister autosampler was obtained in June 2005. This autosampler allows for up to sixteen samples to be run in sequence with minimal operator supervision.

Funding was obtained in mid-2005 through a DOE baseline change request to remodel the current CEMRC garage into a functional GC/MS Laboratory. The design for the remodel was completed in late 2005, and construction began in January 2006. Construction was completed in April 2006, and the OC Group moved into the new laboratory.

Around this time, a backup Agilent 6890/5973 GC/MS system was transferred to CEMRC by the Central Characterization Project (CCP) for use in headspace gas analysis. A backup autosampler for HSG analysis was also purchased by CEMRC. Shortly thereafter a new Agilent 6890/5975 GC/MS was obtained with a portion of the lab setup funding to be used as a backup analysis system for the Confirmatory VOCs Monitoring.

The VOCs Confirmatory Monitoring expanded from 353 samples in 2005 to 430 samples in 2006. Increases in sample load are expected in the coming months due to anticipated changes in closed room sampling requirements.

METHODS FOR CONFIRMATORY VOCs MONITORING

Confirmatory VOCs Monitoring requires method detection limits in the lower parts per billion volume (ppbv) range. This type of analysis requires preconcentration of a given volume of ambient air into a much smaller volume prior to introduction into the GC column. In order to maintain performance of the mass analyzer, most of the water vapor and carbon dioxide present in the air sample must be removed prior to analysis. The Entech 7100 Preconcentrator performs these tasks automatically by flowing the sample through three consecutive cryogenic traps at different controlled temperatures. This results in very low detection limits not obtainable without cryogenic preconcentration.

Stock cylinders of Calibration Standard and Laboratory Control Sample gases are purchased certified from a reputable supplier, and then diluted to working concentrations with Ultra-High Purity (UHP) Nitrogen using the Entech 4600 Dynamic Diluter. Canisters are cleaned after sample analysis using the Entech 3100 Canister Cleaning system, which consists of a computerized control module with vacuum pumps and an oven containing a passivated manifold with fittings for connection of canisters. The control software initiates the cleaning of canisters by heating coupled with multiple pressurization/evacuation cycles. A blank sample is analyzed from each cleaning batch as a control to assure proper cleaning has been achieved.

Analysis of VOCs for Confirmatory Monitoring were conducted under procedures using concepts of EPA Air Analysis Compendium Method TO-14A, "*Sampling and Analysis of Ambient Air*". Special quality assurance requirements for these activities were detailed in the "*Quality Assurance Project Plan for Confirmatory Volatile Organic Compound Monitoring*", prepared by WTS. CEMRC personnel wrote procedures for this project under the CEMRC Quality Assurance Plan, which were verified, validated, and placed in the CEMRC Document Control Program. Procedures were composed to include QA requirements from EPA Method TO-14A and all WIPP documents relevant to the Confirmatory Monitoring Program. See Table 8-2 for a list of CEMRC Procedures for Confirmatory Monitoring.

In November, 2006, the WIPP Permit was modified to refer to EPA Air Analysis Compendium Method TO-15, "*Determination of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography/Mass Spectrometry (GC/MS)*". This method is the most current, having replaced Method TO-14A. It also allows for analysis of a more extensive compound list, in the event that more compounds of interest are added to the list in the future. The CEMRC procedures were modified to account for this change in method.

The permit modification also incorporated an expansion of sampling in the Confirmatory Monitoring Program. Originally, the samples were collected from only two stations in the WIPP underground (VOC-A and VOC-B). The permit change requires sampling from closed rooms within the current panel until the entire panel is full. Therefore, Attachment N now refers to both Repository VOCs Monitoring and Disposal Room Monitoring. The required detection limits for different types of samples are summarized in Table 8-1.

METHODS FOR HEADSPACE GAS ANALYSIS

The analysis of Headspace Gas (HSG) from waste containers has been conducted at various generator sites prior to shipment of waste to WIPP. In response to request from DOE, CEMRC set up a process for HSG analysis based on the process in use at LANL. Per the WIPP Permit, Attachments B, HSG analysis is conducted using the concepts of EPA Method 8260. Since Method 8260 is a method intended for use with waste matrices, some adaptation was required for HSG analysis. Under the analysis scheme used at CEMRC, HSG samples would be collected into clean, evacuated canisters (SUMMA or equivalent) and shipped to CEMRC for analysis. Upon arrival, sample canisters would be pressurized to twice atmospheric pressure by the addition of an internal standard gas mixture, and then simultaneously analyzed for hydrogen and methane by GC/Thermal Conductivity Detector (TCD) and VOCs by GCMS. The sampling system incorporates three autosamplers in series to allow for the analysis of two complete batches of 20 samples each, plus the requisite QC samples. Samples from the autosamplers pass through heated transfer lines into two injection loops attached to an automated valve for injection into the GC.

The process was preparing to come online in 2004, when CEMRC was informed that this analysis was no longer required. In 2005, CEMRC was again requested to bring the process online, this time under the control of the Central Characterization Program (CCP). CCP required CEMRC personnel working on HSG activities to do so under their QA process. This required that OC lab personnel be trained to the CEMRC QA process for VOCs Confirmatory Monitoring and the CCP QA process for HSG analysis.

CEMRC HSG procedures were removed from the CEMRC controlled documents program, rewritten to reflect CCP requirements and formats, and placed under the CCP controlled documents program. The CEMRC procurement process was audited by WTS QA to determine whether it met CCP criteria and items which did not were changed. Two CEMRC analysts completed training as HSG analysts in accordance with CCP qualification requirements. A third analyst began his training as well. CEMRC-owned canisters were sent for gauge calibration and helium leak testing in order to qualify for CCP sampling activities.

CEMRC had two backup GCMS systems modified to conform with the CEMRC analysis instrument configuration and purchased an additional autosampler in order to set up a HSG backup analysis system. CEMRC personnel attended weekly meetings with CCP personnel in order to facilitate bringing the HSG project online. New VOCs standards were purchased from a CCP-approved vendor.

RESULTS AND DISCUSSION

Confirmatory VOCs Monitoring Program

A set of 120 preliminary closed/open room samples were analyzed along with VOC-A and VOC-B samples from April 2004 through September 2005. Official closed room sample submission began in August 2006.

Sets of blank and recovery gas samples collected by Shaw Environmental as part of the sampler cleaning and certification were analyzed in two-day turnaround batches at various times throughout the years, in addition to the regular monitoring samples submitted.

Batch reports are submitted in hardcopy in the EPA Contract Laboratory Program format. An electronic report in the client's specified format is also provided for each batch. Copies of batch reports and all QA records associated with these analyses are maintained according to the CEMRC records management policies, detailed in the QAP.

Headspace Gas Analysis

A preliminary surveillance of the CEMRC Headspace Gas (HSG) Analysis process was conducted by WTS QA in January 2007. Some minor issues were identified and addressed in preparation for the official DOE audit. The DOE audit was conducted in February 2007 by CTAC. CEMRC's HSG analysis process passed the audit and was to be certified to begin HSG sample analysis following successful completion of the Performance Demonstration Program (PDP) cycle in April. PDP samples were received in April 2007 and successfully analyzed. CEMRC was requested by DOE to provide a budget proposal to place the HSG analysis program in cold standby in May 2007.

Future Plans for Expansion for VOCs Monitoring in Air

At the request of WTS, CEMRC analysts investigated the possibility of modifying the method parameters for the HSG GCMS system to allow for screening of high level VOCs in closed room samples and analysis of low level % concentrations of hydrogen and methane. This modification requires no change of the physical configuration of the system. At some future time, the VOCs Confirmatory Monitoring Program may add hydrogen and methane analysis to the Statement of Work. Cost estimate have been provided to WTS for this potential work.

Summary Statements

The success of the Confirmatory VOCs Monitoring Program and the HSG Program demonstrate CEMRC's ability to set up new programs to successfully perform regulatory monitoring tasks in accordance with specific QA/QC requirements. At the time both programs were proposed, CEMRC did not have qualified staff with experience in similar programs. Existing staff gained knowledge and skills necessary to perform these tasks appropriately in order to pass strict audit criteria.

CEMRC presently has the capability to analyze over 2,000 VOC and HSG samples per year.

Table 8-1: Compounds of Interest for WIPP Confirmatory Volatile Organic Compounds Monitoring Program

Compound	Repository Sample Reporting Limit (ppbv)	Closed Room Sample Reporting Limit (ppbv)
1,1-Dichloroethene	5	500
Carbon tetrachloride	2	500
Methylene chloride	5	500
Chloroform	2	500
1,1,2,2-Tetrachloroethane	2	500
1,1,1-Trichloroethane	5	500
Chlorobenzene	2	500
1,2-Dichloroethane	2	500
Toluene	5	500

Table 8-2: CEMRC Procedures for Confirmatory Volatile Organic Compounds Monitoring Program

Procedure Number	Procedure Title	Rev.
OC-PLAN-001	Quality Assurance Plan for Analysis of Volatile Organic Compounds in Canister Samples	2
OC-PROC-002	Preparation of Canisters for Ambient Air and Headspace Gas Sampling	2
OC-PROC-003	Gas Chromatography-Mass Spectrometry of Volatile Organic Compounds (VOCs) in Ambient Air from Canisters at PPBV Concentration Levels	1
OC-PROC-004	Preparation of Calibration Standards in Specially Prepared Canisters for Analysis by Gas Chromatography/Mass Spectrometry	2
OC-PROC-005	Data Validation and Reporting of Volatile Organic Compounds from Gas Chromatography/Mass Spectrometry Analysis of Ambient Air in Canisters for the WIPP Volatile Organic Compound Monitoring Program	2
OC-PROC-006	Receipt, Control, and Storage of Gas Samples in Passivated Canisters	1

CHAPTER 9

The RACER Project

RACER stands for Risk Analysis, Communication, Evaluation and Reduction and it is a new tool and a new process for managing risks from the Los Alamos National Laboratory (LANL). RACER is an effort to develop an open and easy to understand process for reducing the risks to the public from LANL. The RACER project differs from past risk studies that have been conducted at LANL in that the work is being done by the Risk Assessment Corporation (RAC) under a contract with Colorado State University, whereas previous risk studies at LANL have been carried out by the LANL or its contractors. CEMRC has been collaborating in this effort under contracts to CSU and RAC. The independence of the CSU/RAC/CEMRC scientists from LANL provides additional assurance to the public and regulators that an open and unbiased assessment of the data will be provided. Unlike earlier studies, RACER is designed to integrate risks from the entire LANL site.

The goal of the RACER project is to develop a process and tools that can be used to guide the efforts to reduce risk from LANL. These tools will be used together within the RACER process (Fig. 9.1) to identify and rank the sources of public health risk from LANL and to help select the best way to reduce these sources of risk. The sources include smoke stacks, waste burial grounds, and areas where radioactive materials or chemicals have been released into the soil. The RACER process will take into account not only cost, but other issues that are important to people who live in the region such as the need to protect cultural resources or wildlife habitat.

CEMRC has contributed to the design and implementation of several of the tools created for the RACER project. One of these tools provides access to the LANL environmental sample data through a Web interface (http:racerdb.nmsu.edu) (Fig. 9.2). The data are stored in a MySQL database and data can be selected through a series of forms. The data are then displayed either as a table (Fig. 9.3) or a graph (Fig. 9.4). The RACER database is the first implementation of a system that can provide access to environmental data collected by the many environmental management at LANL and the New Mexico Environment Department. It includes data from LANL Meteorology and Air Quality, LANL Remediation Services, LANL Water Quality and Hydrology, the NMED Oversight Bureau, and the NMED Casa Grande File Project. These data provide contaminant concentrations in air, surface water, ground water, storm water, soil, sediment, natural vegetation, wildlife, and various potential food sources. The data include organic, inorganic and radionuclide contaminants. Most data are identified with geographic locations, thus enabling the data to be mapped and subjected to spatial analyses.

RAC is currently designing an extension to the web site that will enable spatial oriented analyses to be conducted using a web-based browser. CEMRC will be collaborating to provide support for this web interface as well. The system will be implementing a web-based version of a tool previously implemented using ACCESS databases and an integrated GIS tool called MapSelect (Fig. 9.5). MapSelect and the underlying database scheme was developed by CEMRC to allow investigators to easily and rapidly select and display data for display on a map. It is designed to run on MS Windows. MapSelect can display industry-standard ERSI shape files (i.e., map layers), such as those produced by ArcInfo and used by ArcView and related products. In addition, data selected from the database can be displayed in a map layer. MapSelect provides interactive capabilities for selecting, grouping or clustering, and summarizing data using the map interface. Points, polygons and lines can be created by MapSelect and stored in the database or as new shape files. MapSelect is integrated into several of the RACER tools for both analyzing data and for evaluating risks.

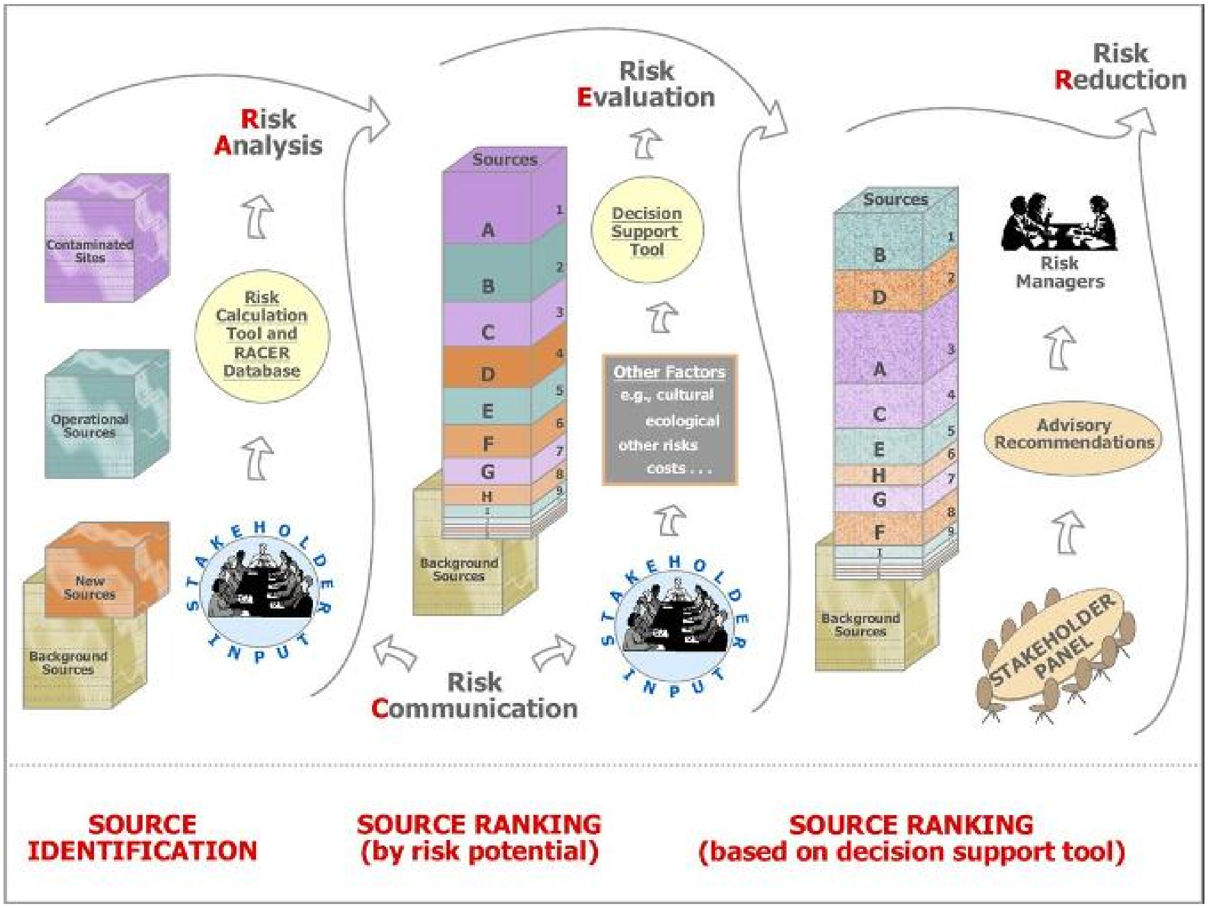
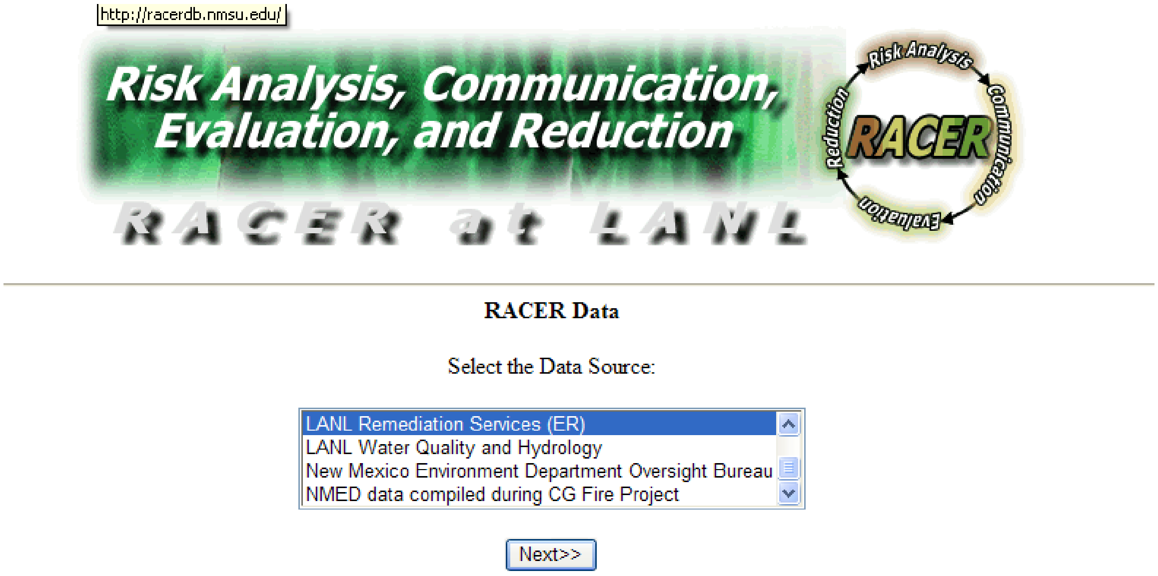


Figure 9.3: The RACER Project is Designed to Both Assess Risks and to Help Manage and Reduce Those Risks

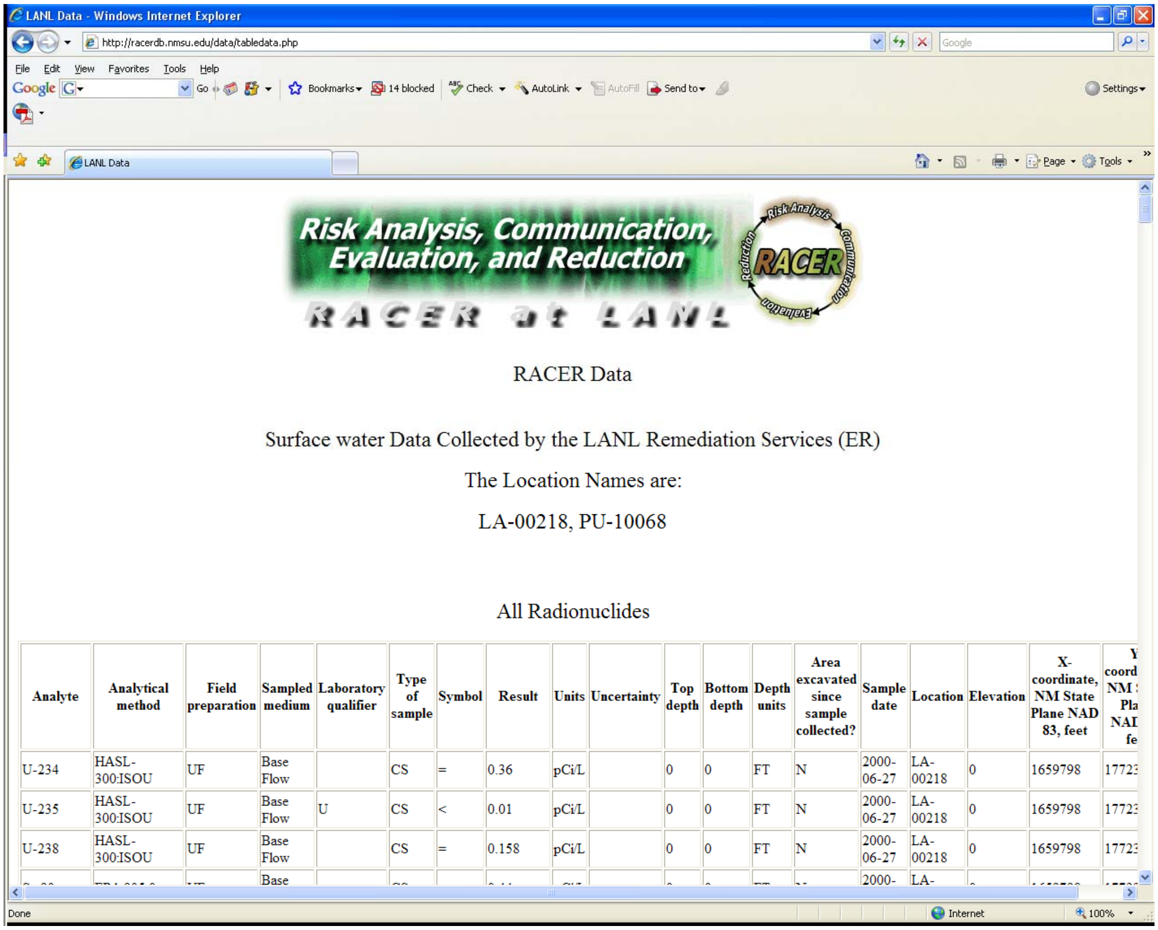


RACER Data

Select the Data Source:

- LANL Remediation Services (ER)
- LANL Water Quality and Hydrology
- New Mexico Environment Department Oversight Bureau
- NMED data compiled during CG Fire Project

Figure 9.2: The Web-based Interface to the RACER Database Developed by CEMRC



RACER Data

Surface water Data Collected by the LANL Remediation Services (ER)

The Location Names are:

LA-00218, PU-10068

All Radionuclides

Analyte	Analytical method	Field preparation	Sampled medium	Laboratory qualifier	Type of sample	Symbol	Result	Units	Uncertainty	Top depth	Bottom depth	Depth units	Area excavated since sample collected?	Sample date	Location	Elevation	X-coordinate, NM State Plane NAD 83, feet	Y coord NM Pla NAI fe
U-234	HASL-300:ISOU	UF	Base Flow		CS	=	0.36	pCi/L		0	0	FT	N	2000-06-27	LA-00218	0	1659798	1772
U-235	HASL-300:ISOU	UF	Base Flow	U	CS	<	0.01	pCi/L		0	0	FT	N	2000-06-27	LA-00218	0	1659798	1772
U-238	HASL-300:ISOU	UF	Base Flow		CS	=	0.158	pCi/L		0	0	FT	N	2000-06-27	LA-00218	0	1659798	1772

Figure 9.3: Typical Tables of Data Selected from the RACER Online Database

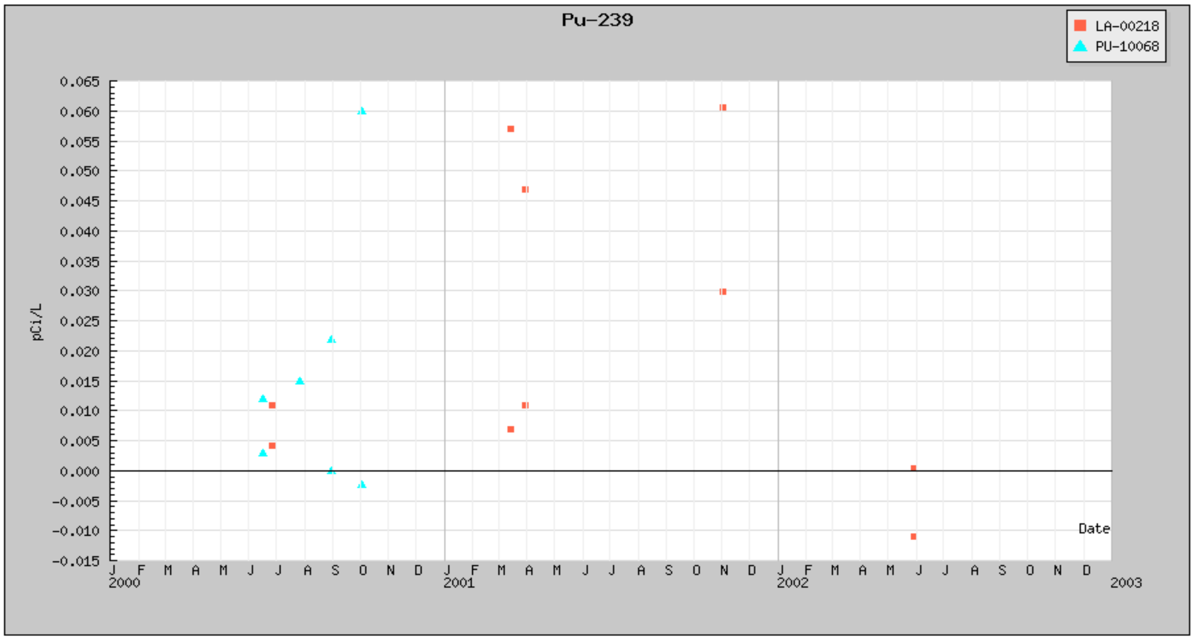
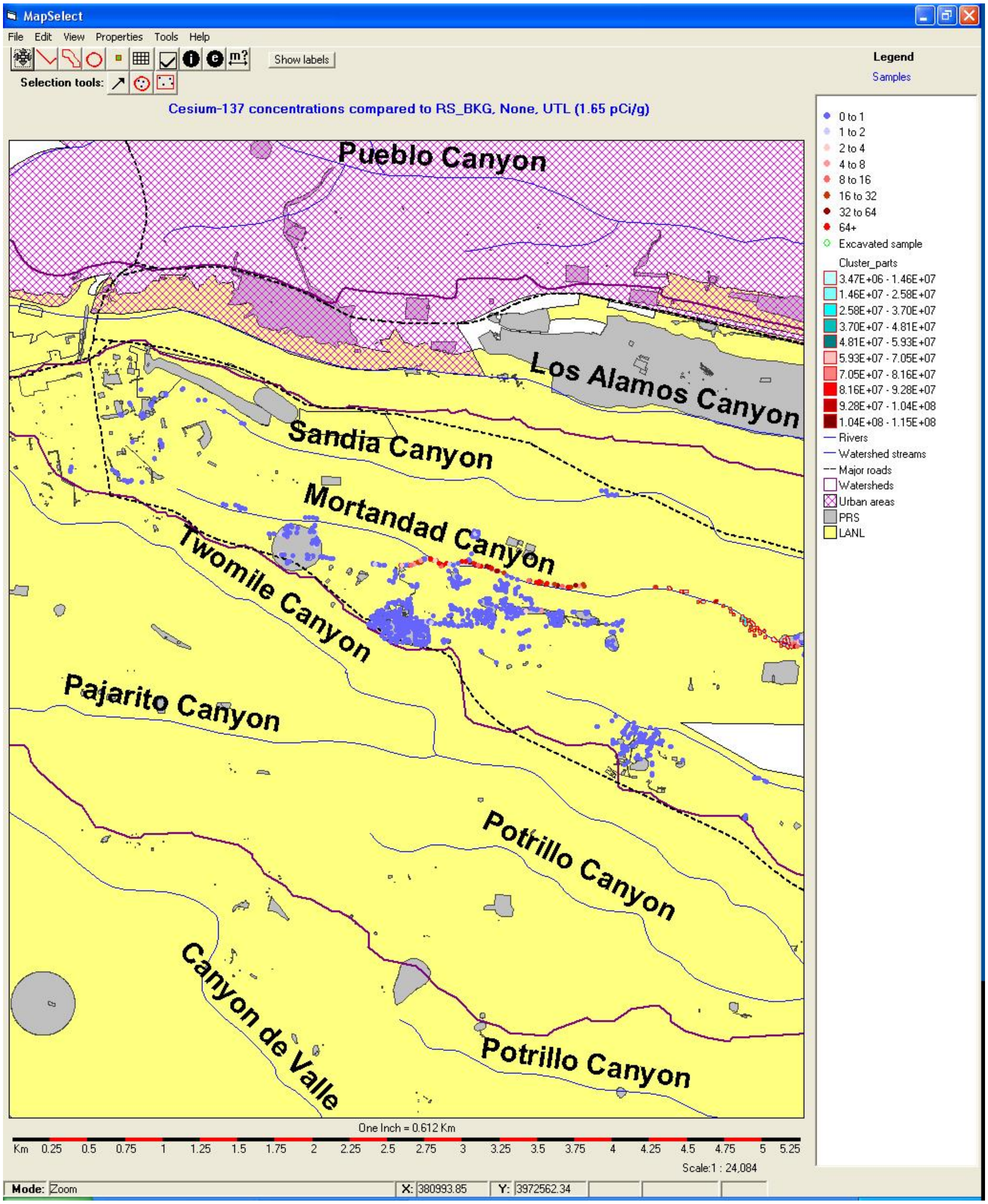


Figure 9.4: Typical Timeseries Graph Produced
Using the RACER Online Database Tool



Mode: Zoom
X: 380993.85
Y: 3972562.34

Figure 9.5: MapSelect is Integrated with the RACER Database to Provide Mapping and Spatial Analyses Functions

CHAPTER 10

First Responder Radiological Response Training

In 2005, CEMRC was approached by one of the Homeland Security Consortium members (EMRTC at New Mexico Tech in Socorro) to develop a training program for first responders (fire, police, EMTs, military) that would cover responding to radiological emergencies such as following a radiological dispersion device (RDD or dirty bomb). The course was to address first responder needs in ways existing rad training does not.

A three-day course was developed for a class of between 20 and 40 trainees, at about $1,000 per person, and implemented on three separate occasions from October 2005 to October 2006. The training was a combination of traditional radworker training, dirty bomb specialized training developed at CEMRC and the MERRTT training developed at WIPP. Included was classroom lecture, hands-on sessions with dosimeters and radiological materials, a medical radiological evacuation session, and a final field exercise with actual explosive materials and the participation of the local fire and police departments, LANL-Carlsbad scientists and the MERRTT team lead by Lynn Eaton with Marsha Beekman from WTS (Fig. 10.1). The response was exceptional and most attendees recommended the training to their home organizations. Besides fire and police, attendees included military from the National Guard WMD Civil Support Team in Albuquerque, EPA enforcement officers, Coast Guard WMD team members, and DHS contractors.

BACKGROUND

RDDs, or dirty bombs, are devices that disperse radioactive materials. They take many forms, from containers of radioactive materials wrapped with conventional explosives, to aerosolized materials sprayed by conventional equipment, to manual dispersion of fine powders into the environment (Koonan, 2002). Also included are radiation-exposure devices (REDs), used to expose people to dangerous levels of radiation but without dispersing material. RDD attacks can produce general panic, immediate death and long-term increases in cancer incidence, long-term loss of property use, disruption of services, and costly remediation of property and facilities.

Radioactive materials are used in many fields in almost all countries around the world, particularly for medical, research, and industrial applications (O'Brian, 2002). Dozens of radiological source producers and suppliers are found on six continents, and about a billion sources exist worldwide although most, like household smoke detectors, have such low activities that they pose no threat (Strub et al., 2003; Van Tuyle et al., 2003). With the increase of radioisotope applications in nuclear medicine, instrument sterilization and food irradiation, the radiological source production and fabrication industry is an emerging growth industry in several countries, particularly in areas with depressed economies.

The rise in the number of terrorist acts during the last ten years has raised concerns about these radiological sources being used in RDDs, or dirty bombs, that could create panic and potentially large economic consequences (Van Tuyle et al., 2003). Because the general public is so frightened about anything radioactive, panic must be anticipated even if there is no real health threat from the radioactive component. At the same time, the threat is no longer theoretical. Several credible designs for a dirty bomb attack against the United States have been found in Al Qaeda records. Two actual dirty bombs were deployed by Chechen separatists. Both were foiled. Of most concern, however, is the presence of dirty material on the world market. As an example, 38 Alazan missiles outfitted with dirty bomb warheads are for sale from a particular weapons factory.

Therefore, the United States must prepare in some way for an eventual non-nuclear radiological attack, and this preparation can take two forms: 1) dirty bomb training programs specifically geared to first responders, and 2) a ^{137}CsCl melting program for the irradiation industry that changes the powdered form into a more RDD-resistant solid form, coupled with international restrictions on the transportation of powdered ^{137}Cs chloride which can only occur if there is a non-powdered alternative acceptable to the industry. Both of these strategies are underway at CEMRC, and if implemented over the next few years should dramatically reduce our vulnerability to this type of attack (Conca, et al., 2005).

RESULTS

Attendees received all training materials to carry back to their home organizations in the form of hard copy and electronic media. Most of the training materials are available on the website at www.cemrc.org. In particular, a simplified executable 12-step guidance for radiological response was developed for all first responders nation-wide that can be contained on a single, double-sided laminated card to carry in any vehicle. This was disseminated throughout specific DHS websites, incorporated into the *DHS LLIS Radiological Dispersal Device Incident Response Planning Working Group*, and appeared in the May 2006 issue of the *Homeland Protection Professional* (Conca et al., 2006). This 12-step guidance is given on the next two pages. Although not necessary, this guidance is best executed after training such as provided by this RDD course. Part of the challenge posed by DHS for this course was to make radiological issues relevant and understandable to first responders without unnecessary and confusing information that is more appropriate to radiation workers but not first responders. An example follows for a discussion of the relative risks of progressive dose limits presently given by DHS for first responders but which are not given in any useful context.

10 rem acute dose - In the working hot zone for a day - no measureable health effects
- Fighting a dumpster fire
- Hand-cuffing an inebriated nuisance

25 rem acute dose - In the working hot zone for a few days
- Fighting a three-alarm fire from the street
- Disarming a perpetrator who has no weapon

50 rem acute dose (DHS responders suggested upper limit for saving life in large numbers) - In the working hot zone for a week
- Running into a burning building not at risk of collapse
- Disarming a perpetrator who has a knife

100 rem acute dose - In the working hot zone (0.1 to 1 rem/hr) for a month/~10 min priority rescue at Ground Zero
- Running into a burning building at risk of collapse
- Disarming a perpetrator who has a gun

First Responder 12-point Guidance in the Event of a Dirty Bomb, RDD or other Radiological Incident

1. **Assume all explosions, particularly car explosions, could be dirty.**
2. **If no dose or activity readings are available, set up an affected or exclusion zone boundary at 500 m from ground zero.**

   If readings are available, set the full exclusion zone (around ground zero) outer boundary as about 1 rem/hr (10 mSv/hr). This boundary will also be the hot zone inner boundary. Set the hot zone outer boundary as about 0.1 rem/hr (1 mSv/hr).

   Within this zone, essential personnel can operate for several hours without accumulating significant dose. Exact adherence may not be feasible because of logistical or geometric issues and plus or minus a factor of 2 can be expected.

   Set the outer boundary of the warm zone (affected area) to about 2 mrem/hr (20 μSv/hr) depending upon operability. Local decisions may warrant establishing boundaries at 2x or 4x background, but these may be miles from ground zero.
3. **All personnel in the hot zone should wear full PPE (turnout or bunker gear) with a particulate full face mask and have an updating, alarming cumulative dosimeter that can be used to track total dose. Take any precaution necessary to avoid inhaling or ingesting dust and particulates. Radioactivity will be in particulate form.**
4. **When it is determined the situation is radiological, immediately alert the appropriate secondary response teams, such as CST, RAP and FBI, as advised in the unified command protocols for your region. If necessary call:**

National Response Center	**1-800-424-8802**	**NRC**	**1-301-816-5100**
National Guard CST	**1-800-343-6701**	**DHS**	**1-202-727-6161**
FBI (ATF bomb)	**1-888-283-2662**	**FEMA**	**1-202-586-8100**
DOE (RAP Coordinator)	**1-505-845-4667**	**DOE OEM**	**1-202-586-8100**

5. **Occupancy time outside the hot zone but within the warm zone is unrestricted for essential personnel for the duration of the initial response (days to weeks).**

   Establish Incident Command upwind of ground zero at the closest point outside the affected zone. Have alternative positions ready in case of change in wind direction.
6. **Evacuate all people from the affected area (> 2 mrem/hr) and exclude non-essential personnel thereafter. Expect self-evacuation for large populations of uninjured persons and provide them with safe designated routes out of the affected area (work with building managers to establish subterranean routes). Try to establish quick dose-rate screening, or radiological monitors, to determine those relatively few needing decontamination, but do not attempt mass decon of large populations. Instead, advise removal of external clothing,**

bag if possible, avoid eating, drinking or touching facial region, go directly home, shower with warm water and soap, and do not use hair conditioner, hair color, or other fixative hygiene products.

Local decisions may warrant establishing large fire hose wash down curtains along decon corridors for rapid decon of evacuees and equipment, however, in large urban settings this will not be feasible.

7. **Do not decontaminate vehicles or structures during the initial response phase. Do not try to contain contaminated water, but allow, or even encourage, it to enter the municipal stormwater drainage system. Alert City Manager or wastewater treatment facility manager for possible diversion strategies.**
8. **For those heavily contaminated persons, e.g., where there is obvious surface radioactive material or where they are heavily injured from the blast, establish decon areas and decon corridors connecting the hot zone to the boundary of the warm zone or affected area. Provide those with heavy external contamination of the upper body with follow-up exams to determine possible contaminant inhalation or ingestion. Countermeasures, e.g., Prussian Blue, should be evaluated promptly.**
9. **Separate persons needing immediate medical attention and remove outer garments, survey for surface contamination, decon if necessary and possible, wrap in clean blankets in decon zone and evacuate. Inform the receiving medical facility that the person has little or no surface contamination or they may deny admittance.**
10. **Commence mapping the affected area to obtain a rough dose profile of the area, marking hot and cold spots to assist in avoiding large doses during operations, and to assess the magnitude of the situation.**
11. **Essential personnel within the affected area should record cumulative dose, if possible, and not exceed about 5 rem (50 mSv) total unless protection of critical infrastructure is deemed imperative and no alternative exists.**

    Do not exceed about 10 rem (100 mSv) except to save lives and protect critical infrastructure. Note: no health effects ever observed for doses less than 10 rem.

    Do not exceed about 25 rem (250 mSv) unless the responder decides voluntarily, and with full knowledge of the risks, to save large numbers of lives and protect critical infrastructure that may harm large populations if not secured.

    Do not exceed about 50 rem (500 mSv).
12. **Sheltering in place is only advisable if the population is aware of the radiological nature ahead of the plume, unlikely in most cases.**

    Evacuate buildings along determined safe routes away from the hot zone.

Do not shut down building ventilation systems. Modern ventilation systems will filter most radioactive particulates and shut down may cause chimney effects.

Figure 10.1: Collage of Activities During a Dirty Bomb Training Course at CEMRC

CHAPTER 11

In situ Aerosol Probe Occlusion Tests at Station A

BACKGROUND

This study was funded by the United States Department of Energy through Washington TRU Solutions. The United States Environmental Protection Agency (EPA) developed National Emission Standards for Hazardous Air Pollutants (NESHAPS) under Section 112(r) (Prevention of Accidental Releases) of the Clean Air Act. For radionuclides other than radon, the EPA established standards for Department of Energy Facilities under 40 CFR 61 Subpart H (Department of Energy Facilities). This regulation requires facility owners and operators to monitor and track emissions, calculate the highest effective dose equivalents, and report that information back to the EPA. Guidance relative to the sampling of airborne radionuclides was provided in ANSI N13.1-1969 (Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities). In 1999, a major revision to ANSI N13.1 –1969 (Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities) was issued, and it identified shrouded probes as the preferred samplers for most applications involving airborne radioactive substances in stacks and ducts of nuclear facilities.

At the Waste Isolation Pilot Plant (WIPP), Station A is used for exhaust-air compliance monitoring purposes, and the aerosol sampling systems deployed there were designed to collect ≥ 50% of the 10 μm diameter aerosols under the expected range of exhaust air velocities (Rodgers, 1987). The samplers in use at Station A are three nearly identical shrouded-probes, and they are of the same basic type as that used to develop the ANSI standard. These probes operate at flow rates of ~170 L min^{-1} (~6 cfm), and each unit consists of a machined stainless steel shroud and inner nozzle. When sampling, the probes are deployed approximately 21 feet below the surface in the exhaust shaft. The air from three aerosol sampling probes flows through separate transfer lines into the Station A enclosure where the air in each line is distributed among three sampling legs. Each of these legs in turn feeds a Fixed Air Sampler (FAS) that operates at ~2 cfm. Normally, Skid A3 is the sampler of record (SOR), A2 is the main back-up sampler (BUS), and A1 is at times used as an alternative back-up sampler or for other purposes.

Laboratory tests have shown that shrouded probes are less sensitive to salt accumulations than several other types of samplers (Chavez et al. 1997), but salt buildup has been observed on the surfaces of the Station A sampling probes and in the transport lines. Further, the encrustation problem is thought to be exacerbated by groundwater seeping into the exhaust shaft. That is, when water vapor is entrained in the effluent air stream, it mixes with the salt, and the wet salt particles deposit on the probe and transport-line surfaces.

This salt fouling of the probes has become a concern because the representativeness of the backup samples collected when the probes are occluded has been called into question (EEG report #80). More specifically, the stated concern is that salt deposits occluding or partially occluding the shroud/nozzle could alter the sampler's air-flow and increase the overall surface roughness of the sampler to the point where its performance would be degraded.

With respect to fouling of the probe, laboratory experiments conducted at Texas A&M demonstrated that when a 3-mm thick layer accumulated on the inside surface of the nozzle (approximately 10% of the inner nozzle occluded), the transmission ratio dropped about 22% relative to a clean probe. In the 1993 report, McFarland made the following statement:

> "…if a 20% reduction is the maximum level that can be accepted in sampling performance for 10 μm aerosol particles at a free stream velocity of 14 m s^{-1}, the system should be cleaned when the diameter of the inner probe (nozzle) is reduced by approx-imately 20% (6 mm)."

Blockage in the shroud alone (i.e., the inner nozzle not occluded) apparently has little impact on the shrouded probe's performance. In wind tunnel experiments, Chandra, et al. (1993) found no difference in the transmission ratio for a 10 μm aerodynamic diameter aerosol (at wind speed of 14 m s^{-1} for a clean probe compared to probe which had one-third of the flow passages between the inside of the shroud and the inner nozzle blocked. This "one-third blockage rule," as determined by a visual inspection, has been adopted as the criterion for determining when the Station A samplers' performance has been compromised.

PURPOSE AND SCOPE

Concerns over salt fouling the probes have persisted despite the results of the laboratory studies of aerosol transmission efficiencies cited above. It is worth emphasizing that to this point there is no empirical evidence indicating that a problem actually exists with the samplers. Indeed, a preliminary study based on data for ^{7}Be and ^{210}Pb (EEG-88, 2003) indicates that neither water in the exhaust shaft nor salt fouling of the probe had a significant effect on the collection of aerosol particles larger than 2 micrometers at Station A. That report also concluded with remarks to the effect that Station A samples were representative of the WIPP exhaust air stream.

Even so, in meetings of the Effluent Monitoring Improvement Group (EMIG), several possible solutions for mitigating the salt encrustation problems have been identified, discussed, and in some cases implemented. First and simplest, it was suggested that sampling and maintenance protocols could be changed to reduce the amount of salt build up and corrosion to the probe surface. Changes in these procedures have in fact been implemented. Second, a more quantitative approach was tested for evaluating and tracking the extent of the salt encrustation problems. The prototype system for this was based on a computerized light-measuring device, but preliminary tests indicated that technical problems involving the depth of field of the images limited its usefulness. Third, an assessment has been performed to evaluate metal coatings that could be applied to the probes to forestall the formation of salt crusts; results of that study were the subject of a report from CEMRC to Washington TRU Solutions (CEMRC, 2004).

The purpose of the tests reported here was to directly address the salt-fouling sampling concerns and secondarily to provide information on primary skid vs. back-up skid variability. It is important to emphasize that no judgments are made about the performance of the probes relative to compliance issues. Rather, this was simple, field-oriented approach for evaluating the effects of probe fouling: the strategy for the studies was to compare the performance of clean versus occluded probes *in situ*. Preliminary studies showed good comparability for trace element and aerosol mass data produced for matched sets of filters collected with the SOR and BUS (see below page 11-32 and 11-42). The comparisons presented here are between normal SOR (Skid A3) filters versus samples collected using an experimentally-occluded (XO) probe deployed at Skid A2.

We note that an alternative strategy for evaluating the salt encrustation problem would be to conduct transmission tests of occluded probes taken from Station A, using test methods similar to those employed by Chandra et al. (1993). While such studies would likely be revealing and may be desirable at some point in the future, they were not pursued at this point because they require access to test facilities, including a wind tunnel, not locally available.

EXPERIMENTAL PROCESS DESCRIPTION

As a major part of its WIPP Environmental Monitoring (WIPP-EM) Program, CEMRC routinely monitors aerosol mass and both gross alpha and beta activities in individual, daily, filter samples collected at Station A. In addition, trace element concentrations are determined for weekly composites of these filters. The methods employed in the Station A studies along with selected results have been presented in the CEMRC annual reports starting in 1999, and a data archive for the WIPP-EM, including the FAS data for Station A, has been established. These WIPP-EM analyses also have provided baseline data that were used in designing the probe-fouling studies.

The strategy for the *in situ* probe-fouling studies is to compare four matched quantities between samples collected with the SOR at Skid A3 vs. an intentionally occluded XO probe deployed at Skid A2; these quantities are: (1) aerosol mass concentrations (micrograms per cubic meter of air sampled)[3], (2 and 3) gross α and β activities reported in several different ways, and (4) trace element concentrations (micrograms per cubic meter). The analyses of the SOR filters were part of the continuing WIPP-EM project, and the additional analyses required for the probe-fouling study were those involving the filters collected with the occluded sampler and the BUS filters.

Quarterly, or more recently (beginning in October 2004) monthly, composites of the FAS samples also are analyzed for a selected set of actinides, but with one exception, the actinide activities have been below method detection limits, and therefore those methods and results generally cannot be used to address the probe-fouling issues of concern here. It is worth noting, however, that the ^{239,240}Pu activities in the SOR and BUS were found to be similar in composites of the second quarter samples from 2003 (see CEMRC Annual Report for 2003). As the fouling study is predicated on comparability

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[3] A limited comparison of matched gravimetrics data for samples collected from Skids A3 and A2 is discussed beginning on page 11-42.

between matched samples collected at Skids A3 and A2 (see Appendices 1 and 2), the similarity in actinide data for the two sets of quarterly samples can be taken as further evidence for good comparability for the sampler of record and back-up unit.

The experimental design called for the space between the shroud and probe on the outlet side of the unit to be occluded in increments (Figure 11.1). Routine inspections of the probes prior to the study showed that fouling was most commonly seen in this portion of the sampler, not the inner nozzle. A probe with one-third of the shroud exhaust occluded was installed at Skid A2 on July 11, 2005. (The installation date was delayed from June 13, 2005 because of problems with birds nesting in the crane. See Table 11-1 for chronology of deployments) Duct Seal™ (Panduit, Tinley Park, IL), a commercially available mastic, was installed in a clean probe between the shroud and the probe near the outlet end of the unit, i.e., the side closer to the filter. For the first test of an occluded probe, one of the three segments was completely sealed with the Duct Seal™ (see Figures 11.2-11.11 for pictures of the probes).

Sample collection from the 1/3 occluded probe began on 27 July 2005. This meant that there were twelve pairs of matched daily samples for comparison for the first test.

The Station A, skid A-2, (1/3 occluded) probe was changed again on the morning of 8 August 2005. On that date, the probe with 1/3 blockage was removed and the 2/3 occluded probe was installed. The Station A, skid A-2, (2/3 occluded) probe was changed on the morning of 12 September 2005 when the probe with 2/3 blockage was removed and the fully occluded probe was installed. The 2/3 occluded probe was removed, and the fully occluded probe was installed on 12 September 2005. Sampling for the final test was concluded on 10 October 2005 when the fully occluded probe was retrieved.

The paired sets of daily SOR and XO FAS filters (that is from skids A3 and A2) were removed from the samplers at Station A and returned to CEMRC where they were desiccated and weighed. After allowing for the decay of short-lived radon daughters, the filters were counted for gross α and β activities with the use of a Canberra LB4100 gas proportional counter (see below page 11-32). Following those analyses, the filters were digested and analyzed for trace elements using the same methods and procedures that have been used for the FAS studies since the inception of the program (see below page 11-42). Weekly composites were prepared from the digestates of the individual filters, and these composite samples were then analyzed for a suite of trace elements by inductively-coupled plasma mass spectrometry (ICP-MS). These elemental methods can provide data for up to ~35 elements, but in practice the concentrations of some elements, including As, Be, Cd, Er, Eu, Sc, Se, Sm, Tl and V are often below detectable or quantifiable levels, and a second set of elements (notably Ag, Li and Sn) have variable concentrations in blank filters which makes their quantification difficult. These two sets of "problem" elements are normally excluded from the data analyses.

The aerosol mass loadings, gross α and β activities, and trace element concentrations (quantified both as mass per filter) were compared to evaluate the differences between the clean probe at A3 and the incrementally occluded probes at A2. These comparisons were based on graphical analyses and in some cases, paired t-tests and correlations between the two sets of samples were calculated using standard statistical procedures and commercially available statistical software (JMP, SAS Institute, Cary North Carolina).

Results and Discussion

Mass Concentrations

At the standard flow rate of 2 cfm (~56 l min^{-1}), each FAS filter should sample ~80.6 m^3 of air during a 24 hr period. This can be seen as a large number of points in a horizontal band at this approximate volume in Figure 11.12, but samples with lower than expected volumes also are evident in that figure. In eight of the low-flow cases (SOR with start dates on 8/8 and 9/26; XO on 7/29, 8/5, 10/2, 10/3, 10/8; BU on 9/26), the flow rates fell to less than ~90% of the standard flow, and the filters were quickly replaced, generally in the afternoon or early evening. In four other cases, all involving the SOR, (with start dates of July 27 and 31 and August 15 and 17), the sample runs were terminated prematurely due to low flows, but the filters were not replaced until the next morning. For each of these cases, the flows for the BU sampler were normal, however, and therefore the continuity of effluent sampling was not compromised.

A time-series plot of aerosol mass concentrations for all samples (Figure 11.13) shows that the three (SOR, XO, and BU) samplers generally had similar aerosol loadings, but on several days, the filters from the XO samplers had obviously higher mass loadings. These elevated mass loadings always occurred towards the end of the test periods and only during the 1/3 and 3/3 occluded sampler deployments, i.e., this effect was not seen for the 2/3 occluded sampler. One BU filter, with a start date of 8/18, showed an anomalously high mass concentration, but a check of the flow records showed that the filter in question had several abnormalities; specifically, the chain of custody form stated the skid was down, but the flow file data indicated that the filter ran in low-flow from approximately 17:49 to the end of the run.

An important point that can be seen in Figure 11.13 is that XO samples with high mass concentrations were not isolated cases involving single filters. Rather, for each of the four, XO, low-flow/rapid replacement scenarios mentioned above, the mass loadings were elevated on the second filter of the pair as well as the first. This suggests that the cause for the increased aerosol loading was not a discrete pulse of air enriched with particulate matter, but rather the elevated masses were the result of a process or processes with timescales probably of the order of hours.

Another way to consider the effects of the occlusions on the performance of the samplers is by direct, point-by-point comparisons between samples collected with the SOR and XO. Such comparisons require that the two samplers collected particles from comparable volumes of air during the same period time. Therefore, the first step for this part of the data analysis was to match the samples by volume and time, and these direct comparisons were made only when the difference in the volumes for the SOR and XO samples was less than or equal to 10%. This is an arbitrary value that was chosen to retain almost all of the samples while also keeping the difference in volumes sampled to a reasonable level.

In six cases involving low-flow SOR and XO filters with prompt replacements, the net masses and volumes for the initial and replacement filters were summed and the summed net masses were divided by the summed volumes to calculate the composite mass concentrations (micrograms per cubic meter). In a seventh case, involving the SOR sample which was started on August 9, the composite volume was less than 10% of that of the XO sampler, and as a result this pair of samples was excluded from the direct comparisons. In all but one other case in which the SOR and XO volumes differed by more than 10%, the samplers ran for near the normal 24 hour period, but the flows were ~50% to 95% of normal. In the final excluded case (SOR 8/23 to 8/24), the volume of air sampled was only about 4 m^3 because the sampler was shut off during an underground CAM alarm. The volumes for the matched samples are shown as a time-series plot in Figure 11.14.

A time-series plot of the matched gravimetric data (Figure 11.15) shows much the same features as the unscreened data, that is, the mass concentrations for some of the 1/3 and 3/3 occluded XO samples taken late in the deployments were higher than the matched SOR filters. An x-y plot of the matched SOR vs. XO gravimetric data (Figure 11.16) shows that most of the mass concentrations for the matched samples fall along a 1:1 line, which demonstrates that the aerosol loadings obtained with the occluded sampler most often were similar to those of the SOR. However, there is a second field of points that are clearly above the 1:1 line, indicating that the occluded sampler sometimes had higher loadings than the SOR. The largest difference is for the samples collected from October 3 to 4; the RPD for this pair of samples was 1.87, reflecting a difference of over 60-fold.

Summaries of the gravimetric data for each of the three deployments, calculated separately for all samples and for the matched sample pairs are presented in Tables 11-2 to 11-4. The most notable result from the studies, as mentioned above, is that the XO sampler had higher mass concentrations than the SOR in some cases but only in the 1/3 and 3/3 occluded tests. The RPDs between the SOR and XO sampler in the 2/3 occluded test were only -12.7% and -6.2% compared with PRDs of ~100 for the four other cases in the 1/3 and 3/3 occluded tests. As shown in these tables, the XO collected on average approximately three times as much mass as the SOR during the 1/3 and 3/3 deployments.

The reason for the differences in results among studies with different levels of occlusion is not clear. Possible influences that might be considered for follow-up analysis are changes in the relative humidity in the underground and differences in the level of mining activities during the three phases of the study.

Another important result that can be seen in the summary tables of the gravimetric data is that the relative standard errors (RSEs, that is, the standard errors divided by the means) are much larger for the XO sampler compared with the SOR, but again only in the 1/3 and 3/3 occluded tests. Indeed, the large RSEs for the XO sampler in the 1/3 and 3/3 occluded tests are a reflection of the fact that the high mass loadings occurred in a relatively small number samples; this point also can be seen in Figures 11.13 and 11.15.

There are at least two possible explanations for the differences in the amounts of material collected by the SOR and XO samplers. The first is that the XO sampler collected more aerosol particles than the SOR, and the second is that the XO sampler collected some non-aerosol material that the SOR did not. The gross α and β data discussed in the next section provide some insight into which of these explanations is more likely.

4.2. Gross Alpha and Beta Activities

Time-series plots of the gross α and β data for the SOR and XO samplers are presented in three ways: (1) as activities per filter (Figure 11.17), (2) as activity concentrations (i.e., the activity per cubic meter of air, in Figure 11.18), and (3) as activity densities (i.e., the activity per gram of aerosol, in Figures 11.19 and 11.20, with the latter showing the data plotted on a logarithmic scale). These plots show that the SOR and XO filters generally had similar gross α and β activities when the data were calculated as activity per filter or as activity per cubic meter of air (Figures 11.17 and 11.18, see also Tables 11.5 to 11.7). There were several instances when one sampler or the other had a higher activity or activity concentration, but no clear or persistent trends were evident when the data were plotted in this way. For example, for several days in late September and early October, the gross α activities for the XO sampler were somewhat higher than those of the SOR, but within a day, the good agreement between samplers returned. Along these same lines, there were three or four isolated incidences of higher gross β activity concentrations for the SOR during the 2/2 XO occluded sampler deployment, but this was not consistently the case for that deployment or the others, and furthermore, corresponding differences between samplers were not seen in the gross α data for the same time period.

Graphs of the gross α and β activity densities, that is the activities divided by the accumulated aerosol masses (Figures 11.19 and 11.20), are especially revealing because the results plotted in this way show some important information with respect to the material responsible for the additional mass collected by the XO sampler. The first point that stands out in these graphs is the high activity densities for two samples from the SOR, one collected from 8/30 to 31 and the other on 9/19 to 20. Further inspection of the data shows that the high activity densities for these samples were the result of low masses (< 1 microgram per cubic meter) rather than differences in the activities of the α and β emitters. As shown above in Tables 11-2 to 11-4, the mean filter masses, which ranged from 56 to 308 $\mu g\ m^{-3}$, were many times higher than what was recorded for these filters; there is, however, no basis for discounting the gravimetrics results for the two anomalous filters.

The more important finding regarding the material collected by the XO sampler can be seen in Figure 11.20, in which the activity densities are plotted on a logarithmic scale. This figure shows that both the gross α and β activity densities for the XO sampler were low in those samples that had elevated mass loadings towards the end of the 1/3 and 3/3 occlusion deployments (see Figure 11.13). This means that the material responsible for the high mass loadings had lower levels of α and β activity per unit mass than is typical of the aerosols normally collected by the samplers.

Salt that had sloughed off of the occluded sampler is the most obvious and likely candidate for the low α and β emitter collected by the XO probe. As shown in the pictures of the occluded probes (Figures 11.3, 11.6, 11.7, 11.10 and 11.11), these samplers had become encrusted with salt. If the additional mass is in fact the result of salt sloughing, one would predict from the plots presented in Figure 11.20 that the encrusting salt would have ~0.1 Bq of alpha activity and ~0.5 Bq of beta activity per gram compared with activity densities of roughly 10 Bq g^{-1} (α) and 50 Bq g^{-1} (β) for aerosols that have been collected with the FAS samplers. The trace element data discussed in the follow section provide some additional insights into the type of material responsible for the high mass loadings in some of the XO samples.

Trace Elements

The elemental data presented here are for composite samples prepared by combining the digestates of individual filters that were prepared with the use of strong acids and a microwave digestion unit. The first XO and SOR sample pair do not match precisely in time because the XO collections commenced between the days on which composite batches were normally started.

The first focus of the analysis of the trace element data was on a set of elements found to satisfy three criteria in the baseline comparison of the SOR with the BU sampler: (1) absolute values of the RPDs between sampler means that were less than or equal to 15%, (2) correlations greater than 80% and (3) data for all thirteen sample pairs (see Appendix 2). Even though these criteria are arbitrary, they do provide a way to select a group of elements that showed good agreement between samplers in the preliminary studies. For convenience, this group of elements, which is composed of Al, Ba, Ce, La, Na, Nd, Pb, Th and Zn, is collectively referred to as Group A. The working null hypothesis for this part of the study was that the test occlusions would have no effect on the XO sampler's collection efficiency, and therefore, the concentrations of the elements would be similar for the SOR and XO samples.

Timeseries plots of the Group A elements (Figure 11.21) shows that with several exceptions, the concentrations for the SOR and XO samplers did indeed agree well. The first exception was the set of Al samples collected in September and October. In those samples, the SOR Al concentrations were 3 to 15 times those of the XO sampler. The reasons for the difference in Al concentrations are unknown, but this element is commonly used as an indicator of mineral dust (e.g., Arimoto et al., 2005), and one cannot exclude the possibility that the samplers simply collected some different materials. On the other hand, what is curious is that other Group A elements, i.e., Ce, La, and Nd, that also are typically associated with mineral dust (Rahn, 1976) showed very good agreement between samplers, except for the first sample pair. In fact, the correlations between the SOR and XO sampler for the ten matched sample pairs were 0.96, 0.93, and 0.94 for Ce, La, and Nd, respectively.

While the first pair of samples was slightly mismatched, it is worth noting that the XO composite had consistently higher concentrations of the Group A elements compared with the SOR (see Figure 11.21 and Section 4.1 above). This is consistent with the observation that the XO filters from the last part of the 1/3 occlusion study that had high mass loadings. Furthermore, the Na concentrations showed much higher concentrations in the XO composite pair and also in the composites for the samples collected towards the end of the 3/3 occlusion study.

The observed differences in the elemental mass concentrations between the SOR and XO sampler were small, and this is further evidence that the experimental occlusions did not compromise the performance of the XO probe. Summary tables for the Group A elements (Table 11-8), show that with the Al was the only element for which the absolute value of the RSD between the SOR and XO sampler exceeded 15%. There were too few samples for a meaningful comparison of Th results, but the RPDs for all other elements ranged from 0 to 14%, with those for Ba, Ce and Zn less than 5%.

Plots of other elements that did not satisfy the Group A criteria are presented in Figure 11.22. Even though the comparability in the preliminary studies was not as good as the elements considered above, this group (Group B) does provide some information on the composition of the material that we hypothesize was responsible for the high mass loadings. In particular, extremely high concentrations of Ca, Mg, and K were found in the XO composites prepared from the latter parts of 1/3 and 3/3 occlusion studies, and this was when the high mass loadings occurred. These elements are likely to be major components of the salt crusts that formed on the occluded probe, and these findings thus support the notion that the sloughing of encrusting salts lead to the high mass concentrations in some of the XO samples. In anticipation of possible follow up studies, some samples of the encrusting salts were collected during a routine probe pull, and these are available for subsequent analyses.

COMPARISON OF GRAVIMETRIC, GROSS ALPHA AND GROSS BETA DATA FOR AEROSOL SAMPLERS AT STATION A

Objective

The Probe-fouling Study at Station A was predicated on comparability between sampling skids, and this preliminary study was conducted to establish that samples collected with the use of a Back-Up Sampler (BUS, usually Skid A2) were similar to those collected with the Sampler of Record (SOR, most often Skid A3). The data used for this study were the aerosol mass concentrations (mass per unit volume of air sampled, i.e., micrograms per cubic meter) and the gross alpha and gross beta activity concentrations (activities per unit volume of air). These data were collected with paired fixed air samplers (FASs).

Approach

Gravimetric analyses of FAS filters from the Station A SOR have been conducted by CERMC since early December 1998, which was when the Center's WIPP-environmental monitoring (EM) program began. In preparation for the Probe-fouling Study, mass determinations for the BUS began in October 2004, and this continued up until July 2005, when the occluded probe was installed. The gravimetric analyses were performed using the same procedures for all samples. Briefly the weighing procedure involved conditioning the filters for at least 24 hr in a dessicator prior to weighing both before and after sampling. The filters are weighed using a microbalance (Mettler UMT 2) to 0.01 mg. The aerosol mass is simply calculated as the filter plus accumulated aerosol mass after sampling minus the filter mass before sampling.

Gross alpha and beta concentrations in FAS filters were determined using the Canberra LB4100 Gas Proportional Counter (GPC). Quality Assurance activities conducted for this project include using an attenuation curve to calibrate detector efficiency, tracking and verification of analytical instrument performance daily, and use of NIST-traceable radionuclide solution control sources. In addition, a 60-minute instrument background history is established as part of the instrument quality assurance. Instrument backgrounds are monitored using an empty planchet holder and a count time of 60 minutes.

Filters were loaded onto the stainless steel planchets and counted for a preset time of 20 hours (1200 minutes). No special preparations were needed to count the filter samples. After the completion of the count, the gross alpha and gross beta raw data counts were used with the sample preparation data (gravimetric data), volumes, calibration data and background history to calculate the sample results using Microsoft Access™.

The comparisons between the SOR and BUS were based on two types of statistical analyses. All statistical analyses were performed using JMP IN Release 5.1.2 – Windows (Academic Product) Copyright 1989 - 2004 SAS Institute Inc. First, paired comparisons were performed to determine whether the SOR and BUS samples had the same aerosol mass concentrations and the same gross alpha and beta activities. These were two-sided, paired Student's t-tests. Twenty-four pairs of samples were excluded from the test comparing gravimetric data because of large (2-fold) differences in the volume of air sampled. Likewise, fourteen pairs of samples were excluded from the gross alpha and gross beta comparisons for the same reason. Such large differences in sampling volumes most often occurred during routine probe pulls.

The second statistical method used to compare the matched gravimetric and gross alpha and gross beta data for the SOR and BUS was an orthogonal regression. This, not the standard least-squares model, which is commonly used, is the preferred method for regressing two variables when both have measurement errors associated with them. The orthogonal regression model is sometimes referred to as a functional regression. The assumption of equal variances was made for the FAS regressions, and this is supported by the similar standard deviations shown in Tables 11-9, 11-10 and 11-11 (below).

Results and Discussion

Paired- t Tests

Summary statistics and the results of a paired t-test comparing the matched gravimetric data from the SOR and BUS are presented in Table 11-9. This comparison of mass concentrations is based on 260 sample pairs, and it shows that the relative percent difference (RPD) calculated from the means for the SOR (86.02 μg m^{-3}) and BUS (86.45

μg m^{-3}) is only 0.5%. The RPD is calculated as the difference between the arithmetic means for the SOR and BUS divided by the average of the two means This comparison thus demonstrates very good agreement in mass concentrations between matched samples from the two skids. Results of a paired t-test indicate that the probability (p) for obtaining a greater absolute t-value by chance alone when there was zero difference in means is $p > 80\%$. Traditionally, a null hypothesis of zero difference in means would be rejected if $p \leq 1\%$ or $p \leq 5\%$. For this test, then, the probability for chance occurrence is such that one would accept the null hypothesis that there was no difference in the mean mass concentrations as determined from the SOR and BUS.

Results of the paired t-tests comparing the gross alpha and gross beta data for the SOR and BUS are presented in Tables 11-10 and 11-11. These comparisons show that the RPDs between the means for the SOR and BUS were 2.5% and 5.4% for the gross alpha and gross beta activities, respectively. These results confirm the good agreement between the two skids as was indicated by the gravimetric data discussed above. The t-ratio calculated for the paired gross alpha activities indicates that the difference in means between the SOR and BUS was not significant, but the probability for the paired t-test of gross beta activities was $p = 0.0035$, which is clearly significant from a statistical standpoint. However, the difference in means was only 5.4%, and therefore, while there was a systematic difference in activities, the difference was small. It is also worth noting that the gross beta counts were generally closer to the minimum detectable activities than were the gross alpha counts.

Time-series Plots

Time-series (Fig. 11.23 and 11.24a-c) plots are presented to graphically illustrate the close agreement between the gravimetric data for the SOR and BUS. In addition to a plot of the entire dataset, three months were chosen to illustrate the close agreement in the gravimetric data for periods of low, high, and intermediate aerosol loadings, these are represented by the months of October 2004 (Figure 11.24a), December 2004 (Figure 11.24b), and May 2005 (Figure 11.24c), respectively. While not useful for assessing statistical significance of the differences between samplers, no evidence of systematic differences between the SOR and BUS is seen in any of these plots of the gravimetric data.

The corresponding time-series plots for the gross alpha and gross beta activities do show some trends in the data, however. As shown in Figure 11.25a, the gross alpha activities measured by the SOR were consistently lower during the first month of the comparison, i.e., in October 2004, but the trend was reversed beginning in December 2004. During the first part of the study the difference was larger, in some cases exceeding 50%, but during the latter part of the study the differences, although consistent, were small, 5% to 10%. The gross beta activities (Figure 11.25b) also showed systematic differences during October 2004, but these differences were generally small, < 10%. Interestingly, the reverse trend as seen in the gross alpha counts was not observed for the gross beta data for December 2004.

Orthogonal Regression Analyses

The orthogonal regression of the mass concentration data (A3 data as X and A2 as Y) produced an intercept of -3.25, a slope of 1.033, and a correlation of 0.912. The corresponding regressions for gross alpha and gross beta activities had intercepts of 0.00004 and -0.00002, slopes of 0.82 and 0.99, and correlations of 0.89 and 0.98, respectively. These results for the gravimetric and gross beta data show that the SOR and BU samplers produced data that agreed to within 1% to 3%, while the agreement for the gross alpha comparison was 11%.

COMPARABILITY OF TRACE ELEMENT DATA FROM AIR SAMPLING TWO SKIDS AT STATION A

Background

Concerns have been raised about the sampling of effluent air from the WIPP exhaust shaft (Webb et al., 2004). The specific concern expressed was that:

> "since the concentration of salt particles and water aerosol is different from one side of the shaft to the other (Fig. 4), the concentration of radioactive particles may be different from one side of the shaft to the other and it may be difficult to collect a representative sample from a single point at Station A."

Recently, a set of air samples collected during the second calendar quarter of 2003 using the "back-up" sampling skid at Station A was provided to CEMRC for a special study. In preparing the samples for that study, whose results have been reported elsewhere, individual filters from the back-up (fixed air) sampler (BUS) were digested, and weekly composites were prepared for trace element determinations using the same methods previously used for the filters from the sampler of record (SOR). The trace element data for the two sets of filters thus provide the opportunity to directly compare results obtained with the SOR and BUS, and in so doing address the representativeness issue raised by EEG. While the results presented here are mostly for non-radiological constituents, two radioactive elements U and Th are included in the analyte list. This appendix summarizes the results of the comparisons.

Samples and Methods

CEMRC routinely determines the concentrations of trace elements in weekly composite samples prepared from the Station A filters as part of its WIPP Environmental Monitoring (WIPP-EM) Program. The methods employed in those studies along with selected results have been presented in the Center's annual reports starting in 1999. A data archive for the WIPP-EM has been established, and this includes the trace element data for the weekly composites prepared from the SOR at Station A. As noted above, a second set of weekly composites was recently prepared from filters collected with the BUS during the second calendar quarter of 2003. The matched trace element data for the SOR and BUS weekly composites from that quarter are the basis for the comparisons presented here

Both sets of FAS samples were prepared and analyzed by the same methods, but they were prepared and analyzed more than six months apart in time, using different reagents, standards, calibrations, etc. Briefly, the individual filters were digested using a mixture of strong acids in a microwave digestion unit, and weekly composites were prepared from the digestates of the individual filters. The weekly composites were then analyzed for a suite of trace elements by inductively-coupled plasma mass spectrometry (ICP-MS). The instrumental methods can provide data for up to ~35 elements, but in practice the concentrations of one set of elements, including As, Be, Cd, Er, Eu, Sc, Se, Sm, Tl and V, are often below detectable or quantifiable levels, and a second set of elements (notably Ag, Li and Sn) have variable concentrations in blank filters which makes their quantification difficult. These two sets of "problem" elements are excluded from the analyses that follow.

The SOR and BU sampler collected slightly different volumes of air during the second quarter of 2003; the SOR sampled a total of 6899 cubic meters of air while the BUS collected 7537 cubic meters. To enhance comparability between data sets, the data for each weekly composite from the BUS were normalized to the SOR by adjusting for the average percentage difference in flow volumes (i.e., 6899/7537). In addition, there also was one day (3/31/03) for which a BU sample was not available, but that minor difference in the data sets was not taken into account.

Results and Discussion

Differences in the trace element concentrations in the matched weekly SOR vs. BUS composites were tested for statistical significance through paired t-tests. For these tests, higher t-values indicate a greater likelihood for real differences between pairs—this is reflected in a lower probabilities for chance occurrence, which are denoted as Prob >|t|. As shown in Table 11-12, the results of these tests show that for most elements, the concentrations obtained with the SOR and BUS were not statistically different. The average probability for a obtaining a greater absolute paired t-value by chance alone, assuming no difference in sample means (that is the null hypothesis), was 0.22. Only two elements (Dy, whose concentration was close to its minimum detectable level of ~0.015, and Fe) had Prob > |t| less than 0.01, that is, low enough to be statistically significant; but several elements (Al, Mg, Mn, Mo, Na, Ni, Sb, Si and Sr) had Prob > |t| values between 0.01 and 0.05, and these would likely be construed as marginally significant.

An estimate of the relative percent difference (RPDs) for each element in the two sets of samples was calculated as the difference between the arithmetic mean concentrations for the SOR and BUS divided by the average of the two means. The ensemble average RPD for all elements was only -13% (Table 11-12), indicating that the BUS had, on average, slightly higher concentrations than the SOR. There are no established standards for comparability of paired aerosol samplers, but to place this difference in perspective, the allowable relative percent difference for duplicate analyses of given element in a single sample (simultaneous preparation) by ICP-MS is ± 20% (EPA Method 6020). Seventeen of the twenty-six elements had RPDs for the paired SOR vs. BUS composites that were less than or equal to 20%; this means that the observed differences between the SOR and BUS for the majority of elements in the study were comparable to, if not less than, the method precision of the ICP-MS.

In addition to the comparisons of concentrations by the paired t-tests and the calculation of RPDs, correlations between the results for the SOR and the BUS were calculated. There were thirteen pairs of weekly composites available for this statistical analysis (for some elements, the number of pairs were less than thirteen owing to concentrations below detection limits), and for reference, at twelve degrees of freedom, the correlation coefficients at the 5% and 1% levels of significance are 0.532 and 0.661, respectively. Results of the analyses show that in almost all cases where the differences in the paired t-values were significant or marginally significant, the concentrations in the paired SOR and BUS composites were highly correlated. In fact, the average correlation for all elements was 0.79, and the correlations for only two elements (Mg and Sr) were not statistically significant, while three others (Cu, K, and Sb) were marginally significant. The results of the correlation analyses are important because they show that even for those elements whose mean concentrations differed between the two samplers, the data for matched samples were strongly correlated. Therefore, one can conclude that even if there were a slight systematic offset in concentrations between the SOR and BUS, either set of samples is arguably representative of the other.

While most of the elements in the study are non-radiogenic, the concentrations of two radioactive elements, Th and U, were determined by the ICP-MS (their concentrations were calculated based on natural isotopic abundances). The RPDs for Th and U were extremely small, -2% and –6%, respectively, and the Prob > |t| for the concentration differences measured by the paired t-tests were clearly not significant (Table 11-12). The correlation coefficients for both U and Th in the two sets of samples were highly significant (0.92 and 0.83). Thus, by all measures, the concentrations of these two radionuclides in the paired SOR and BUS samples were in close agreement.

In summary, the results of direct comparisons of trace element data presented here show that in the overwhelming majority of cases, the differences between the SOR and BUS were insignificant. The differences in concentrations between the SOR and BUS, as determined by paired t-tests, were significant at $p < 0.01$ for less than 10% (2 of 26) of the twenty-six elements considered. Furthermore, for more than 80% (21 of 26) of the elements investigated, the correlation between the paired samples was significant at $p < 0.01$ and for three more elements the correlations were significant at $0.01 < p < 0.05$. This study of trace elements in exhaust air from the WIPP thus demonstrates a high degree inter-comparability between the sampler of record and the back-up sampler.

Conclusions

In summary, the first part of the overall picture that has emerged from the probe occlusion study is that the XO probe and SOR collected comparable amounts of α and β emitting aerosol particles. That is, the differences between the XO probe and SOR in terms of gross α and β activities per filter and activity concentrations were reasonably small, of the order of 10 to 30% (see Tables 5 to 7). This was true for all three levels of occlusion. Furthermore, there was no consistent pattern in terms of which sampler had higher activity, and higher alpha activities in a given set of XO or SOR filters did not necessarily correspond with higher beta activities in that same set of filters. For the most part, both the gross α and the gross β activities of filters from the two samplers also tracked each other well, showing that the occluded sampler captured the variability in the gross α and β emitters as well as the mean values.

The XO sampler did become encrusted with salt to a greater extent than the unblocked sampler, and analysis of the gravimetric data showed that filters collected with the occluded sampler did have systematically higher masses than the SOR in some cases. The elemental data suggest that Ca, Mg, K, and Na contributed to the high mass loadings, most likely due to the sloughing of encrusting salts. Despite greater propensity for salt fouling of the XO probe, these results indicate that the intentional occlusion of the test probe did not lead to significant over- or under-sampling of gross α or β emitters or trace elements in the WIPP exhaust airstream.

Recommendations

The analyses presented here suggest that as salt built up on the surface of the probe, some of the encrusting material sloughed off the probe and was collected on the filter. That salt is predicted to have lower concentrations of alpha and beta emitters compared with the aerosol particles normally collected at Station A. Therefore, determinations of α and β activity for samples of the encrusting salt are recommended as follow-up studies to test the predictions regarding sloughing of salt from encrusted probes. These analyses could be performed at CEMRC. Similarly, elemental analyses of the encrusting salt would be useful for assessing the composition of the excess material collected by the probe and further testing the hypothesis regarding the sloughing of the salt crusts. Follow-up analyses of flow data and information on the relative humidity in the underground also may provide additional insights into the performance of the aerosol samplers used for exhaust-air compliance monitoring.

Table 11-1: Comparisons for the Probe Occlusion Tests

Start	Stop	Test	Comparisons		
			Daily		Weekly
			Mass	Gross α & β	ICP-MS
4/1/2003	6/30/2003	Primary vs. Backup	---	---	Yes
10/1/2004	12/21/2004	Primary vs. Backup	---	Yes	---
10/1/2004	7/11/2005	Primary vs. Backup	Yes	---	---
7/27/2005*	8/8/2005	Primary vs. 1/3 Blocked	Yes	Yes	(Yes)
8/8/2005	9/12/2005	Primary vs. 2/3 Blocked	Yes	Yes	(Yes)
9/12/2005	10/10/2005	Primary vs. 3/3 Blocked	Yes	Yes	(Yes)

*One-third occluded probe was installed on 7/11. Sampling began on 7/27

Table 11-2: Comparison of Gravimetric Data: 1/3 Occluded XO Probe vs. Sampler of Record (SOR)

Group	Sampler	Count	Mean µg m^{-3}	Standard Error µg m^{-3}	RSE	RPD
All Samples	SOR	12	90.31	7.77	8.6%	109.5%
	XO	14	308.77	79.47	25.7%	
Matched Pairs	SOR	9	86.01	10.00	11.6%	94.7%
	XO	9	240.69	70.46	29.3%	

RPD stands for Relative Percent Difference, see text for explanation.

Table 11-3: Comparison of Gravimetric Data: 2/3 Occluded XO Probe vs. Sampler of Record (SOR)

Group	Sampler	Count	Mean µg m^{-3}	Standard Error µg m^{-3}	RSE	RPD
All Samples	SOR	36	65.67	9.77	14.9%	-12.7%
	XO	35	57.84	7.30	12.6%	
Matched Pairs	SOR	29	59.96	8.53	14.2%	-6.2%
	XO	29	56.33	8.16	14.5%	

RPD stands for Relative Percent Difference, see text for explanation.

Table 11-4: Comparison of Gravimetric Data: 3/3 Occluded XO Probe vs. Sampler of Record (SOR)

Group	Sampler	Count	Mean µg m^{-3}	Standard Error µg m^{-3}	RSE	RPD
All Samples	SOR	33	68.17	7.91	11.6%	117.9%
	XO	35	263.87	66.59	25.2%	
Matched Pairs	SOR	26	61.56	6.91	11.2%	100.8%
	XO	26	186.66	60.46	32.4%	

RPD stands for Relative Percent Difference, see text for explanation.

Table 11-5: Comparison of Gross Alpha and Beta Activities: 1/3 Occluded XO Probe vs. Sampler of Record (SOR)

Variable	Sampler	All Samples				Matched Pairs			
		Count	Mean	Std Error	RPD	Count	Mean	Std Error	RPD
Volume (Cubic meters)	SOR	12	77.67	4.76	-23.2%	9	82.90	0.25	-6.2%
	XO	14	69.09	6.13		9	80.42	0.95	
Alpha Activity (Bq/filter)	SOR	12	1.64E-02	1.68E-03	-4.8%	9	1.79E-02	1.90E-03	-7.6%
	XO	14	1.60E-02	1.92E-03		9	1.72E-02	2.07E-03	
Alpha Activity Concentration (Bq/m3)	SOR	12	2.21E-04	2.38E-05	5.3%	9	2.17E-04	2.33E-05	9.3%
	XO	14	2.27E-04	1.43E-05		9	2.28E-04	1.93E-05	
Alpha Activity Density (Bq/g)	SOR	12	2.990	0.677	-3.1%	9	3.231	0.876	23.3%
	XO	14	2.934	1.349		9	3.773	2.040	
Beta Activity (Bq/filter)	SOR	12	4.91E-02	4.75E-03	-23.2%	9	5.36E-02	4.96E-03	-24.4%
	XO	14	4.35E-02	4.93E-03		9	4.73E-02	5.11E-03	
Beta Activity Concentration (Bq/m3)	SOR	12	6.42E-04	5.14E-05	1.5%	9	6.48E-04	6.04E-05	-1.8%
	XO	14	6.47E-04	4.91E-05		9	6.41E-04	5.37E-05	
Beta Activity Density (Bq/g)	SOR	12	9.096	2.365	-22.8%	9	10.092	3.105	1.3%
	XO	14	7.923	3.663		9	10.176	5.528	

RPD stands for Relative Percent Difference, see text for explanation. SOR stands for Sampler of Record, XO represents the Experimental/Occluded Probe

Table 11-6: Comparison of Gross Alpha and Beta Activities: 2/3 Occluded XO Probe vs. Sampler of Record (SOR)

Variable	Sampler	All Samples				Matched Pairs			
		Count	Mean	Std Error	RPD	Count	Mean	Std Error	RPD
Volume (Cubic meters)	SOR	36	75.42	4.10	15.1%	30	82.44	2.88	-0.3%
	XO	35	81.93	2.47		30	82.33	2.86	
Alpha Activity (Bq/filter)	SOR	36	1.53E-02	1.40E-03	29.6%	30	1.61E-02	1.45E-03	21.2%
	XO	35	1.82E-02	1.51E-03		30	1.82E-02	1.71E-03	
Alpha Activity Concentration (Bq/m3)	SOR	36	1.96E-04	1.51E-05	20.3%	30	1.96E-04	1.59E-05	19.7%
	XO	35	2.20E-04	1.74E-05		30	2.19E-04	1.95E-05	
Alpha Activity Density (Bq/g)	SOR	36	14.452	8.980	-64.6%	30	16.441	10.759	-71.2%
	XO	35	8.731	1.908		30	9.296	2.194	
Beta Activity (Bq/filter)	SOR	36	5.70E-02	5.55E-03	-10.0%	30	6.13E-02	5.99E-03	-21.1%
	XO	35	5.40E-02	4.86E-03		30	5.49E-02	5.58E-03	
Beta Activity Concentration (Bq/m3)	SOR	36	7.60E-04	5.71E-05	-31.0%	30	7.44E-04	6.54E-05	-24.6%
	XO	35	6.51E-04	5.48E-05		30	6.55E-04	6.25E-05	
Beta Activity Density (Bq/g)	SOR	36	58.603	35.007	-104.7%	30	64.273	41.959	-102.7%
	XO	35	26.444	5.905		30	28.225	6.782	

RPD stands for Relative Percent Difference, see text for explanation. SOR stands for Sampler of Record, XO represents the Experimental/Occluded Probe

Table 11-7: Comparison of Gross Alpha and Beta Activities: 3/3 Occluded XO Probe vs. Sampler of Record (SOR)

Variable	Sampler	All Samples				Matched Pairs			
		Count	Mean	Std Error	RPD	Count	Mean	Std Error	RPD
Volume (Cubic meters)	SOR	29	77.45	3.01	-11.1%	26	78.91	2.53	8.7%
	XO	31	73.22	3.41		26	82.63	0.71	
Alpha Activity (Bq/filter)	SOR	29	1.82E-02	1.32E-03	23.9%	26	1.90E-02	1.35E-03	32.9%
	XO	31	2.08E-02	1.85E-03		26	2.30E-02	1.89E-03	
Alpha Activity Concentration (Bq/m3)	SOR	29	2.36E-04	1.43E-05	32.1%	26	2.43E-04	1.52E-05	31.2%
	XO	31	2.84E-04	2.00E-05		26	2.90E-04	2.00E-05	
Alpha Activity Density (Bq/g)	SOR	29	11.339	5.562	-151.5%	26	12.310	6.186	-137.4%
	XO	31	4.055	0.825		26	4.778	0.919	
Beta Activity (Bq/filter)	SOR	29	5.69E-02	3.85E-03	-22.4%	26	5.94E-02	3.88E-03	-11.2%
	XO	31	5.08E-02	4.06E-03		26	5.61E-02	4.01E-03	
Beta Activity Concentration (Bq/m3)	SOR	29	7.53E-04	4.66E-05	-15.8%	26	7.71E-04	4.97E-05	-16.1%
	XO	31	6.95E-04	3.98E-05		26	7.10E-04	4.16E-05	
Beta Activity Density (Bq/g)	SOR	29	35.514	17.307	-180.6%	26	38.508	19.251	-166.2%
	XO	31	10.451	2.480		26	12.296	2.820	

RPD stands for Relative Percent Difference, see text for explanation. SOR stands for Sampler of Record, XO represents the Experimental/Occluded Probe

Table 11-8: Comparison of Trace Element Data: Experimental/Occluded Probe (XO) vs. Sampler of Record (SOR)

Element	**Aluminum**		**Barium**		**Cerium**	
Sampler	SOR	XO	SOR	XO	SOR	XO
Number of Samples	10	10	10	10	10	10
Mean (ng m^{-3})	117	75	2.53	2.54	0.169	0.151
Standard Error (ng m^{-3})	20	42	0.39	0.44	0.031	0.032
Relative Percent Difference	-32%		-0%		3%	
Element	**Lanthanum**		**Lead**		**Neodymium**	
Sampler	SOR	XO	SOR	XO	SOR	XO
Number of Samples	10	10	10	10	10	10
Mean (ng m^{-3})	0.097	0.084	1.71	1.46	0.062	0.054
Standard Error (ng m^{-3})	0.017	0.019	0.18	0.11	0.015	0.016
Relative Percent Difference	-10%		-11%		-10%	
Element	**Sodium**		**Thorium**		**Zinc**	
Sampler	SOR	XO	SOR	XO	SOR	XO
Number of Samples	10	10	3	2	10	10
Mean (ng m^{-3})	14394	18051	0.027	0.045	73.60	71.13
Standard Error (ng m^{-3})	2363	3220	0.005	0.002	7.96	8.08
Relative Percent Difference	14%		---		-2%	

Table 11-9: Summary Statistics and t-test Results for a Comparison of Aerosol Mass Concentrations on the Sampler of Record vs. Back-Up Filters

Mean Mass Concentration (Standard Deviation) μg m^{-3}		**Mean Difference**	**Std Error**
Sampler of Record	**Back-Up Sampler**		
86.45 (68.36)	86.02 (70.40)	0.43	1.81
Number of pairs	t-Ratio	DF	Prob* > |t|
260	0.238	259	0.812

*Average probability for obtaining a greater absolute paired t-value by chance alone for a difference between sample means of zero

Table 11-10: Summary Statistics and t-test Results for a Comparison of Gross Alpha Activities on the Sampler of Record vs. Back-Up Filters

Mean Gross Alpha Activity (Standard Deviation), Bq m^{-3}		**Mean Difference**	**Std Error**
Sampler of Record	**Back-Up Sampler**		
1.92×10^{-4} (1.52×10^{-4})	2.02×10^{-4} (1.27×10^{-4})	-9.34×10^{-6}	8.24×10^{-6}
Number of pairs	t-Ratio	DF	Prob* > |t|
72	-1.13	71	0.26

*Average probability as defined in footnote to Table 11-9

Table 11-11: Summary Statistics and t-test Results for a Comparison of Gross Beta Activities on the Sampler of Record vs. Back-Up Filters

Mean Gross Beta Activity (Standard Deviation), Bq m^{-3}		**Mean Difference**	**Std Error**
Sampler of Record	**Back-Up Sampler**		
7.10×10^{-4} (4.33×10^{-4})	6.79×10^{-4} (4.28×10^{-4})	3.11×10^{-5}	1.03×10^{-5}
Number of pairs	t-Ratio	DF	Prob* > |t|
72	3.02	71	0.0035

*Average probability as defined in footnote to Table A2.1

Table 11-12: Trace Element Concentrations in Filter Samples (mg per filter) from Station A

Element	Mean Mass in Weekly Composite		Difference between Means	RPD[3]	N-Pairs	Correlation	t-Ratio	Prob > |t|[4]
	SOR[1]	BUS[2]						
Al	284	330	-46	-15%	13	0.815	-2.35	0.037
Ba	3.67	3.60	0.07	2%	13	0.919	-0.37	0.721
Ca	3769	4600	-831	-20%	13	0.768	-2.16	0.052
Ce	0.373	0.333	0.04	11%	13	0.911	1.43	0.177
Cr	40.7	53.8	-13.2	-28%	9	0.835	-2.02	0.078
Cu	13.5	17.5	-4	-26%	10	0.658	-1.78	0.111
Dy	0.024	0.029	-0.005	-19%	8	0.898	-3.60	0.009
Fe	313	519	-206	-50%	13	0.832	-3.86	0.002
Gd	0.033	0.029	0.004	20%	12	0.714	0.89	0.391
K	415	469	-54	-12%	13	0.538	-1.40	0.187
La	0.172	0.179	-0.007	-4%	13	0.915	-0.63	0.538
Mg	811	1330	-519	-48%	13	0.469	-2.89	0.014
Mn	9.26	12.3	-3.04	-28%	13	0.826	-2.93	0.012
Mo	3.50	5.37	-1.87	-42%	13	0.791	-2.64	0.022
Na	26955	30966	-4011	-14%	13	0.859	-2.19	0.049
Nd	0.144	0.136	0.007	6%	13	0.871	0.65	0.529
Ni	16.8	25.0	-8.2	-39%	13	0.847	-2.43	0.032
Pb	2.54	2.77	-0.23	-9%	13	0.811	-1.42	0.182
Pr	0.042	0.040	0.002	7%	13	0.930	-0.92	0.376
Sb	1.76	1.05	0.71	51%	13	0.639	3.07	0.010
Si	1024	1217	-193	-17%	8	0.837	-2.51	0.040
Sr	34.9	49.2	-14.3	-34%	13	0.389	-2.95	0.012
Th	0.051	0.052	-0.002	-2%	13	0.921	-0.47	0.646
Ti	17.1	16.7	0.33	2%	6	0.940	0.30	0.777
U	0.047	0.050	-0.003	-6%	5	0.827	-0.64	0.557
Zn	44.6	51.3	-6.7	-14%	13	0.893	-1.67	0.120
Average				**-13%**		**0.794**	**-1.36**	**0.219**

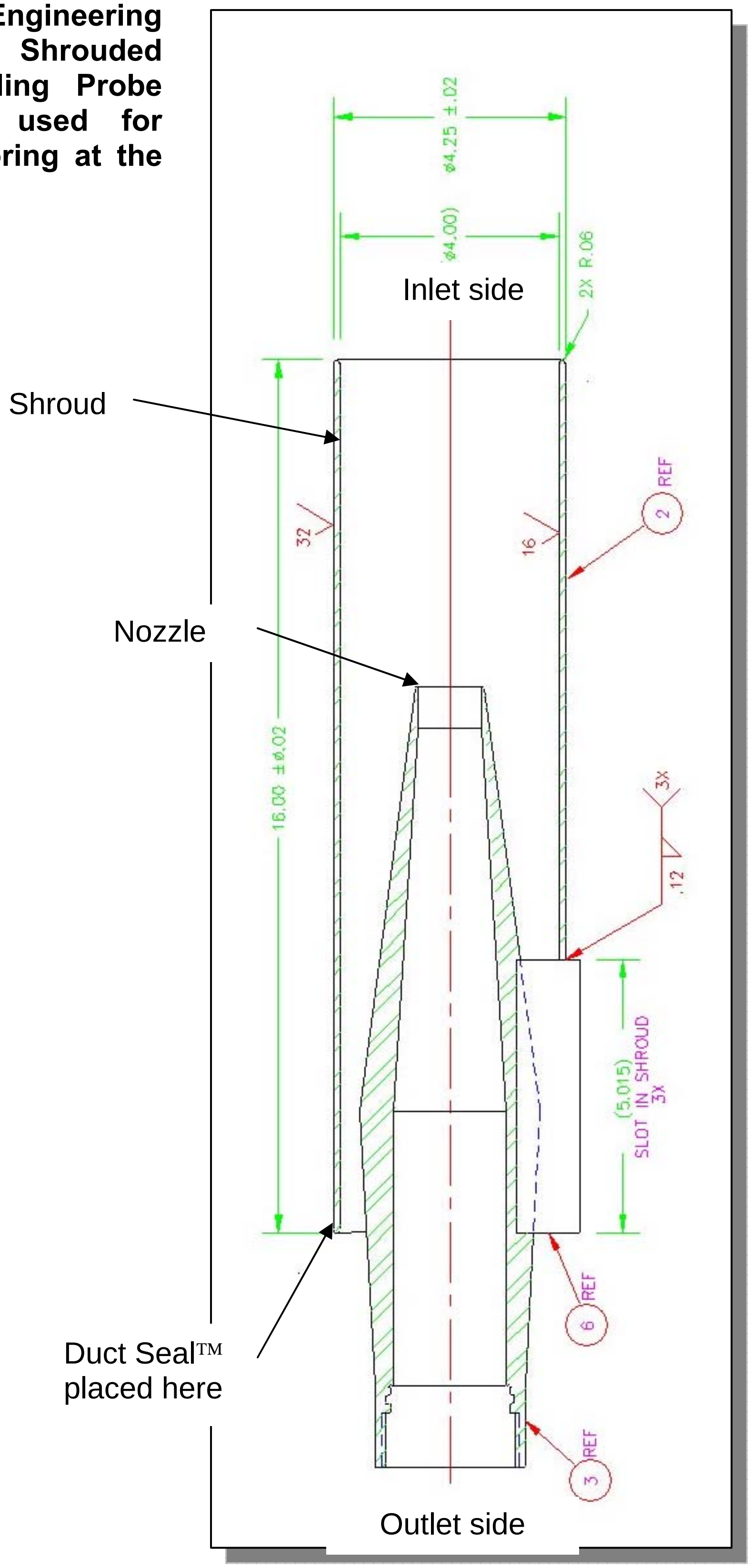
[1] SOR stands for Sample of Record

[2] BU stands for Back Up

[3] RPD stands for Relative Percent Difference

[4] Average probability for a obtaining a greater absolute paired t-value by chance alone for a hypothesized difference of zero between sample means

Figure 11.1: Engineering Drawing of a Shrouded Aerosol Sampling Probe of the Type used for Effluent Monitoring at the WIPP



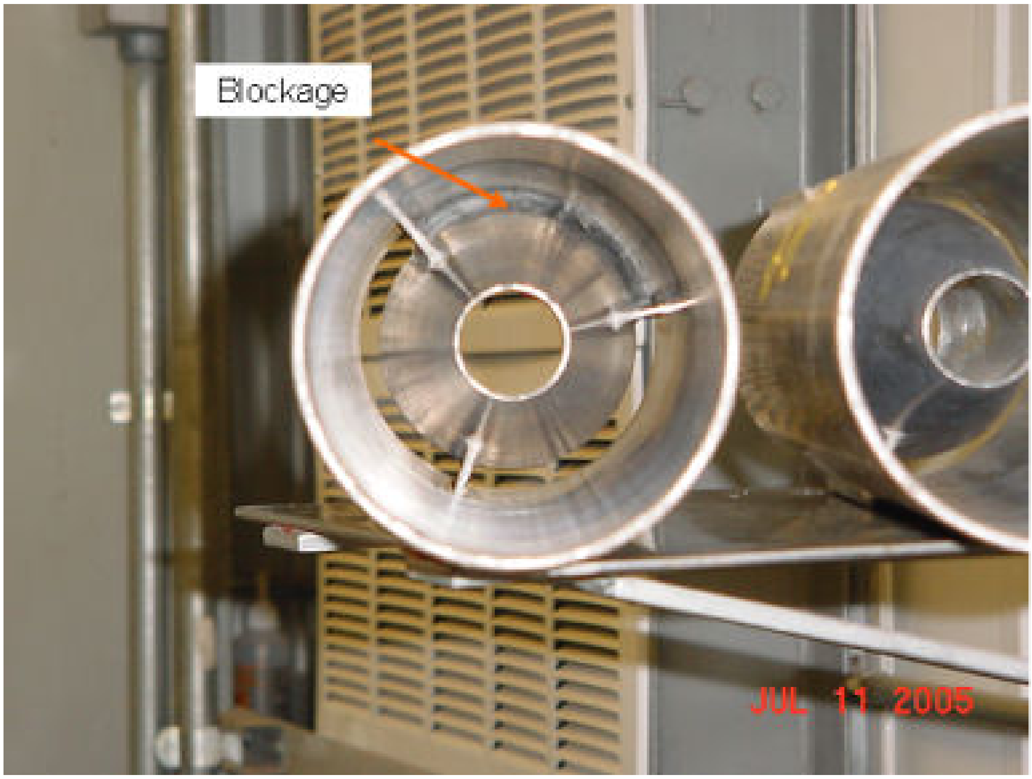


Figure 11.2: Probe One-third Blocked, Prior to Deployment

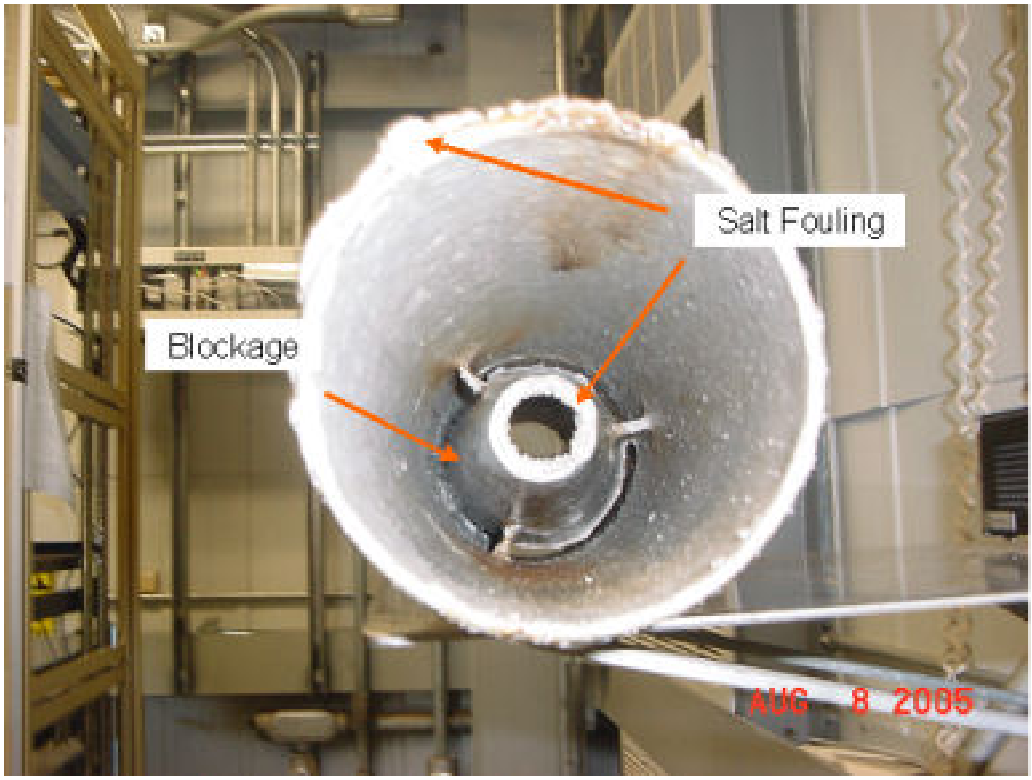


Figure 11.3: Probe One-third Blocked, After Deployment

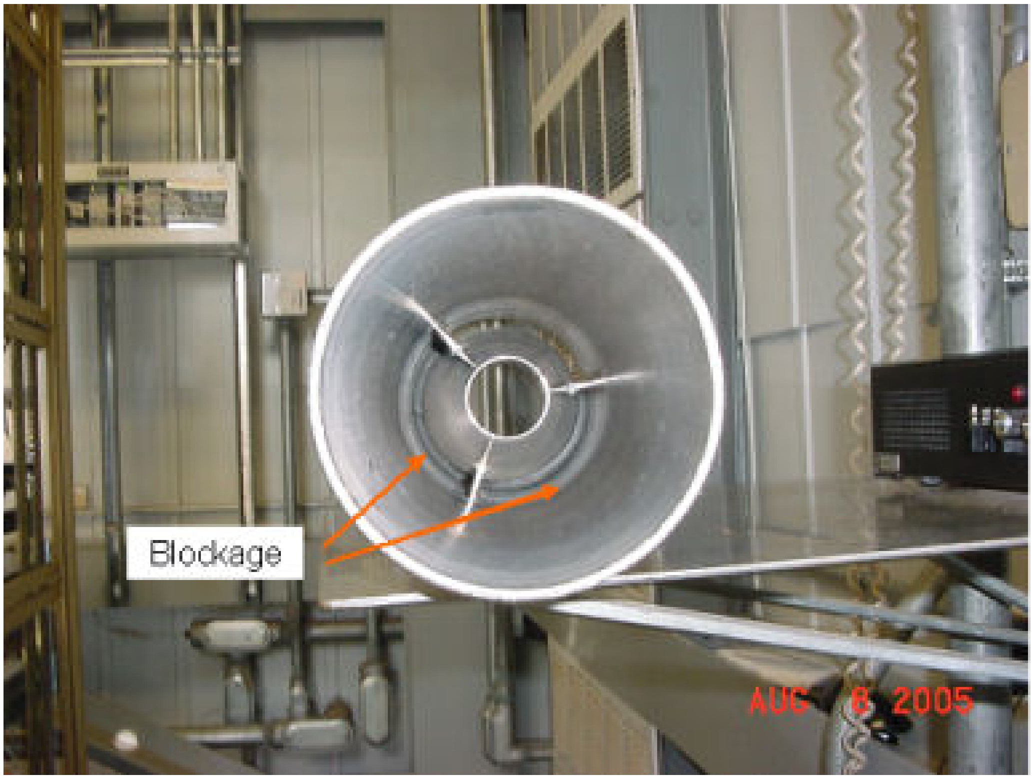


Figure 11.4: Probe Two-thirds Blocked, Prior to Deployment

Figure 11.5: Unblocked (Control) Probe as Recovered September 12, 2005

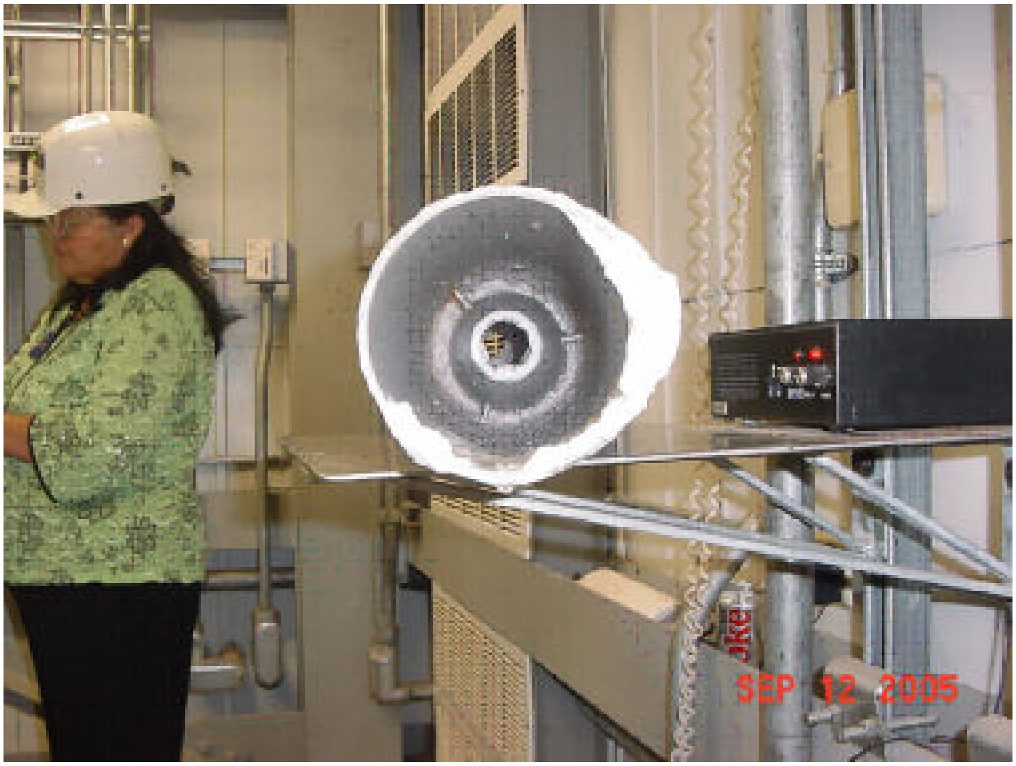


Figure 11.6: Probe Two-thirds Blocked, as Recovered

Figure 11.7: Probe Two-thirds Blocked, as Recovered
(viewed from outlet side)

Figure 11.8: Probe Fully Occluded, Prior to Deployment

Figure 11.9: Probe Fully Occluded, Prior to Deployment (reverse view)

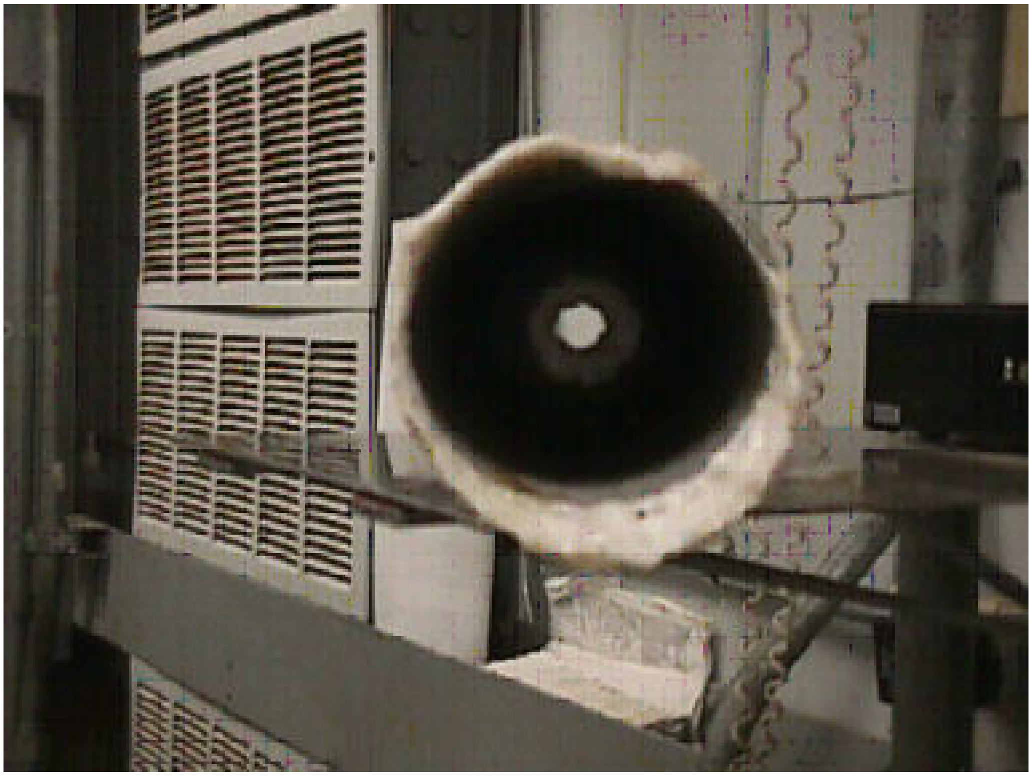


Figure 11.10: Probe Fully Occluded, as Recovered

Figure 11.11: Probe Fully Occluded, as Recovered

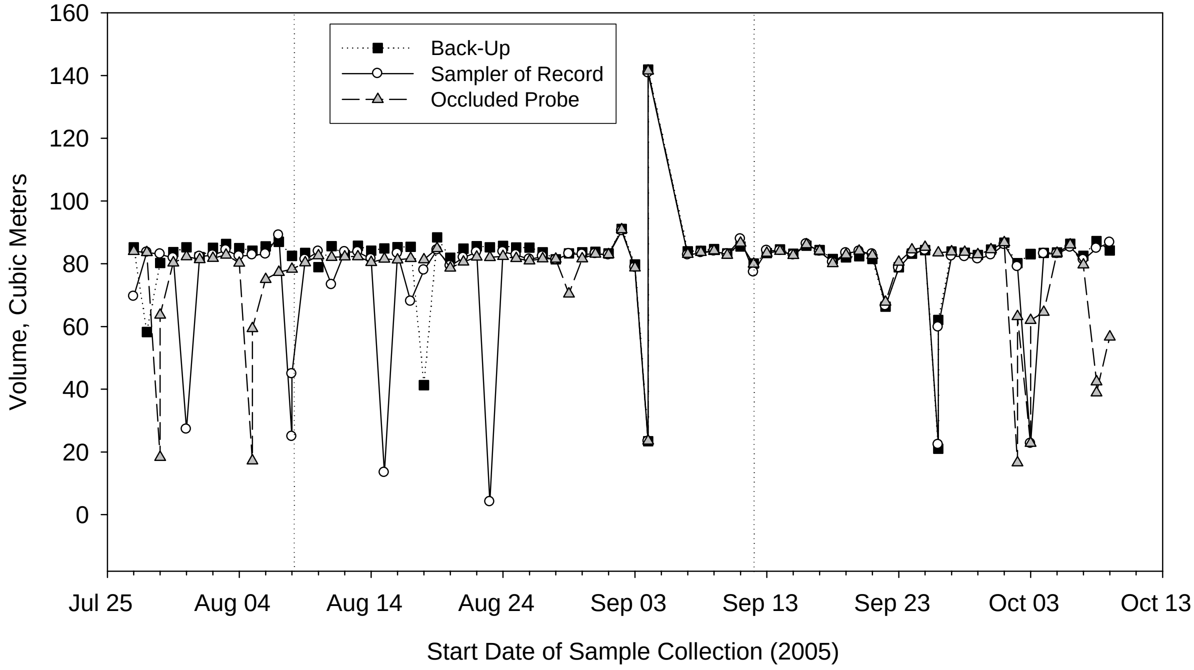


Figure 11.12: Sample volumes for all samples. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

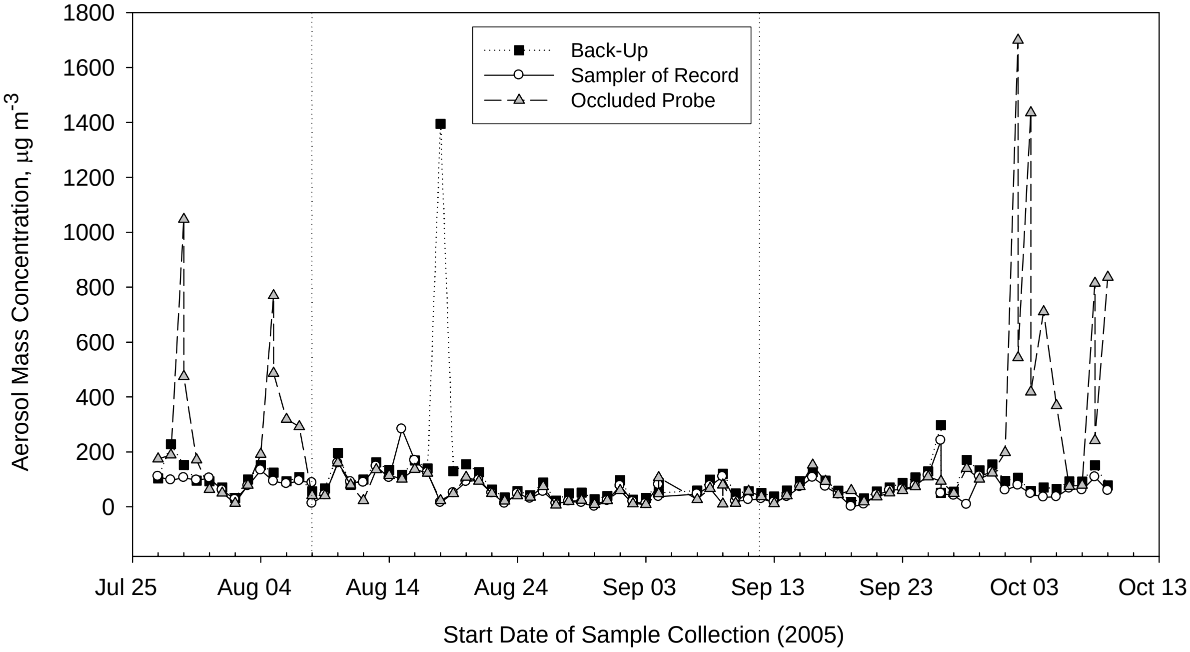


Figure 11.13: Mass concentrations for all samples. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

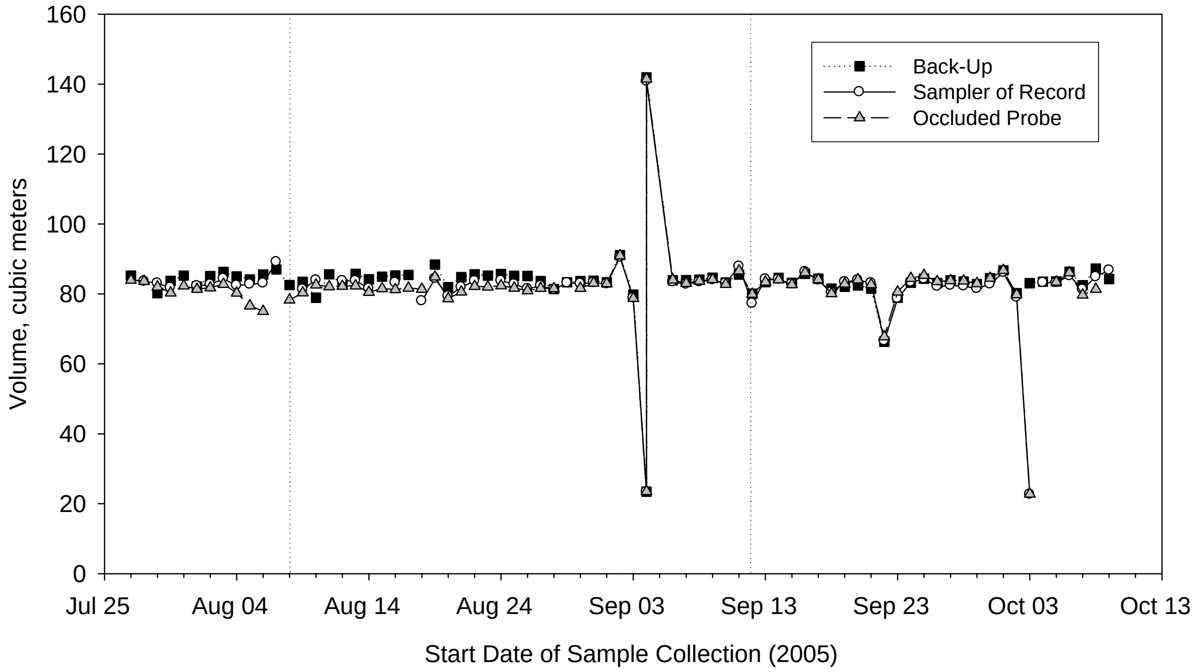


Figure 11.14: Sample volumes for matched samples. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

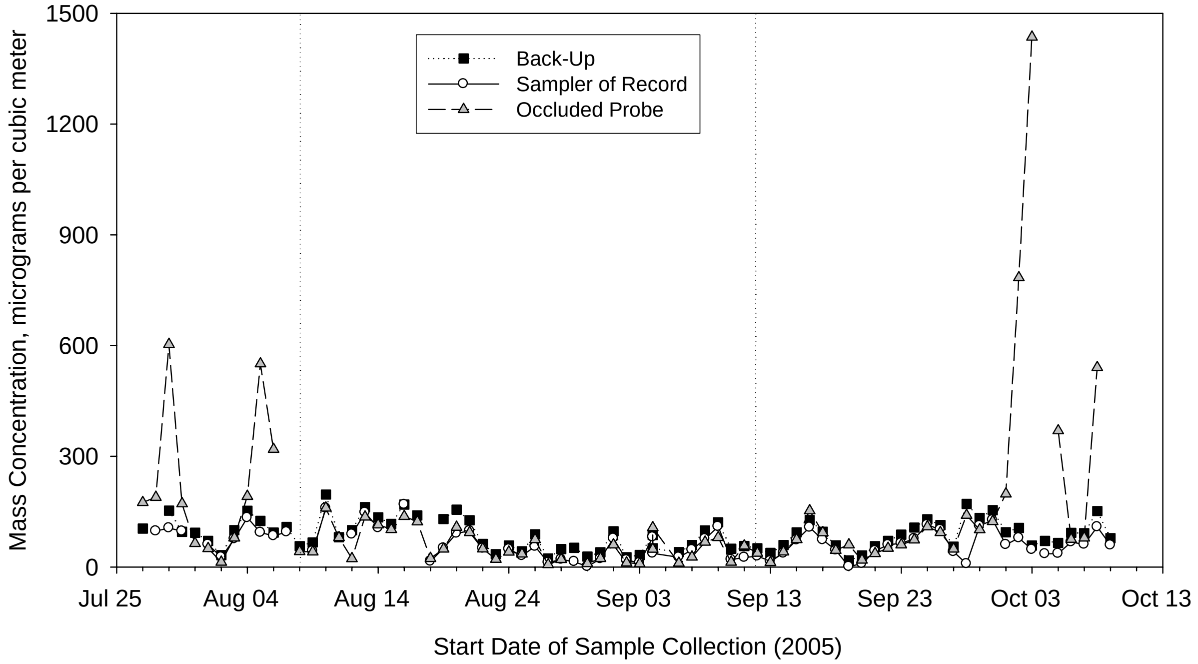


Figure 11.15: Mass concentrations for matched samples. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

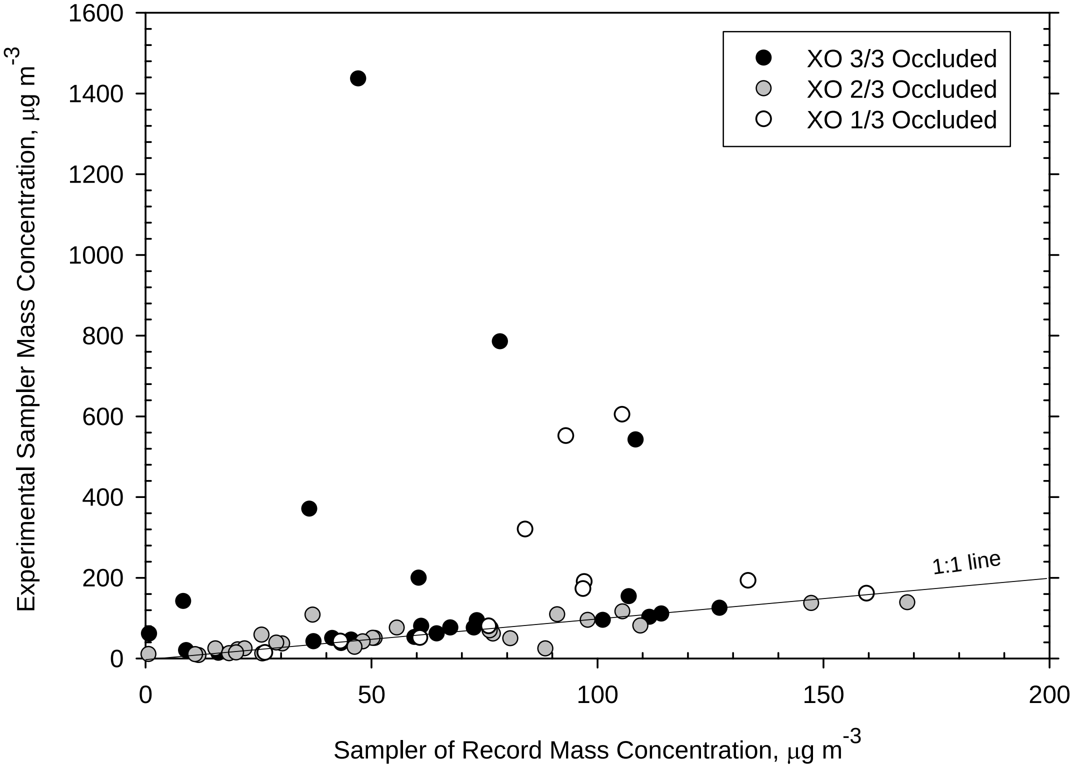


Figure 11.16: Mass concentrations for matched samples from the Experimental/Occluded Sampler vs. the Sampler of Record.

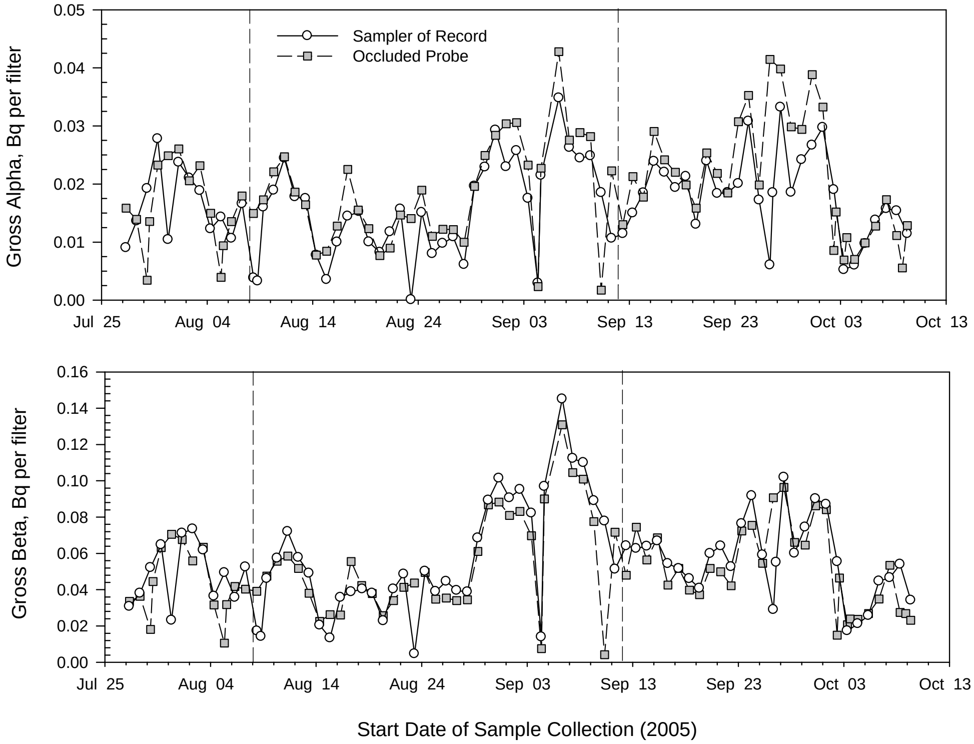


Figure 11.17: Gross alpha and beta activities for all sample filters. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

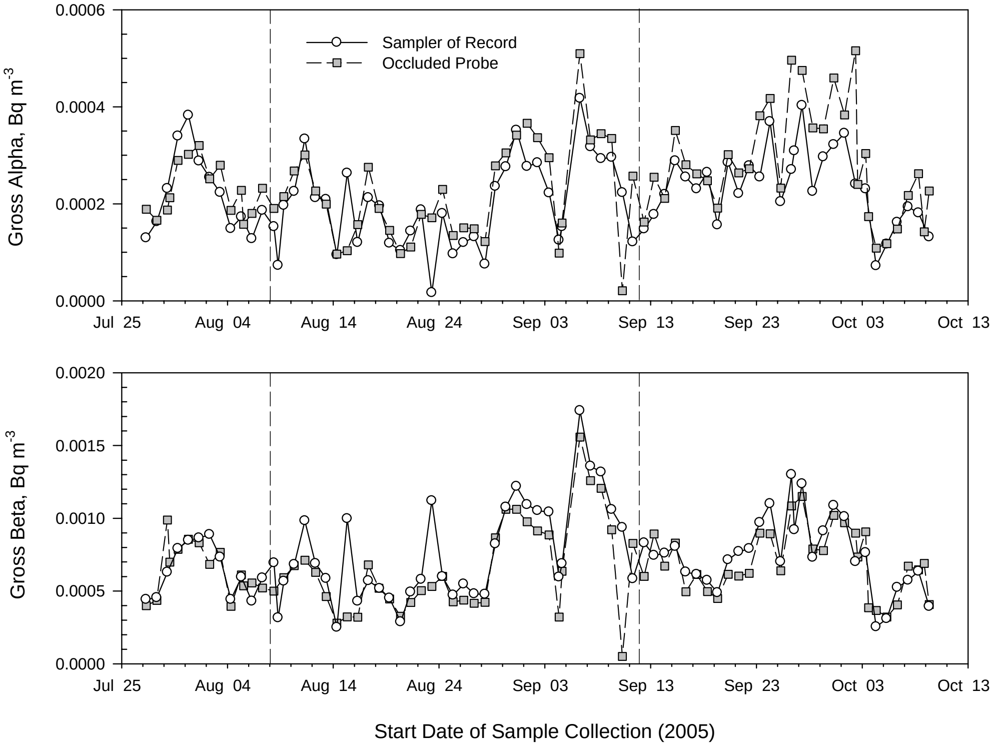


Figure 11.18: Gross alpha and beta activity concentrations for all sample filters. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

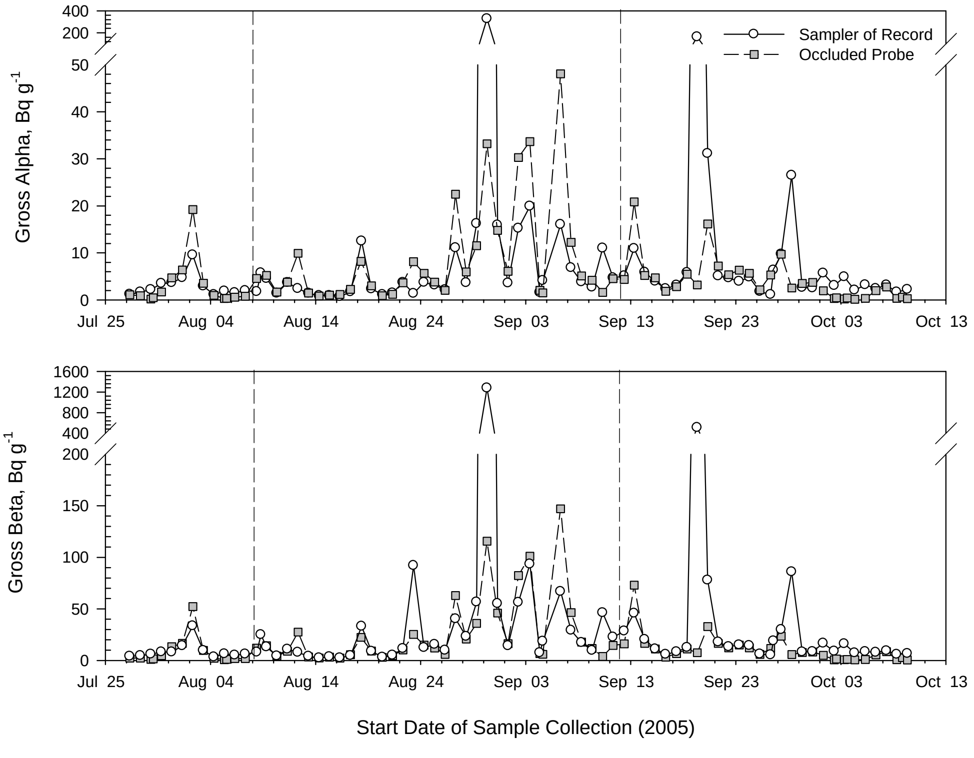


Figure 11.19: Gross alpha and beta activity densities for all sample filters. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

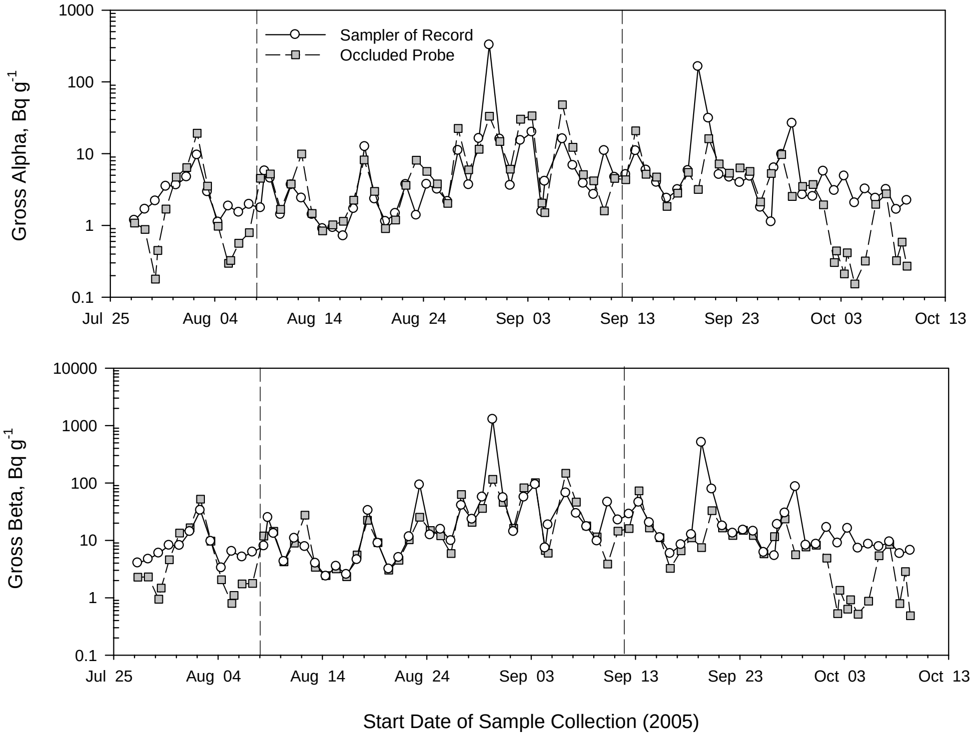


Figure 11.20: Gross alpha and beta activity densities plotted on a logarithmic scale for all sample filters. Dotted vertical lines separate phases of the study: (1) 1/3 occluded 7/11-8/8, (2) 2/3 occluded 8/8-9/12, and (3) 3/3 occluded 9/12-10/10.

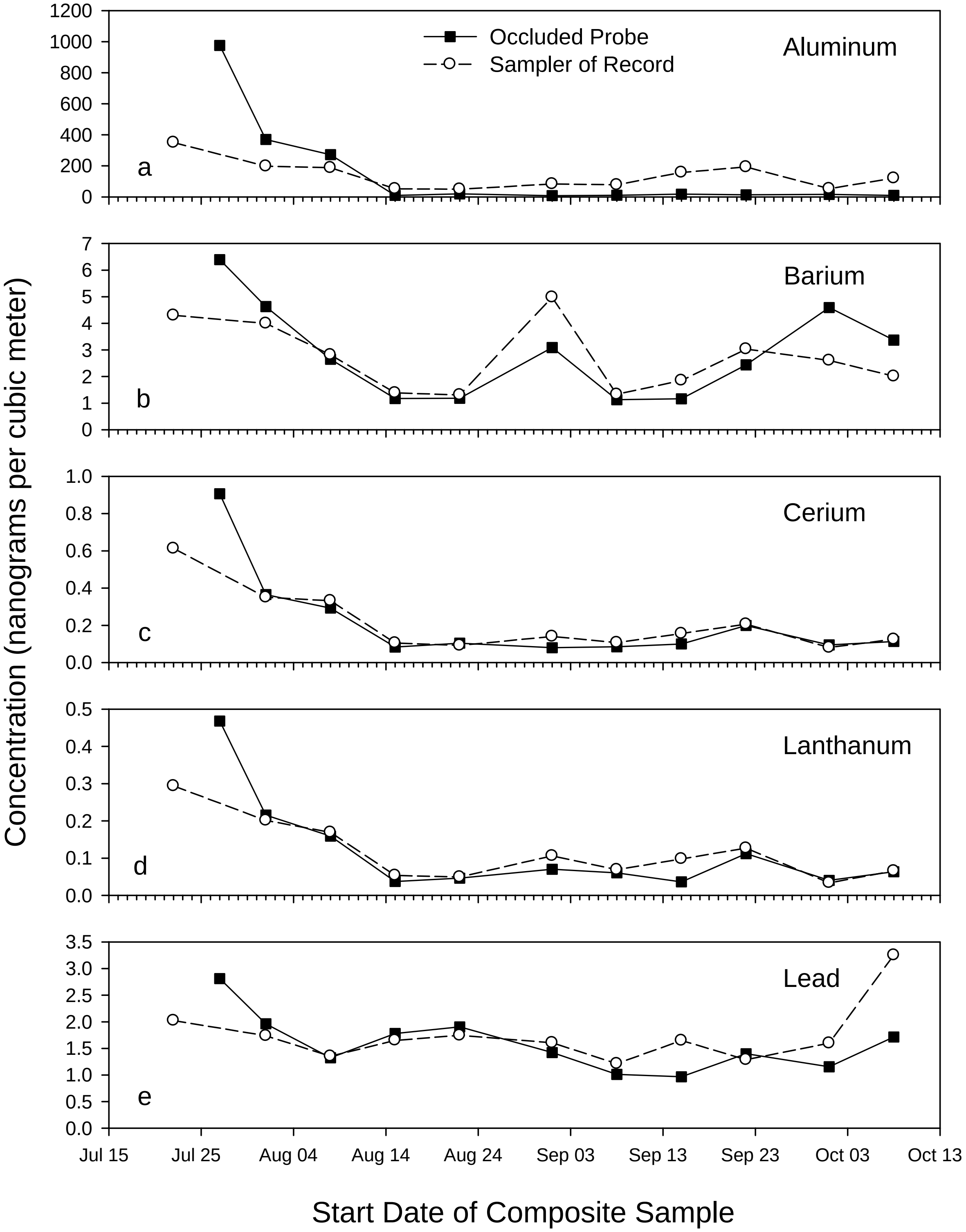


Figure 11.21 (a-e): Timeseries Plots of Group A Trace Elements (see text for explanation of groups)

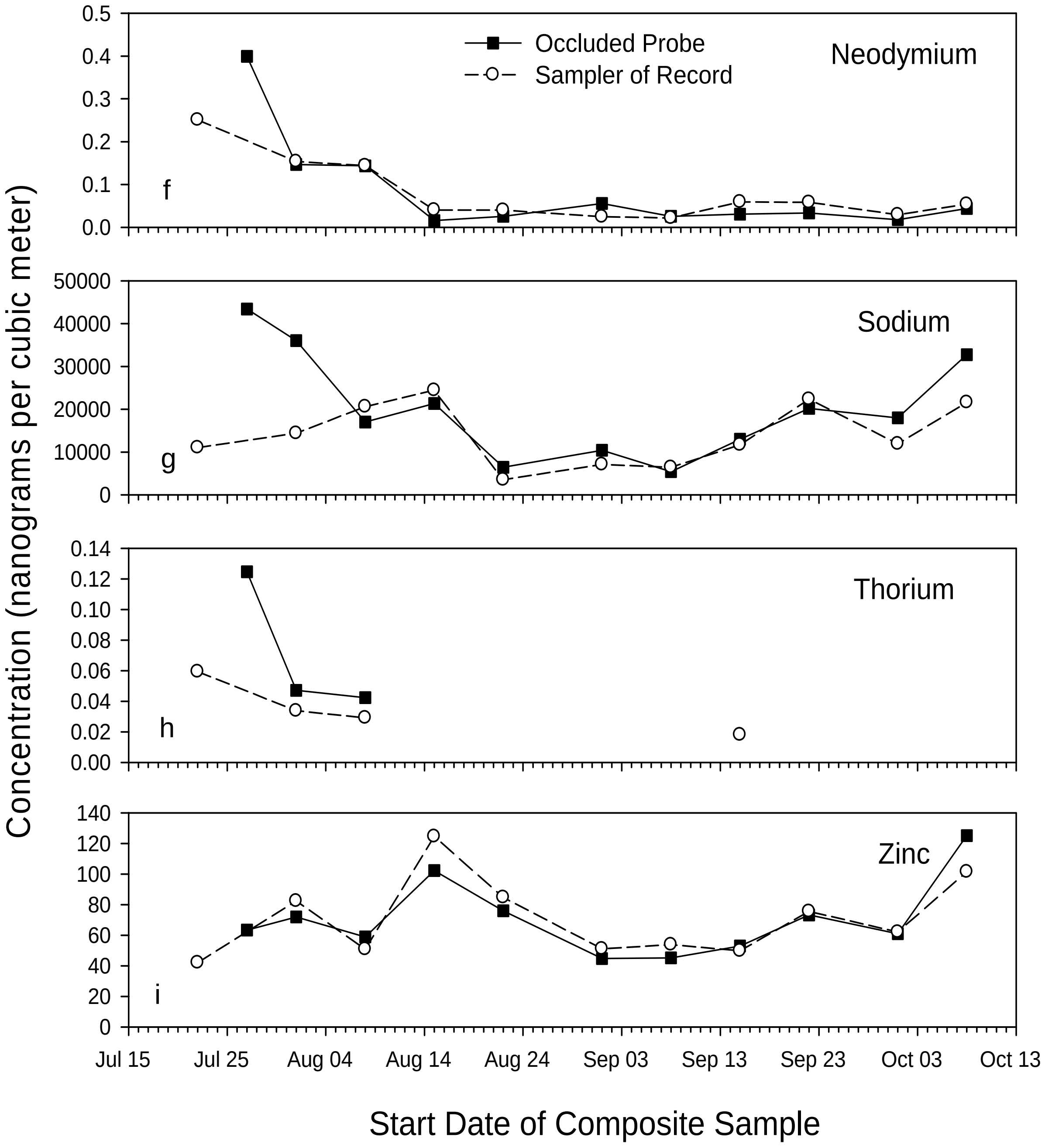


Figure 11.21 (f-i): Timeseries Plots of Group A Trace Elements (see text for explanation of groups)

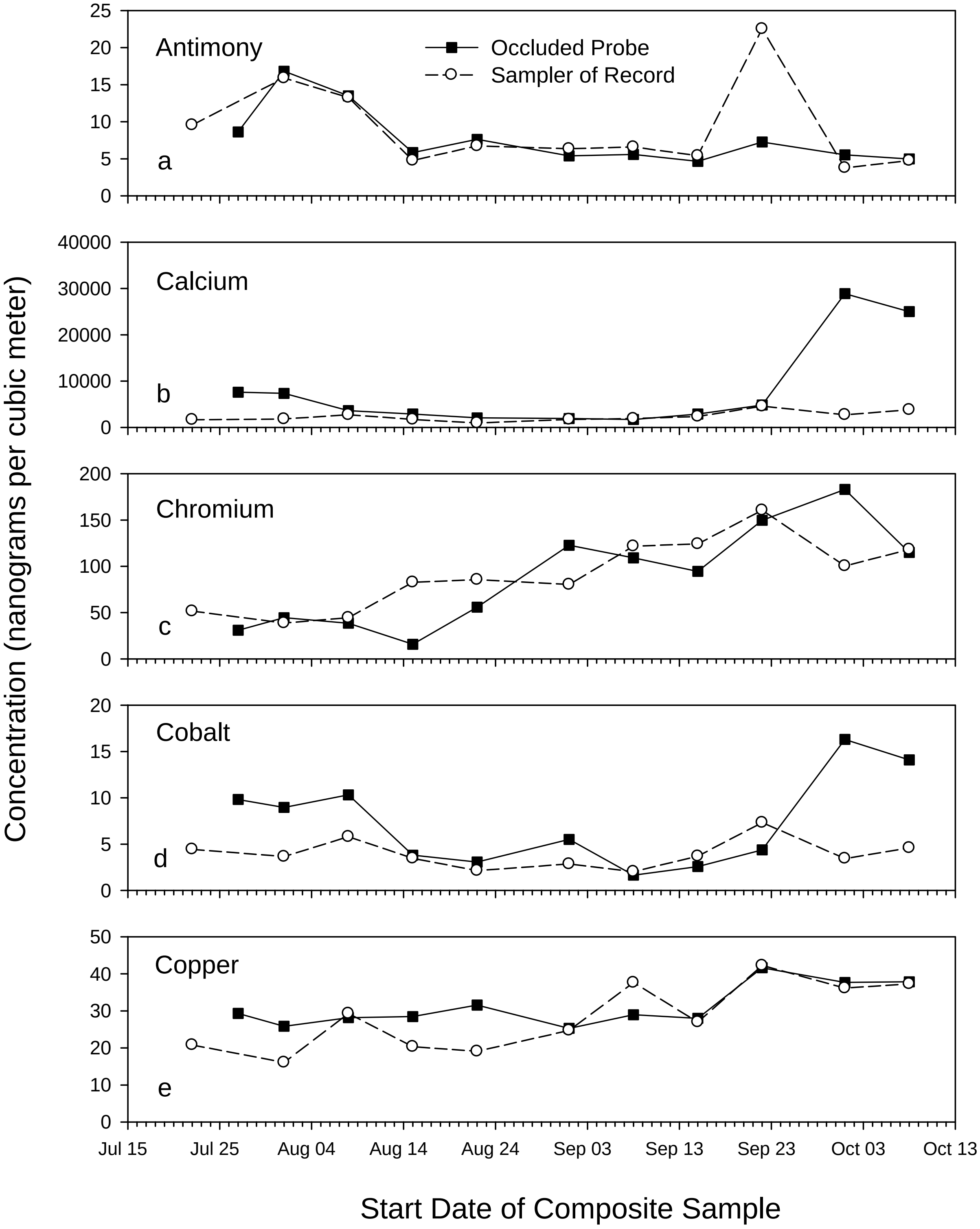


Figure 11.22 (a-e): Timeseries Plots of Group B Trace Elements (see text for explanation of groups)

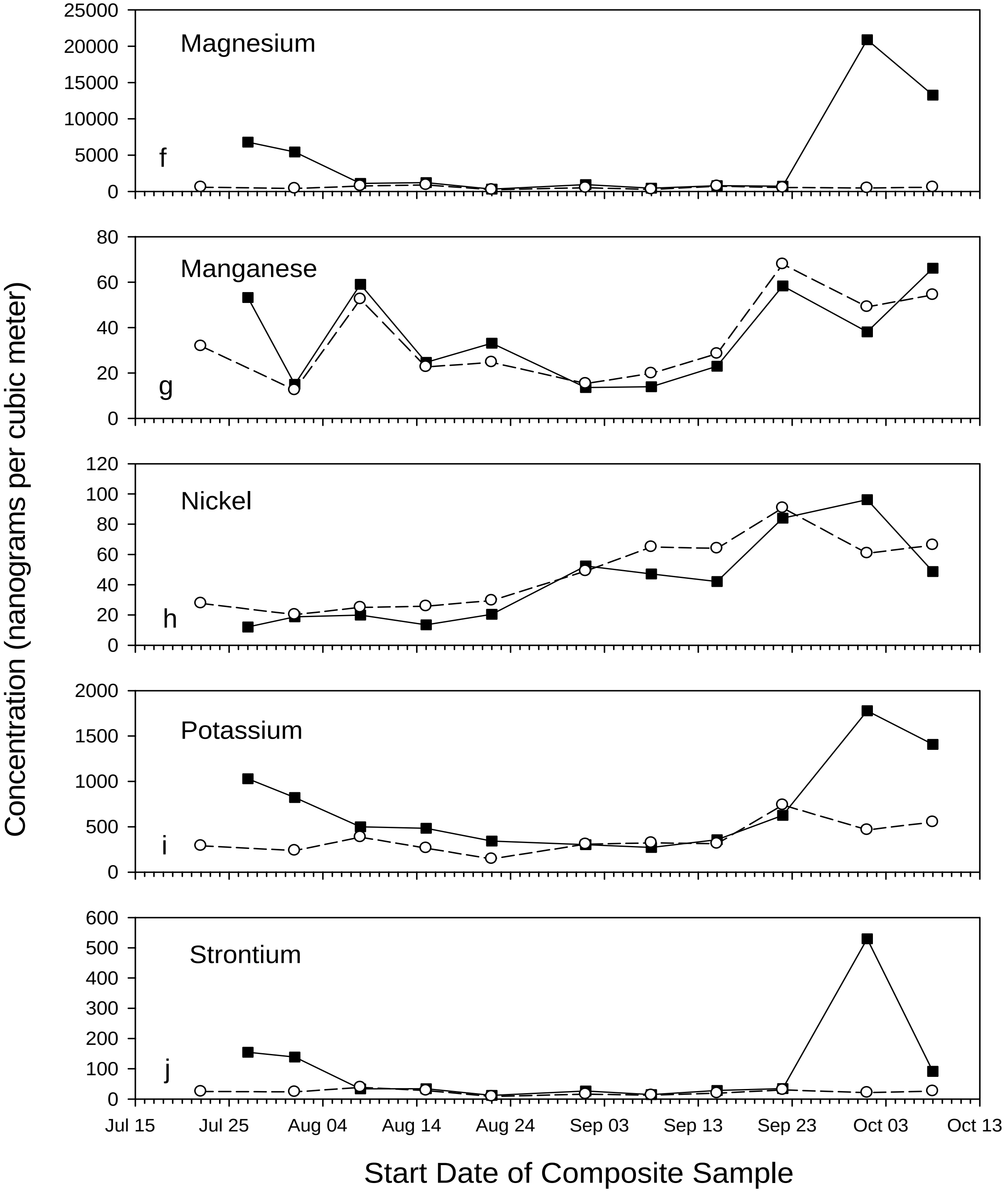


Figure 11.22 (f-j): Timeseries Plots of Group B Trace Elements (see text for explanation of groups)

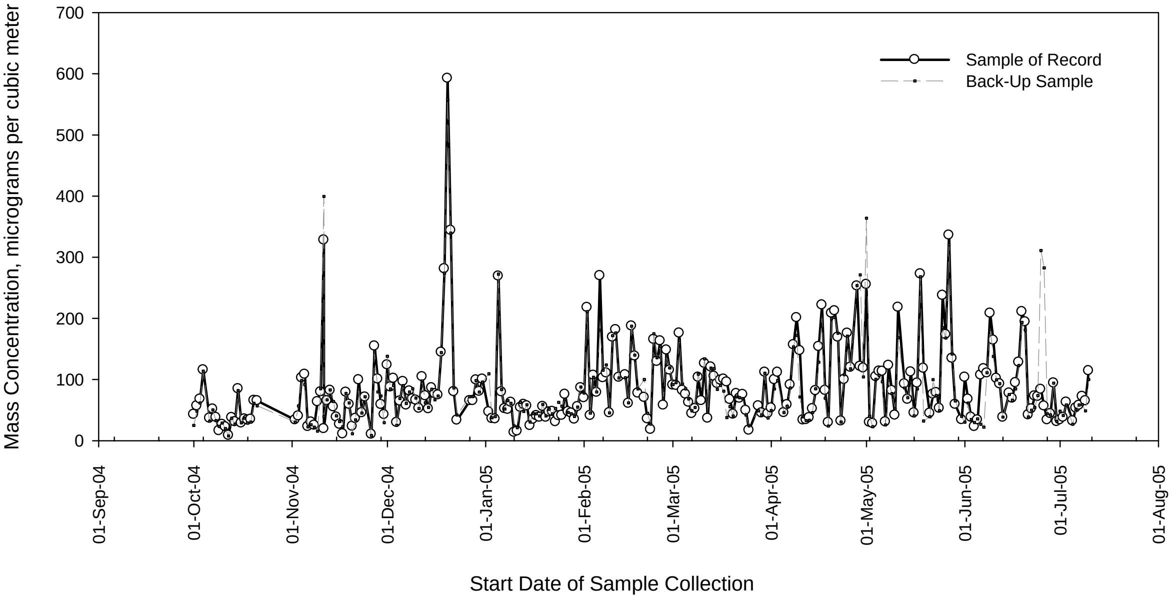


Figure 11.23: Timeseries Plot of Mass Concentrations vs. Time for the Sampler of Record and Back-up Sampler at Station A

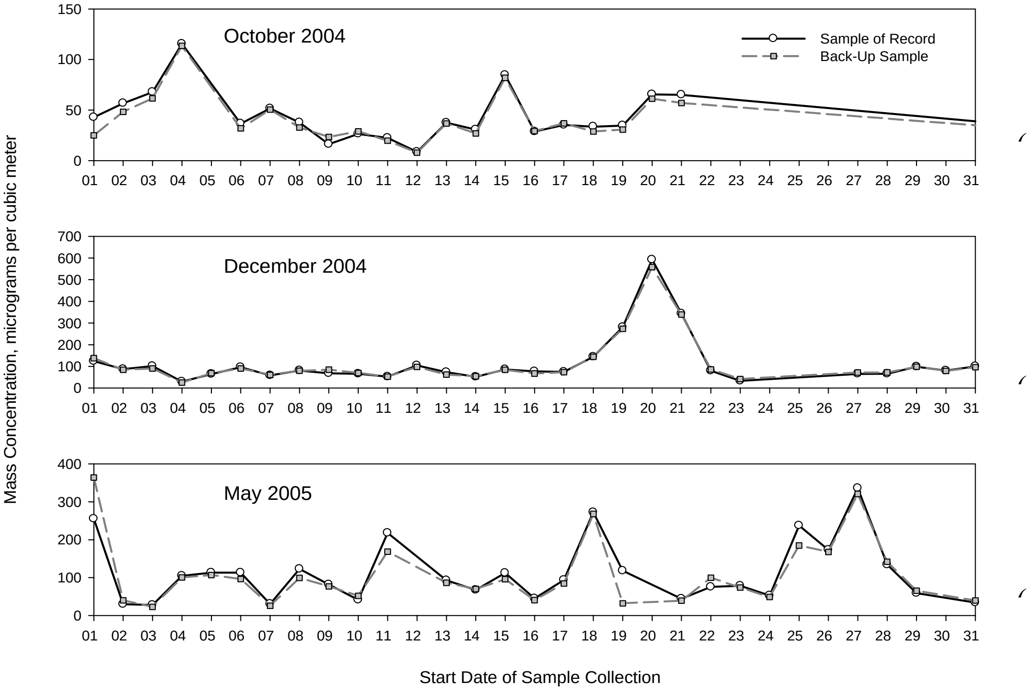


Figure 11.24 (a-c): Selected Monthly Plots of Mass Concentrations vs. Time for the Sampler of Record and Back-Up Sampler at Station A: (a) October 2004, (b) December 2004, and (c) May 2005.

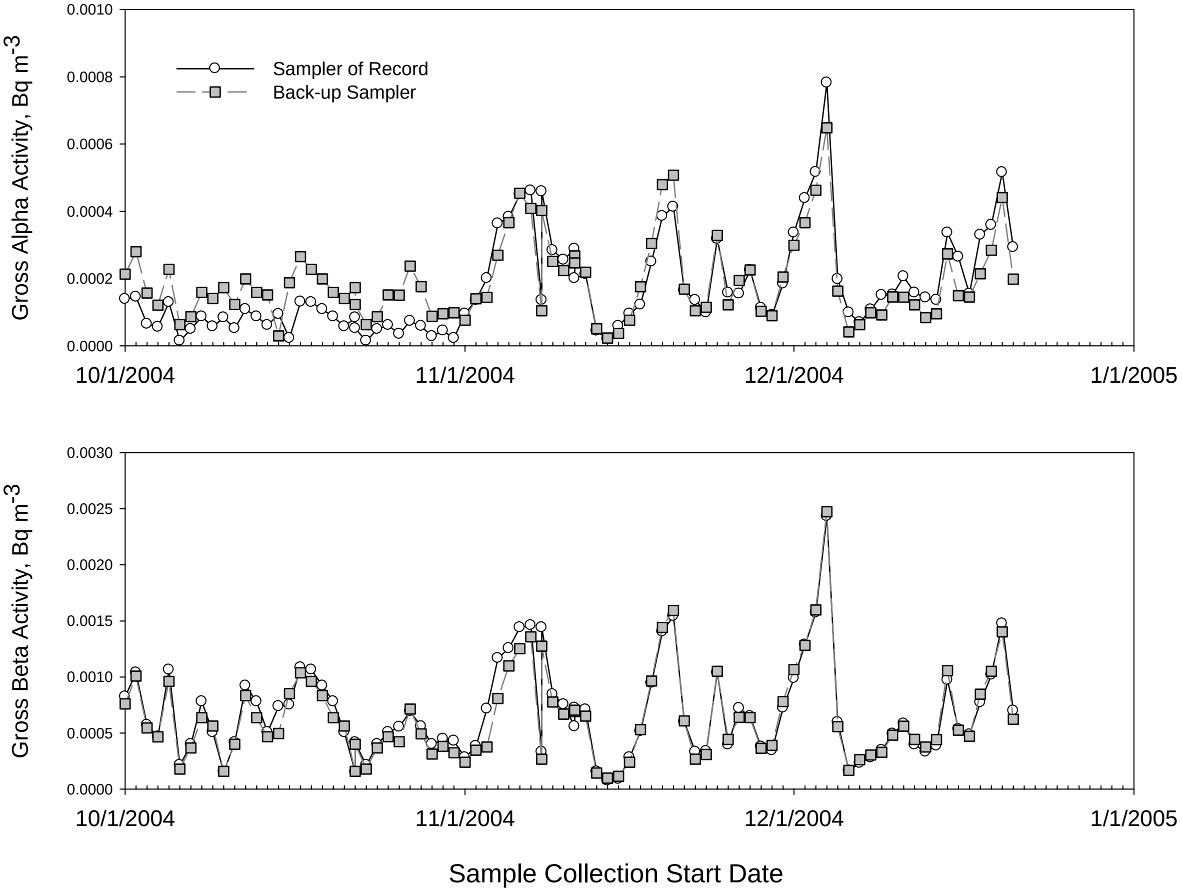
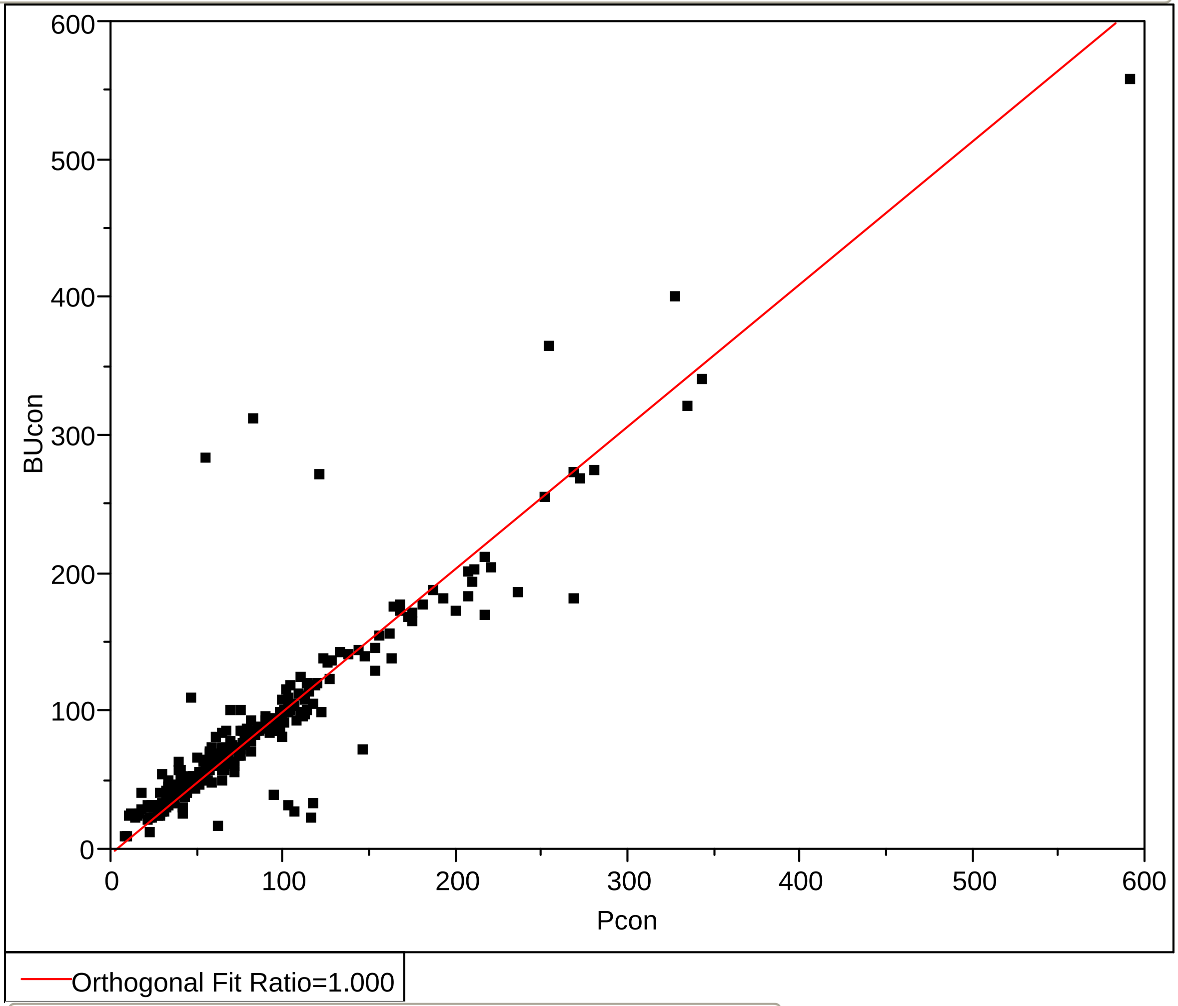


Figure 11.25 (a-b): Timeseries plots for the Sampler of Record and Back-Up Sampler at Station A: (a) gross alpha activity (b) gross beta activity.

Bivariate Fit of BUcon By Pcon



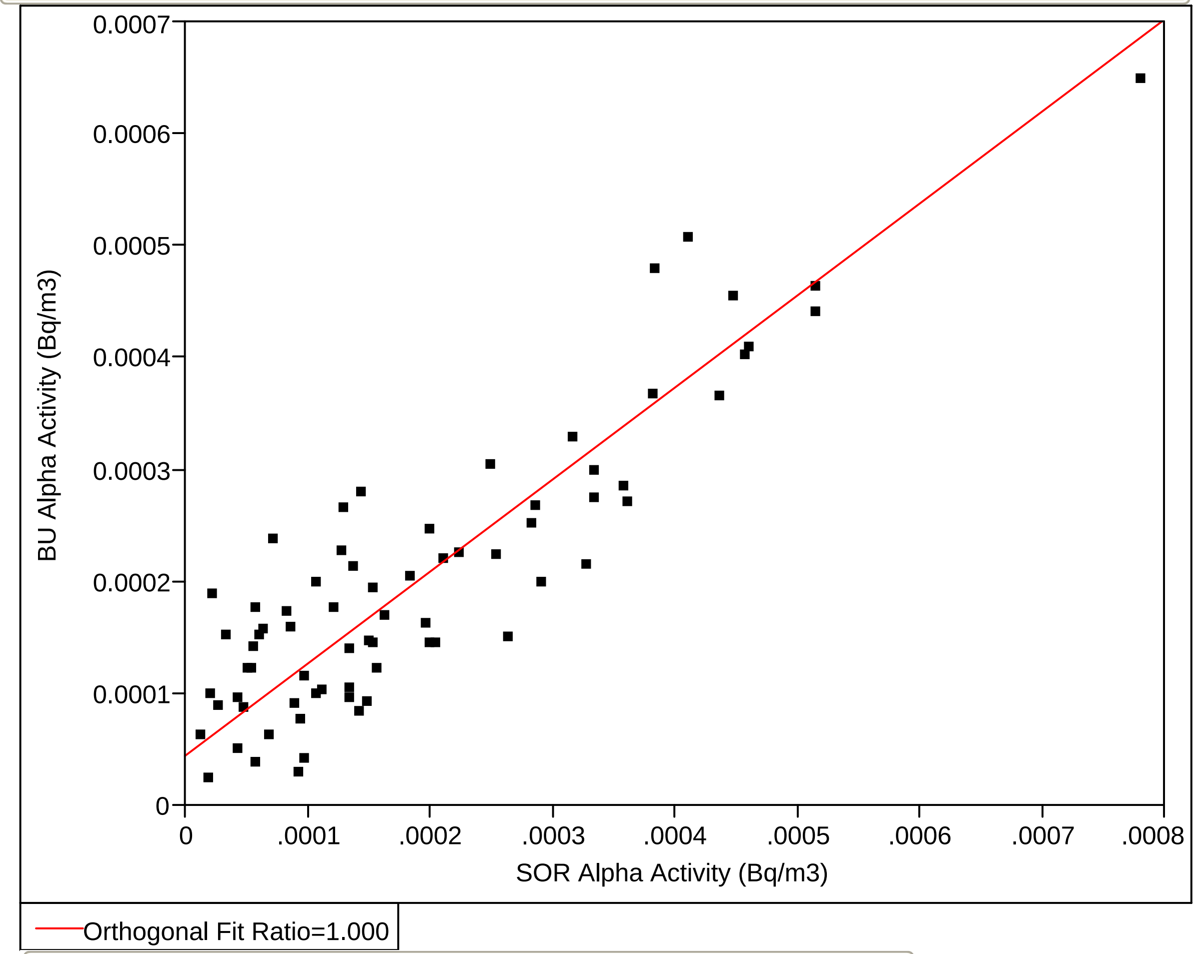
Orthogonal Regression

Variable	Mean	Std Dev	Variance Ratio	Correlation
Pcon	86.44857	68.36458	1	0.9120
BUcon	86.01862	70.39891		

Intercept	Slope	LowerCL	UpperCL	Alpha
-3.25445	1.032673	0.977276	1.091317	0.05000

Figure 11.26: Bivariate Fit of Back-Up Filter versus Primary Filter Mass Concentrations

Bivariate Fit of BUAlpha_Act_(Bq/m3) By PAlpha_Act_(Bq/m3)



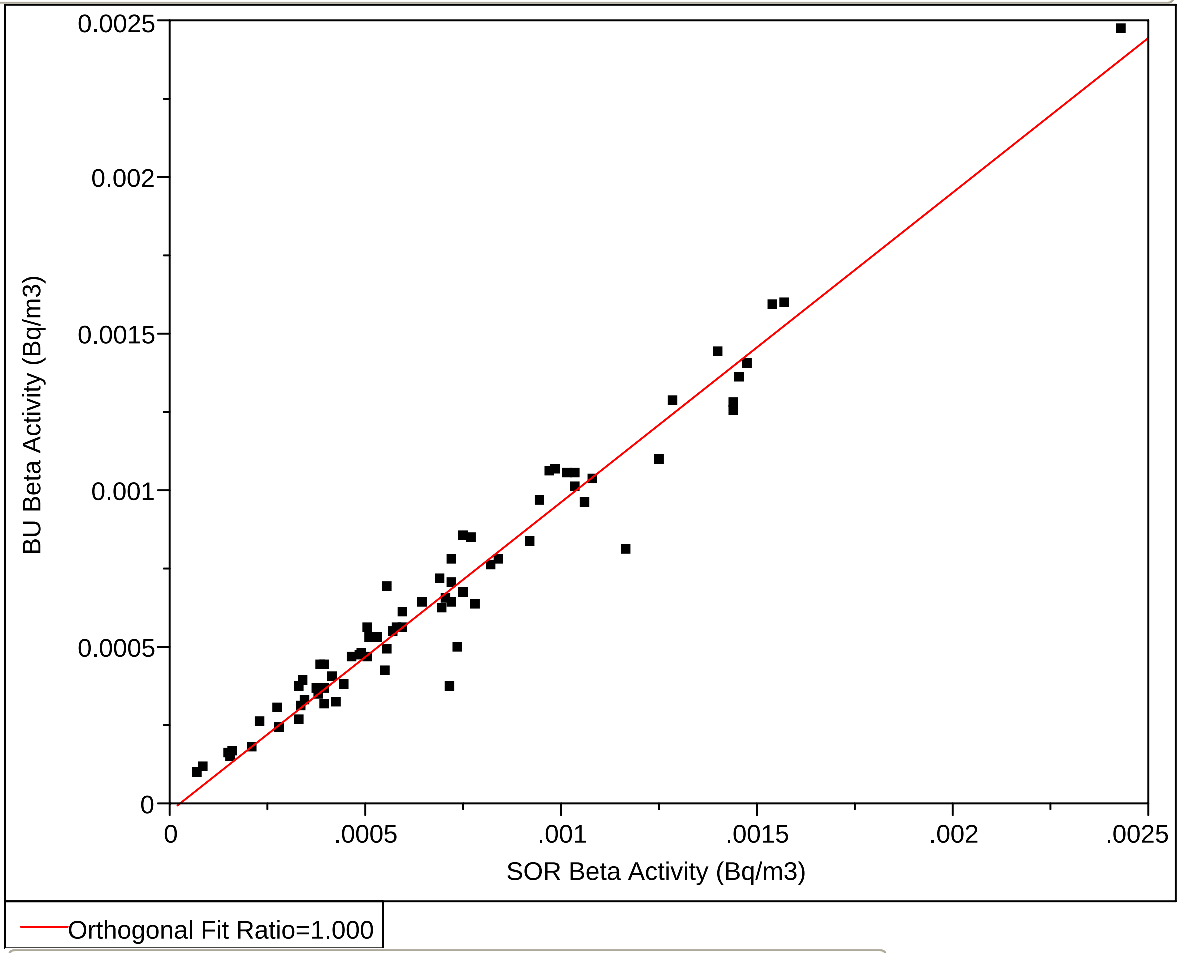
Orthogonal Regression

Variable	Mean	Std Dev	Variance Ratio	Correlation
PAlpha_Act_(Bq/m3)	0.000192	0.000152	1	0.8893
BUAlpha_Act_(Bq/m3)	0.000202	0.000127		

Intercept	Slope	LowerCL	UpperCL	Alpha
0.000044	0.820488	0.724326	0.926664	0.05000

Figure 11.27: Bivariate Fit of Back-Up Filter versus Primary Filter Gross Alpha Activities

Bivariate Fit of BUBeta_Act_(Bq/m3) By PBeta_Act_(Bq/m3)



Orthogonal Regression

Variable	Mean	Std Dev	Variance Ratio	Correlation
PBeta_Act_(Bq/m3)	0.00071	0.000433	1	0.9795
BUBeta_Act_(Bq/m3)	0.000679	0.000428		

Intercept	Slope	LowerCL	UpperCL	Alpha
-0.00002	0.986523	0.93925	1.036141	0.05000

Figure 11.28: Bivariate Fit of Back-Up Filter versus Primary Filter Gross Beta Activities

APPENDICES

Appendix A: Brief History of Carlsbad Environmental Monitoring and Research Program

The Carlsbad Environmental Monitoring & Research Center (CEMRC) was created in 1991 as a division of the Waste-management Education & Research Consortium (WERC), in the College of Engineering at New Mexico State University (NMSU). The CEMRC was conceived as a result of inquiries to WERC by concerned citizens of the Carlsbad region, acting as a grassroots coalition who recognized the need for high quality, independent, health and environmental assessment data. Many individuals and organizations supported the CEMRC's formation including the residents of Carlsbad, NM, and the surrounding region; NMSU; the Carlsbad Department of Development; the New Mexico Congressional Delegation; the New Mexico Radioactive and Hazardous Materials Committee; Westinghouse Electric Corporation; and the U.S. Department of Energy (DOE). The CEMRC was established with a grant entitled "Carlsbad Environmental Monitoring and Research Program" (CEMRP) from DOE to NMSU. The CEMRP initially was funded for $27 million over a seven-year period (1991–1998). Subsequently, the grant was increased to almost $33 million to support operations of the program until 2008.

Dr. Rohinton (Ron) K. Bhada served as Project Director for the CEMRP during 1991-1999. Dr. Donald J. Fingleton served as Director of the CEMRC during 1991-1996. In 1996, Dr. Marsha Conley became Director of Operations and in 1997, Director. Dr. Conley was named CEMRP Project Director in 1999. In July 2001, Dr. Conley retired and Dr. George Hidy acted as an interim director until February 2002, when Mr. Joel Webb was appointed Director of CEMRC. In September 2003, Dr. Deborah Moir became acting interim director during the search for a new permanent director. At the same time, the CEMRP grant ended, the environmental monitoring program stopped, and WTS and LANL provided operating funds to CEMRC for radiochemistry collaborations under contract at CEMRC which included residence of their staff in office and laboratory space at CEMRC. In September 2004, Dr. James Conca was appointed Director of CEMRC. In FY2005 the CEMRP grant was re-instated at about half the annual funding level ($1.2M). Conca still holds that position as of June 2007.

Temporary office accommodations for the CEMRC initially were provided at NMSU-Carlsbad beginning in 1991. In 1992, the CEMRC moved to a leased facility at 800 West Pierce in Carlsbad, which served as a basis for operations through December 1996. Flatow Moore Bryan Shaffer McCabe Architects (Albuquerque, New Mexico) and Research Facilities Design (San Diego, California) were selected in 1991 to design the CEMRC's new facilities. In December of 1993, DOE Secretary Hazel O'Leary made a commitment to provide approximately $7 million in additional funding to support debt service for construction of the new facility. In 1994, the NMSU Board of Regents approved the sale of New Mexico State University Research Corporation Lease Revenue bonds to secure construction money. Construction of the Phase I facility began in August 1995 and was completed in December 1996. The facility is located adjacent to the NMSU-Carlsbad campus, on 22 acres of land donated to NMSU by then New Mexico State Representative Robert S. Light (D-55th District). On March 23, 1997, the Phase I facility was named the Joanna and Robert Light Hall.

In addition to work associated with design and construction of buildings for the CEMRC, a variety of other developmental projects were undertaken to support the CEMRC's scientific activities. In 1993, design began for the Mobile Bioassay Laboratory (MBL) that would complement the facilities planned for the new CEMRC building. Construction of the MBL began in 1994, and the unit was completed and delivered to Carlsbad in 1996. A Radioactive Material License was submitted to the New Mexico Environment Department, and the license was issued in 1996. The MBL was loaned to the DOE Rocky Flats site in Colorado during 2003-2005 to assist in decommissioning of that site which was successfully completed in 2005 and the unit returned to CEMRC. In 2005, funding was obtained by CEMRC from the City of Carlsbad, partially matched by CEMRC, to undertake a major redesign of the radiochemistry laboratory space and build an actinide chemistry laboratory for use by LANL and CEMRC staff to carry out experiments with Pu, U and Np, primarily with the focus of confirming previous WIPP performance assessments with respect to actinide elements in brine under repository conditions. This was completed in 2006. Subsequently, other laboratory improvements occurred in 2006 such as building of a new VOC laboratory and replacement of most of the ventilation system, jointly funded by DOE, WTS and CEMRC.

In 1999, CEMRC was separated from WERC and became a division reporting directly to the Dean of Engineering at NMSU. In July 2006, the College of Engineering at NMSU combined the units CEMRC, WERC and SWTDI under the new Institute for Energy and the Environment (IEE) that is managed by Dr. Abbas Ghassemi, the Associate Dean of Engineering.

Appendix B: Students/Visiting Scientists supported at CEMRC 2005/2006

Student/Scientist	Support Period
Danielle Tatro	1/2005 - present
Janessa Elkins	7-9/2005, 7-9/2006
Chris Kirchner	7-9/2005
Jonathon Burns	7-9/2006
Tennyson Doan	7-9/2006
Dr. Sarah Pepper (post-doc for LANL)	9/2006 - present
Dr. Geof Smith (NMSU sabbatical)	9/2005-8/2006

Appendix C: Publications during 2005/2006

Author	Title	Publisher/Conference
Li, W-W., N. Cardenas, **R. Arimoto**, J. Walton, D. Trujillo, and H. Morales	PM Source Identification at Sunland Park, New Mexico using a simple heuristic meteorological and chemical analysis	Journal of the Air and Waste Management Association, 55, 352-364, 2005
Wang, Y. Q., X. Y. Zhang, **R. Arimoto**, J. J. Cao, and Z. X. Shen	Characteristics of carbonate content and carbon and oxygen isotopic composition of Northern China soil and dust aerosol and its application to tracing dust sources	Atmospheric Environment, 39, 2631-2642, 2005
Che, H. Z., G. Y. Shi, X. Y. Zhang, **R. Arimoto**, J. Q. Zhao, L. Xu, B. Wang, and Z. H. Chen	Analysis of 40 years of solar radiation data from China, 1961-2000	Geophysical Research Letters, 32, L06803, doi 10.1029/2004GL022322, 2005
Zhang, R., **R. Arimoto**, J. An, S. Yabuki, and J. Sun	Ground observations of a strong dust storm in Beijing in March 2002	Journal of Geophysical Research, 110, D18S06, doi:10.1029/2004JD004589, 2005
Mitchell, S. E., C. A. Caldwell, G. Gonzales, W. R. Gould, and **R. Arimoto**	Effects of depleted uranium on survival, growth and metamorphosis in the African clawed frog (<u>Xenopus laevis</u>)	Journal of Toxicology and Environmental Health Part A, 68, 951-965, 2005
Arimoto, R., J. B. Webb, and M. C. Conley	Radioactive contamination of atmospheric dust over southeastern New Mexico	Atmospheric Environment, 39, 4745-4754, 2005
Arimoto, R., B. Stewart, and H. Khaing	Re-suspended Dust as a source for Radioactivity in the Atmosphere near the Waste Isolation Pilot Plant	Proceedings, American Nuclear Society Topical Meeting, Carlsbad, NM, pp., xxx, 2006
Mie, D., **J. L. Conca,** C. den Auwer, R. I. Gabitov, N. J. Hess, P Paviet-Hartmann, P. D. Palmer, V. LoPresti and S. D. Conradson	Chemical speciation of heterogeneously reduced Pu in synthetic brines	*Radiochemica Acta*, vol. 94, p. 249-259, 2006
Conca, J. L. and J. Wright	An Apatite II permeable reactive barrier to remediate groundwater containing Zn, Pb and Cd	*Applied Geochemistry*, vol. 21, p. 1288-1300, 2006
Conca, J. L. and M. H. Reynolds	Dirty Bombs, practical plans	*Homeland Protection Professional*, May 2006 issue, p. 18-22
Conca, J.	A 12-Point Response to a Dirty Bomb Attack	*Transactions of the American Nuclear Society*, La Grange, IL, vol. 95, 2006

Author	Title	Publisher/Conference
Martinez, M. N., S. S. Hightower, G. B. Smith, W. Mueller, **J. L. Conca** and J. Wright	The effect of Apatite II on the biodegradation of TNT and perchlorate in contaminated soil samples	*Sustainable Range Management*, Battelle Press, Columbus, OH. 2006 www.battelle.org/bookstore
Adams, B., N. Yancey, **J. Conca** and J. Wright	PRB Containing Processed Fish Bones Sequesters Metals from Ground Water	*Technology News and Trends*, Environmental Protection Agency EPA 542-N-06-002, Issue 23, p. 5-7, 2006
Raicevic, S., J. V. Wright, V. Veljkovic and **J. L. Conca**	Theoretical stability assessment of uranyl phosphates and apatites: Selection of amendments for in situ remediation of uranium	*Science of the Total Environment,* vol. 355, p. 13-24, 2006
Conca, J.	Addressing the Threat of a Serious 137Cs Dirty Bomb	*Proc. 14th Biennial Topical Meeting of the Radiation Protection and Shielding Division April 2-6,* Amer. Nuclear Society, La Grange, IL, p. 284-287, 2006
Wright, J., **J. L. Conca,** and A. F. Slater	PIMS with Apatite II: A field scale demonstration on a lead contaminated soil	Chapter 4 in *Stabilisation/Solidification Treatment and Remediation,* A. Al-Tabbaa and J, A. Stegemann, (eds), Taylor and Francis Group, London, ISBN 04 1537 460 X, 2005
Wright, J. and **J. L. Conca** (2005)	PIMS™: Remediation of Soil and Groundwater Contaminated With Metals	Environmental Security Technology Certification Program (ESTCP) Cost and Performance Report, (CU-0020), http://www.estcp.org./, 50 pp 2005
Conca, J. L., M. Johnson, and J. R. Wischnewsky	Reducing the Threat of a Serious ^{137}Cs Dirty Bomb	*Proc. of the DHS Conf.: Working Together R&D Partnerships in Homeland Security,* Boston, MA, April 27–28, DHS, Science and Tech. Directorate, Section 4, 2005

Appendix D: Tours, Public Presentations and Other Outreach

Group/Activity
November 2006 Mark D. Ogden (WSU): Structurally Hindered N,N'-bis(2-methylpyridyl) Extractants for Trivalent Actinide Partitioning
November 2006 Mikael Nilsson (WSU): Screening and characterization of solvent extraction systems
November 2006 NM State MESA Program Coordinators - tour and presentation
September 2006 Dr. Ed Askew (CDI): Contaminant Testing in City Wastewater Treatment Systems
October 2006 Dr. Sarah Pepper (WSU): The sorption of metals to iron oxide surfaces
July 2006 Dr. Christophe Jegou (CEA Valrho, France): Long-term behavior of Spent Fuel in a deep geological repository under reducing conditions
2005-2006 nine high school and middle school classes - tours and presentations
April 2006 ANS Topical Meeting in Radiation Protection and Shielding: Dr. Don Wall / Mansour Akberzadeh (WTS): Continuing Education Class in Radiochemistry

Appendix E: Performance Tests and Audits

Below are summaries of external and internal audits, and results for five performance tests run in 2005/2006; one for Whole Body Dosimetry (Table E-2 and Figure E-1), two for ICP-MS (Table E-4) and two for radiochemical analyses (Table E-5). Table E-6 is an example of the daily performance tests for ICP-MS. Table E-4 shows that, of the analytes run, Al, Be, Co and Fe were not acceptable in 2005 and Br, and Cl were not acceptable in 2006. Assume that these analytes have a <20% uncertainty associated with their values as opposed to the normal <10%. In 2006, F had an uncertainty of 25%. Table E-5 shows that, of the radionuclides run, ^{230}Th in acidified water and ^{90}Sr in glass filters were not within the acceptable range: the ^{230}Th value had a difference of 8.5% when the acceptable difference was 6.1%, and the ^{90}Sr value had a difference of 24% when the acceptable difference was 14%.

CEMRC Management Assessment Quality Assurance Report

October 1, 2005 – October 31, 2006

Prepared by: Sharyl McCauley

December 12, 2006

This report serves as a periodic summary of the quality assurance program at the Carlsbad Environmental Monitoring and Research Center (CEMRC). The purpose of this report is to meet the requirement of the CEMRC Quality Assurance Plan (QAP) for an annual management assessment. This report summarizes procedural development, external audits, internal surveillance and nonconformance / non-routine events from Oct. 1, 2005 through Oct. 31, 2006.

Since the implementation of CP-PROC-023 and CP-PROC-024, which enables CEMRC to qualify potential vendors, 23 vendors are currently qualified.

During the year, external audits were performed on two of the programmatic areas at CEMRC. The programmatic areas audited were Internal Dosimetry (also referred to as Radiobioassay) for In Vivo Radiobioassay, and Organic Chemistry (formerly under the Environmental Chemistry program) for Volatile Organic Compounds (VOCs) and Metals. Washington Tru Solutions (WTS) performed these external audits. Additionally, the Internal Dosimetry group was audited by the Dept. of Energy Laboratory Accreditation Program (DOELAP) for its recertification. Summaries and conclusions from the audits are not maintained by the QA Manager but can be found in the records file of these programmatic areas.

Internal audits were performed on all of the programmatic areas, which are as follows: Administration (ADAR-05), Document Control (DCAR-07), Environmental Chemistry (ECAR-06), Field Programs (FPAR-05), Informatics and Modeling (IMAR-05), Organic Chemistry (OCAR-01), Quality Assurance (QAAR-04) and Radiochemistry (RCAR-05). To date, all eight of the audits are closed out. A summary of the programmatic area internal audits can be found in Table E-1 of this report.

There were no non-routine events during this assessment time for a center wide implementation procedure.

Overall, the quality assurance program has made huge strides in its development and must maintain this level for continued success. Overall there has been a lot of consistency and implementation of the QA system as evidenced in the decreasing number of and diminished severity of the findings in all of the programmatic areas.

Table E-1: Internal Audit Summaries (# of Findings)

Area	AD	DC	OC*	EC	FP	IM	RB**	RC	QA
Personnel Qualification & Training	2	NF	1	1	NF	NF	NF	1	NF
Quality Improvement	NF	NF	NF	NF	NF	NF	NF	NF	NF
Document Control	NF	NF	NF	NF	NF	NF	NF	NF	NF
QA Records	NF	NF	1	NF	1	NF	NF	1	1
Procurement	NF	NF	NF	NF	NF	NF	NF	NF	NF
Work Processes	1	NF	1	NF	1	1	NF	NF	NF
Audits/Assessments	NF	NF	NF	NF	1	NF	NF	1	NF
Sample Control	NF	NF	NF	NF	NF	NF	NF	NF	NF
Scientific Investigations	NF	NF	NF	1	NF	NF	NF	NF	NF
Scientific Notebooks	NF	NF	NF	NF	NF	NF	NF	NF	NF
Procedure Violation	NF	4	NF	NF	NF	1	NF	NF	NF

Table Guide

Laboratory Section
AD = administrative
DC = document control
EC = environmental chemistry
FP = field programs
IM = informatics & modeling
OC = organic chemistry
QA = quality assurance
RB = radiobioassay (Internally within CEMRC it is know as Internal Dosimetry)
RC = radiochemistry

Table Results
NF = No Findings

Other
* New programmatic area this year that was extracted from Environmental Chemistry
** As stated in a memorandum dated Aug. 2, 2006, there was a waiver on a RB audit due to 1 external audit and 1 recertification audit conducted on this program.

Table E-2: Blind Check Study for Internal Dosimetry 2006 by the ORNL Intercomparison Studies In-vivo Program

Oak Ridge National Laboratory

Intercomparison Studies In-vivo Program Report
1st Quarter Calendar Year 2006

Carlsbad Environmental Monitoring & Research Center
Set E

ISOTOPE	SPIKE ACTIVITY AS OF 3-9-07 +/- 2 sigma (nCi)	REPORTED ACTIVITY AS OF 3-9-07 +/- 2 sigma (nCi)	% RELATIVE BIAS
Cs-137	119.0 +/- 6.0	120 +/- 6	0.8
Co-60	311.8 +/- 15.6	314 +/- 16	0.7
Co-57	71.0 +/- 3.6	72 +/- 3.6	1.4
Y-88	6.30 +/- 0.32	6.2 +/- 0.31	-1.6
Ba-133	262.9 +/- 13.1	265 +/- 13	0.8

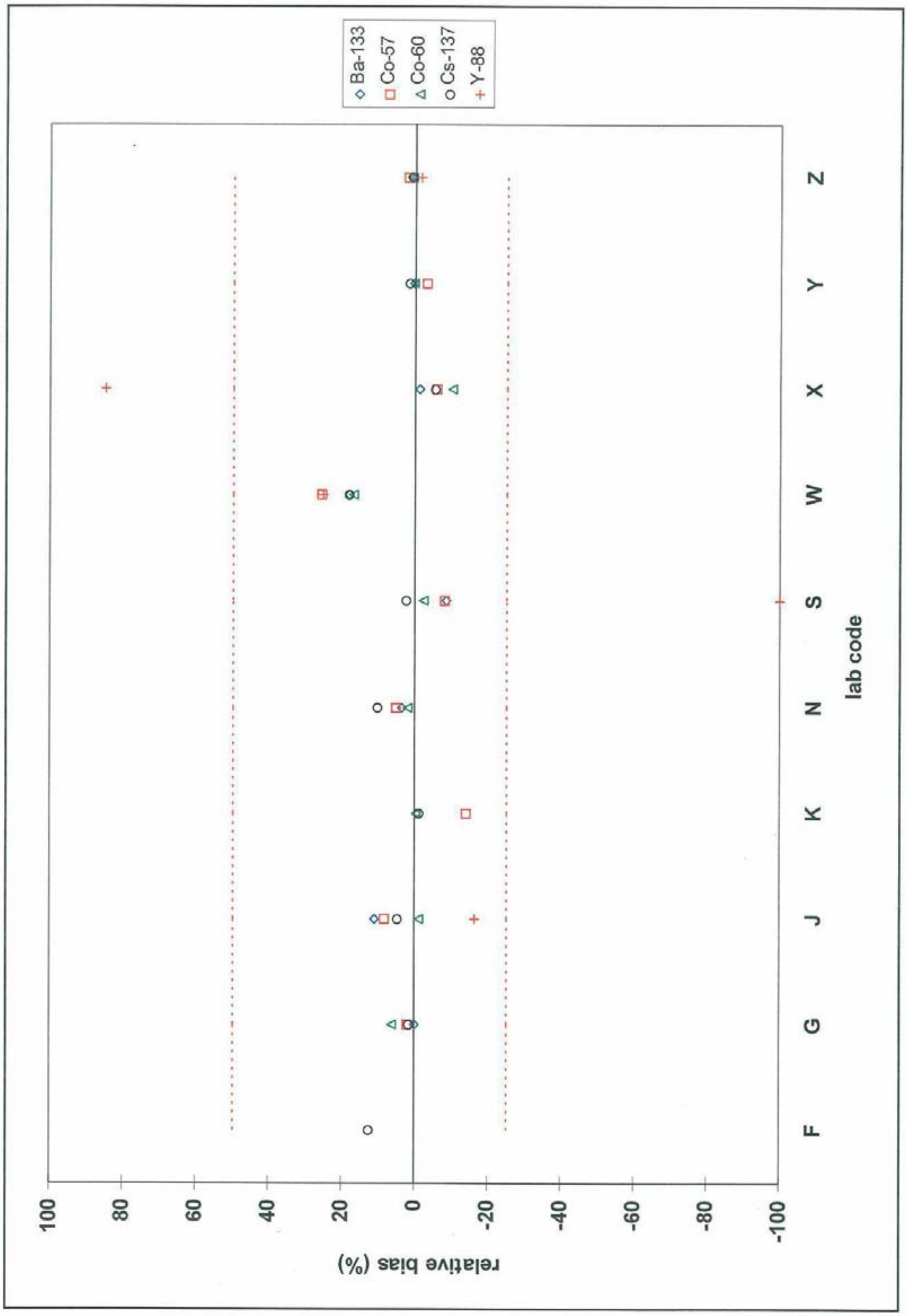


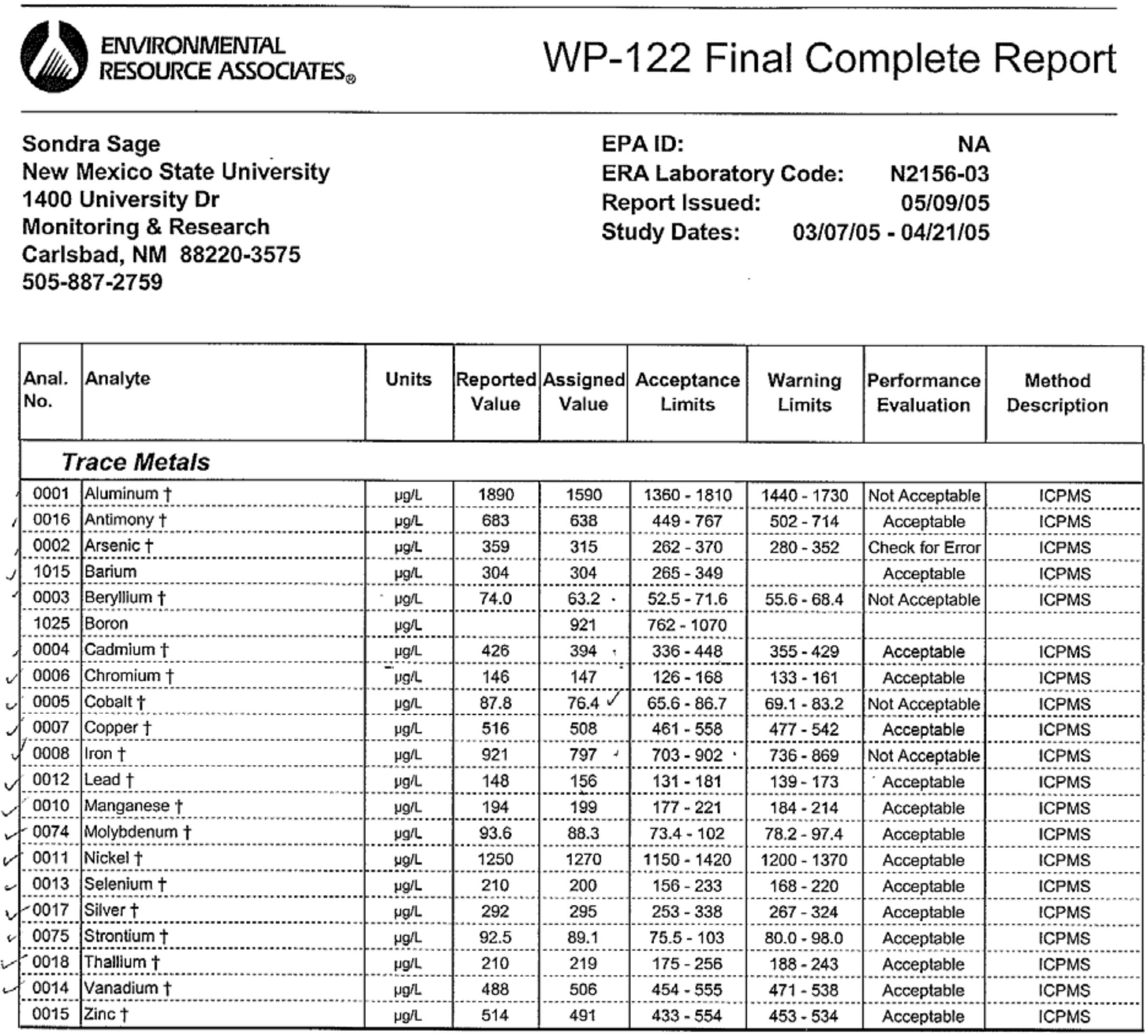
Figure E.1: Comparison of Results for Ten Internal Dosimetry Laboratories in the U.S. During 2006 by the ORNL Intercomparison Studies In-vivo Program

CEMRC is Lab Z. For all years that CEMRC has participated in the ORNL program, CEMRC has consistently performed better than all other labs in this area.

Table E-3
Quality Assurance/Quality Control for Internal Dosimetry
2005-2006 Audits

Agency	Date	Conclusion	Reason
DOELAP	2/28-3/1/2006	Pass	Every 3 years
CEMRC Self-Assessment	9/16-19/06	4 findings, 3 observations. Pass	Quality System
CEMRC Self-Assessment	10/15-16/05	1 finding , 2 observations. Pass	Quality System
CEMRC Self-Assessment	3/23/2005	5 findings, 1 observation. Pass	Quality System
WCS	1/26/2006	1 observation, 1 recommendation, 2 commendation. Pass	Qualification Audit
WTS	6/12-13/06	4 corrected during audit. Pass	Annual
WTS	6/27-28/05	1 noteworthy practice, 1 observation. Pass	Annual
Oak Ridge National Lab, Intercomparison Studies Program	Quarterly	Pass	External QC

Table E-4: Blind Check 2005 Environmental Chemistry Inorganic Analyses



ENVIRONMENTAL RESOURCE ASSOCIATES®

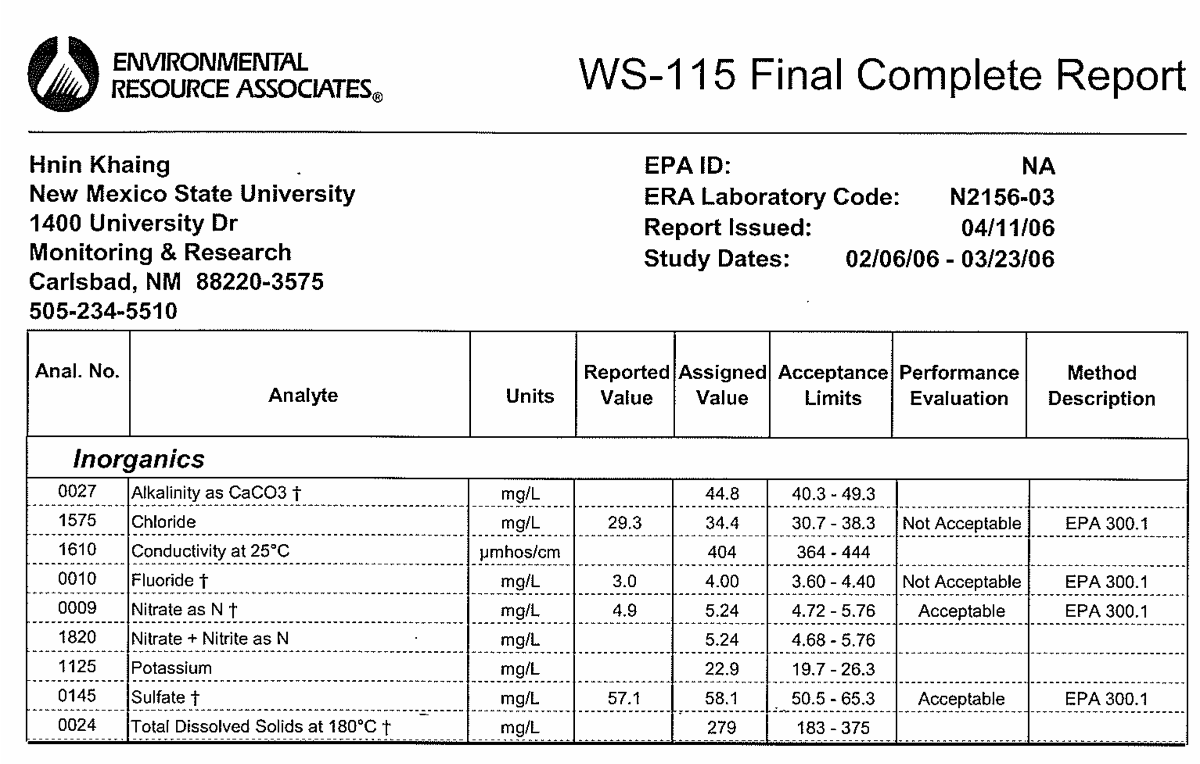
WP-122 Final Complete Report

Sondra Sage
New Mexico State University
1400 University Dr
Monitoring & Research
Carlsbad, NM 88220-3575
505-887-2759

EPA ID: NA
ERA Laboratory Code: N2156-03
Report Issued: 05/09/05
Study Dates: 03/07/05 - 04/21/05

Anal. No.	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Warning Limits	Performance Evaluation	Method Description
Trace Metals								
0001	Aluminum †	µg/L	1890	1590	1360 - 1810	1440 - 1730	Not Acceptable	ICPMS
0016	Antimony †	µg/L	683	638	449 - 767	502 - 714	Acceptable	ICPMS
0002	Arsenic †	µg/L	359	315	262 - 370	280 - 352	Check for Error	ICPMS
1015	Barium	µg/L	304	304	265 - 349		Acceptable	ICPMS
0003	Beryllium †	µg/L	74.0	63.2	52.5 - 71.6	55.6 - 68.4	Not Acceptable	ICPMS
1025	Boron	µg/L		921	762 - 1070			
0004	Cadmium †	µg/L	426	394	336 - 448	355 - 429	Acceptable	ICPMS
0006	Chromium †	µg/L	146	147	126 - 168	133 - 161	Acceptable	ICPMS
0005	Cobalt †	µg/L	87.8	76.4	65.6 - 86.7	69.1 - 83.2	Not Acceptable	ICPMS
0007	Copper †	µg/L	516	508	461 - 558	477 - 542	Acceptable	ICPMS
0008	Iron †	µg/L	921	797	703 - 902	736 - 869	Not Acceptable	ICPMS
0012	Lead †	µg/L	148	156	131 - 181	139 - 173	Acceptable	ICPMS
0010	Manganese †	µg/L	194	199	177 - 221	184 - 214	Acceptable	ICPMS
0074	Molybdenum †	µg/L	93.6	88.3	73.4 - 102	78.2 - 97.4	Acceptable	ICPMS
0011	Nickel †	µg/L	1250	1270	1150 - 1420	1200 - 1370	Acceptable	ICPMS
0013	Selenium †	µg/L	210	200	156 - 233	168 - 220	Acceptable	ICPMS
0017	Silver †	µg/L	292	295	253 - 338	267 - 324	Acceptable	ICPMS
0075	Strontium †	µg/L	92.5	89.1	75.5 - 103	80.0 - 98.0	Acceptable	ICPMS
0018	Thallium †	µg/L	210	219	175 - 256	188 - 243	Acceptable	ICPMS
0014	Vanadium †	µg/L	488	506	454 - 555	471 - 538	Acceptable	ICPMS
0015	Zinc †	µg/L	514	491	433 - 554	453 - 534	Acceptable	ICPMS

Table E-4: Blind Check 2005 Environmental Chemistry Inorganic Analyses (continued)



ENVIRONMENTAL
RESOURCE ASSOCIATES®

WS-115 Final Complete Report

Hnin Khaing
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1400 University Dr
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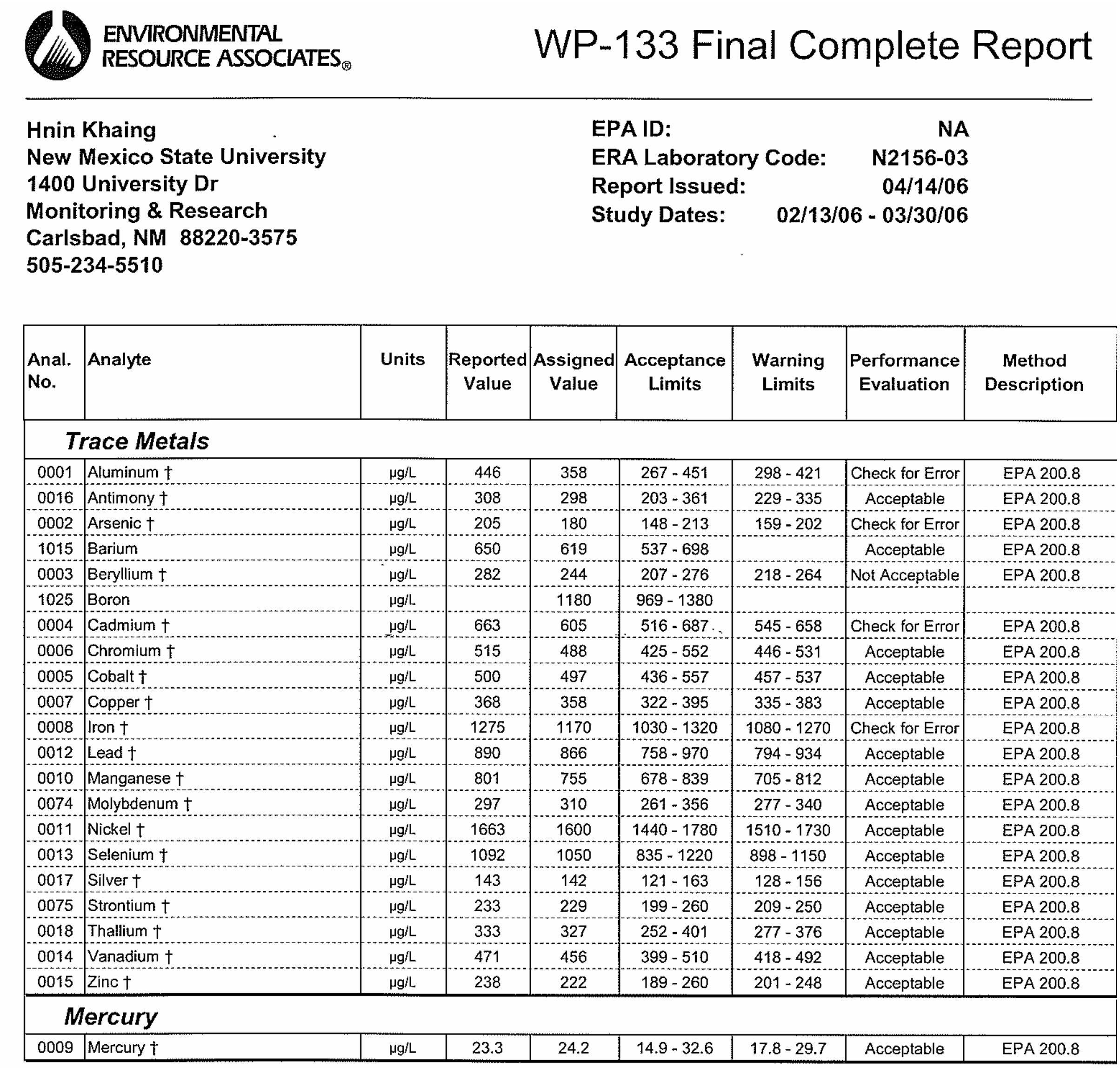
505-234-5510

EPA ID: NA
ERA Laboratory Code: N2156-03
Report Issued: 04/11/06
Study Dates: 02/06/06 - 03/23/06

Anal. No.	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Performance Evaluation	Method Description
Inorganics							
0027	Alkalinity as CaCO3 †	mg/L		44.8	40.3 - 49.3		
1575	Chloride	mg/L	29.3	34.4	30.7 - 38.3	Not Acceptable	EPA 300.1
1610	Conductivity at 25°C	µmhos/cm		404	364 - 444		
0010	Fluoride †	mg/L	3.0	4.00	3.60 - 4.40	Not Acceptable	EPA 300.1
0009	Nitrate as N †	mg/L	4.9	5.24	4.72 - 5.76	Acceptable	EPA 300.1
1820	Nitrate + Nitrite as N	mg/L		5.24	4.68 - 5.76		
1125	Potassium	mg/L		22.9	19.7 - 26.3		
0145	Sulfate †	mg/L	57.1	58.1	50.5 - 65.3	Acceptable	EPA 300.1
0024	Total Dissolved Solids at 180°C †	mg/L		279	183 - 375		

Table E-4: Blind Check 2005 Environmental Chemistry Inorganic Analyses (continued)



ENVIRONMENTAL RESOURCE ASSOCIATES®

WP-133 Final Complete Report

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505-234-5510

EPA ID: NA
ERA Laboratory Code: N2156-03
Report Issued: 04/14/06
Study Dates: 02/13/06 - 03/30/06

Anal. No.	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Warning Limits	Performance Evaluation	Method Description
Trace Metals								
0001	Aluminum †	µg/L	446	358	267 - 451	298 - 421	Check for Error	EPA 200.8
0016	Antimony †	µg/L	308	298	203 - 361	229 - 335	Acceptable	EPA 200.8
0002	Arsenic †	µg/L	205	180	148 - 213	159 - 202	Check for Error	EPA 200.8
1015	Barium	µg/L	650	619	537 - 698		Acceptable	EPA 200.8
0003	Beryllium †	µg/L	282	244	207 - 276	218 - 264	Not Acceptable	EPA 200.8
1025	Boron	µg/L		1180	969 - 1380			
0004	Cadmium †	µg/L	663	605	516 - 687	545 - 658	Check for Error	EPA 200.8
0006	Chromium †	µg/L	515	488	425 - 552	446 - 531	Acceptable	EPA 200.8
0005	Cobalt †	µg/L	500	497	436 - 557	457 - 537	Acceptable	EPA 200.8
0007	Copper †	µg/L	368	358	322 - 395	335 - 383	Acceptable	EPA 200.8
0008	Iron †	µg/L	1275	1170	1030 - 1320	1080 - 1270	Check for Error	EPA 200.8
0012	Lead †	µg/L	890	866	758 - 970	794 - 934	Acceptable	EPA 200.8
0010	Manganese †	µg/L	801	755	678 - 839	705 - 812	Acceptable	EPA 200.8
0074	Molybdenum †	µg/L	297	310	261 - 356	277 - 340	Acceptable	EPA 200.8
0011	Nickel †	µg/L	1663	1600	1440 - 1780	1510 - 1730	Acceptable	EPA 200.8
0013	Selenium †	µg/L	1092	1050	835 - 1220	898 - 1150	Acceptable	EPA 200.8
0017	Silver †	µg/L	143	142	121 - 163	128 - 156	Acceptable	EPA 200.8
0075	Strontium †	µg/L	233	229	199 - 260	209 - 250	Acceptable	EPA 200.8
0018	Thallium †	µg/L	333	327	252 - 401	277 - 376	Acceptable	EPA 200.8
0014	Vanadium †	µg/L	471	456	399 - 510	418 - 492	Acceptable	EPA 200.8
0015	Zinc †	µg/L	238	222	189 - 260	201 - 248	Acceptable	EPA 200.8
Mercury								
0009	Mercury †	µg/L	23.3	24.2	14.9 - 32.6	17.8 - 29.7	Acceptable	EPA 200.8

Table E-5: Radiochemistry NIST-RIP and MAPEP Intercomparison Results

U.S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD

REPORT OF TRACEABILITY

Carlsbad Environmental Monitoring and Research Center
Carlsbad, New Mexico

Test Identification	NRIP05-SS
Matrix Description	^{241}Am, ^{238}Pu, ^{90}Sr, ^{238}U, ^{230}Th in soil[1]
Test Activity Range	30 mBq•sample^{-1} to 180 mBq•sample^{-1}
Reference Time	12:00 EST, April 1, 2005

Measurement Results

Nuclide	***NIST Value*** [2,3]		**Reported Value**[4]		**Difference**[5]
	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	(%)
^{241}Am	1.055	0.63	1.025	9.268	-2.8
^{238}Pu	1.165	0.68	1.127	4.656	-3.3
^{239}Pu	1.102	0.68	1.078	5.251	-2.2
^{234}U	2.619	0.98	2.599	5.425	-0.75
^{235}U	0.125	0.62	0.137	14.728	+9.4
^{238}U	2.719	0.60	2.688	5.860	-1.1
^{90}Sr	2.593	0.74	2.429	8.751	-6.3
^{230}Th	1.314	0.58	1.280	8.484	-2.6

Methods

	NIST[6]	Reporting Laboratory[7]
Activity Measurements	Alpha- and Beta-Spectrometry Mass Spectrometry	Alpha- and Beta-Spectrometry

Evaluation (per ANSI N42.22)

Nuclide	**ANSI N42.22 Traceable**	**Traceability Limit (%)**	**Nuclide**	**ANSI N42.22 Traceable**	**Traceability Limit (%)**
^{241}Am	Yes	14	**^{235}U**	Yes	24
^{238}Pu	Yes	6.8	**^{238}U**	Yes	8.7
^{239}Pu	Yes	7.8	**^{90}Sr**	Yes	12
^{234}U	Yes	8.2	**^{230}Th**	Yes	12

Samples Distributed	February 18, 2005
Reporting Data Received	May 31, 2005

For the Director

Michael P. Unterweger, Acting Leader
Radioactivity Group
Physics Laboratory

U.S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD

REPORT OF TRACEABILITY

Carlsbad Environmental Monitoring and Research Center
Carlsbad, New Mexico

Test Identification	NRIP05-AW
Matrix Description	^{241}Am, ^{238}Pu, ^{90}Sr, ^{238}U, ^{230}Th in acidified water[1]
Test Activity Range	30 mBq•sample^{-1} to 180 mBq•sample^{-1}
Reference Time	12:00 EST, April 1, 2005

Measurement Results

Nuclide	***NIST Value*** [2,3]		**Reported Value**[4]		**Difference**[5]
	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, k=2)	(±%)
^{241}Am	1.786	0.63	1.785	3.558	-0.03
^{238}Pu	1.972	0.68	1.971	2.536	-0.03
^{239}Pu	1.865	0.68	1.874	2.836	+0.49
^{238}U	4.602	0.60	4.674	4.143	+1.6
^{230}Th	2.224	0.58	2.034	4.366	-8.5

NA= Not Applicable **NR= Not Reported**

Methods

	NIST[6]	Reporting Laboratory[7]
Activity Measurements	Alpha- and Beta-Spectrometry Mass Spectrometry	Alpha- and Beta-Spectrometry

Evaluation (per ANSI N42.22)

Nuclide	**N42.22**[8]	
	ANSI N42.22 Traceable	**Traceability Limit (±Percent)**
^{241}Am	Yes	5.4
^{238}Pu	Yes	3.9
^{239}Pu	Yes	4.4
^{238}U	Yes	6.4
^{230}Th	No	6.1

Samples Distributed	June 2, 2005
Reporting Data Received	September 30, 2005

For the Director

Michael P. Unterweger, Acting Leader
Radioactivity Group
Physics Laboratory

U.S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD

REPORT OF TRACEABILITY

Carlsbad Environmental Monitoring and Research Center
Carlsbad, New Mexico

Test Identification	NRIP05-GF
Matrix Description	^{241}Am, ^{238}Pu, ^{239}Pu ^{90}Sr, ^{234}U, ^{238}U, ^{230}Th on Glass-Fiber Filters[1]
Test Activity Range	0.07Bq•sample^{-1} to 3 Bq•sample^{-1}
Reference Time	12:00 EST, April 1, 2005

Measurement Results

Nuclide	***NIST Value*** [2,3]		**Reported Value**[4]		**Difference**[5]
	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, 2s)	Massic Activity Bq•g^{-1}	Relative Expanded Uncertainty (%, 2s)	(±%)
^{241}Am	0.7466	0.67	0.7397	5.10	-0.92
^{238}Pu	0.8246	0.71	0.8175	4.84	-0.87
^{239}Pu	0.7799	0.71	0.7753	4.89	-0.59
^{234}U	1.853	1.00	1.8037	5.91	-2.7
^{238}U	1.924	0.63	1.8850	5.64	-2.0
^{90}Sr	1.835	0.77	1.3951	12.42	-24
^{230}Th	0.9300	0.61	0.8831	8.79	-5.0
NA= Not Applicable				**NR= Not Reported**	
			Methods		
Activity Measurements	NIST[6]		Reporting Laboratory[7]		
	Alpha- and Beta-Spectrometry Mass Spectrometry		Alpha- and Beta-Spectrometry		

Evaluation (per ANSI N42.22)

Nuclide	**N42.22**[8]	
	ANSI N42.22 Traceable	**Traceability Limit (±Percent)**
^{241}Am	Yes	8
^{238}Pu	Yes	7
^{239}Pu	Yes	7
^{234}U	Yes	9
^{238}U	Yes	8
^{90}Sr	No	14
^{230}Th	Yes	13

Samples Distributed	12 January 2005
Reporting Data Received	11 March 2005

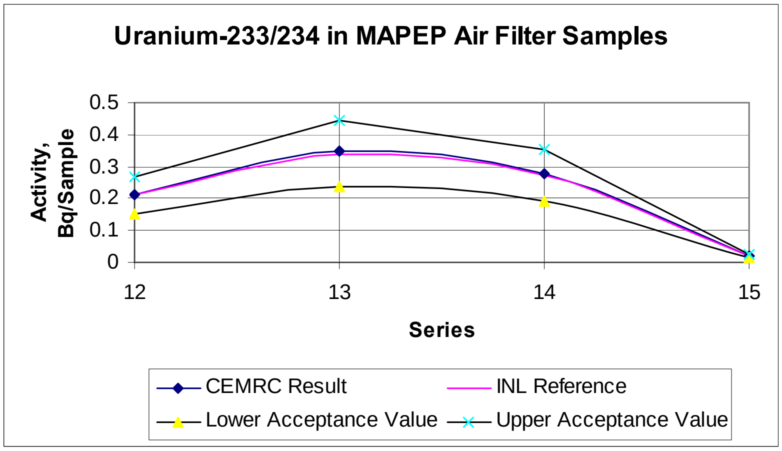
For the Director

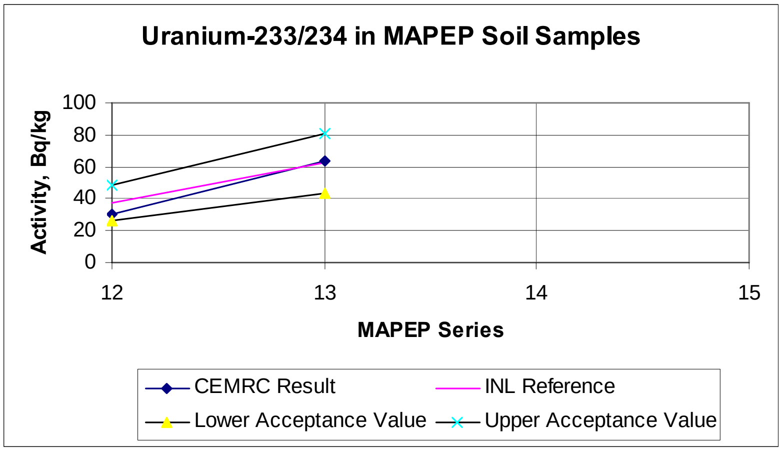
Michael P. Unterweger, Acting Leader
Radioactivity Group Physics Laboratory

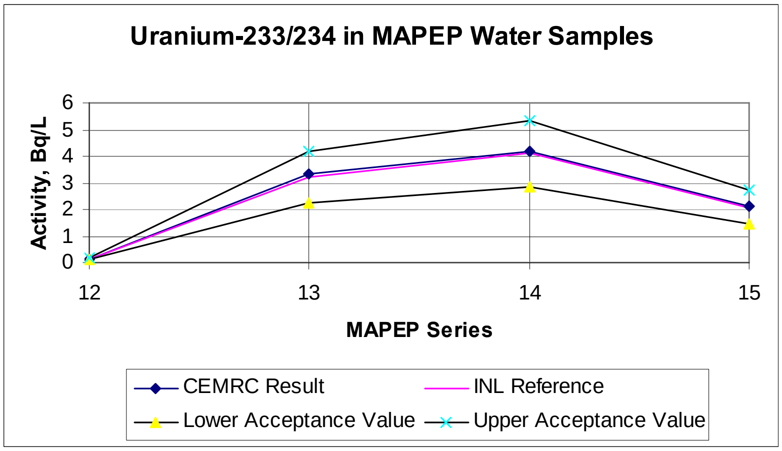
MAPEP Results

Series 12 is 2004, Series 13-14 are 2005, Series 15 is 2006.

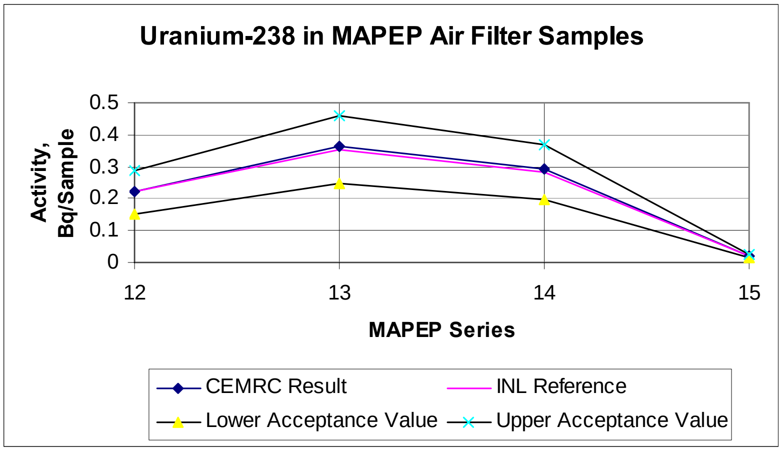
Uranium-233/234

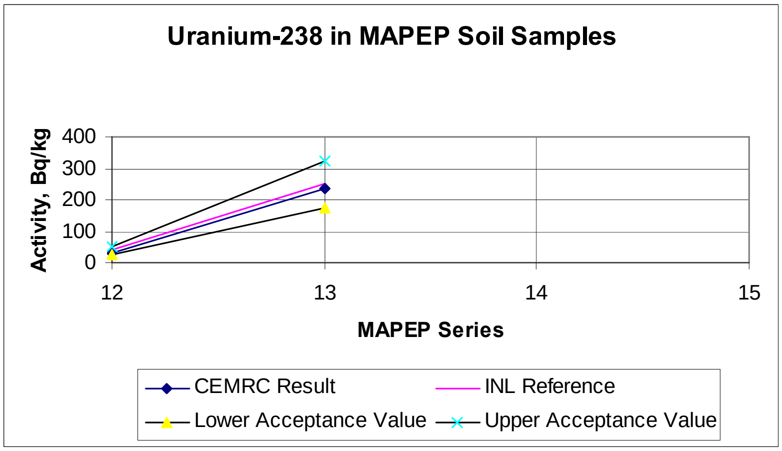


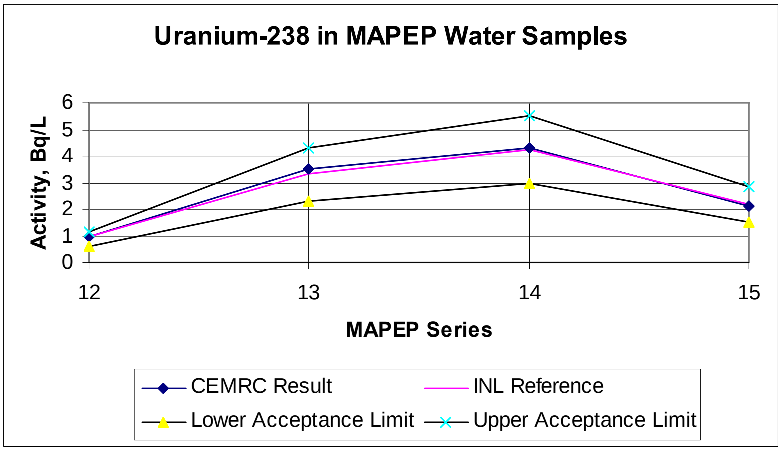




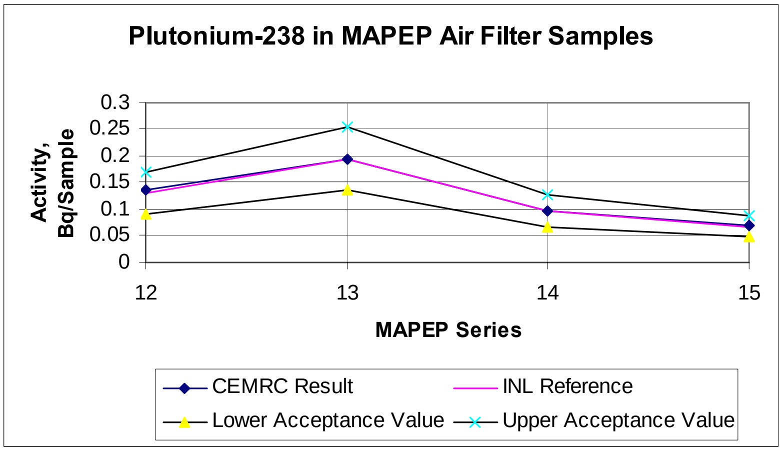
Uranium-238

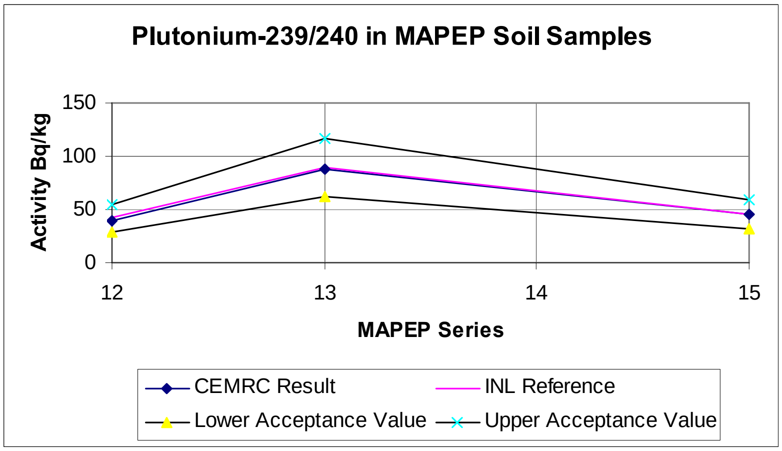

Uranium-238 in MAPEP Air Filter Samples
Activity, Bq/Sample
0.5
0.4
0.3
0.2
0.1
0
12
13
14
15
MAPEP Series
CEMRC Result
INL Reference
Lower Acceptance Value
Upper Acceptance Value

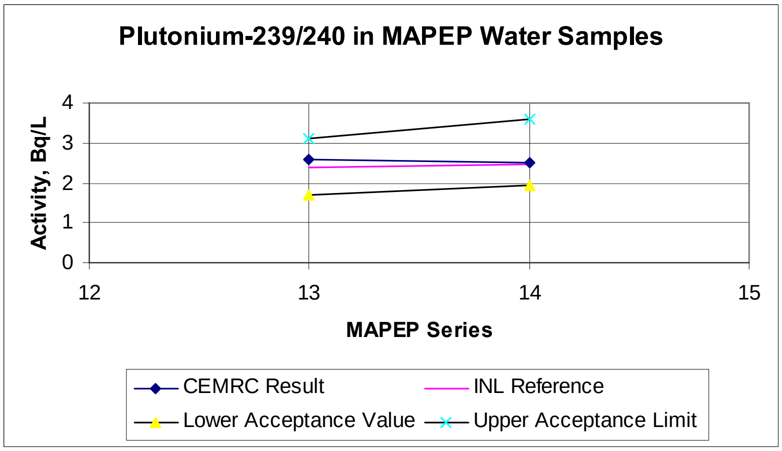

Uranium-238 in MAPEP Soil Samples
Activity, Bq/kg
400
300
200
100
0
12
13
14
15
MAPEP Series
CEMRC Result
INL Reference
Lower Acceptance Value
Upper Acceptance Value


Uranium-238 in MAPEP Water Samples
Activity, Bq/L
6
5
4
3
2
1
0
12
13
14
15
MAPEP Series
CEMRC Result
INL Reference
Lower Acceptance Limit
Upper Acceptance Limit

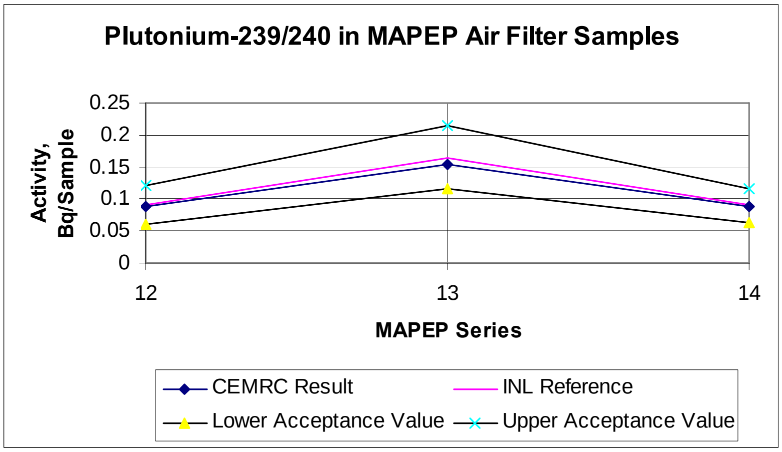
Plutonium-238

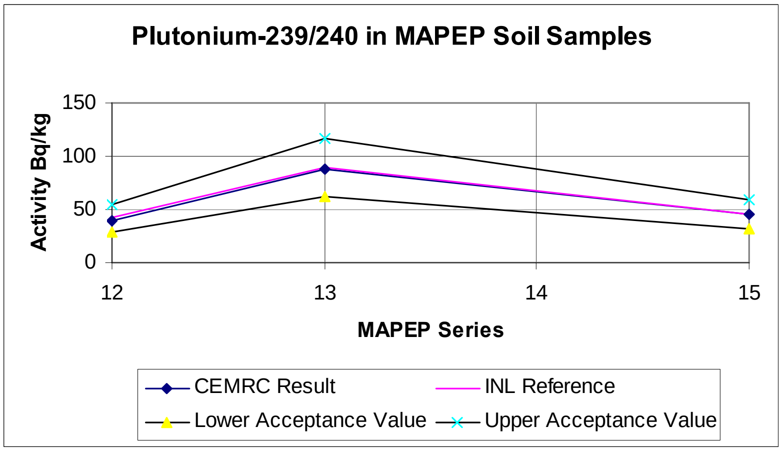


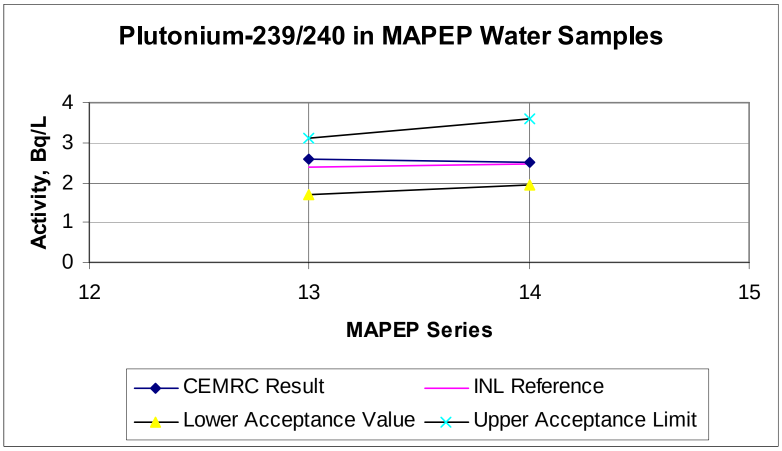




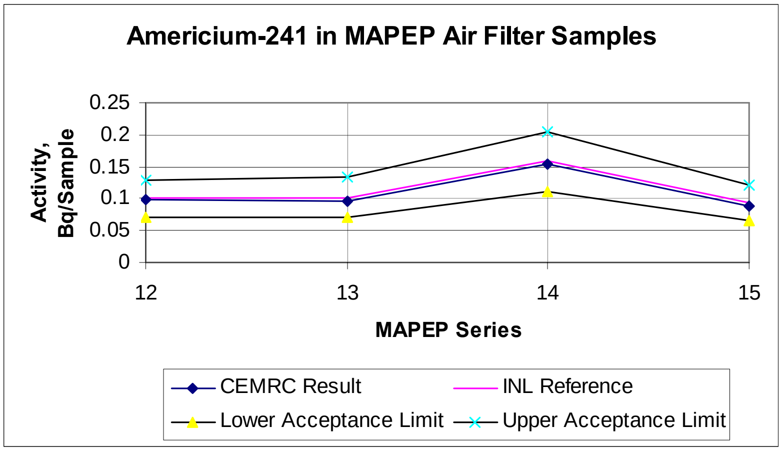
Plutonium-239/240

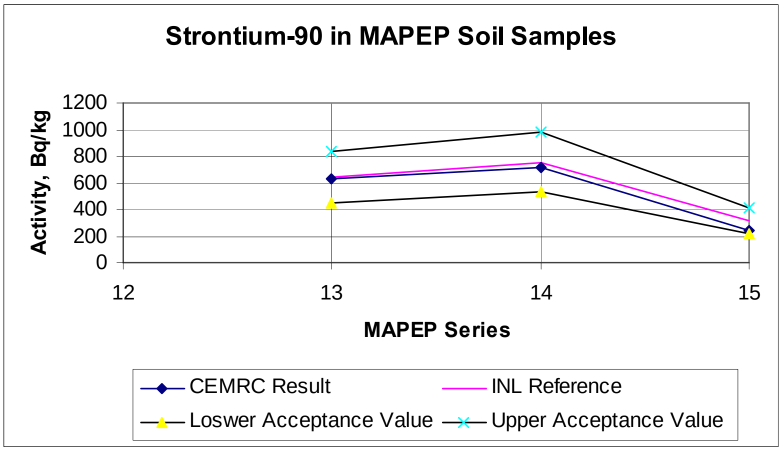


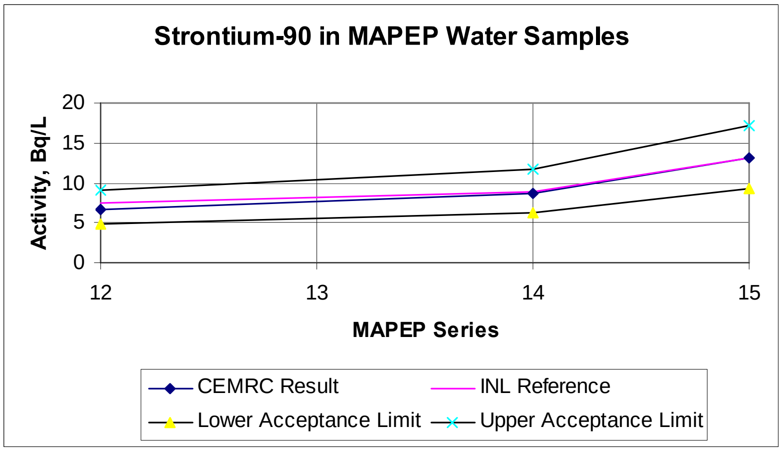




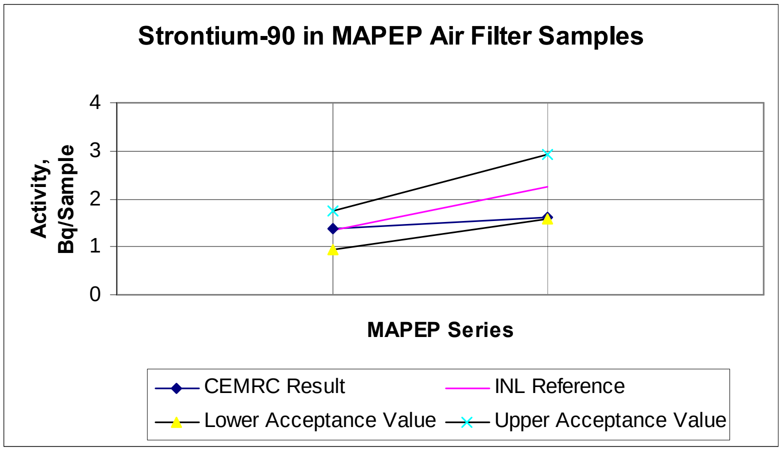
Amercium-241

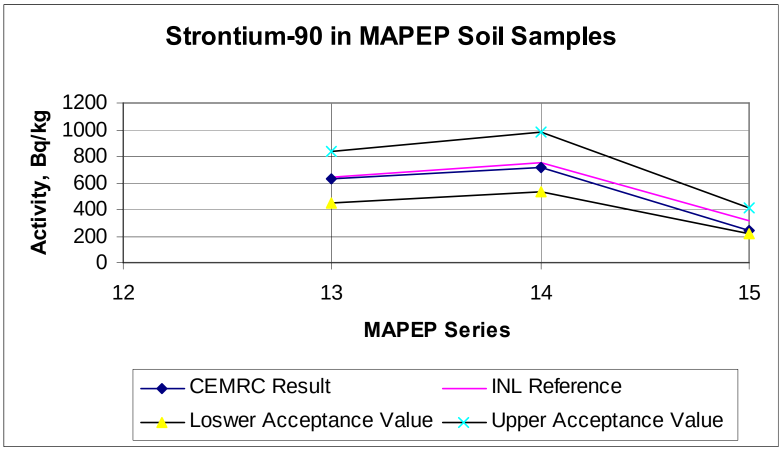


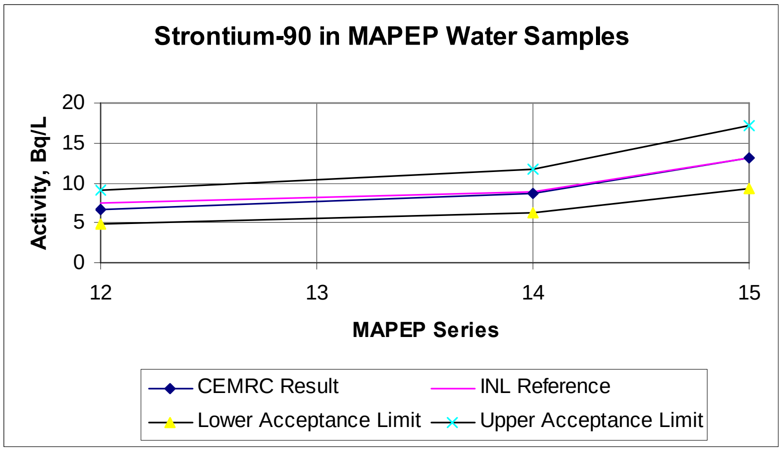


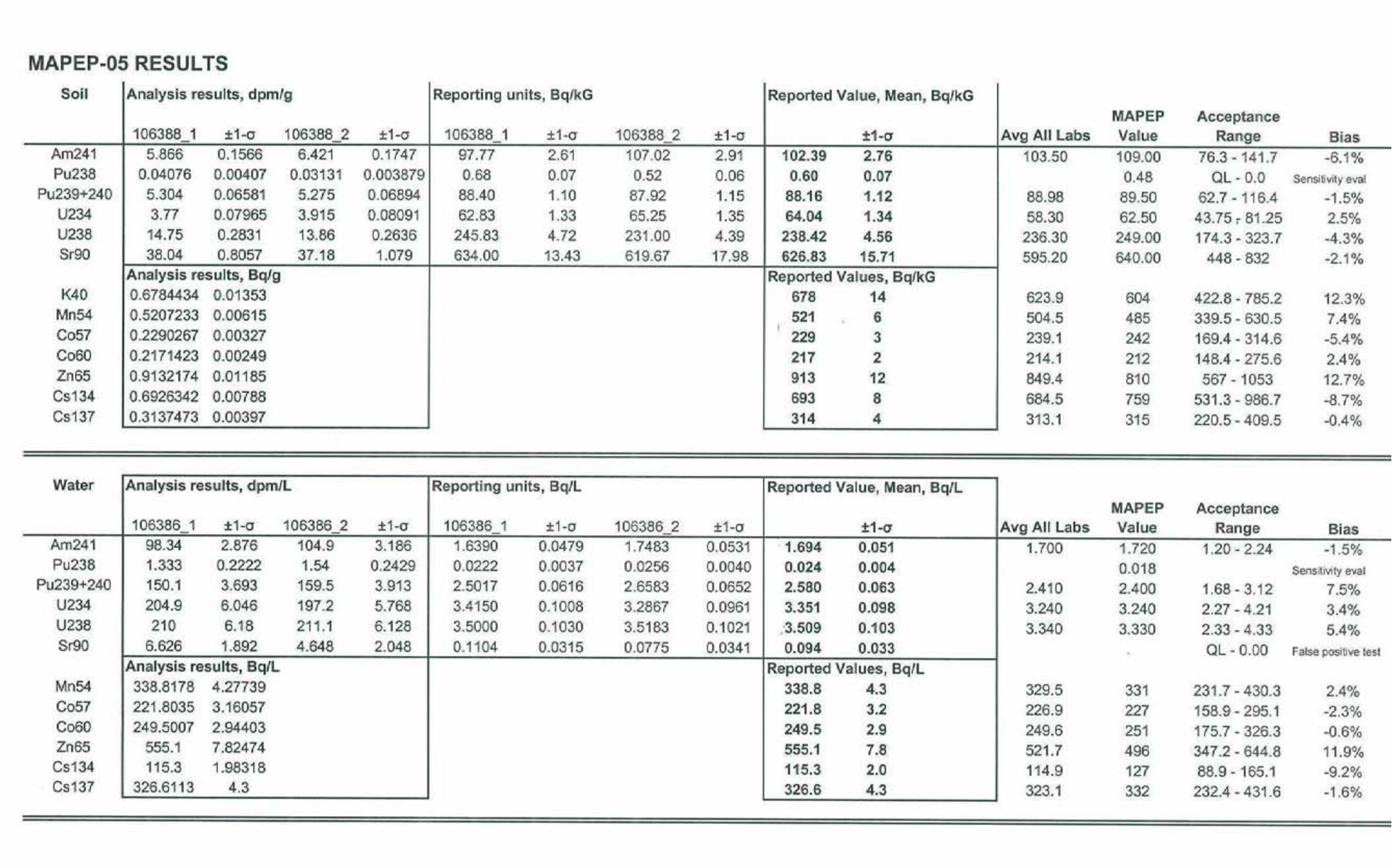


Strontium-90









MAPEP-05 RESULTS

Soil	Analysis results, dpm/g				Reporting units, Bq/kG				Reported Value, Mean, Bq/kG			MAPEP	Acceptance	
	106388_1	±1-σ	106388_2	±1-σ	106388_1	±1-σ	106388_2	±1-σ		±1-σ	Avg All Labs	Value	Range	Bias
Am241	5.866	0.1566	6.421	0.1747	97.77	2.61	107.02	2.91	**102.39**	**2.76**	103.50	109.00	76.3 - 141.7	-6.1%
Pu238	0.04076	0.00407	0.03131	0.003879	0.68	0.07	0.52	0.06	**0.60**	**0.07**		0.48	QL - 0.0	Sensitivity eval
Pu239+240	5.304	0.06581	5.275	0.06894	88.40	1.10	87.92	1.15	**88.16**	**1.12**	88.98	89.50	62.7 - 116.4	-1.5%
U234	3.77	0.07965	3.915	0.08091	62.83	1.33	65.25	1.35	**64.04**	**1.34**	58.30	62.50	43.75 - 81.25	2.5%
U238	14.75	0.2831	13.86	0.2636	245.83	4.72	231.00	4.39	**238.42**	**4.56**	236.30	249.00	174.3 - 323.7	-4.3%
Sr90	38.04	0.8057	37.18	1.079	634.00	13.43	619.67	17.98	**626.83**	**15.71**	595.20	640.00	448 - 832	-2.1%
	Analysis results, Bq/g								Reported Values, Bq/kG					
K40	0.6784434	0.01353							**678**	**14**	623.9	604	422.8 - 785.2	12.3%
Mn54	0.5207233	0.00615							**521**	**6**	504.5	485	339.5 - 630.5	7.4%
Co57	0.2290267	0.00327							**229**	**3**	239.1	242	169.4 - 314.6	-5.4%
Co60	0.2171423	0.00249							**217**	**2**	214.1	212	148.4 - 275.6	2.4%
Zn65	0.9132174	0.01185							**913**	**12**	849.4	810	567 - 1053	12.7%
Cs134	0.6926342	0.00788							**693**	**8**	684.5	759	531.3 - 986.7	-8.7%
Cs137	0.3137473	0.00397							**314**	**4**	313.1	315	220.5 - 409.5	-0.4%

Water	Analysis results, dpm/L				Reporting units, Bq/L				Reported Value, Mean, Bq/L			MAPEP	Acceptance	
	106386_1	±1-σ	106386_2	±1-σ	106386_1	±1-σ	106386_2	±1-σ		±1-σ	Avg All Labs	Value	Range	Bias
Am241	98.34	2.876	104.9	3.186	1.6390	0.0479	1.7483	0.0531	**1.694**	**0.051**	1.700	1.720	1.20 - 2.24	-1.5%
Pu238	1.333	0.2222	1.54	0.2429	0.0222	0.0037	0.0256	0.0040	**0.024**	**0.004**		0.018		Sensitivity eval
Pu239+240	150.1	3.693	159.5	3.913	2.5017	0.0616	2.6583	0.0652	**2.580**	**0.063**	2.410	2.400	1.68 - 3.12	7.5%
U234	204.9	6.046	197.2	5.768	3.4150	0.1008	3.2867	0.0961	**3.351**	**0.098**	3.240	3.240	2.27 - 4.21	3.4%
U238	210	6.18	211.1	6.128	3.5000	0.1030	3.5183	0.1021	**3.509**	**0.103**	3.340	3.330	2.33 - 4.33	5.4%
Sr90	6.626	1.892	4.648	2.048	0.1104	0.0315	0.0775	0.0341	**0.094**	**0.033**			QL - 0.00	False positive test
	Analysis results, Bq/L								Reported Values, Bq/L					
Mn54	338.8178	4.27739							**338.8**	**4.3**	329.5	331	231.7 - 430.3	2.4%
Co57	221.8035	3.16057							**221.8**	**3.2**	226.9	227	158.9 - 295.1	-2.3%
Co60	249.5007	2.94403							**249.5**	**2.9**	249.6	251	175.7 - 326.3	-0.6%
Zn65	555.1	7.82474							**555.1**	**7.8**	521.7	496	347.2 - 644.8	11.9%
Cs134	115.3	1.98318							**115.3**	**2.0**	114.9	127	88.9 - 165.1	-9.2%
Cs137	326.6113	4.3							**326.6**	**4.3**	323.1	332	232.4 - 431.6	-1.6%

Table E-6: An Example of the Daily Performance Tests for ICP-MS

Sample Daily Performance Data of the Elan 6000 ICP-MS for Feb-March 2006
(Proficiency Test WP-133 Spanned the dates 02/13/06 – 03/30/06)

	Acceptable Ranges		2/15/06			2/23/06		
	Recommended Net Intensity Mean of 5 replicate readings*	*Required* Relative Standard Deviation (%)	Measured Mean Intensity	Relative Standard Deviation	Performance Evaluation	Measured Mean Intensity	Relative Standard Deviation	Performance Evaluation
Be	1,000-3,000	0.0 - 5.0%	1284.1	4.2	Acceptable	1370.5	3.0	Acceptable
Mg	25,000-80,000	0.0 - 5.0%	28302	2.4	Acceptable	30741	2.2	Acceptable
In	120,000-230,000	0.0 - 5.0%	122214.7	3.5	Acceptable	203520.8	1.9	Acceptable
Pb	55,000-110,000	0.0 - 5.0%	60329.6	2.7	Acceptable	95613.8	1.1	Acceptable
Ba	600,000-1,300,000	0.0 - 5.0%	617204.2	1.6	Acceptable	1027768.2	1.4	Acceptable
Ba++	≤ 5.0% Ba value	0.0 - 5.0%	2.00%	3.3	Acceptable	2.20%	2.5	Acceptable
Ce	600,000-1,300,000	N/A	717147.5	---	Acceptable	1202009.3	---	Acceptable
CeO	≤ 5.0% Ce value	N/A	2.60%	---	Acceptable	3.20%	---	Acceptable
Bkgd	≤ 25.0	N/A	1.6	---	Acceptable	0.6	---	Acceptable

	Acceptable Ranges		3/17/06			3/27/06		
	Recommended Net Intensity Mean of 5 replicate readings*	*Required* Relative Standard Deviation (%)	Measured Mean Intensity	Relative Standard Deviation	Performance Evaluation	Measured Mean Intensity	Relative Standard Deviation	Performance Evaluation
Be	1,000-3,000	0.0 - 5.0%	1252.3	4.8	Acceptable	2702.9	3.1	Acceptable
Mg	25,000-80,000	0.0 - 5.0%	26001.1	4.4	Acceptable	63750.3	2.3	Acceptable
In	120,000-230,000	0.0 - 5.0%	221700.7	0.6	Acceptable	234935.7	3.6	Check for Error
Pb	55,000-110,000	0.0 - 5.0%	117458.3	0.9	Check for Error	137074.9	4.8	Check for Error
Ba	600,000-1,300,000	0.0 - 5.0%	1017495.3	0.3	Acceptable	1236604.5	4.4	Acceptable
Ba++	≤ 5.0% Ba value	0.0 - 5.0%	3.40%	2.3	Acceptable	3.10%	3.0	Acceptable
Ce	600,000-1,300,000	N/A	1173908.5	---	Acceptable	1423370.1	---	Acceptable
CeO	≤ 5.0% Ce value	N/A	2.90%	---	Acceptable	3.20%	---	Acceptable
Bkgd	≤ 25.0	N/A	2.2	---	Acceptable	1.4	---	Acceptable

*Recommended ranges show typical instrument performance--higher values are acceptable but possible interferences should be explored

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