2009 Report
Carlsbad Environmental Monitoring & Research Center

1400 University Drive
Carlsbad, NM 88220
(575) 887-2759
www.cemrc.org

NM STATE
College of Engineering
Institute for Energy
& the Environment

This page intentionally left blank.

Table of Contents

List of Tables

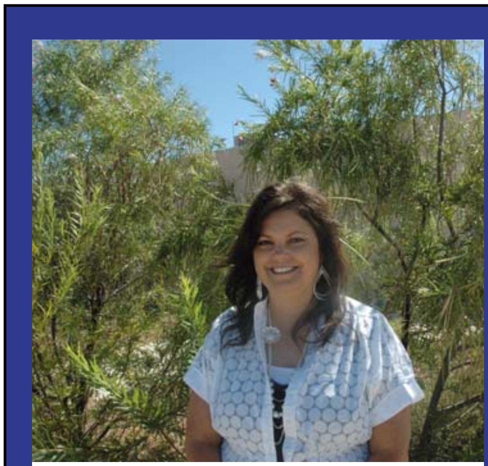
List of Figures

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
FAS	fixed air samples
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	Washington TRU Solutions



A green spring outside CEMRC

A little light reading in the Library

Filling up the liquid nitrogen Dewar in the Whole Body Counter

Light Hall – Home of CEMRC

FORWARD

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 2009.

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 photographs are of the VOC lab, the Whole Body Count chamber, and the Radiochemistry Team. The Forward shows various equipment and laboratories used by scientists at CEMRC.

Reviewing data packages in the VOC lab

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
- 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 in the Institute for Energy and the Environment, 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 radionuclides;
- Provide advanced training and educational opportunities
- Develop improved measurement methods, procedures and sensors
- Establish a health and environmental database accessible to all sectors

Slightly over half of CEMRC's funding comes from the monitoring mission and the rest is split among three direct contracts through which CEMRC provides facility, safety and scientific support to entities such as Los Alamos National Laboratory (LANL), Washington TRU Solutions (WTS and its related entities WSMS and WRES) and the LES National Enrichment Facility (NEF).

KEY ACTIVITIES

The key activities necessary to continue developing CEMRC and monitoring in the vicinity of the WIPP (WIPP Environ-mental Monitoring Project) are:

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

At the end of 2009, the CEMRC employed 24 personnel (Table 1). Three positions were in recruitment.

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

In January 1996, 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 2009, significant facility upgrades included continued roof replacement on the building and ventilation repairs.

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 (RC), (2) environmental chemistry (EC), (3) informatics and modeling (IM), (4) internal dosimetry (ID), and (5) field programs (FP). In 2009, a new program organic chemistry administration (OC), was added. Facility management and records management provide support to the programmatic areas. Detailed descriptions of each program area and associated instrumentation and facilities are on the CEMRC web site at http://www.cemrc.org.

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

The following is a list of grants and contracts generated during FY2009, an overall increase from previous years.

DOE CBFO
- $1.817 million for WIPP Environmental Monitoring and Underground Science

URS Corp. (WTS, WRES, and WSMS)
- $749 thousand for Technical Support, VOC and WBC

Los Alamos National Laboratory
- $368 thousand for Actinide Chemistry scientific support

LES National Enrichment Facility
- $328 thousand for Uranium Enrichment Analytical Scientific Support and facility upgrade.

Sandia National Laboratory
- $160 thousand for Performance Assessment Scientific Support

Other
- $110 thousand from WCS, Korea, IIT and others.

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.

The new underground science project continued in a collaboration among CEMRC, NMSU Las Cruces and DOE CBFO to address low-dose biological effects by setting up a shielded chamber in the WIPP underground to study various cell lines.

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 several papers were published in peer-reviewed scientific journals and books during 2009 (Appendix B). 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 2009, the CEMRC hosted various colloquia presented by visiting scientists, and participated 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 C. As described in a later section, over 800 volunteers from the local community have participated in the “Lie Down and Be Counted” program.

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 2009, undergraduate students worked in laboratory aide positions at CEMRC. These positions provided training and basic skills development relevant to the position assignments. Also, post-docs and visiting scientists worked in the CEMRC facility during 2009 (Appendix D). In particular, The Illinois Institute of Technology (IIT) again brought one of its radiation physics classes (Physics 770) to CEMRC as they recently lost the ability to teach it at Argonne National Laboratory and CEMRC was able to provide an appropriate radiological setting, lab space, and equipment for the course.

Table 1: Listing of CEMRC Staff as of the end of 2009

Name	Position
Baker, David	Assistant Scientist
Ballard, Sally	Science Specialist
Brown, Becky	Assistant to Director
Brown, Bill	Facility Manager
Chancellor, Adrienne	Science Specialist
Conca, James	Director
Greene, Chris	Physical Scientist III
Hinojos, Leo	Technician I
Kelly, Christopher	Technician I
Kirchner, Thomas	Senior Scientist
Lee, Alex	Assistant Analyst
Monk, James	Radiation Safety Specialist
Najera, Angela	Editor/Technical Writer
Navarrette, Adrianne	Lab Assistant
Owen, Lyndi	Technician I
Saul, Tana	Technician I
Schoep, David	Radiation Safety Training Specialist
Stone, Elizabeth	Senior Scientist
Sullivan, Sean	Technician I
Sullivan, Tina	Program Analyst II
Thakur, Punam	Senior Scientist
Ui Chearnaigh, Kim	Assistant Scientist
Van Stippen, Josh	Technician I
Warren, Kaitlan	Technician I
Wood, Fran	Administrative Secretary II

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 demon-stration requirements applicable to the WIPP. Analytical results and interpreta-tions 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 2008 activities for the major environmental medium in the WIPP EM. It is important to note that nuclear waste was first 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 2009.

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 increased radiological contamination in the region of the WIPP that could be attributed to releases from the WIPP. Levels of radiological and non-radiological analytes measured in 2009 were within the range of 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 before disposal phase operations began in 1999.

In 2003, CEMRC reported detection of a small quantity of Pu in a composite aerosol sample from the second calendar quarter. This discovery was corroborated by both EEG and WTS through the analyses of samples that were independently collected and analyzed. 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 minimum detectable concentration (MDC). CEMRC reported in 2007 a small quantity of Pu in composite aerosol samples from the first and third quarters. However, it turns out these resulted from minor contamination during the gross alpha/beta counting measure-ments which has since been corrected, and no Pu was detected in 2007 above MDC.

In 2008 and 2009, CEMRC again detected a small quantity of Pu in composite aerosol samples from the first and second quarters similar to the 2003 detection, also corroborated by WTS. The concentrations are so low (all values are orders of magnitude below compliance or action levels, tens of counts per 7,200 minutes) that it is impossible to determine the origin, whether from dust particulates electrostatically attached to the outside of equipment, personnel or containers, external dust from fallout and the nearby Gnome site chromatographically moving through the underground over years, or Pu actually coming from the waste. Like so much involved in nuclear and environmental issues, detection at these levels becomes a philosophical issue – how low is low enough? Society's obsession with unachievable goals like zero concentrations or zero activities come up against the reality of the physical world.

The choice for CEMRC to monitor at levels orders of magnitude below action or compliance levels, even below background, raises the question as to what does this mean? What should be done, if anything, when positive values are observed? At these levels, even laboratory contamination using traditional procedures becomes more important than for normal situations. It is felt by the authors that, as WIPP fills with waste, such small occasional detections could be expected and the 2003, 2008 and 2009 hits provide a baseline for future events. As there are no historic precedents for this, it will be important to continue monitoring to see what actually does evolve as a deep underground geologic repository fills with nuclear waste.

In the summer of 2001, the Carlsbad Field Office (CBFO) of DOE requested that CEMRC 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 2009 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 the DOE community.

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) personnel loss resulting from the difficulty in attracting and retaining qualified staff in Carlsbad (6) funding changes, and (7) time and resource coordination among the other programs in the facility.

During 2003 and 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 redefinition of the scope of the monitoring program has been driven by three factors: (1) diminishing resources available for the monitoring work, (2) loss of qualified personnel, and (3) the increased emphasis at CEMRC on direct research and technical support of WIPP operations. The challenge that has faced CEMRC during 2009 has been to restructure and optimize the WIPP EM activities 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 regardless of 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. In 2009, that media was drinking water and soil.

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.

The sampling media for the 2009 environmental monitoring program include airborne particulates (both FAS and aerosol), soil, drinking water and human whole body. These samples are analyzed for radionuclides, including natural uranium ($^{233/234}$U, ^{235}U, and ^{238}U); potassium, ^{40}K; transuranic actinides expected to be present in the waste (plutonium ^{238}Pu, $^{239+240}$Pu, and americium ^{241}Am), and major fission products (cesium, ^{137}Cs and cobalt ^{60}Co). Environmental levels of these radionuclides could provide corroborating information on which to base conclusions regarding releases from WIPP facility operations. Appendix E summarizes the list of target radionuclides along with their type of radiation method of detection, and reason for monitoring at the WIPP site.

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, 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 April 2010 and analyses has been completed through June 2009 for the Gamma emitters and radiological analytes. All FAS samples from 2009 have been analyzed with respect to gross alpha/beta, ^{238}Pu, $^{239+240}$Pu ^{241}Am, ^{234}U, ^{235}U, ^{238}U, ^{137}Cs, , ^{60}Co and ^{40}K, and inorganics and are reported herein.

SOILS

Soil samples were collected during 2009 from 16 locations around the WIPP site. The limitation of soil sampling to one period annually is based on the assumption that any input of contaminants to surface soils from WIPP release would occur via aerosol deposition, and since aerosol sampling is conducted continuously, more frequent soil sampling is not warranted unless there is evidence of contaminant increases in aerosols. The measurements were made for gamma emitters and radionuclides.

SURFACE WATER AND SEDIMENTS

During 2009, no surface water and sediment samples were collected or analyzed.

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. During 2009, drinking water samples were collected in the month of December at five of the six drinking water supplies (the sixth was dry as has been the case for several years), and results are reported herein for 2009.

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. It has been difficult to attract new volunteers and to bring back previous volunteers for recounts. Previous fear or concern appears to have waned in the region as WIPP operations continue to proceed with no serious incidents. Results of the LDBC project through December 2009 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. Sometimes the unit Curie (Ci) is used and is equal to 3.7×10^{10} Bq.

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 and radiological facilities. 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 2009 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 audits were performed during 2009 on the following programmatic areas: Environmental Chemistry, Field Programs, Informatics and Modeling, Internal Dosimetry Organic Chemistry, Administrative Services, and Document Control. In addition, an internal surveillance was performed on the Radiochemistry program. A summary of 2009 audits is reported in Appendix F.

Quality Assurance/Quality Control for Organic Chemistry

The following audits were conducted on the Organic Chemistry group:

- A VOCs Confirmatory Monitoring Audit, conducted by WTS QA as part of their routine yearly program audits in compliance with contract require-ments, was passed in March 2009.
- A CEMRC internal audit was conducted on the OC group in October 2009 in compliance with the Center's QAP, and the group passed.

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 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. 20 hour FAS filter blank counts were recorded every two weeks. 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 and ^{244}Cm 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.

The radiochemical equations used for the calculation of minimum detection concentration (MDC), standard deviation (SD) are described in Appendix G. The accuracy of the radiochemical analyses was evaluated by analyzing calibration standards, method blanks (tracer blank), and laboratory control samples (blank spikes). Laboratory control samples are QC samples that check whether the analysis procedure is in control. Analysis of LCSs containing the isotopes of interest was performed on a minimum 10 percent basis (one per every batch of ten or fewer samples). LCS results for each isotope were tracked on a running basis using control charts. All radiological LCS results fell within the acceptable ranges, indicating good accuracy (Tables F-1 through F-4).

Accuracy was also ensured through participation by the laboratory in the DOE Mixed-Analyte Performance Evaluation Program (MAPEP) and NIST-Radiochemistry Intercomparison Program (NIST-NRIP) interlaboratory comparison programs. Under these programs, CEMRC analyzed blind check samples, and the analysis results were compared with the official results measured by the MAPEP, and NRIP laboratories. Performance was established by percent bias, calculated as shown in Table F-6 During 2009-2010, CEMRC radioanalytical program analyzed MAPEP- air filter, water, soil, gross alpha/beta on air filters and NIST-NRIP - glass fiber filters. Isotopes of interest in these performance evolution programs were $^{233/234}$U, ^{238}U, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am. The analyses were carried out using CEMRC's actinide separation procedures, and were treated as a regular sample set to test regular performance. CEMRC's results were consistently close to the known value. MAPEP and NIST-NRIP results are presented in Tables F-4 and F-6. Only one analysis result, which was for $^{239+240}$Pu in soil matrix, did not meet the accuracy acceptance criteria. However, this occurs each year because CEMRC's detection limits are much lower than all other labs and CEMRC always detects slight amounts of $^{239+240}$Pu in the MAPEP samples that are there but are reported by MAPEP and others as below detection. This demonstrates CEMRC's ability to detect Pu when most other labs cannot. Based on the number of A (Acceptable) ratings earned by CEMRC for the analysis of performance evaluation samples, the laboratory provided accurate and reliable radionuclide analysis data for the WIPP environmental samples.

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

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; Laboratory Fortified Blanks, or LFBs;

duplicates and Laboratory Fortified Matrix samples, or LFMs. 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 F.

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% of the fortified value. 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 exceeds 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 2010 (the time period in which the 2009 samples were analyzed) are given in Appendix F. Table F-5 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 $m^3 min^{-1}$, 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:

- Transuranic elements via low energy X-ray in lungs
- ^{241}Am in lungs
- ^{234}Th in lungs
- ^{235}U in lungs
- Fission and activation products in lungs including ^{54}Mn, ^{58}Co, ^{60}Co and ^{144}Ce
- Fission and activation products in total body including ^{134}Cs and ^{137}Cs

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 2009-2010 that included counting phantoms representative of each of the categories listed above. The next testing cycle is 2013/2014.

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 were 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. Appendix F shows an example of results for one quarter. For all years since CEMRC has participated in the ORNL program, CEMRC has consistently out-performed all other laboratories in this area.

This page intentionally left blank.

CHAPTER 1

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 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 proce-dures 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 CEMRC found elevated gross beta radio-activity in the FAS sample filters. Further 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 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. In 2008 and 2009, CEMRC again detected a small quantity of Pu in composite aerosol samples from the first and second quarters similar to the 2003 detection, also corroborated by WTS. Such small occasional detections are to be expected and the 2003, 2008, and 2009 hits provide a baseline for future events.

METHODS

CEMRC commenced sampling of the WIPP exhaust air at Station A on December 12, 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 approxi-mately 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 1.1). The airstream sampled by each skid is split among three legs such that three concurrent samples can be collected from each skid. On January 15, 2000, the CEMRC sampling operations were moved from the original sampling point at Skid A2 (west skid), leg 1 to Skid A1 (east skid), leg 2 to facilitate more direct data comparisons among the three organiza-tions sampling the effluent air. Since that time all groups, CEMRC along with Washington TRU Solutions (WTS) and the Environmental Evaluation Group (EEG) and later the New Mexico Environment Department (NMED) replacing EEG, have sampled from the same skid. In April 2001, primary sampling operations were transferred from Skid A1 to Skid A3 (south skid) to reduce problems associated with water infiltration into the exhaust shaft.

A flow diagram illustrating the handling and analysis of the aerosol sample filters is presented in Figure 1.2. 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 (January 24, 2000 to November 28, 2001), CEMRC and the other organizations changed filters twice daily Monday through Friday. Daily sampling resumed when mass concentrations decreased and flow rates improved. Occasionally, however, 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.

After the 2003 Pu hit, CEMRC imple-mented an additional FAS filter, called the Trip Blank, which is a blank filter that accompanies the sample filter through the whole process, including transport to and from the WIPP site, and is placed on the collector for approximately 15 seconds, then removed. Unlike the laboratory and reagent blanks, the Trip Blank can reflect sampling errors or field contamination that is independent of laboratory procedures and reagents.

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 then, 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, 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, which they were (see 2005/2006 Annual Report).

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). In 2009, the values of gross alpha activity concentration and density (Tables 1-1 and 1-2) ranged from <MDC (≈ 0.1 mBq/m^3) to 1.03 mBq/m^3 and <MDC (≈ 0.9 Bq/g) to 63.5 Bq/g, respectively.

Values of gross beta activity concentration and density ranged from <MDC (≈ 0.2 mBq/ m^3) to 15.8 mBq/m^3 and <MDC (≈ 1.7 Bq/g) to 114 Bq/g respectively.

Elemental 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 2004 for better comparison with other groups who monthly composite. 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. Weekly composites are then analyzed for a suite of trace elements with the use of a Perkin-Elmer (Model Elan 6100), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The ICP-MS methods can provide data for up to ~35 elements, but in practice the concentra-tions 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.

Finally, 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 is separated by anion exchange, AG1-X8, while Am and U are separated on a TRU extraction chromato-graphy column. The sample planchettes are finally prepared for alpha spectrometry using rare-earth micro-coprecipitation. Samples are counted for 5 days, in order to lower the detection limits.

Analyses of gamma emitters are per-formed on the same monthly composites as used for the actinides studies; the gamma analyses are done using a low-background, high-purity Ge co-axial detector with a count time of 48 hours.

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 conditions. 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 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 1.3 through 1.9 discussed below, data points are distinguished by color for the pre-operational and operational monitoring.

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 results from naturally occurring radioactive materials, specifically radon daughters. Summary statistics for mass loading and gross alpha/beta are given in Tables 1-1, 1-2, and 1-3. As shown in Table 1-1, the pre-operational gross alpha activity densities and concentrations were both high compared with the annual mean values for the next five years. Gross alpha activities exhibit clear seasonal variability with peaks occurring in winter (Figures 1.6 and 1.7) and the pre-operational 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 and in 2007 to 2008. In 2009, activities appear to have gone back up to pre-operational levels and a overall slightly increasing trend can be seen over the years from 2003 to 2009.

Similar seasonal trends in gross beta data can be seen in Figures 1.8 and 1.9. The pronounced annual cycle in beta activity concentrations, with high values in December and January and low values mid-year are seen through all the operational monitoring period from 2000 through 2009. The beta activity concentration of 58.4 mBq/m^3 observed in 2001 (Table 1-2 and Figure 1.9) is due to contamination released from an under-ground fire extinguisher. Overall beta activities have remained quite consistent over the years. As shown in Figures 1.8 and 1.9, the average beta density and concentration have not increased during the monitoring period. The average alpha density and concentration have increased (Figures 1.10 and 1.11) during 2007 and 2008, but in 2009 the activity measured was below pre-operational level. 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 pre-disposal levels. 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 volume 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 time-series plot of the aerosol mass loadings (Figure 1.5) shows a trend towards lower sample masses beginning in 2004 and also less scatter in the gravimetric data that then increases again in late 2007 and 2008. The latter point is also evident in Table 1-3, which shows that the relative standard error, i.e. the standard error divided by the arithmetic mean and expressed as a percentage, was ≤ 8% in the last seven years of the study compared with 10% to 20% in three of the first four years of the program. This decrease in aerosol mass loadings would directly contribute to the high alpha activity densities observed in the more recent years of the WIPP-EM.

A plot of the matched beta vs. alpha activities per filter (Figure 1.12) 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.

ACTINIDE DATA

Results of actinide analyses performed on monthly FAS composite samples are pre-sented in Table 1-4. Whenever the word “sample” is used in this section, it should be taken to mean “composite sample”.

No detectable concentrations of ^{238}Pu, $^{239+240}$Pu or ^{241}Am were observed in any of 2009 samples except for the months of January and April 2009. For January 2009, $^{239+240}$Pu concentration slightly higher than MDC was detected. This is mainly because of long counting time which lowers CEMRC’s MDCs values. For the month of April both primary and back-up showed $^{239+240}$Pu and ^{241}Am activities above detection limit. Similar hits of $^{239+240}$Pu were also observed by WIPP Laboratories for the month of April 2009. The Pu hit of 2009 is similar to that which occurred during June 2003 and February 2008 at Station A. Since the MDCs for $^{239+240}$Pu are usually a factor of 2-5 higher than the measured concentrations, it appears very probable that $^{239+240}$ Pu could be detected in future samples by dust-loaded ambient air circulating through the underground with environmental levels of Pu from global fallout as opposed to a release from WIPP operations. Such small occasional detections of Pu could provide a baseline for future events. The time series of the $^{239+240}$Pu and ^{241}Am activity concentrations in the WIPP exhaust air from the period from 1998 to 2009 are shown in Figure 1.13. The concentrations of Pu and Am in 2003, 2008, and 2009 are above detection. In these years, only one of the composite samples had Pu and Am concentrations greater than the MDCs.

Over twelve years of environmental monitoring of the WIPP, CEMRC has detected only three composite samples, out of more than 100 tested, that were above MDCs. Individual hits in 2003, 2008, and 2009 are shown in Figure 1.13. As can be seen in Figure 1.14, Pu is detected in primary as well as in back-up composite samples. These activities, however, were extremely low and hundreds of thousands of times below the action level of 37 Bq/m^3 that triggers the Continuous Air Alarms (CAMs) that are distributed throughout the WIPP.

The naturally occurring isotopes of U were detected in all monthly FAS composites in 2009. The average of ^{234}U/^{238}U activity ratio of 1.57±0.30 in the WIPP underground air samples indicates the presence of natural U (Table 1-5). ^{234}U results were similar to those of ^{238}U for activity concentration and density, indicating secular equilibrium between the two isotopes. These results are consistent with those reported in previous CEMRC, reports.

With the exception of occasional hits from ^{40}K, no detectable gamma-emitting radio-nuclides were observed during the monitoring period 2009. The results of ^{137}Cs, ^{60}Co, and ^{40}K in the monthly composites are summarized in Table 1-4. The minimum, maximum, and average concentrations of radionuclides for the 2009 FAS composites samples are summarized in Table 1-6.

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. Time-series plots of selected trace element data are presented in Figures 1.15 - 1.20. There is some data missing from the elemental data plots because of a sample holding time issue in the fourth quarter of 2004.

Data shown only reflects concentrations above MDC. MDCs are re-calculated each year, and vary slightly from year to year. In 2009, concentrations for Cd, Th, and U never exceeded the MDC.

No marked differences are evident in the baseline vs. operational samples. Al is of interest because of the correlation between the Al concentrations in ambient aerosols and the activities of $^{239+240}$Pu and ^{241}Am (Arimoto, et al. 2002, 2005, and 2006). Windblown dust is the main source of Al and many other elements (Fe, Mn, Sc, and the rare earth elements) and is the main source of naturally occurring radionuclides, including U, and fallout radionuclides such as Pu and Am. Kirchner, et al. (2002) have also shown relationships between Al and various radionuclides, both artificial and naturally occurring, in soils.

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 also 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.

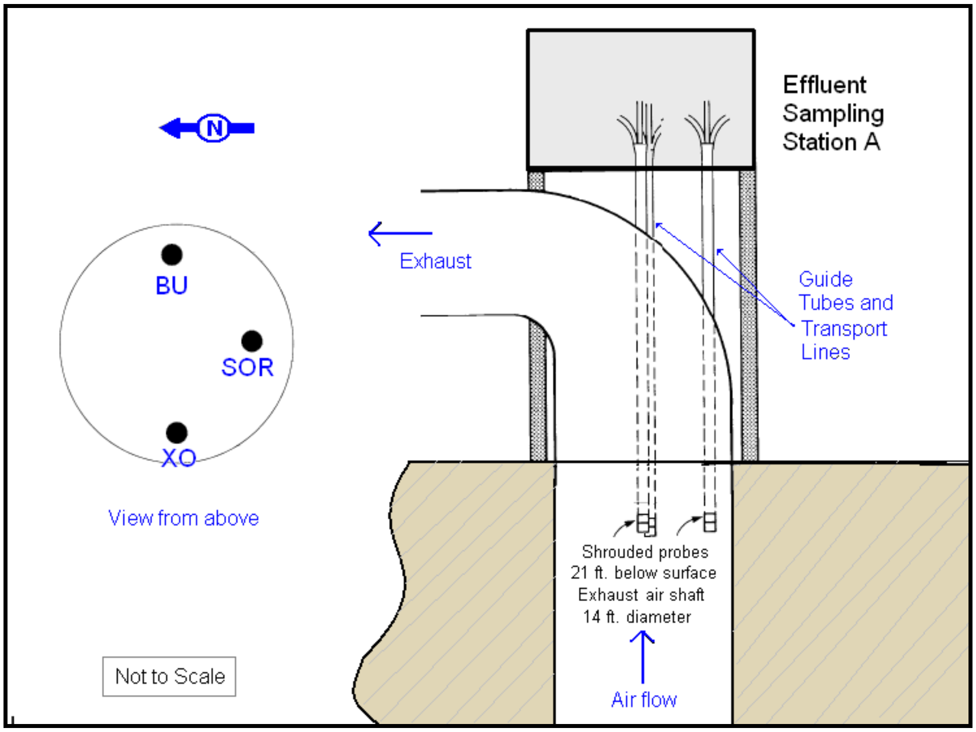


Figure 1.1: Fixed Air Samplers at Station A

BU: Backup, SOR: Skid of Record, XO: Extra Probe

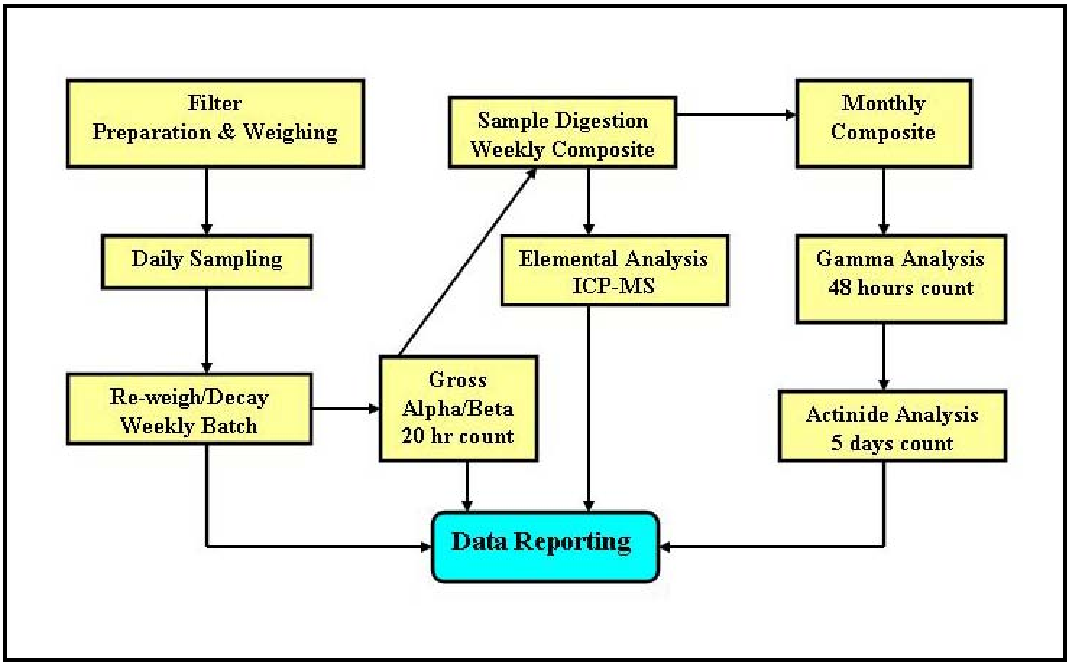


Figure 1.2: Flow Diagram Showing the Handling and Analysis of FAS Filters

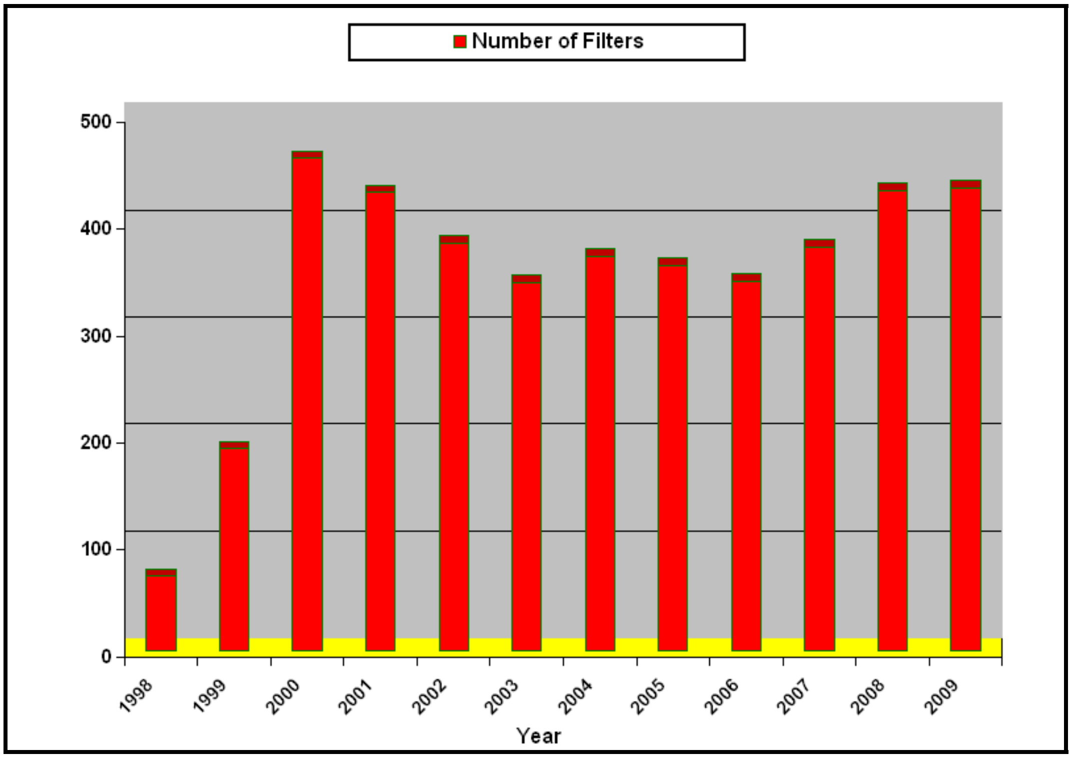


Figure 1.3: FAS Samples Collected from Station A

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

		Activity Density (Bq/g)				Activity Concentration (mBq/m3)			
Group	**N**	**% <MDC**	**Mean**	**SE**	**Max**	**% <MDC**	**Mean**	**SE**	**Max**
Pre-Disposal	70	0%	3.6	0.59	36.7	0%	0.315	0.031	1.49
1999*	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
2007	378	0%	9.1	1.3	421.2	0%	0.444	0.014	1.44
2008	431	1%	10.1	1.2	345.1	1%	0.455	0.011	1.53
2009	433	4%	7.1	0.35	63.5	4%	0.357	0.008	1.03

N = Number of samples
MDC = Minimum Detectable Concentration
Mean = Arithmetic mean
SE = Standard Error
Max = Maximum observed value
*From 26 March to 31 December 1999

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

		Activity Density (Bq/g)				Activity Concentration (mBq/m3)			
Group	**N**	**% <MDC**	**Mean**	**SE**	**Max**	**% <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
2007	378	2%	11.3	1.89	616	2%	0.50	0.02	1.88
2008	431	3%	12.6	1.53	438	3%	0.52	0.01	2.25
2009	433	6%	11.3	0.64	114	6%	0.56	0.04	15.84

N = Number of samples
MDC = Minimum Detectable Concentration
Mean = Arithmetic mean
SE = Standard Error
Max = Maximum observed value
*From 26 March to 31 December 1999

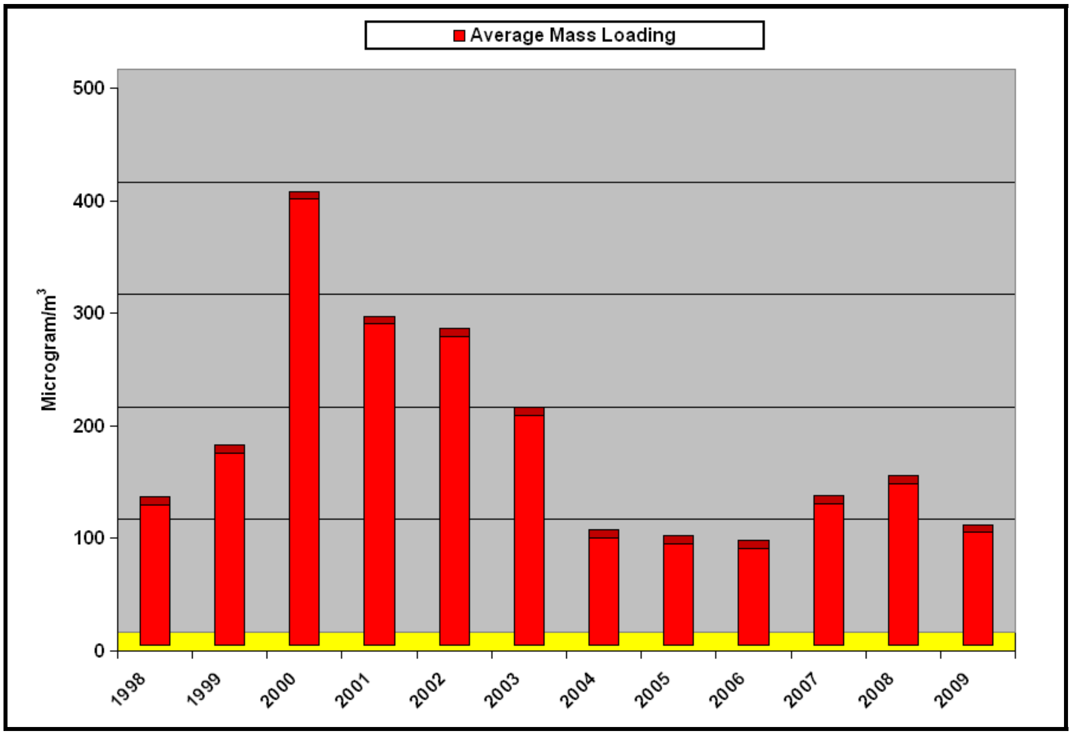


Figure 1.4: Average Aerosol Mass Loadings on FAS Samples from Station A

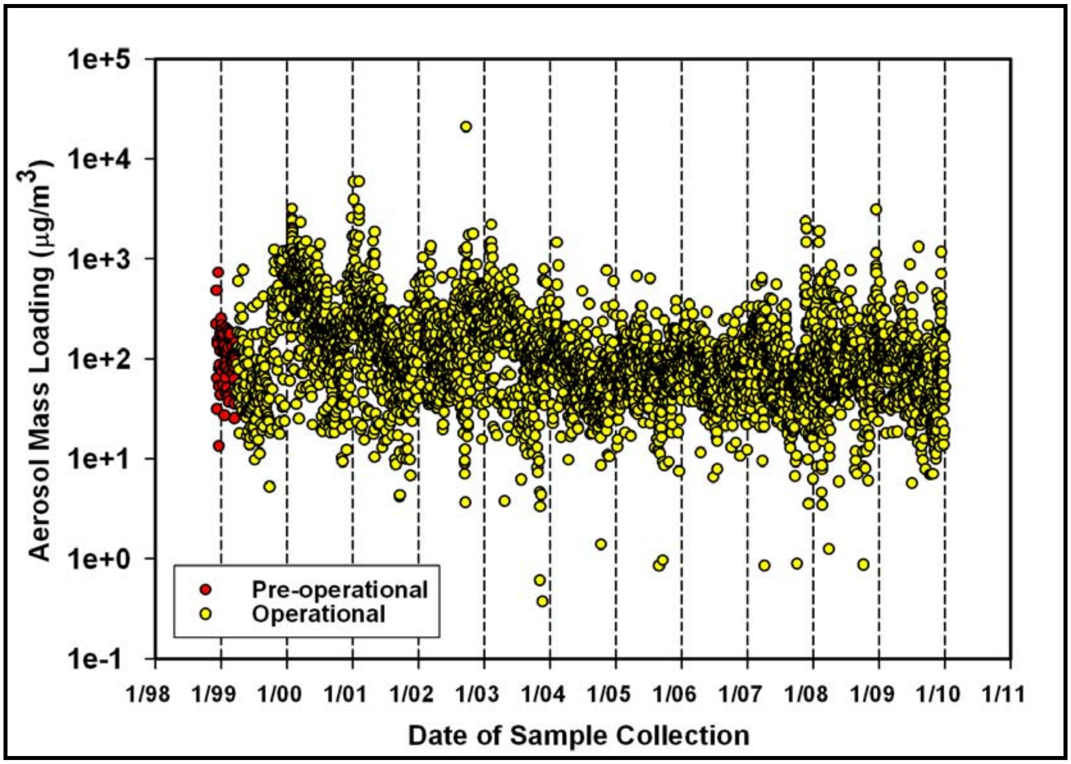


Figure 1.5: Aerosol Mass Loadings in FAS Samples from Station A

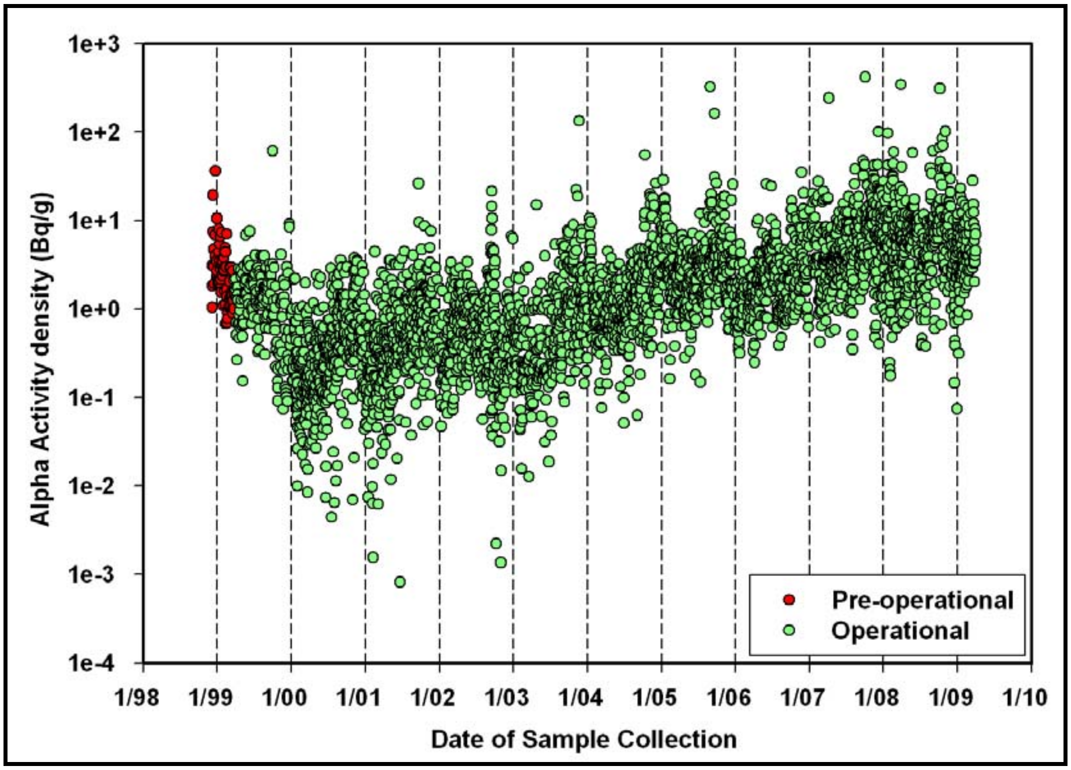


Figure 1.6: Gross Alpha Activity Densities in FAS Samples

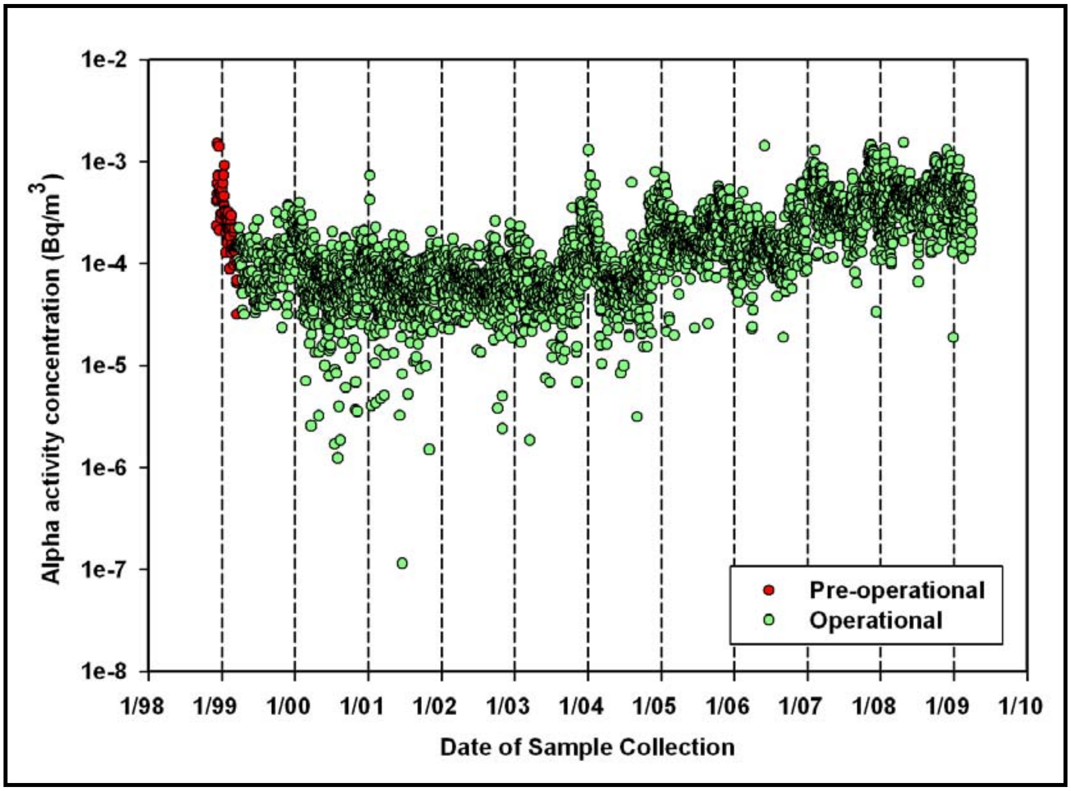


Figure 1.7: Gross Alpha Activity Concentrations in FAS Samples

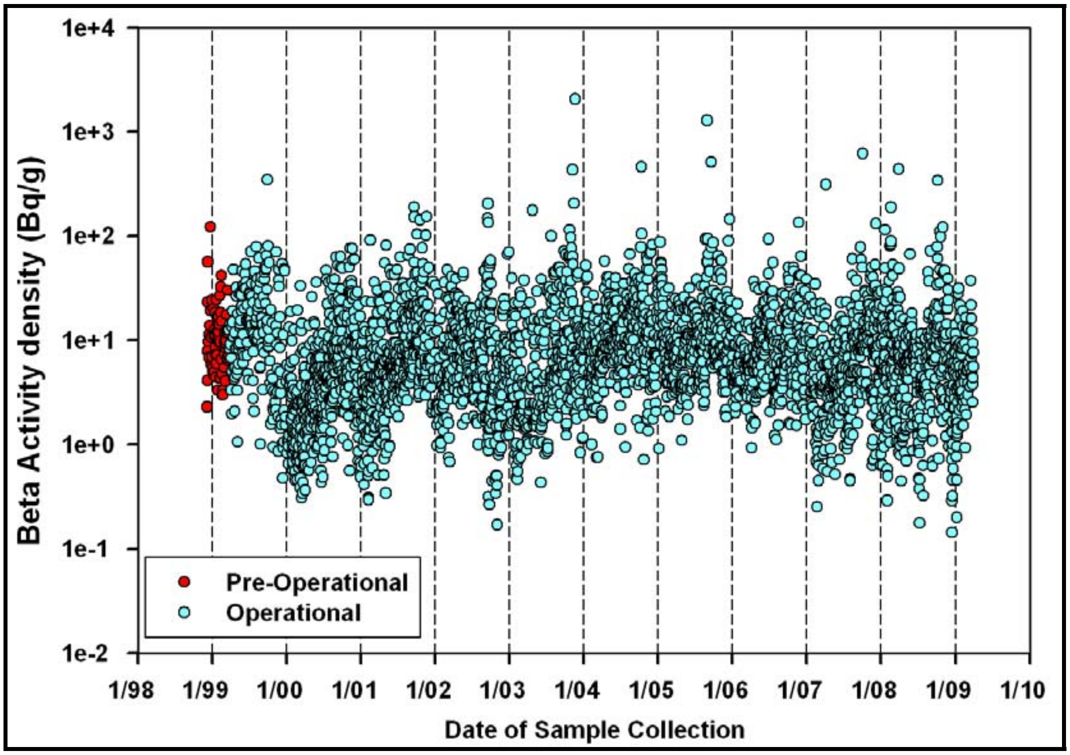


Figure 1.8: Gross Beta Activity Densities in FAS Samples

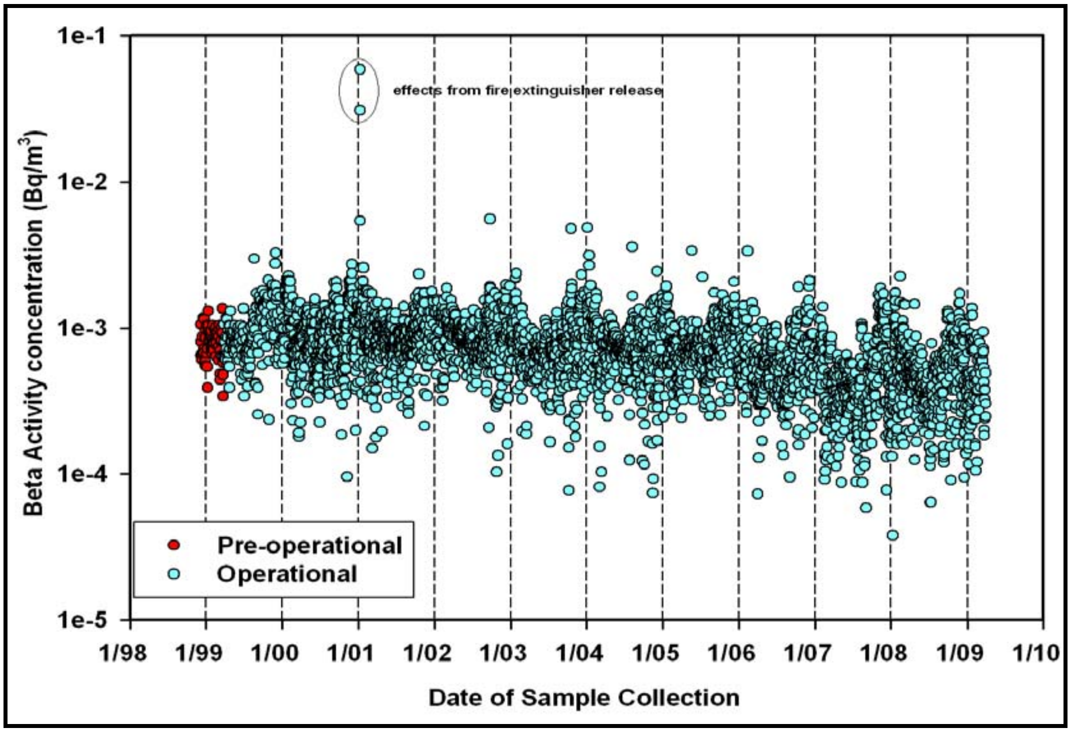


Figure 1.9: Gross Beta Activity Concentrations in FAS Samples

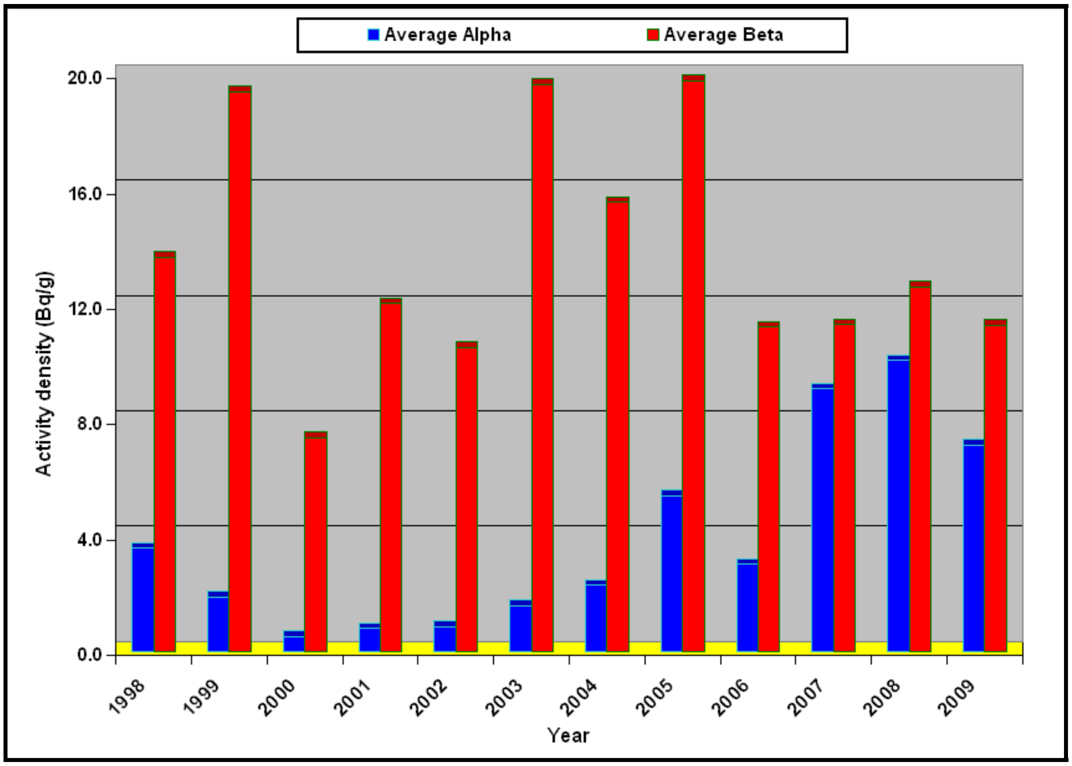


Figure 1.10: Average Alpha and Beta Activity Densities in FAS Filters

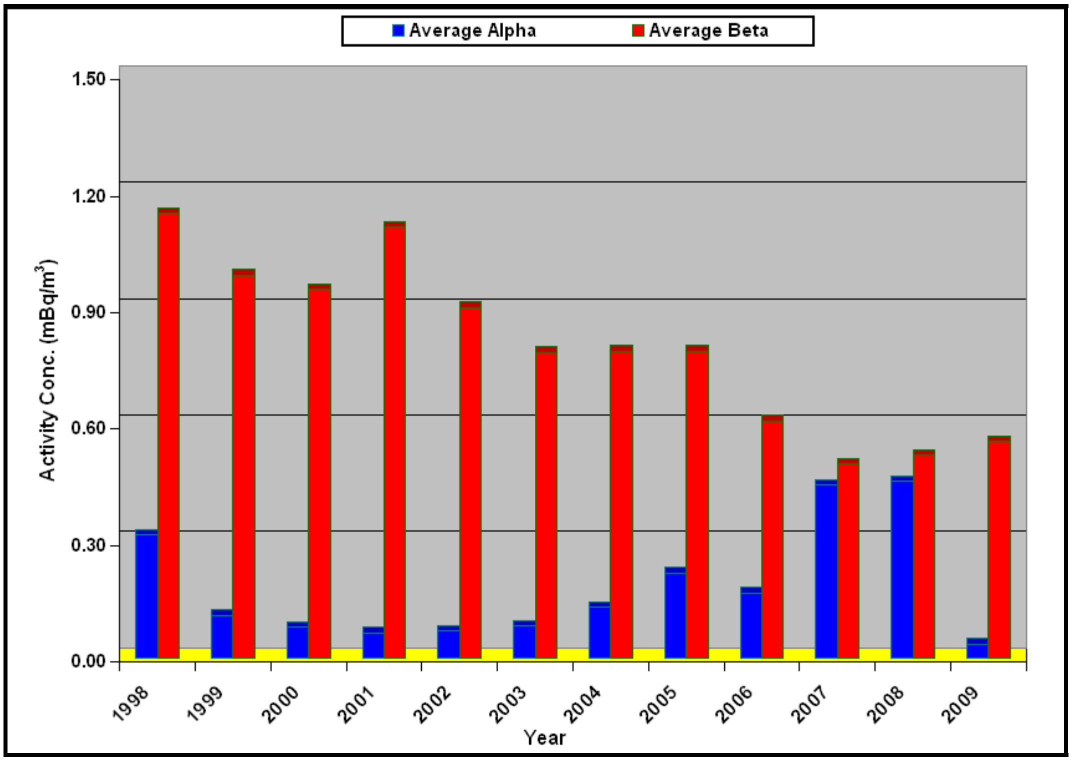


Figure 1.11: Average Alpha and Beta Activity Concentrations in FAS Filters

Table 1-3: Summary Statistics for Aerosol Mass Loadings on FAS Filters ($\mu g/m^3$ per filter)

Group	N	Mean	SE	RSE (%)
Pre-Disposal	70	125.0	12.2	9.8
1999*	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
2007	378	125.2	10.2	8.1
2008	431	143.5	11.2	7.8
2009	433	100.2	6.0	6.0

N = Number of samples
Mean = Arithmetic mean
SE = Standard Error
RSE = Relative Standard Error in percentage (Standard error divided by Mean)
* From 26 March to 31 December 1999

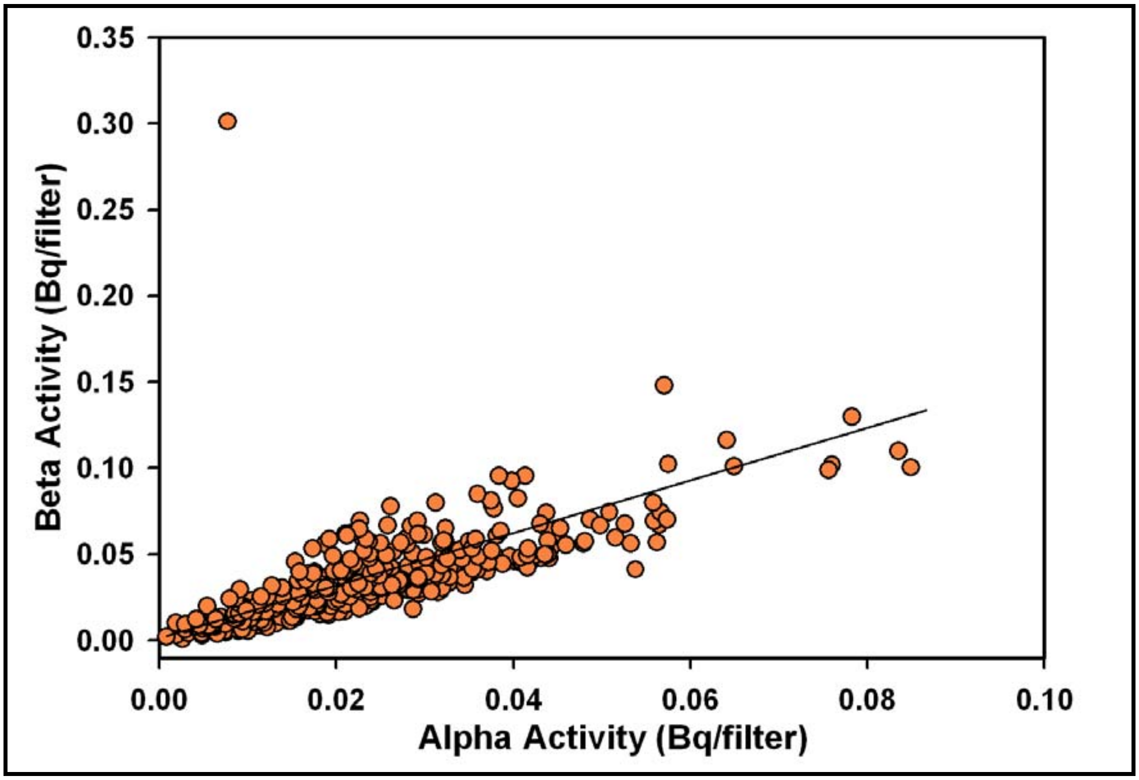


Figure 1.12: Beta Activity vs. Alpha Activity in FAS Filters in 2009

Table 1-4: Activity of Monthly Composite FAS Samples from Station A

	Activity Concentration (Bq/m^3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
January 2009						
^{241}Am	3.72E-08	3.24E-08	1.01E-07	3.07E-04	2.68E-04	8.32E-04
^{238}Pu	2.76E-08	3.49E-08	1.31E-07	2.26E-04	2.86E-04	1.07E-03
$^{239+240}$Pu	2.38E-07	6.99E-08	1.76E-07	1.95E-03	5.72E-04	1.44E-03
^{234}U	6.15E-07	7.08E-08	9.74E-08	5.07E-03	5.85E-04	8.04E-04
^{235}U	4.26E-08	2.39E-08	7.21E-08	3.52E-04	1.98E-04	5.96E-04
^{238}U	3.65E-07	5.36E-08	7.15E-08	3.01E-03	4.43E-04	5.91E-04
^{137}Cs	8.02E-06	1.66E-05	5.50E-05	6.62E-02	1.37E-01	4.54E-01
^{60}Co	9.71E-06	8.70E-06	4.06E-05	8.02E-02	7.18E-02	3.35E-01
^{40}K	7.93E-05	1.39E-04	4.62E-04	6.55E-01	1.15E+00	3.81E+00
February 2009						
^{241}Am	8.71E-09	2.00E-08	2.70E-08	8.94E-05	2.05E-04	2.78E-04
^{238}Pu	-1.42E-08	3.51E-08	1.56E-07	-1.46E-04	3.60E-04	1.60E-03
$^{239+240}$Pu	8.84E-08	5.42E-08	1.76E-07	9.07E-04	5.56E-04	1.80E-03
^{234}U	5.20E-07	9.92E-08	4.85E-08	5.34E-03	1.02E-03	4.98E-04
^{235}U	1.56E-07	9.65E-08	3.23E-07	1.60E-03	9.90E-04	3.32E-03
^{238}U	6.10E-07	1.16E-07	2.13E-07	6.26E-03	1.19E-03	2.19E-03
^{137}Cs	3.25E-05	1.44E-05	4.72E-05	3.33E-01	1.48E-01	4.85E-01
^{60}Co	1.90E-05	9.24E-06	4.28E-05	1.95E-01	9.49E-02	4.39E-01
^{40}K	2.07E-04	1.80E-04	5.93E-04	2.13E+00	1.84E+00	6.08E+00
March 2009						
^{241}Am	1.98E-08	3.09E-08	1.05E-07	2.48E-04	3.87E-04	1.32E-03
^{238}Pu	2.92E-09	2.90E-08	1.26E-07	3.46E-05	3.44E-04	1.49E-03
$^{239+240}$Pu	-3.48E-08	3.62E-08	1.69E-07	-4.13E-04	4.29E-04	2.00E-03
^{234}U	1.94E-07	6.09E-08	1.74E-07	2.43E-03	7.61E-04	2.17E-03
^{235}U	7.17E-08	3.16E-08	3.23E-08	8.97E-04	3.96E-04	4.04E-04
^{238}U	2.74E-07	6.34E-08	1.54E-07	3.43E-03	7.93E-04	1.92E-03
^{137}Cs	2.79E-01	1.63E-01	5.36E-01	2.23E-05	1.30E-05	4.29E-05
^{60}Co	1.60E-01	9.42E-02	4.28E-01	1.28E-05	7.53E-06	3.42E-05
^{40}K	4.99E+00	1.44E+00	4.63E+00	3.99E-04	1.15E-04	3.70E-04
April 2009						
^{241}Am	1.68E-06	1.44E-07	1.44E-07	1.56E-02	1.33E-03	1.34E-03
BU	2.26E-06	1.59E-07	9.14E-08	2.15E-02	1.51E-03	8.70E-04
^{238}Pu	2.33E-07	5.37E-08	3.15E-08	2.15E-03	4.96E-04	2.92E-04
BU	3.10E-07	6.63E-08	1.13E-07	2.95E-03	6.31E-04	1.07E-03
$^{239+240}$Pu	1.01E-05	4.10E-07	3.15E-08	9.37E-02	3.79E-03	2.92E-04
BU	1.31E-05	4.93E-07	1.46E-07	1.25E-01	4.69E-03	1.39E-03
^{234}U	1.13E-06	1.24E-07	1.56E-07	1.05E-02	1.14E-03	1.44E-03
^{235}U	2.90E-07	6.72E-08	3.98E-08	2.68E-03	6.21E-04	3.68E-04
^{238}U	3.42E-07	6.68E-08	9.63E-08	3.16E-03	6.17E-04	8.90E-04
^{137}Cs	9.18E-06	1.56E-05	5.18E-05	8.48E-02	1.45E-01	4.79E-01
^{60}Co	2.88E-05	9.18E-06	4.17E-05	2.67E-01	8.48E-02	3.86E-01
^{40}K	4.06E-05	1.93E-04	6.40E-04	3.76E-01	1.78E+00	5.91E+00

Table 1-4: Activity of Monthly Composite FAS Samples from Station A (continued)

	Activity Concentration (Bq/m^3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
May 2009						
^{241}Am	1.76E-09	2.57E-08	9.47E-08	1.70E-05	2.49E-04	9.17E-04
^{238}Pu	-1.32E-08	4.76E-08	1.98E-07	-1.28E-04	4.61E-04	1.92E-03
$^{239+240}$Pu	1.72E-08	3.57E-08	1.42E-07	1.67E-04	3.45E-04	1.38E-03
^{234}U	6.95E-07	1.06E-07	1.92E-07	6.72E-03	1.02E-03	1.85E-03
^{235}U	2.48E-08	4.05E-08	1.66E-07	2.40E-04	3.92E-04	1.60E-03
^{238}U	1.66E-07	6.48E-08	1.92E-07	1.61E-03	6.27E-04	1.85E-03
^{137}Cs	2.04E-05	1.67E-05	5.52E-05	1.97E-01	1.62E-01	5.34E-01
^{60}Co	1.30E-05	1.01E-05	4.68E-05	1.26E-01	9.76E-02	4.53E-01
^{40}K	-5.32E-05	2.10E-04	7.02E-04	-5.15E-01	2.04E+00	6.79E+00
June 2009						
^{241}Am	1.67E-08	2.56E-08	8.41E-08	1.90E-04	2.90E-04	9.53E-04
^{238}Pu	1.01E-08	2.52E-08	1.06E-07	1.15E-04	2.86E-04	1.20E-03
$^{239+240}$Pu	1.66E-08	4.18E-08	1.62E-07	1.88E-04	4.75E-04	1.84E-03
^{234}U	5.34E-07	7.39E-08	1.16E-07	6.06E-03	8.38E-04	1.31E-03
^{235}U	4.07E-08	2.66E-08	8.60E-08	4.61E-04	3.02E-04	9.75E-04
^{238}U	2.54E-07	6.04E-08	1.54E-07	2.88E-03	6.85E-04	1.74E-03
^{137}Cs	1.97E-01	1.62E-01	5.34E-01	7.03E-02	1.58E-01	5.25E-01
^{60}Co	1.26E-01	9.76E-02	4.53E-01	-4.66E-03	9.81E-02	4.58E-01
^{40}K	-5.15E-01	2.04E+00	6.79E+00	4.83E+00	1.28E+00	4.10E+00
July 2009						
^{241}Am	-1.61E-08	1.78E-08	8.25E-08	-2.02E-04	2.23E-04	1.03E-03
^{238}Pu	6.69E-08	3.54E-08	9.84E-08	8.39E-04	4.44E-04	1.23E-03
$^{239+240}$Pu	1.17E-07	5.47E-08	1.60E-07	1.47E-03	6.86E-04	2.01E-03
^{234}U	2.57E-06	1.89E-07	1.81E-07	3.23E-02	2.38E-03	2.27E-03
^{235}U	1.33E-07	5.08E-08	1.23E-07	1.67E-03	6.38E-04	1.54E-03
^{238}U	2.56E-06	1.85E-07	1.22E-07	3.21E-02	2.33E-03	1.53E-03
^{137}Cs	2.14E-05	1.32E-05	4.33E-05	2.68E-01	1.65E-01	5.43E-01
^{60}Co	-2.78E-06	8.16E-06	3.82E-05	-3.48E-02	1.02E-01	4.80E-01
^{40}K	1.40E-04	1.66E-04	5.48E-04	1.76E+00	2.08E+00	6.87E+00
August 2009						
^{241}Am	3.66E-08	2.93E-08	8.84E-08	5.46E-04	4.36E-04	1.32E-03
^{238}Pu	1.05E-08	3.15E-08	1.26E-07	1.56E-04	4.69E-04	1.88E-03
$^{239+240}$Pu	9.36E-08	3.80E-08	9.86E-08	1.40E-03	5.66E-04	1.47E-03
^{234}U	1.78E-06	1.37E-07	7.60E-08	2.65E-02	2.04E-03	1.13E-03
^{235}U	7.14E-08	4.97E-08	1.71E-07	1.06E-03	7.41E-04	2.55E-03
^{238}U	1.75E-06	1.37E-07	1.13E-07	2.61E-02	2.04E-03	1.68E-03
^{137}Cs	2.69E-05	1.34E-05	4.39E-05	4.01E-01	1.99E-01	6.54E-01
^{60}Co	1.35E-05	8.11E-06	3.70E-05	2.01E-01	1.21E-01	5.52E-01
^{40}K	3.18E-04	1.68E-04	5.51E-04	4.74E+00	2.50E+00	8.22E+00

Table 1-4: Activity of Monthly Composite FAS Samples from Station A (continued)

	Activity Concentration (Bq/m^3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
September 2009						
^{241}Am	NR	NR	NR	NR	NR	NR
^{238}Pu	8.44E-08	5.17E-08	1.55E-07	1.32E-03	8.11E-04	2.44E-03
$^{239+240}$Pu	1.81E-07	8.06E-08	2.27E-07	2.84E-03	1.27E-03	3.56E-03
^{234}U	3.98E-06	3.11E-07	3.71E-07	6.25E-02	4.87E-03	5.81E-03
^{235}U	2.59E-07	8.53E-08	6.89E-08	4.06E-03	1.34E-03	1.08E-03
^{238}U	3.65E-06	2.94E-07	3.28E-07	5.73E-02	4.61E-03	5.14E-03
^{137}Cs	2.20E-05	1.37E-05	4.50E-05	3.18E-01	1.98E-01	6.50E-01
^{60}Co	9.68E-06	7.32E-06	3.33E-05	1.40E-01	1.06E-01	4.81E-01
^{40}K	2.50E-04	1.75E-04	5.76E-04	3.61E+00	2.52E+00	8.31E+00
October 2009						
^{241}Am	2.38E-08	2.83E-08	9.28E-08	5.80E-04	6.88E-04	2.26E-03
^{238}Pu	-1.10E-08	2.92E-08	1.32E-07	-2.68E-04	7.10E-04	3.22E-03
$^{239+240}$Pu	9.83E-08	3.99E-08	1.04E-07	2.39E-03	9.71E-04	2.52E-03
^{234}U	2.00E-06	1.73E-07	1.72E-07	4.87E-02	4.21E-03	4.18E-03
^{235}U	1.62E-07	5.39E-08	4.39E-08	3.95E-03	1.31E-03	1.07E-03
^{238}U	2.43E-06	1.88E-07	1.06E-07	5.92E-02	4.58E-03	2.58E-03
^{137}Cs	2.62E-05	1.31E-05	4.30E-05	6.38E-01	3.19E-01	1.05E+00
^{60}Co	2.17E-05	7.42E-06	3.31E-05	5.29E-01	1.81E-01	8.05E-01
^{40}K	2.70E-04	1.61E-04	5.28E-04	6.56E+00	3.91E+00	1.29E+01
November 2009						
^{241}Am	7.16E-08	3.52E-08	9.45E-08	1.60E-03	7.87E-04	2.12E-03
^{238}Pu	-1.13E-08	2.98E-08	1.35E-07	-2.52E-04	6.67E-04	3.03E-03
$^{239+240}$Pu	1.13E-08	4.06E-08	1.59E-07	2.52E-04	9.10E-04	3.56E-03
^{234}U	2.33E-06	1.73E-07	1.69E-07	5.21E-02	3.88E-03	3.79E-03
^{235}U	5.01E-08	4.10E-08	1.46E-07	1.12E-03	9.18E-04	3.28E-03
^{238}U	2.28E-06	1.74E-07	2.06E-07	5.11E-02	3.90E-03	4.60E-03
^{137}Cs	7.88E-06	1.32E-05	4.38E-05	1.76E-01	2.96E-01	9.82E-01
^{60}Co	2.96E-05	7.59E-06	3.43E-05	6.64E-01	1.70E-01	7.69E-01
^{40}K	1.75E-04	1.64E-04	5.43E-04	3.91E+00	3.68E+00	1.22E+01
December 2009						
^{241}Am	NR	NR	NR	NR	NR	NR
^{238}Pu	1.03E-07	6.40E-08	2.07E-07	1.15E-03	7.20E-04	2.33E-03
$^{239+240}$Pu	1.23E-07	6.16E-08	1.86E-07	1.39E-03	6.93E-04	2.09E-03
^{234}U	3.49E-06	2.94E-07	2.82E-07	3.93E-02	3.30E-03	3.18E-03
^{235}U	1.52E-07	7.49E-08	2.10E-07	1.71E-03	8.42E-04	2.36E-03
^{238}U	3.25E-06	2.90E-07	3.75E-07	3.65E-02	3.26E-03	4.22E-03
^{137}Cs	2.29E-06	1.27E-05	4.21E-05	2.57E-02	1.43E-01	4.74E-01
^{60}Co	1.96E-05	7.29E-06	3.27E-05	2.20E-01	8.21E-02	3.68E-01
^{40}K	8.00E-05	1.64E-04	5.43E-04	9.00E-01	1.84E+00	6.11E+00

BU = back up filter
SD = Standard deviation (1 sigma)
MDC = Minimum Detectable Concentration
Station A = composited monthly due to the large number of samples
NR = Not reported

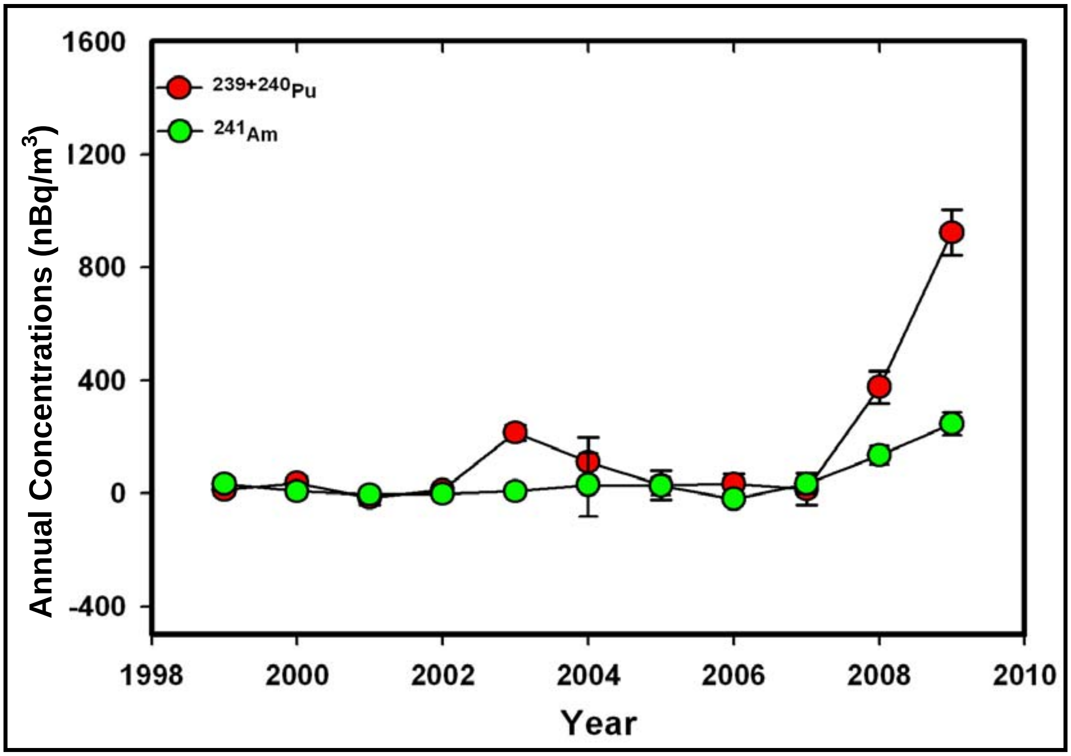


Figure 1.13: Annual $^{239+240}$Pu and ^{241}Am Activity Concentrations in WIPP Exhaust Air from 1998-2009

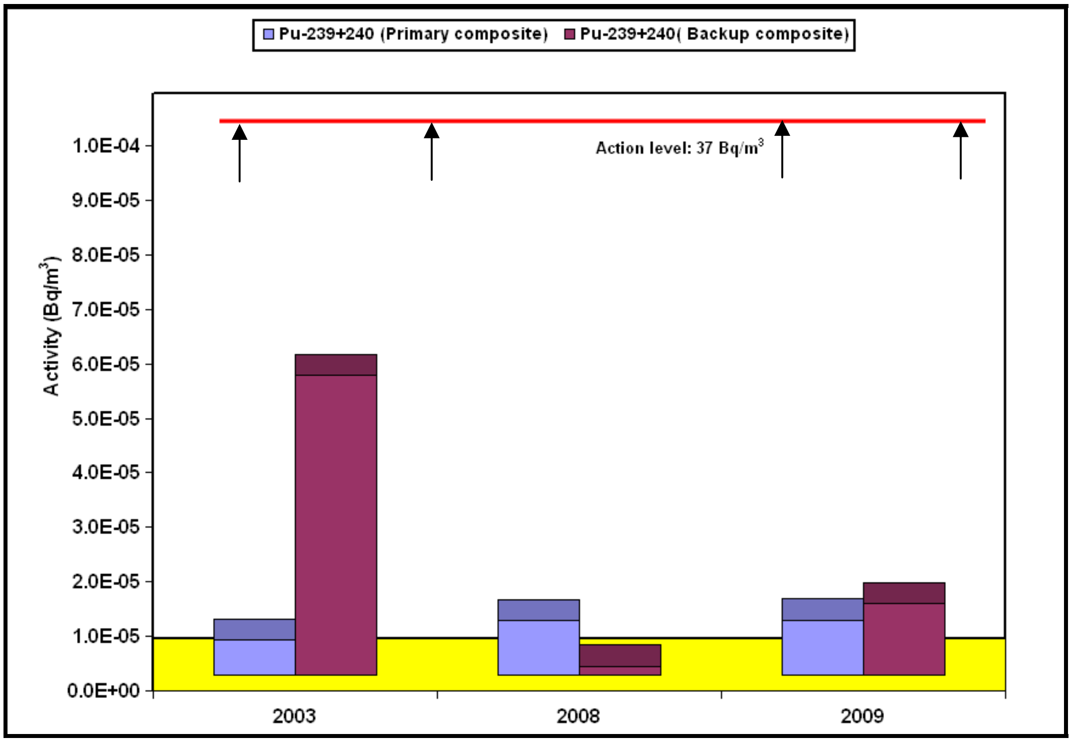


Figure 1.14: $^{239+240}$Pu Activity (>MDC) Detected in FAS Composites for 2003, 2008, and 2009

Table 1-5. Activity Ratios of Uranium Isotopes in FAS Composites in 2009

Month	^{234}U	^{238}U	^{234}U/^{238}U
January	7.87E-04	4.68E-04	1.68
February	5.87E-04	6.88E-04	0.85
March	2.45E-04	3.45E-04	0.71
April	1.19E-03	3.59E-04	3.31
May	7.02E-04	1.68E-04	4.17
June	6.54E-04	3.11E-04	2.10
July	3.17E-03	3.15E-03	1.01
August	2.21E-03	2.18E-03	1.01
September	3.25E-03	2.98E-03	1.09
October	2.46E-03	3.00E-03	0.82
November	2.86E-03	2.80E-03	1.02
December	4.37E-03	4.06E-03	1.07
		Average	**1.57**
		Std Error	**0.30**

Table 1-6: Minimum, Maximum, and Average Radionuclide Activity Concentrations (Bq/m^3) and Densities (Bq/g) in FAS Composites

		Activity Concentration (Bq/m^3)			Activity Concentration (Bq/g)		
Radionuclides		**Conc.**	**SD**	**MDC**	**Conc.**	**SD**	**MDC**
^{241}Am	Min	-1.61E-08	1.78E-08	2.70E-08	-2.02E-04	2.05E-04	2.78E-04
	Max	2.26E-06	1.59E-07	1.05E-07	2.15E-02	1.51E-03	2.26E-03
	Avg	2.46E-07	4.04E-08	8.61E-08	2.48E-03	5.04E-04	1.19E-03
^{238}Pu	Min	-1.42E-08	2.52E-08	3.15E-08	-2.68E-04	2.86E-04	2.92E-04
	Max	2.33E-07	6.40E-08	2.07E-07	2.15E-03	8.11E-04	3.22E-03
	Avg	4.07E-08	3.89E-08	1.34E-07	4.34E-04	5.04E-04	1.81E-03
$^{239+240}$Pu	Min	-3.48E-08	3.57E-08	3.15E-08	-4.13E-04	3.45E-04	2.92E-04
	Max	1.01E-05	4.10E-07	2.27E-07	9.37E-02	3.79E-03	3.56E-03
	Avg	9.24E-07	8.02E-08	1.49E-07	8.86E-03	9.38E-04	2.00E-03
^{234}U	Min	1.94E-07	6.09E-08	4.85E-08	2.43E-03	5.85E-04	4.98E-04
	Max	3.98E-06	3.11E-07	3.71E-07	6.25E-02	4.87E-03	5.81E-03
	Avg	1.65E-06	1.51E-07	1.70E-07	2.48E-02	2.17E-03	2.37E-03
^{235}U	Min	2.48E-08	2.39E-08	3.23E-08	2.40E-04	1.98E-04	3.68E-04
	Max	2.90E-07	9.65E-08	3.23E-07	4.06E-03	1.34E-03	3.32E-03
	Avg	1.21E-07	5.35E-08	1.23E-07	1.65E-03	7.24E-04	1.60E-03
^{238}U	Min	1.66E-07	5.36E-08	7.15E-08	1.61E-03	4.43E-04	5.91E-04
	Max	3.65E-06	2.94E-07	3.75E-07	5.92E-02	4.61E-03	5.14E-03
	Avg	1.49E-06	1.41E-07	1.77E-07	2.36E-02	2.09E-03	2.41E-03
^{137}Cs	Min	2.29E-06	1.27E-05	4.21E-05	2.57E-02	1.37E-01	4.54E-01
	Max	1.97E-01	1.62E-01	5.34E-01	6.38E-01	3.19E-01	1.05E+00
	Avg	1.65E-02	1.35E-02	4.46E-02	2.38E-01	1.86E-01	6.13E-01
^{60}Co	Min	-2.78E-06	7.29E-06	3.27E-05	-3.48E-02	7.18E-02	3.35E-01
	Max	1.26E-01	9.76E-02	4.53E-01	6.64E-01	1.81E-01	8.05E-01
	Avg	1.05E-02	8.14E-03	3.78E-02	2.12E-01	1.09E-01	4.96E-01
^{40}K	Min	-5.15E-01	1.15E-04	3.70E-04	-5.15E-01	1.15E+00	3.81E+00
	Max	3.99E-04	2.04E+00	6.79E+00	6.56E+00	3.91E+00	1.29E+01
	Avg	-4.28E-02	1.70E-01	5.66E-01	2.83E+00	2.17E+00	7.15E+00

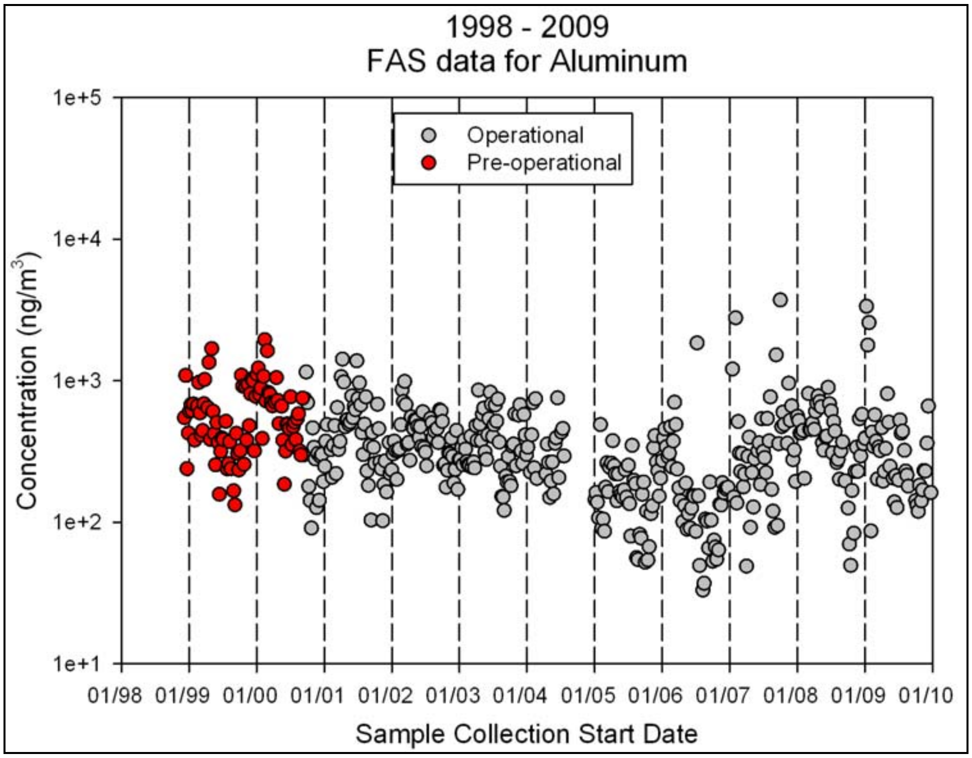


Figure 1.15: Concentrations of Al in WIPP Exhaust Air

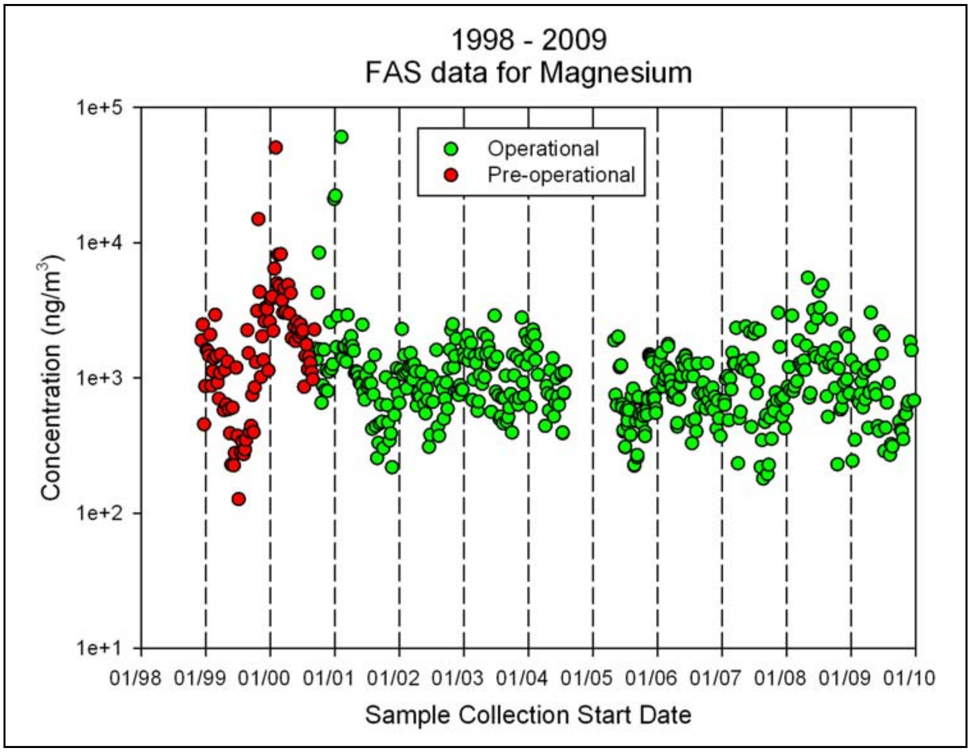


Figure 1.16: Concentrations of Mg in WIPP Exhaust Air

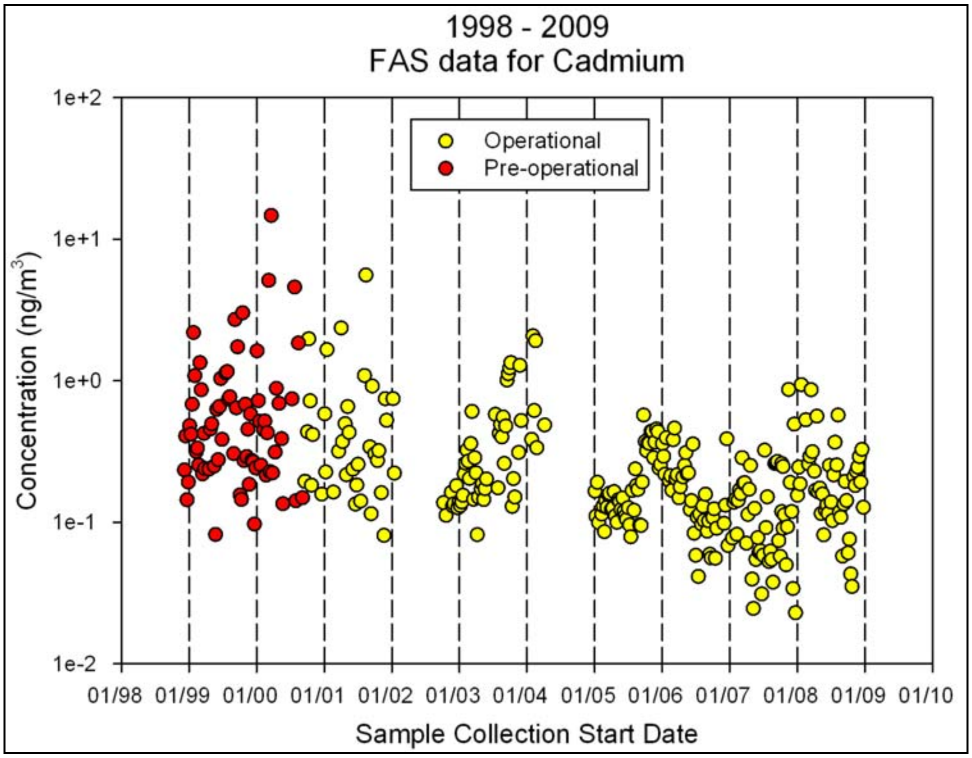


Figure 1.17: Concentrations of Cd in WIPP Exhaust Air

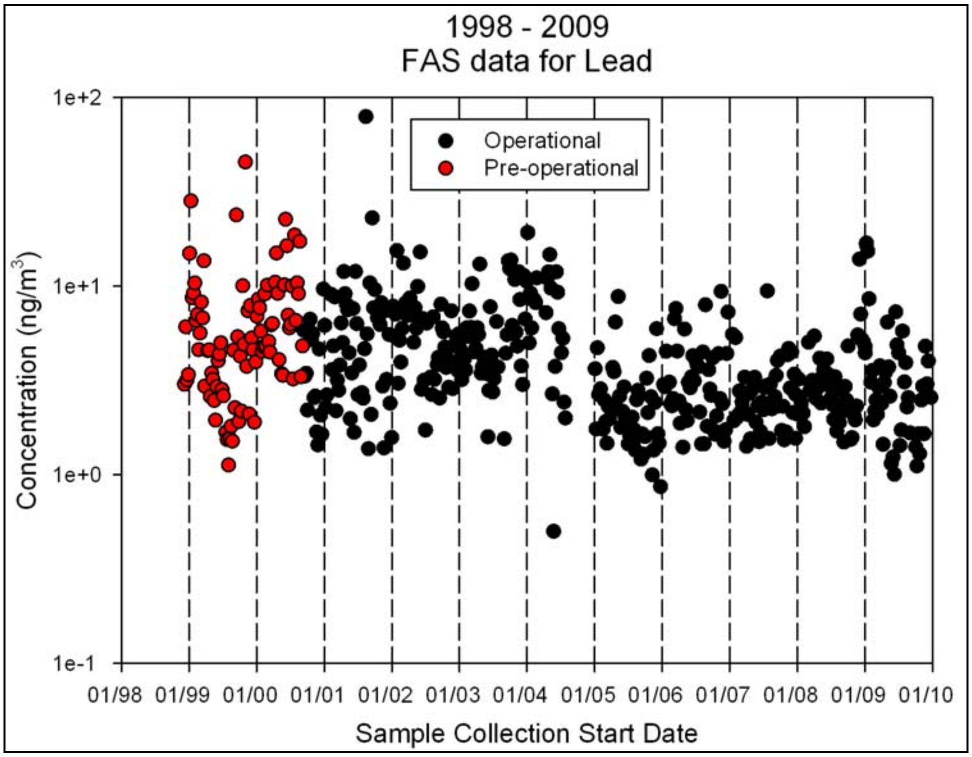


Figure 1.18: Concentrations of Pb in WIPP Exhaust Air

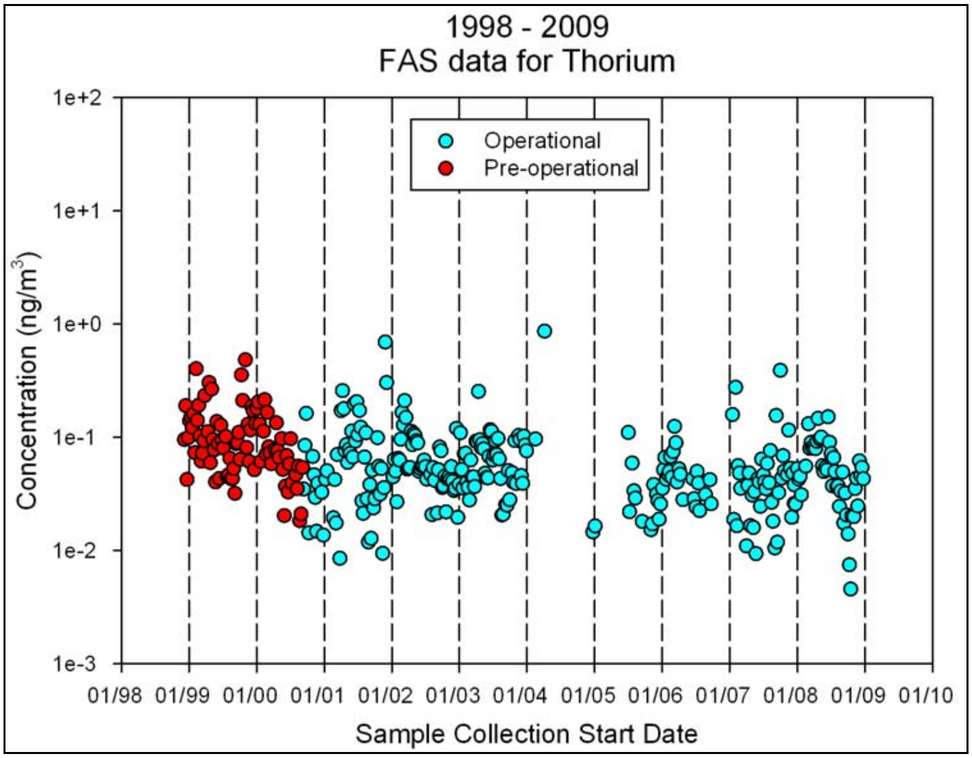


Figure 1.19: Concentrations of Th in WIPP Exhaust Air

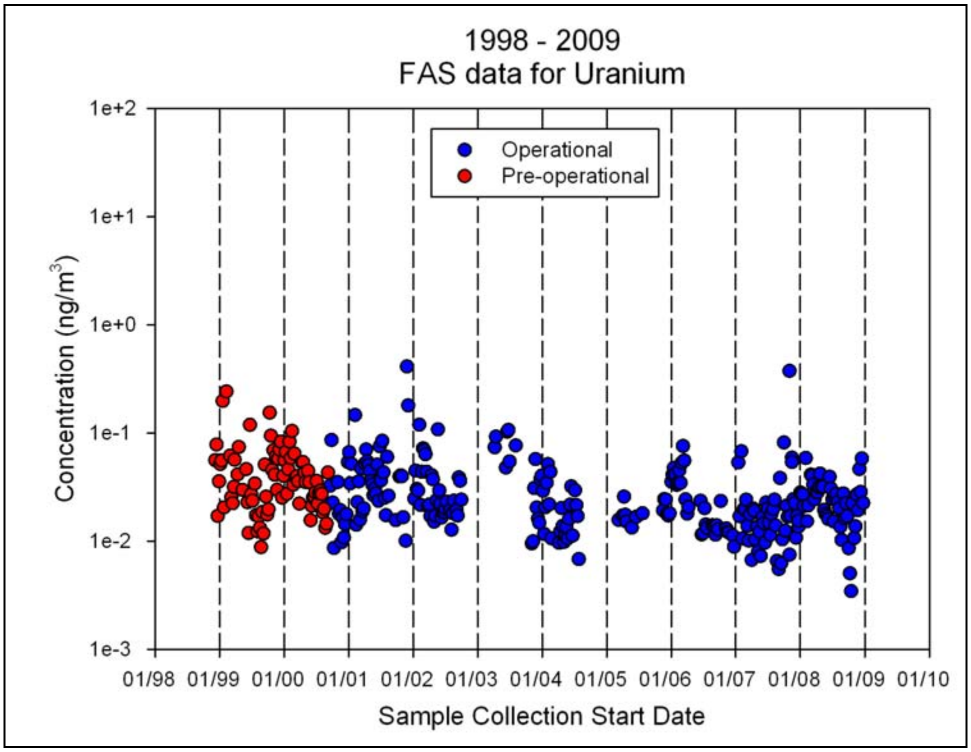


Figure 1.20: Concentrations of U in WIPP Exhaust Air

This page intentionally left blank.

CHAPTER 2

Radionuclides and Inorganics in Selected Water Sources

INTRODUCTION

During 2009, water samples were collected for CEMRC environmental monitoring studies from five drinking water sources in the region of the WIPP. 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 several 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 (*www.cemrc.org*). Present results as well as the results of previous analyses of drinking water were 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.

Analyses reported herein are for 2009 for drinking water samples, analyzed for both inorganics and radionuclides.

METHODS

The alpha-emitting radionuclides ^{238}Pu and $^{239+240}$Pu were analyzed in these drinking water samples. Discussions with stakeholders will determine if further analyses of other radioanalytes will be performed on these samples.

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, (3) 1 L for anion tests and (4) 500 mL for Hg analysis. 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 possible future gamma spectroscopy analyses.

CEMRC performed non-radiological analyses of drinking water samples using ICP-MS and IC, shown in Table 2-1. 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.

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

Table 2-2 shows the radionuclide activity concentrations for radionuclides of U, Pu, Am, Cs and K in regional drinking water samples from 2009. Neither Pu nor Am have been measured above the MDC (0.00008 Bq/L) in any drinking water samples since monitoring commenced in 1997. 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 MDCs at CEMRC.

Natural U and K, and Cs from bomb fallout, are common elements in drinking water sources, especially in New Mexico, but are at levels below concern. Measured values for the drinking water samples collected during 2009 ranged between 9.2-53.5 mBq/L for ^{238}U, 0.4-3.8 m Bq/L for ^{235}U and 24.8-147.0 mBq/L for ^{234}U, all well within historic values. The greatest variations appear in ^{235}U amounts.

Figure 2.1 shows the uranium isotopes measured in drinking water samples, averaged for each year from 1998 to 2009. The low concentration of ^{235}U in water samples is consistent with the lower concentration of ^{235}U in the natural environment as compared to the concentrations of ^{234}U and ^{238}U. The presence of ^{234}U results from decay of ^{238}U. One microgram of natural uranium contains 12.4 mBq [0.33 pCi (picocurie)] of ^{238}U, 0.37 mBq [0.01 pCi] of ^{235}U, and 12.4 mBq [0.33 pCi] of ^{234}U. Natural activity ratios are typically unity for $^{234}U/^{238}U$ and 0.045 for $^{235}U/^{238}U$.

Table 2-3 gives the ratios of uranium isotopes in the drinking water samples averaged from 1998 to 2009 for each site. Because ^{234}U forms from the decay of ^{238}U, their activities are usually similar, referred to as secular equilibrium, meaning as much ^{234}U is being formed and decaying as the amount of ^{238}U that is decaying, over a time- scale greater than 10^6 yr. $^{234}U/^{238}U$ ratios of 1 indicate secular equilibrium, higher ratios indicate radioactive disequilibrium between ^{234}U and ^{238}U. Disequilibrium occurs because of weathering and other geological processes that preferentially remove one isotope over the other. ^{238}U exists in crustal rocks primarily in the +4 state. During radioactive decay, electrons can be lost from the nucleus of the ^{234}U daughter such that some ^{234}U ends up in the +6 state. U(+6) is much more soluble, especially in waters during weathering, because of the formation of strong complexes between uranyl and carbonate ions. Thus, the activity ratio of ^{234}U /^{238}U often exceeds 1 in surface waters as can be seen in Table 2.3 for almost all the samples. Natural activity ratios are typically 0.045 for $^{235}U/^{238}U$, reflecting the natural concentrations in crustal rocks, as they are not directly tied to each through natural decay.

Non-Radiological 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, as it is for all natural waters.

The 2009 measurements exhibit a high level of consistency with past results that provides a useful characterization of each source (Table 2-1).

As per the grant requirements, these results are not used in assessing regulatory compliance. However, CEMRC results for drinking water agree well with, and are generally below, measurements for the same elements published by the City of Carlsbad Municipal Water System (*2009 Annual Consumer Report on the Quality of Your Drinking Water* (*www.cityofcarlsbadnm.com/documents/CCR2009.pdf*)).

Table 2-1: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2009 at Five Locations

Carlsbad								
	1998-2008				2009			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Avg Conc. w/Blank Subt[5] (µg/L)	Avg Conc. w/o Blank Subt[5] (µg/L)
Ag	10	2	1.23E-02	1.75E-02	1.60E-01	4.19E-03	<MDC	<MDC
Al	13	6	2.34E+00	5.95E+01	7.00E+01	1.36E+01	<MDC	<MDC
As	13	7	3.45E-01	1.10E+00	5.32E+00	-1.18E-01	<MDC	<MDC
B	2	2	2.89E+01	3.07E+01	5.00E+00	-3.35E-01	2.89E+01	2.89E+01
Ba	13	13	6.64E+01	8.25E+01	3.07E+01	8.90E-03	7.04E+01	7.04E+01
Be	11		N/A	N/A	4.10E+00	-1.41E-03	<MDC	<MDC
Ca	11	11	6.54E+04	8.06E+04	N/A	N/A	N/A	N/A
Cd	10		N/A	N/A	N/A	N/A	N/A	N/A
Ce	11	2	3.42E-02	4.20E-02	2.30E-01	5.65E-03	<MDC	<MDC
Co	12	9	8.80E-02	3.41E-01	8.10E-01	-1.70E-03	<MDC	<MDC
Cr	13	10	1.24E+00	7.15E+00	2.54E+00	-1.50E-01	<MDC	<MDC
Cu	13	11	1.23E+00	1.67E+01	4.58E+00	2.27E-02	<MDC	<MDC
Dy	12		N/A	N/A	2.30E-01	1.79E-03	<MDC	<MDC
Er	12		N/A	N/A	4.30E-02	4.46E-04	<MDC	<MDC
Eu	10	6	1.35E-02	2.43E-02	1.48E-01	8.13E-04	<MDC	<MDC
Fe	12	5	2.14E+01	2.24E+02	6.70E+02	1.76E+00	<MDC	<MDC
Gd	10		N/A	N/A	7.20E-02	1.98E-03	<MDC	<MDC
Hg	9		N/A	N/A	N/A	N/A	N/A	N/A
K	11	11	1.04E+03	3.56E+03	N/A	N/A	N/A	N/A
La	10	5	1.41E-02	4.48E-02	7.40E-02	2.82E-03	<MDC	<MDC
Li	10	10	5.14E+00	7.87E+00	1.68E+00	1.61E-02	6.62E+00	6.62E+00
Mg	13	13	3.14E+04	3.47E+04	2.33E+01	1.26E-01	3.21E+04	3.21E+04
Mn	13	8	5.50E-02	9.40E-01	6.02E+00	-3.86E-01	<MDC	<MDC
Mo	11	10	7.03E-01	1.26E+00	N/A	N/A	N/A	N/A
Na	12	12	8.16E+03	9.94E+04	3.70E+02	2.37E+01	1.11E+04	1.11E+04
Nd	12		N/A	N/A	1.00E+00	3.12E-03	<MDC	<MDC
Ni	12	11	1.01E+00	2.89E+00	2.12E+00	1.95E-03	2.45E+00	2.45E+00
P	3	2	1.49E+01	1.61E+01	N/A	N/A	N/A	N/A
Pb	11	8	1.63E-01	1.51E+00	4.60E+00	1.50E-03	<MDC	<MDC
Pr	12		N/A	N/A	1.96E-01	1.65E-03	<MDC	<MDC
Sb	12	6	3.00E-02	1.99E-01	3.91E-01	4.78E-02	<MDC	<MDC
Sc	9	9	1.32E+00	3.11E+00	1.15E+00	1.10E-01	1.64E+00	1.64E+00
Se	9	3	9.25E-02	1.75E+00	1.70E+01	-3.82E-01	<MDC	<MDC
Si	7	7	5.31E+03	6.97E+03	3.80E+02	-2.45E+00	5.84E+03	5.84E+03
Sr	13	13	2.59E+02	4.59E+02	2.55E+00	2.35E-02	3.13E+02	3.13E+02
Th	9	1	1.98E-02	1.98E-02	1.98E-01	1.99E-03	<MDC	<MDC
Tl	10	10	8.20E-02	1.54E-01	N/A	N/A	N/A	N/A
U	12	12	8.21E-01	1.04E+00	9.30E-02	1.26E-03	9.04E-01	9.04E-01
V	13	13	3.54E+00	5.90E+00	1.83E+00	-5.14E-02	3.54E+00	3.54E+00
Zn	13	12	2.33E+00	1.52E+01	4.40E+01	1.79E+00	<MDC	<MDC

[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 2-1: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2009 at Five Locations (*Continued)*

Double Eagle								
	1998-2008				2009			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Avg Conc. w/Blank Subt[5] (µg/L)	Avg Conc. w/o Blank Subt[5] (µg/L)
Ag	10	2	3.62E-03	1.78E-01	1.60E-01	4.19E-03	1.78E-01	1.78E-01
Al	12	6	2.57E+00	7.22E+01	7.00E+01	1.36E+01	<MDC	<MDC
As	11	11	4.26E+00	7.80E+00	N/A	N/A	N/A	N/A
B	2	2	2.98E+01	7.00E+01	5.00E+00	-3.35E-01	2.98E+01	2.98E+01
Ba	11	11	3.82E+01	1.26E+02	3.07E+01	8.90E-03	3.82E+01	3.82E+01
Be	9	1	3.63E-02	3.63E-02	4.10E+00	-1.41E-03	<MDC	<MDC
Ca	10	10	5.18E+03	5.83E+04	N/A	N/A	N/A	N/A
Cd	9	3	1.87E-02	1.85E-01	N/A	N/A	N/A	N/A
Ce	10	3	3.18E-03	3.22E-02	2.30E-01	5.65E-03	<MDC	<MDC
Co	12	7	8.45E-02	1.12E+00	8.10E-01	-1.70E-03	<MDC	<MDC
Cr	11	11	1.22E+00	3.25E+01	N/A	N/A	N/A	N/A
Cu	12	11	8.09E-01	5.69E+00	4.58E+00	2.27E-02	<MDC	<MDC
Dy	12		N/A	N/A	2.30E-01	1.79E-03	<MDC	<MDC
Er	12		N/A	N/A	4.30E-02	4.46E-04	<MDC	<MDC
Eu	11	6	1.68E-02	2.86E-02	1.48E-01	8.13E-04	<MDC	<MDC
Fe	10	6	7.93E+01	9.32E+02	6.70E+02	1.76E+00	<MDC	<MDC
Gd	10		N/A	N/A	7.20E-02	1.98E-03	<MDC	<MDC
Hg	7		N/A	N/A	N/A	N/A	N/A	N/A
K	10	10	2.51E+03	2.94E+04	N/A	N/A	N/A	N/A
La	11	5	1.19E-02	6.26E-02	7.40E-02	2.82E-03	<MDC	<MDC
Li	9	9	9.97E+00	1.90E+01	1.68E+00	1.61E-02	9.97E+00	9.97E+00
Mg	12	12	1.09E+03	1.25E+04	4.66E+00	1.26E-01	1.08E+04	1.08E+04
Mn	11	10	1.91E-01	6.04E+00	N/A	N/A	N/A	N/A
Mo	9	9	1.43E+00	6.70E+00	N/A	N/A	N/A	N/A
Na	11	11	3.84E+03	4.04E+04	3.70E+02	2.37E+01	1.87E+04	1.87E+04
Nd	12	1	5.37E-03	5.37E-03	1.00E+00	3.12E-03	<MDC	<MDC
Ni	12	11	8.00E-01	4.03E+00	2.12E+00	1.95E-03	<MDC	<MDC
P	2	1	1.04E+01	1.04E+01	N/A	N/A	N/A	N/A
Pb	10	9	2.56E-01	4.21E+00	4.60E+00	1.50E-03	<MDC	<MDC
Pr	12	1	9.05E-04	9.05E-04	1.96E-01	1.65E-03	<MDC	<MDC
Sb	10	6	2.41E-02	1.39E-01	3.91E-01	4.78E-02	<MDC	<MDC
Sc	7	7	2.64E+00	6.59E+00	N/A	N/A	N/A	N/A
Se	7	4	2.28E+00	3.53E+00	N/A	N/A	N/A	N/A
Si	5	5	7.37E+03	1.81E+04	3.80E+02	-2.45E+00	7.37E+03	7.37E+03
Sr	12	12	5.06E+01	5.63E+02	2.55E+00	2.35E-02	2.39E+02	2.39E+02
Th	9	3	4.32E-03	1.36E-02	1.98E-01	1.99E-03	<MDC	<MDC
Tl	8	2	2.73E-02	4.84E-02	N/A	N/A	N/A	N/A
U	12	12	1.17E+00	2.38E+00	9.30E-02	1.26E-03	1.17E+00	1.17E+00
V	12	12	7.71E+00	3.26E+01	1.83E+00	-5.14E-02	7.71E+00	7.71E+00
Zn	12	11	1.80E+00	1.25E+01	4.40E+01	1.79E+00	<MDC	<MDC

[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 2-1: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2009 at Five Locations (*Continued)*

Hobbs								
	1998-2008				2009			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Avg Conc. w/Blank Subt[5] (µg/L)	Avg Conc. w/o Blank Subt[5] (µg/L)
Ag	10	2	3.86E-03	1.04E-01	1.60E-01	4.19E-03	<MDC	<MDC
Al	11	8	3.03E+00	1.14E+02	7.00E+01	1.36E+01	8.31E+01	9.66E+01
As	11	9	4.51E+00	7.37E+00	5.32E+00	-1.18E-01	<MDC	<MDC
B	3	3	1.41E+02	1.70E+02	5.00E+00	-3.35E-01	1.68E+02	1.68E+02
Ba	11	11	5.65E+01	6.52E+01	3.07E+01	8.90E-03	6.14E+01	6.14E+01
Be	9	1	5.39E-02	5.39E-02	4.10E+00	-1.41E-03	<MDC	<MDC
Ca	8	8	8.09E+03	1.00E+05	N/A	N/A	N/A	N/A
Cd	8	1	1.57E-01	1.57E-01	N/A	N/A	N/A	N/A
Ce	10	5	5.10E-03	2.60E-02	2.30E-01	5.65E-03	<MDC	<MDC
Co	11	7	9.78E-02	3.61E-01	8.10E-01	-1.70E-03	<MDC	<MDC
Cr	11	9	7.33E-01	1.13E+01	2.54E+00	-1.50E-01	<MDC	<MDC
Cu	11	9	1.06E+00	6.93E+00	4.58E+00	2.27E-02	<MDC	<MDC
Dy	11	1	4.18E-03	4.18E-03	2.30E-01	1.79E-03	<MDC	<MDC
Er	11		N/A	N/A	4.30E-02	4.46E-04	<MDC	<MDC
Eu	10	5	1.31E-02	1.97E-02	1.48E-01	8.13E-04	<MDC	<MDC
Fe	9	5	3.64E+01	4.44E+02	6.70E+02	1.76E+00	<MDC	<MDC
Gd	10		N/A	N/A	7.20E-02	1.98E-03	<MDC	<MDC
Hg	6	2	1.06E-02	1.42E-02	N/A	N/A	N/A	N/A
K	8	8	2.32E+03	2.53E+04	N/A	N/A	N/A	N/A
La	10	4	1.51E-02	5.01E-02	7.40E-02	2.82E-03	<MDC	<MDC
Li	9	9	2.65E+01	3.18E+01	1.68E+00	1.61E-02	2.93E+01	2.93E+01
Mg	12	12	2.11E+03	2.79E+04	2.33E+01	1.26E-01	2.66E+04	2.66E+04
Mn	11	9	3.79E-01	2.67E+00	6.02E+00	-3.86E-01	<MDC	<MDC
Mo	8	8	2.60E+00	3.31E+00	N/A	N/A	N/A	N/A
Na	10	10	4.97E+03	5.80E+04	3.70E+02	2.37E+01	5.61E+04	5.61E+04
Nd	11	3	3.01E-03	1.28E-02	1.00E+00	3.12E-03	<MDC	<MDC
Ni	11	11	1.08E+00	4.16E+00	2.12E+00	1.95E-03	2.59E+00	2.59E+00
P	2	1	2.53E+01	2.53E+01	N/A	N/A	N/A	N/A
Pb	10	7	9.44E-02	6.93E-01	4.60E+00	1.50E-03	<MDC	<MDC
Pr	11	1	1.57E-03	1.57E-03	1.96E-01	1.65E-03	<MDC	<MDC
Sb	9	6	3.88E-02	7.02E-02	3.91E-01	4.78E-02	<MDC	<MDC
Sc	8	8	4.30E+00	1.05E+01	1.15E+00	1.10E-01	4.30E+00	4.30E+00
Se	7	3	3.50E+00	6.23E+00	1.70E+01	-3.82E-01	<MDC	<MDC
Si	6	6	2.54E+04	2.86E+04	3.80E+02	-2.45E+00	2.65E+04	2.65E+04
Sr	11	11	7.89E+01	1.06E+03	2.55E+00	2.35E-02	9.62E+02	9.62E+02
Th	9	2	4.54E-03	4.56E-03	1.98E-01	1.99E-03	<MDC	<MDC
Tl	6	2	2.24E-02	2.31E-02	N/A	N/A	N/A	N/A
U	11	11	2.90E+00	3.77E+00	9.30E-02	1.26E-03	3.34E+00	3.34E+00
V	11	11	2.95E+01	3.71E+01	1.83E+00	-5.14E-02	2.95E+01	2.95E+01
Zn	11	8	1.47E+00	4.37E+00	4.40E+01	1.79E+00	<MDC	<MDC

[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 2-1: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2009 at Five Locations (*Continued)*

Loving								
	1998-2008				2009			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Avg Conc. w/Blank Subt[5] (µg/L)	Avg Conc. w/o Blank Subt[5] (µg/L)
Ag	11	4	2.55E-03	2.17E-01	1.60E-01	4.19E-03	2.17E-01	2.17E-01
Al	11	5	3.76E+00	3.76E+02	7.00E+01	1.36E+01	8.13E+01	9.48E+01
As	10	7	1.20E+00	2.16E+00	N/A	N/A	N/A	N/A
B	2	2	7.55E+01	9.86E+01	5.00E+00	-3.35E-01	9.86E+01	9.86E+01
Ba	11	11	2.86E+01	3.47E+01	3.07E+01	8.90E-03	3.18E+01	3.18E+01
Be	8	1	9.35E-02	9.35E-02	4.10E+00	-1.41E-03	<MDC	<MDC
Ca	8	8	9.14E+03	1.04E+05	N/A	N/A	N/A	N/A
Cd	9		N/A	N/A	N/A	N/A	N/A	N/A
Ce	9	2	9.74E-04	2.53E-01	2.30E-01	5.65E-03	<MDC	<MDC
Co	11	7	1.02E-01	4.04E-01	8.10E-01	-1.70E-03	<MDC	<MDC
Cr	11	8	1.21E+00	7.44E+00	2.54E+00	-1.50E-01	<MDC	<MDC
Cu	11	9	1.71E+00	5.59E+00	4.58E+00	2.27E-02	<MDC	<MDC
Dy	11		N/A	N/A	2.30E-01	1.79E-03	<MDC	<MDC
Er	11		N/A	N/A	4.30E-02	4.46E-04	<MDC	<MDC
Eu	10	5	7.00E-03	1.01E-02	1.48E-01	8.13E-04	<MDC	<MDC
Fe	10	4	1.56E+01	2.57E+02	6.70E+02	1.76E+00	<MDC	<MDC
Gd	9	3	2.15E-03	1.04E-02	7.20E-02	1.98E-03	<MDC	<MDC
Hg	5		N/A	N/A	N/A	N/A	N/A	N/A
K	8	8	1.85E+03	1.98E+04	N/A	N/A	N/A	N/A
La	10	4	7.27E-03	2.22E-02	7.40E-02	2.82E-03	<MDC	<MDC
Li	8	8	1.66E+01	1.96E+01	1.68E+00	1.61E-02	1.85E+01	1.85E+01
Mg	11	11	4.04E+03	4.36E+04	2.33E+01	1.26E-01	4.21E+04	4.21E+04
Mn	11	7	1.43E-02	1.77E+00	6.02E+00	-3.86E-01	<MDC	<MDC
Mo	9	7	1.41E+00	1.81E+00	N/A	N/A	N/A	N/A
Na	9	9	2.33E+03	2.82E+04	3.70E+02	2.37E+01	2.82E+04	2.82E+04
Nd	11	1	3.37E-03	3.37E-03	1.00E+00	3.12E-03	<MDC	<MDC
Ni	11	9	1.19E+00	3.43E+00	2.12E+00	1.95E-03	2.33E+00	2.33E+00
P	3	1	3.37E+01	3.37E+01	N/A	N/A	N/A	N/A
Pb	10	8	3.15E-01	1.67E+00	4.60E+00	1.50E-03	<MDC	<MDC
Pr	10		N/A	N/A	1.96E-01	1.65E-03	<MDC	<MDC
Sb	9	5	3.51E-02	1.84E-01	3.91E-01	4.78E-02	<MDC	<MDC
Sc	8	8	1.91E+00	4.72E+00	1.15E+00	1.10E-01	2.39E+00	2.39E+00
Se	5		N/A	N/A	N/A	N/A	N/A	N/A
Si	6	6	8.54E+03	1.09E+04	3.80E+02	-2.45E+00	1.02E+04	1.02E+04
Sr	11	11	7.60E+01	9.37E+02	2.55E+00	2.35E-02	7.29E+02	7.29E+02
Th	9	2	5.69E-03	9.63E-03	1.98E-01	1.99E-03	<MDC	<MDC
Tl	8	1	4.32E-02	4.32E-02	N/A	N/A	N/A	N/A
U	11	11	1.98E+00	2.26E+00	9.30E-02	1.26E-03	1.99E+00	1.99E+00
V	11	11	1.11E+01	1.44E+01	1.83E+00	-5.14E-02	1.11E+01	1.11E+01
Zn	11	10	4.13E+00	2.09E+01	4.40E+01	1.79E+00	<MDC	<MDC

[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 2-1: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2009 at Five Locations (Continued)

Otis								
	1998-2007				2009			
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Avg Conc. w/Blank Subt[5] (µg/L)	Avg Conc. w/o Blank Subt[5] (µg/L)
Ag	9	1	2.63E-02	2.63E-02	1.60E+00	4.19E-03	<MDC	<MDC
Al	10	3	5.74E+00	1.06E+03	7.00E+02	1.36E+01	1.06E+03	1.08E+03
As	10	5	6.53E-01	2.34E+00	N/A	N/A	N/A	N/A
B	3	3	1.46E+02	2.39E+02	5.00E+01	-3.35E-01	2.39E+02	2.39E+02
Ba	11	10	1.35E+01	1.75E+01	3.07E+02	8.90E-03	<MDC	<MDC
Be	8		N/A	N/A	4.10E+01	-1.41E-03	<MDC	<MDC
Ca	8	8	2.14E+05	3.83E+05	N/A	N/A	N/A	N/A
Cd	8		N/A	N/A	N/A	N/A	N/A	N/A
Ce	8	1	2.75E-02	2.75E-02	2.30E+00	5.65E-03	<MDC	<MDC
Co	10	8	1.19E-01	9.51E-01	8.10E+00	-1.70E-03	<MDC	<MDC
Cr	11	9	8.76E-01	6.67E+00	2.54E+01	-1.50E-01	<MDC	<MDC
Cu	11	9	2.43E+00	6.02E+00	4.58E+01	2.27E-02	<MDC	<MDC
Dy	10	1	3.39E-03	3.39E-03	2.30E+00	1.79E-03	<MDC	<MDC
Er	10		N/A	N/A	4.30E-01	4.46E-04	<MDC	<MDC
Eu	9	3	3.42E-03	9.48E-03	1.48E+00	8.13E-04	<MDC	<MDC
Fe	10	9	2.87E+00	1.02E+03	6.70E+03	1.76E+00	<MDC	<MDC
Gd	8		N/A	N/A	7.20E-01	1.98E-03	<MDC	<MDC
Hg	7		N/A	N/A	N/A	N/A	N/A	N/A
K	9	9	2.75E+03	4.01E+03	N/A	N/A	N/A	N/A
La	9	2	3.97E-03	6.30E-03	7.40E-01	2.82E-03	<MDC	<MDC
Li	8	8	3.74E+01	6.79E+01	1.68E+01	1.61E-02	6.79E+01	6.79E+01
Mg	11	11	5.16E+04	1.08E+05	2.33E+01	1.26E-01	8.56E+04	8.56E+04
Mn	10	6	1.78E-01	2.32E+00	6.02E+01	-3.86E-01	<MDC	<MDC
Mo	8	8	2.39E+00	3.13E+00	N/A	N/A	N/A	N/A
Na	10	10	1.16E+03	1.97E+05	3.70E+03	2.37E+01	1.97E+05	1.97E+05
Nd	10	3	4.80E-03	3.97E-02	1.00E+01	3.12E-03	<MDC	<MDC
Ni	10	9	2.45E+00	1.06E+01	2.12E+01	1.95E-03	<MDC	<MDC
P	2	2	4.54E+01	9.97E+01	N/A	N/A	N/A	N/A
Pb	9	7	1.08E-01	5.04E-01	4.60E+01	1.50E-03	<MDC	<MDC
Pr	10		N/A	N/A	1.96E+00	1.65E-03	<MDC	<MDC
Sb	9	6	3.50E-02	4.10E-01	3.91E+00	4.78E-02	<MDC	<MDC
Sc	8	7	1.80E+00	5.35E+00	1.15E+01	1.10E-01	<MDC	<MDC
Se	7		N/A	N/A	N/A	N/A	N/A	N/A
Si	6	6	9.77E+03	1.39E+04	3.80E+03	-2.45E+00	1.39E+04	1.39E+04
Sr	11	11	3.31E+01	4.62E+03	2.55E+01	2.35E-02	4.62E+03	4.62E+03
Th	8	2	3.44E-03	2.67E-02	1.98E+00	1.99E-03	<MDC	<MDC
Tl	7		N/A	N/A	N/A	N/A	N/A	N/A
U	10	10	3.73E+00	5.88E+00	9.30E-01	1.26E-03	5.88E+00	5.88E+00
V	11	10	1.05E+01	1.29E+01	1.83E+01	-5.14E-02	<MDC	<MDC
Zn	11	9	1.54E+00	1.64E+01	4.40E+02	1.79E+00	<MDC	<MDC

[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 2-2: Radionuclide Activity Concentrations in Drinking Water Sources

Location and sample collection date	Radionuclide	Activity Concentration Bq/L	SD (Bq/L)	MDC (Bq/L)
Carlsbad 12/16/2009	$^{239+240}$Pu	5.68E-05	5.68E-05	2.04E-04
	^{238}Pu	3.78E-05	4.64E-05	1.76E-04
	^{241}Am	2.79E-05	3.17E-05	1.11E-04
	^{238}U	9.24E-03	4.12E-04	1.46E-04
	^{235}U	3.57E-04	8.33E-05	1.67E-04
	^{234}U	2.48E-02	8.40E-04	1.72E-04
	^{137}Cs	7.34E-03	5.60E-02	1.86E-01
	^{40}K	-7.83E-01	5.35E-01	1.80E+00
Hobbs 12/17/2009	$^{239+240}$Pu	7.71E-05	5.80E-05	1.95E-04
	^{238}Pu	-1.68E-10	5.12E-05	2.18E-04
	^{241}Am	-8.06E-06	2.46E-05	1.14E-04
	^{238}U	3.86E-02	1.31E-03	1.38E-04
	^{235}U	1.99E-03	2.07E-04	2.39E-04
	^{234}U	8.94E-02	2.73E-03	2.35E-04
	^{137}Cs	6.32E-02	5.64E-02	1.86E-01
	^{40}K	-7.06E-01	5.48E-01	1.84E+00
Double Eagle 12/17/2009	$^{239+240}$Pu	-9.82E-11	4.24E-05	1.97E-04
	^{238}Pu	1.13E-04	6.51E-05	2.02E-04
	^{241}Am	-2.01E-05	3.17E-05	1.44E-04
	^{238}U	2.89E-02	9.44E-04	2.44E-04
	^{235}U	6.61E-03	7.55E-04	8.28E-04
	^{234}U	6.97E-02	1.96E-03	2.34E-04
	^{137}Cs	-2.38E-04	5.67E-02	1.88E-01
	^{40}K	-1.07E+00	5.38E-01	1.82E+00
Otis 12/16/2009	$^{239+240}$Pu	-9.75E-5	9.45E-5	5.25E-4
	^{238}Pu	7.87E-05	8.14E-05	2.94E-04
	^{241}Am	-5.50E-05	3.71E-05	1.76E-04
	^{238}U	5.35E-02	1.43E-03	2.17E-04
	^{235}U	3.80E-03	2.77E-04	2.14E-04
	^{234}U	1.47E-01	3.43E-03	1.90E-04
	^{137}Cs	-5.55E-02	7.02E-02	2.34E-01
	^{40}K	2.51E+00	5.84E-01	1.87E+00
Loving 12/16/2009	$^{239+240}$Pu	-1.73E-10	5.30E-05	2.25E-04
	^{238}Pu	-3.74E-05	3.75E-05	2.02E-04
	^{241}Am	-8.11E-06	3.04E-05	1.34E-04
	^{238}U	2.22E-02	7.76E-04	2.75E-04
	^{235}U	1.26E-03	1.53E-04	1.58E-04
	^{234}U	7.42E-02	2.07E-03	1.64E-04
	^{137}Cs	-3.06E-02	5.62E-02	1.87E-01
	^{40}K	-1.21E+00	5.26E-01	1.78E+00

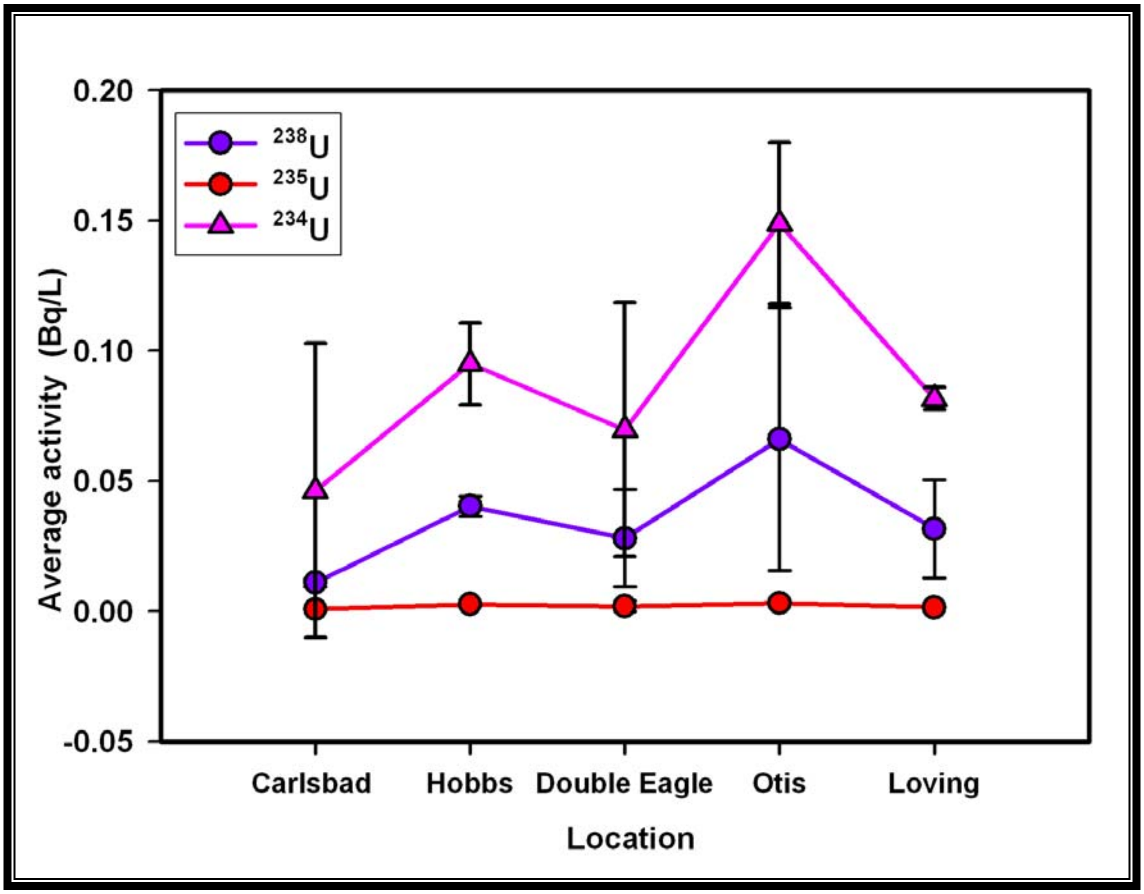


Figure 2.1: ^{234}U, ^{235}U, and ^{238}U in Bq/L in Regional Drinking Water
Results from 1998 to 2009 are averaged for each site.
All are below the EPA Action level of 0.56 Bq/L and within the range expected in waters from this region.

Table 2-3: Activity Concentrations and Activity Ratios of Uranium Isotopes Measured in Drinking Water from 1999-2009 (Bq/L)

Location	^{234}U	^{238}U	^{235}U	Total U	$^{234}U/^{238}U$	$^{235}U/^{238}U$
2009						
Carlsbad	0.025	0.009	0.000	0.034	2.68	0.04
Double Eagle	0.070	0.029	0.007	0.105	2.41	0.23
Hobbs	0.089	0.039	0.002	0.130	2.32	0.05
Otis	0.147	0.054	0.004	0.204	2.74	0.07
Loving	0.074	0.022	0.001	0.098	3.34	0.06
2008						
Carlsbad	0.077	0.032	0.003	0.112	2.43	0.10
Double Eagle	0.186	0.079	0.007	0.272	2.34	0.08
Hobbs	0.287	0.131	0.012	0.430	2.19	0.09
Otis	0.389	0.153	0.014	0.556	2.54	0.09
Loving	0.256	0.077	0.005	0.338	3.32	0.07
2005						
Carlsbad	0.028	0.011	0.002	0.040	2.47	0.14
Double Eagle	0.058	0.025	0.002	0.085	2.35	0.06
Hobbs	0.098	0.043	0.003	0.144	2.30	0.06
Otis	0.003	0.044	0.003	0.049	0.06	0.06
Loving	0.081	0.026	0.001	0.109	3.08	0.05
2003						
Carlsbad	0.029	0.011	0.001	0.040	2.77	0.05
Double Eagle	0.043	0.016	0.001	0.060	2.64	0.06
Hobbs	0.130	0.046	0.003	0.179	2.82	0.05
Otis	0.134	0.034	0.003	0.171	3.92	0.07
Loving	0.079	0.024	0.001	0.104	3.30	0.06
2002						
Carlsbad	0.030	0.013	0.001	0.044	2.39	0.06
Double Eagle	0.042	0.018	0.001	0.060	2.36	0.07
Hobbs	0.094	0.041	0.002	0.137	2.32	0.06
Otis	0.147	0.053	0.003	0.204	2.75	0.06
Loving	0.088	0.028	0.002	0.118	3.12	0.06
2001						
Carlsbad	0.032	0.012	0.001	0.045	2.60	0.08
Double Eagle	0.041	0.017	0.001	0.059	2.36	0.05
Hobbs	0.075	0.033	0.003	0.111	2.27	0.08
Otis	0.162	0.060	0.003	0.225	2.69	0.05
Loving	0.081	0.025	0.002	0.107	3.24	0.06
2000						
Carlsbad	0.028	0.011	0.001	0.040	2.61	0.08
Double Eagle	0.054	0.022	0.001	0.077	2.47	0.06
Hobbs	0.091	0.040	0.002	0.133	2.27	0.06
Otis	0.144	0.199	0.003	0.346	0.72	0.01
Loving	0.084	0.026	0.002	0.111	3.23	0.06
1999						
Carlsbad	0.029	0.011	0.001	0.041	2.57	0.06
Double Eagle	0.062	0.023	0.001	0.086	2.67	0.05
Hobbs	0.088	0.039	0.002	0.129	2.28	0.06
Otis	0.150	0.053	0.003	0.206	2.82	0.05
Loving	0.082	0.026	0.002	0.109	3.10	0.06

This page intentionally left blank.

CHAPTER 3

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, especially those who live in the vicinity of the WIPP. The data collected prior to the opening of the WIPP facility (March 26, 1999) serve as a baseline for comparisons with periodic follow-up measurements that are slated to continue throughout the approximate 35-year operational phase of the WIPP. It is important to note that these data represent an interim summary (through December 31, 2009) of an ongoing study.

Participating in the LDBC consists of having a lung and whole body count. 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 December 31, 2009, 883 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 296 recount bioassays had been performed through December 31, 2009. In addition, 310 new volunteers have participated in the program since October 1, 2002.

While not part of the LDBC program, CEMRC has also counted over 3,000 rad-trained workers in the region from WIPP, WCS, and NEF.

Demographic characteristics (Table 3-1) 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

---

[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.

between the LDBC cohort and 2000 census is under-sampling of latinos. 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.

Baseline monitoring includes only the initial count of individuals made prior to March 26, 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 3-2 for 2008/2009 and 2009/2010. 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, and ^{232}Th via the decay of ^{228}Ac (Table 3-2). 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 below).

For the operational monitoring counts (Table 3-3, N = 804), 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 76% 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 2009 and ranged from 792 to 5558 Bq per person with an overall mean (± SE) of 2494 (± 24) 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 3068 (± 28) Bq per person, which was significantly greater ($p < 0.0001$) than that of females, which was 1893 (± 20) 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 22 ± 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 and Kirchner, 2000). Detectable ^{137}Cs body burdens ranged from 4.9 to 132 Bq per person with an overall mean (± SE) of 11.7 (± 0.8) Bq per person. The mean ^{137}Cs body burden for males (± SE), was 13.1 (± 1.2) 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 (CEMRC Reports; Webb and Kirchner, 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 (28.5 %) as compared to non-smokers (23.8 %). 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 has been no observable effects 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 3-1: Demographic Characteristics of the "Lie Down and Be Counted" Population Sample through December 31, 2009

Characteristic		2009 Sample Group[a] (margin of error)	[b]Census, 2000
Gender	Male	48.1% (44.8 to 51.4%)	48.2 %
	Female	51.9% (48.6 to 55.2%)	51.8 %
Ethnicity	Latino	17.2% (14.7 to 19.7%)	36.7 %
	Non-latino	81.8% (79.2 to 84.3%)	63.3 %
Age 60 or older		24.9% (22.4 to 27.4%)	24.5 %
Currently or previously classified as a radiation worker		8.0% (6.5 to 9.6%)	[c]NA
Consumption of wild game within 3 months prior to count		21.6% (19.2 to 23.9%)	NA
Medical treatment other than X-rays using radionuclides		7.3% (5.8 to 8.8%)	NA
European travel within 2 years prior to the count		5.1% (3.9 to 6.4%)	NA
Current smoker		13.8% (11.8 to 15.8%)	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 3-2: Minimum Detectable Activities

2008-2009 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	0.17	0.23	0.31	0.35	0.49	0.70	1.00
Ce-144	133.50	0.48	0.56	0.72	0.80	1.05	1.40	1.86
Cf-252	19.20	19.47	34.24	79.93	112.80	280.03	749.63	1962.46
Cm-244	18.10	17.10	33.96	87.90	128.41	357.32	1081.36	3179.24
Eu-155	105.30	0.26	0.34	0.45	0.49	0.68	0.94	1.30
Np-237	86.50	0.46	0.61	0.82	0.93	1.29	1.83	2.57
Pu-238	17.10	17.47	40.20	116.57	179.34	564.87	1945.76	6542.12
Pu-239	17.10	43.46	100.01	290.03	446.20	1405.42	4841.12	16277.04
Pu-240	17.10	17.08	39.29	113.94	175.29	552.13	1901.87	6394.55
Pu-242	17.10	20.60	47.40	137.45	211.46	666.06	2294.32	7714.06
Ra-226	186.10	1.78	1.92	2.37	2.58	3.23	4.13	5.24
Th-232 via Pb-212	238.60	0.15	0.18	0.22	0.24	0.31	0.40	0.52
Th-232	59.00	33.23	44.39	60.25	68.21	95.02	135.74	192.74
Th-232 via Th-228	84.30	4.63	6.23	8.40	9.50	13.15	18.71	26.39
U-233	440.30	0.63	0.74	0.92	1.00	1.25	1.56	2.00
U-235	185.70	0.11	0.12	0.15	0.16	0.20	0.26	0.32
Nat U via Th-234	63.30	1.50	2.02	2.76	3.13	4.36	6.23	8.85

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.77
Ba-140	537	1.50
Ce-141	145	1.70
Co-58	811	0.36
Co-60	1333	0.35
Cr-51	320	4.46
Cs-134	604	0.34
Cs-137	662	0.42
Eu-152	344	1.57
Eu-154	1275	0.93
Eu-155	105	4.06
Fe-59	1099	0.66
I-131	365	0.46
I-133	530	0.36
Ir-192	317	0.57
Mn-54	835	0.44
Ru-103	497	0.38
Ru-106	622	3.22
Sb-125	428	0.13
Th-232 via Ac-228	911	1.24
Y-88	898	0.38
Zn-65	1116	1.09
Zr-95	757	0.58

Table 3-2: Minimum Detectable Activities *(Continued)*

2009-2010 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	0.31	0.35	0.48	0.69	0.98
Ce-144	133.50	0.46	0.55	0.71	0.78	1.02	1.37	1.81
Cf-252	19.20	18.40	35.70	83.06	117.26	290.67	779.21	2044.61
Cm-244	18.10	17.24	36.08	91.90	134.84	370.50	1104.05	3219.25
Eu-155	105.30	0.27	0.33	0.43	0.48	0.65	0.90	1.23
Np-237	86.50	0.48	0.60	0.81	0.90	1.24	1.74	2.43
Pu-238	17.10	18.99	43.15	122.46	186.89	574.02	1939.37	6365.37
Pu-239	17.10	47.25	107.35	304.68	464.99	1428.18	4825.23	15837.28
Pu-240	17.10	18.56	42.17	119.70	182.67	561.07	1895.63	6221.79
Pu-242	17.10	22.39	50.88	144.39	220.37	676.85	2286.79	7505.65
Ra-226	186.10	1.61	1.90	2.35	2.56	3.21	4.11	5.24
Th-232 via Pb-212	238.60	0.15	0.17	0.22	0.24	0.30	0.39	0.50
Th-232	59.00	34.13	43.28	58.76	66.47	92.27	131.46	186.15
Th-232 via Th-228	84.30	4.85	6.12	8.20	9.23	12.67	17.85	24.99
U-233	440.30	0.63	0.75	0.92	1.00	1.25	1.59	2.01
U-235	185.70	0.10	0.12	0.15	0.16	0.20	0.25	0.32
Nat U via Th-234	63.30	1.56	2.00	2.69	3.05	4.23	6.02	8.50

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.82
Ba-140	537	1.56
Ce-141	145	1.78
Co-58	811	0.37
Co-60	1333	0.36
Cr-51	320	4.75
Cs-134	604	0.36
Cs-137	662	0.44
Eu-152	344	1.68
Eu-154	1275	0.95
Eu-155	105	4.09
Fe-59	1099	0.68
I-131	365	0.50
I-133	530	0.44
Ir-192	317	0.59
Mn-54	835	0.46
Ru-103	497	0.41
Ru-106	622	3.35
Sb-125	428	1.41
Th-232 via Ac-228	911	1.26
Y-88	898	0.39
Zn-65	1116	1.13
Zr-95	757	0.60

Table 3-3: "Lie Down and Be Counted" Results through December 31, 2009

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 2009) N = 804
		% of Results ≥ [b]L_C	% of Results ≥ L_C
^{241}Am	Lung	5.2 (4.0 to 6.4)	4.2 (3.5 to 4.9)
^{144}Ce	Lung	4.6 (3.5 to 5.7)	3.9 (3.2 to 4.5)
^{252}Cf	Lung	4.1 (3.1 to 5.1)	5.5 (4.7 to 6.3)
^{244}Cm	Lung	5.7 (4.5 to 7.0)	4.7 (4.0 to 5.5)
^{155}Eu	Lung	7.1 (5.8 to 8.4)	5.2 (4.4 to 6.0)
^{237}Np	Lung	3.6 (2.6 to 4.5)	4.1 (3.4 to 4.8)
^{210}Pb	Lung	4.4 (3.3 to 5.4)	6.5 (5.6 to 7.4)
Plutonium Isotope	Lung	5.7 (4.5 to 7.0)	5.8 (5.0 to 6.7)
[d] ^{232}Th via ^{212}Pb	Lung	34.2 (31.7 to 36.6)	33.4 (31.8 to 35.1)
^{232}Th	Lung	4.9 (3.8 to 6.0)	5.2 (4.5 to 6.0)
^{232}Th via ^{228}Th	Lung	4.1 (3.1 to 5.1)	4.7 (4.0 to 5.5)
^{233}U	Lung	5.7 (4.5 to 7.0)	9.6 (8.5 to 10.6)
^{235}U/^{226}Ra	Lung	10.7 (9.0 to 12.3)	11.2 (10.1 to 12.3)
Natural Uranium via ^{234}Th	Lung	5.2 (4.0 to 6.4)	6.1 (5.3 to 6.9)
^{133}Ba	Whole Body	3.6 (2.6 to 4.5)	3.1 (2.5 to 3.7)
^{140}Ba	Whole Body	5.2 (4.0 to 6.4)	4.1 (3.4 to 4.8)
^{141}Ce	Whole Body	3.6 (2.6 to 4.5)	4.6 (3.9 to 5.3)
^{58}Co	Whole Body	4.4 (3.3 to 5.4)	2.9 (2.3 to 3.5)
[d] ^{60}Co	Whole Body	54.6 (52.0 to 57.2)	26.8 (25.2 to 28.3)
^{51}Cr	Whole Body	5.7 (4.5 to 7.0)	3.9 (3.2 to 4.5)
^{134}Cs	Whole Body	1.6 (1.0 to 2.3)	2.7 (2.2 to 3.3)
^{137}Cs	Whole Body	28.4 (26.1 to 30.8)	20.0 (18.6 to 21.5)
^{152}Eu	Whole Body	7.4 (6.0 to 8.7)	6.1 (5.3 to 6.9)
^{154}Eu	Whole Body	3.8 (2.8 to 4.8)	2.9 (2.3 to 3.5)
^{155}Eu	Whole Body	3.8 (2.8 to 4.8)	3.5 (2.8 to 4.1)
^{59}Fe	Whole Body	3.8 (2.8 to 4.8)	5.5 (4.7 to 6.3)
^{131}I	Whole Body	5.2 (4.0 to 6.4)	4.1 (3.4 to 4.8)
^{133}I	Whole Body	3.3 (2.3 to 4.2)	4.0 (3.3 to 4.7)
^{193}Ir	Whole Body	4.1 (3.1 to 5.1)	4.0 (3.3 to 4.7)
^{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)	11.8 (10.7 to 13.0)
^{103}Ru	Whole Body	2.2 (1.4 to 3.0)	1.9 (1.4 to 2.3)
^{106}Ru	Whole Body	4.4 (3.3 to 5.4)	3.9 (3.2 to 4.5)
^{125}Sb	Whole Body	5.2 (4.0 to 6.4)	3.9 (3.2 to 4.5)
^{232}Th via ^{228}Ac	Whole Body	34.7 (32.2 to 37.2)	25.3 (23.8 to 26.9)
^{88}Y	Whole Body	7.7 (6.3 to 9.0)	6.1 (5.3 to 7.0)
^{95}Zr	Whole Body	6.6 (5.3 to 7.9)	3.7 (3.1 to 4.4)

[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

This page intentionally left blank.

CHAPTER 4

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. Compounds consistently detected in ambient air samples in the underground may be added to the list of compounds of interest. The current list of analytes is presented in Table 4-1.

Monitoring is conducted in accordance with the *"Volatile Organic Compound Confirmatory 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. The program was established and successfully audited by the WTS QA group prior to acceptance of actual samples and is audited yearly since 2004. 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 purchased a HSG analysis system consisting of a 6890/5973N Agilent GC/MS with a loop injection system and three Entech 7032 Autosamplers installed in series were 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.

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 old 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 Volatile Organic Compound Monitoring expanded from 353 samples in 2005 to 430 samples in 2006. Analysis of closed room samples for VOCs, hydrogen, and methane began in 2007 as well and continues to the present. In 2007, CEMRC analyzed a total of 749 samples for VOCs and 182 samples for hydrogen and methane. In 2008, a total of 608 samples were analyzed for VOCs and 254 samples were analyzed for hydrogen and methane, while in 2009, a total of 571 samples were analyzed for VOCs and 339 samples were analyzed for hydrogen and methane.

Although CEMRC performed well on the DOE audit for the headspace gas analysis project, a decision was made not to submit these samples for analysis at CEMRC. However, some equipment obtained for this project is currently being used for analysis of closed room samples for VOCs and percent levels of hydrogen and methane

METHODS FOR VOLATILE ORGANIC COMPOUND 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.

Analyses for Volatile Organic Compound Monitoring were conducted under procedures using concepts of EPA 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)" (1999).
Special quality assurance requirements for these activities were detailed in the *"Quality Assurance Project Plan for 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-15 and all WIPP documents relevant to the Confirmatory Monitoring Program. See Table 4-2 for a list of CEMRC Procedures for Confirmatory Monitoring.

In November 2006, a WIPP permit modification incorporated an expansion of sampling in the Volatile Organic Compounds 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 4-1.

METHODS FOR HYDROGEN AND METHANE ANALYSIS

The analysis of hydrogen and methane in closed room samples began in August 2007. Under the analysis scheme used at CEMRC, sample canisters would be pressurized to twice atmospheric pressure (if not already received at above atmospheric pressure) by the addition of ultra high purity nitrogen, and then simultaneously analyzed for hydrogen and methane by GC/Thermal Conductivity Detector (TCD) and screened for VOCs by GCMS. The sampling system incorporates three autosamplers in series to allow for the analysis of two complete batches of six 6L samples per run. Samples from the autosamplers pass through heated transfer lines into two injection loops attached to an automated valve for simultaneous injection into the GC. The VOC screening results are used to determine pre-analysis dilutions required for analysis by Method TO-15. The hydrogen and methane analysis results are reported in separate data packages from the VOCs results.

RESULTS AND DISCUSSION

The OC laboratory analyzed 531 routine ambient air samples for VOCs during 2009 with 100% completeness. Sets of blank and recovery gas samples collected by Shaw Environmental as part of the sampler cleaning and certification were analyzed in expedited turnaround batches at various times throughout the years, resulting in analysis of 40 additional samples with 100% completeness. A total of 339 samples were analyzed for hydrogen and methane, with 100% completeness.

Batch reports for VOCs results 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.

Hardcopy and electronic reports for hydro-gen and methane analyses are submitted in the formats specified by the client.

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.

Summary Statements

Because of the proprietary nature of the VOC data, none are reported herein.

The success of the VOCs Monitoring Program and the successful HSG Program audit demonstrate CEMRC's ability to initiate 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 hydrogen/ methane samples per year.

Table 4-1: 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 4-2: CEMRC Procedures for Confirmatory Volatile Organic Compounds Monitoring Program

Procedure Number	Procedure Title
OC-PLAN-001	Quality Assurance Project Plan for Analysis of Volatile Organic Compounds and/or Hydrogen and Methane in Canister Samples
OC-PROC-002	Preparation of Canisters and Sample Trains for Ambient Air Sampling
OC-PROC-003	Gas Chromatography-Mass Spectrometry Analysis of Vol Organic Compounds (VOCs) in Ambient Air from Caniste PPBV Concentration Levels
OC-PROC-004	Preparation of Calibration Standards in Specially Prepared Canisters for Analysis by Gas Chromatography/Mass Spectrometry
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 Plan
OC-PROC-006	Receipt, Control, and Storage of Gas Samples in Passivated Canisters
OC-PROC-009	Analysis of Hydrogen and Methane in Passivated Canisters Using Gas Chromatography with Thermal Conductivity Detection

This page intentionally left blank.

CHAPTER 5

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 Pu and Am that are major components of the wastes emplaced at the WIPP. The main objective of 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 articles specifically based on the WIPP-EM aerosol research have been published in peer-reviewed journals (Arimoto et al. 2002 and 2006).

The element of particular interest for the WIPP-EM is plutonium (Pu, atomic number 94) and americium (Am, atomic number, 96). CEMRC has been monitoring the concentration of plutonium and americium in the area around the WIPP sites for many years as isotopes of these elements are the major radioactive constituents in the TRU waste. The source of Pu and Am in and around the WIPP site prior to arrival of the TRU waste at the site can be attributed to the nuclear weapons testing in the 1950s to1980s, controlled releases from the operation of nuclear power plants and nuclear reprocessing facilities and nuclear accidents.

Alpha spectrometry is generally used for the determination of ^{238}Pu and $^{239+240}$Pu. Due to similar energies of the alpha particles from ^{239}Pu (5.16 MeV-71%, half-life, $t_{1/2}$ = 24,110 yr) and ^{240}Pu (5.17 MeV-73%, $t_{1/2}$ = 6563 yr) the isotopes cannot be distinguished by standard alpha spectrometry using Si detectors. 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 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 (Figure 5-1); these are (1) On Site station, which is about 0.1 km northwest (downwind) of the WIPP exhaust shaft, (2) Near Field Station, about 1 km northwest of the facility; and (3) Cactus Flats Station, about 19 km southeast (upwind) of the WIPP site, collecting total suspended particulate (TSP) matter. 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.

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 inch by 10 inch 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 5-1.

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 (Table 5-1). 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 6 hr of heating in a muffle furnace at 500° C, which drives off organics. The tracers and the iron carrier are added and each filter is treated with $HF+HNO_3$ up to the complete decomposition of silica. Then it is treated with conc. $HClO_4$ and HNO_3 for the removal of fluoride ions. The actinides are then separated as a group by co-precipitation on $Fe(OH)_3$. The nuclides of interest were precipitated with LaF_3, deposited onto filters, mounted on planchettes, and counted on Oxford Oasis alpha spectroscopy for five days. Gamma-emitting are measured in the air filters by Gamma spectrometry for 48 hours.

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).

RESULTS AND DISCUSSION

Summary data reported for high volume aerosol samples (hi-vols) are presented in Table 5-2. $^{239+240}$Pu is frequently detected, whereas ^{238}Pu is detected infrequently with activity concentrations slightly above minimum detectable concentration (MDC). As in prior years, the $^{239+240}$Pu activity concentrations showed a strong annual cycle with activities greatest in the spring (Figure 5.2).

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, at On Site in 2004, and at Near field in 2008 exhibited slightly higher $^{239+240}$Pu activity concentrations (Figure 5.2) than surrounding data points. The points correspond with higher activity densities as well (Figure 5.2). 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 in 2001. The activity concentrations of ^{241}Am (Figure 5.3) in the high-volume samples closely tracked those of $^{239+240}$Pu as shown in Figure 5.2. Most notably, strong springtime peaks in ^{241}Am activity concentrations were evident in the samples from 2001 through 2002, and 2004 through 2009. Data from 2003 do not exhibit these springtime peaks. A time series plot for ^{241}Am activity density is presented in (Figure 5.4).

The average activity concentration (activity per unit volume air sampled) for $^{239+240}$Pu ranges from 8.9-16.7 nBq/m^3 at On Site, 4.9-18.5 nBq/m^3 at Near Field, 6.6-20.3 nBq/m^3 at cactus flat and that of ^{241}Am from 2.2-4.8 nBq/m^3 for On Site station, 1.9-4.5 nBq/m^3 for Near Field and 2.5-7.0 nBq/m^3 for Cactus Flats, however, their concentrations were consistently lower than those of $^{239+240}$Pu. The average $^{239+240}$Pu, ^{241}Am, and ^{238}Pu concentrations alongside the average mass concentrations in these three stations are shown in Figures (5.5 to 5.7). Secondly, average activity density (activity per unit mass aerosol collected) which is used as an index to elucidate contribution of resuspension of $^{239+240}$Pu on the aerosol filters ranges from 0.27-0.48 nBq/m^3 at On Site, 0.37-0.53 nBq/m^3 at Near Field, 0.38-0.59 nBq/m^3 at Cactus Flats (Figures 5.8-5.10). The ^{241}Am activity density ranging from 0.10-0.16 mBq/g for On Site, 0.11-0.19 mBq/g for Near Field and 0.17-0.84 mBq/g for Cactus Flat.

The plutonium activity concentration and density are usually higher in Cactus flat samples and the activity follows the order: Cactus Flat>Near Field>On Site. In contrast to actinide data, the aerosol mass loadings follows the trend: On Site (27±14 µg/m^3) > Near Field (24±10 µg/m^3) < Cactus Flat (34±15 µg/m^3). 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 5-2 and Figure 5.11) 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 5-2 and Figure 5.3). 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 probably particles from construction dusts or salt from the underground operations.

The minimum, maximum, and average concentrations of radionuclides for all sampling locations combined are reported in Tables 5-3, 5-4 and 5-5. ^{238}Pu, $^{239+240}$Pu, and ^{241}were detected in some samples. Concentrations of ^{40}K were detected in most of the samples. ^{40}K is ubiquitous in the earth's crust and thus would be expected to show up in environmental air samples. There was no significant difference in the concentrations of ^{40}K among locations. ^{137}Cs and ^{60}Co were not detected in any of the samples.

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.

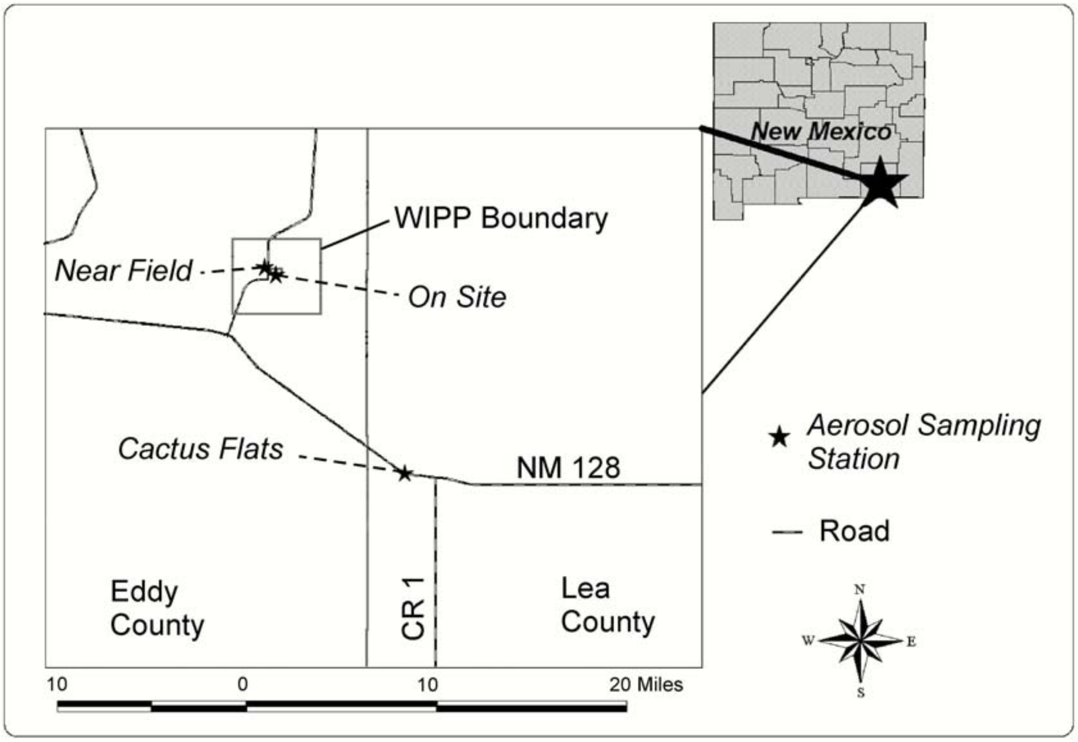


Figure 5.1: WIPP-EM Ambient Aerosol Sampling Stations

Table 5-1: Aerosol Sampling Status for the WIPP EM

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 41Filter	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.

Table 5-2: Summary Statistics for Aerosol Mass Loadings and Actinide Activities in High-Volume Aerosol Samples around the WIPP Site

Station		Cactus Flats	Near Field	On Site
Type of Sample		**TSP**	**TSP**	**TSP**
Number of Samples		97	99	99
Aerosol Mass, micrograms per cubic meter	[a]N	97	99	99
	Mean	27	24	32
	StdDev	14	10	15
^{241}Am Activity Concentration, Bq/m^3	N	48	46	54
	Mean	5.5E-09	3.9E-09	1.4E-07
	StdDev	4.6E-09	2.0E-09	9.9E-09
^{241}Am Activity Density, Bq/g	N	48	46	54
	Mean	2.1E-04	1.6E-04	6.1E-03
	StdDev	1.8E-04	6.9E-05	4.4E-02
^{60}Co Activity Concentration, Bq/m^3	[a]N	2	0	0
	Mean	5.6E-07	0	0
	StdDev	3.1E-07	0	0
^{60}Co Activity Density, Bq/g	N	2	0	0
	Mean	2.7E-02	0	0
	StdDev	1.3E-02	0	0
^{40}K Activity Concentration, Bq/m^3	N	12	18	13
	Mean	2.2E-05	2.5E-05	2.4E-05
	StdDev	1.6E-05	1.2E-05	1.3E-05
^{40}K Activity Density, Bq/g	N	12	18	13
	Mean	1.3E+00	1.4E+00	9.3E-01
	StdDev	1.2E+00	8.6E-01	8.8E-01
^{238}Pu Activity Concentration, Bq/m^3	N	9	2	9
	Mean	6.1E-09	1.2E-09	2.9E-09
	StdDev	1.1E-08	4.6E-10	1.5E-09
^{238}Pu Activity Density, Bq/g	N	9	2	9
	Mean	2.7E-04	3.8E-05	7.9E-05
	StdDev	5.5E-04	5.1E-06	3.3E-05
$^{239+240}$Pu Activity Concentration, Bq/m^3	N	86	93	92
	Mean	1.5E-08	1.2E-08	1.2E-08
	StdDev	1.1E-08	8.7E-09	7.7E-09
$^{239+240}$Pu Activity Density, Bq/g	N	86	93	92
	Mean	5.2E-04	4.9E-04	3.5E-04
	StdDev	2.0E-04	2.2E-04	1.9E-04

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

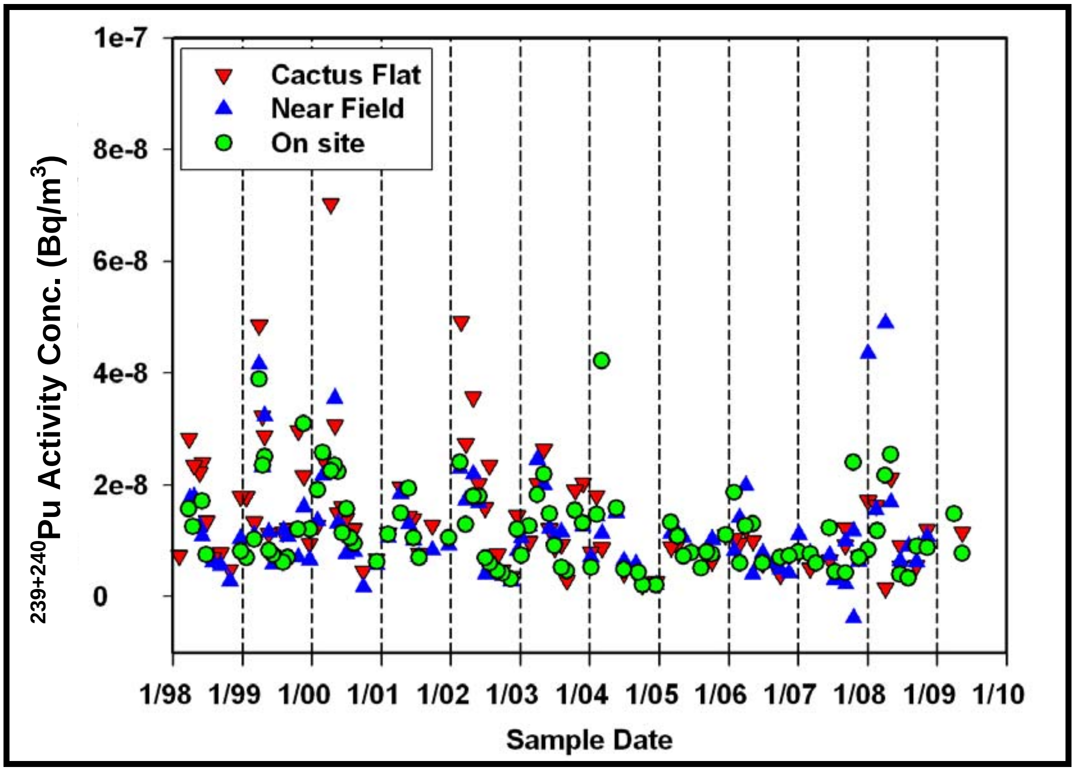


Figure 5.2: High Volume Ambient Aerosol $^{239+240}$Pu Activity Concentrations

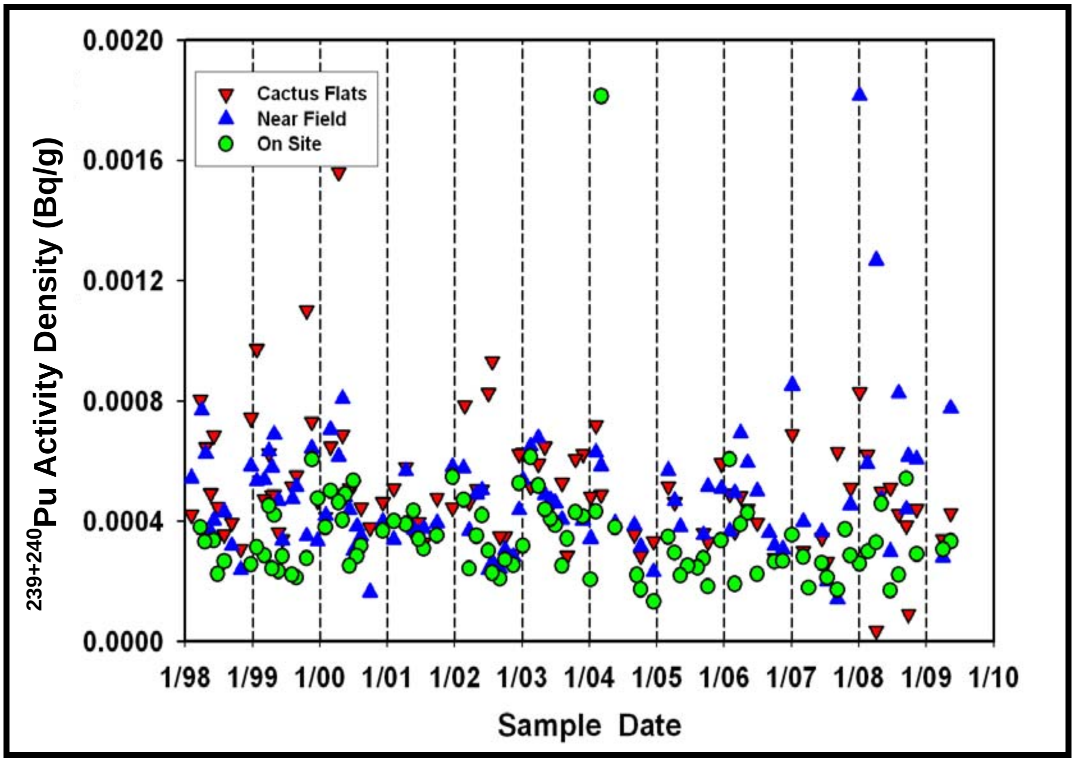


Figure 5.3: High Volume Ambient Aerosol $^{239+240}$Pu Activity Densities

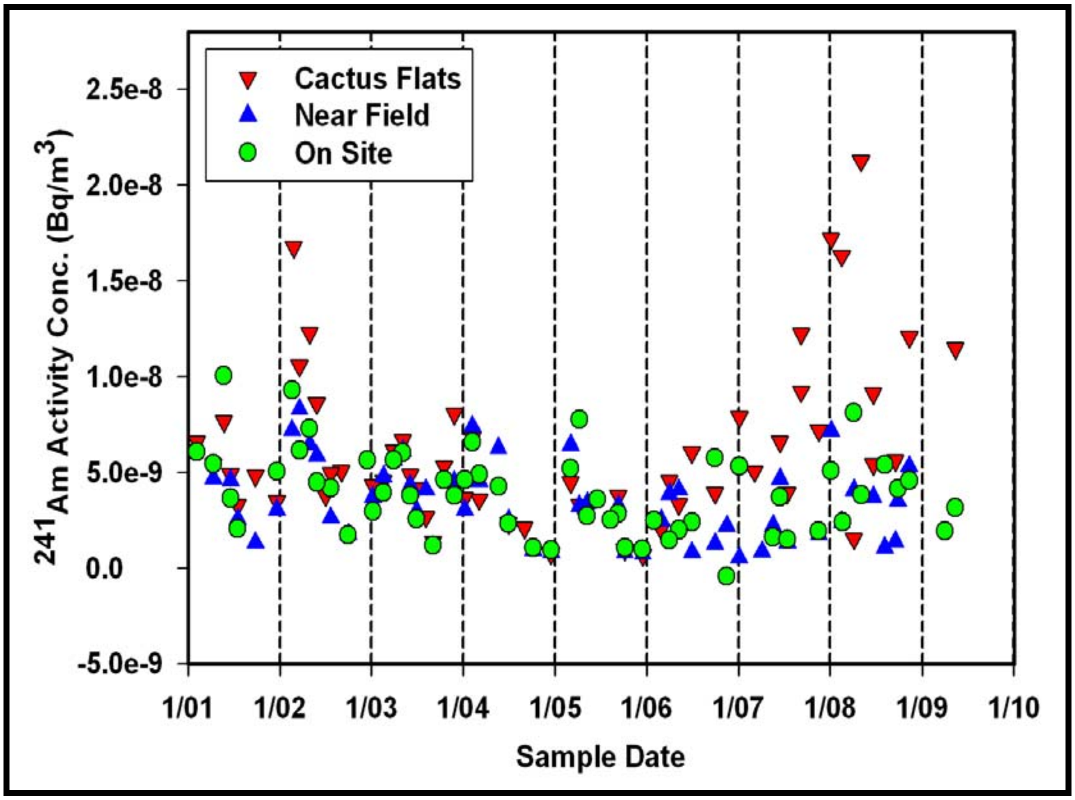


Figure 5.4: High Volume Ambient Aerosol ^{241}Am Activity Concentrations

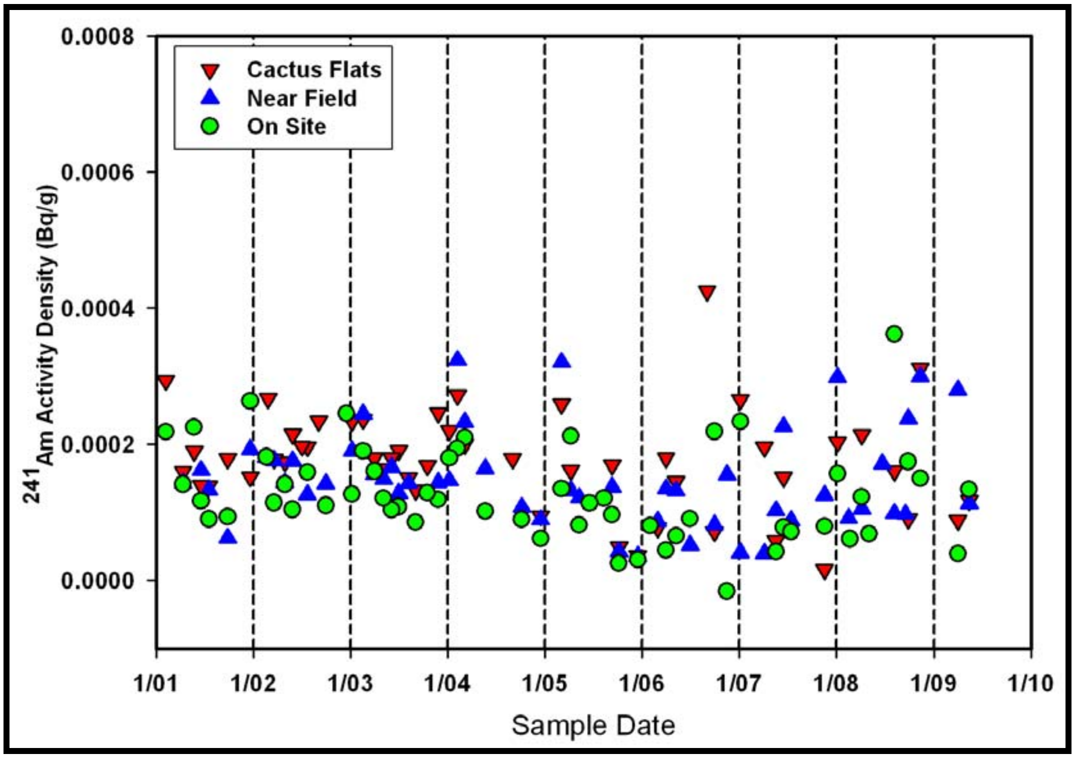


Figure 5.5: High Volume Ambient Aerosol ^{241}Am Activity Densities

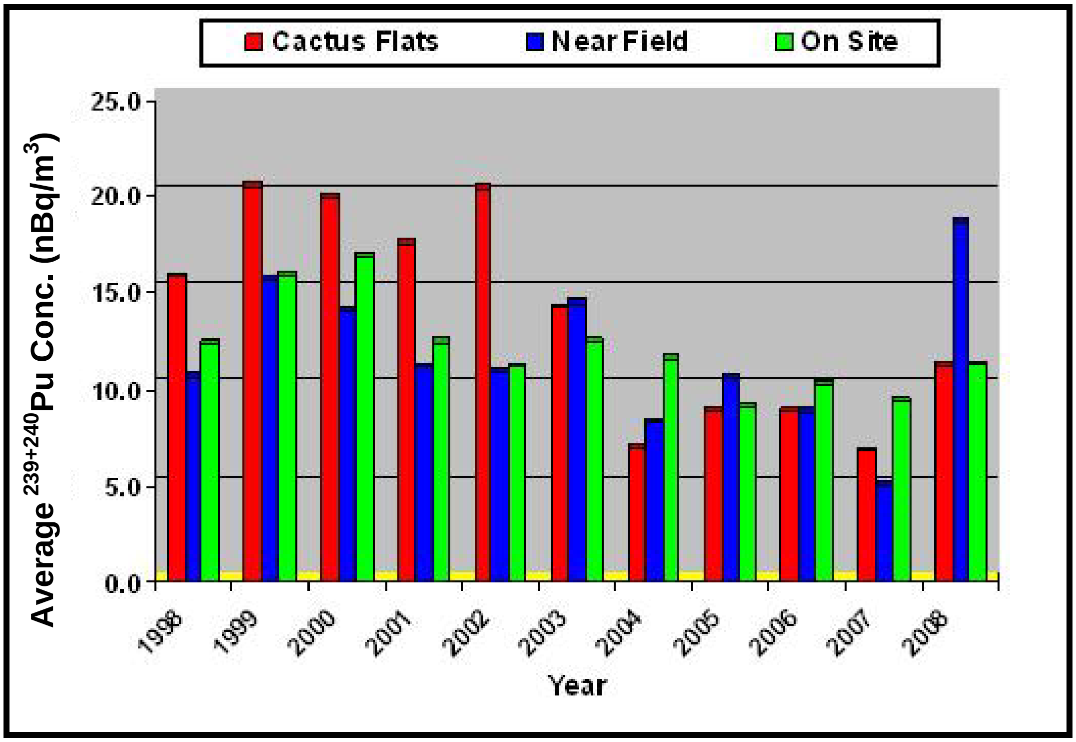


Figure 5.6: Average High Volume Ambient Aerosol $^{239+240}$Pu Activity Concentrations around the WIPP Site

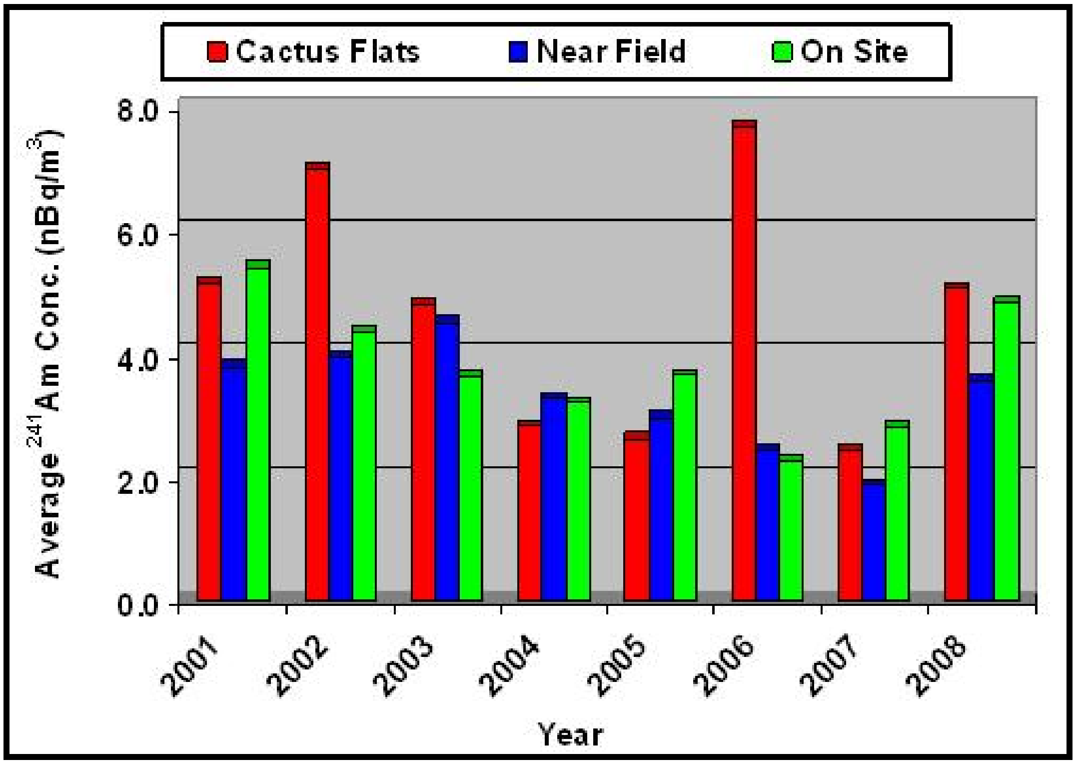


Figure 5.7: Average High Volume Ambient Aerosol ^{241}Am Activity Concentrations around the WIPP Site

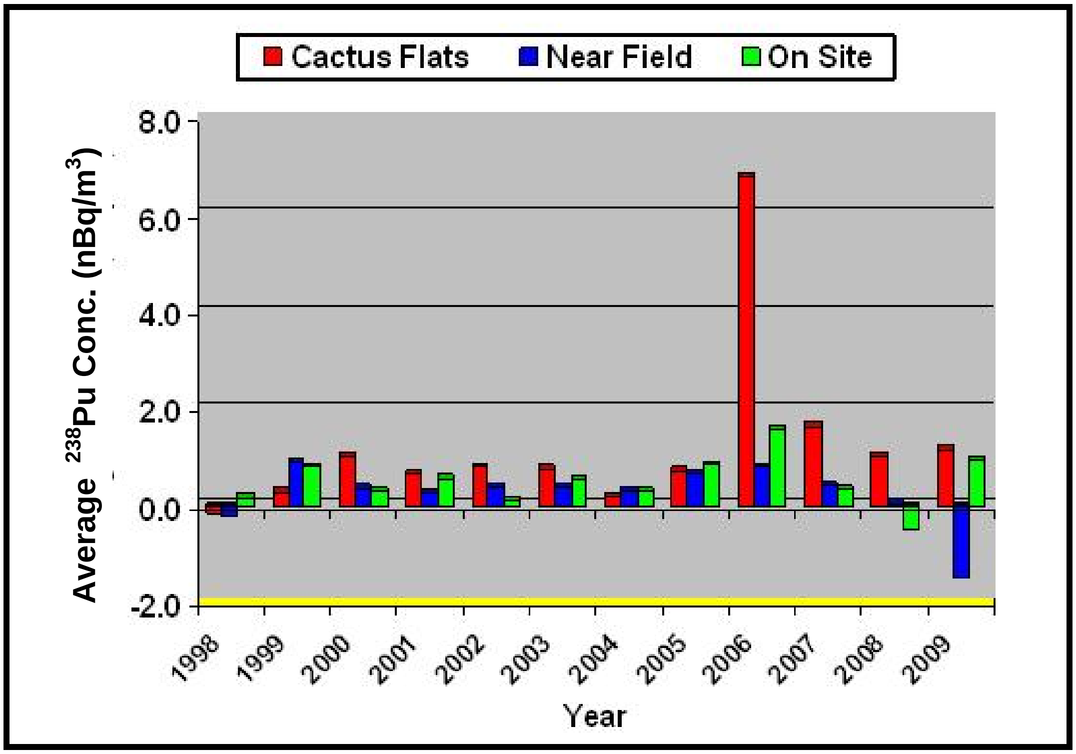


Figure 5.8: Average High Volume Ambient Aerosol ^{238}Pu Activity Concentrations around the WIPP Site

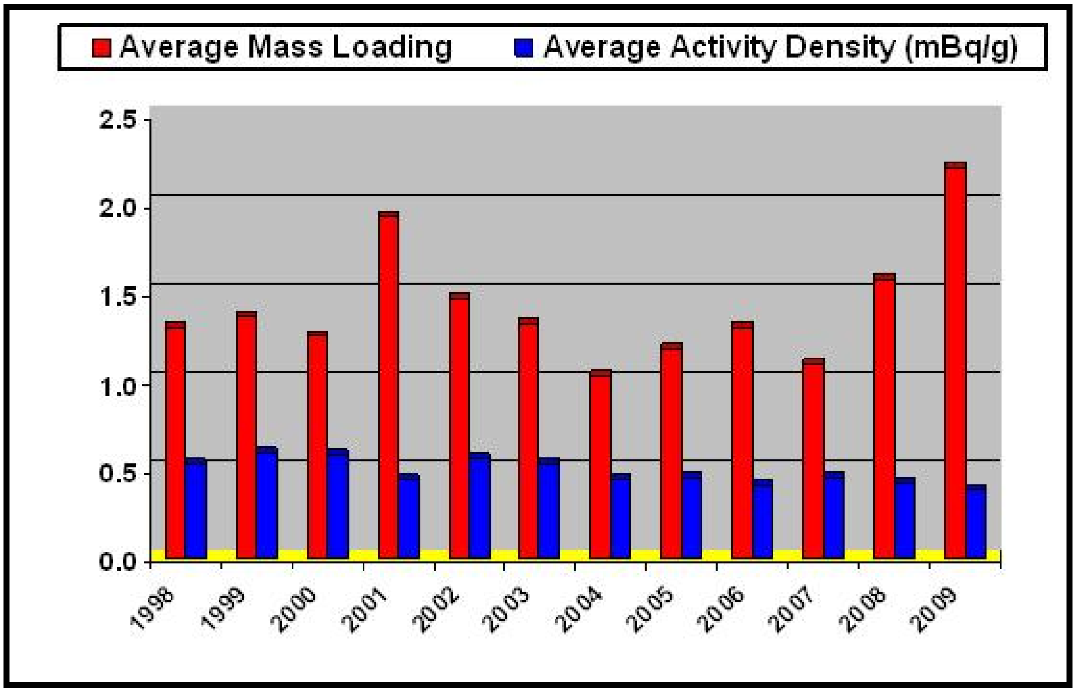


Figure 5.9: Average High Volume Ambient Aerosol Mass Concentrations and $^{239+240}$Pu Activity Densities at Cactus Flats Station

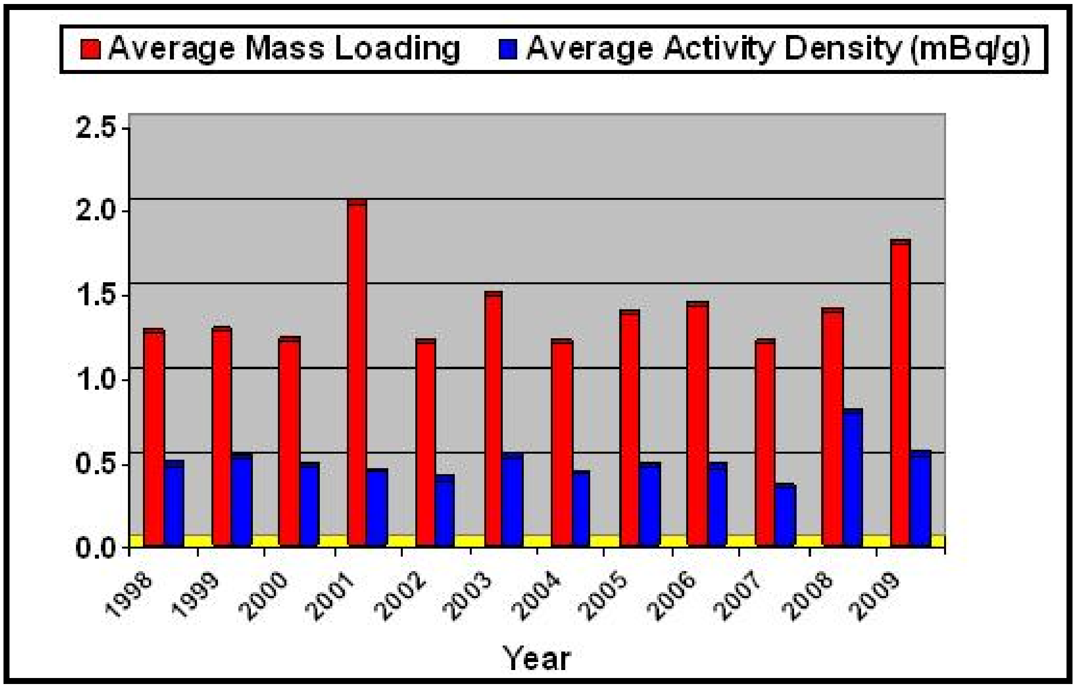


Figure 5.10: Average High Volume Ambient Aerosol Mass Concentrations and $^{239+240}$Pu Activity Densities at Near Field Station

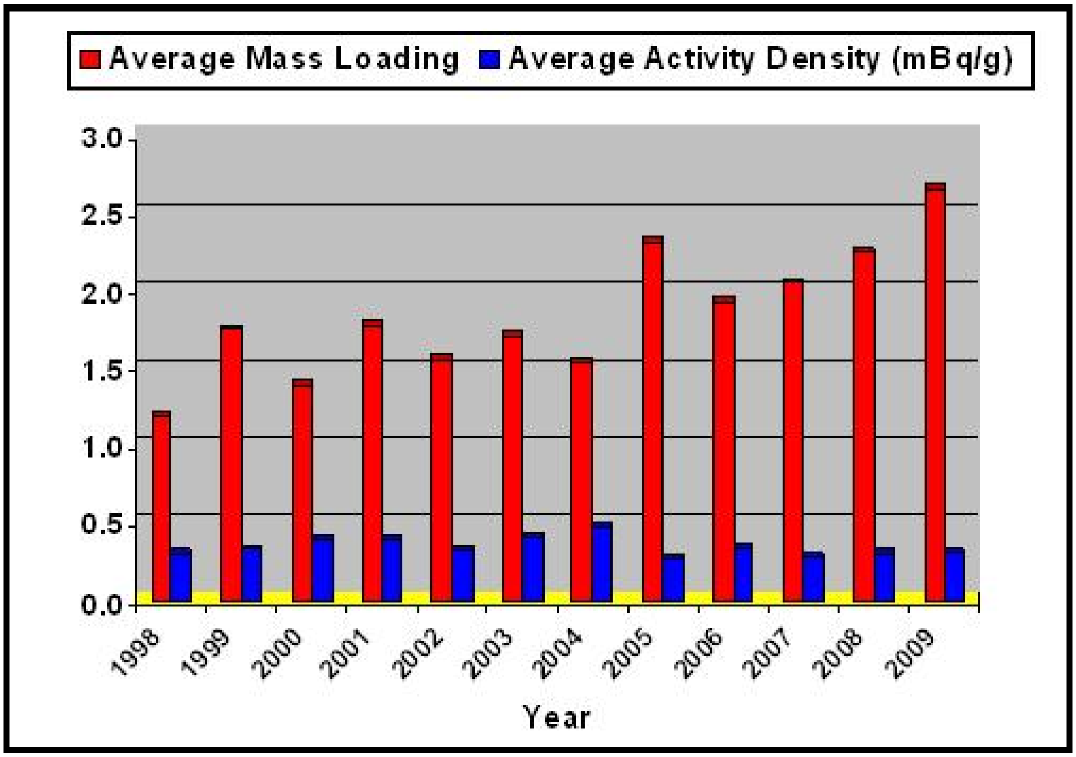


Figure 5.11: Average High Volume Ambient Aerosol Mass Concentrations and $^{239+240}$Pu Activity Densities at On Site Station

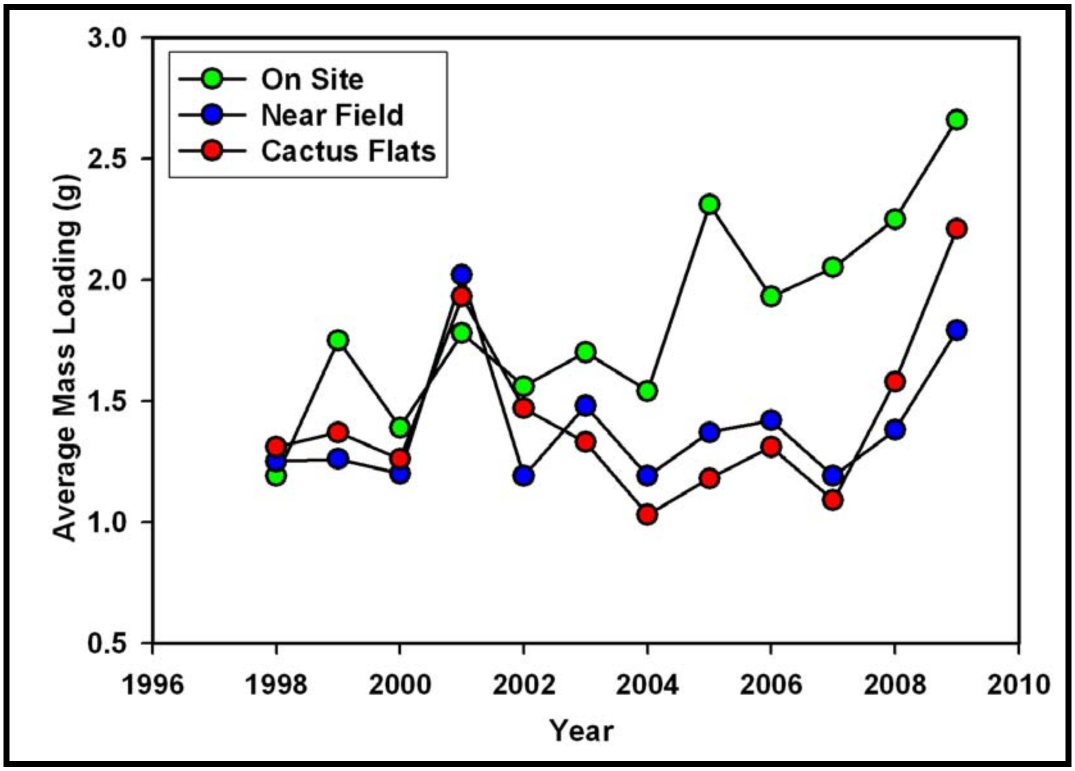


Figure 5.12: Average Ambient Aerosol Mass Loading in Air Filters around the WIPP Site

Table 5-3: Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at On Site Station

Radionuclide		Concentration	SD	MDC
	2007			
^{241}Am	Minimum	1.51E-09	4.97E-10	9.83E-10
	Maximum	<MDC	3.78E-09	1.44E-08
	Average	<MDC	1.88E-09	5.41E-09
^{238}Pu	Minimum	<MDC	4.00E-10	1.86E-09
	Maximum	<MDC	2.54E-09	1.08E-08
	Average	<MDC	1.33E-09	5.24E-09
$^{239+240}$Pu	Minimum	4.32E-09	1.22E-09	2.15E-09
	Maximum	2.40E-08	4.57E-09	9.44E-09
	Average	9.23E-09	2.21E-09	4.32E-09
^{137}Cs	Minimum	<MDC	2.00E-07	6.64E-07
	Maximum	<MDC	5.44E-07	1.80E-06
	Average	<MDC	3.63E-07	1.20E-06
^{60}Co	Minimum	<MDC	2.05E-07	6.74E-07
	Maximum	<MDC	2.96E-06	9.90E-06
	Average	<MDC	7.41E-07	2.47E-06
^{40}K	Minimum	4.19E-06	1.39E-06	3.73E-06
	Maximum	3.65E-05	4.09E-06	1.32E-05
	Average	1.59E-05	2.81E-06	8.71E-06
	2008			
^{241}Am	Minimum	1.92E-09	7.48E-10	4.90E-10
	Maximum	8.11E-09	1.77E-09	3.47E-09
	Average	4.29E-09	1.20E-09	1.95E-09
^{238}Pu	Minimum	<MDC	9.80E-10	1.14E-09
	Maximum	<MDC	4.44E-09	2.37E-08
	Average	<MDC	1.79E-09	7.36E-09
$^{239+240}$Pu	Minimum	3.31E-09	1.72E-09	1.01E-09
	Maximum	2.54E-08	5.42E-09	1.68E-08
	Average	1.16E-08	2.88E-09	6.35E-09
^{137}Cs	Minimum	<MDC	2.08E-07	6.89E-07
	Maximum	<MDC	1.35E-06	4.49E-06
	Average	<MDC	4.12E-07	1.37E-06
^{60}Co	Minimum	<MDC	2.49E-07	8.09E-07
	Maximum	<MDC	9.04E-07	2.93E-06
	Average	<MDC	3.70E-07	1.22E-06
^{40}K	Minimum	<MDC	1.95E-06	5.51E-06
	Maximum	5.95E-05	6.82E-06	1.99E-05
	Average	1.14E-05	2.82E-06	8.90E-06
	2009			
^{241}Am	Minimum	3.14E-09	8.93E-10	1.51E-09
	Maximum	1.92E-09	8.31E-10	6.78E-10
	Average	2.53E-09	8.62E-10	1.09E-09
^{238}Pu	Minimum	<MDC	1.51E-09	1.34E-09
	Maximum	3.74E-09	1.35E-04	1.45E-09
	Average	<MDC	6.77E-05	1.39E-09
$^{239+240}$Pu	Minimum	7.81E-09	2.34E-09	4.12E-09
	Maximum	1.48E-08	2.58E-09	4.42E-09
	Average	1.13E-08	2.46E-09	4.27E-09
^{137}Cs	Minimum	<MDC	2.12E-07	7.04E-07
	Maximum	<MDC	5.04E-07	1.67E-06
	Average	<MDC	3.07E-07	1.02E-06
^{60}Co	Minimum	<MDC	1.78E-07	5.95E-07
	Maximum	<MDC	1.10E-06	3.73E-06
	Average	<MDC	4.08E-07	1.35E-06
^{40}K	Minimum	<MDC	2.02E-06	6.71E-06
	Maximum	3.12E-05	3.10E-06	9.80E-06
	Average	1.10E-05	2.54E-06	8.03E-06

Table 5-4: Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filter at Near Field Station

Radionuclide		Concentration	SD	MDC
	2006			
^{241}Am	Minimum	5.32E-10	3.63E-10	4.94E-10
	Maximum	4.65E-09	1.37E-09	2.89E-09
	Average	1.89E-09	7.65E-10	1.55E-09
^{238}Pu	Minimum	<MDC	4.31E-10	8.78E-10
	Maximum	<MDC	5.33E-09	2.61E-08
	Average	<MDC	1.94E-09	7.92E-09
$^{239+240}$Pu	Minimum	<MDC	9.78E-10	9.43E-10
	Maximum	<MDC	6.06E-09	2.80E-08
	Average	<MDC	2.59E-09	8.01E-09
^{137}Cs	Minimum	<MDC	2.00E-07	6.58E-07
	Maximum	<MDC	5.28E-07	1.74E-06
	Average	<MDC	3.78E-07	1.25E-06
^{60}Co	Minimum	<MDC	1.95E-07	6.41E-07
	Maximum	<MDC	6.09E-07	2.05E-06
	Average	<MDC	3.59E-07	1.19E-06
^{40}K	Minimum	<MDC	1.48E-06	3.83E-06
	Maximum	3.81E-05	4.06E-06	1.35E-05
	Average	2.01E-05	2.54E-06	7.57E-06
	Average			
^{241}Am	Minimum	<MDC	5.80E-10	1.29E-09
	Maximum	7.16E-09	2.34E-09	5.52E-09
	Average	3.58E-09	1.30E-09	2.50E-09
^{238}Pu	Minimum	<MDC	1.06E-09	4.35E-09
	Maximum	<MDC	2.00E-09	1.14E-08
	Average	<MDC	1.59E-09	7.30E-09
$^{239+240}$Pu	Minimum	6.25E-09	2.02E-09	2.00E-09
	Maximum	4.90E-08	5.87E-09	8.32E-09
	Average	1.85E-08	3.31E-09	5.21E-09
^{137}Cs	Minimum	<MDC	1.99E-07	6.60E-07
	Maximum	<MDC	1.32E-06	4.39E-06
	Average	<MDC	4.69E-07	1.55E-06
^{60}Co	Minimum	<MDC	2.21E-07	7.25E-07
	Maximum	<MDC	9.17E-07	3.03E-06
	Average	<MDC	4.25E-07	1.41E-06
^{40}K	Minimum	<MDC	1.73E-06	4.77E-06
	Maximum	5.83E-05	7.00E-06	2.07E-05
	Average	1.94E-05	3.01E-06	9.17E-06
	2009			
^{241}Am	Minimum	6.83E-09	1.82E-09	3.00E-09
	Maximum	<MDC	6.83E-10	1.75E-09
	Average	4.27E-09	1.25E-09	2.37E-09
^{238}Pu	Minimum	<MDC	2.04E-09	9.58E-09
	Maximum	<MDC	2.23E-09	1.07E-08
	Average	<MDC	2.14E-09	1.02E-08
$^{239+240}$Pu	Minimum	<MDC	3.74E-09	9.26E-09
	Maximum	9.97E-09	3.18E-09	6.39E-09
	Average	1.08E-08	3.46E-09	7.82E-09
^{137}Cs	Minimum	<MDC	1.84E-07	6.15E-07
	Maximum	<MDC	3.91E-07	1.31E-06
	Average	<MDC	3.03E-07	1.01E-06
^{60}Co	Minimum	<MDC	1.50E-07	5.02E-07
	Maximum	<MDC	3.28E-07	1.11E-06
	Average	<MDC	2.10E-07	7.03E-07
^{40}K	Minimum	<MDC	1.95E-06	5.41E-06
	Maximum	2.45E-05	4.07E-06	1.33E-05
	Average	1.23E-05	2.66E-06	8.37E-06

Table 5-5: Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filter at Cactus Flats Station

Radionuclide		***Concentration***	***SD***	***MDC***
	2007			
^{241}Am	Minimum	<MDC	7.19E-10	1.42E-09
	Maximum	<MDC	3.01E-09	1.03E-08
	Average	<MDC	1.24E-09	3.56E-09
^{238}Pu	Minimum	<MDC	7.19E-10	1.42E-09
	Maximum	<MDC	3.01E-09	1.03E-08
	Average	<MDC	1.66E-09	5.09E-09
$^{239+240}$Pu	Minimum	3.91E-09	1.48E-09	2.61E-09
	Maximum	<MDC	9.04E-09	3.27E-08
	Average	<MDC	3.44E-09	1.05E-08
^{137}Cs	Minimum	<MDC	7.19E-10	1.42E-09
	Maximum	<MDC	9.04E-09	3.27E-08
	Average	<MDC	3.22E-09	1.04E-08
^{60}Co	Minimum	<MDC	2.11E-07	6.92E-07
	Maximum	<MDC	3.40E-06	1.14E-05
	Average	<MDC	7.75E-07	2.59E-06
^{40}K	Minimum	<MDC	1.41E-06	3.91E-06
	Maximum	2.18E-05	4.28E-06	1.42E-05
	Average	<MDC	2.99E-06	9.69E-06
	2008			
^{241}Am	Minimum	<MDC	6.27E-10	1.45E-09
	Maximum	9.20E-09	1.90E-09	2.74E-09
	Average	5.08E-09	1.24E-09	2.01E-09
^{238}Pu	Minimum	<MDC	7.38E-10	6.56E-10
	Maximum	<MDC	4.28E-09	1.86E-08
	Average	<MDC	1.80E-09	6.38E-09
$^{239+240}$Pu	Minimum	1.53E-09	1.35E-09	6.56E-10
	Maximum	2.13E-08	3.97E-09	7.25E-09
	Average	1.11E-08	2.57E-09	4.39E-09
^{137}Cs	Minimum	<MDC	2.05E-07	6.70E-07
	Maximum	<MDC	1.36E-06	4.52E-06
	Average	<MDC	4.62E-07	1.53E-06
^{60}Co	Minimum	<MDC	1.53E-07	5.00E-07
	Maximum	<MDC	9.54E-07	3.11E-06
	Average	<MDC	3.34E-07	1.10E-06
^{40}K	Minimum	<MDC	1.77E-06	4.87E-06
	Maximum	7.16E-05	6.74E-06	1.88E-05
	Average	1.98E-05	2.89E-06	8.66E-06
	2009			
^{241}Am	Maximum	3.17E-09	7.50E-10	1.27E-09
	Maximum	<MDC	1.78E-09	4.99E-09
	Maximum	3.17E-09	1.27E-09	3.13E-09
^{238}Pu	Maximum	<MDC	1.81E-09	5.08E-09
	Maximum	<MDC	3.58E-09	1.56E-08
	Maximum	<MDC	2.69E-09	1.03E-08
$^{239+240}$Pu	Maximum	1.15E-08	2.76E-09	5.08E-09
	Maximum	<MDC	5.08E-09	1.44E-08
	Maximum	1.19E-08	3.92E-09	9.76E-09
^{137}Cs	Minimum	<MDC	1.89E-07	6.29E-07
	Maximum	<MDC	4.10E-07	1.36E-06
	Average	<MDC	2.75E-07	9.12E-07
^{60}Co	Minimum	<MDC	1.52E-07	5.00E-07
	Maximum	<MDC	3.50E-07	1.18E-06
	Average	<MDC	2.27E-07	7.54E-07
^{40}K	Minimum	<MDC	2.08E-06	6.45E-06
	Maximum	1.54E-05	4.23E-06	1.38E-05
	Average	9.93E-06	2.91E-06	9.41E-06

This page intentionally left blank.

CHAPTER 6

Surface Soil Radionuclide Studies

INTRODUCTION

Soils are of high interest to the WIPP-EM because aerosol releases of contaminants would eventually be deposited in surface soil, which then can serve as a source for continuing contaminant exposure and uptake via direct contact, food chain pathways, and re-suspension. From this perspective, soil is an integrating medium of primary concern in predictive eco-system and contaminant transport modeling, that requires good information about the dispersion of analytes of concern across the landscape. The sources of transuranic radionuclides in soils are mainly integrated global fallout from the testing of above-ground nuclear devices; these include ^{238}Pu injected into the stratosphere by the burn-up of a failed radioactive thermal generator in 1964, release at the Gnome Site, and the regional fallout from the above-ground testing at the Nevada Test Site(NTS). Each of these sources has a characteristic radionuclide signature and/or abundance that can, in principle, be used to identify their presence in the soils and to estimate their concentrations. Results reported herein are from soil samples collected during 2009 from a grid of 16 locations surrounding the WIPP site (the Near Field grid). Also reported are summary statistics for the 1998-2005 data for the Near Field grid (Figure 6.1). Measurements were made by CEMRC on the 2009 surface soil samples for ^{137}Cs, ^{40}K, ^{60}Co, $^{239+240}$Pu, ^{238}Pu and ^{241}Am.

METHODS

The 16 sampling locations constituting each grid are distributed over approxi-mately 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. As in 2005, one sample was collected at each of the 16 grid nodes in 2009. 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 about 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 (500 g) 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 analysis was conducted using high purity Ge (HPGe) detector for 48 hours. A set of soil matrix standards procured from Eckert and Ziegler, Analytics (GA) was used to establish matrix-specific calibra-tion and counting efficiencies. For analyses of alpha-emitting radionuclides, 10 g of sample were heated in a muffle furnace at 500°C for 6 hours to combust organic material. Each sample was then spiked with a radioactive trace and digested in a Teflon beaker with a mixture of nitric, hydrochloric, and hydrofluoric acids. The sample residues were heated with nitric and boric acids to remove hydrofluoric acid. Finally, the residues were dissolved in nitric acid for the measurement of the individual radionuclide concentrations. Multiple precipitation, co-precipitation and ion exchange and/or extraction chromatography procedures were then used to separate and purify the desired elements. The radionuclides of interest were then precipitated with La, deposited onto filters, mounted and counted on the alpha spectrometer for five days. All radiochemical recoveries were 50-95%. Mean minimal detection concentrations (MDCs) observed were 0.014 mBq/g for ^{238}Pu, 0.02 mBq/g for $^{239+240}$Pu and 0.015 mBq/g for ^{241}Am.

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.

RESULTS AND DISCUSSION

^{238}Pu, $^{239+240}$Pu, ^{241}Am and gamma radionuclides ^{40}K, ^{137}Cs and ^{60}Co were analyzed for all the soil samples. The mean concentrations of these radio-nuclides measured in 2009 soil samples are summarized in Table 6-1. Individual concentrations of these radionuclides are presented in Table 6-2. ^{241}Am concentration slightly greater than MDC was detected in 13 samples whereas ^{238}Pu was detected in 11 samples. $^{239+240}$Pu was detected in every soil samples with one exception in which it was not detected. All detected concentration of ^{238}Pu, $^{239+240}$Pu and ^{241}Am were extremely low and were relatively close to the respective MDCs. The maximum $^{239+240}$Pu concentration (0.24 mBq/g) in CEMRC samples was within the range reported by Kenny et al., (1995, *Radionuclide Baseline in Soil Near Project Gnome and the waste Isolation Pilot Plant*, *Environmental Evaluation Group, Carlsbad, New Mexico*) at the WIPP (0.0-0.74 mBq/g). The Gnome Site lies approximately 9 km southwest of the WIPP Site and was contaminated with actinide and fission products in 1961 when an underground detonation of a 3 kilotons ^{239}Pu device vented to the atmosphere. The concentrations of $^{239+240}$Pu, ^{238}Pu, and ^{241}Am in Gnome soil were in the range 0.073-155 mBq/g, 0.016-219 mBq/g and 0.043-346 mBq/g, respectively with an overall mean of 149.0 mBq/g, 28.8 mBq/g and 36.1 mBq/g, respectively (CEMRC Annual Report, 2005/2006).

The mean concentration of $^{239+240}$Pu in 1998 soil samples collected from the Near Field grid were 0.11 mBq/g, which is consistent with the mean value of 0.10 mBq/g measured in 2009 soil samples collected from the same grid. The corresponding values for ^{238}Pu and ^{241} Am were slightly lower in 2009 than in 1998. The mean concentrations of ^{238}Pu, $^{239+240}$Pu and ^{241}Am in 2009 soil samples from the Near Field grid are shown in Figure 6.2.

^{40}K was detected in every sample (Table 6-3). This naturally occurring gamma-emitting radionuclide is ubiquitous in soils. There was no significant difference between concentrations of ^{40}K among sampling locations and the values fell within the range of concentrations previously observed in WIPP soils. ^{137}Cs was detected in all soil samples except one (Table 6-3). Variability among the ^{137}Cs concentrations was not very significant. Although ^{137}Cs is a fission product, it is ubiquitous in soils because of global fallout from atmospheric weapons testing (Beck and Bennett, 2002; and UNSCEAR, 2000). ^{60}Co was not detected at any sampling locations. The average concentration of ^{137}Cs and ^{60}Co observed in 2009 soil samples are shown in Figure 6.3. The concentrations for ^{137}Cs and ^{60}Co fell within the range of values previously measured for the WIPP soil samples. On the other hand, the WIPP ^{137}Cs concentration in the surface soil was significantly lower than the Gnome soil (CEMRC Annual Report, 2005/2006). The maximum concentration of ^{137}Cs for the Gnome samples, 2.89E+03 Bq/kg, was more than 100 times larger than the largest concentration seen in the 2009 WIPP-EM surface soil samples (mean 2.27E+00 Bq/kg).

The mean activity ratio of ^{137}Cs to $^{239+240}$Pu (23.51±0.92) from WIPP samples is significantly lower than the mean ratio (3591.26±1635.70) from Gnome samples (Table 6-4) This ratio strongly suggests that Pu and Cs in the WIPP soils is from world-wide fallout from the testing of nuclear weapons and are typical “background soils”. The mean ratio of ^{238}Pu to $^{239+240}$Pu from the WIPP samples (0.16) are not significantly different than the mean ratio for the Gnome samples (0.14±0.02). In either case the ^{238}Pu/$^{239+240}$Pu ratios for both WIPP and Gnome exceed the global fallout ratio of ~0.061 (Mitchell et al, 1997). This ratio suggests that the fallout in the vicinity of the WIPP is a mixture of global fallout from thermonuclear devices and the local fallout from the above-ground testing at the Nevada Test Site (NTS).

The average concentrations of $^{239+240}$Pu, ^{238}Pu and ^{241}Am around the WIPP site across the years are shown in Figures 6.4-6.7 and the combined average, minimum, and maximum concentrations (Bq/kg) of selected radionuclides for all soil samples collected from the Near Field grid are presented in Table 6-5.

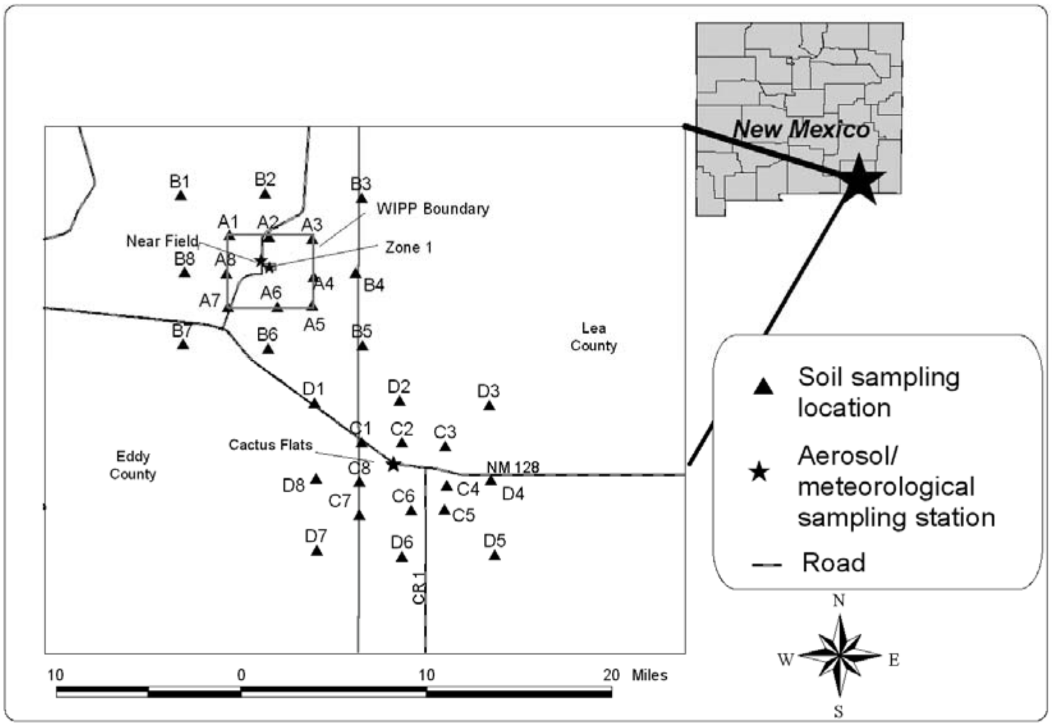


Figure 6.1: Soil Sampling Locations in the Vicinity of the WIPP Site
Also shown are aerosol sampling and meteorological monitoring sites at Near Field and Cactus Flats.

Table 6-1: Summary Statistics for Radionuclides in Soils Collected in 2009

Analyte	Unit	Near Field			
		[a]N	[b]Mean	SD	Range
^{241}Am	Bq/kg	13	3.79E-02	8.53E-03	9.57E-03- 6.84E-02
^{137}Cs	Bq/kg	17	2.39E+00	7.98E-02	4.97E-01 -5.12E+00
^{40}K	Bq/kg	18	2.21E+02	4.50E+00	1.49E+02 -2.89E+02
^{238}Pu	Bq/kg	11	1.50E-02	5.83E-03	5.88E-03 - 3.52E-02
$^{239+240}$Pu	Bq/kg	17	1.02E-02	1.37E-02	2.10E-02 -2.38E-01

[a] N = number of samples > MDC
[b] Mean = arithmetic mean

Table 6-2: Americium and Plutonium Concentrations in Soils near the WIPP site

Analyte	Grid Node	Activity (Bq/kg)	SD (Bq/kg)	MDC (Bq/kg)
^{241}Am	A-1	4.12E-02	8.57E-03	4.37E-03
	A-2	2.79E-02	9.38E-03	2.61E-02
	A-3	1.18E-02	8.18E-03	2.69E-02
	A-4	6.92E-03	6.33E-03	2.03E-02
	A-5	2.88E-02	6.55E-03	3.54E-03
	A-5	3.60E-02	8.34E-03	1.44E-02
	A-6	6.76E-03	6.23E-03	2.15E-02
	A-7	1.35E-02	7.60E-03	2.23E-02
	A-8	4.34E-02	1.02E-02	1.81E-02
	B-1	2.74E-02	6.83E-03	4.03E-03
	B-2	2.44E-02	8.21E-03	1.79E-02
	B-3	6.69E-02	1.01E-02	3.81E-03
	B-4	4.83E-02	1.06E-02	2.14E-02
	B-4	6.84E-02	1.08E-02	1.16E-02
	B-5	2.36E-02	7.97E-03	1.51E-02
	B-6	3.28E-03	5.33E-03	1.81E-02
	B-7	9.57E-03	4.49E-03	4.05E-03
	B-8	4.66E-02	8.89E-03	1.09E-02
^{238}Pu	A-1	1.41E-01	5.73E-02	5.46E-02
	A-2	4.46E-02	2.98E-02	4.02E-02
	A-3	6.16E-02	4.11E-02	5.56E-02
	A-4	6.75E-02	3.78E-02	4.57E-02
	A-5	1.20E-01	4.49E-02	4.04E-02
	A-5	-1.14E-01	5.98E-02	4.98E-01
	A-6	1.15E-01	5.65E-02	6.24E-02
	A-7	2.90E-01	8.24E-02	2.06E-01
	A-8	-4.38E-02	3.87E-02	1.92E-01
	B-1	1.18E-02	2.63E-02	1.09E-01
	B-2	7.32E-02	3.46E-02	9.68E-02
	B-3	1.46E-01	5.91E-02	5.65E-02
	B-4	1.94E-01	5.23E-02	5.37E-02
	B-4	8.61E-02	3.80E-02	3.88E-02
	B-5	4.84E-02	3.61E-02	1.19E-01
	B-6	6.35E-02	3.41E-02	9.64E-02
	B-7	8.09E-02	4.34E-02	1.23E-01
	B-8	1.34E-01	4.17E-02	8.20E-02
$^{239+240}$Pu	A-1	1.28E-01	1.84E-02	3.05E-02
	A-2	1.06E-01	1.52E-02	2.11E-02
	A-3	5.63E-02	1.09E-02	1.84E-02
	A-4	7.05E-02	1.13E-02	4.65E-03
	A-5	7.49E-02	1.34E-02	4.68E-02
	A-5	1.29E-01	1.65E-02	5.44E-03
	A-6	2.10E-02	7.43E-03	1.88E-02
	A-7	9.71E-02	1.51E-02	2.94E-02
	A-8	1.15E-01	1.31E-02	3.98E-03
	B-1	9.00E-02	1.17E-02	1.53E-02
	B-2	6.06E-02	1.02E-02	1.90E-02
	B-3	2.38E-01	1.98E-02	1.66E-02
	B-4	1.31E-01	1.55E-02	1.29E-02
	B-4	1.54E-01	1.59E-02	1.16E-02
	B-5	6.57E-02	1.32E-02	2.36E-02
	B-6	1.11E-02	8.31E-03	2.81E-02
	B-7	5.80E-02	1.10E-02	5.32E-03
	B-8	1.33E-01	1.38E-02	1.02E-02

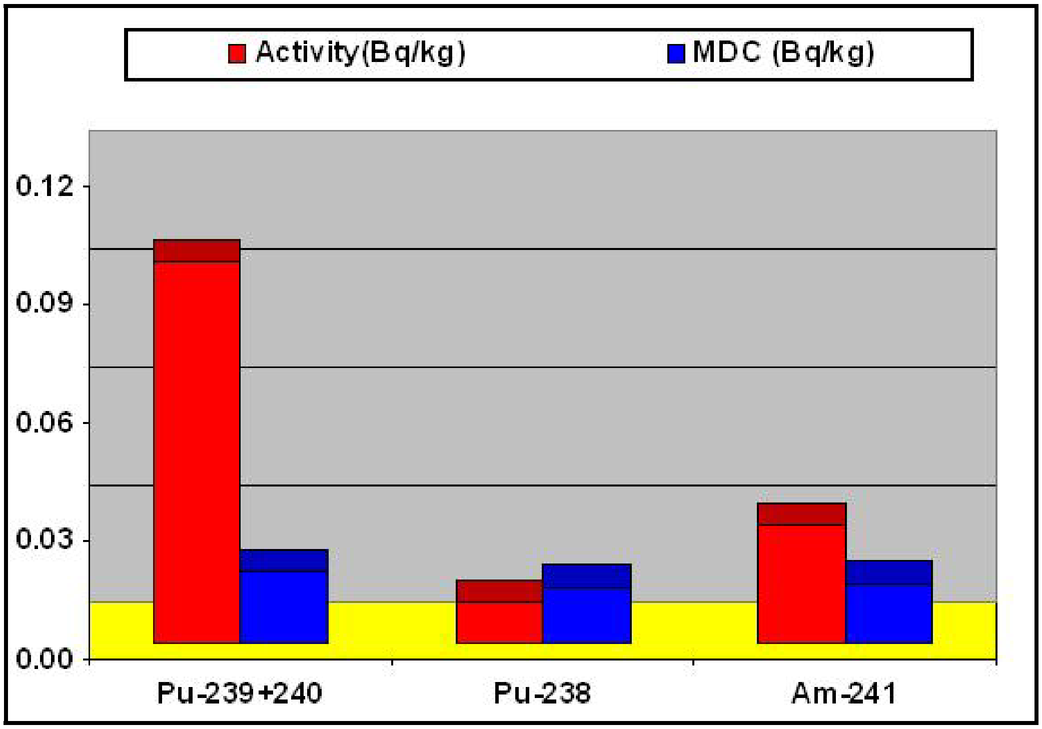


Figure 6.2: Average Concentrations of ^{238}Pu, $^{239+240}$Pu and ^{241}Am in Near Field Soil in 2009

Table 6-3: Selected Radionuclide Activity Concentrations in Soils near the WIPP site

	Grid Node	Activity (Bq/kg)	SD (Bq/kg)	MDC (Bq/kg)
^{137}Cs	A-1	3.45E+00	9.52E-02	2.23E-01
	A-2	2.62E+00	7.48E-02	1.77E-01
	A-3	1.72E+00	6.94E-02	1.87E-01
	A-4	1.05E+00	6.20E-02	1.82E-01
	A-5	2.02E+00	6.91E-02	1.77E-01
	A-5	3.73E+00	9.86E-02	2.23E-01
	A-6	4.97E-01	6.72E-02	2.13E-01
	A-7	2.43E+00	7.25E-02	1.74E-01
	A-8	2.80E+00	8.39E-02	2.07E-01
	B-1	2.09E+00	7.71E-02	2.06E-01
	B-2	1.66E+00	7.67E-02	2.14E-01
	B-3	5.12E+00	1.04E-01	1.90E-01
	B-4	3.33E+00	9.87E-02	2.43E-01
	B-4	3.56E+00	8.90E-02	2.02E-01
	B-5	1.33E+00	6.84E-02	1.95E-01
	B-6	1.91E-01	6.89E-02	2.25E-01
	B-7	7.96E-01	7.07E-02	2.17E-01
	B-8	2.48E+00	7.91E-02	1.98E-01
^{40}K	A-1	2.68E+02	5.40E+00	2.05E+00
	A-2	1.89E+02	3.85E+00	1.96E+00
	A-3	1.82E+02	3.76E+00	2.09E+00
	A-4	1.71E+02	3.53E+00	1.97E+00
	A-5	1.87E+02	3.82E+00	1.93E+00
	A-5	2.30E+02	4.70E+00	2.07E+00
	A-6	2.20E+02	4.49E+00	1.88E+00
	A-7	1.79E+02	3.68E+00	2.01E+00
	A-8	2.66E+02	5.34E+00	2.46E+00
	B-1	2.64E+02	5.29E+00	2.20E+00
	B-2	2.16E+02	4.43E+00	2.02E+00
	B-3	2.25E+02	4.54E+00	2.04E+00
	B-4	2.89E+02	5.81E+00	2.25E+00
	B-4	2.55E+02	5.09E+00	2.06E+00
	B-5	1.49E+02	3.14E+00	1.77E+00
	B-6	2.08E+02	4.31E+00	2.03E+00
	B-7	2.42E+02	4.91E+00	2.12E+00
	B-8	2.39E+02	4.82E+00	2.16E+00
^{60}Co	A-1	-4.51E-02	5.46E-02	2.41E-01
	A-2	1.03E-01	4.04E-02	1.72E-01
	A-3	1.08E-01	4.38E-02	1.87E-01
	A-4	1.15E-01	4.05E-02	1.70E-01
	A-5	1.25E-02	4.04E-02	1.72E-01
	A-5	-9.08E-03	5.16E-02	2.20E-01
	A-6	-4.49E-02	4.95E-02	2.17E-01
	A-7	6.89E-03	4.15E-02	1.80E-01
	A-8	9.72E-02	5.11E-02	2.13E-01
	B-1	3.74E-02	4.66E-02	1.95E-01
	B-2	7.55E-02	4.94E-02	2.11E-01
	B-3	2.03E-02	4.40E-02	1.89E-01
	B-4	-1.90E-02	5.61E-02	2.41E-01
	B-4	1.29E-02	4.62E-02	2.01E-01
	B-5	-4.67E-03	4.46E-02	1.95E-01
	B-6	-4.88E-02	5.38E-02	2.36E-01
	B-7	4.87E-02	5.14E-02	2.20E-01
	B-8	4.04E-02	4.63E-02	2.01E-01

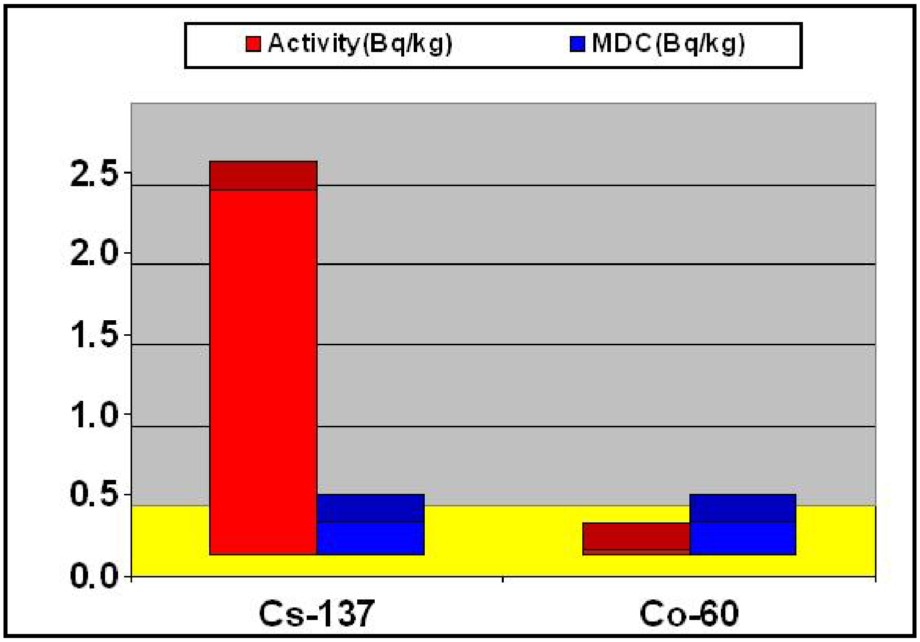


Figure 6.3: Average Concentrations of ^{137}Cs and ^{60}Co in Near Field Soil in 2009

Table 6-4: Ratios of ^{137}Cs and ^{238}Pu to $^{239+240}$Pu in WIPP Samples in Comparison to Mean Values for Gnome Soils

Sample ID	Grid	^{137}Cs/$^{239+240}$Pu	^{238}Pu/$^{239+240}$Pu
23870	A-1	27.04	0.12
23867	A-2	24.80	0.06
23868	A-3	30.55	0.13
23863	A-4	14.87	0.14
23861	A-5	26.97	<MDC
23862	A-5	28.99	0.13
23866	A-6	23.69	0.58
23865	A-7	25.00	0.36
23856	A-8	24.43	<MDC
23853	B-1	23.24	<MDC
23854	B-2	27.37	<MDC
23857	B-3	21.50	0.06
23858	B-4	25.41	0.08
23859	B-4	23.08	0.14
23860	B-5	20.23	<MDC
23864	B-6	<MDC	<MDC
23869	B-7	13.73	<MDC
23855	B-8	18.73	0.13
WIPP	Mean	23.51	0.17
	Standard Error	0.92	0.05
	n	17	10
Gnome	Mean	3591.26	0.14
	Standard Error	1635.70	0.025
	n	11	8

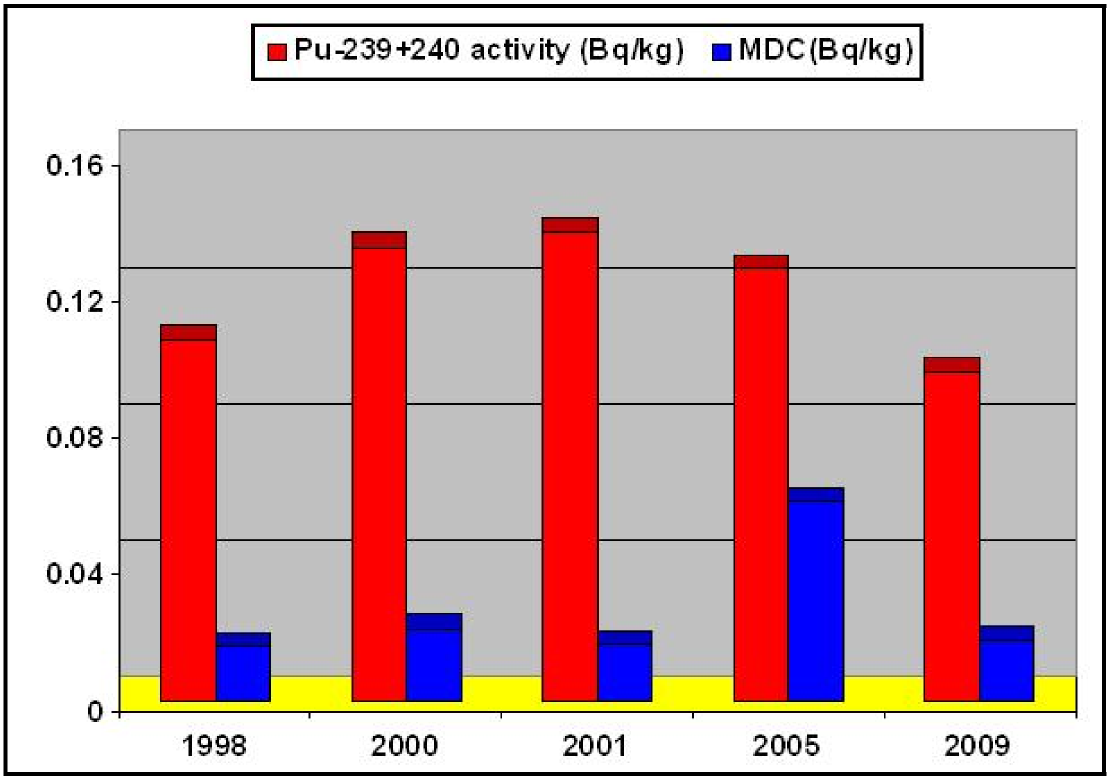


Figure 6.4: Average Activity Concentrations of $^{239+240}$Pu in WIPP Soil from 1998-2009

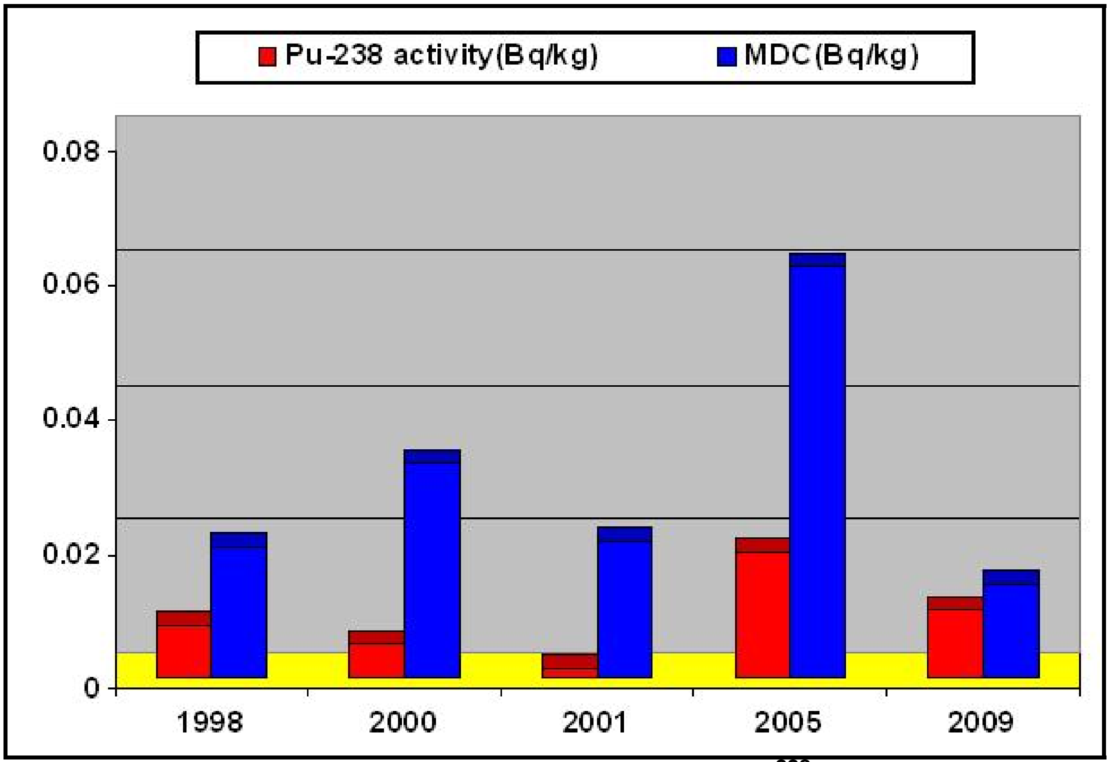


Figure 6.5: Average Activity Concentrations of ^{238}Pu in WIPP Soil from 1998-2009

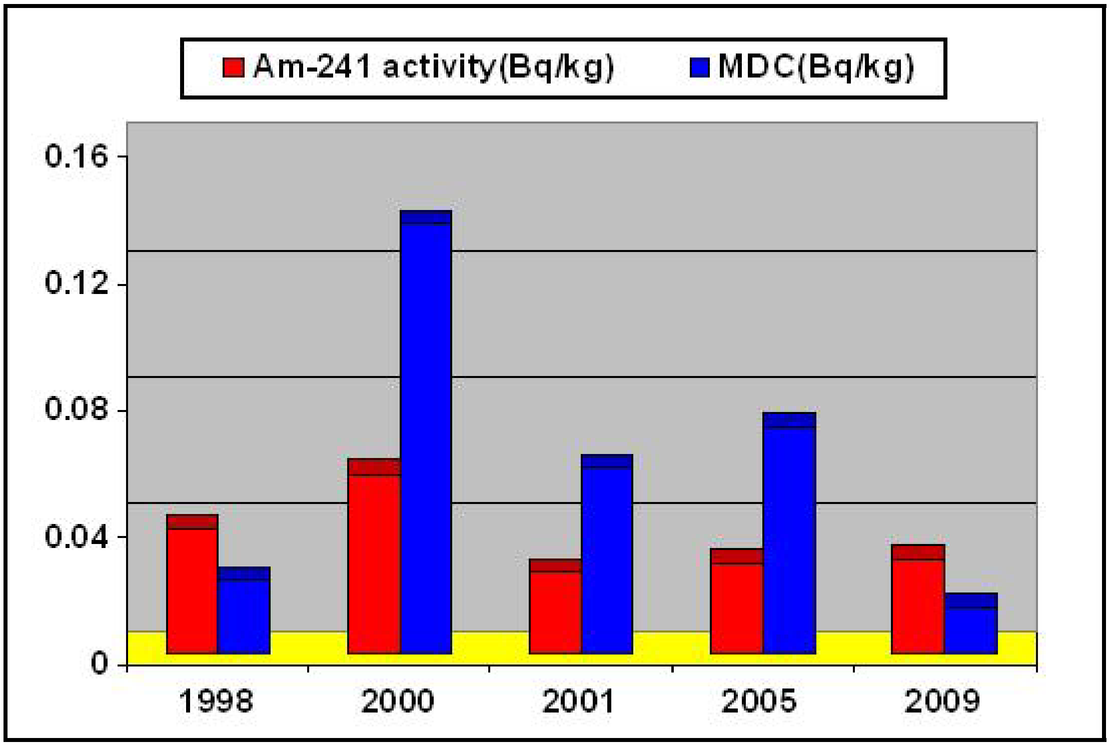


Figure 6.6: Average Activity Concentrations of ^{241}Am in WIPP Soil from 1998-2009

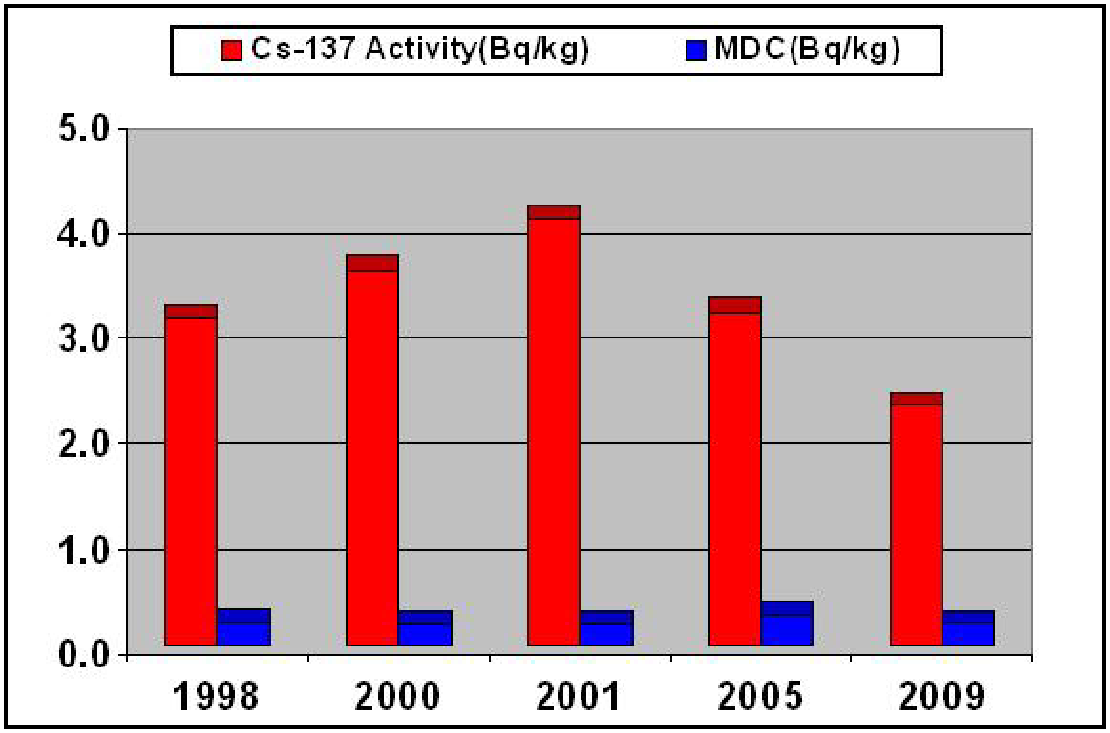


Figure 6.7 Average Activity Concentrations of ^{137}Cs in WIPP Soil from 1998-2009

Table 6-5: Maximum, Minimum and Mean Concentrations of Radionuclides in Soils from 1998-2005 in the Near Fields Grid

Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
A1	^{241}Am	5.31E-02	1.08E-02	1.77E-02	1.43E-02	9.37E-02
	$^{239+240}$Pu	1.40E-01	1.72E-02	2.55E-02	6.64E-02	3.89E-01
	^{238}Pu	1.62E-02	6.93E-03	1.22E-02	1.62E-02	1.62E-02
	^{137}Cs	4.10E+00	1.23E-01	2.12E-01	1.79E+00	6.88E+00
	^{40}K	2.51E+02	4.30E+00	3.49E+00	2.13E+02	2.83E+02
A2	^{241}Am	3.41E-02	8.81E-03	1.76E-02	2.20E-02	4.28E-02
	$^{239+240}$Pu	9.63E-02	1.23E-02	1.59E-02	5.21E-02	1.41E-01
	^{238}Pu	7.37E-03	7.84E-03	2.67E-02	2.36E-03	1.36E-02
	^{137}Cs	2.22E+00	6.49E-02	1.89E-01	9.46E-01	4.00E+00
	^{40}K	1.99E+02	3.62E+00	3.42E+00	1.80E+02	2.27E+02
A3	^{241}Am	3.85E-02	9.19E-03	1.73E-02	2.31E-02	5.30E-02
	$^{239+240}$Pu	1.25E-01	1.52E-02	1.86E-02	7.19E-02	1.92E-01
	^{238}Pu	4.33E-03	7.29E-03	2.49E-02	-5.05E-04	1.17E-02
	^{137}Cs	3.41E+00	3.31E-01	2.18E-01	2.13E+00	4.39E+00
	^{40}K	1.81E+02	3.35E+00	3.15E+00	1.73E+02	1.91E+02
A4	^{241}Am	3.74E-02	8.30E-03	1.52E-02	2.28E-02	5.04E-02
	$^{239+240}$Pu	7.27E-02	9.97E-03	1.68E-02	1.45E-02	9.84E-02
	^{238}Pu	5.27E-03	6.24E-03	2.27E-02	-2.57E-03	1.16E-02
	^{137}Cs	2.57E+00	7.67E-02	1.95E-01	4.29E-01	3.98E+00
	^{40}K	2.05E+02	3.65E+00	3.23E+00	1.94E+02	2.30E+02
A5	^{241}Am	3.72E-02	8.09E-03	1.50E-02	1.84E-02	5.89E-02
	$^{239+240}$Pu	9.92E-02	1.36E-02	1.78E-02	7.33E-02	1.31E-01
	^{238}Pu	5.56E-03	7.82E-03	2.53E-02	-2.51E-03	1.76E-02
	^{137}Cs	2.36E+00	8.42E-02	2.20E-01	5.41E-01	3.55E+00
	^{40}K	1.86E+02	3.44E+00	3.30E+00	1.61E+02	2.04E+02
A6	^{241}Am	3.67E-02	1.07E-02	2.09E-02	3.67E-02	3.67E-02
	$^{239+240}$Pu	4.37E-02	9.02E-03	1.34E-02	3.70E-02	5.23E-02
	^{238}Pu	3.34E-03	6.62E-03	2.11E-02	-3.04E-03	1.01E-02
	^{137}Cs	7.19E-01	1.40E-01	1.99E-01	2.97E-01	1.10E+00
	^{40}K	1.94E+02	3.58E+00	3.35E+00	1.85E+02	2.06E+02
A7	^{241}Am	3.05E-02	7.20E-03	1.37E-02	2.20E-02	4.48E-02
	$^{239+240}$Pu	6.27E-02	1.01E-02	1.78E-02	1.86E-02	1.10E-01
	^{238}Pu	1.03E-03	8.43E-03	3.14E-02	-1.28E-02	8.17E-03
	^{137}Cs	2.38E+00	9.89E-02	2.21E-01	6.11E-01	3.32E+00
	^{40}K	2.08E+02	3.76E+00	3.33E+00	1.89E+02	2.50E+02
A8	^{241}Am	6.05E-02	1.09E-02	1.78E-02	4.12E-02	8.45E-02
	$^{239+240}$Pu	1.88E-01	1.83E-02	2.01E-02	7.18E-02	2.59E-01
	^{238}Pu	1.60E-02	6.91E-03	1.44E-02	1.55E-02	1.65E-02
	^{137}Cs	5.29E+00	1.28E-01	2.47E-01	3.17E+00	7.49E+00
	^{40}K	2.84E+02	4.87E+00	3.80E+00	2.27E+02	3.66E+02

Table 6-5: Maximum, Minimum and Mean Concentrations of Radionuclides in Soils from 1998-2005 in the Near Fields Grid (continued)

Grid Node	Nuclide	Mean Activity (Bq/kg)	Mean Uncertainty (Bq/kg)	Mean MDC (Bq/kg)	Minimum Activity (Bq/kg)	Maximum Activity (Bq/kg)
B1	^{241}Am	4.53E-02	8.56E-03	1.62E-02	3.29E-02	5.97E-02
	$^{239+240}$Pu	1.42E-01	1.59E-02	1.89E-02	1.10E-01	1.67E-01
	^{238}Pu	5.56E-03	7.15E-03	2.28E-02	-6.72E-03	1.23E-02
	^{137}Cs	3.87E+00	1.04E-01	2.45E-01	1.63E+00	5.25E+00
	^{40}K	2.72E+02	4.69E+00	3.24E+00	2.47E+02	3.21E+02
B2	^{241}Am	4.26E-02	1.02E-02	1.91E-02	2.64E-02	6.44E-02
	$^{239+240}$Pu	1.39E-01	1.66E-02	3.14E-02	5.45E-02	2.14E-01
	^{238}Pu	1.84E-02	7.30E-03	1.52E-02	1.84E-02	1.84E-02
	^{137}Cs	4.28E+00	1.24E-01	2.44E-01	1.88E+00	5.96E+00
	^{40}K	2.46E+02	4.32E+00	3.44E+00	1.95E+02	2.97E+02
B3	^{241}Am	6.33E-02	1.07E-02	1.60E-02	4.37E-02	9.73E-02
	$^{239+240}$Pu	1.77E-01	1.75E-02	2.14E-02	1.42E-01	3.14E-01
	^{238}Pu	6.41E-02	1.07E-02	5.48E-02	6.41E-02	6.41E-02
	^{137}Cs	5.80E+00	1.20E-01	2.23E-01	4.28E+00	8.83E+00
	^{40}K	2.52E+02	4.37E+00	3.50E+00	2.32E+02	2.71E+02
B4	^{241}Am	5.67E-02	8.98E-03	1.46E-02	1.94E-02	1.02E-01
	$^{239+240}$Pu	1.54E-01	1.60E-02	1.89E-02	1.08E-01	2.52E-01
	^{238}Pu	3.39E-03	7.35E-03	2.42E-02	-1.57E-03	5.56E-03
	^{137}Cs	4.65E+00	1.01E-01	2.17E-01	2.67E+00	8.45E+00
	^{40}K	2.38E+02	4.13E+00	3.16E+00	2.05E+02	2.64E+02
B5	^{241}Am	6.32E-02	1.13E-02	1.84E-02	1.29E-02	1.27E-01
	$^{239+240}$Pu	9.93E-02	1.27E-02	1.79E-02	6.43E-02	1.38E-01
	^{238}Pu	4.02E-03	6.09E-03	1.93E-02	-3.19E-03	8.43E-03
	^{137}Cs	3.52E+00	7.95E-02	2.23E-01	2.29E+00	4.88E+00
	^{40}K	1.64E+02	3.17E+00	3.41E+00	1.41E+02	1.97E+02
B6	^{241}Am	2.53E-02	6.36E-03	1.24E-02	1.54E-02	3.51E-02
	$^{239+240}$Pu	5.54E-02	8.66E-03	1.19E-02	1.94E-02	1.54E-01
	^{238}Pu	9.68E-04	2.73E-03	1.79E-02	-1.40E-03	3.76E-03
	^{137}Cs	2.32E+00	4.88E-01	2.24E-01	3.13E-01	5.22E+00
	^{40}K	1.70E+02	3.22E+00	3.30E+00	1.45E+02	1.88E+02
B7	^{241}Am	3.80E-02	7.90E-03	1.49E-02	1.70E-02	6.37E-02
	$^{239+240}$Pu	7.61E-02	1.08E-02	1.64E-02	3.72E-02	1.46E-01
	^{238}Pu	3.73E-03	6.29E-03	2.05E-02	-6.86E-03	1.36E-02
	^{137}Cs	2.76E+00	8.21E-02	2.04E-01	7.96E-01	5.82E+00
	^{40}K	2.07E+02	3.72E+00	3.11E+00	1.62E+02	2.34E+02
B8	^{241}Am	5.13E-02	1.00E-02	1.72E-02	3.32E-02	6.90E-02
	$^{239+240}$Pu	1.68E-01	1.85E-02	2.48E-02	1.03E-01	2.29E-01
	^{238}Pu	6.58E-02	1.72E-02	3.64E-02	6.26E-02	6.91E-02
	^{137}Cs	4.57E+00	1.28E-01	2.33E-01	2.90E+00	5.95E+00
	^{40}K	2.37E+02	4.17E+00	3.42E+00	1.98E+02	2.94E+02

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 in exchange 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). The grant funding was increased in 2007 to $1.84M and WTS funding was increased to accommodate new VOC analyses. LES NEF in Eunice began developing a program with CEMRC which was implemented in 2008. Dr. Conca still holds the Director position as of December 2009.

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. A new sector-field mass spectrometry laboratory for uranium analysis was completed at CEMRC in 2008. Replacement of major portions of the facility began in 2008 and will continue to 2011, including replacement of the roof, major detectors, the phone system, upgrade of the electrical system and ventilation system, and upgrade of the Radioactive Materials License to accommodate higher activities.

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.

Appendix B: Recent Publications

Author	Title	Publisher/Conference
J. Conca	Developing Safe and Sustainable Energy	*International Innovation Magazine*, J. Dallison (editor), August edition, United Kingdom, ISSN 2041-4552, p. 19 – 21, 2009
R. R. Parra, V. F. Medina, and **J. L. Conca**	The use of fixatives for response to a radiation dispersal devise attack – a review of the current state-of-the-art	*Journal of Environmental Radioactivity*, vol. 100, p. 923 - 934. 2009
J. Conca and J. Wright	A Single Global Nuclear Repository	*Proceedings of the 2009 Waste Management Symposia,* Phoenix, AZ, paper #9085, p. 1-9. http://www.wmsym.org. http://www.wmsym.org/index.php?option=com_content&view=article&id=138&Itemid=112. 2009
J. Wright, and **J. L. Conca**	The GeoPolitics of Energy: Engaging the Public and Policymakers	*Proceedings of the 2009 Waste Management Symposia,* Phoen AZ paper #9557, p. 1-10. http://www.wmsym.org/index.ph option=com_content&view=arti id=138&Itemid=112. 2008
P. Thakur, J. L. Conca, L. J. Van de Burgt and G. R. Choppin	Complexation and the Laser Luminescence Study of Eu(III), Am(III) and Cm(III) with EDTA, CDTA and PDTA and their Ternary Complexation with Dicarboxylates	*Journal of Coordination Chemistry,* Vol. 62, No. 23, p. 3719–3737. 2009
John E. Stout and **Richard Arimoto**	Threshold wind velocities for sand movement in the Mescalero Sands of southeastern New Mexico	Journal of Arid Environments, Elsevier Ltd. London, p. 1-5 doi:10.1016/j.jaridenv.2010.05.011. 2010

Appendix C: Tours, Public Presentations and Other Outreach

Group/Activity
CEMRC hosted the State MESA schools science program for developing energy curricula in public schools, June 2009
CEMRC worked with local Carlsbad high school science teachers and students in 2009 to obtain science teaching grants
CEMRC participated in the annual Relay For Life
CEMRC participated in the annual Riverblitz
2009 Conca – gave seminars to five classes at NMSU Las Cruces, four at NMSU Carlsbad branch, five to Carlsbad high school and middle school classes – many CEMRC tours and presentations
2009 host of the monthly American Nuclear Society section meetings
P. Thakur, J. L. Conca and G.R. Choppin. September 2009. Complexation Thermodynamics and the Structure of the Binary Complexes of Trivalent Actinide and Lanthanide Cations by DTPA, MS-325 and HMDTPA and their Ternary Complexes with Oxalic Acid. Migration 09, Kennewick, Washington
P. Thakur, J. Monk and J.L. Conca. October 2009. Environmental Monitoring of the Nuclear Waste Repository- Advances and the Challenges. New Mexico State University Research Fair, Las Cruces, New Mexico
P. Thakur, T. Kirchner, J. Monk and J.L. Conca, M. Akbarzadeh. October 2009. Overview of WIPP Environmental Monitoring Program. 55th Radiobioassay and Radiochemical Measurements Conference, San Antonio, Texas
P. Thakur, J. L. Conca and G.R. Choppin. November 2009. EDTA and Mixed – Ligands Complexes of Trivalent and Tetravalent Actinides High Ionic Strength. ACS Southwest Regional Meeting, El Paso, Texas
P. Thakur, T. Kirchner, J. Monk, M. Akbarzadeh and J.L Conca. November - December 2009. Environmental Monitoring of Radioactive and Non-radioactive constituents in the vicinity of WIPP- A CEMRC Perspective. Asia Pacific Symposium on Radiochemistry Chemistry (APSORC)-NAPA

Appendix D: Students/Visiting Scientists supported at CEMRC 2009

Student/Scientist	Support Period
Students (9) – Illinois Institute of Tech	Summer 2009 Radiation Physics 770 at ITT
Dr. Jeff Terry, Illinois Institute of Tech	Summer 2009 training
Dr. Geof Smith, NMSU Las Cruces	Visiting Professor 2009
Diana Norden, Campbell University	Undergraduate student
Dan Olive, Illinois Institute of Tech	Post-doctoral Research Associate 2009

Appendix E: Radioactive and Non-Radioactive Nuclides Monitored at WIPP

Radionuclide	Radiation	Detection Method	Reason for Monitoring
^{234}U	Alpha	Alpha spectroscopy	Naturally occurring
^{235}U	Alpha	Alpha spectroscopy	Naturally occurring
^{238}U	Alpha	Alpha spectroscopy	Naturally occurring
^{40}K	Gamma	Gamma spectroscopy	Ubiquitous in nature
^{238}Pu	Alpha	Alpha spectroscopy	Component of waste
$^{239+240}Pu$	Alpha	Alpha spectroscopy	Component of waste
^{241}Am	Alpha	Alpha spectroscopy	Component of waste
^{137}Cs	Gamma	Gamma spectroscopy	Fission product/potential component of waste
^{60}Co	Gamma	Gamma spectroscopy	Fission product/potential component of waste
Non-Radioactive nuclides			
Elemental Analysis Total number of elements 36	-	ICP-MS	Some of the elements are present in mixed waste
SO_4^{2-}	-	Ion chromatography	Present in drinking water
CO_3^-,	-	Ion chromatography	Present in drinking water
CO_2^-,	-	Ion chromatography	Present in drinking water
Cl^-	-	Ion chromatography	Present in drinking water
Br^-	-	Ion chromatography	Present in drinking water
PO_4^{3-}	-	Ion chromatography	Present in drinking water
NH^{4+}	-	Ion chromatography	Present in drinking water
K^+	-	Ion chromatography	Present in drinking water
Li^+	-	Ion chromatography	Present in drinking water
Na^+	-	Ion chromatography	Present in drinking water
Mg^{2+}	-	Ion chromatography	Present in drinking water
Ca^{2+}	-	Ion chromatography	Present in drinking water

The radionuclides ^{243}Am, ^{242}Pu, and ^{232}U are used as tracers in the CEMRC, Radiochemistry Laboratory.

Radionuclides are considered "detected" in a sample if the measured concentration or activity is greater than the total propagated uncertainty (SD) at the 2 sigma (2 × SD) level, and greater than the minimum detectable concentration (MDC). The MDC is determined by the analytical laboratories based on the natural background radiation, the analytical technique, and inherent characteristics of the analytical equipment. The MDC represents the minimum concentration of a radionuclide detectable in a given sample using the given equipment and techniques with a specific statistical confidence (usually 95 percent). The SD is an estimate of the uncertainty in the measurement due to all sources, including counting error, measurement error, chemical recovery error, detector efficiency, randomness of radioactive decay, and any other sources of uncertainty. Measurements of radioactivity are actually probabilities due to the random nature of the disintegration process. A sample is decaying as it is being measured, so no finite value can be assigned. Instead, the ranges of possible activities are reported by incorporating the SDs of the method.

Appendix F: Performance Tests and Audits

Below are summaries of external and internal (Table F-1) audits, and results for three performance tests; one for Whole Body Dosimetry (Table F-2, Table F-3, and Figure F.1), one for ICP-MS (Figure F.2), and two for radiochemical analyses (Tables F-4 and F-6). Table F-5 shows two examples of the daily performance tests for ICP-MS. Figure F.2 shows that all analytes run were acceptable within 10% of the assigned value. In addition, daily QA/QC checks using NIST-traceable must show acceptable within 5% before work can begin (Table F-5).

Table F-4 shows MAPEP results for three matrices; soil, water, and air filters. Specific selected analytes are tested each year and may be different for each matrix and between years. A value in the Result column means that analyte was tested for. Ref Values are the nominally correct answer and the Acceptance Range gives the range of values that are acceptable. Only one analysis result, which was for $^{239+240}$Pu in the soil matrix, did not meet the acceptance criteria. This is mainly because of a long counting time which significantly lowered the detection limits, and CEMRC always detects small amounts of $^{239+240}$Pu in the MAPEP samples which are reported by MAPEP and others ast <MDC.

Table F-6 shows NIST results for the glass-fiber filters. All NIST bias results met the acceptance criteria for all radionuclides of interest at the WIPP site. Ovreall, the difference form the NIST values observed for the test nuclides are ≤ 10%.

CEMRC Management Assessment Quality Assurance Report

December 20, 2008 – December 31, 2009

This report serves as a periodic review 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, vendor qualification, external audits, internal assessments and nonconformance/non-routine events from December 20, 2008 through December 31, 2009.

Currently, there are 68 active procedures under the CEMRC Controlled Document Program. These procedures are scheduled for review every two years. Thirty-one vendors are currently qualified.

External audits were conducted during the past year on two CEMRC programmatic areas: Organic Chemistry and Internal Dosimetry. In May 2009, Washington TRU Solutions (WTS) audited the Volatile Organic Compound Monitoring Program (Organic Chemistry), which was followed in July by an audit of the In Vivo Radiobioassay Program (Internal Dosimetry). The audits led to recertification of each program with one condition closed during audit and three observations for the Volatile Organic Compound Monitoring Program audit (E09-06), and one observation for the In Vivo Radiobioassay Program audit (E09-10). From this quality assurance perspective both programs continue to demonstrate sound performance.

In addition to the WTS audits cited above, internal audits or surveillances were conducted on three CEMRC programmatic areas in 2009. A summary of the internal audit findings is presented in Table F-1, none of which significantly impacted CEMRC activities.[1] The surveillances will be used as a guideline to address areas that need improvement.

Twenty-eight non-routine events (NREs) and no nonconformances (NCRs) were recorded for most recent assessment. All NREs have been closed with the exception of one (NRE 101409OC09), which is to be closed with the next issuance of the related procedures. As with the previous annual assessment, none of the incidents involved implementation of a center-wide procedure. It should also be noted that NREs, per se, do not necessarily indicate a weakness in any particular programmatic area, but rather may reflect a more robust corrective action program, which benefits Center activities.

In conclusion, the Quality Assurance Program at CEMRC continues to be effectively implemented as demonstrated by the recertification of Center programs and the absence of any serious conditions encountered during internal audits. CEMRC continues to be challenged by limited resources and turnover in personnel, which emphasizes the need for effective planning and execution of QA duties. It is the goal of the current QA Manager to fulfill this need.

[1] Consequences identified as Grade A (High Impact) or Grade B (Moderate Impact)--as stated in Appendix 13.2 of current revision of CP-PROC-012 (*Nonconformances and Non-Routine Events*).

Table F-1: Internal Audit Summaries 2009 (# of Findings)

Aspect/Programmatic Area	AD	RC	OC	EC	FP	IM	ID
Personnel Qualification & Training	NF	NA	NA	NA	NA	NF	1
Quality Improvement	NF	NA	NA	NA	NA	NF	NF
Document Control	NF	NA	NA	NA	NA	NF	NF
QA Records	1	NA	NA	NA	NA	1	NF
Procurement	NF	NA	NA	NA	NA	NF	NF
Work Processes	3	NA	NA	NA	NA	NF	NF
Audits/Assessments	NF	NA	NA	NA	NA	NF	NF
Sample Control	NF	NA	NA	NA	NA	NF	NF
Scientific Investigations	NF	NA	NA	NA	NA	NF	NF
Scientific Notebooks	NF	NA	NA	NA	NA	NF	NF
Procedure Violation	1	NA	NA	NA	NA	NF	1

Table Guide

Programmatic Area
AD = Administrative
DC = Document Control
EC = Environmental Chemistry
FP = Field Programs
ID = Internal Dosimetry (also referred as RB for Radiobioassay)
IM = Informatics & Modeling
OC = Organic Chemistry
QA = Quality Assurance
RC = Radiochemistry

Table Results
NF = No Findings
NA = Internal audit not performed in this period

Table F-2: Blind Check Study for Internal Dosimetry 2009 by the ORNL Intercomparison Studies In-vivo Program

Oak Ridge National Laboratory

Intercomparison Studies In-vivo Program Report

1st Quarter Calendar Year 2009

Carlsbad Environmental Monitoring & Research Center

Set F

ISOTOPE	SPIKE ACTIVITY As Of 3-26-09 +/- 2 sigma (nCi)	REPORTED ACTIVITY As Of 3-26-09 +/- 2 sigma (nCi)	% RELATIVE BIAS
Cs-137	73.4 +/- 3.67	73.77 +/- 3.69	1.1
Co-60	178.54 +/- 8.93	178.34 +/- 8.92	0.7
Co-57	229.11 +/- 11.46	233.10 +/- 11.65	4.3
Y-88	31.03 +/- 1.55	31.14 +/- 1.56	1.8
Ba-133	236.91 +/- 11.85	239.22 +/- 11.96	2.5

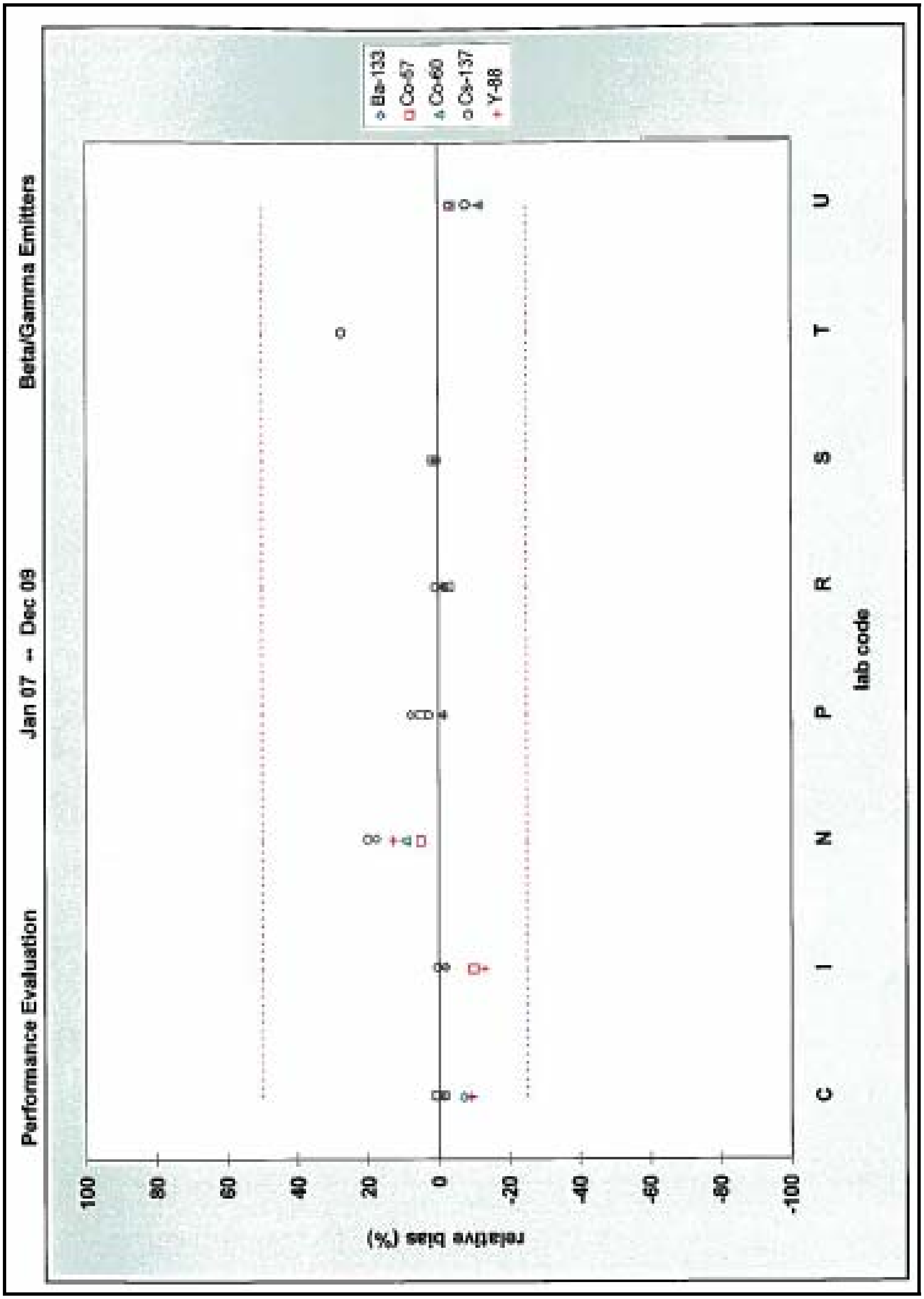
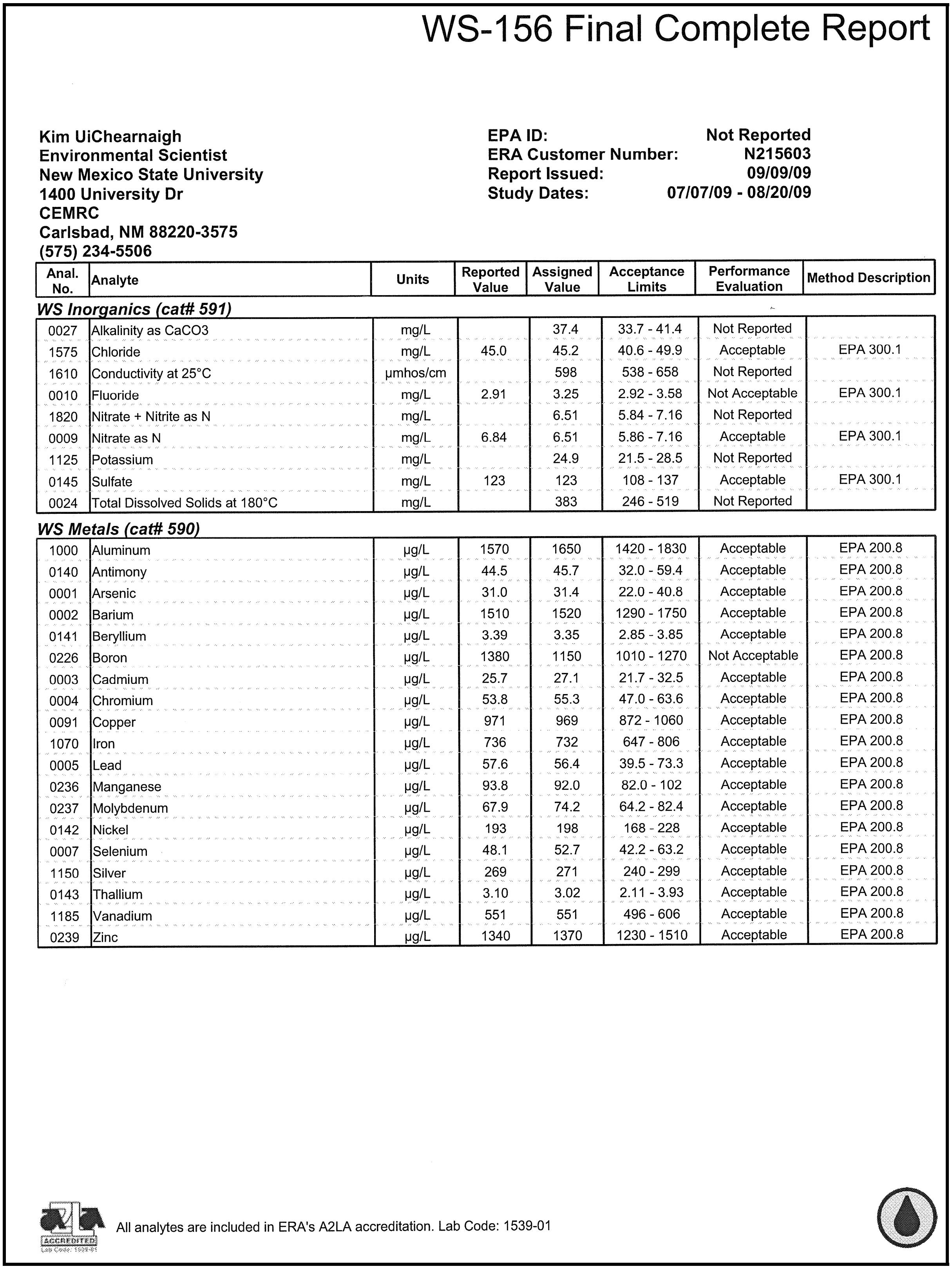


Figure F.1: Comparison of Results for Ten Internal Dosimetry Laboratories in the U.S. During 2009 by the ORNL Intercomparison Studies In-vivo Program
CEMRC is Lab S. For all years that CEMRC has participated in the ORNL program, CEMRC has consistently performed better than all other labs in this area.

Table F-3: Quality Assurance/Quality Control for Internal Dosimetry 2009 Audits

Agency	Date	Conclusion	Reason
DOELAP	8/4/09-8/6/09		
Oak Ridge National Lab, Intercomparison Studies Program	Quarterly	Pass	External QC
WCS	7/27/09	No findings, 1 observation, 2 noteworthy practices, 3 recommendations. Pass	Annual
WTS	7/28/09-7/29/09	No findings, 1 observation. Pass	Annual
CEMRC Self Assessment	5/27/09-5/28/09	2 findings and 1 observation. Pass	Quality System



WS-156 Final Complete Report

Kim UiChearnaigh
Environmental Scientist
New Mexico State University
1400 University Dr
CEMRC
Carlsbad, NM 88220-3575
(575) 234-5506

EPA ID: Not Reported
ERA Customer Number: N215603
Report Issued: 09/09/09
Study Dates: 07/07/09 - 08/20/09

WS Inorganics (cat# 591)

Anal. No.	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Performance Evaluation	Method Description
0027	Alkalinity as CaCO3	mg/L		37.4	33.7 - 41.4	Not Reported	
1575	Chloride	mg/L	45.0	45.2	40.6 - 49.9	Acceptable	EPA 300.1
1610	Conductivity at 25°C	µmhos/cm		598	538 - 658	Not Reported	
0010	Fluoride	mg/L	2.91	3.25	2.92 - 3.58	Not Acceptable	EPA 300.1
1820	Nitrate + Nitrite as N	mg/L		6.51	5.84 - 7.16	Not Reported	
0009	Nitrate as N	mg/L	6.84	6.51	5.86 - 7.16	Acceptable	EPA 300.1
1125	Potassium	mg/L		24.9	21.5 - 28.5	Not Reported	
0145	Sulfate	mg/L	123	123	108 - 137	Acceptable	EPA 300.1
0024	Total Dissolved Solids at 180°C	mg/L		383	246 - 519	Not Reported	

WS Metals (cat# 590)

Anal. No.	Analyte	Units	Reported Value	Assigned Value	Acceptance Limits	Performance Evaluation	Method Description
1000	Aluminum	µg/L	1570	1650	1420 - 1830	Acceptable	EPA 200.8
0140	Antimony	µg/L	44.5	45.7	32.0 - 59.4	Acceptable	EPA 200.8
0001	Arsenic	µg/L	31.0	31.4	22.0 - 40.8	Acceptable	EPA 200.8
0002	Barium	µg/L	1510	1520	1290 - 1750	Acceptable	EPA 200.8
0141	Beryllium	µg/L	3.39	3.35	2.85 - 3.85	Acceptable	EPA 200.8
0226	Boron	µg/L	1380	1150	1010 - 1270	Not Acceptable	EPA 200.8
0003	Cadmium	µg/L	25.7	27.1	21.7 - 32.5	Acceptable	EPA 200.8
0004	Chromium	µg/L	53.8	55.3	47.0 - 63.6	Acceptable	EPA 200.8
0091	Copper	µg/L	971	969	872 - 1060	Acceptable	EPA 200.8
1070	Iron	µg/L	736	732	647 - 806	Acceptable	EPA 200.8
0005	Lead	µg/L	57.6	56.4	39.5 - 73.3	Acceptable	EPA 200.8
0236	Manganese	µg/L	93.8	92.0	82.0 - 102	Acceptable	EPA 200.8
0237	Molybdenum	µg/L	67.9	74.2	64.2 - 82.4	Acceptable	EPA 200.8
0142	Nickel	µg/L	193	198	168 - 228	Acceptable	EPA 200.8
0007	Selenium	µg/L	48.1	52.7	42.2 - 63.2	Acceptable	EPA 200.8
1150	Silver	µg/L	269	271	240 - 299	Acceptable	EPA 200.8
0143	Thallium	µg/L	3.10	3.02	2.11 - 3.93	Acceptable	EPA 200.8
1185	Vanadium	µg/L	551	551	496 - 606	Acceptable	EPA 200.8
0239	Zinc	µg/L	1340	1370	1230 - 1510	Acceptable	EPA 200.8

All analytes are included in ERA's A2LA accreditation. Lab Code: 1539-01

Figure F.2: Blind Check 2009 Environmental Chemistry Inorganic Analyses

Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results

The full MAPEP reports are available at www/inl.gov/resl/mapep/

Matrix: Water (Bq/L) MAPEP-10-MaW22					Matrix: Air Filters (Bq/Filter) MAPEP-10-RdF22			
Nuclides	Reported value	MAPEP[a] value	E[b]	% Bias	Reported value	MAPEP value	E	%Bias
^{241}Am	1.22	1.30	A	-6.2	0.141	0.146	A	-3.4
$^{239+240}$Pu	0.01	0.009	A	N/A[c]	0.084	0.0832	A	1.0
^{238}Pu	1.76	1.93	A	-8.8	0.00021	0.0010	A	
^{57}Co	29.5	28.3	A	4.2	NR[g]	-	-	-
^{65}Zn	47.0	40.7	A	15.5	NR[g]	-	-	-
^{137}Cs	64.9	60.6	A	7.1	NR[g]	-	-	-
^{54}Mn	28.8	26.9	A	7.1	NR[g]	-	-	-
Matrix: Soil (Bq/kg) MAPEP-10-MaS22					**Gross Alpha/Beta Air Filter MAPEP-10-GrF22**			
Gross alpha	NR	-	-	-	0.221	0.427	A	-48.2
Gross beta	NR	-	-	-	1.48	1.29	A	14.7
^{241}Am	0.0252	f	A	N/A[c]	-	-	-	-
$^{239+240}$Pu	0.18	0	N	N/A[d]	-	-	-	-
^{238}Pu	24.6	24.1	A	2.1	-	-	-	-
^{234}U	57.2	60	A	-4.7	-	-	-	-
^{235}U	3.45	f	f	f	-	-	-	-
^{238}U	61.7	64	A	-3.6	-	-	-	-

[a] Mixed Analyte Performance Evaluation Program

[b] Evaluation Rating (A = acceptable, W = Acceptable with warning, N = Not acceptable)

[c] Not applicable statistically zero result per MAPEP

[d] Not applicable for non-detect per MAPEP

[f] Information not provided by MAPEP

[g] Not reported

Table F-5: An Example of the Daily Performance Tests for ICP-MS

Sample Daily Performance Data of the Elan 6100 ICP-MS for July-August 2009
(Proficiency Test WS-144 was measured on July 22, 2009)

	Acceptable Ranges		7/15/2009			7/20/2009		
	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%	1,936.3	2.7	Acceptable	2,632.0	2.7	Acceptable
Mg	20,000-80,000	0.0 - 5.0%	59,232.0	1.1	Acceptable	64,750.1	2.1	Acceptable
In	120,000-300,000	0.0 - 5.0%	310,313.8	0.6	Check for high counts	299,513.7	2.1	Acceptable
Pb	70,000-180,000	0.0 - 5.0%	165,700.8	1.4	Acceptable	164,317.5	1.1	Acceptable
Ba	900,000-2,500,000	0.0 - 5.0%	2,550,005.2	0.8	Acceptable	2,435,096.3	2.4	Acceptable
Ba++	≤ 5.0% Ba value	N/A	2.3%	N/A	Acceptable	2.2%	N/A	Acceptable
Ce	900,000-3,300,000	0.0 - 5.0%	3,122,177.7	1.8	Acceptable	2,957,342.2	1.3	Acceptable
CeO	≤ 5.0% Ce value	N/A	2.3%	N/A	Acceptable	2.1%	N/A	Acceptable
Bkgd	≤ 25.0	N/A	10.4	N/A	Acceptable	8.2	N/A	Acceptable

	Acceptable Ranges		8/20/2009			8/31/2009		
	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%	3,005.3	0.7	Acceptable	1,965.7	3.7	Acceptable
Mg	20,000-80,000	0.0 - 5.0%	49,010.4	2.4	Acceptable	33,195.9	1.4	Acceptable
In	120,000-300,000	0.0 - 5.0%	336,983.6	1.4	Check for high counts	222,036.9	2.6	Acceptable
Pb	70,000-180,000	0.0 - 5.0%	144,062.0	0.9	Acceptable	114,955.8	2.1	Acceptable
Ba	900,000-2,500,000	0.0 - 5.0%	2,544,956.7	1.9	Check for high counts	1,877,067.4	4.8	Acceptable
Ba++	≤ 5.0% Ba value	N/A	2.7%	N/A	Acceptable	1.9%	N/A	Acceptable
Ce	900,000-3,300,000	0.0 - 5.0%	3,271,672.9	1.4	Acceptable	2,293,197.5	1.0	Acceptable
CeO	≤ 5.0% Ce value	N/A	2.6%	N/A	Acceptable	2.8%	N/A	Acceptable
Bkgd	≤ 25.0	N/A	8.8	N/A	Acceptable	7.6	N/A	Acceptable

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

Table F-6. Participation in NIST Radiochemistry Intercomparison Program

Media	Radionuclides	Percent Bias	Results
Glass-fiber filters NRIP10-GF	^{241}Am	-1.7	Traceable, 9%
	$^{239+240}$Pu	3.2	Traceable, 9%
	^{238}Pu	2.9	Traceable, 10%
	^{238}U	-5.8	Traceable, 7%
	^{234}U	-5.6	Traceable, 7%

Percent bias = calculated as the CEMRC measured value minus the NIST known value, expressed as a percentage relative to the known value.
Results and Traceability limit (expressed in percent) for NIST Traceability are defined under ANSI 42.22.
ANSI N42.22 defines the acceptance criteria for traceability to NIST for performance testing as:

$$\left|V_C - V_N\right| < 3 \times \sqrt{\sigma_C^2 - \sigma_N^2}$$

V_C = CEMRC value.
V_N = NIST value.
σ_C = 1 sigma total uncertainty of V_C
σ_N = 1 sigma total uncertainty of V_N

Appendix G: Radiochemical Equations

Detection

All radionuclides with the exception of the gamma spectroscopy targets (^{137}Cs, ^{60}Co, and ^{40}K) are considered "detected" if the radionuclide activity or concentration is greater than the minimum detectable concentration and greater than the total propagated uncertainty at the 2 sigma level. The gamma radionuclides are considered detected when the above criteria are met and the gamma spectroscopy software used to identify the peak generates an associated identification confidence of 90 percent or greater (ID Confidence >0.90).

Minimum Detectable Concentration (MDC)

The MDC is the smallest amount (activity or mass) of a radionuclide in a sample that will be detected with a 5 percent probability of nondetection while accepting a 5 percent probability of erroneously deciding that a positive quantity of a radionuclide is present in an appropriate blank sample. This method assures that any claimed MDC has at least a 95 percent chance of being detected. It is possible to achieve a very low level of detection by analyzing a large sample size and counting for a very long time. CEMRC uses the following equation for calculating the MDCs for each radionuclide in various sample matrices:

$$\mathbf{MDC} = \frac{4.65\sqrt{\sigma^{2}\mathbf{bkg}\,\frac{\mathbf{T_{blank}}}{\mathbf{T_{bkg}}}}}{\mathbf{KT_{bkg}}} + \frac{2.71}{\mathbf{KT_{bkg}}}$$

Where:

K = A correction factor that includes items such as unit conversions, sample volume/weight, decay correction, detector efficiency, chemical recovery and abundance correction, etc.

T_{blank} = Blank count time

T_{bkg} = Background count time. For further evaluation of the MDC, refer to ANSI N13.30, *Performance Criteria for Radiobioassay*.

Standard Deviation (SD)

The SD is an estimate of the uncertainty in the measurement due to all sources, including counting error, measurement error, chemical recovery error, detector efficiency, randomness of radioactive decay, and any other sources of uncertainty. The SD for each data point is reported at the 1σ level. SD is found by using the following equation:

$$\mathbf{SD} = \frac{\sqrt{\frac{\mathbf{C_s}}{\mathbf{t_s^2}} + \frac{\mathbf{C_{BK}}}{\mathbf{t^2_{BK}}}.\mathbf{S_{Tr}}}}{\mathbf{N_{Tr}.U}}$$

Where:

SD = Standard deviation

Cs = Total sample counts for analyte of interest

C_{BK} = Total background counts for the analyte of interest

t_s = sample count time

t_{BK} = background count time

S_{Tr} = Initial activity of the tracer added to the sample

N_{Tr} = Net count rate of the tracer

U = Conversion factor taking into account branching ration, radioactive decay during counting, etc.

Percent Bias (% Bias)

The percent bias is a measure of the accuracy of radiochemical separation methods and counting instruments; that is, a measure of how reliable the results of analyses are when compared to the actual values.

$$\%\mathbf{BIAS} = \frac{[\mathbf{A_m} - \mathbf{A_k}]}{\mathbf{A_k}} * 100\,\%$$

Where:
% BIAS = Percent Bias
A_m = Measured Sample Activity
A_k = Known Sample Activity

Table G-1: % Chemical Recovery of Radionuclides in FAS Samples

Radionuclide	Minimum	Maximum	Average	SD
^{241}Am	77.46	112.54	97.84	8.14
^{238}Pu	33.46	100.60	67.44	19.54
$^{239+240}$Pu	33.46	100.60	67.44	19.54
^{234}U	43.43	108.36	81.41	16.36
^{235}U	43.43	108.36	81.41	16.36
^{238}U	43.43	108.36	81.41	16.36

Table G-2: % Chemical Recovery of Radionuclides in Drinking Water Samples

Radionuclide	Minimum	Maximum	Average	SD
^{241}Am	94.49	97.80	96.34	1.31
^{238}Pu	59.63	63.13	60.96	1.52
$^{239+240}$Pu	59.63	63.13	60.96	1.52
^{234}U	76.67	87.19	81.58	4.01
^{235}U	76.67	87.19	81.58	4.01
^{238}U	76.67	87.19	81.58	4.01

Table G-3: % Chemical Recovery of Radionuclides in Soil Samples

Radionuclide	Minimum	Maximum	Average	SD
^{241}Am	71.46	92.40	85.46	5.79
^{238}Pu	58.59	92.23	77.53	8.64
$^{239+240}$Pu	58.59	92.23	77.53	8.64

Table G-4: % Chemical Recovery of Radionuclides in Ambient Aerosol Samples

Radionuclide	Minimum	Maximum	Average	SD
^{241}Am	21.82	125.00	75.88	26.09
^{238}Pu	20.22	83.06	40.50	18.37
$^{239+240}$Pu	20.22	83.06	40.50	18.37

REFERENCES

ANSI. 1996. Performance Criteria for Radiobioassay. ANSI-N13.30. American National Standards Institute. New York.

ANSI. 1969. Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities. ANSI N13.1. American National Standards Institute. New York.

ANSI 1999. Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities. ANSI N13.1. American National Standards Institute. New York.

APHA. 1981. Standard Methods for the Examination of Water and Wastewater, 15th Edition. American Public Health Association.

Arimoto, R., T. Kirchner, J. Webb, M. Conley, B. Stewart, D. Schoep, and M. Walthall. 2002. ^{239,240}Pu and inorganic substances in aerosols from the vicinity of the Waste Isolation Pilot Plant: The importance of resuspension. Health Physics, 83:456.

Arimoto, R and the Effluent Monitoring Improvement Group, In situ probe occlusion tests at the Waste Isolation Pilot Plant, Abstract TAM-A.9, Book of Abstracts, 51st Annual Meeting of the Health Physics Society, Providence, RI, 2006.

Arimoto, R., B. Stewart, H. Khaing, and D. P. Tatro. Biogeochemical recycling on aerosol particles. Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract A53A-0175, 2006.

Arimoto, R., J. B. Webb, and M. C. Conley. 2005. Radioactive contamination of atmospheric dust over southeastern New Mexico, Atmospheric Environment, 39, 4745-4754, 2005.

Barisic, D., A. Vertacnik, and S. Lulic. 1999. Cesium contamination and vertical distribution in undisturbed soils in Croatia. J. Environ. Radioactivity, 46:361-374.

Beck, H. L. and G. B. Bennet. 2002. Historical overview of atmospheric nuclear weapon testing and estimates of fallout in the continental United States. Health Phys 82: 591-608.

Boulyga, S. F. Zoriy, M. Ketterer M.E. and Becker. J.S. 2003. Depth profiling of Pu, ^{241}Am, and ^{137}Cs in soils from southern Belarus measured by ICP-MS and a and g spectrometry. J. Environ. Monit. 5: 661-666.

Breban, D. C. J., J. Moreno, and N. Mocanu. 2003. Activities of Pu radionuclides and ^{241}Am in soil samples from an alpine pasture in Romania. J. Radioanal. Nucl. Chem. 258: 613-617.

Bunzl, K., H. W. Kofuji, Schimmack, A. Tsumura, K.Ueno, and M. Yamamoto. 1995. Residence Times of Global Weapons Testing Fallout ^{237}Np in a Grassland Soil Compared to ^{239,240}Pu, ^{241}Am, and ^{137}Cs. Health Phys. 68: 89-93.

CEMRC. 1998. Survey of Factors Related to Radiation Exposure and Perceptions of Environmental Risks in Carlsbad, Loving, Malaga and Hobbs, New Mexico. Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

CEMRC. 1999 Report. Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

CEMRC. 2000 Report. Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

CEMRC. 2001 Report. Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

CEMRC. 2002 Report. Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

CEMRC. 2005-2006 Report. Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

CEMRC. 2004. Summary Report: Tests of Coatings to Reduce Salt Encrustation on Metal Coupons (REP-CEMRC-2004-05). Carlsbad Environmental Monitoring & Research Center. Carlsbad, New Mexico.

Chandra, S., C. A. Ortiz, and A. R. McFarland. 1993. Effects of Salt Loading and Flow Blockage on the WIPP Shrouded Probe. Report 8248A/01/08/93/SC, Aerosol Technology Laboratory, Texas A&M University Department of Mechanical Engineering, College Station, TX.

Chavez, M. C., D. L., O'Neal, A., McFarland, and C. Ortiz. 1997. An Analysis of Salt Deposition on the Performance of the WIPP Station A Air Sampling System, Final Report. Task 3 through 6, Contract 75-WJJ64181M7, Energy Systems Laboratory, Texas A&M University, College Station, TX.

Chugg, J., G. Anderson, D. King, and L. Jones. 1971. Soil Survey of Eddy County, New Mexico, U. S. Dept. of Agriculture Soil Conservation Service, U.S. Government Printing Office, Washington, D.C.

City of Carlsbad Municipal Water System. 1998. Annual Consumer Report on the Quality of Your Drinking Water. Carlsbad, New Mexico.

City of Carlsbad Municipal Water System. 1999. Annual Consumer Report on the Quality of Your Drinking Water. Carlsbad, New Mexico.

City of Carlsbad Municipal Water System. 2000. Annual Consumer Report on the Quality of Drinking Water. Carlsbad, New Mexico.

City of Carlsbad Municipal Water System. 2001. Annual Consumer Report on the Quality of Tap Water. Carlsbad, New Mexico.

City of Carlsbad Municipal Water System. 2002. Annual Consumer Report on the Quality of Tap Water. Carlsbad, New Mexico.

Clark, R. H., J. Dunster, J-C. Nenot, H. Smith and G. Voeltz. 1996. The environmental safety and health implications of plutonium J. Radiol. Prot. 16: 91-105.

Collins, A., D. Walling, H. Sichingabula, and G. Leeks. 2001. Using ^{137}Cs measurements to quantify soil erosion and redistribution rates for areas under different land use in the Upper Kaleya River basin, southern Zambia. Geoderma, 104:299-323.

Conca, J., M. Johnson, and J. R. Wischnewsky. 2005. Reducing the Threat of a Serious ^{137}Cs Dirty Bomb, in the Proceedings of the DHS Conference: Working Together: Research & Development (R&D) Partnerships in Homeland Security, Boston, MA, April 27–28, the Department of Homeland Security, Science and Technology Directorate, Section 4, p. 1-10.

Conca, J. and M. H. Reynolds. 2006. Dirty Bombs, Practical Plans, Homeland Protection Professional, May 2006 issue, p. 18-22.

Coppinger, K., W. Reiners, I. Burke, and R. Olson. 1991. Net erosion on a sagebrush steppe landscape as determined by Cs-137 distribution, Soil Sci. Soc. Am. J., 55:254-258.

DOE/WIPP. 2006. Waste Isolation Pilot Plant Annual Site Environmental Report for 2005, DOE/WIPP-06-2225

EEG. 2001. Recommendations to Address Air Sampling Issues at WIPP, EEG-80, DOE/AL58309-80, 17 pp. + appendices. Environmental Evaluation Group. Albuquerque, New Mexico.

EEG. 2003. Gray, D. H., Application of Beryllium-7 and Lead-210 concentrations measurements to monitoring the validity of effluent air sampling at the Waste Isolation Pilot Plant, December 2003. Environmental Evaluation Group. Albuquerque, New Mexico.

EPA. 1999. Understanding variation in partitioning coefficients, Kd, values. Volumes I and II. U.S. Environmental Protection Agency, Washington, D.C. 20460.

Faller, S. 1994. Residual soil radioactivity at the Gnome Test Site in Eddy County, New Mexico, Report No. EPA 600/R-94/117, July 1994. Washington, D.C., Environmental Protection Agency.

Gaca, P., E. Tomankiewicz, J.W. Mietelski, S. Grabowska, and B. Kubica. 2006. Radionuclides in two raised peat profiles collected from Koscieliska Valley in the Tatra Mountains. J. Radioanalytical and Nuclear Chemistry 267: 443-448.

Gee, G. W. and J. W. Bauder. 1986. Particle-Size Analysis. In A. Klute. Methods of Soil Analysis: Part 1 – Physical and Mineralogical Methods, Agronomy Monograph no. 9 (2nd Edition), American Society of Agronomy – Soil Science Society of America, Madison, WI.

Hodge, V., C. Smith, and C. Whiting.1996. Radiocesium and plutonium still together in “background” soils after more than thirty years. Chemsphere 32: 2067-2075.

Hulse, S. E., S. A. Ibrahim, F. W. Whicker, P. L. Chapman. 1996. Comparison of ^{241}Am, ^{239,240}Pu and ^{137}Cs concentrations in soils around Rocky Flats. Health Physics 76:275-287.

Isaksson, M., B. Erlandsson, and S. Mattsson. 2000. A 10-year study of the ^{137}Cs distribution in soil and a comparison of Cs soil inventory with precipitation-determined deposition, J. of Environ. Radioactivity, 55:47-59.

Kenney, J. W. 1994. Preoperational Radiation Surveillance of the WIPP Project by EEG during 1992. EEG-54.

Kenney, J.W. Downes, P.S. Gray, D.H. Ballard, S.C. Environmental Evaluation Group, 1995. Radionuclide Baseline in soil near project Gnome and the Waste Isolation Pilot Plant. EEG-58.

Kirchner, T. B., J. L. Webb, S. B. Webb, R. Arimoto, D. A. Schoep, and B. D. Stewart. 2002. Variability in background levels of surface soil radionuclides in the vicinity of the Waste Isolation Pilot Plant. Journal of Environmental Radioactivity 60:275-291.

Kochan, I. G. and I. I. Shuktomova. 1995. Soil factor influence on the plutonium isotope distribution among soil profile layers and mobile forms in the 30 km Chernobyl zone. J. Radioanal. Nucl. Chem., Letters 201: 371-379.

Komosa, A. 1999. Migration of plutonium isotopes in forest soil profiles in Lublin region (Eastern Poland). J. Radioanal. Nucl. Chem. 240: 19-24.

Koonin, S. E., Statement delivered before the Senate Foreign Relations Committee on Radiological Terrorism, March 6, 2002.

McAninch, J., T. Hamilton, T. Brown, T. Jokela, J. Knezovich, T. Ognibene, I. Proctor, M. Roberts, E. Sideras-Haddad, J. Southon and J. Vogel. 2000. Plutonium measurements by accelerator mass spectrometry (AMS) at LLNL. Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms 172: 711-716.

McFarland, A.R. 1993. Air Sampling with Shrouded Probes at the WIPP Site. Final Report, Westinghouse Purchase Order WGS56486S7, Drawer S, College Station TX.

Mitchell, P., L. Vintró, H. Dahlgaard, C. Gascó and J.A. Sánchez-Cabeza. 1997. Purturbations in the ^{240}Pu/^{239}Pu global fallout ratio in local sediments following nuclear accidents at Thule (Greenland) and Palomares (Spain). Science of the Total Environment 202: 147-153.

O'Brien, H. A., "Radioactive Sources in Medicine and Industry," O'Brien & Associates Report No. OB&A/OB-02-01, 2002.

Owens, P., D. Walling, and Q. He. 1996. The behavior of bomb-derived Cesium-137 fallout in catchment soils, J. Environ. Radioactivity, 32:169-191.

Perkins, R. W. and C. W. Thomas. 1980. Worldwide Fallout. In: Hanson W. C., ed. Transuranic Elements in the Environment. U.S. Department of Energy: DOE/TIC-22800, 53-82.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123.

Rahn, K. (1976). The chemical comosition of the atmospheric aerosol, Tech. Report, Grad. Sch. of Oceanogr., Univ. Rhode Island, Kingston.

Rodgers, J. C. (1987). Exhaust stack monitoring issues at the Waste Isolation Pilot Plant. Report EEG-37; DOE/AL/10752-37. Environmental Evaluation Group, Environmental Improvement Division, Health and Environment Department, State of New Mexico, P.O. Box 968, Santa Fe, NM 87503.

Ritchie, J. C., and J. R. McHenry. 1990. Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review, J. Environ. Qual., 19:215-233.

Schimmack, W., K. Auerswald, and K. Bunzl. 2002. Estimation of soil erosion and deposition rates at an agricultural site in Bavaria, Germany, as derived from fallout radiocesium and plutonium as tracers, Naturwissenschaften, 89:43-46.

Staunton, S. and P. Levacic. 1999. Cs adsorption on the clay-sized fraction of various soils: effect of organic matter destruction and charge compensating cation, J. Environ. Radioactivity, 45:161-172.

Strub, T. and G. J. Van Tuyle, "Large Radiological Source Production and Utilization and Implications Regarding RDDs", Los Alamos National Laboratory Report LA-UR-03-5432, 2003.

Tatro, D. P., R., Arimoto, N. McMillian, and M. Barnes, Characterization of ^{239,240}Pu radionuclide adsorption to soil particles and mineral dust aerosols. Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract A53D-0225, 2006.

Turner, M., M. Rudin, J. Cizdziel and V. Hodge. 2003. Excess plutonium in the soil near the Nevada test Site, USA. Env. Pollution 125: 193-203.

US AEC. 1973. Gnome/Coach site disposal options. U.S. Atomic Energy Commission NVO-131. Las Vegas, NV.

UNSCEAR. 2000. Sources and effects of ionizing radiation. 2000 Report, Vol. 1. United Nations Scientific Committee on the Effects of Atomic Radiation.

U.S. Department of Energy. 1998. Department of Energy Laboratory Accreditation Program for Radiobioassay. DOE-STD-1112-98, Washington, DC.

U.S. Environmental Protection Agency. 1991a. 40 CFR 61, Subpart H. National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities. Code of Federal Regulations. Washington, DC, U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1991b. 40 CFR 60, Appendix A. Method 1 - . Sample and Velocity Traverses for Stationary Sources. Code of Federal Regulations. Washington, DC, U.S. Government Printing Office.

U.S. Environmental Protection Agency. 2000. 40 CFR 61, National Emission Standards for Hazardous Air Pollutants; Standard for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities; Standard for Radionuclide Emissions From Federal Facilities Other Than Nuclear Regulatory Commission Licensees and Not Covered by Subpart H. Federal Register, May 9, 2000, Volume 65, Number 90, Proposed Rules, pages 29933-29939. Washington, DC, U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1999. Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially–Prepared Canisters and Analyzed By Gas Chromatography/Mass Spectrometry (GC/MS). EPA Method TO-15.

U.S. Environmental Protection Agency. 1997. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. EPA/SW-846.

U.S. Environmental Protection Agency. 1994. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. EPA/SW-846.

U.S. Environmental Protection Agency. 1994. U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review. EPA 540/R-94013.

U.S. Environmental Protection Agency. 1983. Methods for Chemical Analysis of Water and Wastes. EPA 600/4-79-020.

USDA. 1961. Diagnosis and improvement of saline and alkali soils. Salinity Laboratory Staff. U.S. Department of Agriculture Handbook No. 60. U.S. Govt. Printing Office, Washington, D.C.

van Tuyle, G. J., T. Strub, H. O'Brien, C. F. V. Mason and S. Gitomer, "Reducing RDD Concerns Related to Large Radiological Source Applications", LANL Report LA-UR-03-6664, 2003.

Walling, D. E. and T. A. Quine. 1991. Use of Cs-137 measurements to investigate soil erosion on arable fields in the UK: potential applications and limitations, Journal of Soil Science, 42:147-165.

Waste Isolation Pilot Plant. 2001. Quality Assurance Project Plan for Confirmatory Volatile Organic Compound Monitoring". WP 12-VC.02, Revision 4.

Waste Isolation Pilot Plant. 2000. Confirmatory Volatile Organic Compound Monitoring Plan". WP 12-VC.01 Revision 3.

Webb, J. L. and T. B. Kirchner. 2000. An evaluation of in vivo sensitivity via public monitoring. Radiation Protection Dosimetry, 89 (3-4): 183-191.

Whicker, J., D. Breshears, P. Wasiolek, T. Kirchner, R. Tavani, D. Schoep, and J. Rodgers. 2002. Temporal and spatial variation of episodic wind erosion in unburned and burned semiarid shrubland, J. Environ. Qual., 31:599-612.

Whicker, R. D. 2005. Vertical migration of ^{134}Cs bearing soil particles in arid soils: Implications for plutonium redistribution. Thesis, Dept. of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO.

White, G. C., T. E. Hakonson and A. J. Ahlquist. 1981. Factors affecting radionuclide availability to vegetables grown at Los Alamos. J. Environ. Qual. 10: 294-299.