# 2010 Report
# Carlsbad Environmental Monitoring & Research Center

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NM STATE
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# Acronyms and Abbreviations

| | |
|---|---|
| μBq | microBecquerel |
| μm | micrometer |
| AA, AAS | atomic absorption, atomic absorption spectrometry |
| Ag | silver |
| Al | aluminum |
| Am | americium |
| As | arsenic |
| ASTM | American Society for Testing and Materials |
| Ba | barium |
| Be | beryllium |
| Bq | Becquerel |
| C | centigrade |
| Ca | calcium |
| Cd | cadmium |
| Ce | cerium |
| CEMRC | Carlsbad Environmental Monitoring & Research Center |
| CEMRP | Carlsbad Environmental Monitoring & Research Program |
| CFR | Code of Federal Regulations |
| Ci | Curie |
| CLP | Contract Laboratory Program |
| cm | centimeter |
| Cm | curium |
| Co | cobalt |
| Cr | chromium |
| CRDL | Contract Required Detection Limit |
| CRM | certified reference materials |
| Cs | cesium |
| Cu | copper |
| DL | detection limit |
| DOE | U.S. Department of Energy |
| Dy | dysprosium |
| EM | Environmental Monitoring |
| EML | Environmental Monitoring Laboratory |
| EPA | U.S. Environmental Protection Agency |
| Er | erbium |
| ERA | Environmental Research Associates |
| Eu | europium |
| F | fluoride |
| FAS | fixed air samples |
| Fe | iron |
| FY | fiscal year |
| g | gram |
| GC/MS | Gas Chromatography / Mass Spectrometry |
| 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 |
| TCD | Thermal Conductivity Detector |
| Th | thorium |
| Ti | titanium |
| TIMS | thermal ionization mass spectrometry |
| Tl | thallium |
| TSP | total suspended particulates |
| U | uranium |
| UVB | Ultra-Violet B |
| V | vanadium |
| VOCs | Volatile Organic Compounds |
| W | watt |
| WERC | Waste-management Education & Research Consortium |
| WID | Waste Isolation Division |
| WIPP | Waste Isolation Pilot Plant |
| WTS | Washington TRU Solutions |

# OVERVIEW

## Current Program Status

### 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 2010.

Production of this report is supported as part of the Carlsbad Environmental Monitoring & Research Center, by a grant from the U.S. Department of Energy (DOE) 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.

### HISTORY

CEMRC was established in 1991 with a grant from the 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 administratively located 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 Environmental 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 2010, the CEMRC employed 19 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 2010, 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 FY2010, an overall increase from previous years.

   *DOE CBFO*
   - $2.144 million for WIPP Environmental Monitoring and Underground Science

   *URS Corp. (WTS, WRES, and WSMS)*
   - $624 thousand for Technical Support, VOC and WBC

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

   *LES National Enrichment Facility*
   - $60 thousand for Uranium Enrichment Analytical Scientific Support

*Sandia National Laboratory*

- $47 thousand for Performance Assessment Scientific Support

*Other*

- $54 thousand from WCS, CDC, 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 2010 (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 2010, 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 2010, 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 2010 (Appendix D). In particular, The Illinois Institute of Technology (IIT) again brought one of its radiation physics classes (Physics 770) to CEMRC during July. CEMRC provided an appropriate radiological setting, lab space, and equipment for the course.

## Table 1: Listing of CEMRC Staff as of the End of 2010

| Name | Position |
|---|---|
| Baker, David | Associate Research Scientist |
| Ballard, Sally | Senior Research Assistant |
| Brown, Becky | Operations Manager |
| Brown, Bill | Facilities Services Manager |
| Chancellor, Adrienne | Associate Research Scientist |
| Hinojos, Leo | Lab Technician |
| Jung, Jae | Intermediate Research Scientist |
| Kirchner, Thomas | Senior Research Scientist |
| Kumar, Anuj | Intermediate Research Scientist |
| Monk, James | Radiation Safety Specialist |
| Mulholland, George | Interim Director |
| Najera, Angela | Editor |
| Navarrette, Adrianne | Research Engineer Technician |
| Owens, Lyndi | General Administrative Assistant |
| Scappaticci, Jess | Technician V |
| Schoep, David | Radiation Safety Training Specialist |
| Sullivan, Tina | Senior Systems Analyst |
| Thakur, Punam | Intermediate Research Scientist |
| Tulk, Kaitlan | Lab Assistant |

# WIPP Environmental Monitoring Project

## PROJECT CONCEPT

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

A detailed description of the WIPP-EM concepts, sampling design, and baseline studies is presented on the CEMRC web page. The following is a summary of 2010 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 2010.

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 2010 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 measurements which has since been corrected, and no Pu was detected in 2007 above MDC.

In 2010, CEMRC again detected a small quantity of Pu in composite aerosol samples from the third quarter (July composite sample) similar to the 2003, 2008 and 2009 detection, also corroborated by WTS. The concentrations are so low (all values are orders of magnitude below compliance or action levels) 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 atmospheric nuclear tests have been the major source of radiological contamination to date in the environment. Approximately 6 tons of $^{239}$Pu were introduced into the environment from more than 500 atmospheric weapon tests conducted between 1945 and 1980. Fallout was distributed globally at an approximately 3:1 ratio between the northern hemisphere and the southern hemisphere. Additionally, local and regional contaminations of plutonium in the environment have resulted from nuclear accidents such as Chernobyl and Fukushima. These events resulted in the release of substantial quantities of radioactive contaminants into the global environment. Currently, $^{238}$Pu, $^{239}$Pu and $^{240}$Pu isotopes can be measured as traces in environmental samples with a $^{238}$Pu/$^{239+240}$Pu activity ratio of 0.03 at mean latitudes of $40^{o}$-$50^{o}$ N tracing their global origin. At present, almost all plutonium being introduced into the atmosphere can be found in the surface soil. Depending on meteorological conditions, physiochemical properties of soil and human activity, plutonium can migrate vertically at various rates, can be taken up by plants, or resuspended into the air with eroded soil particles. In the Carlsbad area, where WIPP is located, there is an additional potential local source of anthropogenic radioactivity from an underground nuclear test during the Plowshare project. One particular test occurred at the Gnome site, about 8.8 km southwest of the WIPP site, in 1961 when an underground test of a 3.3-kiloton $^{239}$Pu device vented radioactive materials to the surface. Cleanup efforts at this site have been carried out in several campaigns since that time, and the surface contamination is now well below the risk-based action levels. However, $^{137}$Cs and plutonium have been detected in some samples of surface soils at the Gnome site. These contaminated soils are of practical concern because they are a potential source of contamination for environmental samples being collected to monitor potential release of radionuclides from the WIPP.

In the 2010 July composite sample, CEMRC detected only $^{239+240}$Pu; the $^{238}$Pu and $^{241}$Am activities were not detected. Therefore, activity ratio calculation could not be made to understand the source of Pu in the FAS composite samples. However, both $^{238}$Pu and $^{239+240}$Pu were detected above MDC in one of the composite samples in 2008 and 2009 and they exhibit $^{238}$Pu/$^{239+240}$Pu activity ratio of $0.025 \pm 0.004$ which reflect the source being largely from global fallout.

The choice for CEMRC to monitor at levels orders of magnitude below action or compliance levels, even below background levels, 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.

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 2010 the Center has been working with 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 for 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 faced CEMRC during 2010 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, identify missing elements in our understanding of the WIPP environment that are not addressed by the ongoing and proposed long-term monitoring studies, and initiate research programs to compliment these activities. The sampling schedule for the years 2011-2015 are shown in the following table.

**WIPP-EM Sampling Schedule**
(Aerosol includes FAS, Glass Fiber Hi-Vol, and Whatman 41 Hi-Vol)

| | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| 1st Qtr | Aerosol | Aerosol | Aerosol; Drinking Water | Aerosol | Aerosol; Surface Water and Sediment |
| 2nd Qtr | Aerosol; Surface Water and Sediment | Aerosol; Drinking Water | Aerosol | Aerosol | Aerosol; Drinking Water |
| 3rd Qtr | Aerosol; Drinking Water | Aerosol | Aerosol; Surface Water and Sediment | Aerosol; Drinking Water | Aerosol |
| 4th Qtr | Aerosol | Aerosol; Soil | Aerosol | Aerosol; Soil | Aerosol |

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 2010, 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 other programs supporting the WIPP also move in new directions.

The sampling media for the 2010 environmental monitoring program included airborne particulates (both FAS and aerosol), soil, drinking water and human whole body. These samples were 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 July 2011 and analyses has been completed through December 2010 for the Gamma emitters and radiological analytes. All FAS samples from 2010 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 2010 from 16 locations from the Near Field sampling grid. 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 2010, 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 2010, 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 2010.

## 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 2010 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 $3.7 \times 10^{10}$ 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 2010 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 2010 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 2010 audits is reported in Appendix F.

### Quality Assurance/Quality Control for Organic Chemistry

A VOCs Confirmatory Monitoring Audit, conducted by WTS QA as part of their routine yearly program audits in compliance with contract requirements, was passed in May 2010.

### 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, while 20 hours FAS filter blank counts were recorded every two weeks. The sixty minutes background chart for both alpha and beta counts are illustrated in Appendix G. Two blanks per week for the FAS program were counted for 20 hours and were used as a background history for calculating results. The daily efficiency checks of alpha and beta detectors are presented in Appendix G.

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) and standard deviation (SD) are described in Appendix H. 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 H-1 through H-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 2010-2011, the CEMRC radioanalytical program analyzed MAPEP- air filter, water, soil, gross alpha/beta on air filters and water, 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 and some gamma radionuclides. 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 Appendix I. Only one analysis result, which was for $^{241}$Am in soil matrix, did not meet the accuracy acceptance criteria. 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 or 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 $m^3min^{-1}$, but the frequency of filter replacement is based on optimal loading for radioanalysis.

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

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

## Quality Assurance/Quality Control for Internal Dosimetry

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

- 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 that CEMRC has participated in the ORNL program, CEMRC has consistently out-performed all other laboratories in this area.

## Executive Summary

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

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 2010 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.

### *ORGANIZATION OF THE MONITORING PROGRAM*

The challenges that faced CEMRC during 2010 have 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, identify missing elements in our understanding of the WIPP environment that are not addressed by the ongoing and proposed long-term monitoring studies, and initiate research programs to compliment these activities. The sampling schedule for the years 2011-2015 are shown in the following table.

**WIPP-EM Sampling Schedule**
(Aerosol includes FAS, Glass Fiber Hi-Vol, and Whatman 41 Hi-Vol)

| | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| 1st Qtr | Aerosol | Aerosol | Aerosol; Drinking Water | Aerosol | Aerosol; Surface Water and Sediment |
| 2nd Qtr | Aerosol; Surface Water and Sediment | Aerosol; Drinking Water | Aerosol | Aerosol | Aerosol; Drinking Water |
| 3rd Qtr | Aerosol; Drinking Water | Aerosol | Aerosol; Surface Water and Sediment | Aerosol; Drinking Water | Aerosol |
| 4th Qtr | Aerosol | Aerosol; Soil | Aerosol | Aerosol; Soil | Aerosol |

### *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).

Continuous sampling of aerosol particles was conducted through July 2011 and analyses has been completed through December 2010 for the Gamma emitters and radiological analytes. All FAS samples from 2010 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 for 2010.

The CEMRC ambient aerosol monitoring studies focus on both man-made and naturally-occurring radionuclides. 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 actinide studies.

The element of particular interest for the WIPP-EM is Pu (atomic number 94) and 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 TRU waste at the site can be attributed to nuclear weapons testing in the 1950s to1980s, controlled releases from the operation of nuclear power plants and nuclear reprocessing facilities, and nuclear accidents such as Chernobyl and Fukushima. 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).

The results presented in this report 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.

## SOILS

Soil samples were collected during 2010 from 16 locations from the Near Field sampling grid. 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; 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 2010, 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. 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. During 2010, drinking water samples were collected during 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 2010.

Isotopes of naturally occurring uranium were detected in all the drinking water samples in 2010. Measured values for the drinking water samples collected during 2010 ranged between 9.2-153 mBq/L for $^{238}$U, 0.36-13.5 mBq/L for $^{235}$U and 24.7-399.0 mBq/L for $^{234}$U. The uranium concentration is well below the reference concentration level for radiological protection, i.e. 3.0 Bq/L. The greatest variations appeared in $^{235}$U. 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 highest activity concentrations in water were found in Otis water. 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. The concentration of uranium in ground water and the $^{234}$U/$^{238}$U activity ratio in drinking water sources have been the subject of extensive investigations in the U.S. (U.S. EPA 2000; Orloff et al., 2004).

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)*).

## HUMAN POPULATION (Internal Dosimetry)

The *Lie Down and Be Counted* (LDBC) project, conducted by the Internal Dosimetry laboratory, 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. The LDBC 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, 2010) of an ongoing study. 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.

As of December 31, 2010, 935 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 303 recount bioassays had been performed through December 31, 2010. In addition, 358 new volunteers have participated in the program since October 1, 2002.

$^{40}$K results were positive for all participants through December 2010 and ranged from 792 to 5558 Bq per person with an overall mean (± SE) of 2477 (± 23) 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 3059 (± 27) Bq per person, which was significantly greater ($p < 0.0001$) than that of females, which was 1884 (± 19) 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 21.4 ± 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 12 (± 0.9) Bq per person. The mean $^{137}$Cs body burden for males (± SE), was 13.6 (± 1.2) Bq per person, which was significantly greater ($p = 0.002$) than that of females, which was 8.6 (± 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 (27.9 %) as compared to non-smokers (23.2 %). 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.

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. These results, particularly the absence of detectable levels of plutonium, suggest that there **have been no observable effects from WIPP**.

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

## RADIONUCLIDES AND INORGANICS IN WIPP EXHAUST AIR

For monitoring of the WIPP underground air, there are three shrouded-probe aerosol Fixed Air Samplers (FAS) at a location designated as Station A. 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 be detected in the event of a release. Therefore, CEMRC has developed procedures and methods to provide a "quick look" (i.e. weeks where possible) at radioactive materials in the exhaust air. This addresses a strategic need for the monitoring program because most of the other WIPP-EM analyses require several months or more to complete. That is, the data from Station A provide a preliminary look at the monitoring results and, while these results are less specific and less detailed than those from the other studies, the data can be used to trigger more detailed investigations when appropriate.

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.

## ACTINIDE DATA

No detectable concentrations of $^{238}$Pu, $^{239+240}$Pu or $^{241}$Am were observed in any of 2010 samples except for the month of July 2010. For the month of July both primary and back-up samples showed $^{239+240}$Pu and $^{241}$Am activities above detection limits. Similar hits of $^{239+240}$Pu were also observed by WIPP Laboratories for the month of July 2010. The Pu hit of 2010 is similar to that which occurred during June 2003, February 2008, and April 2009 at Station A. Since the Minimum Detectable Concentration (MDC) for $^{239+240}$Pu is usually a factor of 2-5 higher than the measured concentration, 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.

It is important to note that during the twelve years of environmental monitoring of the WIPP, CEMRC has detected only four composite samples, out of more than 100 tested, that were above MDCs. Such small activity of Pu was also detected in one of the FAS composite sample in 2003, but unlike the samples in 2008, 2009 and 2010, Am was not detected. However, these activities were extremely low and well below the action level of 37 Bq/m$^3$ that triggers the Continuous Air Alarms (CAMs) that are distributed throughout the WIPP.

## ELEMENTAL DATA

Prior studies at Station A have shown that concentrations of hazardous metals and various trace elements can be highly variable over time; this was true even in the samples collected prior to receipt of the mixed waste in September 2000. In 2010, concentrations for Cd, Th, and U never exceeded the MDC. The concentrations of Cd, Th, U regularly hover just above the MDC. No marked differences are evident in the baseline vs. operational samples. Aluminum (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 uranium (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.

## ANALYSIS OF VOLATILE ORGANIC COMPOUNDS

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.

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.

The OC lab analyzed a total of 1152 samples in 2010, which is a higher number than any of the previous years. All of the samples were analyzed and reported in a timely manner under an extensive quality assurance (QA)/quality control (QC) program. The 1152 samples consisted of 711 samples for VOCs measurement (643 routine air samples, 68 blank and recovery gas samples) and 441 samples for hydrogen and methane analysis. All of these samples achieved 100% completeness. Blank and recovery gas samples were collected by Shaw Environmental and were part of the sampler cleaning and certification program; they were analyzed in expedited turnaround batches at various times throughout the years. The OC lab also received a number of canisters and passivated sampling kits (sample trains) for cleaning and certification at various times throughout the year. All of the canisters and sample trains were cleaned and certified with appropriate QA/QC in place. Because of the proprietary nature of the VOC data, none of the data are presented in this report.

## SURFACE SOIL RADIONUCLIDES

Soils are of high interest to the WIPP-EM because aerosol releases of contaminants would eventually be deposited in surface soils, which then can serve as a source for continuing contaminant exposure and uptake via direct contact, food chain pathways, and re-suspension. From these perspectives, soils are an integrating medium of primary concern in predictive ecosystem 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 due to integrated global fallout from the testing of above-ground nuclear devices. The plutonium isotope $^{238}$Pu has been injected into the stratosphere by the burn-up of a failed radioactive thermal generator in 1964, release at the Gnome Site, and regional fallout from above-ground testing at the Nevada Test Site(NTS). Each of these sources has characteristic radionuclide signatures and /or abundances 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 2010 from a grid of 16 locations surrounding the WIPP site. Also reported are summary statistics for the 1998-2009 data.

$^{238}$Pu, $^{239+240}$Pu, $^{241}$Am and gamma radionuclides $^{40}$K, $^{137}$Cs and $^{60}$Co were analyzed for all the soil samples. $^{241}$Am concentrations slightly greater than MDC were detected in 16 samples whereas $^{238}$Pu was not detected in any soil samples in 2010. $^{239+240}$Pu was detected in every soil sample with one exception. All detected concentrations 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 (1.74 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 (0.0-743 mBq/g). The mean concentration of $^{239+240}$Pu in 1998 soil samples collected from the Near Field grid were 0.21 Bq/g, which is consistent with the mean value of 0.17 Bq/g measured in 2010 soil samples collected from the same grid. The corresponding values for $^{238}$Pu and $^{241}$ Am were slightly higher in 2010 than in 1998.

$^{40}$K was detected in every sample. 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 observed previously in WIPP soils. $^{137}$Cs was detected in all soil samples except one. 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 location. The concentrations for $^{137}$Cs and $^{60}$Co fell within the range of values previously measured for the WIPP soil samples.

## QUALITY ASSURANCE

The CEMRC is subject to the policies, procedures and guidelines adopted by New Mexico State University (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 2010 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.

Internal audits were performed during 2010 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.

### Quality Assurance/Quality Control for Organic Chemistry

A VOCs Confirmatory Monitoring Audit, conducted by WTS QA as part of their routine yearly program audits in compliance with contract requirements, was passed in May 2010.

### 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.

The radiochemical equations used for the calculation of minimum detection concentration (MDC) and standard deviation (SD) are described in Appendix H. 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.

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. During 2010-2011, CEMRC radioanalytical program analyzed MAPEP- air filter, water, soil, gross alpha/beta on air filters and water 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 ${}^{241}Am$ and some gamma radionuclides. 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 Appendix I. Only one analysis result, which was for ${}^{241}Am$ in soil matrix, did not meet the accuracy acceptance criteria. 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.

### 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.

## 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.

## NUCLEAR DISASTER IN FUKUSHIMA, JAPAN

The earthquake and tsunami that hit northern Japan on March 11, 2011 created the worst nuclear crisis since the Chernobyl disaster. The three active reactors at the Fukushima Daiichi Nuclear Power Station 170 miles north of Tokyo overheated and partially melted down after the quake knocked out the plant's power and the tsunami disabled the backup generators meant to keep cooling systems working. The damage caused the failure of cooling and safety systems resulting in the atmospheric release of radiological materials from the reactor site. As the danger and radioactivity levels rose, tens of thousands of residents were evacuated or told to stay inside.

In response to the Japanese nuclear incident, the CEMRC accelerated and increased sampling frequency and analysis to confirm that there were no harmful levels of radiation reaching the U.S. from Japan and to inform the public about any level of radiation detected. The report covers the first three months of air radiation monitoring following the Fukushima nuclear disaster and is intended to inform a wider public about the exact time and nature of the arrival of fission products to the Carlsbad area. On March 14-April 01, 2011 we detected the first arrival of the airborne fission products $^{131}$I, $^{132}$Te, $^{134}$Cs and $^{137}$Cs in Carlsbad, NM, USA by identifying their characteristic gamma rays using a germanium detector. From a public health standpoint, the isotopes of $^{131}$I and $^{137}$Cs are of most interest, because if high concentrations of $^{131}$I are inhaled or ingested, the radioactive iodine can concentrate in the thyroid and thereby increase the risk for cancer in that organ. Additionally, cesium is chemically similar to potassium and so will behave like potassium in the body; therefore, inhalation or ingestion of high concentrations of radioactive cesium can build up in multiple locations throughout the body, which can lead to an increased risk of various cancers. It is important to note that all of the radiation levels detected by CEMRC have been very low, well below any level of public health concern. We saw decreasing radiation levels during April and May. Since May, sample analyses have predominantly shown no detections of radionuclides associated with the Japanese nuclear incident. The activity of $^{131}$I measured was at least a factor of ~1500 below the limit given by the Environmental Protection Agency (EPA) of 3.7 Bq/m$^3$.

## RESEARCH PROGRAM

While the primary mission for CEMRC is environmental monitoring in the vicinity of the WIPP site, a concerted effort is underway to develop a research effort which supports the WIPP and utilizes the unique capabilities of CEMRC. The current research effort at CEMRC is a multi-year program funded by the Department of Energy's Carlsbad Field Office (DOE/CBFO). This effort entitled, Low Background Radiation Experiment (LBRE), is supervised by Dr. G. Smith, a professor of biology at New Mexico State University. Also, programs have been initiated by the lead scientists in radiochemistry (Dr. P. Thakur), organic chemistry/environmental chemistry (Dr. A. Kumar), and internal dosimetry (Dr. P. Ila). Brief descriptions for each proposed effort are presented in Chapter 8 of this report.

# CHAPTER 1

# Radionuclides and Inorganics in WIPP Exhaust Air

By
Punam Thakur and Adrienne Chancellor

## INTRODUCTION

For monitoring of the WIPP underground air, there are three shrouded-probe aerosol Fixed Air Samplers (FAS) at a location designated as Station A. 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 be detected in the event of a release. Therefore, CEMRC has developed procedures and methods to provide a "quick look" (i.e. weeks where possible) at radioactive materials in the exhaust air. This addresses a strategic need for the monitoring program because most of the other WIPP-EM analyses require several months or more to complete. That is, the data from Station A provide a preliminary look at the monitoring results and, while these results are less specific and less detailed than those from the other studies, the data can be used to trigger more detailed investigations when appropriate.

Indeed, the sensitivity of the monitoring program at Station A was dramatically demonstrated in January 2001 when CEMRC found elevated gross beta radioactivity 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 Plutonium (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 February, 2009 April and 2010 July CEMRC again detected a small quantity of Pu in composite aerosol samples similar to the 2003 detection, also corroborated by WTS. Such small occasional detections are to be expected and the 2003, 2008, 2009 and 2010 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 filters (Versapor membrane filter, PALL Corporation) with the use of a shrouded probe, commonly referred to as a fixed air sampler or FAS. The airflow through the FAS is approximately 170 liters per minute.

There are actually three shrouded-probe aerosol samplers at Station A; these are located on three separate sampling skids denoted A1, A2, and A3 (Figure 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 organizations 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 during holidays, when a filter will often 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, Figure 1.3.

After the 2003 Pu hit, CEMRC implemented 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, they are counted for gross alpha/beta activities using a low-background gas proportional counter (LB4100 Canberra, and more recently starting in April 2006, a Protean MPC9604). The use of such a counter is described in an American National Standards Institute Publication (ANSI 1997). The gas proportional counter can operate in two modes: (1) alpha then beta and (2) alpha/beta (ANSI 1997). Mode (1) is more useful, as it allows simultaneous detection. In this case, the detector operates at the β- plateau, while alpha and beta particles can be distinguished by either pulse height or pulse shape or both (Currie and Lindstrom 1973; Wink et al. 1993). The main interference is from crosstalk or spillover in the case of pulse height or pulse shape, respectively. Gross screening analyses are not accurate nor as precise as more detailed radiochemical separations. Rather, they are intended to provide rapid information associated with a particular action level with minimal chemical preparation. Additionally, these types of analyses are not intended to give "absolute" activity measurements, but rather "order-of magnitude". Its main advantages are relatively low costs and simplicity, Semkow et al., 2004.

In preparation for gross alpha/beta counting, the filter is centered on a stainless steel planchet. The standard planchets for the alpha and beta were prepared from certified solutions of $^{239}$Pu and $^{90}$Sr/$^{90}$Y obtained from Analytics, Inc. (Atlanta, GA, USA). The planchet is counted on a low background gas proportional counter for 1200 minutes. The sample detectors are gas flow window type counters with an ultra-thin window. The counting gas was P-10, which is a mixture of 90% argon and 10% methane. The operating voltage on the detector was selected as 1,450V. All samples flow at a pressure slightly exceeding atmospheric. The window consists of 80 μg/cm Mylar foil with a tint of evaporated Au. The small size of the detector and the guard ensure a very low background in this system, ~0.5 and ~0.04 counts per minute for beta and alpha respectively. Daily performance checks are done using calibration sources, $^{239}$Pu for alpha and $^{90}$Sr/$^{90}$Y for beta, for efficiency control charting ($2\sigma$ warning and $3\sigma$ limits) and ensuring that alpha/beta cross-talk are within limits ($\leq 0\%$ $\alpha$ into beta and$\leq 0.1\%$ beta into alpha ). Sixty minutes background counts are also recorded daily (count must be within the mean background $\pm 3\sigma$) by counting an empty planchet. The self-absorption curve was obtained individually for alpha and beta and used for all sample counts. The mean counting efficiencies for the system are found to be 25% for alpha and 40% for beta.

Air filters were kept in desiccators for five days before counting to ensure complete decay of daughter products of $^{222}$Rn. Since the levels of radioactivity encountered in environmental samples are typically low, long counting time is often necessary. The detection limit, i.e., minimum detectable concentration (MDC), is calculated from a combination of instrument calibration parameters (efficiency, attenuation factor, background and background counting time) and sample parameters (residual mass, volume and sample counting time). The levels not detected or less than MDA occur when the activity concentration is less than calculated uncertainty.

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 (Bq/m$^3$). Second, *activity density* is calculated as the activity per unit aerosol mass collected (Bq/g). In 2010, the values of gross alpha activity concentration and density (Tables 1-1 and 1-2) ranged from <MDC (≈0.1 mBq/m$^3$) to 3.37 mBq/m$^3$ and <MDC (≈0.9 Bq/g) to 815 Bq/g, respectively. Values of gross beta activity concentration and density ranged from <MDC (≈0.2 mBq/m$^3$) to 4.41 mBq/m$^3$ and <MDC (≈1.7 Bq/g) to 4780 Bq/g, respectively.

Elemental analyses by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) are conducted on weekly composites of the filters. Individual FAS filters are digested using a mixture of strong acids in a MARS Express microwave digestion unit. Weekly composites are then prepared from the digestates of the individual filters and analyzed for a wide-range of metals using a Perkin-Elmer (Model Elan 6100), ICP-MS. The ICP-MS method can provide data for up to ~35 elements, but in practice the concentrations of some elements, including, but not limited to, 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 after metals analysis by ICP-MS. Quarterly composites were initially used for the determination of actinide activities, but monthly compositing was implemented in July of 2004 for better comparison with other groups who use monthly composites. These monthly composites are used for the determination of gamma emitter radionuclides using a low-background, high-purity Ge co-axial detector with a count time of 48 hours. The same monthly composites are also used for actinide analyses. Only one half of the composite sample is normally used for the determination of the actinide activities. The remaining aliquot is archived. The composite samples are spiked with appropriate tracers and are evaporated to dryness, and then 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 Iron (III) Oxide, $Fe(OH)_3$. After dissolution, Pu is separated by anion exchange, AG1-X8, while Am and U are separated on a TRU extraction chromatography 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.

## 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 1.4 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, but have gone back up above the pre-operational levels during 2007-2010. Gross alpha activities exhibit clear seasonal variability with peaks occurring in the winter (Figures 1.6 and 1.7). An especially pronounced annual cycle in alpha activity concentrations, with high values in December and January and low values mid-year was seen in 2004 to 2005 and again in 2007 to 2008. In 2010, activities appear to have gone back up to pre-operational levels and an overall slightly increasing trend can be seen over the years from 2003 to 2010.

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 2010. 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 consistent over the years. As shown in Figures 1.8 and 1.9, the beta density and concentration have not increased during the monitoring period. 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 through 2010. 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 $\leq$ 8% in the last seven years of the study compared with 10% to 20% in 1999, 2001, 2002 and 2010. 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.

The monthly average of gross alpha and gross beta activity concentrations measured in Station A samples from 1998 to 2010 are shown in Figures 1.10 and 1.11. Gross activity concentrations appear to increase during summer and autumn months. The annual average of gross alpha and beta activity concentration measured in Station A samples are shown in Figure 1.12. The activity concentrations of 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 2007 and 2008 began to increase again to pre-disposal levels, while beta activity remains slightly lower than pre-operational levels. The observed trends may be due to environmental phenomena, changes in WIPP operational practices, or a combination of these factors. The most noticeable decrease in these measurements appeared to coincide with increased mining activity at the WIPP. Plots of the frequency distribution show histograms for logarithms of gross alpha and gross beta activities in the analyzed WIPP exhaust air samples, Figures 1.13 and 1.14. The maximum detectable concentrations of gross alpha and beta as well as aerosol mass loading in Station A filters from 1998 to 2010 are summarized in Table 1-4. The high mass loading is usually associated with low gross alpha/beta activity. This is consistent with the previous studies in which it has been shown that WIPP salts contain lower amounts of naturally occurring radioactive elements (e.g., U and Th) than crustally derived materials (USDOE, 2000). This suggests that operations at the WIPP (e.g., salt from the underground mining, construction or road dust) may have generated some aerosols that contributed to the mass loadings but contain less naturally occurring radionuclides than ambient aerosols typically do. . It would be expected that as the proportion of salt per unit of aerosol mass increases, radioactivity per unit mass in WIPP effluents would decrease.

## ACTINIDE DATA

Results of actinide analyses performed on monthly FAS composite samples are presented in Table 1-5. 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 2010 samples except for the month of July 2010. The activity concentrations of $^{239+240}$Pu, $^{238}$Pu, $^{241}$Am and $^{137}$Cs measured in 2010 monthly composite samples are shown in Figures 1.15 to 1.18. For the month of July both primary and back-up samples showed $^{239+240}$Pu and $^{241}$Am activities above detection limits. Similar hits of $^{239+240}$Pu were also observed by WIPP Laboratories for the month of July 2010. The Pu hit of 2010 is similar to that which occurred during June 2003, February 2008, and April 2009 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 and $^{239+240}$Pu and $^{238}$Pu activity concentrations in the WIPP exhaust air from the period from 1998 to 2010 are shown in Figures 1.19 and 1.20, respectively. The concentrations of Pu and Am in 2003, 2008, and 2009 are above detection. In those years, only one of the composite samples had Pu and Am concentrations greater than the MDCs.

It is important to note that during the twelve years of environmental monitoring of the WIPP, CEMRC has detected only four composite samples, out of more than 100 tested, that were above MDCs. Individual hits in 2003, 2008, 2009 and 2010 are shown in Figure 1.20. Such small activity of Pu was also detected in one of the FAS composite sample in 2003, but unlike the sample in 2008, 2009 and 2010, Am was not detected. As can be seen in Figure 1.21, Pu is detected in primary as well as in back-up composite samples. However, these activities were extremely low and well below the action level of 37 Bq/m$^3$ that triggers the Continuous Air Alarms (CAMs) that are distributed throughout the WIPP.

As both $^{238}$Pu and $^{239+240}$Pu were detected above MDC in one composite from 2008 and 2009, activity ratios between $^{238}$Pu / $^{239+240}$Pu were calculated in order to understand the source of these radionuclides. The mean $^{238}$Pu /$^{239+240}$Pu activity ratio of 0.025±0.004 (Table 1-6) is indicative of their global fallout origin. Atmospheric nuclear tests have been the major source of radiological contamination to date in the environment. Approximately 6 tons of $^{239}$Pu were introduced into the environment from more than 500 atmospheric weapon tests conducted between 1945 and 1980 (Vincent et al., 1997). Fallout was distributed globally at an approximately 3:1 ratio between the northern hemisphere and the southern hemisphere. Additionally, local and regional contaminations of plutonium in the environment have resulted from nuclear accidents such as Chernobyl and Fukushima. These events resulted in the release of substantial quantities of radioactive contaminants into the global environment. Currently, $^{238}$Pu, $^{239}$Pu and $^{240}$Pu isotopes can be measured as traces in environmental samples with a $^{238}$Pu/$^{239+240}$Pu activity ratio of 0.03 at mean latitudes of 40°-50° N (UNSCEAR, 1982).

The naturally occurring isotopes of U were detected in all monthly FAS composites in 2010. The average $^{234}$U/$^{238}$U activity ratio of 1.48±0.16 in the WIPP underground air samples indicates the presence of natural U (Table 1-7). $^{234}$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 2010. The results of $^{137}$Cs, $^{60}$Co, and $^{40}$K in the monthly composites are summarized in Table 1-5. The minimum, maximum, and average concentrations of radionuclides for the 2010 FAS composite samples are summarized in Table 1-8.

## ELEMENTAL DATA

Prior studies at Station A have shown that 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 1.22-1.27 and their respective concentrations for 2010 FAS samples in Figures 1.28-1.33. 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 2010, concentrations for Cd, Th, and U never exceeded the MDC. The concentrations of Cd, Th, U regularly hover just above the MDC.

No marked differences are evident in the baseline vs. operational samples. Aluminum (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 uranium (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.

Wikipedia search on particulates: Sea salt is considered the second-largest contributor in the global aerosol budget, and consists mainly of sodium chloride originated from sea spray; other constituents of atmospheric sea salt reflect the composition of sea water, and thus include magnesium, sulfate, calcium, potassium, etc.

Several potentially toxic elements (i.e., Lead (Pb), Cadmium (Cd), Uranium (U), and Thorium (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**.

According to the Environmental Protection Agency, Lead (Pb) is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been from fuels in on-road motor vehicles (such as cars and trucks) and industrial sources. The major sources of lead emissions to the air today are from ore and metals processing and piston-engine aircraft operating on leaded aviation gasoline. The EPA primary standard (established limits to protect the public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly) for lead in ambient air is 0.15 ug/m$^3$ averaged over a rolling 3-month average. (U.S. Environmental Protection Agency, National Ambient Air Quality Standards, http://www.epa.gov/air/criteria.html). Even the highest measured concentration of lead (2001) in WIPP Exhaust Air is an order of magnitude below the EPA primary standard.

The increase in metal concentrations for December of 2010 is likely seasonal since the winter of 2010 was noticeably dryer and windier than in recent history. However, levels of Al, Cd, Mg, Pb, Th, and U, do not exceed pre-operational levels.

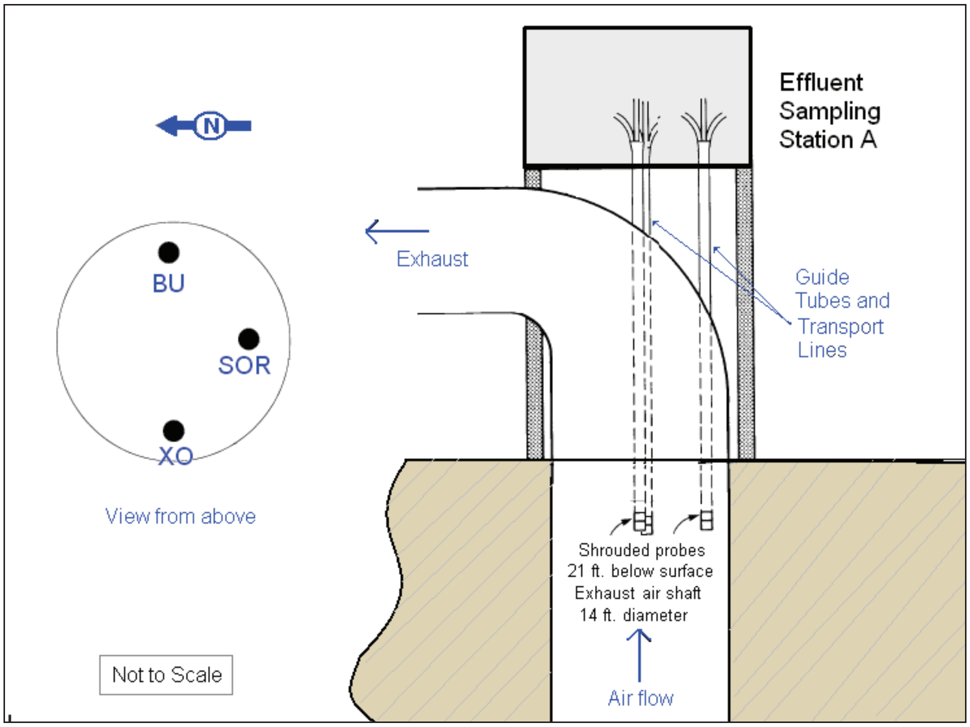

**Figure 1.1: Fixed Air Samplers at Station A**
BU: Backup, SOR: Skid of Record, XO: Extra Probe

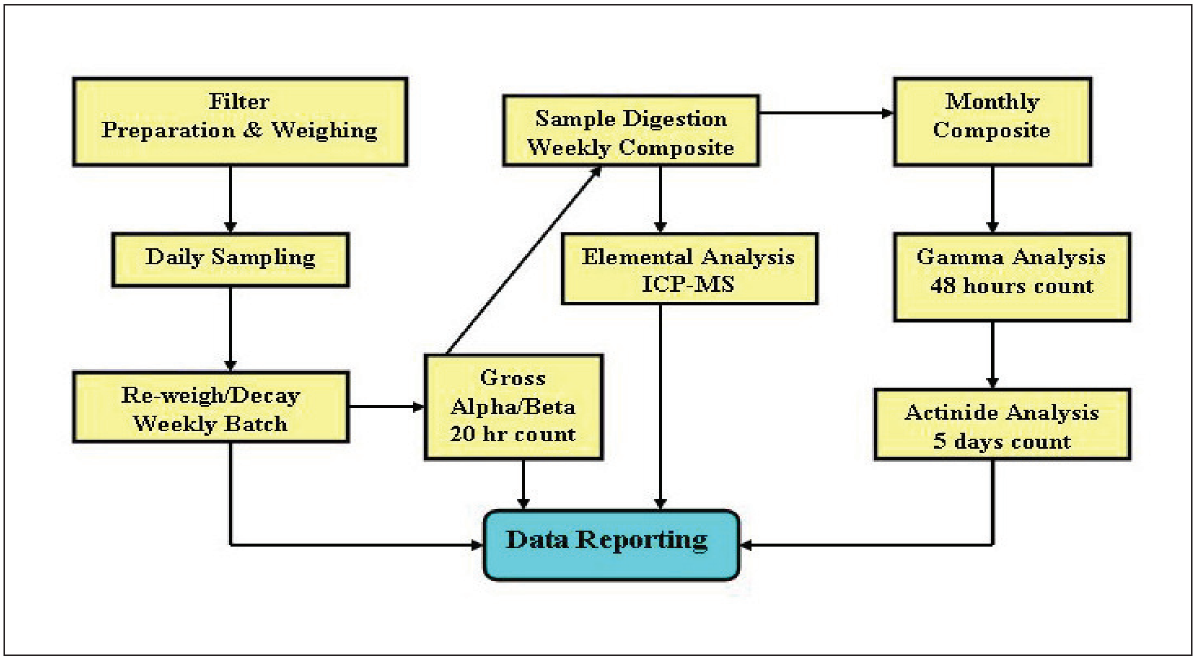

Figure 1.2: Flow Diagram Showing the Handling and Analysis of FAS Filters

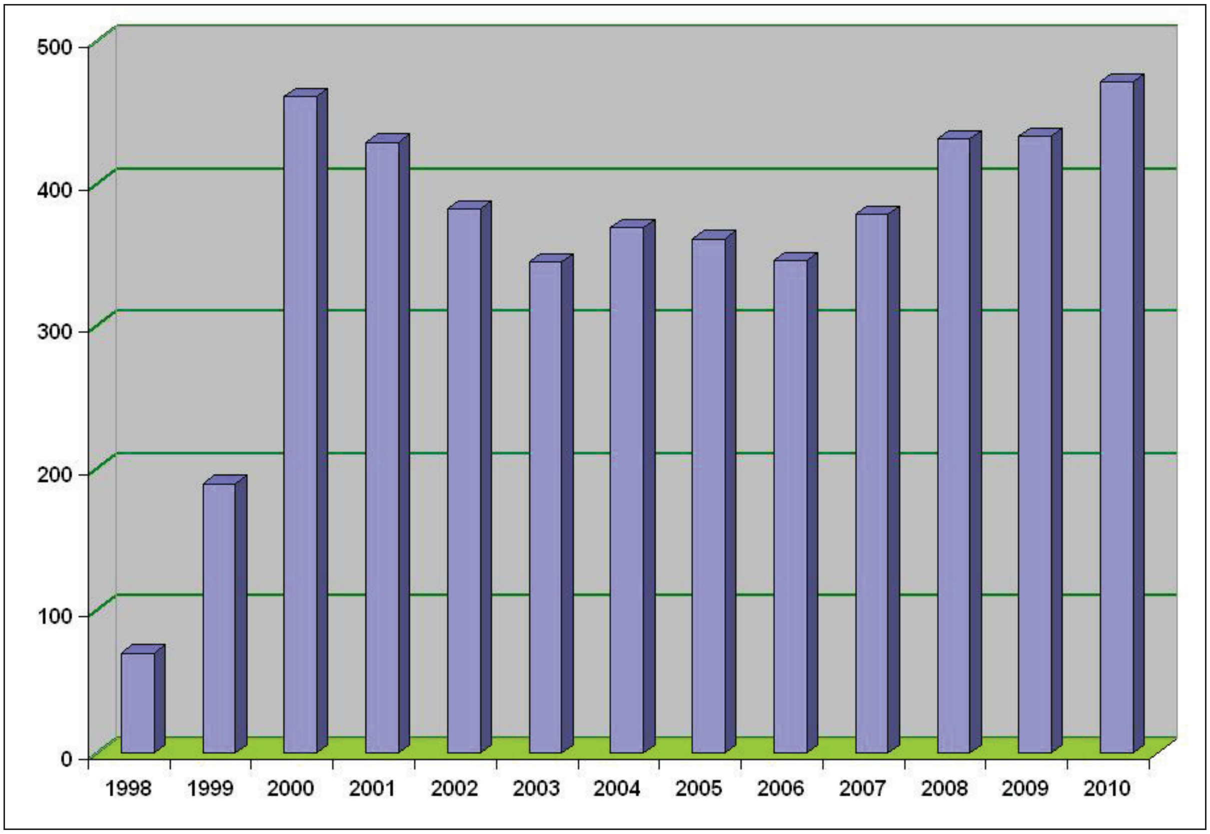

Figure 1.3: Number of FAS Filters Collected from Station A

## 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 | 1.20 | 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 |
| 2010 | 471 | 6% | 4.6 | 1.74 | 815.0 | 6% | 0.199 | 0.009 | 3.37 |

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/$m^3$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **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 |
| 2010 | 471 | 3% | 20.7 | 10.2 | 4780 | 3% | 0.65 | 0.03 | 4.41 |

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

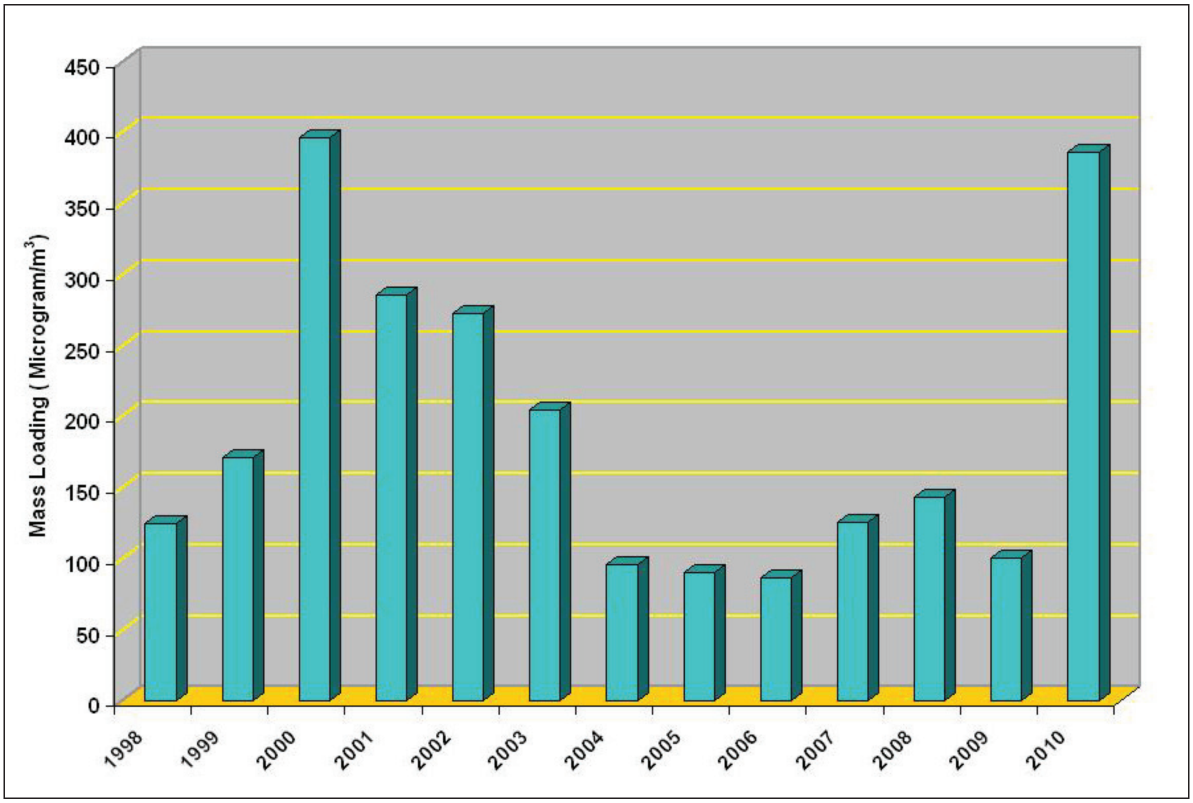

**Figure 1.4: Average Aerosol Mass Loadings on FAS Samples from Station A**

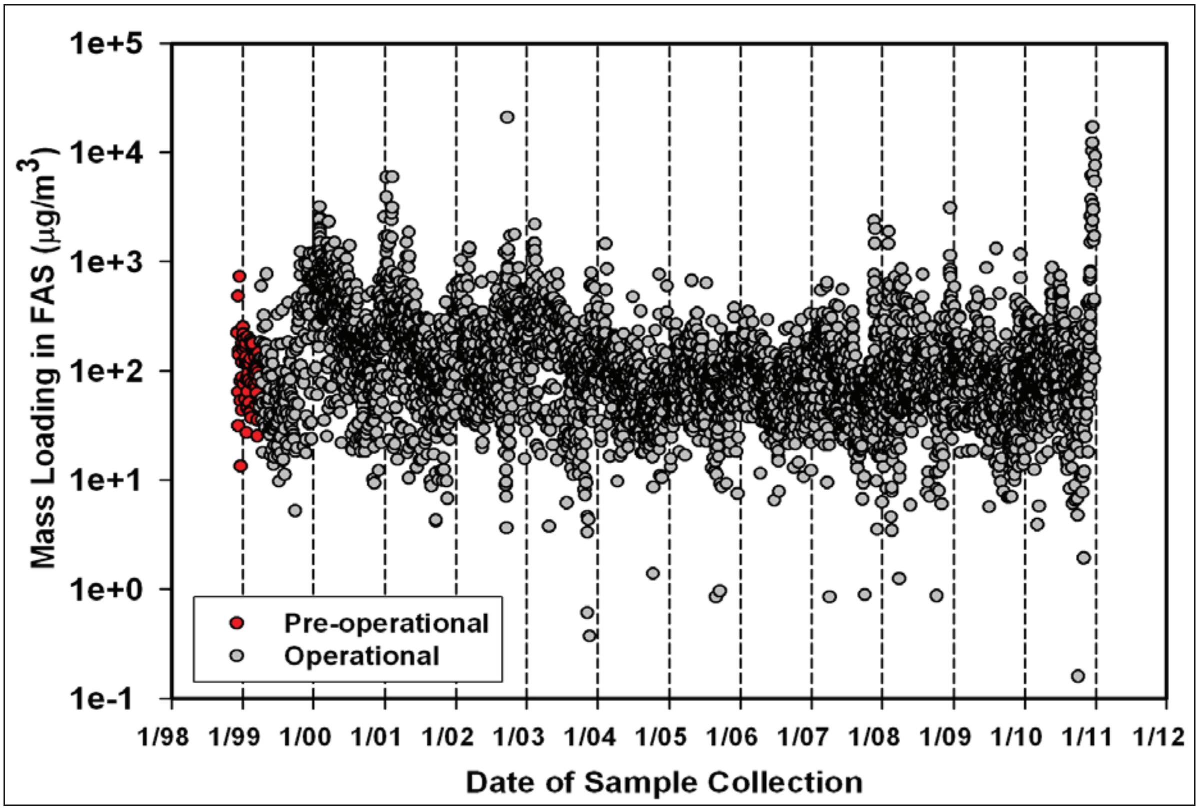

**Figure 1.5: Aerosol Mass Loadings in FAS Samples from Station A**

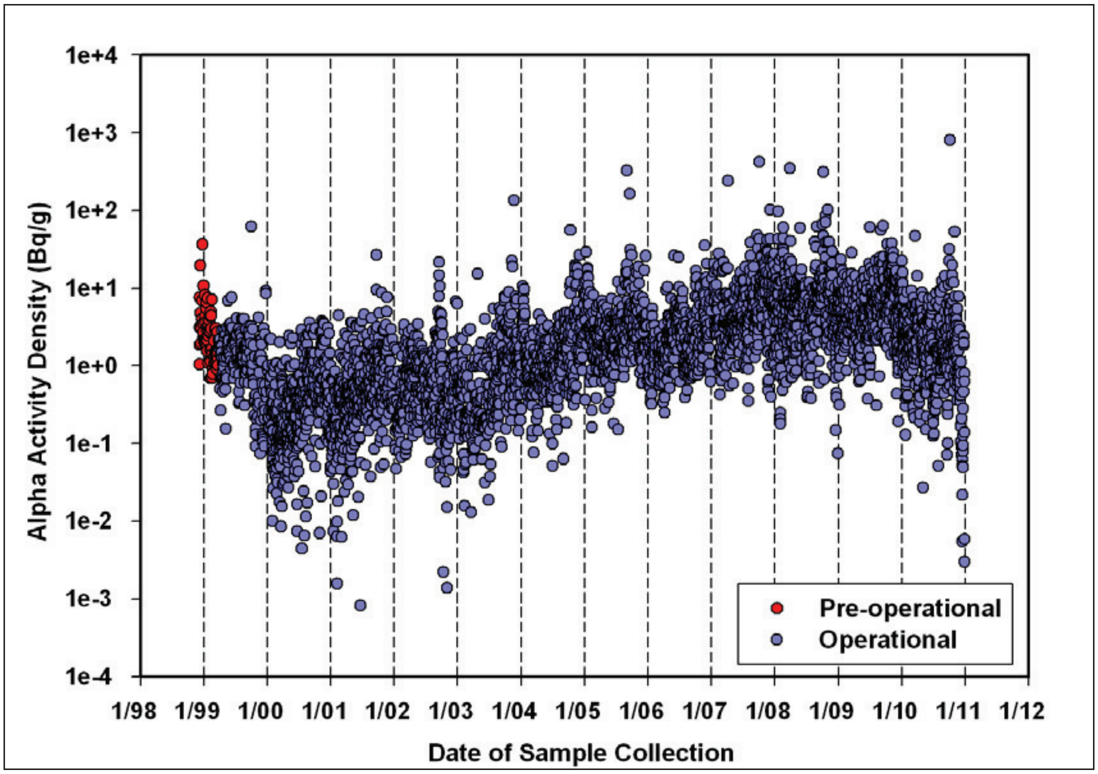

Figure 1.6: Gross Alpha Activity Densities in FAS Samples

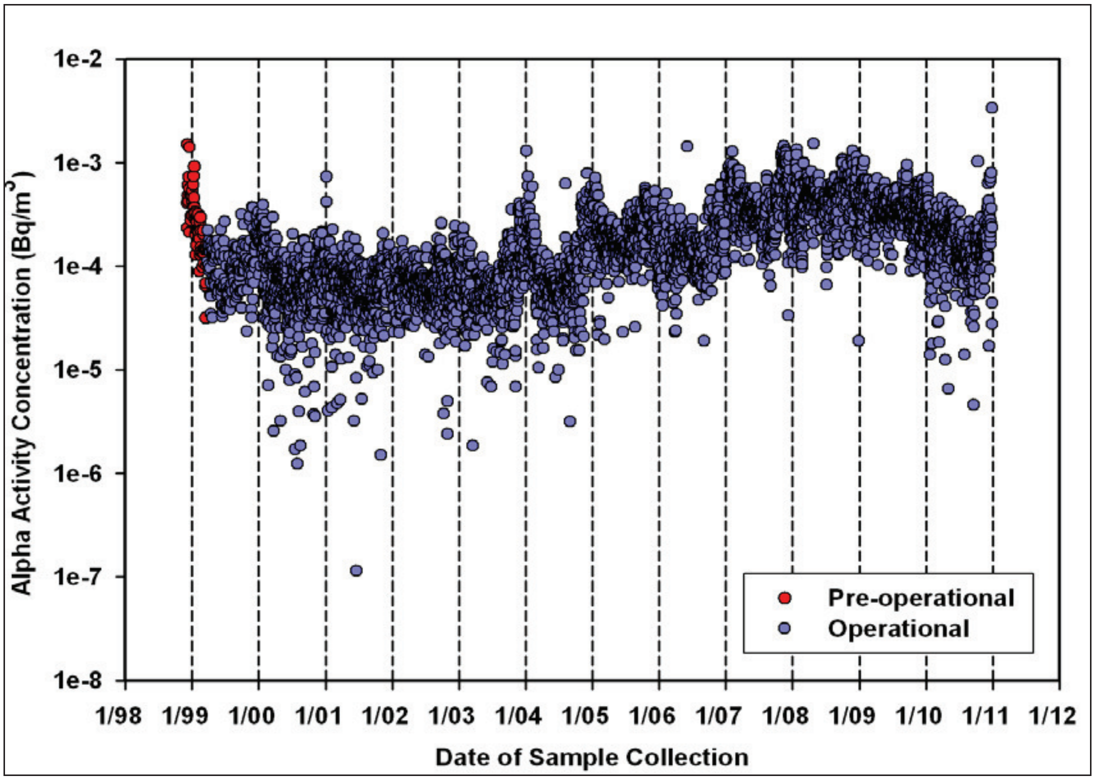

Figure 1.7: Gross Alpha Activity Concentrations in FAS Samples

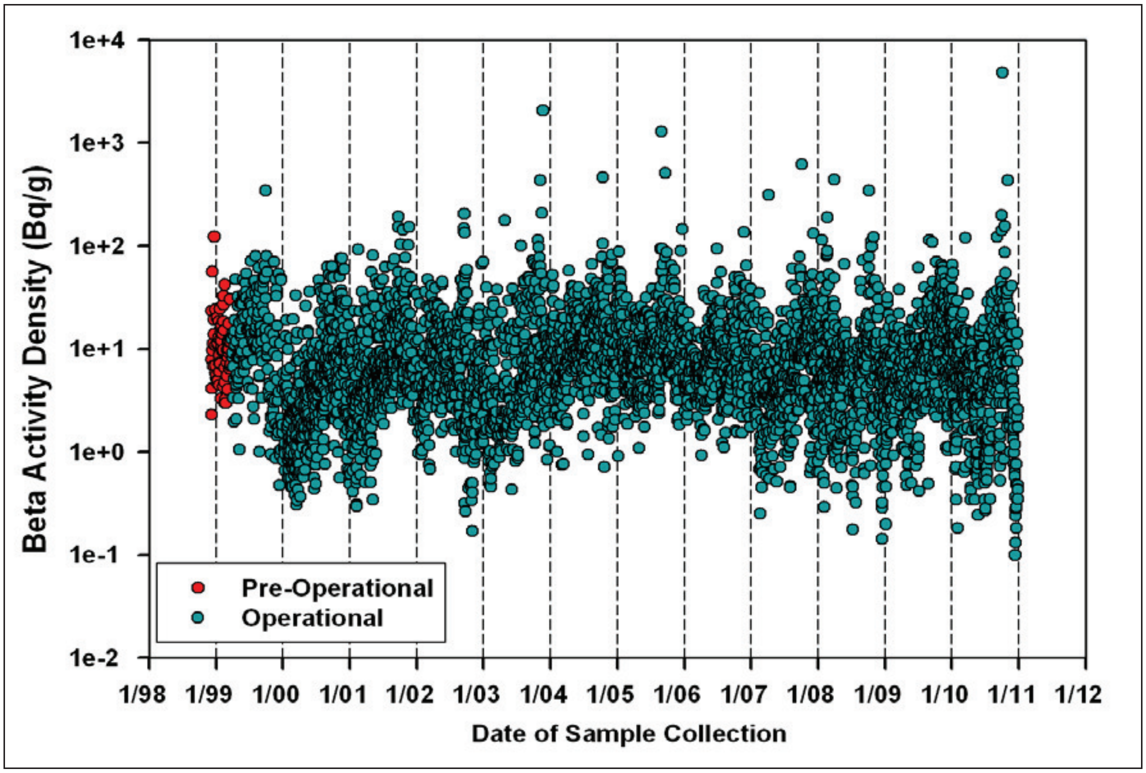

Figure 1.8: Gross Beta Activity Densities in FAS Samples

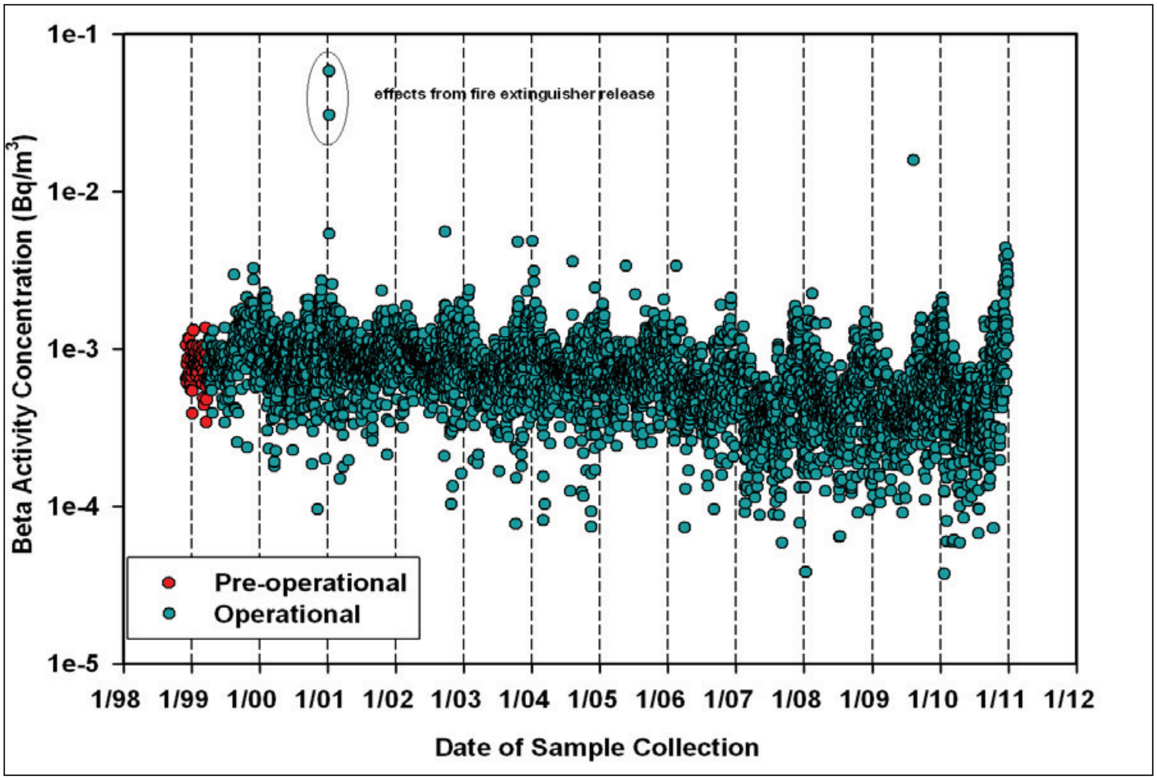

Figure 1.9: Gross Beta Activity Concentrations in FAS Samples

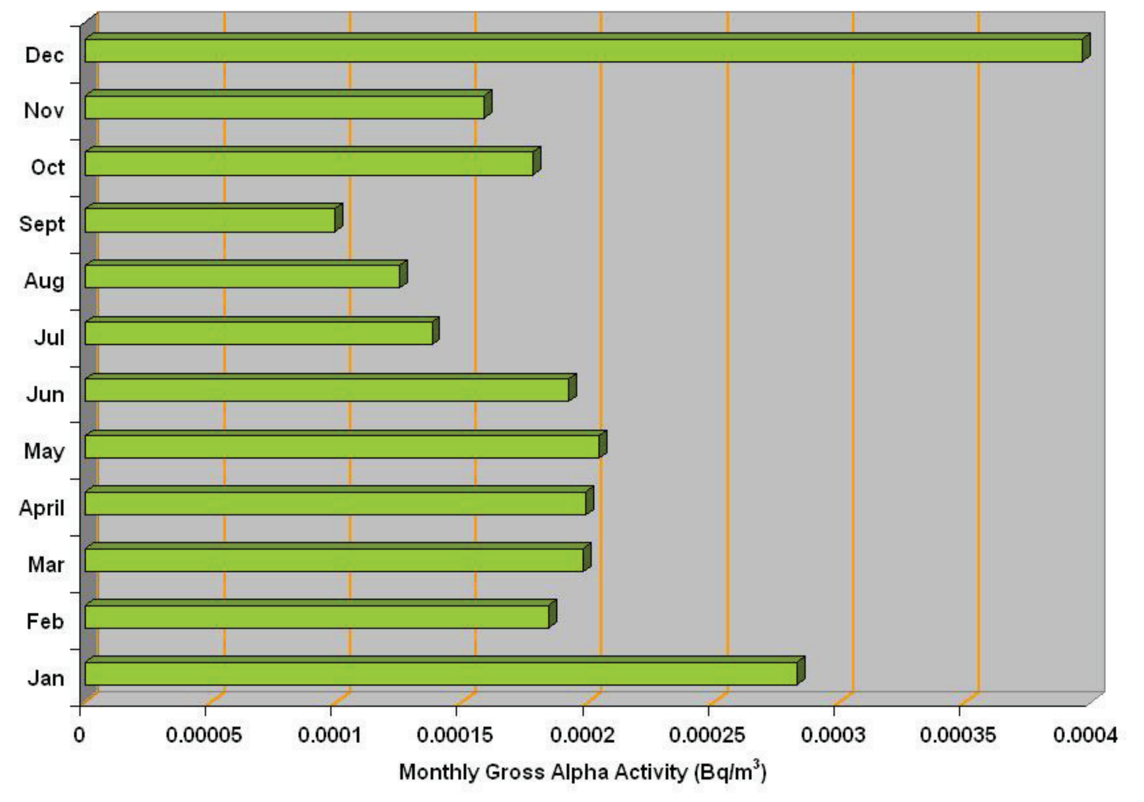

Figure 1.10: Monthly Average Gross Alpha Activity Concentrations in FAS Samples in 2010

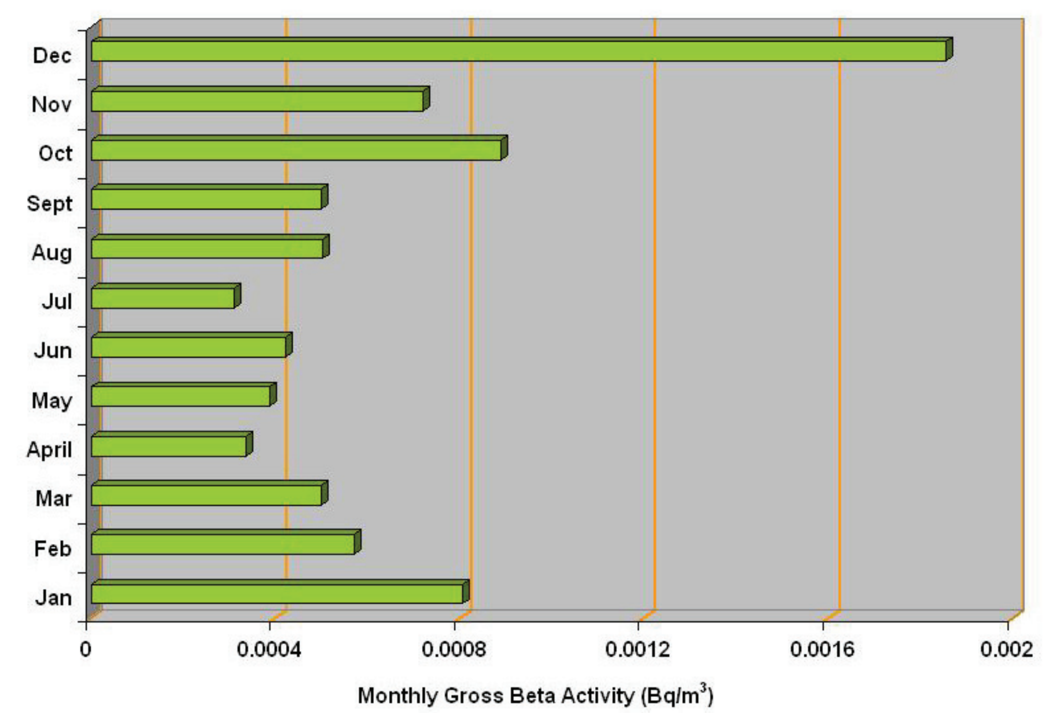

Figure 1.11: Monthly Average Gross Beta Activity Concentrations in FAS Samples in 2010

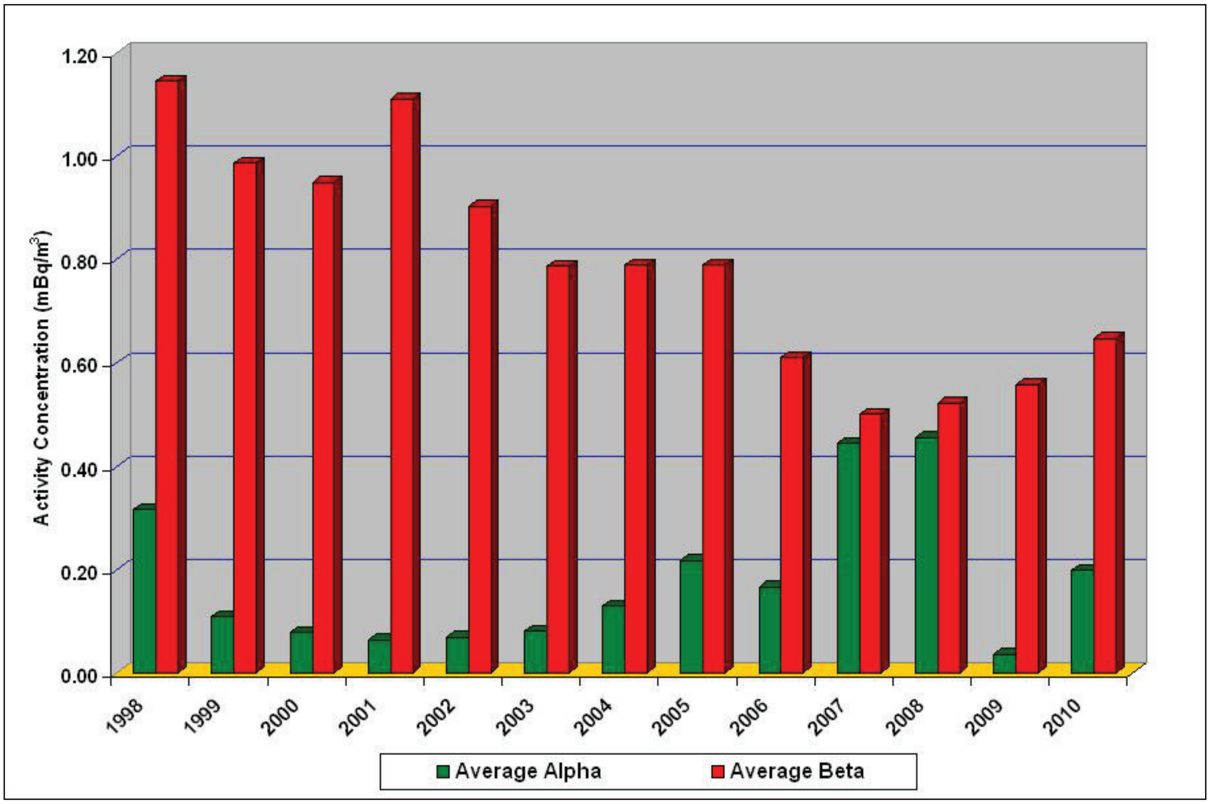

Figure 1.12: Average Alpha and Beta Activity Concentrations in FAS Filters

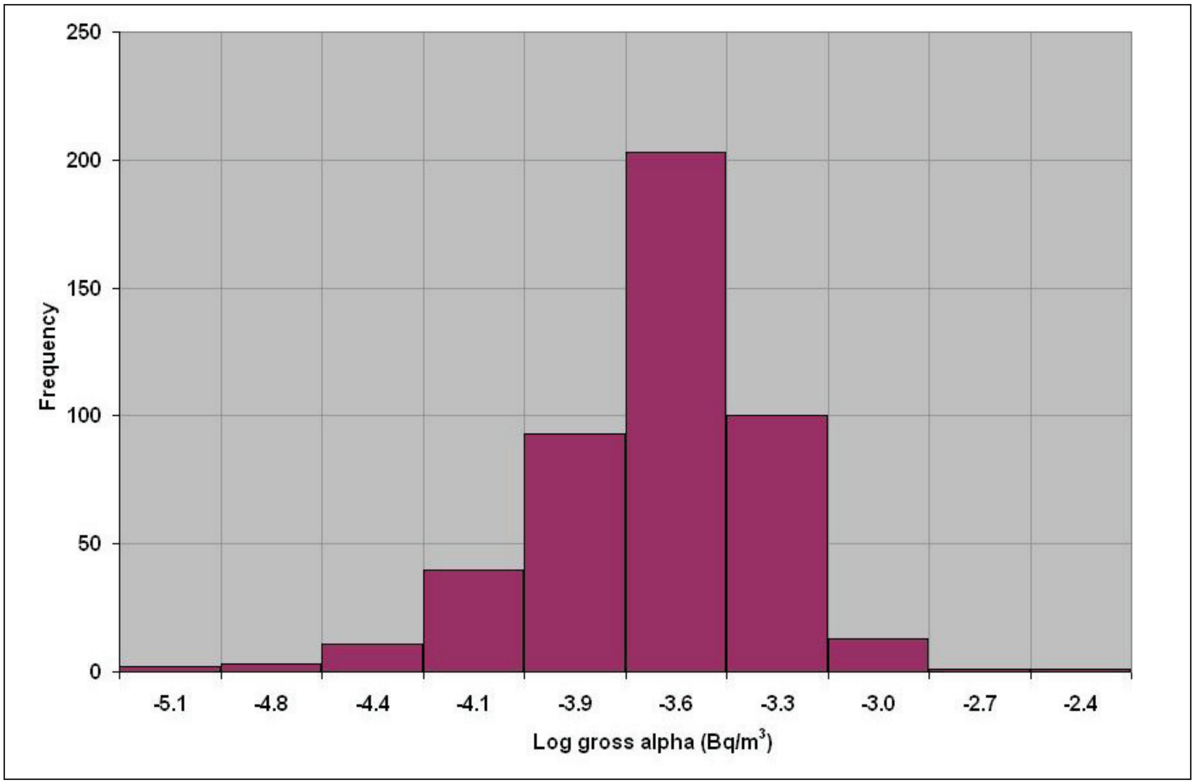

Figure 1.13: Frequency Distribution Histogram of Gross Alpha Activities

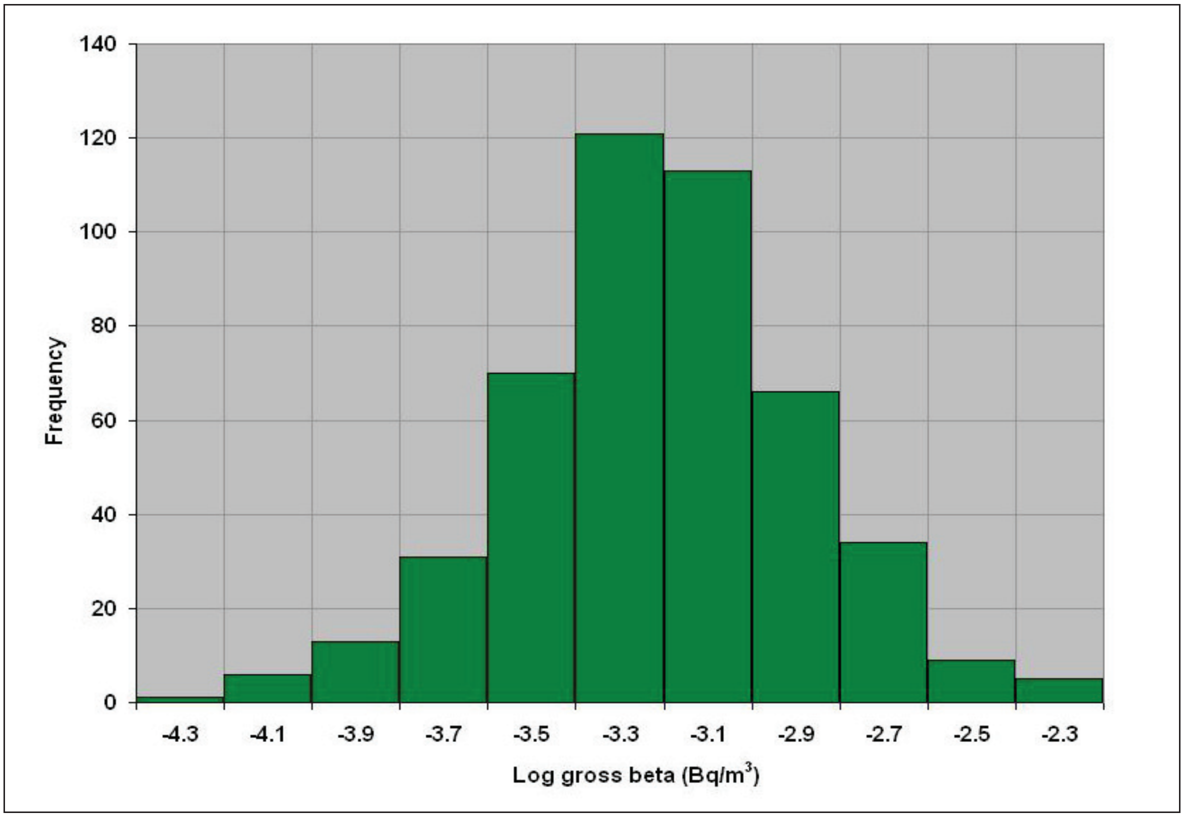

Figure 1.14: Frequency Distribution Histogram of Gross Beta Activities

### Table 1-3: Summary Statistics for Aerosol Mass Loadings on FAS Filters (µg/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 |
| 2010 | 471 | 385.5 | 70.5 | 18.3 |

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

### Table 1-4: Summary Statistics of Maximum Gross Alpha and Beta Activities and the Corresponding Mass Loading on the FAS Filters from 1998-2010

| Year | Max. mass loading (mg) | Alpha activity Bq | Beta activity Bq | Max. alpha activity, Bq | Mass Loading (mg) | Max. beta activity, Bq | Mass loading (mg) |
|---|---|---|---|---|---|---|---|
| 1998 | 26.23 | 0.036 | 0.124 | 0.181 | 4.94 | 0.606 | 4.94 |
| 1999 | 87.66 | 0.008 | 0.042 | 0.067 | 7.84 | 0.430 | 7.98 |
| 2000 | 87.94 | 0.014 | 0.073 | 0.065 | 24.77 | 0.759 | 12.90 |
| 2001 | 307.51 | 0.016 | 0.237 | 0.030 | 19.32 | 0.491 | 3.21 |
| 2002 | 148.85 | 0.000 | 0.025 | 0.029 | 17.95 | 0.500 | 17.95 |
| 2003 | 92.68 | 0.013 | 0.156 | 0.035 | 69.20 | 0.248 | 10.82 |
| 2004 | 79.02 | 0.041 | 0.116 | 0.083 | 8.45 | 0.260 | 8.90 |
| 2005 | 31.73 | 0.021 | 0.068 | 0.106 | 19.93 | 0.355 | 19.93 |
| 2006 | 79.44 | 0.021 | 0.057 | 0.122 | 4.65 | 0.282 | 2.08 |
| 2007 | 76.46 | 0.037 | 0.048 | 0.125 | 4.22 | 0.162 | 4.22 |
| 2008 | 121.58 | 0.018 | 0.035 | 0.161 | 5.42 | 0.213 | 5.42 |
| 2009 | 32.52 | 0.034 | 0.036 | 0.085 | 10.56 | 0.301 | 24.91 |
| 2010 | 321.2 | 0.0003 | 0.032 | 0.188 | 302.1 | 0.197 | 89.5 |

## Table 1-5: 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 2010** | | | | | | |
| $^{241}$Am | 2.50E-09 | 1.66E-08 | 7.06E-08 | 2.52E-05 | 1.68E-04 | 7.13E-04 |
| $^{238}$Pu | 1.16E-08 | 3.07E-08 | 1.25E-07 | 1.17E-04 | 3.10E-04 | 1.26E-03 |
| $^{239+240}$Pu | 3.48E-08 | 3.85E-08 | 1.39E-07 | 3.52E-04 | 3.89E-04 | 1.41E-03 |
| $^{234}$U | 3.93E-07 | 7.20E-08 | 1.28E-07 | 3.97E-03 | 7.27E-04 | 1.29E-03 |
| $^{235}$U | 1.31E-08 | 4.74E-08 | 1.85E-07 | 1.33E-04 | 4.79E-04 | 1.87E-03 |
| $^{238}$U | 2.23E-07 | 5.74E-08 | 1.27E-07 | 2.25E-03 | 5.80E-04 | 1.29E-03 |
| $^{137}$Cs | -2.37E-05 | 1.87E-05 | 6.23E-05 | -2.39E-01 | 1.89E-01 | 6.29E-01 |
| $^{40}$K | -2.62E-04 | 1.82E-04 | 6.12E-04 | -2.65E+00 | 1.84E+00 | 6.18E+00 |
| $^{60}$Co | 6.15E-07 | 1.31E-05 | 5.68E-05 | 6.21E-03 | 1.32E-01 | 5.74E-01 |
| **February 2010** | | | | | | |
| $^{241}$Am | -4.82E-09 | 2.09E-08 | 8.65E-08 | -5.29E-05 | 2.29E-04 | 9.49E-04 |
| $^{238}$Pu | -5.16E-08 | 2.86E-08 | 1.37E-07 | -5.66E-04 | 3.13E-04 | 1.51E-03 |
| $^{239+240}$Pu | 6.82E-08 | 3.00E-08 | 8.28E-08 | 7.48E-04 | 3.29E-04 | 9.09E-04 |
| $^{234}$U | 3.15E-07 | 6.04E-08 | 1.26E-07 | 3.45E-03 | 6.63E-04 | 1.38E-03 |
| $^{235}$U | 2.07E-08 | 2.54E-08 | 9.63E-08 | 2.28E-04 | 2.79E-04 | 1.06E-03 |
| $^{238}$U | 2.43E-07 | 5.75E-08 | 1.40E-07 | 2.66E-03 | 6.31E-04 | 1.53E-03 |
| $^{137}$Cs | 6.21E-07 | 1.45E-05 | 4.82E-05 | 6.81E-03 | 1.59E-01 | 5.29E-01 |
| $^{40}$K | 2.72E-04 | 1.90E-04 | 6.26E-04 | 2.99E+00 | 2.08E+00 | 6.86E+00 |
| $^{60}$Co | -4.47E-06 | 1.20E-05 | 5.20E-05 | -4.90E-02 | 1.32E-01 | 5.70E-01 |
| **March 2010** | | | | | | |
| $^{241}$Am | -4.82E-08 | 2.30E-08 | 1.22E-07 | -4.30E-04 | 2.05E-04 | 1.09E-03 |
| $^{238}$Pu | 1.59E-08 | 4.21E-08 | 1.71E-07 | 1.42E-04 | 3.75E-04 | 1.53E-03 |
| $^{239+240}$Pu | 1.11E-07 | 6.16E-08 | 1.91E-07 | 9.93E-04 | 5.50E-04 | 1.70E-03 |
| $^{234}$U | 4.93E-07 | 6.94E-08 | 1.08E-07 | 4.40E-03 | 6.20E-04 | 9.61E-04 |
| $^{235}$U | 6.09E-08 | 2.88E-08 | 7.47E-08 | 5.44E-04 | 2.57E-04 | 6.67E-04 |
| $^{238}$U | 1.64E-07 | 4.65E-08 | 1.16E-07 | 1.46E-03 | 4.15E-04 | 1.03E-03 |
| $^{137}$Cs | 8.44E-06 | 1.33E-05 | 4.40E-05 | 7.54E-02 | 1.19E-01 | 3.93E-01 |
| $^{40}$K | -4.08E-05 | 1.84E-04 | 6.13E-04 | -3.64E-01 | 1.64E+00 | 5.47E+00 |
| $^{60}$Co | -1.16E-05 | 1.12E-05 | 5.02E-05 | -1.03E-01 | 1.00E-01 | 4.48E-01 |
| **April 2010** | | | | | | |
| $^{241}$Am | 1.81E-09 | 1.62E-08 | 6.60E-08 | 2.08E-05 | 1.86E-04 | 7.56E-04 |
| $^{238}$Pu | 0.00E+00 | 2.06E-08 | 8.74E-08 | 0.00E+00 | 2.35E-04 | 1.00E-03 |
| $^{239+240}$Pu | 5.21E-08 | 2.83E-08 | 8.74E-08 | 5.96E-04 | 3.24E-04 | 1.00E-03 |
| $^{234}$U | 3.17E-07 | 4.82E-08 | 5.07E-08 | 3.63E-03 | 5.52E-04 | 5.80E-04 |
| $^{235}$U | 5.91E-08 | 3.07E-08 | 9.17E-08 | 6.76E-04 | 3.51E-04 | 1.05E-03 |
| $^{238}$U | 1.72E-07 | 3.85E-08 | 7.40E-08 | 1.97E-03 | 4.40E-04 | 8.47E-04 |
| $^{137}$Cs | 2.46E-05 | 1.31E-05 | 4.30E-05 | 2.82E-01 | 1.50E-01 | 4.91E-01 |
| $^{40}$K | -1.25E-05 | 1.82E-04 | 6.06E-04 | -1.43E-01 | 2.09E+00 | 6.94E+00 |
| $^{60}$Co | -5.63E-06 | 1.11E-05 | 5.03E-05 | -6.44E-02 | 1.27E-01 | 5.76E-01 |

## Table 1-5: 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 2010** | | | | | | |
| $^{241}$Am | 2.82E-09 | 1.54E-08 | 6.53E-08 | 1.57E-05 | 8.53E-05 | 3.62E-04 |
| $^{238}$Pu | -7.04E-14 | 2.48E-08 | 1.09E-07 | -3.91E-10 | 1.38E-04 | 6.06E-04 |
| $^{239+240}$Pu | -1.01E-08 | 3.36E-08 | 1.43E-07 | -5.63E-05 | 1.87E-04 | 7.94E-04 |
| $^{234}$U | 3.61E-07 | 6.58E-08 | 1.28E-07 | 2.01E-03 | 3.65E-04 | 7.13E-04 |
| $^{235}$U | 2.01E-08 | 2.70E-08 | 1.04E-07 | 1.12E-04 | 1.50E-04 | 5.77E-04 |
| $^{238}$U | 2.89E-07 | 5.60E-08 | 9.73E-08 | 1.61E-03 | 3.11E-04 | 5.40E-04 |
| $^{137}$Cs | -3.43E-06 | 1.48E-05 | 4.93E-05 | -1.90E-02 | 8.21E-02 | 2.74E-01 |
| $^{40}$K | 2.52E-04 | 1.87E-04 | 6.15E-04 | 1.40E+00 | 1.04E+00 | 3.42E+00 |
| $^{60}$Co | 1.27E-05 | 1.11E-05 | 4.85E-05 | 7.07E-02 | 6.17E-02 | 2.69E-01 |
| **June 2010** | | | | | | |
| $^{241}$Am | 2.11E-09 | 1.51E-08 | 6.28E-08 | 2.30E-05 | 1.65E-04 | 6.84E-04 |
| $^{238}$Pu | 7.46E-09 | 1.97E-08 | 8.03E-08 | 8.12E-05 | 2.15E-04 | 8.74E-04 |
| $^{239+240}$Pu | -1.77E-08 | 2.40E-08 | 1.08E-07 | -1.92E-04 | 2.61E-04 | 1.17E-03 |
| $^{234}$U | 2.38E-07 | 4.46E-08 | 7.51E-08 | 2.59E-03 | 4.85E-04 | 8.17E-04 |
| $^{235}$U | 1.72E-08 | 2.11E-08 | 8.01E-08 | 1.88E-04 | 2.30E-04 | 8.72E-04 |
| $^{238}$U | 1.60E-07 | 3.77E-08 | 7.49E-08 | 1.74E-03 | 4.10E-04 | 8.16E-04 |
| $^{137}$Cs | 2.24E-05 | 1.39E-05 | 4.59E-05 | 2.43E-01 | 1.52E-01 | 4.99E-01 |
| $^{40}$K | 5.93E-04 | 1.29E-04 | 4.12E-04 | 6.46E+00 | 1.41E+00 | 4.49E+00 |
| $^{60}$Co | 8.58E-06 | 1.08E-05 | 4.60E-05 | 9.34E-02 | 1.17E-01 | 5.01E-01 |
| **July 2010** | | | | | | |
| $^{241}$Am | 1.54E-07 | 4.67E-08 | 1.12E-07 | 6.32E-04 | 1.91E-04 | 4.56E-04 |
| $^{238}$Pu | -6.05E-08 | 5.33E-08 | 2.64E-07 | -2.47E-04 | 2.18E-04 | 1.08E-03 |
| $^{239+240}$Pu | 1.03E-06 | 1.71E-07 | 3.51E-07 | 4.20E-03 | 6.99E-04 | 1.44E-03 |
| $^{234}$U | 5.14E-07 | 7.49E-08 | 1.23E-07 | 2.10E-03 | 3.06E-04 | 5.03E-04 |
| $^{235}$U | 5.39E-08 | 2.86E-08 | 7.93E-08 | 2.21E-04 | 1.17E-04 | 3.25E-04 |
| $^{238}$U | 3.57E-07 | 6.64E-08 | 1.38E-07 | 1.46E-03 | 2.72E-04 | 5.63E-04 |
| $^{137}$Cs | 6.66E-06 | 2.12E-05 | 7.03E-05 | 2.73E-02 | 8.68E-02 | 2.88E-01 |
| $^{40}$K | -4.63E-05 | 2.04E-04 | 6.81E-04 | -1.89E-01 | 8.36E-01 | 2.78E+00 |
| $^{60}$Co | -6.04E-06 | 1.42E-05 | 6.07E-05 | -2.47E-02 | 5.81E-02 | 2.49E-01 |
| **July 2010 BU** | | | | | | |
| $^{241}$Am | 1.30E-07 | 3.68E-08 | 6.38E-08 | 7.96E-04 | 2.26E-04 | 3.92E-04 |
| $^{238}$Pu | 1.06E-08 | 1.49E-08 | 2.86E-08 | 6.49E-05 | 9.18E-05 | 1.76E-04 |
| $^{239+240}$Pu | 7.29E-07 | 9.25E-08 | 1.14E-07 | 4.48E-03 | 5.68E-04 | 6.98E-04 |
| $^{234}$U | 4.78E-07 | 9.25E-08 | 1.93E-07 | 2.94E-03 | 5.68E-04 | 1.18E-03 |
| $^{235}$U | 7.94E-08 | 4.76E-08 | 1.47E-07 | 4.87E-04 | 2.93E-04 | 9.05E-04 |
| $^{238}$U | 1.54E-07 | 7.02E-08 | 2.13E-07 | 9.44E-04 | 4.31E-04 | 1.31E-03 |
| **August 2010** | | | | | | |
| $^{241}$Am | -5.18E-09 | 1.93E-08 | 7.74E-08 | -7.25E-05 | 2.70E-04 | 1.08E-03 |
| $^{238}$Pu | 2.88E-08 | 2.88E-08 | 1.06E-07 | 4.03E-04 | 4.03E-04 | 1.48E-03 |
| $^{239+240}$Pu | 2.88E-08 | 4.99E-08 | 1.89E-07 | 4.03E-04 | 6.98E-04 | 2.64E-03 |
| $^{234}$U | 4.21E-07 | 6.20E-08 | 9.19E-08 | 5.89E-03 | 8.67E-04 | 1.29E-03 |
| $^{235}$U | 9.46E-09 | 2.84E-08 | 1.14E-07 | 1.32E-04 | 3.97E-04 | 1.59E-03 |
| $^{238}$U | 4.20E-07 | 6.09E-08 | 8.22E-08 | 5.88E-03 | 8.52E-04 | 1.15E-03 |
| $^{137}$Cs | -3.90E-06 | 1.93E-05 | 6.41E-05 | -5.45E-02 | 2.70E-01 | 8.96E-01 |
| $^{40}$K | -1.58E-04 | 1.90E-04 | 6.36E-04 | -2.21E+00 | 2.66E+00 | 8.89E+00 |
| $^{60}$Co | -1.03E-05 | 1.29E-05 | 5.65E-05 | -1.44E-01 | 1.81E-01 | 7.90E-01 |

## Table 1-5: 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 2010** | | | | | | |
| $^{241}$Am | 3.98E-08 | 2.51E-08 | 7.48E-08 | 4.96E-04 | 3.12E-04 | 9.31E-04 |
| $^{238}$Pu | 9.14E-09 | 3.03E-08 | 1.20E-07 | 1.14E-04 | 3.78E-04 | 1.49E-03 |
| $^{239+240}$Pu | 1.28E-07 | 4.84E-08 | 1.37E-07 | 1.59E-03 | 6.03E-04 | 1.71E-03 |
| $^{234}$U | 3.61E-07 | 9.66E-08 | 2.32E-07 | 4.50E-03 | 1.20E-03 | 2.89E-03 |
| $^{235}$U | 1.42E-07 | 6.11E-08 | 1.49E-07 | 1.77E-03 | 7.62E-04 | 1.86E-03 |
| $^{238}$U | 1.64E-07 | 8.36E-08 | 2.59E-07 | 2.04E-03 | 1.04E-03 | 3.23E-03 |
| $^{137}$Cs | -2.64E-05 | 2.00E-05 | 6.66E-05 | -3.28E-01 | 2.49E-01 | 8.30E-01 |
| $^{40}$K | -3.01E-05 | 1.93E-04 | 6.42E-04 | -3.75E-01 | 2.40E+00 | 7.99E+00 |
| $^{60}$Co | -5.69E-06 | 1.32E-05 | 5.73E-05 | -7.08E-02 | 1.65E-01 | 7.14E-01 |
| **October 2010** | | | | | | |
| $^{241}$Am | 1.48E-08 | 1.60E-08 | 4.80E-08 | 2.12E-04 | 2.29E-04 | 6.87E-04 |
| $^{238}$Pu | 2.58E-08 | 2.23E-08 | 3.48E-08 | 3.69E-04 | 3.19E-04 | 4.99E-04 |
| $^{239+240}$Pu | 1.81E-08 | 5.84E-08 | 2.20E-07 | 2.58E-04 | 8.37E-04 | 3.16E-03 |
| $^{234}$U | 4.38E-07 | 5.73E-08 | 7.27E-08 | 6.28E-03 | 8.20E-04 | 1.04E-03 |
| $^{235}$U | 0.00E+00 | 1.67E-08 | 7.75E-08 | 0.00E+00 | 2.39E-04 | 1.11E-03 |
| $^{238}$U | 2.56E-07 | 5.06E-08 | 1.12E-07 | 3.67E-03 | 7.24E-04 | 1.61E-03 |
| $^{137}$Cs | -1.44E-06 | 1.96E-05 | 6.50E-05 | -2.07E-02 | 2.80E-01 | 9.31E-01 |
| $^{40}$K | -4.17E-05 | 1.88E-04 | 6.25E-04 | -5.96E-01 | 2.69E+00 | 8.95E+00 |
| $^{60}$Co | -3.00E-06 | 1.28E-05 | 5.51E-05 | -4.30E-02 | 1.83E-01 | 7.88E-01 |
| **November 2010** | | | | | | |
| $^{241}$Am | -6.85E-09 | 2.20E-08 | 8.96E-08 | -6.95E-05 | 2.24E-04 | 9.10E-04 |
| $^{238}$Pu | 2.12E-08 | 4.25E-08 | 1.59E-07 | 2.16E-04 | 4.31E-04 | 1.62E-03 |
| $^{239+240}$Pu | 0.00E+00 | 2.60E-08 | 1.14E-07 | 0.00E+00 | 2.64E-04 | 1.16E-03 |
| $^{234}$U | 2.11E-07 | 5.82E-08 | 1.38E-07 | 2.14E-03 | 5.91E-04 | 1.40E-03 |
| $^{235}$U | 5.22E-08 | 4.52E-08 | 1.57E-07 | 5.30E-04 | 4.59E-04 | 1.59E-03 |
| $^{238}$U | 1.79E-07 | 5.08E-08 | 1.13E-07 | 1.82E-03 | 5.16E-04 | 1.15E-03 |
| $^{137}$Cs | -2.65E-05 | 1.95E-05 | 6.50E-05 | -2.69E-01 | 1.98E-01 | 6.60E-01 |
| $^{40}$K | -2.00E-04 | 1.87E-04 | 6.26E-04 | -2.03E+00 | 1.90E+00 | 6.36E+00 |
| $^{60}$Co | -1.30E-05 | 1.28E-05 | 5.46E-05 | -1.32E-01 | 1.30E-01 | 5.54E-01 |
| **December 2010** | | | | | | |
| $^{241}$Am | 4.62E-08 | 3.35E-08 | 9.32E-08 | 1.44E-05 | 1.05E-05 | 2.92E-05 |
| $^{238}$Pu | 7.19E-08 | 4.40E-08 | 1.32E-07 | 2.25E-05 | 1.38E-05 | 4.14E-05 |
| $^{239+240}$Pu | 0.00E+00 | 2.54E-08 | 1.32E-07 | 0.00E+00 | 7.96E-06 | 4.14E-05 |
| $^{234}$U | 5.02E-06 | 3.91E-07 | 2.88E-07 | 1.57E-03 | 1.22E-04 | 9.03E-05 |
| $^{235}$U | 3.32E-07 | 1.24E-07 | 3.08E-07 | 1.04E-04 | 3.89E-05 | 9.63E-05 |
| $^{238}$U | 3.79E-06 | 3.50E-07 | 4.46E-07 | 1.19E-03 | 1.09E-04 | 1.39E-04 |
| $^{137}$Cs | -3.49E-05 | 2.76E-05 | 9.20E-05 | -1.09E-02 | 8.64E-03 | 2.88E-02 |
| $^{40}$K | 4.59E-04 | 2.71E-04 | 8.92E-04 | 1.44E-01 | 8.49E-02 | 2.79E-01 |
| $^{60}$Co | 9.94E-06 | 1.80E-05 | 7.97E-05 | 3.11E-03 | 5.64E-03 | 2.50E-02 |

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

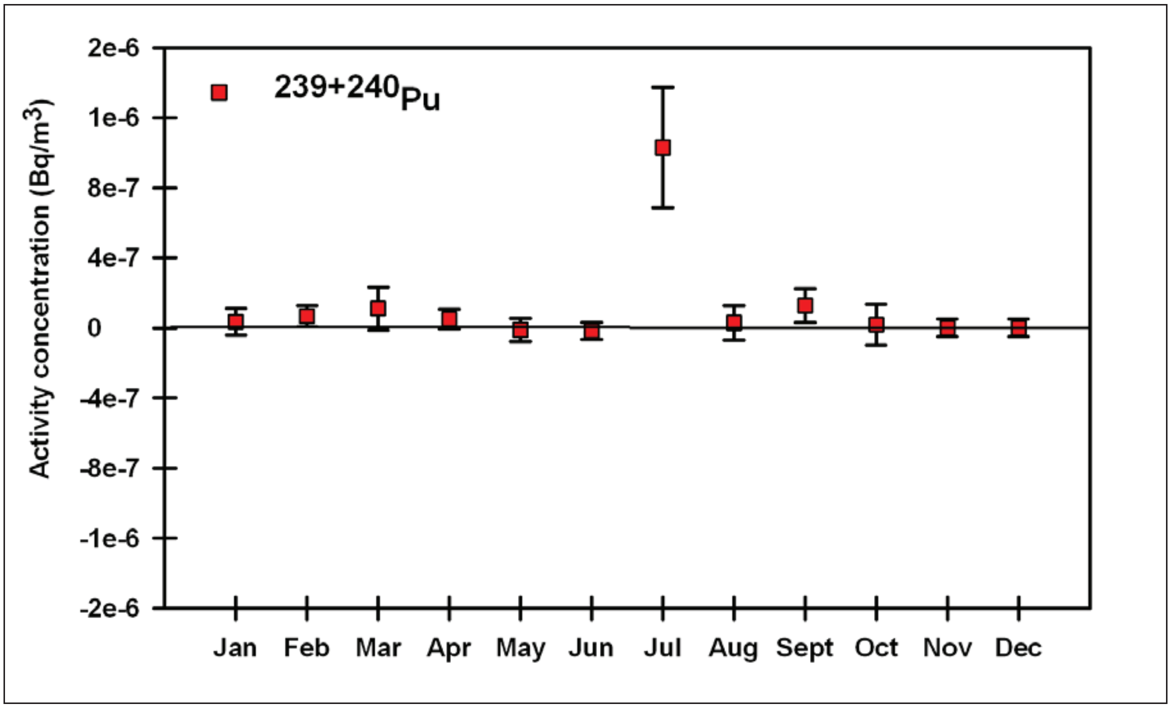

Figure 1.15: $^{239+240}$Pu Concentrations in FAS Composite Samples Collected in 2010

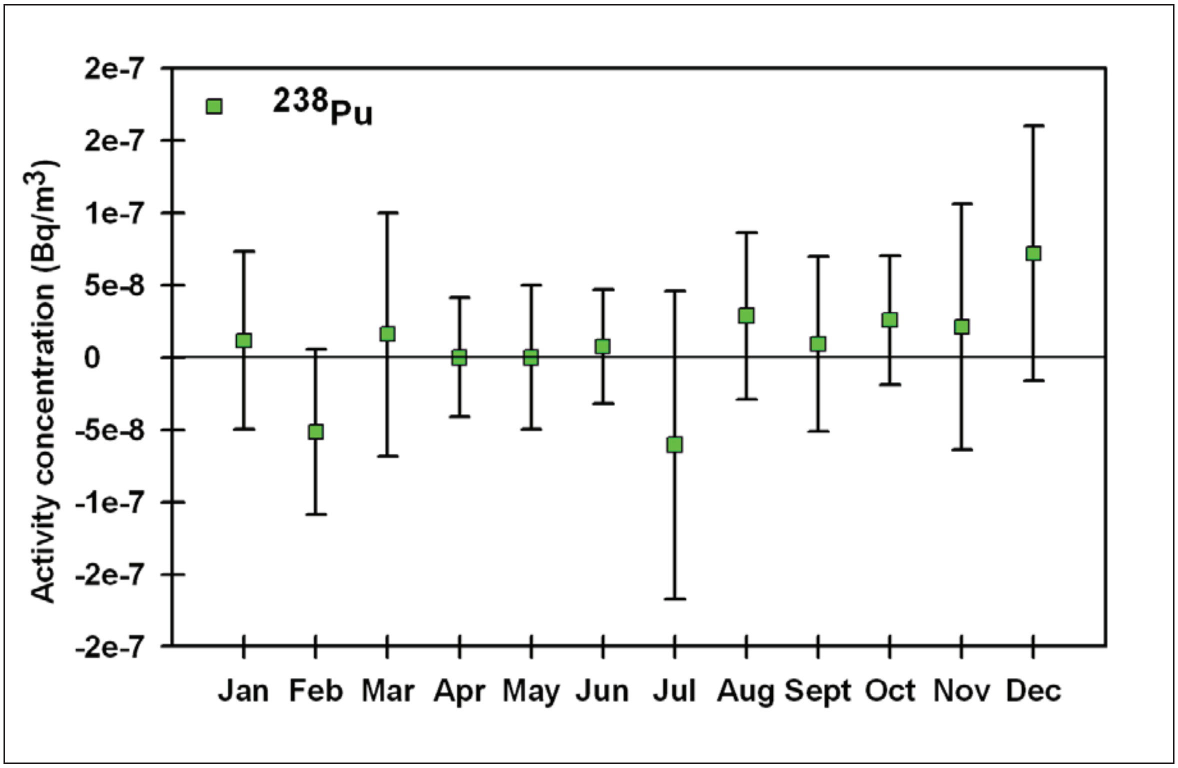

Figure 1.16: $^{238}$Pu Concentrations in FAS Composite Samples Collected in 2010

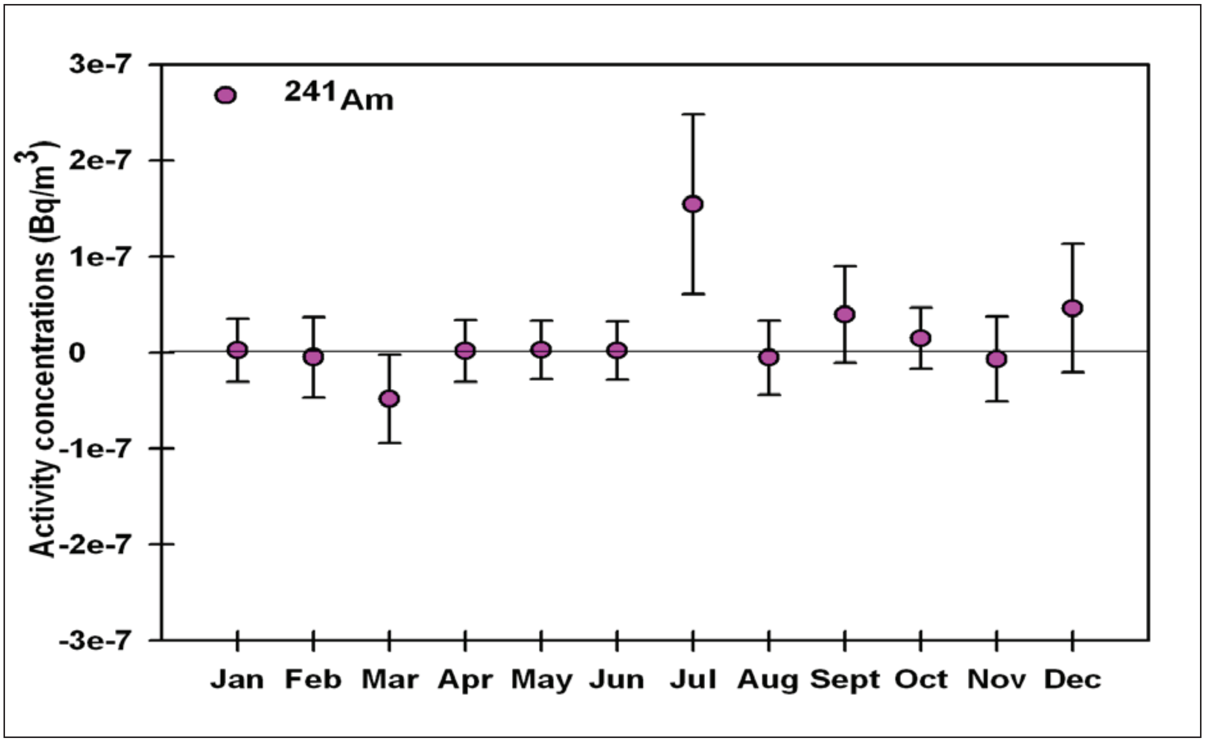

Figure 1.17: $^{241}$Am Concentrations in FAS Composite Samples Collected in 2010

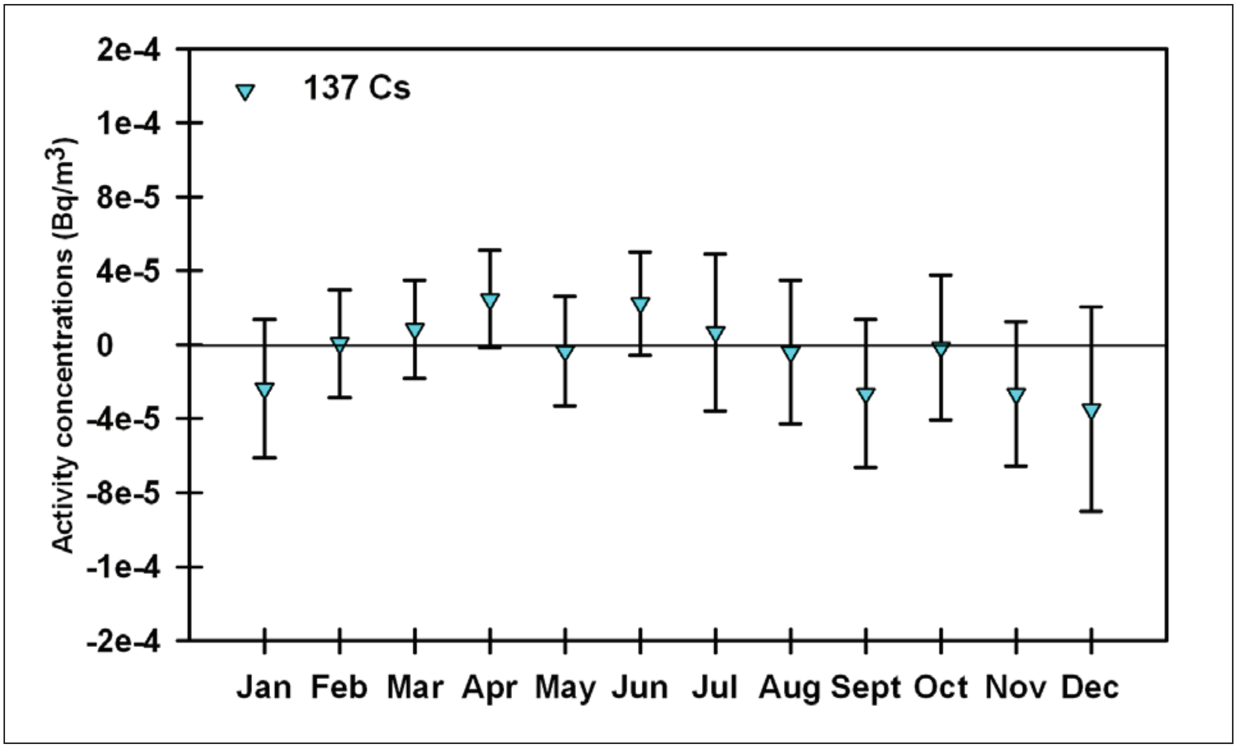

Figure 1.18: $^{137}$Cs Concentrations in FAS Composite Samples Collected in 2010

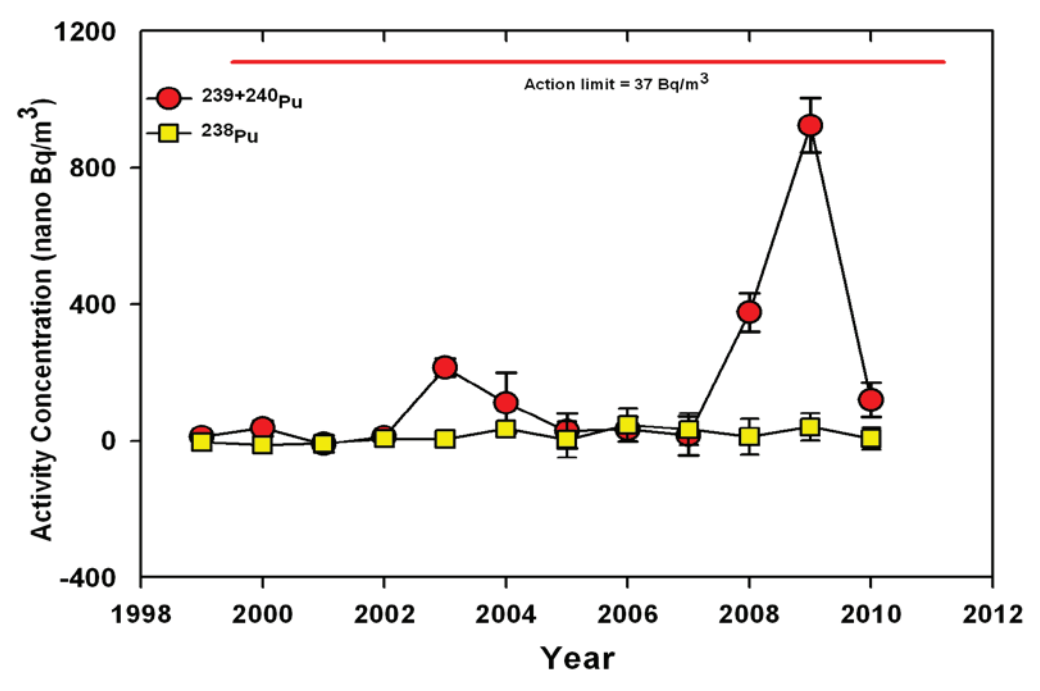

**Figure 1.19: Annual Average Activity Concentrations of $^{239+240}$Pu and $^{241}$Am in WIPP Exhaust Air from 1998-2010**

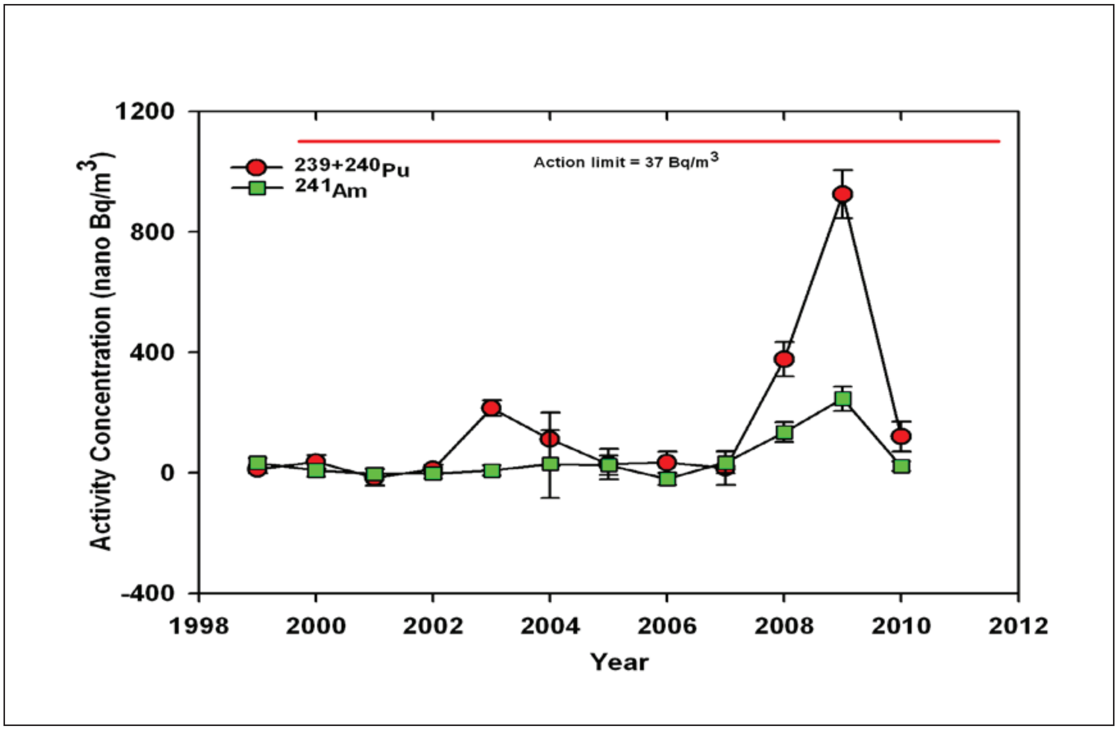

**Figure 1.20: Annual Average Activity Concentrations of $^{239+240}$Pu and $^{238}$Pu in WIPP Exhaust Air from 1998-2010**

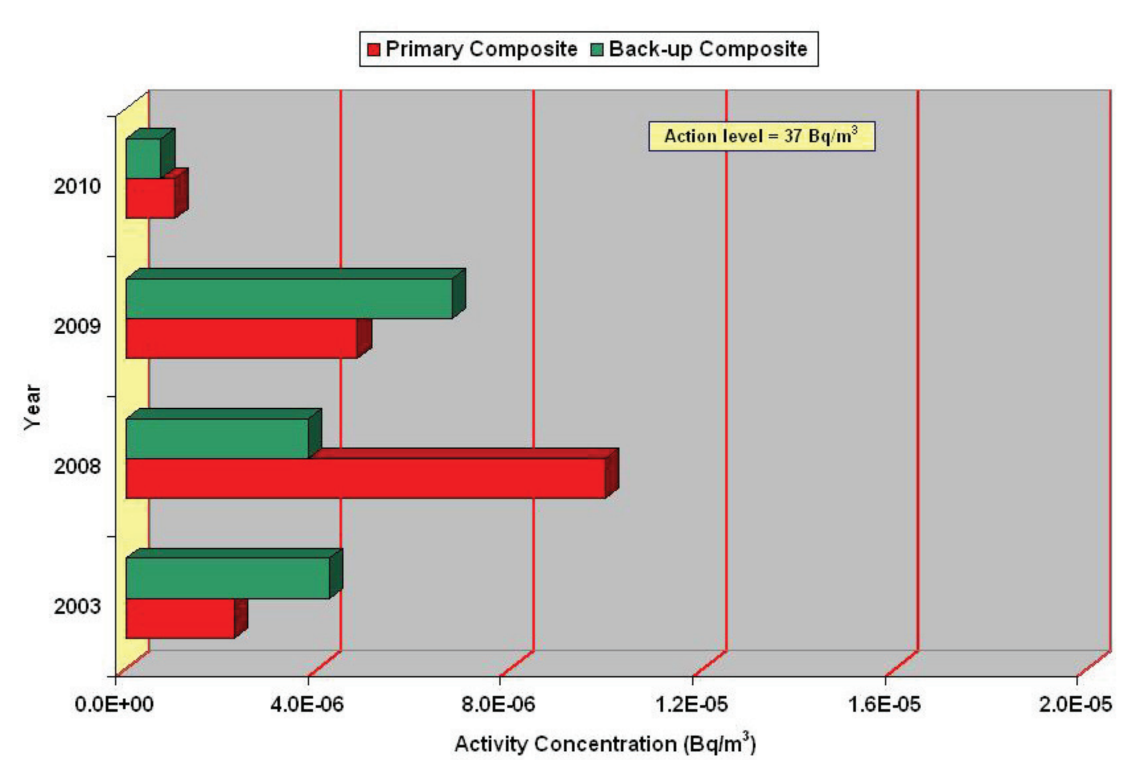

**Figure 1.21: $^{239+240}$Pu Activity (>MDC) Detected in FAS Composites for 2003, 2008, 2009 and 2010**

**Table 1-6: $^{238}$Pu/$^{239+240}$Pu Activity Ratios in Station A Samples**

| Composite ID | Count time days | $^{238}$Pu activity, dpm | $^{239+240}$Pu activity, dpm | $^{238}$Pu/$^{239+240}$Pu ratio |
|---|---|---|---|---|
| **2008, Feb** | 5 | 2.105E-02 | 5.346E-01 | 0.039 |
| | 15 | 1.046E-02 | 5.425E-01 | 0.019 |
| | 21 | 9.250E-03 | 5.422E-01 | 0.017 |
| | 42 | 1.437E-02 | 5.451E-01 | 0.026 |
| | 47 | 1.405E-02 | 5.452E-01 | 0.026 |
| | 50 | 1.396E-02 | 5.440E-01 | 0.026 |
| | | | | |
| **2009, April** | 5 | 2.097E-02 | 8.850E-01 | 0.024 |
| | 11 | 1.805E-02 | 8.974E-01 | 0.020 |
| | 15 | 1.913E-02 | 8.803E-01 | 0.022 |
| | 21 | 1.908E-02 | 8.687E-01 | 0.022 |
| | 25 | 1.816E-02 | 8.714E-01 | 0.021 |
| | 33 | 1.766E-02 | 8.783E-01 | 0.020 |
| | 40 | 1.836E-02 | 8.824E-01 | 0.021 |
| | 45 | 1.704E-02 | 8.861E-01 | 0.019 |
| | 50 | 1.702E-02 | 8.879E-01 | 0.019 |
| | | | **Average** | **0.025** |
| | | | **STDEV** | **0.004** |

## Table 1-7: Activity Ratios of Uranium Isotopes in 2010 FAS Composites

| Month | $^{234}$U (Bq) | $^{238}$U (Bq) | $^{234}$U/$^{238}$U |
|---|---|---|---|
| January | 4.73E-04 | 2.68E-04 | 1.77 |
| February | 5.59E-04 | 4.31E-04 | 1.30 |
| March | 8.33E-04 | 2.77E-04 | 3.01 |
| April | 6.27E-04 | 3.40E-04 | 1.84 |
| May | 5.12E-04 | 4.09E-04 | 1.25 |
| June | 4.38E-04 | 2.94E-04 | 1.49 |
| July | 6.81E-04 | 4.72E-04 | 1.44 |
| August | 7.48E-04 | 7.47E-04 | 1.00 |
| September | 6.03E-04 | 2.74E-04 | 2.20 |
| October | 8.20E-04 | 4.79E-02 | 1.71 |
| November | 3.93E-04 | 3.33E-04 | 1.18 |
| December | 4.64E-03 | 3.51E-03 | 1.32 |
| | | **Average** | **1.48** |
| | | **Std Error** | **0.16** |

## Table 1-8: Minimum, Maximum, and Average Radionuclide Activity Concentrations (Bq/m$^3$) and Densities (Bq/g) in 2010 FAS Composites

| | | Activity Concentration (Bq/m$^3$) | | | Activity Concentration (Bq/g) | | |
|---|---|---|---|---|---|---|---|
| **Radionuclides** | | **Conc.** | **SD** | **MDC** | **Conc.** | **SD** | **MDC** |
| $^{241}$Am | Min | -4.82E-08 | 1.51E-08 | 4.80E-08 | -4.30E-04 | 1.05E-05 | 2.92E-05 |
| | Max | 1.54E-07 | 4.67E-08 | 1.22E-07 | 7.96E-04 | 3.12E-04 | 1.09E-03 |
| | Avg | 2.53E-08 | 2.36E-08 | 7.94E-08 | 1.24E-04 | 1.92E-04 | 6.96E-04 |
| $^{238}$Pu | Min | -6.05E-08 | 1.49E-08 | 2.86E-08 | -5.66E-04 | 1.38E-05 | 4.14E-05 |
| | Max | 7.19E-08 | 5.33E-08 | 2.64E-07 | 4.03E-04 | 4.31E-04 | 1.62E-03 |
| | Avg | 6.95E-09 | 3.10E-08 | 1.20E-07 | 5.51E-05 | 2.65E-04 | 1.01E-03 |
| $^{239+240}$Pu | Min | -1.77E-08 | 2.40E-08 | 8.28E-08 | -1.92E-04 | 7.96E-06 | 4.14E-05 |
| | Max | 1.03E-06 | 1.71E-07 | 3.51E-07 | 4.48E-03 | 8.37E-04 | 3.16E-03 |
| | Avg | 1.67E-07 | 5.29E-08 | 1.55E-07 | 1.03E-03 | 4.40E-04 | 1.37E-03 |
| $^{234}$U | Min | 2.11E-07 | 4.46E-08 | 5.07E-08 | 1.57E-03 | 1.22E-04 | 9.03E-05 |
| | Max | 5.02E-06 | 3.91E-07 | 2.88E-07 | 6.28E-03 | 1.20E-03 | 2.89E-03 |
| | Avg | 7.36E-07 | 9.17E-08 | 1.35E-07 | 3.50E-03 | 6.07E-04 | 1.09E-03 |
| $^{235}$U | Min | 0.00E+00 | 1.67E-08 | 7.47E-08 | 0.00E+00 | 3.89E-05 | 9.63E-05 |
| | Max | 3.32E-07 | 1.24E-07 | 3.08E-07 | 1.77E-03 | 7.62E-04 | 1.87E-03 |
| | Avg | 6.62E-08 | 4.09E-08 | 1.28E-07 | 3.94E-04 | 3.12E-04 | 1.04E-03 |
| $^{238}$U | Min | 1.54E-07 | 3.77E-08 | 7.40E-08 | 9.44E-04 | 1.09E-04 | 1.39E-04 |
| | Max | 3.79E-06 | 3.50E-07 | 4.46E-07 | 5.88E-03 | 1.04E-03 | 3.23E-03 |
| | Avg | 5.06E-07 | 7.89E-08 | 1.53E-07 | 2.21E-03 | 5.18E-04 | 1.17E-03 |
| $^{137}$Cs | Min | -3.49E-05 | 1.31E-05 | 4.30E-05 | -3.28E-01 | 8.64E-03 | 2.88E-02 |
| | Max | 2.46E-05 | 2.76E-05 | 9.20E-05 | 2.82E-01 | 2.80E-01 | 9.31E-01 |
| | Avg | -4.79E-06 | 1.80E-05 | 5.96E-05 | -2.56E-02 | 1.62E-01 | 5.37E-01 |
| $^{60}$Co | Min | -1.30E-05 | 1.08E-05 | 4.60E-05 | -1.44E-01 | 5.64E-03 | 2.50E-02 |
| | Max | 1.27E-05 | 1.80E-05 | 7.97E-05 | 9.34E-02 | 1.83E-01 | 7.90E-01 |
| | Avg | -2.32E-06 | 1.28E-05 | 5.56E-05 | -3.81E-02 | 1.16E-01 | 5.05E-01 |
| $^{40}$K | Min | -2.62E-04 | 1.29E-04 | 4.12E-04 | -2.65E+00 | 8.49E-02 | 2.79E-01 |
| | Max | 5.93E-04 | 2.71E-04 | 8.92E-04 | 6.46E+00 | 2.69E+00 | 8.95E+00 |
| | Avg | 6.55E-05 | 1.91E-04 | 6.32E-04 | 2.03E-01 | 1.72E+00 | 5.72E+00 |

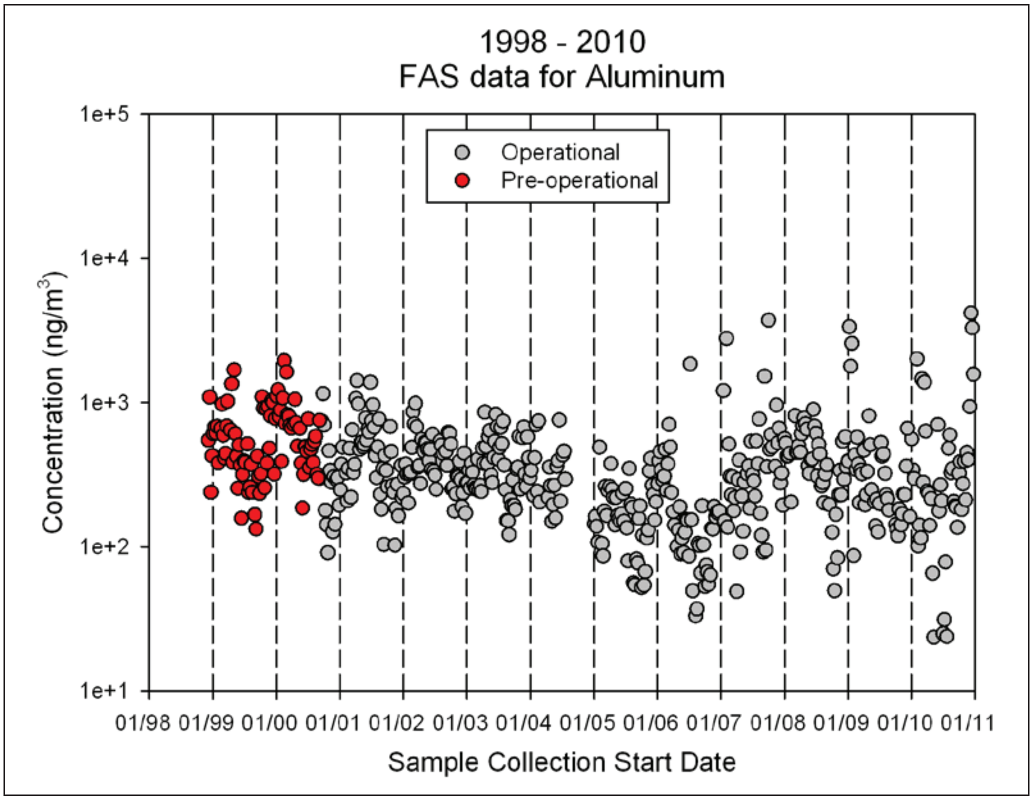

Figure 1.22: Concentrations of Al in WIPP Exhaust Air

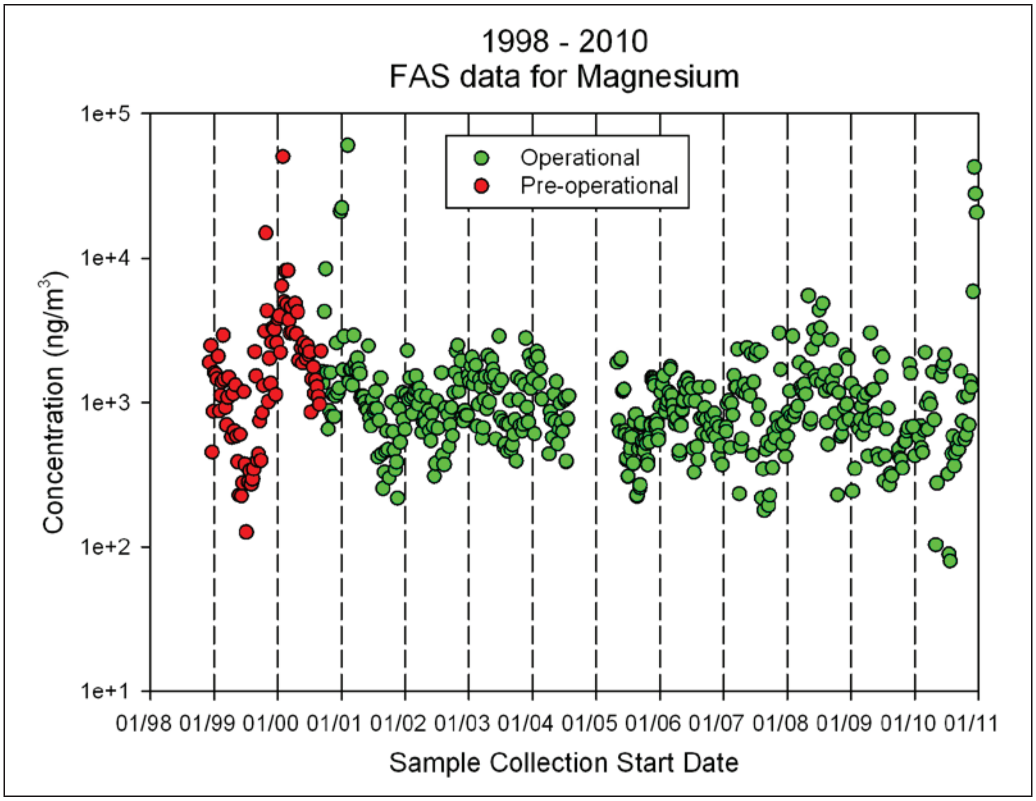

Figure 1.23: Concentrations of Mg in WIPP Exhaust Air

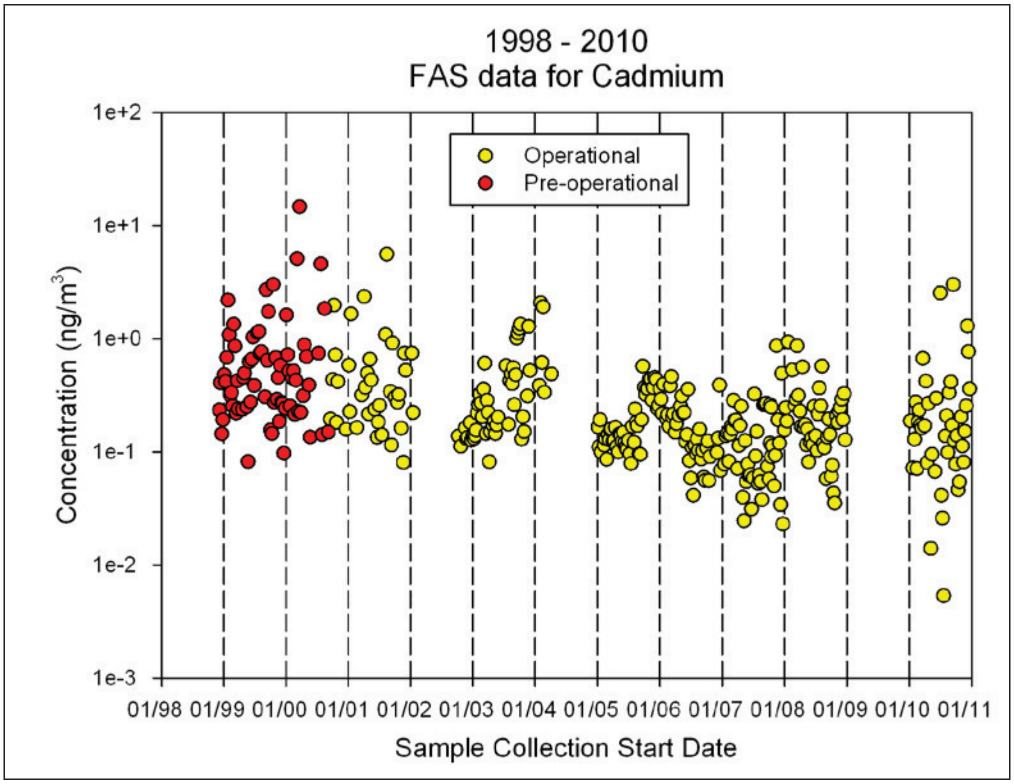

**Figure 1.24: Concentrations of Cd in WIPP Exhaust Air**

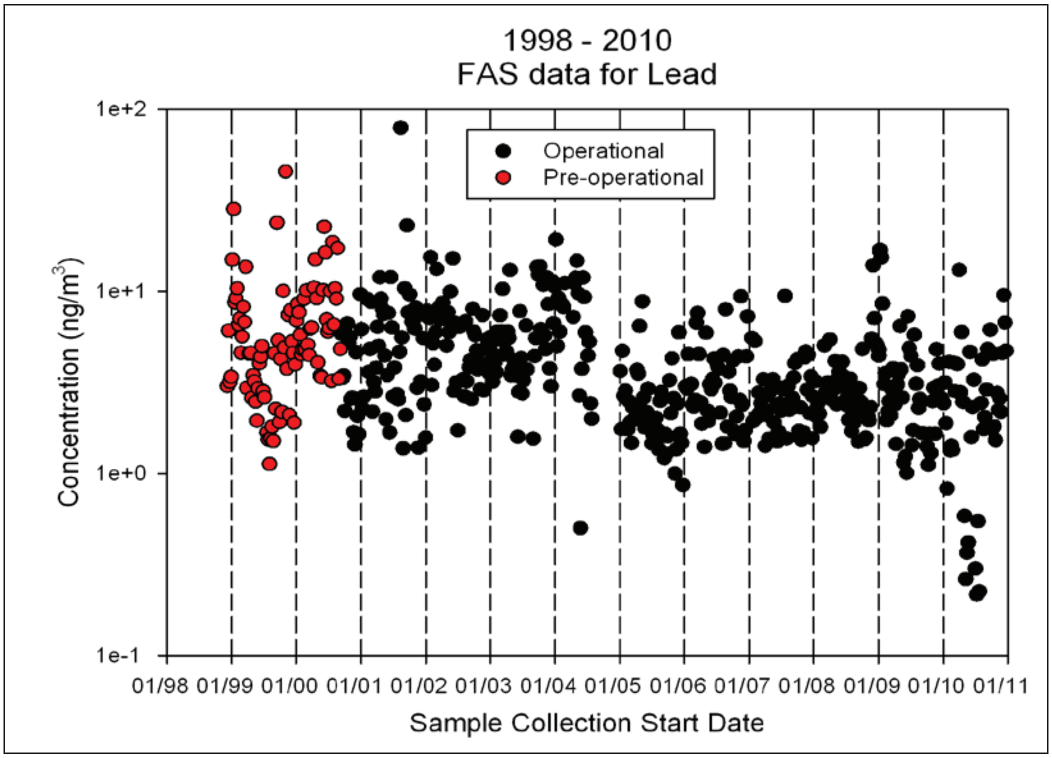

**Figure 1.25: Concentrations of Pb in WIPP Exhaust Air**

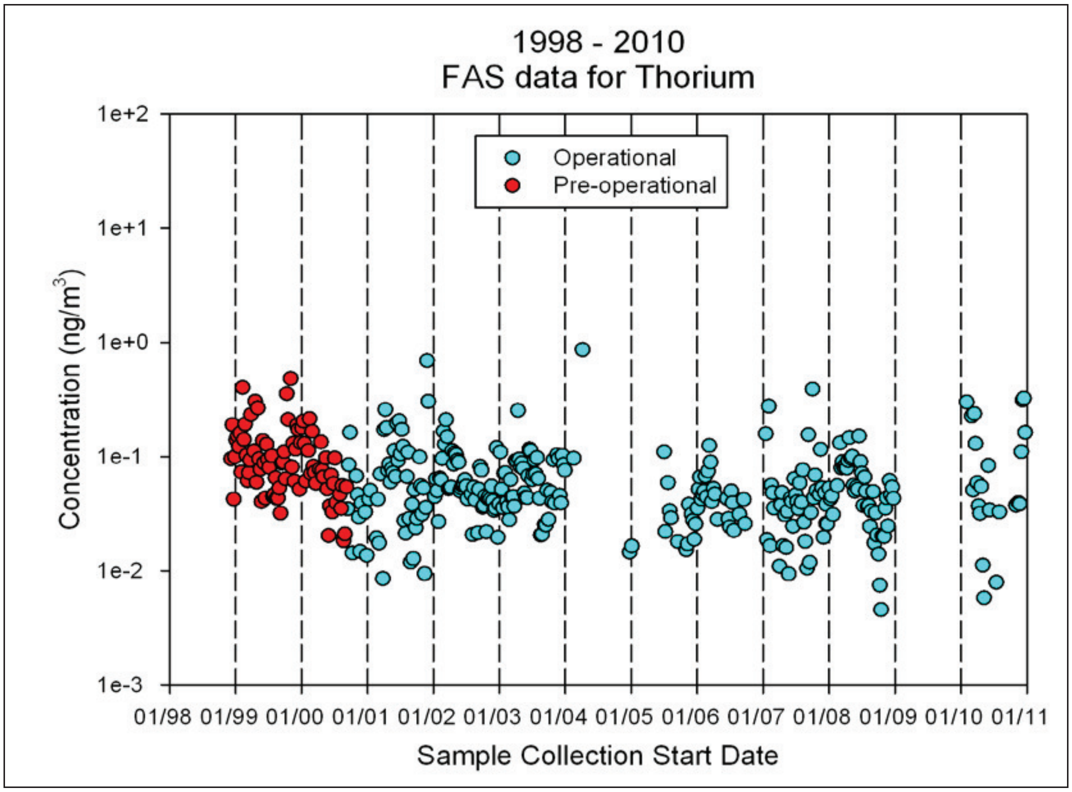

Figure 1.26: Concentrations of Th in WIPP Exhaust Air

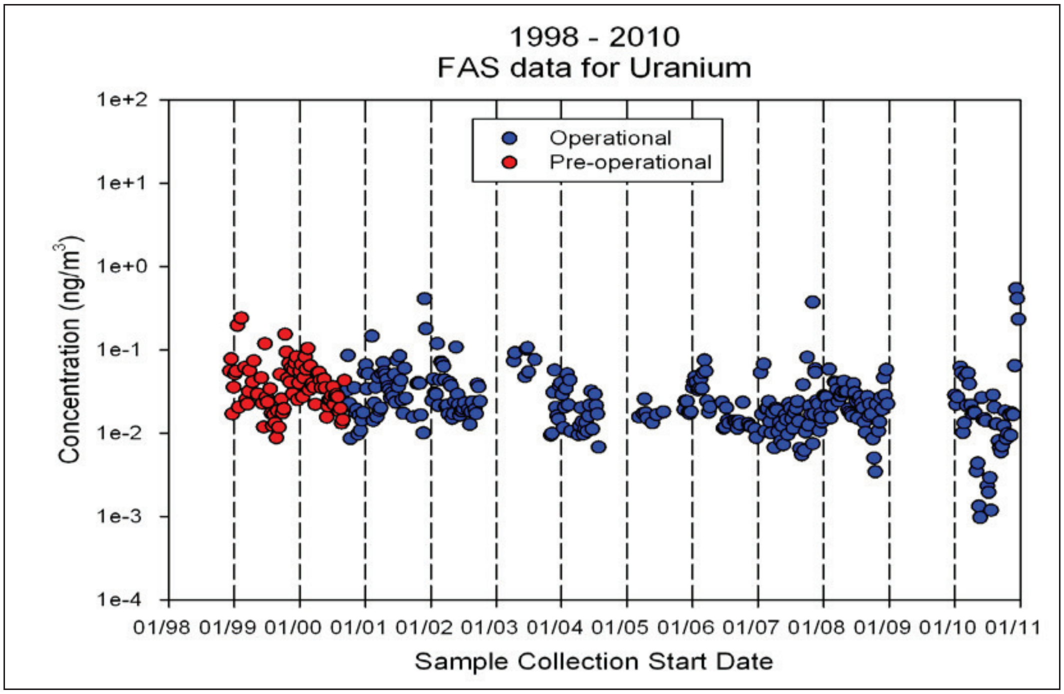

Figure 1.27: Concentrations of U in WIPP Exhaust Air

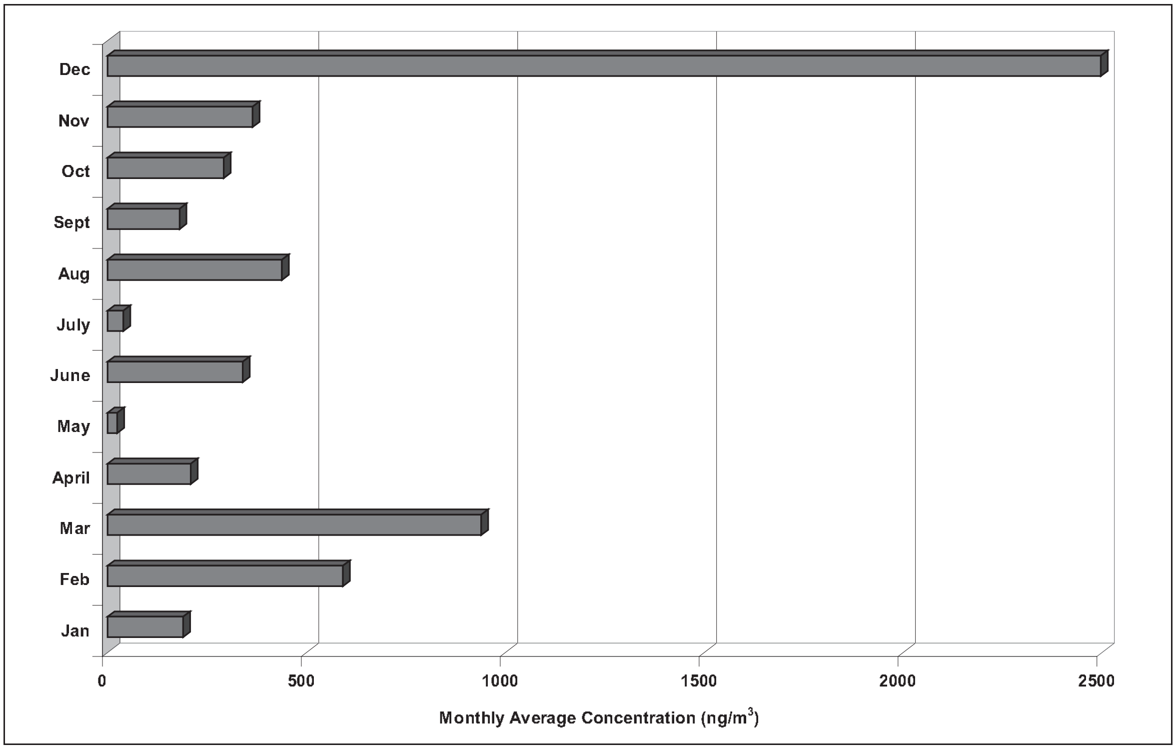

Figure 1.28: Monthly Average Concentrations of Al for 2010 FAS Samples

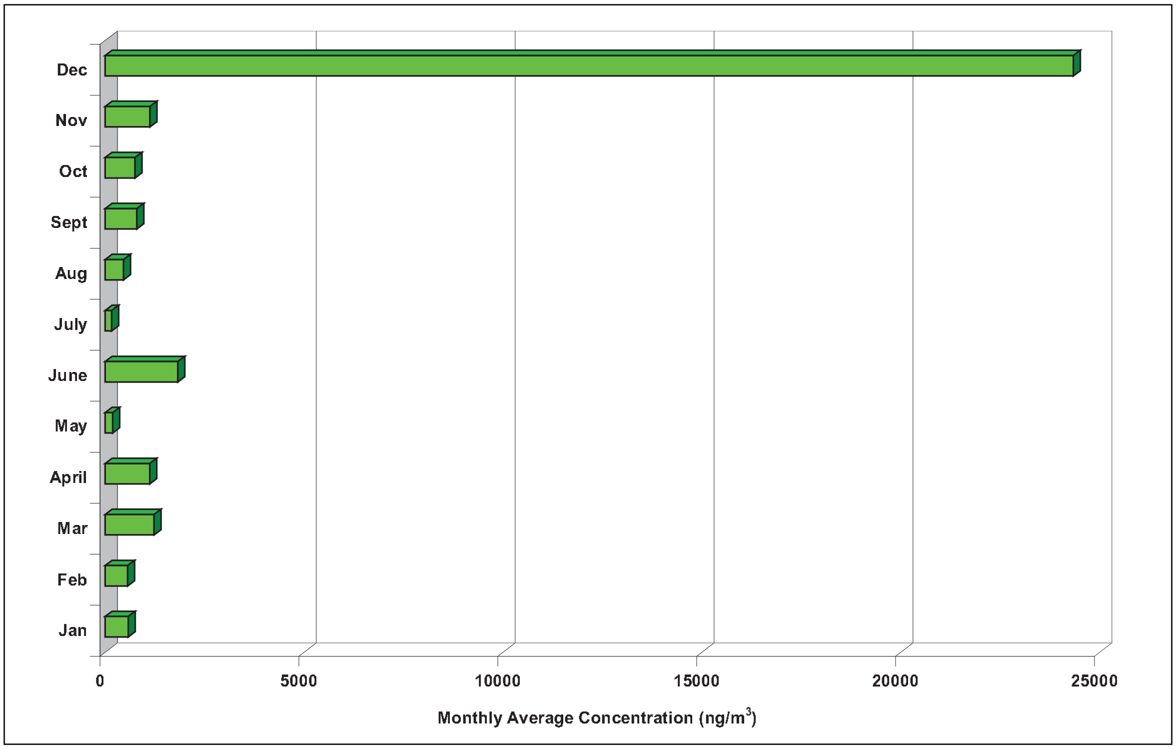

Figure 1.29: Monthly Average Concentrations of Mg for 2010 FAS Samples

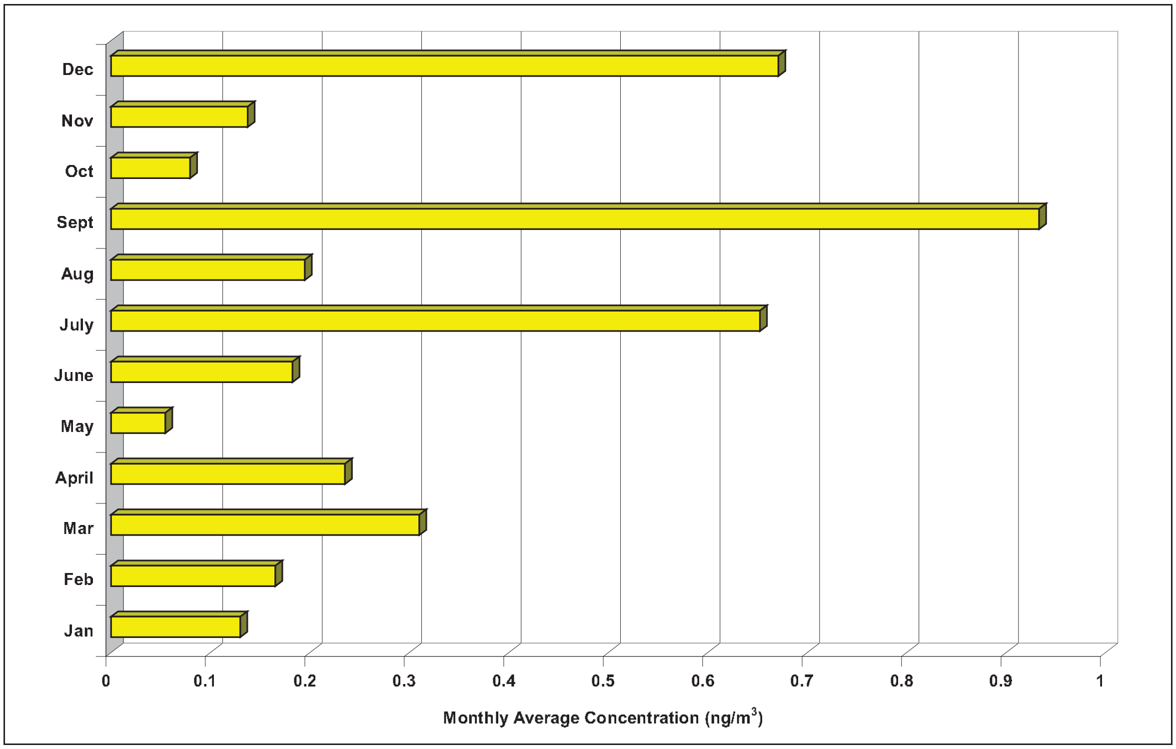

Figure 1.30: Monthly Average Concentrations of Cd for 2010 FAS Samples

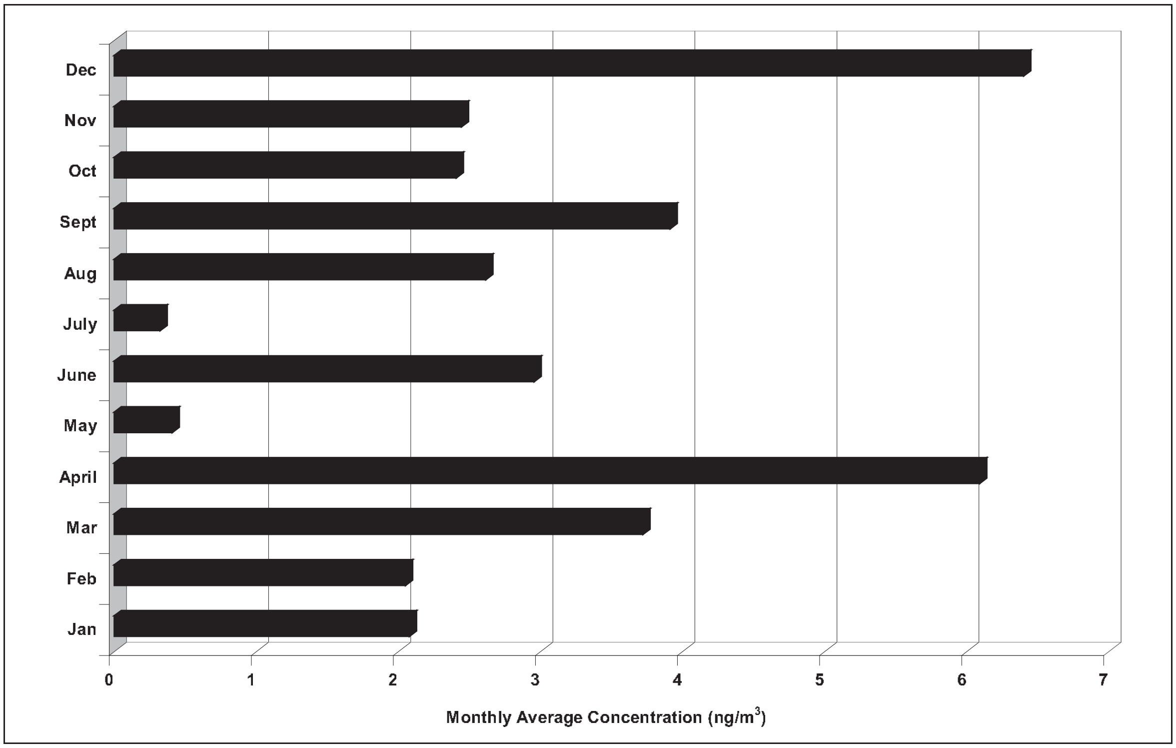

Figure 1.31: Monthly Average Concentrations of Pb for 2010 FAS Samples

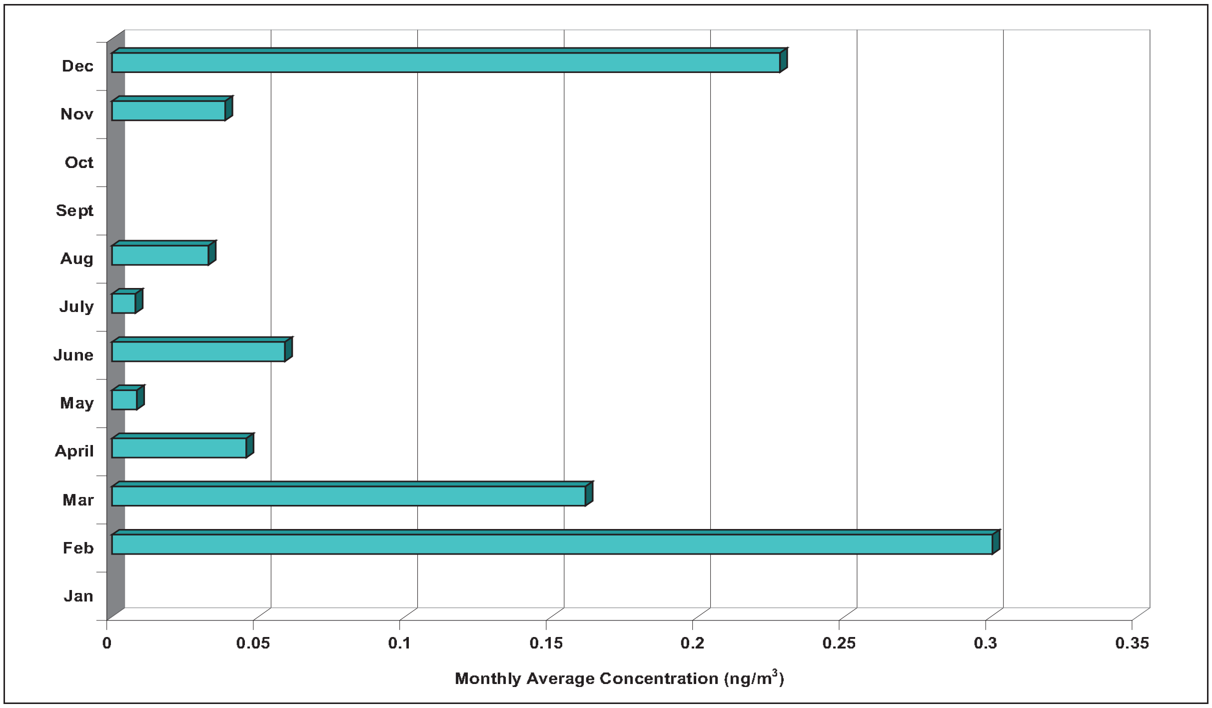

Figure 1.32: Monthly Average Concentrations of Th for 2010 FAS Samples

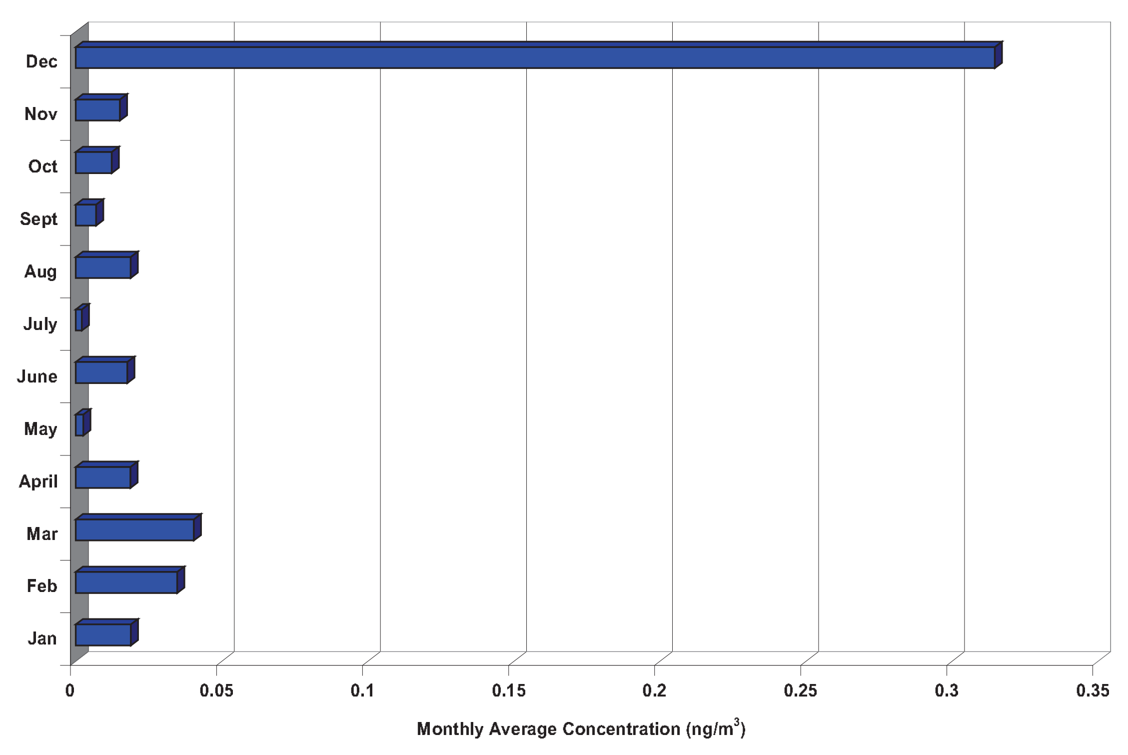

Figure 1.33: Monthly Average Concentrations of U for 2010 FAS Samples

## REFERENCES

American National Standards Institute. Calibration and usage of alpha /beta proportional counters. New York: IEEE; N42.25; 1997.

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.

Currie, L.A., Lindstrom, R.M., (1973). The NBS Measurement System for Natural Argon-37. In: Noble Gases Proceedings of the US EPA Symposium, CONF-730915, Washington, DC: US Government Printing Office, 694-527/8:40-57.

Semkow, T.M., Bari, A., Parekh, P.P., Haines, D.K., Gao, H., Bolden, A.N., Dahms, K.S., Scarpitta, Thern, R.E., Velazquez, S. Appl. Radiat. Isot. 60, 879

The Next Generation Underground Observatory of the Universe, 2000.U.S. DOE Workshop, Carlsbad, NM, June 12-14.

Vincent, C., Vallon, M., Pinglot, J.F., Funk, M., Reynaud, L., (1997). Snow accumulation and ice flow at Dome Du Gouter (4300 m), Mont Blanc, French Alps, J. Glaciol. 43, 513-521

UNSCEAR, 1982. A. ionizing radiation: Sources and biological effects United Nations Scientific Committee on the Effects of Atomic Radiation New York: United Nations; 1982.

Wink, R., Anselmann, P.; Dorflinger, D.; Hampel, W.; Heusser, G.; Kirsten, T.; Mogel, P., Pernicka, E.; Plaga, R., Schlosser, C., 1993. The miniaturized proportional counter HD2(FE)/(Si) for the GALLEX solar neutrino experiment. Nucl. Instr. Meth. Phys. Res.A329:541-550.

# CHAPTER 2

## Radionuclides and Inorganics in Selected Water Sources

By
Punam Thakur and Adrienne Chancellor

## INTRODUCTION

During 2010, 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 2010 drinking water samples, analyzed for both inorganics and radionuclides.

### Sampling, Sample Preparation and Measurements

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. Samples were acidified to approximately pH 2 with nitric acid upon collection to avoid losses through microbial activity and adsorption onto the vessel walls. The samples were then transferred into 3 L Marinelli beakers for the measurement of the gamma-emitting radionuclides $^{40}$K, $^{60}$Co, and $^{137}$Cs, by gamma spectroscopy using a high purity (HPGe) detector.

Before the measurements, the gamma system was calibrated for energy and efficiency to enable both qualitative and quantitative analysis of the water samples to be performed. The energy and efficiency calibration were carried out using mixed standards material procured from Eckert and Ziegler, Analytics (GA) in the energy range between 60 to 2000 keV for 3 L Marinelli geometry. The counting time for each sample was 48 h.

The 1 L samples were used for uranium and transuranic radionuclides. Tracers ($^{232}$U, $^{243}$Am, and $^{242}$Pu) were added and the samples were digested using concentrated nitric and hydrochloric acid. The samples were then heated to dryness and wet-ashed using concentrated nitric and perchloric acid. Finally, the samples were heated to dryness again, and the isotopic separation process was initiated. The samples were prepared for counting by co-precipitating the target isotopes and corresponding tracers with an iron carrier, performing ion exchange and chromatographic separations of the individual radionuclides, and micro-precipitating the separated radionuclides onto planchets for counting uranium/transuranics by alpha spectroscopy.

Basic information about contaminants in drinking water is listed in Table 2-1. CEMRC performed non-radiological analyses of drinking water samples using ICP-MS and IC, shown in Table 2-2. 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 2-3 shows the radionuclide activity concentrations for radionuclides of uranium ($^{234}$U, $^{235}$U, and $^{238}$U), plutonium ($^{238}$Pu, $^{239+240}$Pu), americium ($^{241}$Am), cesium ($^{137}$Cs), cobalt ($^{60}$Co) and potassium ($^{40}$K) in regional drinking water samples from 2010. The alpha radionuclides, $^{238}$Pu, $^{239+240}$Pu, and $^{241}$Am were not detected in any of the drinking water samples since monitoring commenced in 1997. The federal and state action level for gross alpha emitters, which includes isotopes of plutonium and uranium, is 15 pCi/L (0.56 Bq/L). This is over 10,000 times the MDCs at CEMRC.

Isotopes of naturally occurring uranium were detected in all the drinking water samples in 2010 as shown in Table 2-3. Measured values for the drinking water samples collected during 2010 ranged between 9.2-153 mBq/L for $^{238}$U, 0.36-13.5 m Bq/L for $^{235}$U and 24.7-399.0 mBq/L for $^{234}$U. The uranium concentration is well below the reference concentration level for radiological protection, i.e. 3.0 Bq/L. The greatest variations appear in $^{235}$U amounts. The average activity concentrations of $^{234}$U, $^{235}$U, and $^{238}$U in drinking water from the different sources are presented in Figures 2.1-2.3. 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 highest activity concentrations in water were found in Otis water. 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. The concentration of uranium in ground water and the $^{234}$U/$^{238}$U activity ratio in drinking water sources have been the subject of extensive investigations in the U.S. (U.S. EPA 2000; Orloff et al., 2004).

Natural activity ratios are typically unity for $^{234}$U/$^{238}$U and 0.045 for $^{235}$U/$^{238}$U. Higher activity of $^{234}$U in waters is the results of the $^{234}$U atom displacement from the crytal lattice. The recoil atom $^{234}$U is liable to be oxidized to the hexavalent state and can be leached into water phase more easily than its parent nuclide $^{238}$U. The oxidation of U(IV) to U(VI) is an important step in leaching into water, because compounds of U(VI) have a higher solubility in water, because of the formation of strong complexes between uranyl and carbonate ions. All tetravalent compounds of uranium are practically insoluble UNSCEAR, 1977. The natural level of uranium in water can be enhanced due to human activity which moves naturally occurring radionuclides from inaccessible locations to the environment. Another source of the enhanced level of natural radionuclides in water can be the use of phosphate fertilizers in agriculture. The phosphate fertilizers contain uranium which can be leached by moving water from the drainage area to rivers and lakes UNSCEAR, 1982, Fleischer, 1980. Thus, the activity ratio of $^{234}$U /$^{238}$U often exceeds one in waters as can be seen in Table 2-4 for almost all the samples. It has been reported that the activity of natural water from $^{234}$U is higher than $^{238}$U. The $^{234}$U/$^{238}$U activity ratio usually ranges between 1.0 and 3.0, Cherdynstev, 1971, Gilkeson et al., 1982. The average activity ratio of $^{235}$U and $^{238}$U in the water samples collected around the WIPP site ranged from 0.039-0.049 which is close to the value 0.045 for uranium in nature. The uranium isotope ratios, especially $^{235}$U/$^{238}$U, do not change substantially in the natural environment. The $^{235}$U/$^{238}$U ratio in environmental samples differing from the natural ratio is the result of anthropogenic nuclear activities. The results of the activity ratios in this study compared very well with data observed in other countries as presented in Table 2-4. The obtained $^{234}$U/$^{238}$U activity ratio varies between 2 and 3 which means that two isotopes are not in radioactive equilibrium. Results for $^{238}$Pu, $^{239+240}$Pu, and $^{241}$Am are shown in Figures 2.4-2.8.

For most people in the world, the intake of uranium through food is around 1μg/day. The worldwide average of dietary uranium has been assessed to be 1.3 μg/day from which the portion from drinking water is 0.2 μg/day (UNSCEAR 2001). Thus drinking water is not usually the main source of ingested uranium. However, if the intake of uranium through drinking water is significantly higher than through food, then it would be the main pathway of uranium ingestion. Thus, similar $^{234}$U/$^{238}$U isotopic ratios of uranium in the dinking water consumed by an individual and in the urine, hair, and nail samples collected from the same person could provide strong evidence that drinking water is the main source of exposure to uranium.

## 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 2010 measurements exhibit a high level of consistency with past results that provides a useful characterization of each source (Table 2-2).

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: Basic Information About Drinking Water Contaminants

| Contaminant | MCL (year promulgated | Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term | Sources of Contaminant in Drinking Water |
|---|---|---|---|
| Radium-226/-228 combined | 5 pCi/L (1976) | Increased risk of cancer | Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation. |
| Gross Alpha | 15 pCi/L (not including radon or uranium) (1976 | Increased risk of cancer | Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation. |
| Beta Particle and Photon emitters | 4 mrem/year (1976) | Increased risk of cancer | Erosion of natural deposits. |
| Uranium | 30 ug/L as of 12/08/03 | Increased risk of cancer, kidney toxicity | Erosion of natural deposits. |
| Antimony | 0.006 mg/L | Increase in blood cholesterol; decrease in blood sugar | Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder |
| Arsenic | 0.010 mg/L as of 01/23/06 | Skin damage or problems with circulatory systems, and may have increased risk of getting cancer. | Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes. |
| Beryllium | 0.004 mg/L | Intestinal lesions | Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries. |
| Cadmium | 0.005 mg/L | Kidney damage | Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints. |
| Chromium (total) | 0.1 mg/L | Allergic dermatitis | Discharge from steel and pulp mills; erosion of natural deposits. |
| Copper | Action level 1.3 | Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level. | Corrosion of household plumbing systems; erosion of natural deposits |

| | | | |
|---|---|---|---|
| Cyanate (as free cyanide) | 0.2 mg/L | Nerve damage or thyroid problems. | Discharge from steel/metal factories; discharge from plastic and fertilizer factories. |
| Fluoride | 4.0 mg/L | Bone disease (pain and tenderness of the bones); Children may get mottled teeth. | Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories. |
| Lead | zero | Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities.<br>Adults: Kidney problems; high blood pressure | Corrosion of household plumbing systems; erosion of natural deposits |
| Mercury | 0.002 mg/L | Kidney damage. | Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands. |
| Selenium | 0.05 mg/L | Hair or fingernail loss; numbness in fingers or toes; circulatory problems. | Discharge from petroleum refineries; erosion of natural deposits; discharge from mines. |
| Thallium | 0.002 | Hair loss; changes in blood; kidney, intestine, or liver problems. | Leaching from ore-processing sites; discharge from electronics, glass, and drug factories. |

MCL= Minimum contaminants Level

# Table 2-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2010 at Five Locations

| Carlsbad | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1998-2009 | | | | 2010 | | | |
| 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 | 2 | 1.23E-02 | 1.75E-02 | 1.04E-02 | 1.91E-03 | <MDC | <MDC |
| Al | 14 | 6 | 2.34E+00 | 5.95E+01 | 2.27E+00 | 2.66E+00 | <MDC | 4.60E+00 |
| As | 15 | 8 | 3.45E-01 | 1.41E+00 | 8.07E-01 | 7.94E-01 | 1.41E+00 | 1.41E+00 |
| B | 3 | 3 | 2.89E+01 | 4.44E+01 | 1.50E+00 | 1.41E-01 | 4.44E+01 | 4.44E+01 |
| Ba | 15 | 15 | 6.64E+01 | 8.25E+01 | 2.49E-01 | 1.51E-02 | 7.07E+01 | 7.07E+01 |
| Be | 12 | | N/A | N/A | 5.25E-02 | 4.99E-03 | <MDC | <MDC |
| Ca | 13 | 13 | 6.54E+04 | 8.06E+04 | 3.25E+02 | 1.24E+02 | 7.16E+04 | 7.16E+04 |
| Cd | 11 | | N/A | N/A | 2.04E-01 | -7.16E-02 | <MDC | <MDC |
| Ce | 12 | 3 | 8.31E-03 | 4.20E-02 | 1.63E-03 | 8.76E-04 | 8.31E-03 | 8.31E-03 |
| Co | 13 | 10 | 8.80E-02 | 3.41E-01 | 1.18E-02 | 1.93E-03 | 1.15E-01 | 1.15E-01 |
| Cr | 14 | 11 | 1.24E+00 | 7.15E+00 | 4.53E-01 | 1.73E-01 | 3.03E+00 | 3.03E+00 |
| Cu | 14 | 12 | 1.23E+00 | 1.67E+01 | 1.01E-01 | 4.09E-02 | 3.14E+00 | 3.14E+00 |
| Dy | 13 | | N/A | N/A | 5.53E-03 | 8.29E-04 | <MDC | <MDC |
| Er | 13 | 1 | 3.38E-03 | 3.38E-03 | 1.91E-03 | 1.15E-03 | 3.38E-03 | 3.38E-03 |
| Eu | 11 | 7 | 1.35E-02 | 2.43E-02 | 5.55E-03 | 9.24E-04 | 2.18E-02 | 2.18E-02 |
| Fe | 14 | 7 | 2.14E+01 | 2.24E+02 | 2.21E+01 | 1.58E+01 | 8.48E+01 | 1.11E+02 |
| Gd | 11 | | N/A | N/A | 1.62E-02 | 1.07E-03 | <MDC | <MDC |
| Hg | 10 | | N/A | N/A | 2.31E-01 | 7.28E-01 | <MDC | <MDC |
| K | 12 | 12 | 1.04E+03 | 3.56E+03 | 3.05E+01 | 8.20E+00 | 1.07E+03 | 1.07E+03 |
| La | 11 | 6 | 8.45E-03 | 4.48E-02 | 5.54E-03 | 1.22E-03 | 8.45E-03 | 8.45E-03 |
| Li | 10 | 10 | 5.14E+00 | 7.87E+00 | N/A | N/A | N/A | N/A |
| Mg | 15 | 15 | 3.14E+04 | 3.47E+04 | 1.04E+01 | 2.14E+00 | 3.21E+04 | 3.21E+04 |
| Mn | 14 | 9 | 5.50E-02 | 2.04E+00 | 3.78E-01 | 7.19E-02 | 2.04E+00 | 2.04E+00 |
| Mo | 12 | 11 | 7.03E-01 | 1.26E+00 | 6.78E-02 | 7.46E-02 | 1.22E+00 | 1.30E+00 |
| Na | 13 | 13 | 8.16E+03 | 9.94E+04 | 4.96E+00 | 3.98E+00 | 1.21E+04 | 1.21E+04 |
| Nd | 13 | | N/A | N/A | 1.45E-02 | 1.58E-04 | <MDC | <MDC |
| Ni | 13 | 12 | 1.01E+00 | 3.14E+00 | 3.11E-02 | 1.04E-02 | 3.14E+00 | 3.14E+00 |
| P | 4 | 3 | 1.49E+01 | 2.29E+01 | 8.14E+00 | 1.88E+00 | 2.29E+01 | 2.29E+01 |
| Pb | 12 | 9 | 1.63E-01 | 1.51E+00 | 1.00E-01 | 1.34E-02 | 9.82E-01 | 9.82E-01 |
| Pr | 13 | | N/A | N/A | 4.75E-03 | 5.35E-04 | <MDC | <MDC |
| Sb | 13 | 6 | 3.00E-02 | 1.99E-01 | 5.39E-02 | 3.86E-03 | <MDC | <MDC |
| Sc | 10 | 10 | 1.32E+00 | 3.11E+00 | 2.76E-02 | 8.72E-02 | 1.51E+00 | 1.59E+00 |
| Se | 10 | 3 | 9.25E-02 | 1.75E+00 | 5.73E+00 | 2.43E+00 | <MDC | <MDC |
| Si | 8 | 8 | 5.31E+03 | 6.97E+03 | 7.99E+00 | 4.81E+00 | 6.21E+03 | 6.21E+03 |
| Sr | 13 | 13 | 2.59E+02 | 4.59E+02 | N/A | N/A | N/A | N/A |
| Th | 10 | 1 | 1.98E-02 | 1.98E-02 | 1.04E-02 | 1.81E-03 | <MDC | <MDC |
| Tl | 11 | 11 | 8.20E-02 | 1.62E-01 | 4.42E-02 | 6.93E-04 | 1.62E-01 | 1.62E-01 |
| U | 13 | 13 | 8.21E-01 | 1.05E+00 | 8.79E-03 | 4.85E-04 | 1.05E+00 | 1.05E+00 |
| V | 14 | 14 | 3.54E+00 | 5.90E+00 | 5.29E-02 | 2.83E-02 | 5.41E+00 | 5.41E+00 |
| Zn | 14 | 13 | 2.33E+00 | 1.52E+01 | 1.63E+00 | 2.03E-01 | 5.09E+00 | 5.09E+00 |

[1] El = Element analyzed;

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

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

[4] MDC = Minimum detectable concentration;

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

[6] N/A = Not Applicable

# Table 2-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2010 at Five Locations
(Continued)

| Double Eagle | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1998-2009 | | | | 2010 | | | |
| 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 | 2 | 3.62E-03 | 1.78E-01 | 1.04E-02 | 1.91E-03 | <MDC | <MDC |
| Al | 13 | 6 | 2.57E+00 | 7.22E+01 | 2.27E+00 | 2.66E+00 | <MDC | <MDC |
| As | 13 | 13 | 4.26E+00 | 7.80E+00 | 8.07E-01 | 7.94E-01 | 5.47E+00 | 6.32E+00 |
| B | 3 | 3 | 2.98E+01 | 8.55E+01 | 1.50E+00 | 1.41E-01 | 8.55E+01 | 8.55E+01 |
| Ba | 13 | 13 | 3.82E+01 | 1.26E+02 | 2.49E-01 | 1.51E-02 | 7.50E+01 | 7.50E+01 |
| Be | 10 | 1 | 3.63E-02 | 3.63E-02 | 5.25E-02 | 4.99E-03 | <MDC | <MDC |
| Ca | 12 | 12 | 5.18E+03 | 5.83E+04 | 3.25E+02 | 1.24E+02 | 4.49E+04 | 4.49E+04 |
| Cd | 10 | 3 | 1.87E-02 | 1.85E-01 | 2.04E-01 | -7.16E-02 | <MDC | <MDC |
| Ce | 11 | 3 | 3.18E-03 | 3.22E-02 | 1.63E-03 | 8.76E-04 | <MDC | <MDC |
| Co | 13 | 8 | 6.48E-02 | 1.12E+00 | 1.18E-02 | 1.93E-03 | 6.48E-02 | 6.48E-02 |
| Cr | 12 | 12 | 1.22E+00 | 3.25E+01 | 4.53E-01 | 1.73E-01 | 2.06E+00 | 2.06E+00 |
| Cu | 13 | 12 | 8.09E-01 | 5.69E+00 | 1.01E-01 | 4.09E-02 | 9.44E-01 | 9.44E-01 |
| Dy | 13 | | N/A | N/A | 5.53E-03 | 8.29E-04 | <MDC | <MDC |
| Er | 13 | | N/A | N/A | 1.91E-03 | 1.15E-03 | <MDC | <MDC |
| Eu | 12 | 7 | 1.68E-02 | 2.86E-02 | 5.55E-03 | 9.24E-04 | 1.72E-02 | 1.72E-02 |
| Fe | 12 | 7 | 7.93E+01 | 9.32E+02 | 4.43E+00 | 1.58E+01 | 1.24E+02 | 1.24E+02 |
| Gd | 11 | | N/A | N/A | 1.62E-02 | 1.07E-03 | <MDC | <MDC |
| Hg | 8 | | N/A | N/A | 2.31E-01 | 7.28E-01 | <MDC | <MDC |
| K | 11 | 11 | 2.31E+03 | 2.94E+04 | 3.05E+01 | 8.20E+00 | 2.31E+03 | 2.31E+03 |
| La | 12 | 5 | 1.19E-02 | 6.26E-02 | 5.54E-03 | 1.22E-03 | <MDC | <MDC |
| Li | 9 | 9 | 9.97E+00 | 1.90E+01 | N/A | N/A | N/A | N/A |
| Mg | 14 | 14 | 1.09E+03 | 1.25E+04 | 1.04E+00 | 2.14E+00 | 8.51E+03 | 8.51E+03 |
| Mn | 12 | 11 | 1.91E-01 | 6.04E+00 | 3.78E-01 | 7.19E-02 | 9.21E-01 | 9.21E-01 |
| Mo | 10 | 10 | 1.43E+00 | 6.70E+00 | 6.78E-02 | 7.46E-02 | 1.69E+00 | 1.77E+00 |
| Na | 12 | 12 | 3.84E+03 | 4.04E+04 | 2.48E+01 | 3.98E+00 | 2.82E+04 | 2.82E+04 |
| Nd | 13 | 1 | 5.37E-03 | 5.37E-03 | 1.45E-02 | 1.58E-04 | <MDC | <MDC |
| Ni | 13 | 12 | 8.00E-01 | 4.03E+00 | 3.11E-02 | 1.04E-02 | 1.66E+00 | 1.66E+00 |
| P | 3 | 1 | 1.04E+01 | 1.04E+01 | 8.14E+00 | 1.88E+00 | <MDC | <MDC |
| Pb | 11 | 10 | 2.56E-01 | 4.21E+00 | 1.00E-01 | 1.34E-02 | 4.24E-01 | 4.24E-01 |
| Pr | 13 | 1 | 9.05E-04 | 9.05E-04 | 4.75E-03 | 5.35E-04 | <MDC | <MDC |
| Sb | 11 | 6 | 2.41E-02 | 1.39E-01 | 5.39E-02 | 3.86E-03 | <MDC | <MDC |
| Sc | 8 | 8 | 2.64E+00 | 6.59E+00 | 2.76E-02 | 8.72E-02 | 3.06E+00 | 3.14E+00 |
| Se | 8 | 4 | 2.28E+00 | 3.53E+00 | 5.73E+00 | 2.43E+00 | <MDC | <MDC |
| Si | 6 | 6 | 7.37E+03 | 1.81E+04 | 7.99E+00 | 4.81E+00 | 1.41E+04 | 1.41E+04 |
| Sr | 12 | 12 | 5.06E+01 | 5.63E+02 | N/A | N/A | N/A | N/A |
| Th | 10 | 3 | 4.32E-03 | 1.36E-02 | 1.04E-02 | 1.81E-03 | <MDC | <MDC |
| Tl | 9 | 2 | 2.73E-02 | 4.84E-02 | 4.42E-02 | 6.93E-04 | <MDC | <MDC |
| U | 13 | 13 | 1.17E+00 | 2.38E+00 | 8.79E-03 | 4.85E-04 | 1.56E+00 | 1.56E+00 |
| V | 13 | 13 | 7.71E+00 | 3.26E+01 | 5.29E-02 | 2.83E-02 | 2.53E+01 | 2.53E+01 |
| Zn | 13 | 12 | 1.80E+00 | 1.25E+01 | 1.63E+00 | 2.03E-01 | 3.00E+00 | 3.00E+00 |

[1] El = Element analyzed;

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

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

[4] MDC = Minimum detectable concentration;

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

[6] N/A = Not Applicable

## Table 2-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2010 at Five Locations

(Continued)

| Hobbs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1998-2009 | | | | 2010 | | | |
| 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 | 2 | 3.86E-03 | 1.04E-01 | 2.08E-02 | 1.91E-03 | <MDC | <MDC |
| Al | 12 | 9 | 3.03E+00 | 1.14E+02 | 4.54E+00 | 2.66E+00 | 6.86E+00 | 9.52E+00 |
| As | 13 | 11 | 4.51E+00 | 7.37E+00 | 1.61E+00 | 7.94E-01 | 6.01E+00 | 6.87E+00 |
| B | 4 | 4 | 1.41E+02 | 1.97E+02 | 3.00E+00 | 1.41E-01 | 1.97E+02 | 1.97E+02 |
| Ba | 13 | 13 | 5.65E+01 | 6.52E+01 | 4.98E-01 | 1.51E-02 | 6.03E+01 | 6.03E+01 |
| Be | 10 | 1 | 5.39E-02 | 5.39E-02 | 1.05E-01 | 4.99E-03 | <MDC | <MDC |
| Ca | 10 | 10 | 8.09E+03 | 1.00E+05 | 1.57E+02 | 1.24E+02 | 8.28E+04 | 8.28E+04 |
| Cd | 9 | 1 | 1.57E-01 | 1.57E-01 | 4.08E-01 | -7.16E-02 | <MDC | <MDC |
| Ce | 11 | 6 | 5.10E-03 | 3.56E-02 | 3.26E-03 | 8.76E-04 | 3.56E-02 | 3.56E-02 |
| Co | 12 | 8 | 9.78E-02 | 3.61E-01 | 2.36E-02 | 1.93E-03 | 1.52E-01 | 1.52E-01 |
| Cr | 12 | 10 | 7.33E-01 | 1.13E+01 | 9.06E-01 | 1.73E-01 | 2.10E+00 | 2.10E+00 |
| Cu | 12 | 10 | 1.06E+00 | 6.93E+00 | 2.02E-01 | 4.09E-02 | 2.32E+00 | 2.32E+00 |
| Dy | 12 | 1 | 4.18E-03 | 4.18E-03 | 1.11E-02 | 8.29E-04 | <MDC | <MDC |
| Er | 12 | | N/A | N/A | 3.82E-03 | 1.15E-03 | <MDC | <MDC |
| Eu | 11 | 6 | 1.31E-02 | 1.97E-02 | 1.11E-02 | 9.24E-04 | 1.42E-02 | 1.42E-02 |
| Fe | 11 | 7 | 3.64E+01 | 4.44E+02 | 2.21E+01 | 1.58E+01 | 4.95E+01 | 7.60E+01 |
| Gd | 11 | | N/A | N/A | 3.24E-02 | 1.07E-03 | <MDC | <MDC |
| Hg | 7 | 2 | 1.06E-02 | 1.42E-02 | 2.31E-01 | 7.28E-01 | <MDC | <MDC |
| K | 9 | 9 | 2.32E+03 | 2.53E+04 | 6.10E+01 | 8.20E+00 | 2.34E+03 | 2.34E+03 |
| La | 11 | 5 | 1.25E-02 | 5.01E-02 | 1.11E-02 | 1.22E-03 | 1.25E-02 | 1.25E-02 |
| Li | 9 | 9 | 2.65E+01 | 3.18E+01 | N/A | N/A | N/A | N/A |
| Mg | 14 | 14 | 2.11E+03 | 2.79E+04 | 1.04E+01 | 2.14E+00 | 2.02E+04 | 2.02E+04 |
| Mn | 12 | 10 | 3.79E-01 | 3.62E+00 | 7.56E-01 | 7.19E-02 | 3.62E+00 | 3.62E+00 |
| Mo | 9 | 9 | 2.60E+00 | 3.31E+00 | 1.36E-01 | 7.46E-02 | 2.64E+00 | 2.72E+00 |
| Na | 11 | 11 | 4.97E+03 | 5.80E+04 | 2.48E+01 | 3.98E+00 | 4.41E+04 | 4.41E+04 |
| Nd | 12 | 3 | 3.01E-03 | 1.28E-02 | 2.90E-02 | 1.58E-04 | <MDC | <MDC |
| Ni | 12 | 12 | 1.08E+00 | 4.78E+00 | 6.22E-02 | 1.04E-02 | 4.78E+00 | 4.78E+00 |
| P | 3 | 2 | 2.44E+01 | 2.53E+01 | 1.63E+01 | 1.88E+00 | 2.44E+01 | 2.44E+01 |
| Pb | 11 | 8 | 9.44E-02 | 1.19E+00 | 2.00E-01 | 1.34E-02 | 1.19E+00 | 1.19E+00 |
| Pr | 12 | 1 | 1.57E-03 | 1.57E-03 | 9.50E-03 | 5.35E-04 | <MDC | <MDC |
| Sb | 10 | 6 | 3.88E-02 | 7.02E-02 | 1.08E-01 | 3.86E-03 | <MDC | <MDC |
| Sc | 9 | 9 | 4.30E+00 | 1.05E+01 | 5.52E-02 | 8.72E-02 | 5.27E+00 | 5.36E+00 |
| Se | 8 | 3 | 3.50E+00 | 6.23E+00 | 1.15E+01 | 2.43E+00 | <MDC | <MDC |
| Si | 7 | 7 | 2.41E+04 | 2.86E+04 | 1.60E+01 | 4.81E+00 | 2.41E+04 | 2.41E+04 |
| Sr | 11 | 11 | 7.89E+01 | 1.06E+03 | N/A | N/A | N/A | N/A |
| Th | 10 | 2 | 4.54E-03 | 4.56E-03 | 2.08E-02 | 1.81E-03 | <MDC | <MDC |
| Tl | 7 | 2 | 2.24E-02 | 2.31E-02 | 8.84E-02 | 6.93E-04 | <MDC | <MDC |
| U | 12 | 12 | 2.90E+00 | 3.98E+00 | 1.76E-02 | 4.85E-04 | 3.98E+00 | 3.98E+00 |
| V | 12 | 12 | 2.95E+01 | 3.71E+01 | 1.06E-01 | 2.83E-02 | 3.60E+01 | 3.60E+01 |
| Zn | 12 | 9 | 1.47E+00 | 4.37E+00 | 3.26E+00 | 2.03E-01 | 4.11E+00 | 4.11E+00 |

[1] El = Element analyzed;

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

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

[4] MDC = Minimum detectable concentration;

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

[6] N/A = Not Applicable

## Table 2-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2010 at Five Locations

(Continued)

| Loving | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1998-2009 | | | | 2010 | | | |
| 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 | 12 | 4 | 2.55E-03 | 2.17E-01 | 1.04E-02 | 1.91E-03 | <MDC | <MDC |
| Al | 12 | 6 | 3.76E+00 | 3.76E+02 | 2.27E+00 | 2.66E+00 | 5.81E+00 | 8.47E+00 |
| As | 12 | 9 | 1.20E+00 | 2.34E+00 | 8.07E-01 | 7.94E-01 | 1.49E+00 | 2.34E+00 |
| B | 3 | 3 | 7.55E+01 | 1.12E+02 | 3.00E+00 | 1.41E-01 | 1.12E+02 | 1.12E+02 |
| Ba | 13 | 13 | 2.86E+01 | 3.47E+01 | 2.49E-01 | 1.51E-02 | 3.34E+01 | 3.34E+01 |
| Be | 9 | 1 | 9.35E-02 | 9.35E-02 | 5.25E-02 | 4.99E-03 | <MDC | <MDC |
| Ca | 10 | 10 | 9.14E+03 | 1.04E+05 | 3.25E+02 | 1.24E+02 | 6.71E+04 | 6.71E+04 |
| Cd | 10 | | N/A | N/A | 2.04E-01 | -7.16E-02 | <MDC | <MDC |
| Ce | 10 | 3 | 9.74E-04 | 2.53E-01 | 1.63E-03 | 8.76E-04 | 7.57E-03 | 7.57E-03 |
| Co | 12 | 8 | 1.02E-01 | 4.04E-01 | 1.18E-02 | 1.93E-03 | 1.12E-01 | 1.12E-01 |
| Cr | 12 | 9 | 1.21E+00 | 7.44E+00 | 4.53E-01 | 1.73E-01 | 3.27E+00 | 3.27E+00 |
| Cu | 12 | 10 | 1.71E+00 | 5.59E+00 | 1.01E-01 | 4.09E-02 | 1.80E+00 | 1.80E+00 |
| Dy | 12 | | N/A | N/A | 5.53E-03 | 8.29E-04 | <MDC | <MDC |
| Er | 12 | | N/A | N/A | 1.91E-03 | 1.15E-03 | <MDC | <MDC |
| Eu | 11 | 6 | 7.00E-03 | 1.01E-02 | 5.55E-03 | 9.24E-04 | 8.14E-03 | 8.14E-03 |
| Fe | 12 | 6 | 1.56E+01 | 2.57E+02 | 4.43E+00 | 1.58E+01 | 2.98E+01 | 5.63E+01 |
| Gd | 10 | 3 | 2.15E-03 | 1.04E-02 | 1.62E-02 | 1.07E-03 | <MDC | <MDC |
| Hg | 6 | | N/A | N/A | 2.31E-01 | 7.28E-01 | <MDC | <MDC |
| K | 9 | 9 | 1.85E+03 | 1.98E+04 | 3.05E+01 | 8.20E+00 | 1.88E+03 | 1.88E+03 |
| La | 11 | 4 | 7.27E-03 | 2.22E-02 | 5.54E-03 | 1.22E-03 | <MDC | <MDC |
| Li | 8 | 8 | 1.66E+01 | 1.96E+01 | N/A | N/A | N/A | N/A |
| Mg | 13 | 13 | 4.04E+03 | 4.36E+04 | 1.04E+01 | 2.14E+00 | 3.03E+04 | 3.03E+04 |
| Mn | 12 | 8 | 1.43E-02 | 1.77E+00 | 3.78E-01 | 7.19E-02 | 4.42E-01 | 4.42E-01 |
| Mo | 10 | 8 | 1.41E+00 | 1.81E+00 | 6.78E-02 | 7.46E-02 | 1.63E+00 | 1.70E+00 |
| Na | 10 | 10 | 2.33E+03 | 2.82E+04 | 4.96E+00 | 3.98E+00 | 1.96E+04 | 1.96E+04 |
| Nd | 12 | 1 | 3.37E-03 | 3.37E-03 | 1.45E-02 | 1.58E-04 | <MDC | <MDC |
| Ni | 12 | 10 | 1.19E+00 | 3.43E+00 | 3.11E-02 | 1.04E-02 | 3.10E+00 | 3.10E+00 |
| P | 4 | 2 | 2.53E+01 | 3.37E+01 | 8.14E+00 | 1.88E+00 | 2.53E+01 | 2.53E+01 |
| Pb | 11 | 8 | 3.15E-01 | 1.67E+00 | 1.00E-01 | 1.34E-02 | <MDC | <MDC |
| Pr | 11 | | N/A | N/A | 4.75E-03 | 5.35E-04 | <MDC | <MDC |
| Sb | 10 | 5 | 3.51E-02 | 1.84E-01 | 5.39E-02 | 3.86E-03 | <MDC | <MDC |
| Sc | 9 | 9 | 1.91E+00 | 4.72E+00 | 2.76E-02 | 8.72E-02 | 2.46E+00 | 2.55E+00 |
| Se | 6 | | N/A | N/A | 5.73E+00 | 2.43E+00 | <MDC | <MDC |
| Si | 7 | 7 | 8.54E+03 | 1.09E+04 | 7.99E+00 | 4.81E+00 | 9.60E+03 | 9.60E+03 |
| Sr | 11 | 11 | 7.60E+01 | 9.37E+02 | N/A | N/A | N/A | N/A |
| Th | 10 | 2 | 5.69E-03 | 9.63E-03 | 1.04E-02 | 1.81E-03 | <MDC | <MDC |
| Tl | 9 | 1 | 4.32E-02 | 4.32E-02 | 4.42E-02 | 6.93E-04 | <MDC | <MDC |
| U | 12 | 12 | 1.98E+00 | 2.30E+00 | 8.79E-03 | 4.85E-04 | 2.30E+00 | 2.30E+00 |
| V | 12 | 12 | 1.11E+01 | 1.44E+01 | 5.29E-02 | 2.83E-02 | 1.43E+01 | 1.43E+01 |
| Zn | 12 | 11 | 4.13E+00 | 2.09E+01 | 1.63E+00 | 2.03E-01 | 1.31E+01 | 1.31E+01 |

[1] El = Element analyzed;

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

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

[4] MDC = Minimum detectable concentration;

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

[6] N/A = Not Applicable

# Table 2-2: Measured Concentration of Selected Inorganic Analytes in Drinking Water from 1998 to 2010 at Five Locations
(Continued)

| Otis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1998-2009 | | | | 2010 | | | |
| 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 | 1 | 2.63E-02 | 2.63E-02 | 5.20E-02 | 1.91E-03 | <MDC | <MDC |
| Al | 11 | 3 | 5.74E+00 | 1.06E+03 | 1.14E+01 | 2.66E+00 | <MDC | <MDC |
| As | 12 | 5 | 6.53E-01 | 2.34E+00 | 4.03E+00 | 7.94E-01 | <MDC | <MDC |
| B | 4 | 4 | 1.46E+02 | 2.39E+02 | 7.50E+00 | 1.41E-01 | 1.75E+02 | 1.75E+02 |
| Ba | 13 | 12 | 1.35E+01 | 1.75E+01 | 1.25E+00 | 1.51E-02 | 1.53E+01 | 1.53E+01 |
| Be | 9 | | N/A | N/A | 2.62E-01 | 4.99E-03 | <MDC | <MDC |
| Ca | 10 | 10 | 2.14E+05 | 3.83E+05 | 3.25E+03 | 1.24E+02 | 2.46E+05 | 2.46E+05 |
| Cd | 9 | | N/A | N/A | 1.02E+00 | -7.16E-02 | <MDC | <MDC |
| Ce | 9 | 1 | 2.75E-02 | 2.75E-02 | 8.15E-03 | 8.76E-04 | <MDC | <MDC |
| Co | 11 | 9 | 1.19E-01 | 9.51E-01 | 5.90E-02 | 1.93E-03 | 4.44E-01 | 4.44E-01 |
| Cr | 12 | 10 | 8.76E-01 | 6.67E+00 | 2.27E+00 | 1.73E-01 | 3.00E+00 | 3.00E+00 |
| Cu | 12 | 10 | 2.43E+00 | 6.02E+00 | 5.05E-01 | 4.09E-02 | 5.02E+00 | 5.02E+00 |
| Dy | 11 | 1 | 3.39E-03 | 3.39E-03 | 2.77E-02 | 8.29E-04 | <MDC | <MDC |
| Er | 11 | | N/A | N/A | 9.55E-03 | 1.15E-03 | <MDC | <MDC |
| Eu | 10 | 3 | 3.42E-03 | 9.48E-03 | 2.78E-02 | 9.24E-04 | <MDC | <MDC |
| Fe | 12 | 11 | 2.87E+00 | 1.02E+03 | 2.21E+01 | 1.58E+01 | 2.03E+02 | 2.29E+02 |
| Gd | 9 | | N/A | N/A | 8.10E-02 | 1.07E-03 | <MDC | <MDC |
| Hg | 8 | | N/A | N/A | 2.31E-01 | 7.28E-01 | <MDC | <MDC |
| K | 10 | 10 | 2.75E+03 | 4.01E+03 | 1.53E+02 | 8.20E+00 | 2.99E+03 | 2.99E+03 |
| La | 10 | 2 | 3.97E-03 | 6.30E-03 | 2.77E-02 | 1.22E-03 | <MDC | <MDC |
| Li | 8 | 8 | 3.74E+01 | 6.79E+01 | N/A | N/A | N/A | N/A |
| Mg | 13 | 13 | 5.16E+04 | 1.08E+05 | 1.04E+01 | 2.14E+00 | 8.39E+04 | 8.39E+04 |
| Mn | 11 | 6 | 1.78E-01 | 2.32E+00 | 1.89E+00 | 7.19E-02 | <MDC | <MDC |
| Mo | 9 | 9 | 2.39E+00 | 3.13E+00 | 3.39E-01 | 7.46E-02 | 2.75E+00 | 2.83E+00 |
| Na | 11 | 11 | 1.16E+03 | 1.97E+05 | 2.48E+02 | 3.98E+00 | 1.18E+05 | 1.18E+05 |
| Nd | 11 | 3 | 4.80E-03 | 3.97E-02 | 7.25E-02 | 1.58E-04 | <MDC | <MDC |
| Ni | 11 | 10 | 2.45E+00 | 1.26E+01 | 1.55E-01 | 1.04E-02 | 1.26E+01 | 1.26E+01 |
| P | 3 | 3 | 4.54E+01 | 1.52E+02 | 4.07E+01 | 1.88E+00 | 1.52E+02 | 1.52E+02 |
| Pb | 10 | 8 | 1.08E-01 | 6.98E-01 | 5.00E-01 | 1.34E-02 | 6.98E-01 | 6.98E-01 |
| Pr | 11 | | N/A | N/A | 2.37E-02 | 5.35E-04 | <MDC | <MDC |
| Sb | 10 | 6 | 3.50E-02 | 4.10E-01 | 2.69E-01 | 3.86E-03 | <MDC | <MDC |
| Sc | 9 | 8 | 1.80E+00 | 5.35E+00 | 1.38E-01 | 8.72E-02 | 2.91E+00 | 3.00E+00 |
| Se | 8 | | N/A | N/A | 2.86E+01 | 2.43E+00 | <MDC | <MDC |
| Si | 7 | 7 | 9.38E+03 | 1.39E+04 | 3.99E+01 | 4.81E+00 | 9.38E+03 | 9.38E+03 |
| Sr | 11 | 11 | 3.31E+01 | 4.62E+03 | N/A | N/A | N/A | N/A |
| Th | 9 | 2 | 3.44E-03 | 2.67E-02 | 5.20E-02 | 1.81E-03 | <MDC | <MDC |
| Tl | 8 | | N/A | N/A | 2.21E-01 | 6.93E-04 | <MDC | <MDC |
| U | 11 | 11 | 3.73E+00 | 5.88E+00 | 4.40E-02 | 4.85E-04 | 4.83E+00 | 4.83E+00 |
| V | 12 | 11 | 1.05E+01 | 1.29E+01 | 2.65E-01 | 2.83E-02 | 1.17E+01 | 1.17E+01 |
| Zn | 12 | 9 | 1.54E+00 | 1.64E+01 | 8.15E+00 | 2.03E-01 | <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 2-3: Radionuclide Activity Concentrations in Drinking Water Sources

| Location and sample collection date | Radionuclide | Activity[a] Concentration Bq/L | SD[b] (Bq/L) | MDC[c] (Bq/L) |
|---|---|---|---|---|
| **Carlsbad**<br>12/2/2010 | $^{239+240}$Pu | 4.88E-05 | 5.39E-05 | 1.95E-04 |
| | $^{238}$Pu | 1.68E-05 | 4.31E-05 | 1.75E-04 |
| | $^{241}$Am | 1.85E-05 | 3.09E-05 | 1.05E-04 |
| | $^{234}$U | 2.99E-02 | 8.26E-04 | 1.57E-04 |
| | $^{235}$U | 5.64E-04 | 9.85E-05 | 1.19E-04 |
| | $^{238}$U | 1.17E-02 | 4.46E-04 | 1.56E-04 |
| | $^{137}$Cs | 2.56E-02 | 3.61E-02 | 1.19E-01 |
| | $^{40}$K | 7.29E-02 | 3.67E-01 | 1.22E+00 |
| | $^{60}$Co | 2.00E-02 | 1.70E-02 | 7.77E-02 |
| **Hobbs**<br>12/2/2010 | | | | |
| | $^{239+240}$Pu | 4.58E-05 | 4.98E-05 | 1.78E-04 |
| | $^{238}$Pu | 2.52E-05 | 3.56E-05 | 1.36E-04 |
| | $^{241}$Am | -5.20E-05 | 2.74E-05 | 1.48E-04 |
| | $^{234}$U | 1.04E-01 | 2.72E-03 | 1.79E-04 |
| | $^{235}$U | 2.23E-03 | 2.25E-04 | 2.20E-04 |
| | $^{238}$U | 4.59E-02 | 1.37E-03 | 2.17E-04 |
| | $^{137}$Cs | -5.57E-02 | 3.74E-02 | 1.25E-01 |
| | $^{40}$K | 4.49E-01 | 3.59E-01 | 1.18E+00 |
| | $^{60}$Co | 1.53E-02 | 1.71E-02 | 8.04E-02 |
| **Double Eagle**<br>12/2/2010 | | | | |
| | $^{239+240}$Pu | 7.46E-05 | 4.48E-05 | 1.39E-04 |
| | $^{238}$Pu | -1.05E-04 | 4.48E-05 | 2.37E-04 |
| | $^{241}$Am | 1.53E-05 | 2.74E-05 | 9.00E-05 |
| | $^{234}$U | 4.89E-02 | 1.44E-03 | 2.34E-04 |
| | $^{235}$U | 7.80E-04 | 1.36E-04 | 1.62E-04 |
| | $^{238}$U | 2.01E-02 | 7.52E-04 | 2.51E-04 |
| | $^{137}$Cs | -1.17E-02 | 3.67E-02 | 1.22E-01 |
| | $^{40}$K | -4.55E-02 | 3.62E-01 | 1.20E+00 |
| | $^{60}$Co | 4.32E-02 | 1.70E-02 | 7.72E-02 |
| **Otis**<br>12/3/2010 | | | | |
| | $^{239+240}$Pu | 1.96E-04 | 9.43E-05 | 2.71E-04 |
| | $^{238}$Pu | -1.69E-04 | 9.33E-05 | 4.49E-04 |
| | $^{241}$Am | 5.12E-05 | 6.56E-05 | 1.02E-04 |
| | $^{234}$U | 1.54E-01 | 4.37E-03 | 2.38E-04 |
| | $^{235}$U | 2.66E-03 | 2.57E-04 | 3.12E-04 |
| | $^{238}$U | 5.41E-02 | 1.72E-03 | 2.02E-04 |
| | $^{137}$Cs | -3.66E-02 | 3.64E-02 | 1.21E-01 |
| | $^{40}$K | 3.37E-02 | 3.68E-01 | 1.22E+00 |
| | $^{60}$Co | 8.08E-03 | 1.70E-02 | 7.87E-02 |
| **Loving**<br>12/3/2010 | | | | |
| | $^{239+240}$Pu | 1.11E-04 | 4.72E-05 | 1.25E-04 |
| | $^{238}$Pu | 2.69E-05 | 2.69E-05 | 9.91E-05 |
| | $^{241}$Am | -8.78E-06 | 1.80E-05 | 3.44E-05 |
| | $^{234}$U | 8.00E-02 | 2.01E-03 | 2.48E-04 |
| | $^{235}$U | 1.20E-03 | 1.55E-04 | 1.71E-04 |
| | $^{238}$U | 2.49E-02 | 8.04E-04 | 1.95E-04 |
| | $^{137}$Cs | -1.70E-02 | 3.67E-02 | 1.22E-01 |
| | $^{40}$K | -1.93E-01 | 3.69E-01 | 1.23E+00 |
| | $^{60}$Co | 2.67E-02 | 1.69E-02 | 7.62E-02 |

| **Otis (DUP)**<br>12/3/2010 | | | | |
|---|---|---|---|---|
| | $^{239+240}$Pu | 6.87E-05 | 6.88E-05 | 2.45E-04 |
| | $^{238}$Pu | -6.12E-05 | 6.12E-05 | 2.88E-04 |
| | $^{241}$Am | 4.52E-05 | 6.67E-05 | 2.39E-04 |
| | $^{234}$U | 1.49E-01 | 4.32E-03 | 1.86E-04 |
| | $^{235}$U | 2.18E-03 | 2.27E-04 | 1.98E-04 |
| | $^{238}$U | 5.23E-02 | 1.70E-03 | 2.07E-04 |
| | $^{137}$Cs | -2.40E-02 | 3.67E-02 | 1.22E-01 |
| | $^{40}$K | 3.19E-02 | 3.67E-01 | 1.22E+00 |
| | $^{60}$Co | 5.53E-03 | 1.78E-02 | 8.08E-02 |

[a] Activity concentration as defined in CEMRC Report 1997

[b] SD = Standard Deviation as defined in CEMRC Report 1997

[c] MDC = Minimum Detectable Concentration as defined in CEMRC Report 1997

Dup = Duplicate

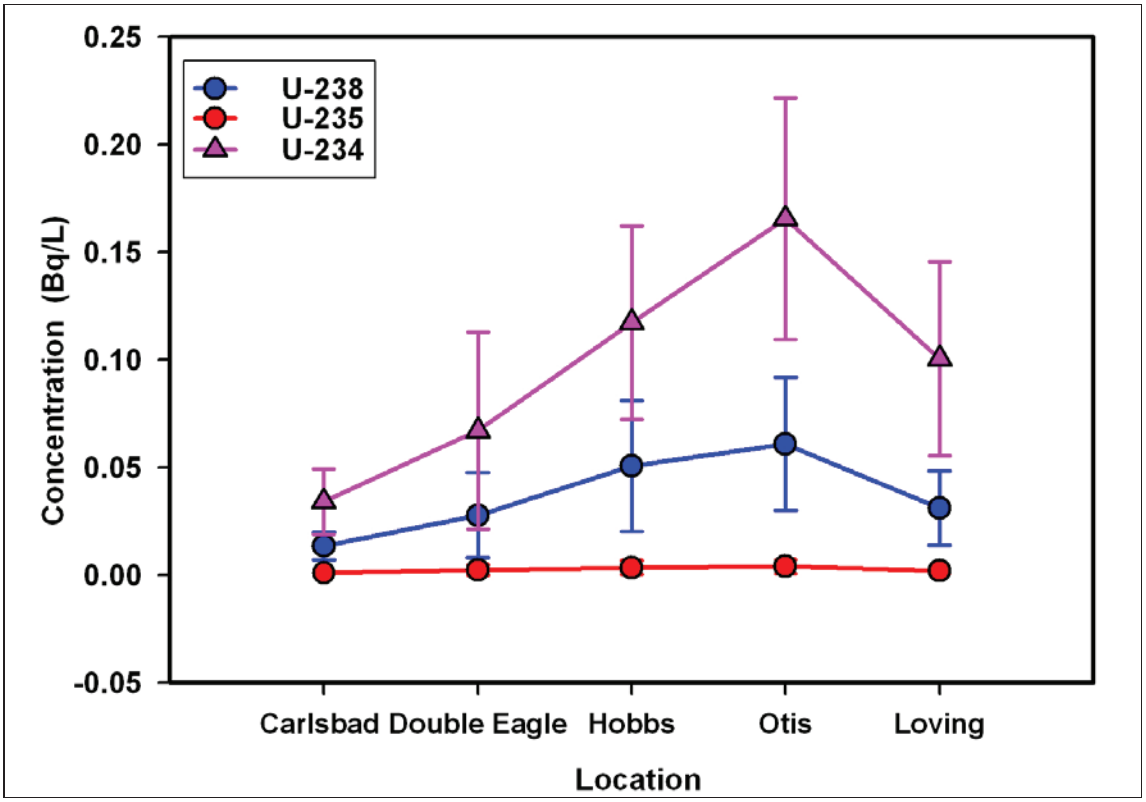

**Figure 2.1: $^{234}$U, $^{235}$U, and $^{238}$U in Bq/L in Regional Drinking Water**
Results from 1998 to 2010 are averaged for each site. All are below the EPA Action level of 0.56 Bq/L and within the range expected in waters from this region.

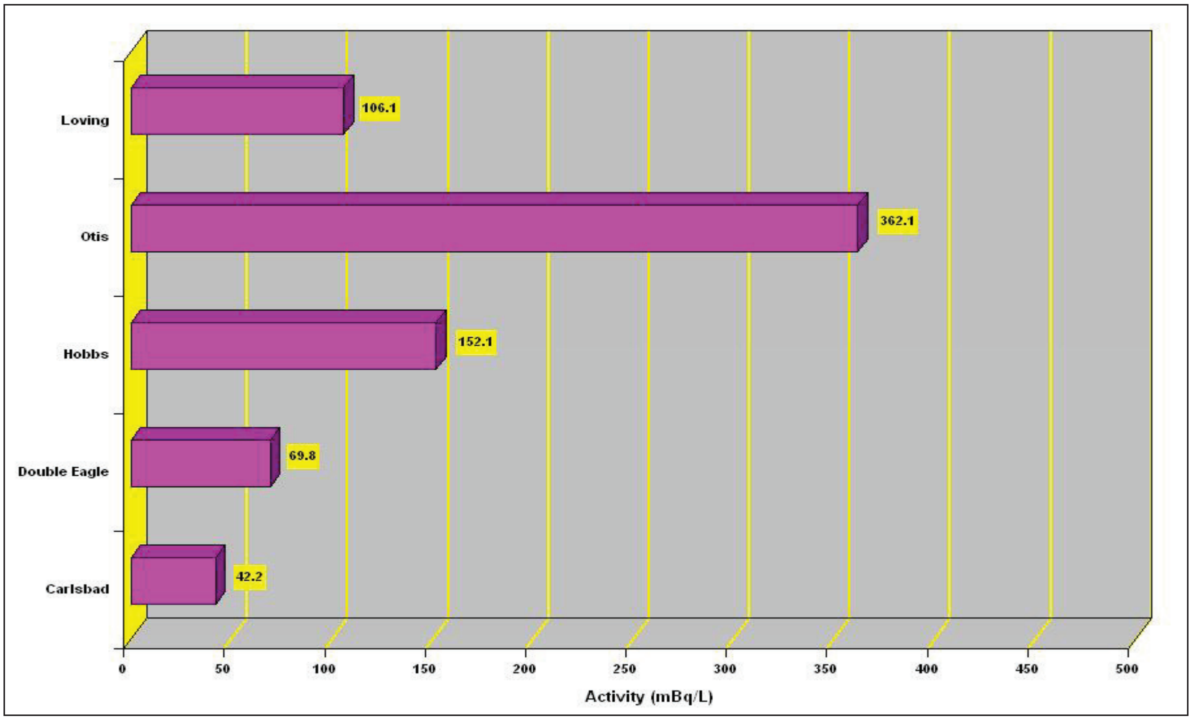

Figure 2.2: Total Uranium Concentration in mBq/L in Regional Drinking Water Collected During 2010

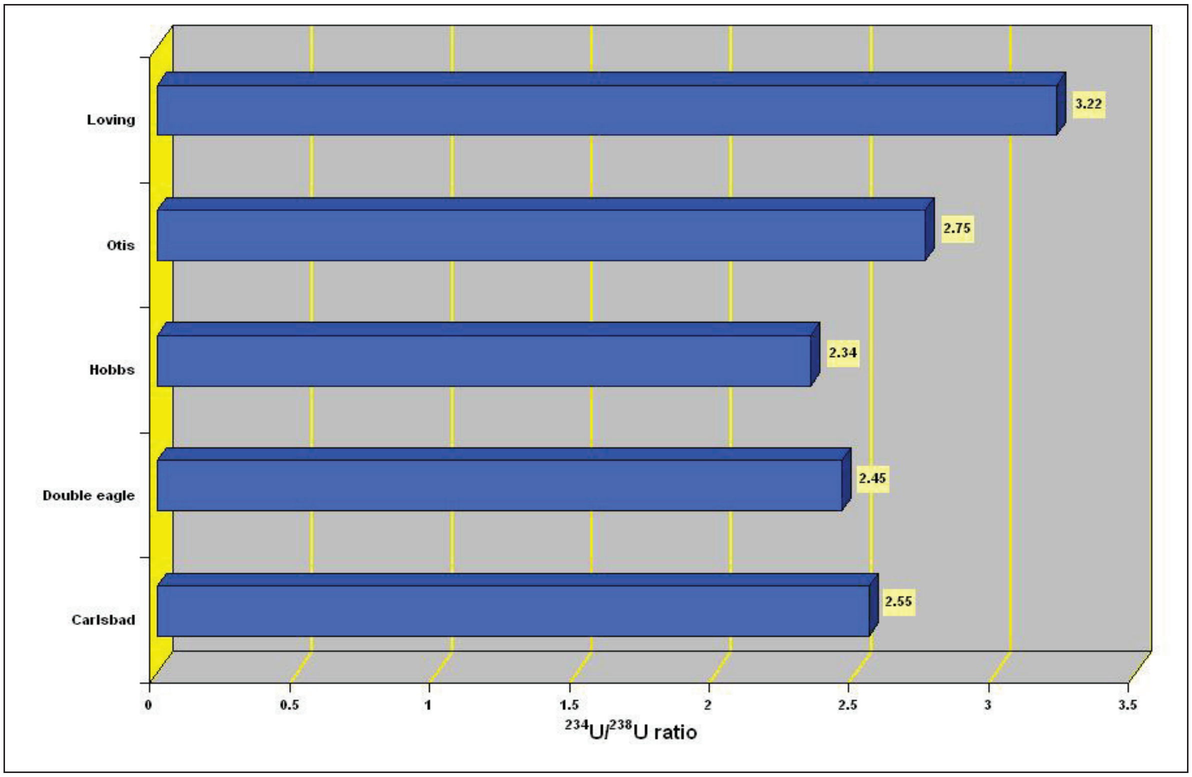

Figure 2.3: Average $^{234}U/^{238}U$ Activity Ratio in Regional Drinking Water Results from 1998 to 2010 are averaged for each site.

### Table 2-4: Comparison of Activity Concentration Ratios of $^{234}U/^{238}U$ and $^{235}U/^{238}U$ Ratio in Water Samples Collected Near the WIPP Site with Other Countries

| Source of water sample | Type of water | $^{234}U/^{238}U$ | $^{235}U/^{238}U$ | Reference |
|---|---|---|---|---|
| Carlsbad | Drinking water | 2.86 | 0.048 | Present work |
| Double Eagle | Drinking water | 2.43 | 0.039 | Present work |
| Hobbs | Drinking water | 2.26 | 0.049 | Present work |
| Otis | Drinking water | 2.86 | 0.042 | Present work |
| Loving | Drinking water | 3.21 | 0.048 | Present work |
| UK | Water | 1.0-3.0 | - | Gilkeson et al. |
| Poland | Mineral water | 0.82-1.12 | - | Nguyen et al. |
| India | Sea water | 1.11-1.14 | 0.045-0.047 | Joshi et al. |
| Ghana, Obuasi | Ground water | 1.07-1.44 | 0.042-0.045 | Awudu et al. |
| Ghana, Obuasi | Surface water | 1.06-1.76 | 0.044-0.045 | Awudu et al. |
| Ghana, Obuasi | Tap water | 1.06-1.73 | 0.044-0.045 | Awudu et al. |
| INL, Idaho | Ground water | 1.5-3.1 | - | Roback et al. |
| Tunisia | Mineral water | 1.16-2.46 | - | Gharbi et al. |

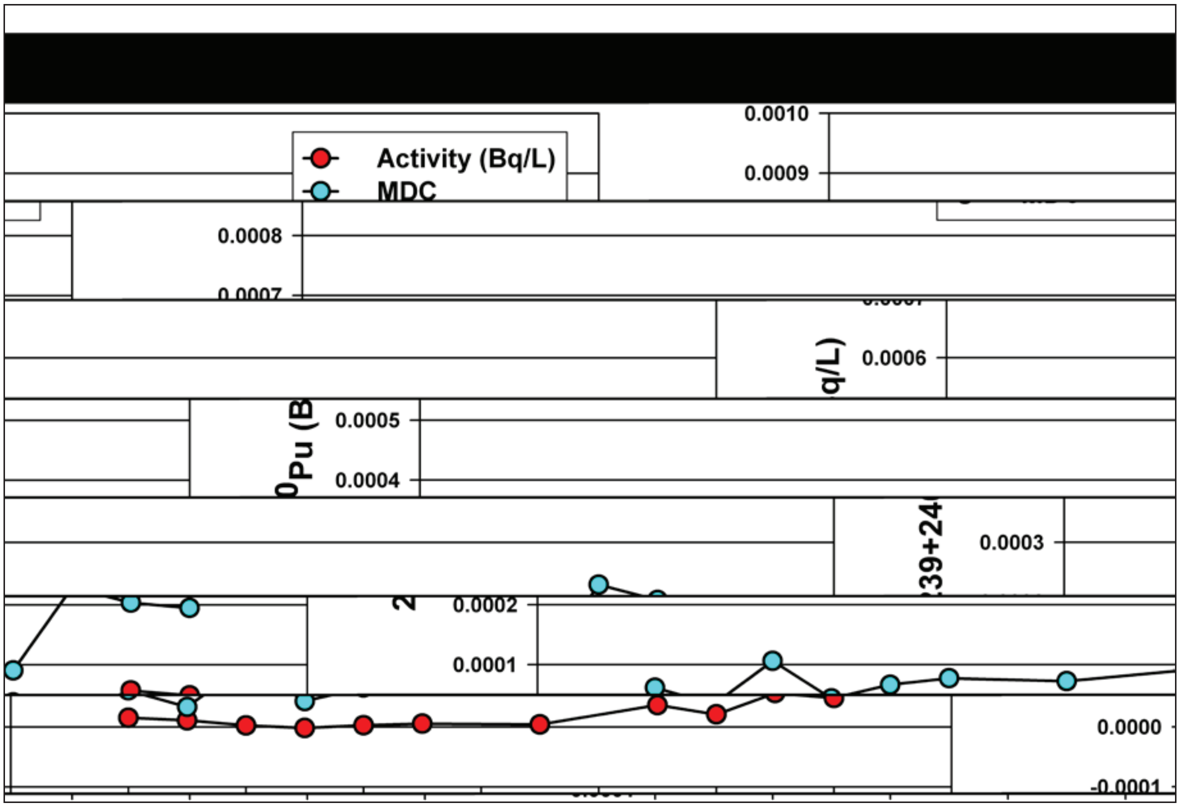

**Figure 2.4:** $^{239+240}$**Pu in Carlsbad Drinking Water from 1998-2010**
EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L).

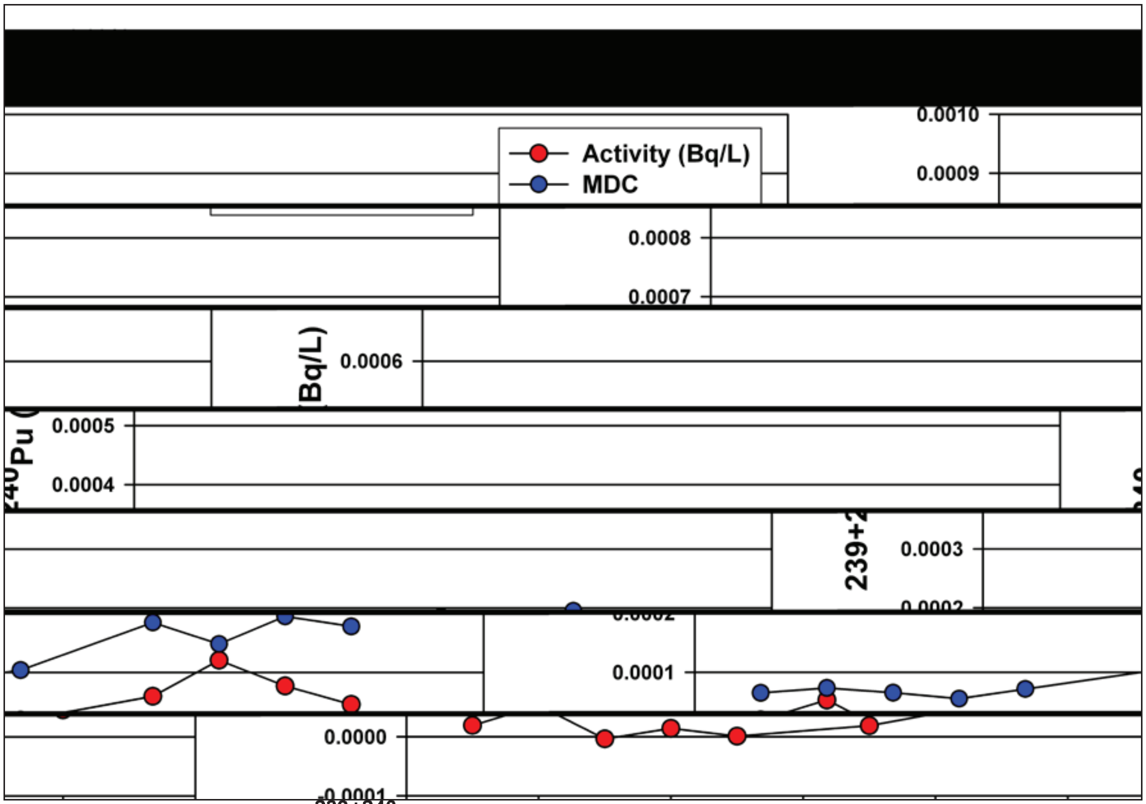

**Figure 2.5:** $^{239+240}$**Pu in Hobbs Drinking Water from 1998-2010**
EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L).

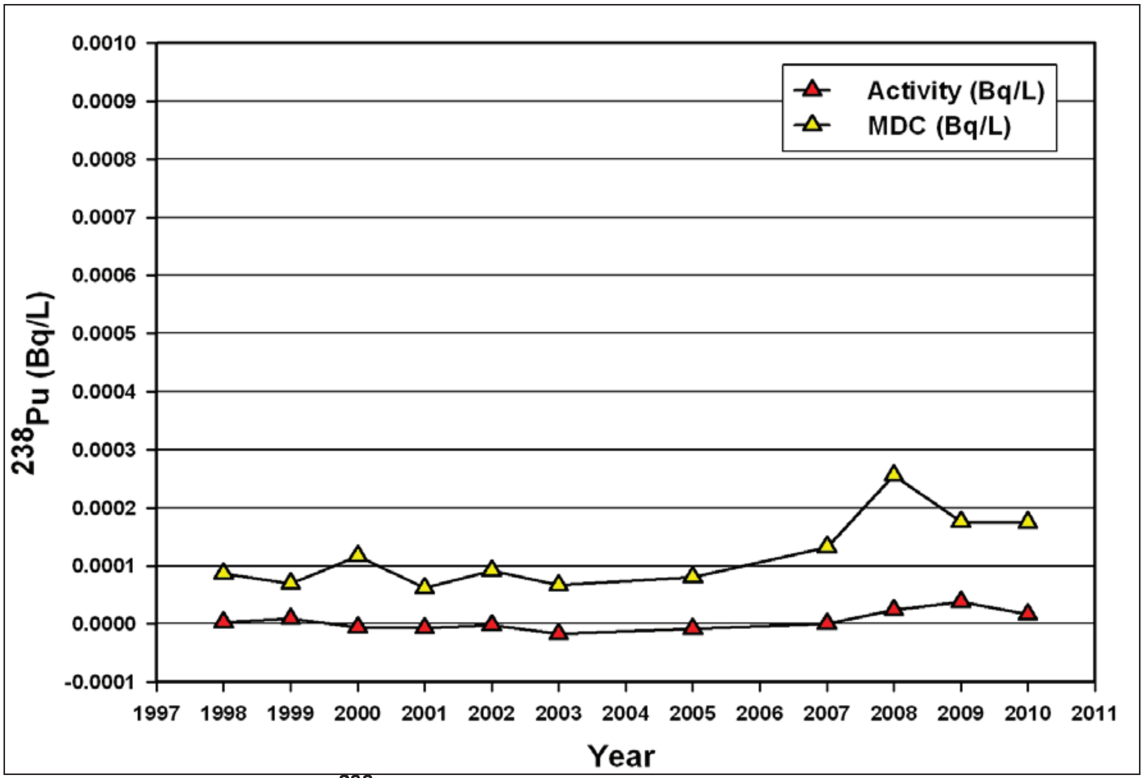

**Figure 2.6:** $^{238}$**Pu in Hobbs Drinking Water from 1998-2010**
EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L).

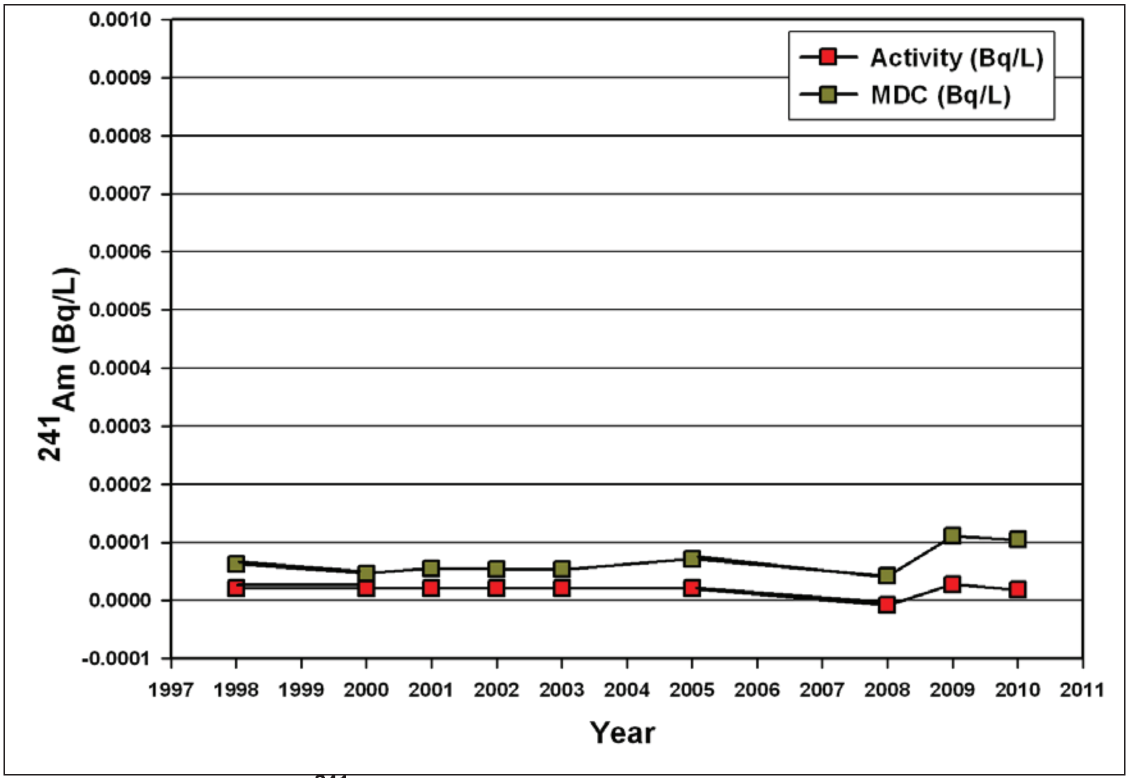

**Figure 2.7: $^{241}$Am in Carlsbad Drinking Water from 1998-2010**
EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L).

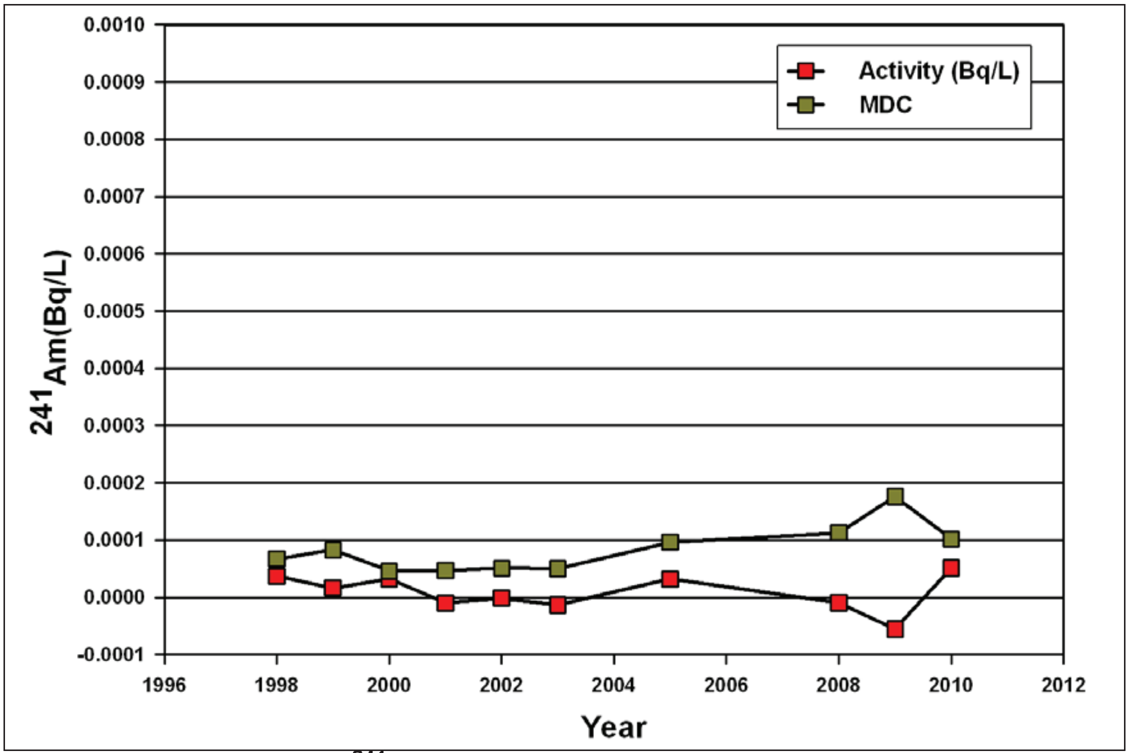

**Figure 2.8: $^{241}$Am in Otis Drinking Water from 1998-2010**
EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L).

## REFERENCES

Cherdynstev V.V (1971) Uranium-234. Program for scientific translations Ltd. Keter Press, Jerusalem, p 234

Fleischer, R.L (1980) Isotopic disequilibrium of uranium: alpha-recoil damage and preferential solution effects. Science 207, 979–981

Gharbi, F., Baccouche, S., Abdelli, W., Samaali, M., Oueslati, M., Trabelsi, A (2010) 589-590.

Gilkeson R.H., Coward JB (1982) A preliminary report on U-238 series disequilibrium in ground water of the Cambriam-Ordovician aquifer system of Northeastern Illinois. In: Perry EC, Montgomery CW (eds) Isotope studies of hydrologic processes. Northern Illinois University Press, Dekalb, IL, pp 109–118

Joshi, U., Zingde, D (1988) Uranium series disequilibrium in the coastal surface sediments and sea water of the Arabian Sea. J Radioanal Nucl Chem 120, 275–280.

Nguyen, D.C., Barbara, M (2009) Natural radioactivity in bottled natural spring, mineral and therapeutic waters in Poland. J. Radioanal Nucl Chem 279, 121–129.

Orloff, K.G., Mistry, K., Charp, P., Metcalf, S., Marino, R., Shelly, T., Melaro, E., Donnohoe, A.M., Jones, R.L., (2004). Human exposure to uranium in ground water. Environ. Res 94, 319-326.

Roback, R.C., Johnson, T. M., McLing, T., Murrell, M.T., Luo, S., T.L. Ku., (2001) Uranium isotopic evidence for groundwater chemical evolution and flow patterns in the eastern Snake River Plain aquifer, Idaho GSA Bulletin, 113, 1133-1141 (2001).

UNSCEAR (1982) Ionizing radiation: sources and biological effects. United Nations, New York.

UNSCEAR (1977) Sources and effects of ionizing radiation. United Nations, New York.

UNSCEAR (2000) Sources and effects of ionizing radiation. United Nations, New York. Report to the General assembly, with scientific annexes. Volume I: Sources. J. Radiol Prot 21, 83-86 (2001)

# CHAPTER 3

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

By

Jim Monk

## 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, 2010) 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, 2010, 935 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 303 recount bioassays had been performed through December 31, 2010. In addition, 358 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.

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

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 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, 2009/2010 and 2010/2011. 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 = 863), 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 80% 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.

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[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.

$^{40}$K results were positive for all participants through December 2010 and ranged from 792 to 5558 Bq per person with an overall mean (± SE) of 2477 (± 23) 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 3059 (± 27) Bq per person, which was significantly greater ($p < 0.0001$) than that of females, which was 1884 (± 19) 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 21.4 ± 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 12 (± 0.9) Bq per person. The mean $^{137}$Cs body burden for males (± SE), was 13.6 (± 1.2) Bq per person, which was significantly greater ($p = 0.002$) than that of females, which was 8.6 (± 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 (27.9 %) as compared to non-smokers (23.2 %). 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, 2010

| Characteristic | | 2010 Sample Group[a] (margin of error) | [b]Census, 2000 |
|---|---|---|---|
| Gender | Male | 47.1% (43.9 to 50.3%) | 48.2 % |
| | Female | 52.9% (49.7 to 56.1%) | 51.8 % |
| Ethnicity | Latino | 18.0% (15.5 to 20.4%) | 36.7 % |
| | Non-Latino | 82.0% (79.6 to 84.5%) | 63.3 % |
| Age 60 or older | | 23.9% (21.5 to 26.3%) | 24.5 % |
| Currently or previously classified as a radiation worker | | 8.1% (6.6 to 9.7%) | [c]NA |
| Consumption of wild game within 3 months prior to count | | 21.8% (19.5 to 24.1%) | NA |
| Medical treatment other than X-rays using radionuclides | | 7.3% (5.9 to 8.8%) | NA |
| European travel within 2 years prior to the count | | 5.0% (3.7 to 6.2%) | NA |
| Current smoker | | 13.4% (11.5 to 15.3%) | 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 3-2: Minimum Detectable Activities
(Continued)

## 2010-2011 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 | 0.67 | 0.93 |
| Ce-144 | 133.50 | 0.47 | 0.57 | 0.72 | 0.79 | 1.01 | 1.33 | 1.74 |
| Cf-252 | 19.20 | 17.98 | 35.53 | 84.73 | 120.80 | 307.52 | 847.33 | 2286.97 |
| Cm-244 | 18.10 | 16.81 | 35.78 | 93.35 | 137.65 | 387.66 | 1185.62 | 3546.51 |
| Eu-155 | 105.30 | 0.28 | 0.34 | 0.44 | 0.48 | 0.64 | 0.86 | 1.16 |
| Np-237 | 86.50 | 0.49 | 0.61 | 0.80 | 0.90 | 1.20 | 1.66 | 2.26 |
| Pu-238 | 17.10 | 18.46 | 42.54 | 123.50 | 189.02 | 594.43 | 2045.16 | 6876.17 |
| Pu-239 | 17.10 | 45.94 | 105.85 | 307.28 | 470.28 | 1478.98 | 5088.44 | 17108.17 |
| Pu-240 | 17.10 | 18.05 | 41.59 | 120.72 | 184.75 | 581.03 | 1999.03 | 6721.07 |
| Pu-242 | 17.10 | 21.77 | 50.17 | 145.63 | 222.88 | 700.92 | 2411.53 | 8107.95 |
| Ra-226 | 186.10 | 1.65 | 1.94 | 2.37 | 2.57 | 3.21 | 4.07 | 5.14 |
| Th-232 via Pb-212 | 238.60 | 0.15 | 0.17 | 0.21 | 0.23 | 0.29 | 0.38 | 0.48 |
| Th-232 | 59.00 | 34.41 | 43.09 | 57.62 | 64.83 | 88.56 | 124.16 | 172.65 |
| Th-232 via Th-228 | 84.30 | 4.88 | 6.09 | 7.98 | 8.92 | 11.99 | 16.48 | 22.54 |
| U-233 | 440.30 | 0.65 | 0.75 | 0.91 | 0.98 | 1.21 | 1.51 | 1.88 |
| 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 | 1.64 | 2.04 | 2.72 | 3.06 | 4.17 | 5.82 | 8.08 |

### Radionuclides Deposited in the Whole Body

| Radionuclide | Energy (keV) | MDA (nCi) |
|---|---|---|
| Ba-133 | 356 | 0.79 |
| Ba-140 | 537 | 1.53 |
| Ce-141 | 145 | 1.70 |
| Co-58 | 811 | 0.37 |
| Co-60 | 1333 | 0.36 |
| Cr-51 | 320 | 4.56 |
| Cs-134 | 604 | 0.36 |
| Cs-137 | 662 | 0.42 |
| Eu-152 | 344 | 1.63 |
| Eu-154 | 1275 | 0.95 |
| Eu-155 | 105 | 3.92 |
| Fe-59 | 1099 | 0.67 |
| I-131 | 365 | 0.48 |
| I-133 | 530 | 0.43 |
| Ir-192 | 317 | 0.56 |
| Mn-54 | 835 | 0.45 |
| Ru-103 | 497 | 0.40 |
| Ru-106 | 622 | 3.34 |
| Sb-125 | 428 | 1.37 |
| Th-232 via Ac-228 | 911 | 1.25 |
| Y-88 | 898 | 0.38 |
| Zn-65 | 1116 | 1.12 |
| Zr-95 | 757 | 0.59 |

## Table 3-3: "Lie Down and Be Counted" Results through December 31, 2010

| 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 2010) N = 863 |
|---|---|---|---|
| | | % of Results ≥ [b]$L_C$ | % of Results ≥ $L_C$ |
| $^{241}$Am | Lung | 5.2 (4.0 to 6.4) | 4.3 (3.6 to 5.0) |
| $^{144}$Ce | Lung | 4.6 (3.5 to 5.7) | 4.2 (3.5 to 4.9) |
| $^{252}$Cf | Lung | 4.1 (3.1 to 5.1) | 5.7 (4.9 to 6.5) |
| $^{244}$Cm | Lung | 5.7 (4.5 to 7.0) | 4.8 (4.0 to 5.5) |
| $^{155}$Eu | Lung | 7.1 (5.8 to 8.4) | 5.1 (4.3 to 5.8) |
| $^{237}$Np | Lung | 3.6 (2.6 to 4.5) | 3.9 (3.3 to 4.6) |
| $^{210}$Pb | Lung | 4.4 (3.3 to 5.4) | 6.6 (5.8 to 7.5) |
| Plutonium Isotope | Lung | 5.7 (4.5 to 7.0) | 5.7 (4.9 to 6.5) |
| [d] $^{232}$Th via $^{212}$Pb | Lung | 34.2 (31.7 to 36.6) | 32.8 (31.2 to 34.4) |
| $^{232}$Th | Lung | 4.9 (3.8 to 6.0) | 5.0 (4.3 to 5.7) |
| $^{232}$Th via $^{228}$Th | Lung | 4.1 (3.1 to 5.1) | 5.2 (4.5 to 6.0) |
| $^{233}$U | Lung | 5.7 (4.5 to 7.0) | 9.3 (8.3 to 10.3) |
| $^{235}$U/$^{226}$Ra | Lung | 10.7 (9.0 to 12.3) | 11.5 (10.4 to 12.6) |
| Natural Uranium via $^{234}$Th | Lung | 5.2 (4.0 to 6.4) | 5.8 (5.0 to 6.6) |
| $^{133}$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 4.7) |
| $^{141}$Ce | Whole Body | 3.6 (2.6 to 4.5) | 4.6 (3.9 to 5.4) |
| $^{58}$Co | Whole Body | 4.4 (3.3 to 5.4) | 3.0 (2.4 to 3.6) |
| [d] $^{60}$Co | Whole Body | 54.6 (52.0 to 57.2) | 26.1 (24.6 to 27.6) |
| $^{51}$Cr | Whole Body | 5.7 (4.5 to 7.0) | 3.8 (3.2 to 4.5) |
| $^{134}$Cs | Whole Body | 1.6 (1.0 to 2.3) | 2.7 (2.1 to 3.2) |
| $^{137}$Cs | Whole Body | 28.4 (26.1 to 30.8) | 19.3 (17.9 to 20.6) |
| $^{152}$Eu | Whole Body | 7.4 (6.0 to 8.7) | 6.1 (5.3 to 7.0) |
| $^{154}$Eu | Whole Body | 3.8 (2.8 to 4.8) | 3.2 (2.6 to 3.9) |
| $^{155}$Eu | Whole Body | 3.8 (2.8 to 4.8) | 3.5 (2.9 to 4.1) |
| $^{59}$Fe | Whole Body | 3.8 (2.8 to 4.8) | 5.6 (4.8 to 6.3) |
| $^{131}$I | Whole Body | 5.2 (4.0 to 6.4) | 3.9 (3.3 to 4.6) |
| $^{133}$I | Whole Body | 3.3 (2.3 to 4.2) | 4.1 (3.4 to 4.7) |
| $^{193}$Ir | Whole Body | 4.1 (3.1 to 5.1) | 3.8 (3.2 to 4.5) |
| $^{40}$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) | 12.2 (11.1 to 13.3) |
| $^{103}$Ru | Whole Body | 2.2 (1.4 to 3.0) | 1.7 (1.3 to 2.2) |
| $^{106}$Ru | Whole Body | 4.4 (3.3 to 5.4) | 4.1 (3.4 to 4.7) |
| $^{125}$Sb | Whole Body | 5.2 (4.0 to 6.4) | 3.9 (3.3 to 4.6) |
| $^{232}$Th via $^{228}$Ac | Whole Body | 34.7 (32.2 to 37.2) | 25.4 (23.9 to 26.9) |
| $^{88}$Y | Whole Body | 7.7 (6.3 to 9.0) | 6.2 (5.3 to 7.0) |
| $^{95}$Zr | Whole Body | 6.6 (5.3 to 7.9) | 3.9 (3.3 to 4.6) |

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

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

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

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

# CHAPTER 4

## Analysis of Volatile Organic Compounds

By
Anuj Kumar

## 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 has been 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 an HSG analysis system consisting of a 6890/5973N Agilent GC/MS with a loop injection system and three Entech 7032 Autosamplers installed in series. 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. In 2010, CEMRC analyzed a total of 711 samples for VOCs and 441 samples 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, certified from a reputable supplier, are purchased 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 a 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 VOC results.

## LABORATORY CONTROL SAMPLES

Laboratory Control Sample (LCS) is a standard that contains known concentration of compounds of interest which has been prepared from a different source than that used to prepare the calibration standard. An LCS is the same as a spiked blank or blank spike. The percent recovery of the LCS is used in evaluating method accuracy. A comparison of LCS and LCS-duplicate results are used in evaluating method precision.

LCS and LCS-duplicate in VOC quality control checks are analyzed at a rate of once per batch, or once each ten samples, whichever is more frequent, to verify instrument calibration and quantitative analytical accuracy, whereas LCS and LCS-duplicate in hydrogen and methane quality control checks are run for each analysis batch. The LCS % recovery must be within ± 40% for all target VOCs and ± 30% for hydrogen and methane. The relative percentage difference (RPD) must be 25% or less for all compounds. The laboratory achieved and maintained method precision limit for all the target compounds. Figures 4.1-4.4 show an example of LCS % recovery and RPD for one of the target VOCs (Carbon tetrachloride) and Hydrogen.

## RESULTS AND DISCUSSION

The OC lab analyzed a total of 1152 samples in 2010, which is a higher number than any of the previous years. All of the samples were analyzed and reported in a timely manner under an extensive quality assurance (QA)/quality control (QC) program. The 1152 samples consisted of 711 samples for VOCs measurement (643 routine air samples, 68 blank and recovery gas samples) and 441 samples for hydrogen and methane analysis. All of these samples achieved 100% completeness. Blank and recovery gas samples were collected by Shaw Environmental and were part of the sampler cleaning and certification program; they were analyzed in expedited turnaround batches at various times throughout the year. The OC lab also received a number of canisters and passivated sampling kits (sample trains) for cleaning and certification at various times throughout the year. All of the canisters and sample trains were cleaned and certified with appropriate QA/QC in place.

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 hydrogen 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 Volatile Organic Compounds (VOCs) in Ambient Air from Canisters at 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 |

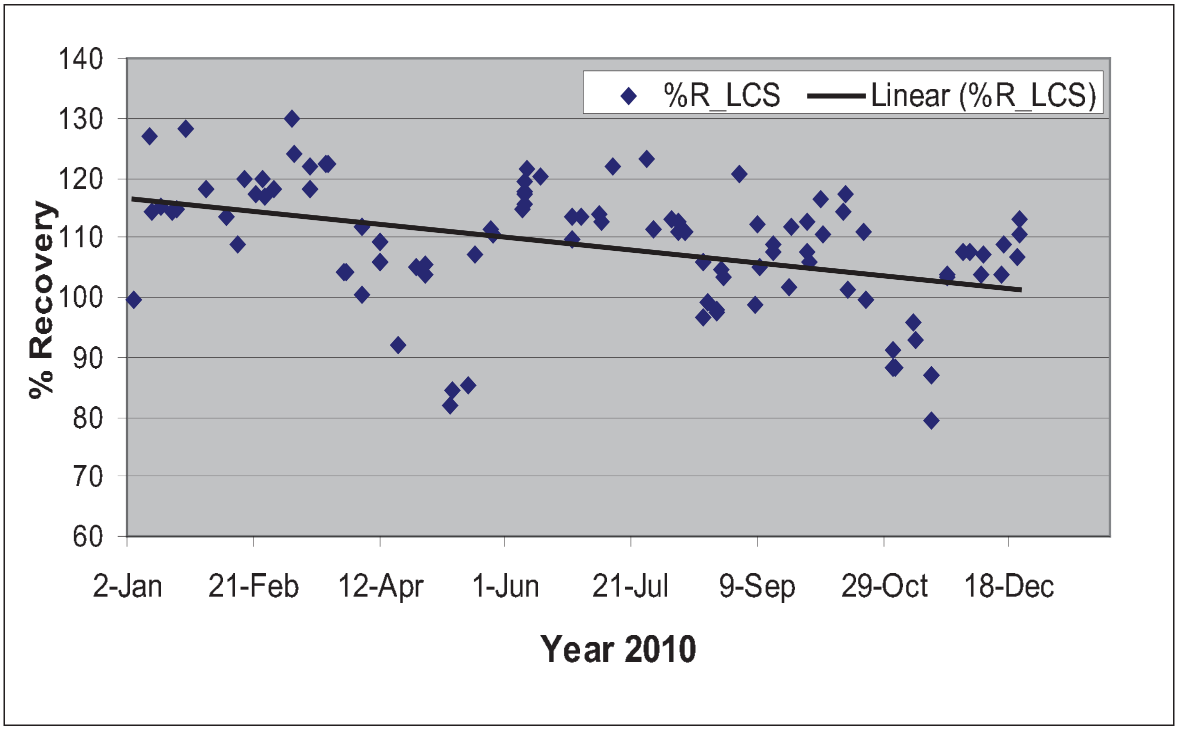

**Figure 4.1: Percent Recovery of Carbon Tetrachloride in LCS**
(Recovery range: 60-140%)

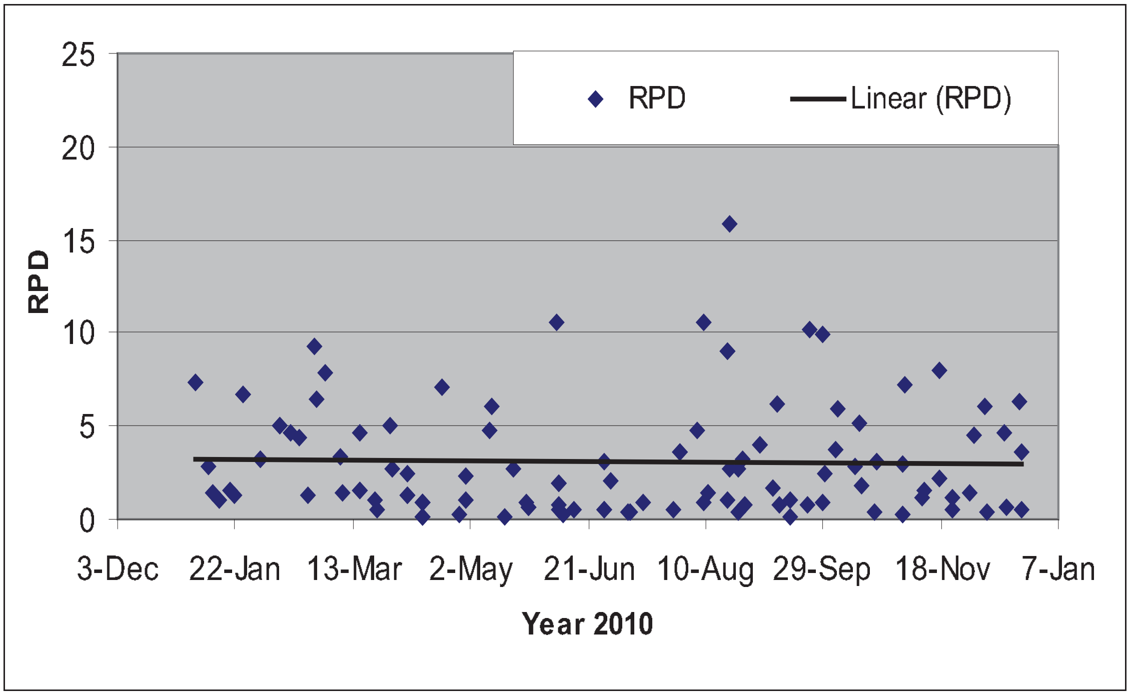

**Figure 4.2: Relative Percent Deviation (RPD) Between LCS and LCS-Duplicate for Carbon Tetrachloride**
(RPD range: ≤25%)

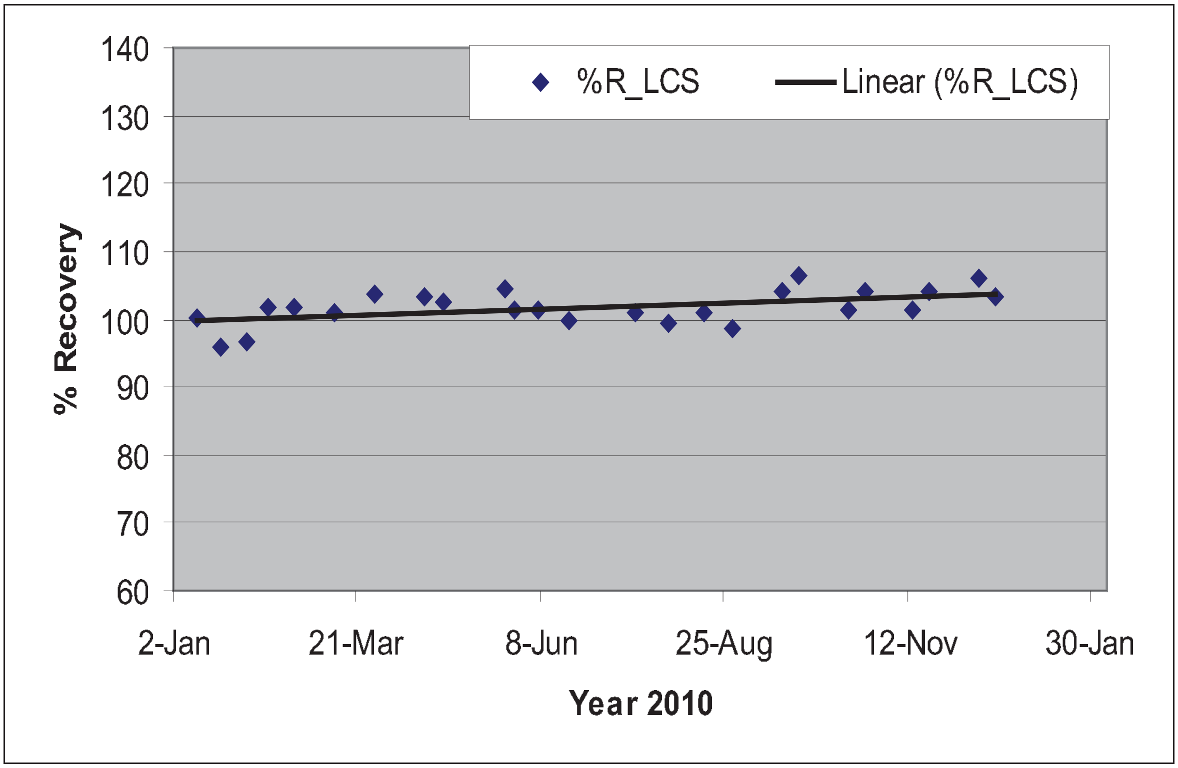

**Figure 4.3: Percent Recovery of Hydrogen in LCS**
(Recovery range: 70-130%)

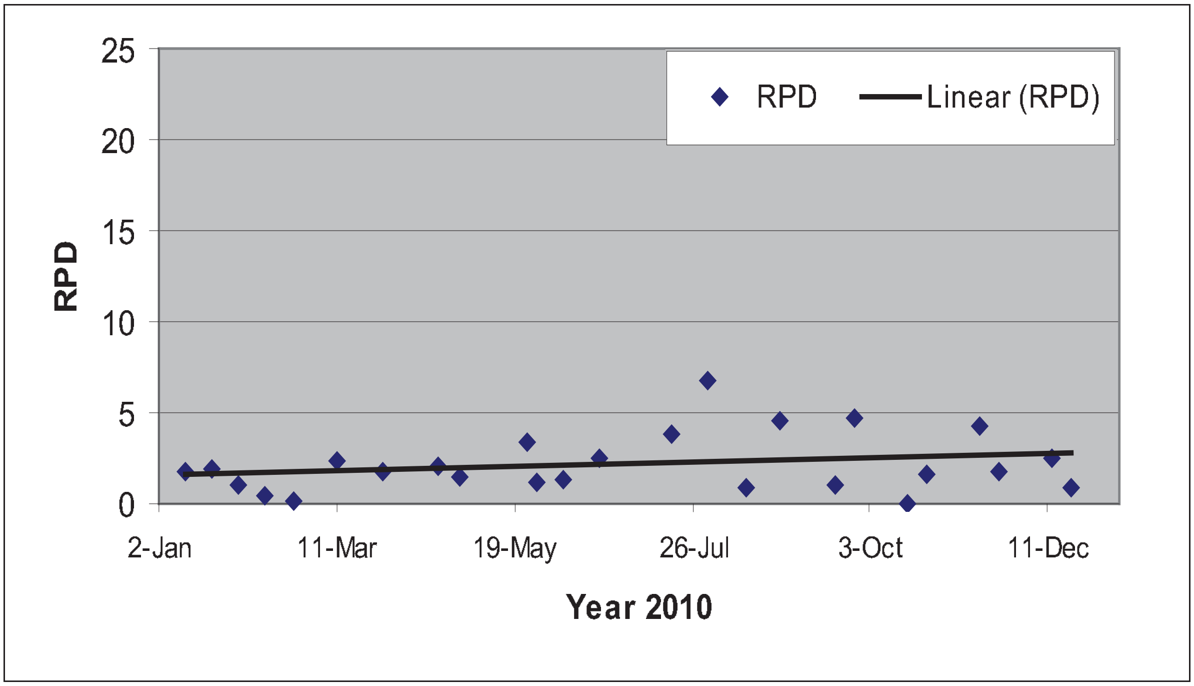

**Figure 4.4: Relative Percent Deviation (RPD) Between LCS and LCS-Duplicate for Hydrogen**
(RPD range: ≤25%)

# CHAPTER 5

# Ambient Aerosol Studies for the WIPP-EM

By
Punam Thakur

## INTRODUCTION

The CEMRC ambient aerosol monitoring studies focus on both man-made and naturally-occurring radionuclides, but special emphasis is given to plutonium (Pu) and americium (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 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 2005).

The element of particular interest for the WIPP-EM is Pu (atomic number 94) and 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 TRU waste at the site can be attributed to nuclear weapons testing in the 1950s to1980s, controlled releases from the operation of nuclear power plants and nuclear reprocessing facilities, and nuclear accidents such as Chernobyl and Fukushima.

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 Chapter 1.

## METHODS

### Description of Ambient Air Sampling Stations

High-volume aerosol sampling was conducted at three (3) sites. The sites were selected on the basis of the most probable scenario for radioactivity release if there is an accident during the operation of the WIPP. In establishing these sites, it was recognized that there was no ideal "control" location from which to collect samples, that is, a site far enough from the WIPP to ensure complete isolation from aerosol releases while adequately replicating key ecological features, aerosol composition, soil topology, biota and weather conditions, etc. The cactus flats station was used as a reference location because it represents a reasonable compromise based on these considerations. The locations of the air sampling stations are depicted on Figure 5.1. These stations are designated as:

> **Station #106 (On Site Station):** located in a primarily downwind position about 0.1 km northwest of the WIPP exhaust shaft.
>
> **Station #107 (Near Field Station):** located about 1 km northwest of the WIPP site.
>
> **Station # 108 (Cactus Flats Station):** located about 19 km southeast (upwind) of the WIPP site.

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. The Near Field and Cactus Flats stations also supported a second hivol sampler for studies of $PM_{10}$ samples (particulate matter less than 10 µm aerodynamic equivalent diameter), but the $PM_{10}$ sampling was terminated in December 2000. The decision to use TSP samplers rather than $PM_{10}$ samplers was based on the overall objective of the WIPP-EM, which is to evaluate any possible impacts of the WIPP. In particular this decision was made because it could be argued that the $PM_{10}$ samplers would not capture any releases of the largest aerosol particles as effective as the TSP samplers. 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 because WIPP is located approximately 61 km (38 miles) from Hobbs and an ambient air baseline had been established for the vicinity of Hobbs during prior years. Sample filters are weighed before and after sampling to determine the weight of solid material collected on the filters. Aerosols were sampled on 20x25 cm A/E$^{TM}$ glass fiber filters (Pall Gelman Laboratory, Ann Arbor, MI), taken over a period of 3 to 6 weeks depending on the levels of particulate matter that accumulated on the filters. Gravimetric measurements of the glass fiber filters were made to determine the mass of aerosol material that accumulated over the sampling interval.

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. These 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; 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.

The high-volume samples were analyzed for selected radionuclides, including $^{238}$Pu, $^{239+240}$Pu, $^{241}$Am and recently $^{235}$U, $^{234}$U and $^{238}$U 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 by Oxford Oasis alpha spectroscopy for five days. Gamma-emitting nuclides in the air filters are measured 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. The isotope $^{239+240}$Pu is frequently detected, whereas $^{238}$Pu is detected infrequently with activity concentrations slightly above the minimum detectable concentration (MDC). As in prior years, the $^{239+240}$Pu activity concentrations data from 2010 do not exhibit 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 5.3). 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. 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 and 2010 do not exhibit these springtime peaks. A time series plot for $^{241}$Am activity concentrations and densities are presented in (Figure 5.4 and 5.5).The activity concentrations of $^{241}$Am (Figure 5.4) in the high-volume samples closely tracked those of $^{239+240}$Pu. A strong correlation exists between $^{241}$Am and $^{239+240}$Pu activity concentrations ($R^2$ = 0.60, 0.64 and 0.72, respectively, for On Site, Near Field and Cactus Flats stations) even though neither $^{239}$Pu nor $^{240}$Pu are immediate progeny of $^{241}$Am (Figures 5.6-5.8).

The seasonal fluctuation for $^{238}$Pu is not as pronounced as for $^{239+240}$Pu and $^{241}$Am. The $^{239+240}$Pu and $^{241}$Am are frequently detected, whereas $^{238}$Pu is detected infrequently in aerosol filters, presumably because $^{238}$Pu is not primarily from weapons fallout, but instead was released by the burn-up of nuclear satellite such as SNAP-9A (Hardy, 1973)

The average activity concentration (activity per unit volume air sampled) for $^{239+240}$Pu ranges from 5.5-16.7 nBq/m$^3$ at On Site, 4.9-18.5 nBq/m$^3$ at Near Field, 2.3-20.3 nBq/m$^3$ at Cactus Flat; for $^{241}$Am the concentrations ranged from 1.9-5.4 nBq/m$^3$ for On Site station, 1.4-4.5 nBq/m$^3$ for Near Field and 1.7-7.7 nBq/m$^3$ for Cactus Flats. However, the $^{241}$Am concentrations were consistently lower than those of $^{239+240}$Pu. The average $^{239+240}$Pu, $^{241}$Am, and $^{238}$Pu concentrations in these three stations are shown in Figures (5.9-5.11). In 2010, the average $^{239+240}$Pu, $^{241}$Am and $^{238}$Pu activity concentrations in aerosol filters were measured below the pre-operational level. The average $^{239+240}$Pu activity density (activity per unit mass aerosol collected) ranges from 0.13-0.41 mBq/g at On Site, 0.19-0.77 mBq/g at Near Field, 0.12-0.59 mBq/g at Cactus Flats (Figures 5.12-5.14) while that of $^{241}$Am ranged from 0.05-0.16 mBq/g for On Site, 0.06-0.23 mBq/g for Near Field and 0.09-0.38 mBq/g for Cactus Flats.

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 (34.4±14.3 μg/m$^3$)> Cactus Flat (26.2±13.2 μg/m$^3$) > Near Field (24.3±9.6 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 5.15); this data 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). The combination of $^{239+240}$Pu and gravimetrics data 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 underground operations.

The concentrations of $^{239+240}$Pu, $^{238}$Pu, $^{241}$Am, and $^{137}$Cs measured in ambient aerosol samples collected during 2010 are presented in Figures 5.16-5.19. 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 $^{241}$Am 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.

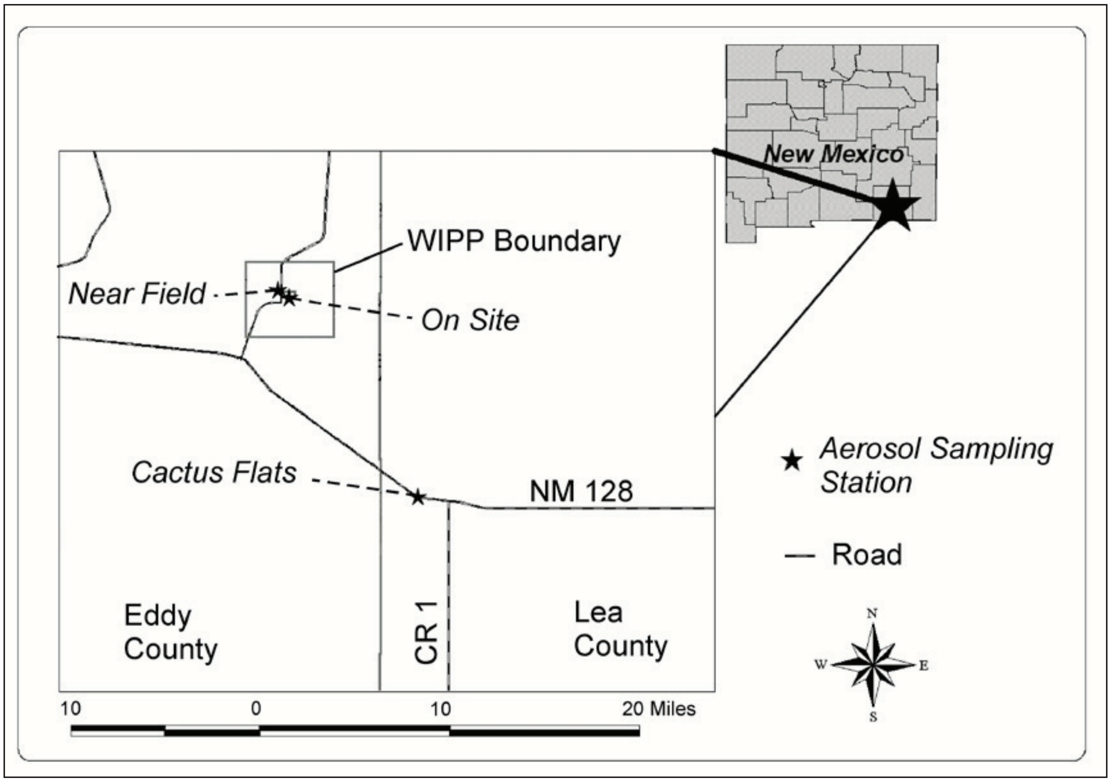

Figure 5.1: WIPP-EM Ambient Aerosol Sampling Stations

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

| Site | [a]Sampler | Analyses | Frequency | Comments |
|---|---|---|---|---|
| **Station A**<br>(Exhaust Shaft) | PM$_{10}$-Shrouded Probe | Mass, Gross Alpha and Beta Activities, Trace Elements, Gamma Emitters, Actinides | Daily | Monthly Composites |
| **Station B**<br>(Post Filtration) | | Gross Alpha and Beta Activities, Actinides | Weekly | Monthly Composites |
| **Cactus Flats**<br>**Near Field**<br>**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 Near the WIPP Site

| Station | | Cactus Flats | Near Field | On Site |
|---|---|---|---|---|
| **Type of Sample** | | **TSP** | **TSP** | **TSP** |
| Number of Samples | | 110 | 111 | 110 |
| Aerosol Mass, micrograms per cubic meter | N | 110 | 111 | 110 |
| | Mean | 26.64 | 24.32 | 34.38 |
| | StdDev | 13.18 | 9.61 | 14.35 |
| $^{241}$Am Activity Concentration, Bq/m$^3$ | N | 54 | 51 | 60 |
| | Mean | 5.68E-09 | 4.10E-09 | 1.26E-07 |
| | StdDev | 4.73E-09 | 2.01E-09 | 9.43E-07 |
| $^{241}$Am Activity Density, Bq/g | N | 54 | 51 | 60 |
| | Mean | 2.21E-04 | 1.66E-04 | 5.47E-03 |
| | StdDev | 1.78E-04 | 7.21E-05 | 4.14E-02 |
| $^{60}$Co Activity Concentration, Bq/m$^3$ | [a]N | 0 | 2 | 0 |
| | Mean | N/A | 5.64E-07 | N/A |
| | StdDev | N/A | 3.10E-07 | N/A |
| $^{60}$Co Activity Density, Bq/g | N | 0 | 2 | 0 |
| | Mean | N/A | 2.72E-02 | N/A |
| | StdDev | N/A | 1.28E-02 | N/A |
| $^{40}$K Activity Concentration, Bq/m$^3$ | N | 15 | 23 | 19 |
| | Mean | 2.18E-05 | 2.49E-05 | 2.52E-05 |
| | StdDev | 1.51E-05 | 1.16E-05 | 1.72E-05 |
| $^{40}$K Activity Density, Bq/g | N | 15 | 23 | 19 |
| | Mean | 1.17E+00 | 1.31E+00 | 8.58E-01 |
| | StdDev | 1.13E+00 | 7.88E-01 | 7.71E-01 |
| $^{238}$Pu Activity Concentration, Bq/m$^3$ | N | 9 | 2 | 10 |
| | Mean | 6.13E-09 | 1.20E-09 | 2.98E-09 |
| | StdDev | 1.14E-08 | 4.61E-10 | 1.47E-09 |
| $^{238}$Pu Activity Density, Bq/g | N | 9 | 2 | 10 |
| | Mean | 2.69E-04 | 3.76E-05 | 8.24E-05 |
| | StdDev | 5.45E-04 | 5.14E-06 | 3.30E-05 |
| $^{239+240}$Pu Activity Concentration, Bq/m$^3$ | N | 89 | 100 | 97 |
| | Mean | 1.53E-08 | 1.22E-08 | 1.21E-08 |
| | StdDev | 1.12E-08 | 8.52E-09 | 7.68E-09 |
| $^{239+240}$Pu Activity Density, Bq/g | N | 89 | 100 | 97 |
| | Mean | 5.22E-04 | 4.80E-04 | 3.42E-04 |
| | StdDev | 2.01E-04 | 2.22E-04 | 1.89E-04 |

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

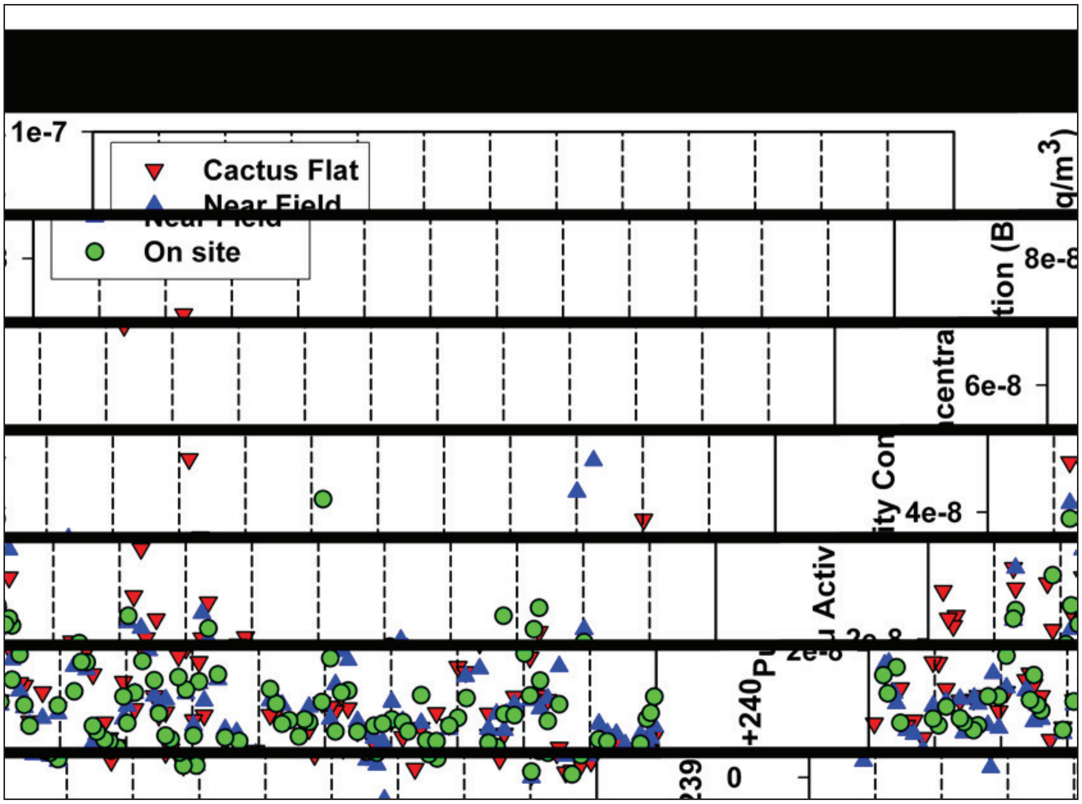

Figure 5.2: High Volume Ambient Aerosol $^{239+240}$Pu Activity Concentrations

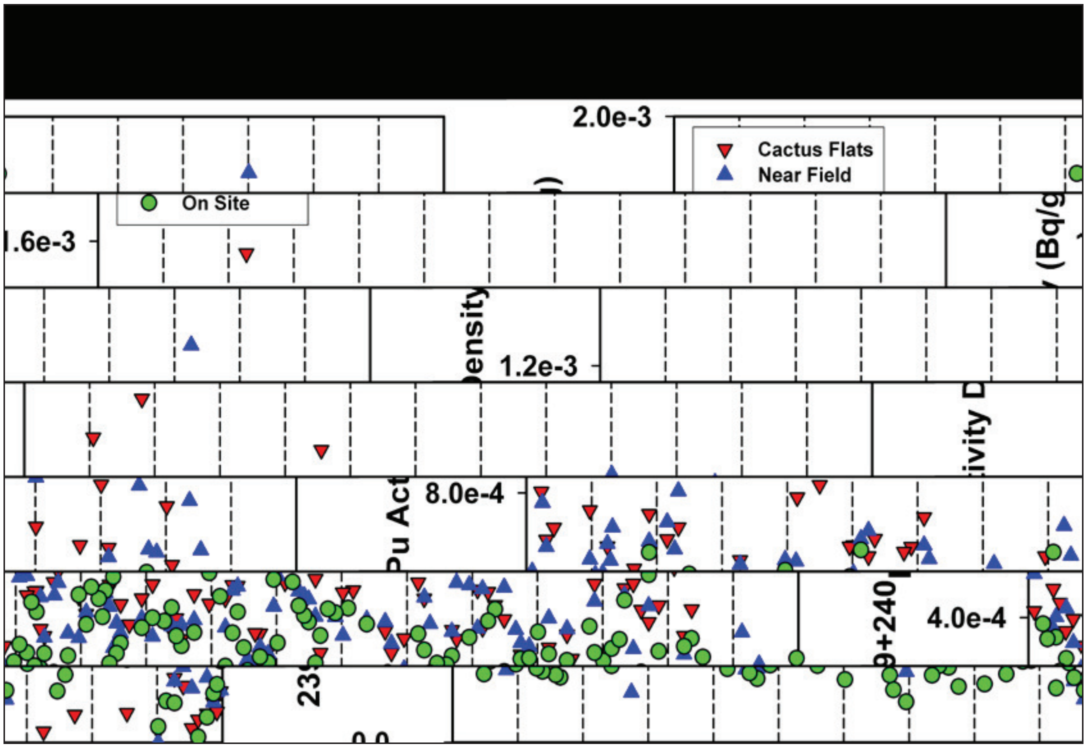

Figure 5.3: High Volume Ambient Aerosol $^{239+240}$Pu Activity Densities

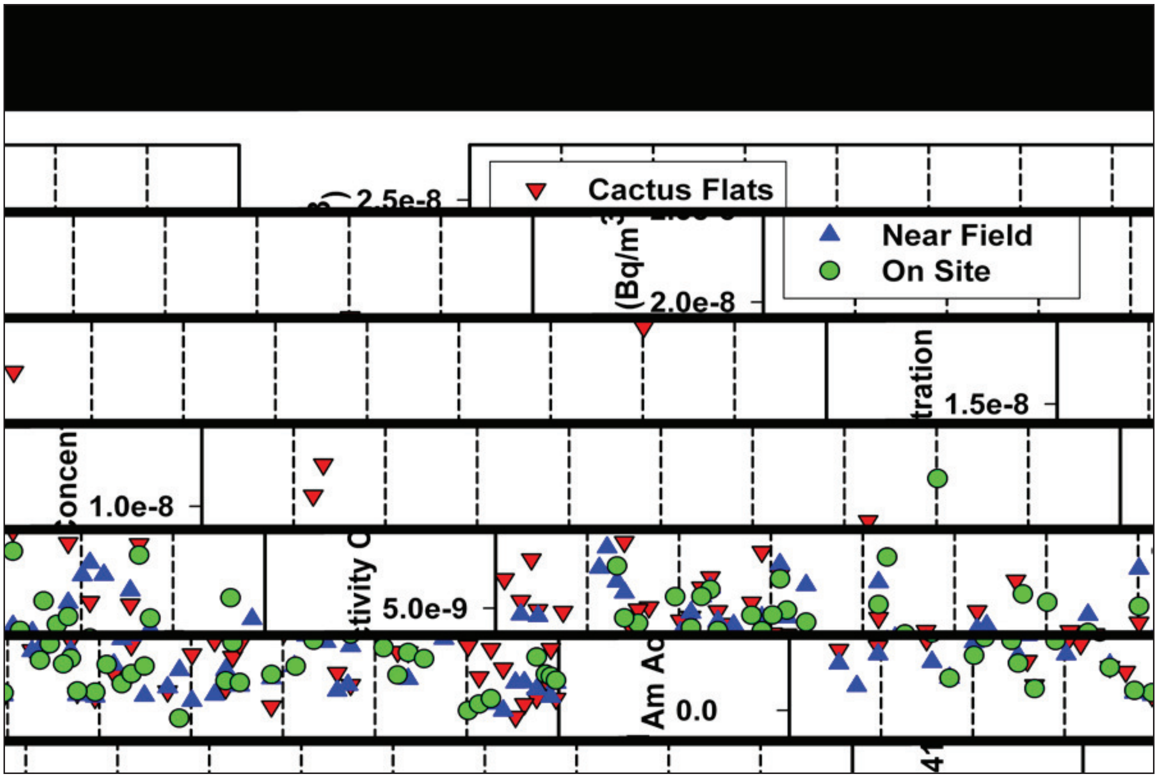

Figure 5.4: High Volume Ambient Aerosol $^{241}$Am Activity Concentrations

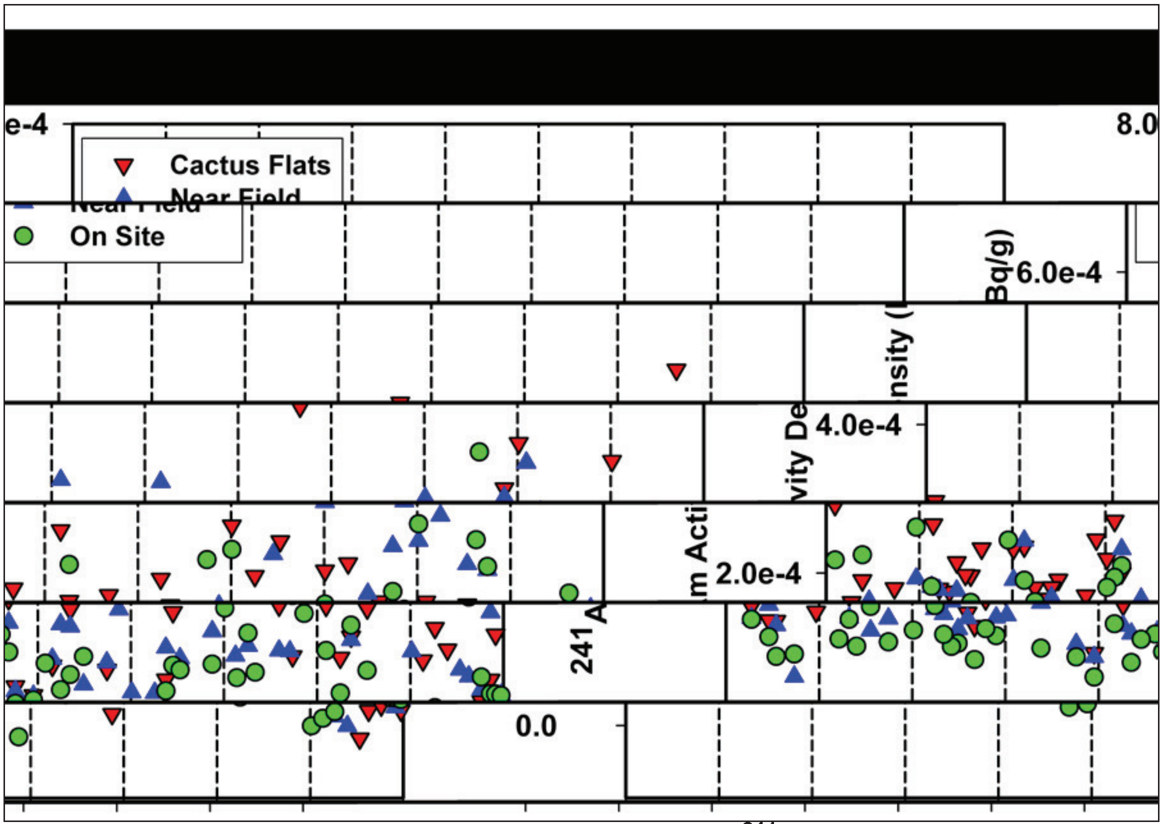

Figure 5.5: High Volume Ambient Aerosol $^{241}$Am Activity Densities

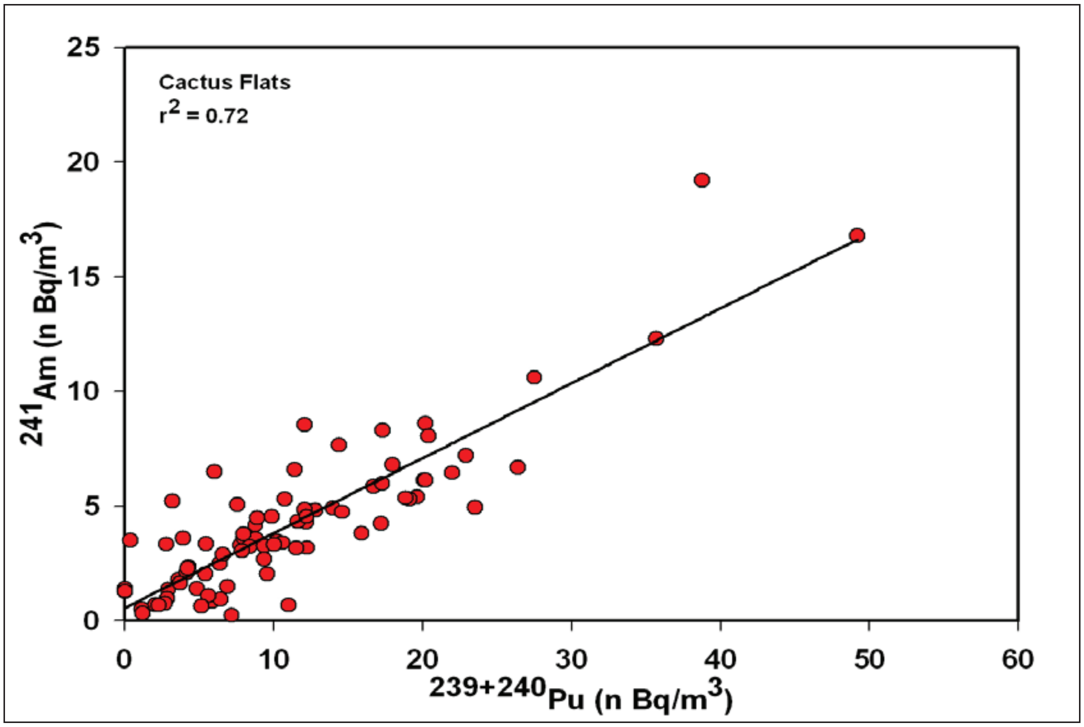

Figure 5.6: Correlation Between $^{239+240}$Pu and $^{241}$Am Activity Concentrations in Aerosol Samples Collected from Cactus Flats Stations

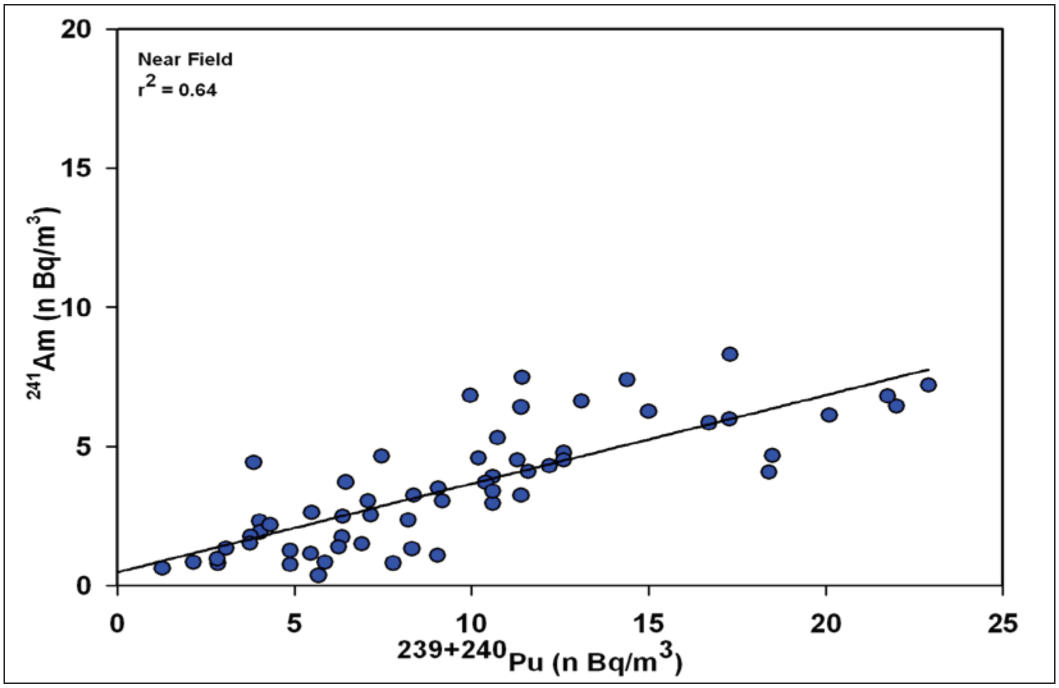

Figure 5.7: Correlation Between $^{241}$Am and $^{239+240}$Pu Activity Concentrations in Aerosol Samples Collected from Near Field Stations

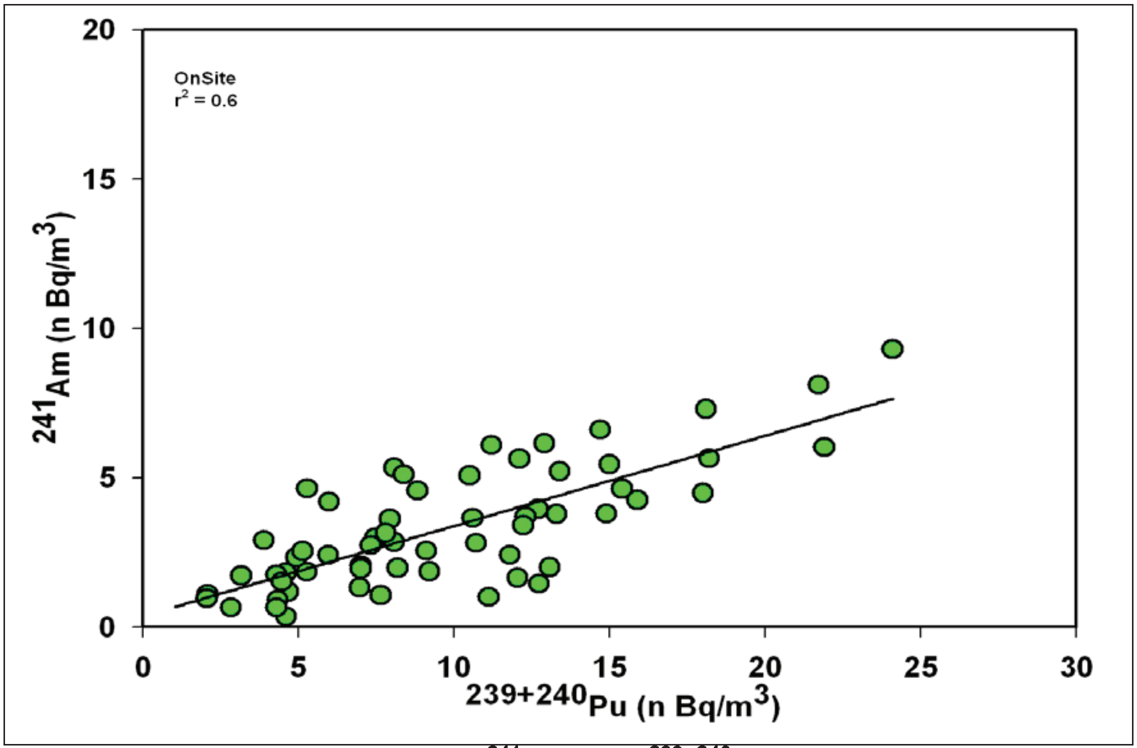

Figure 5.8: Correlation Between $^{241}$Am and $^{239+240}$Pu Activity Concentrations in Aerosol Samples Collected from On Site Stations

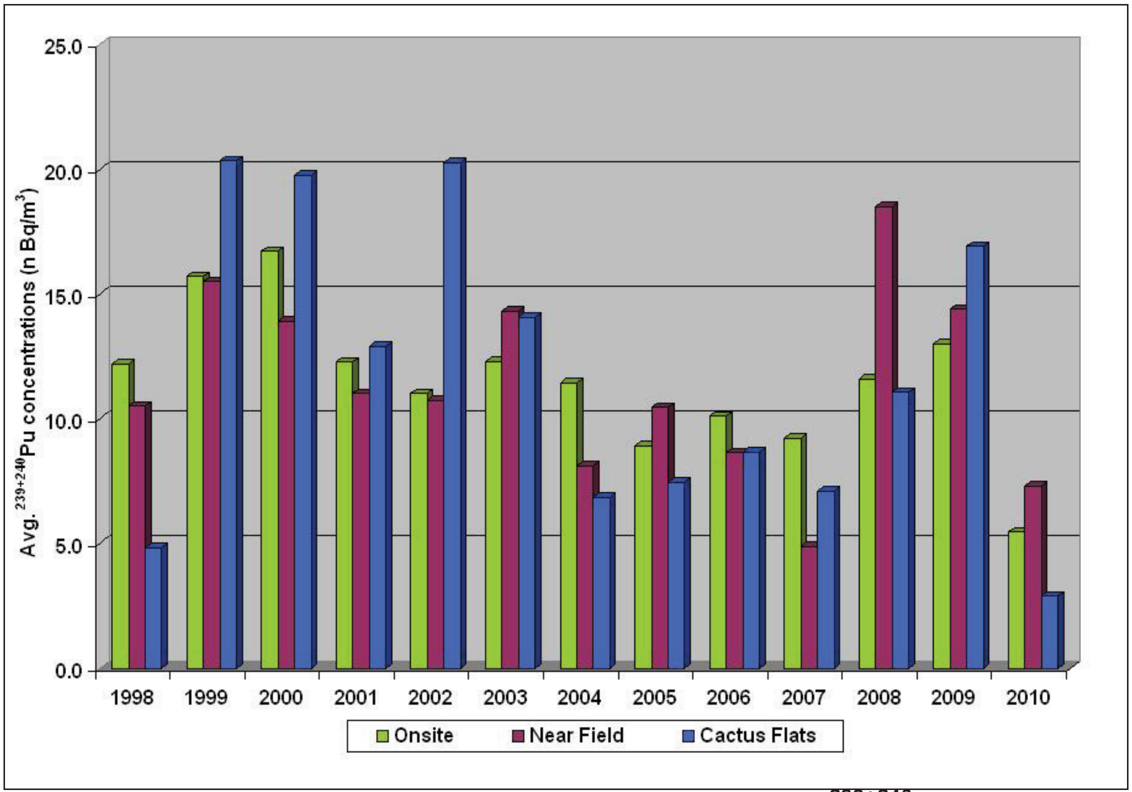

Figure 5.9: Average High Volume Ambient Aerosol $^{239+240}$Pu Activity Concentrations Near the WIPP Site

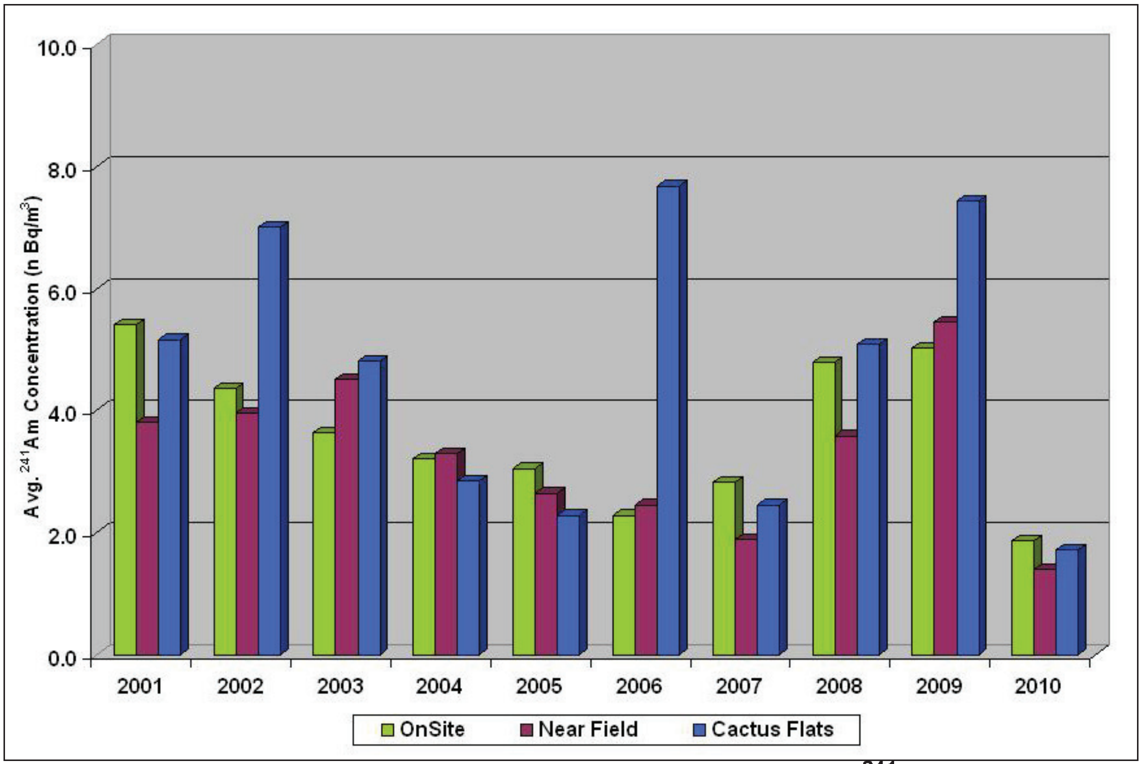

Figure 5.10: Average High Volume Ambient Aerosol $^{241}$Am Activity Concentrations Near the WIPP Site

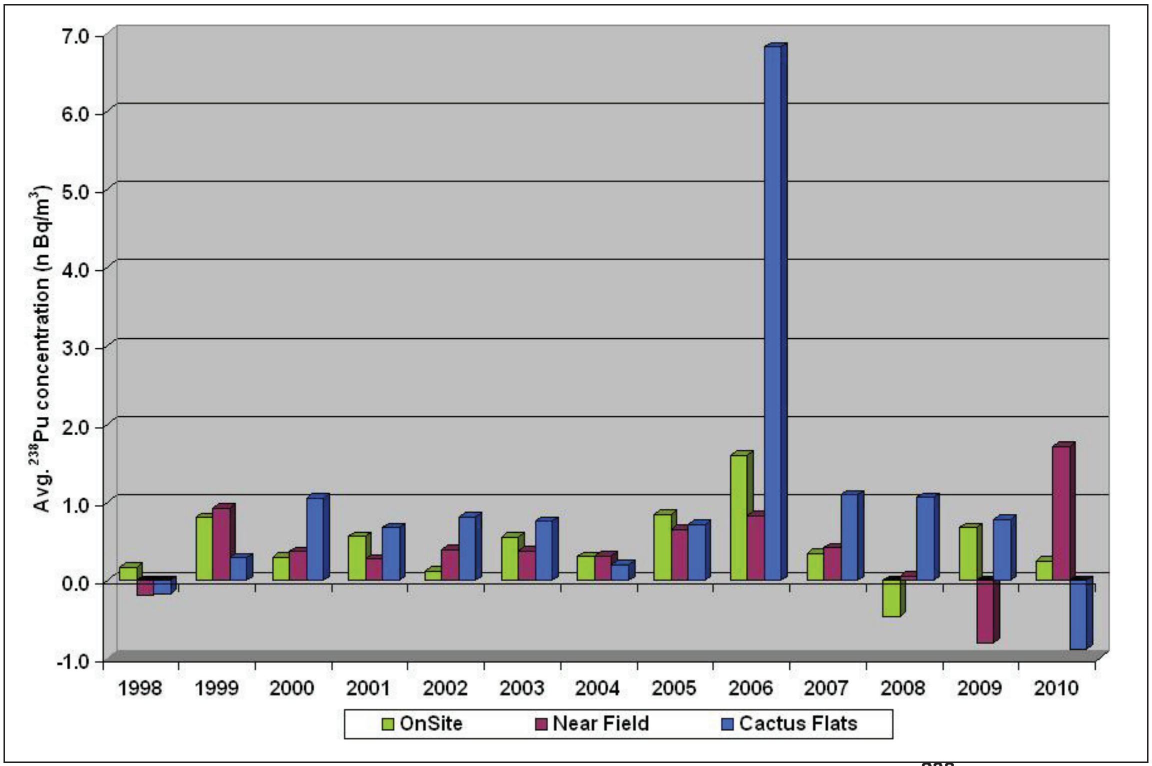

Figure 5.11: Average High Volume Ambient Aerosol $^{238}$Pu Activity Concentrations Near the WIPP Site

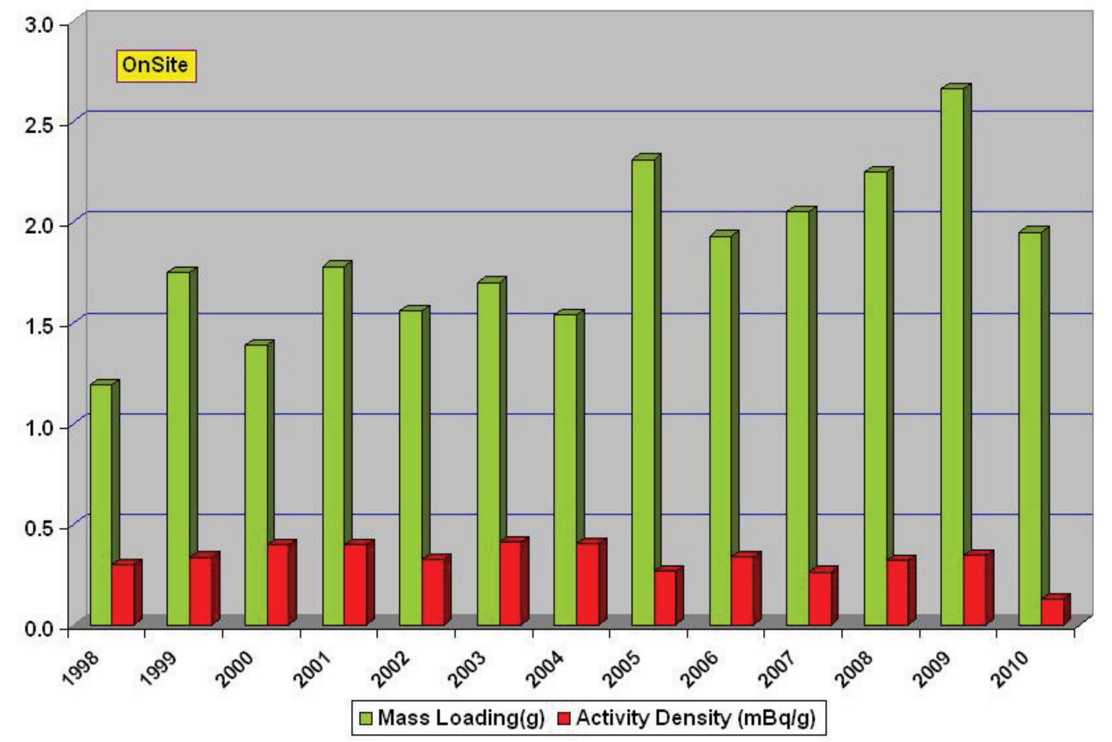

Figure 5.12: Average High Volume Ambient Aerosol Mass Loading and $^{239+240}$Pu Activity Densities at On Site Station

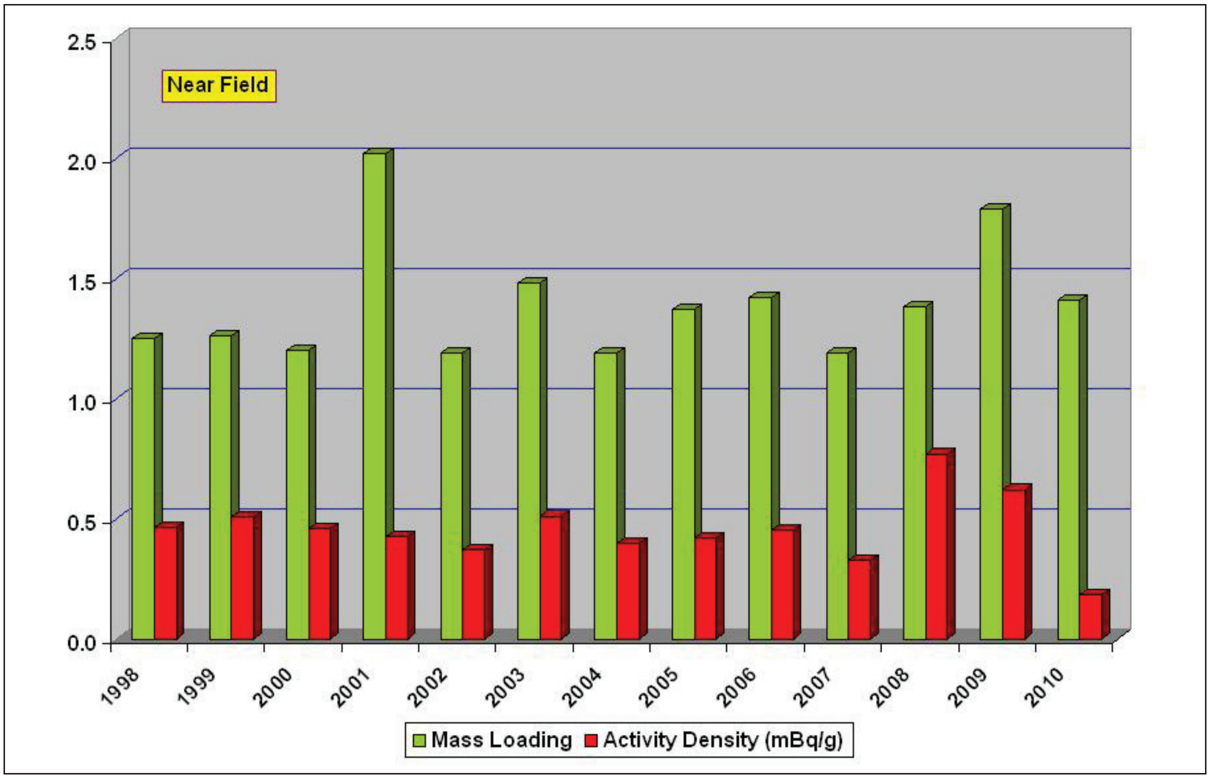

Figure 5.13: Average High Volume Ambient Aerosol Mass Loading and $^{239+240}$Pu Activity Densities at Near Field Station

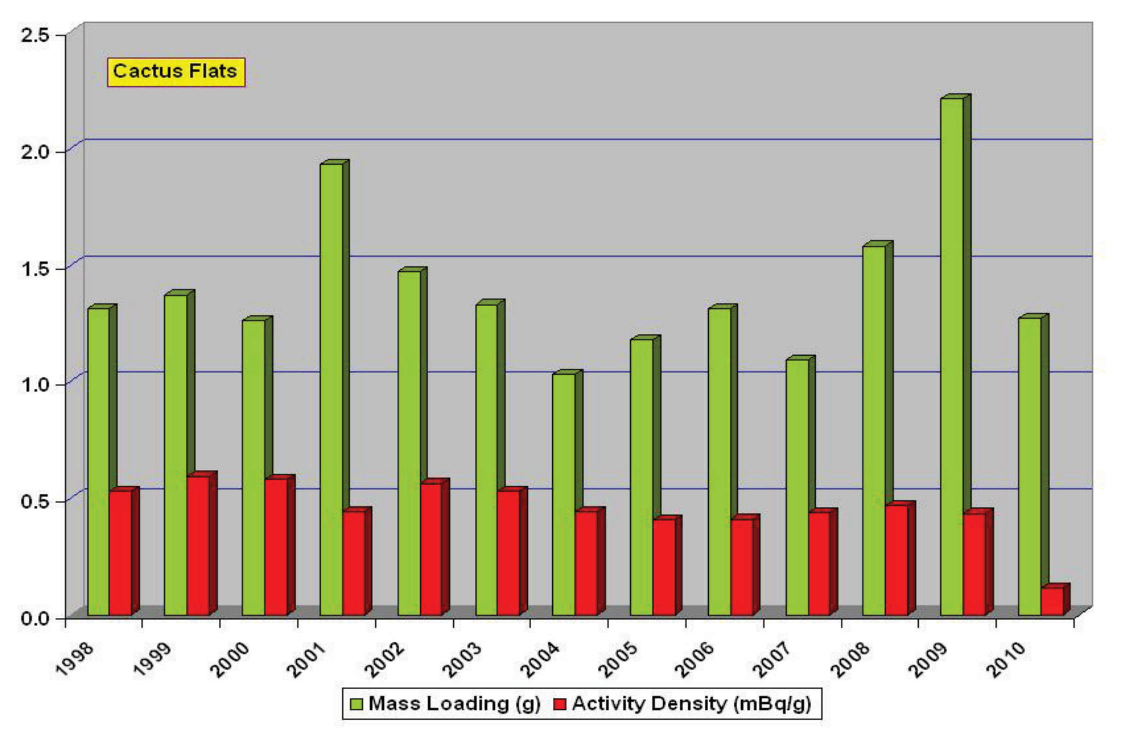

Figure 5.14: Average High Volume Ambient Aerosol Mass Loading and $^{239+240}$Pu Activity Densities at Cactus Flats Station

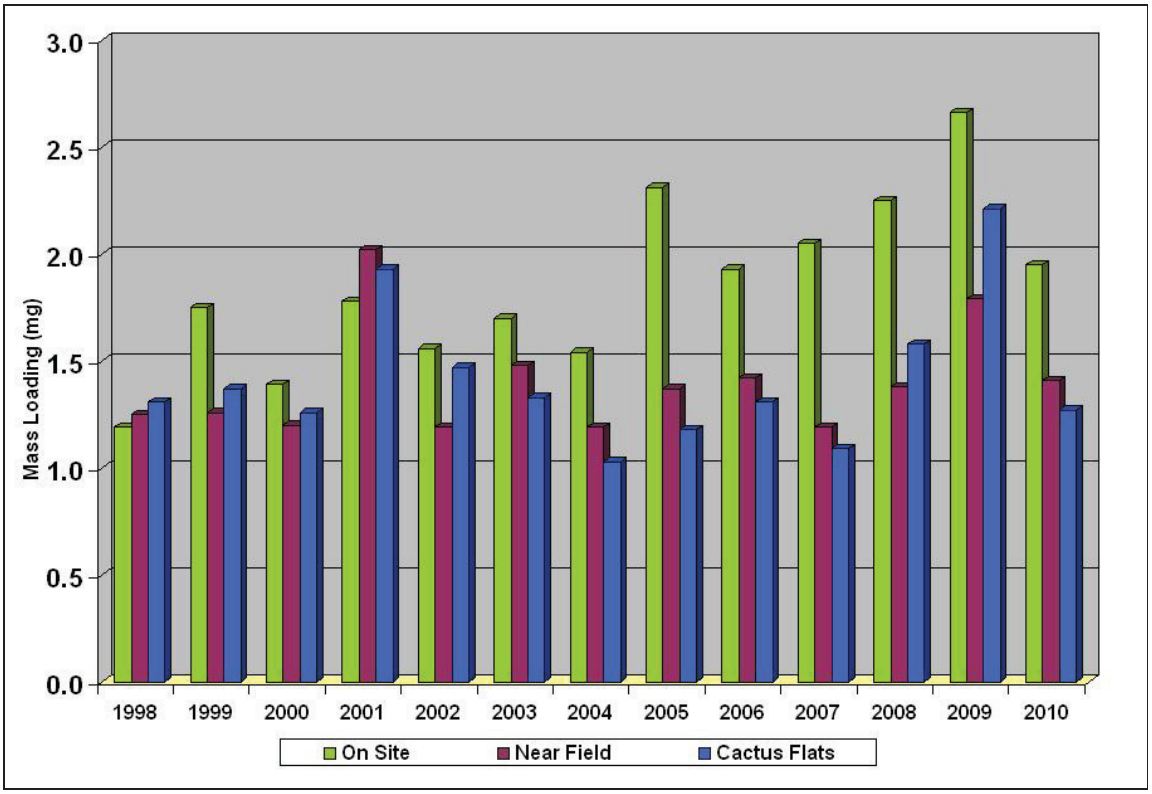

Figure 5.15: Average Ambient Aerosol Mass Loading in Aerosol Air Filters Near the WIPP Site

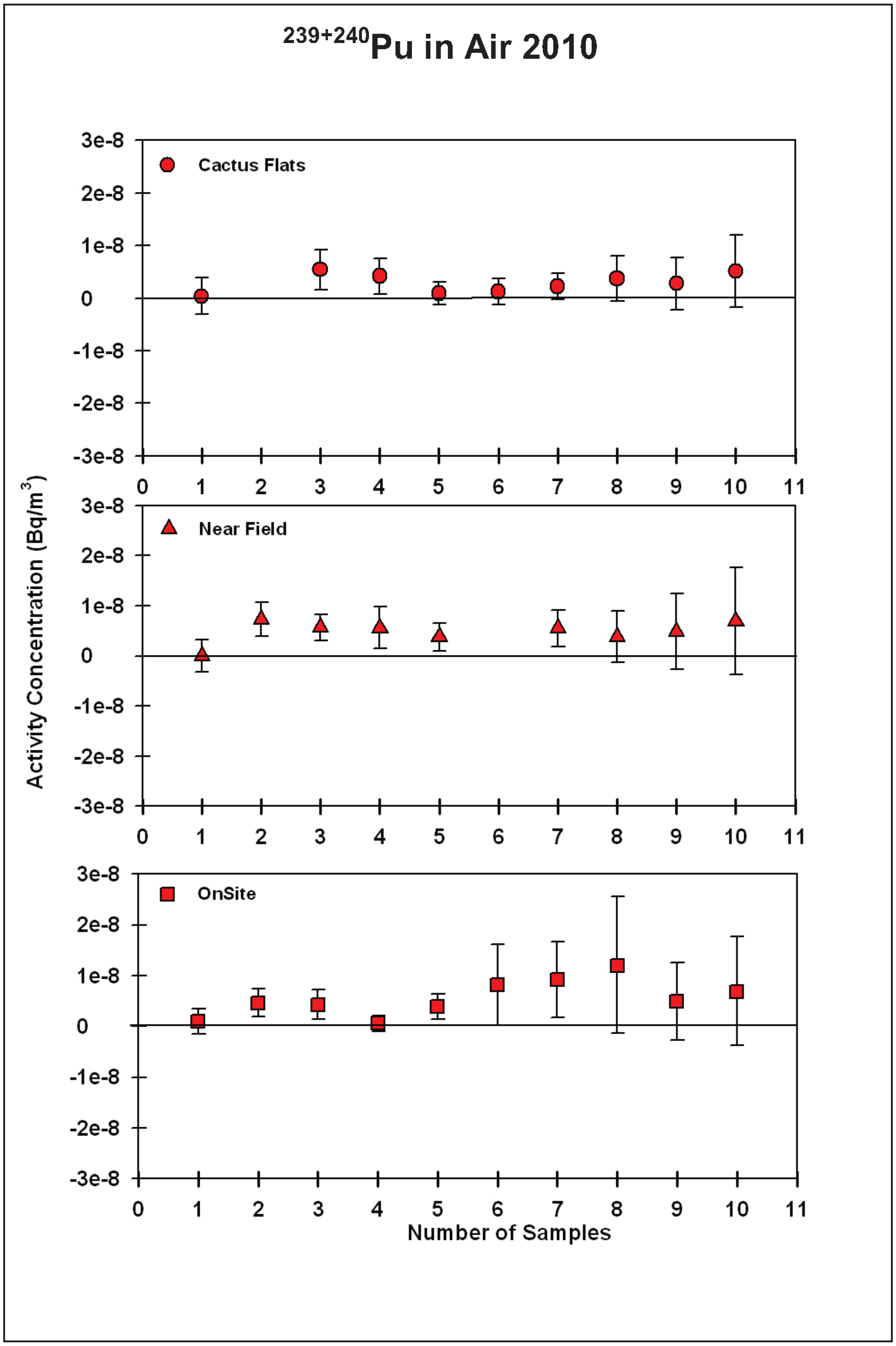

Figure 5.16: $^{239+240}$Pu Concentrations in Aerosol Filters Collected in 2010

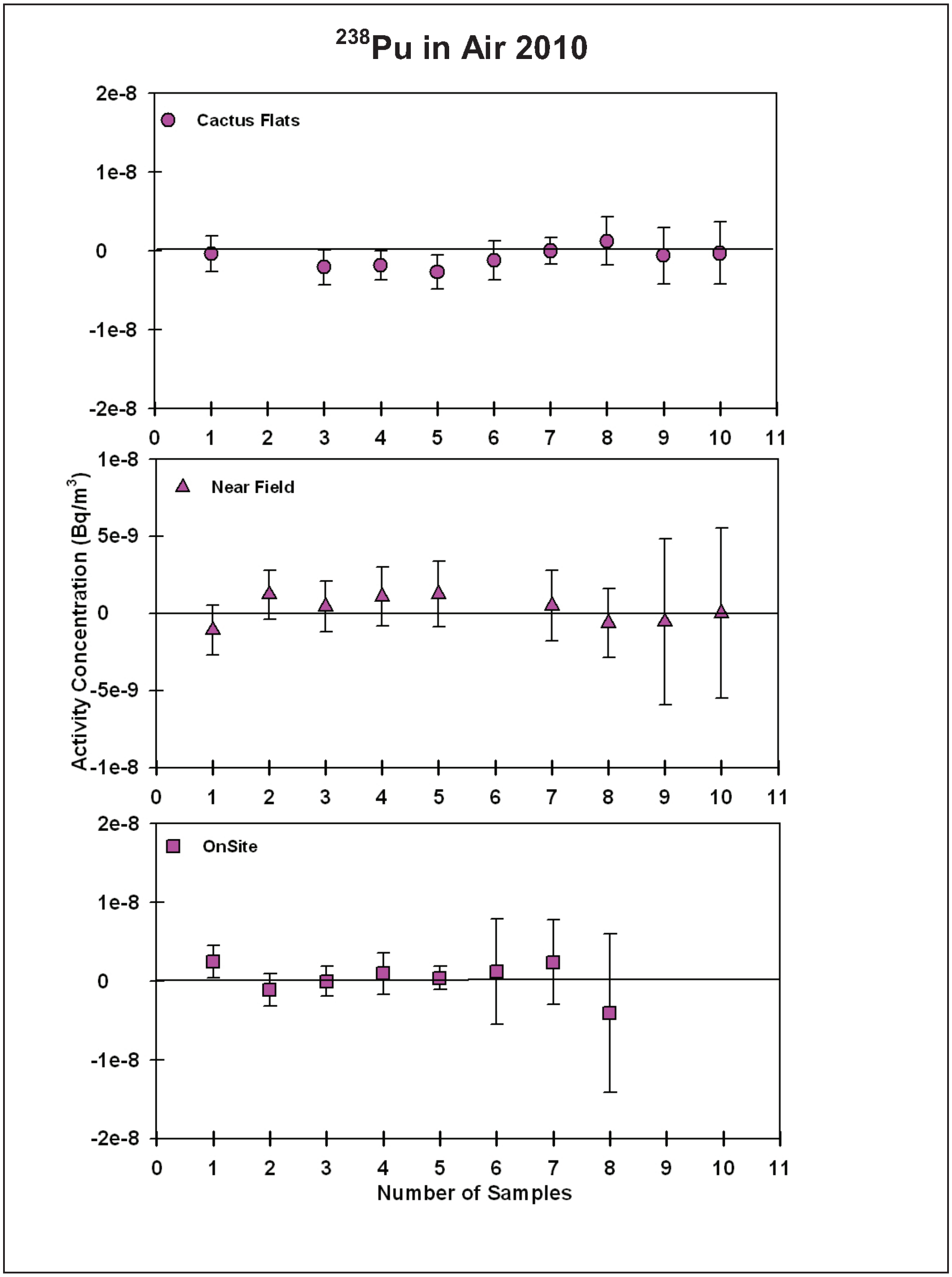

Figure 5.17: $^{238}$Pu Concentrations in Aerosol Filters Collected in 2010

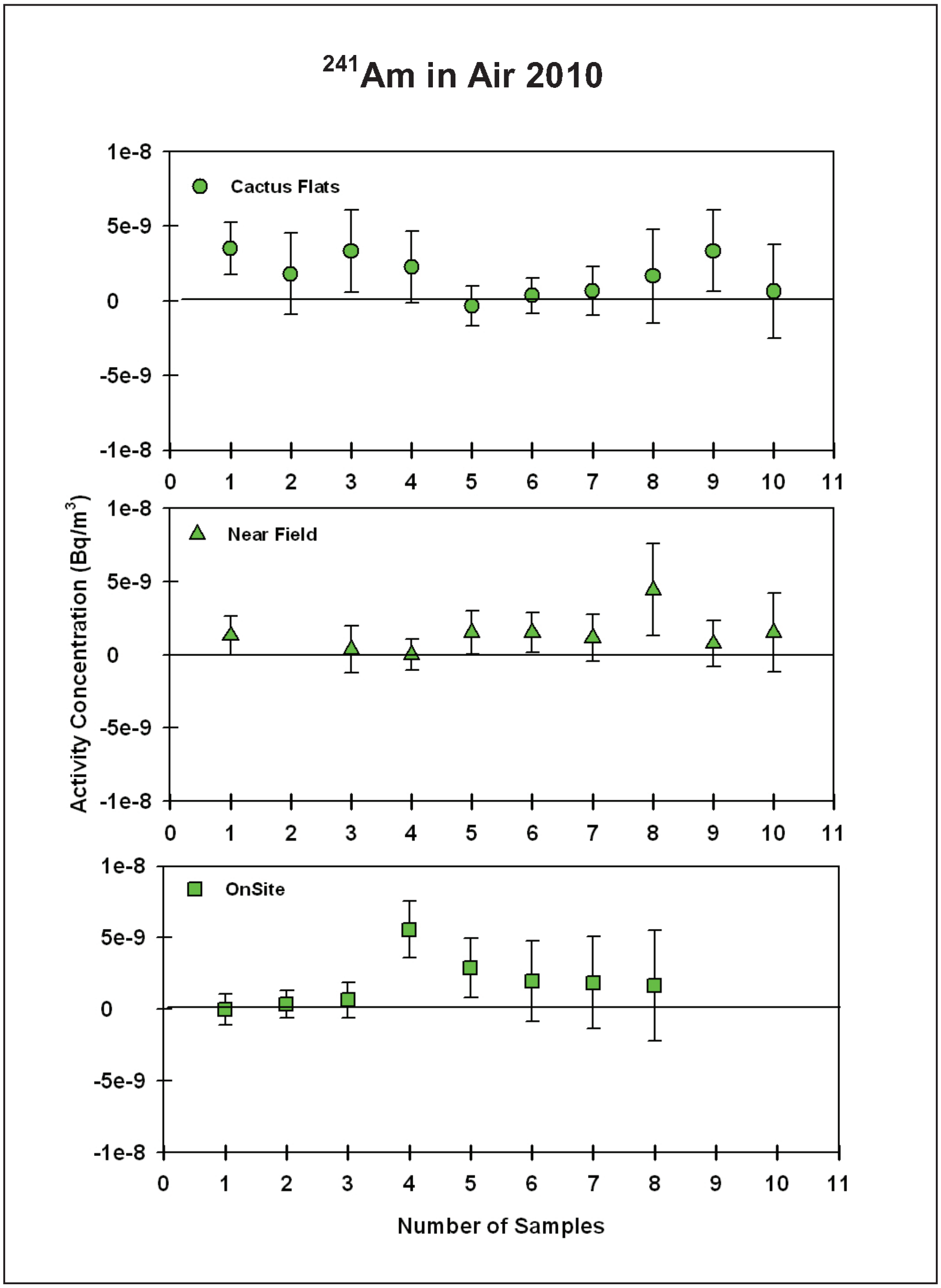

Figure 5.18: $^{241}$Am Concentrations in Aerosol Filters Collected in 2010

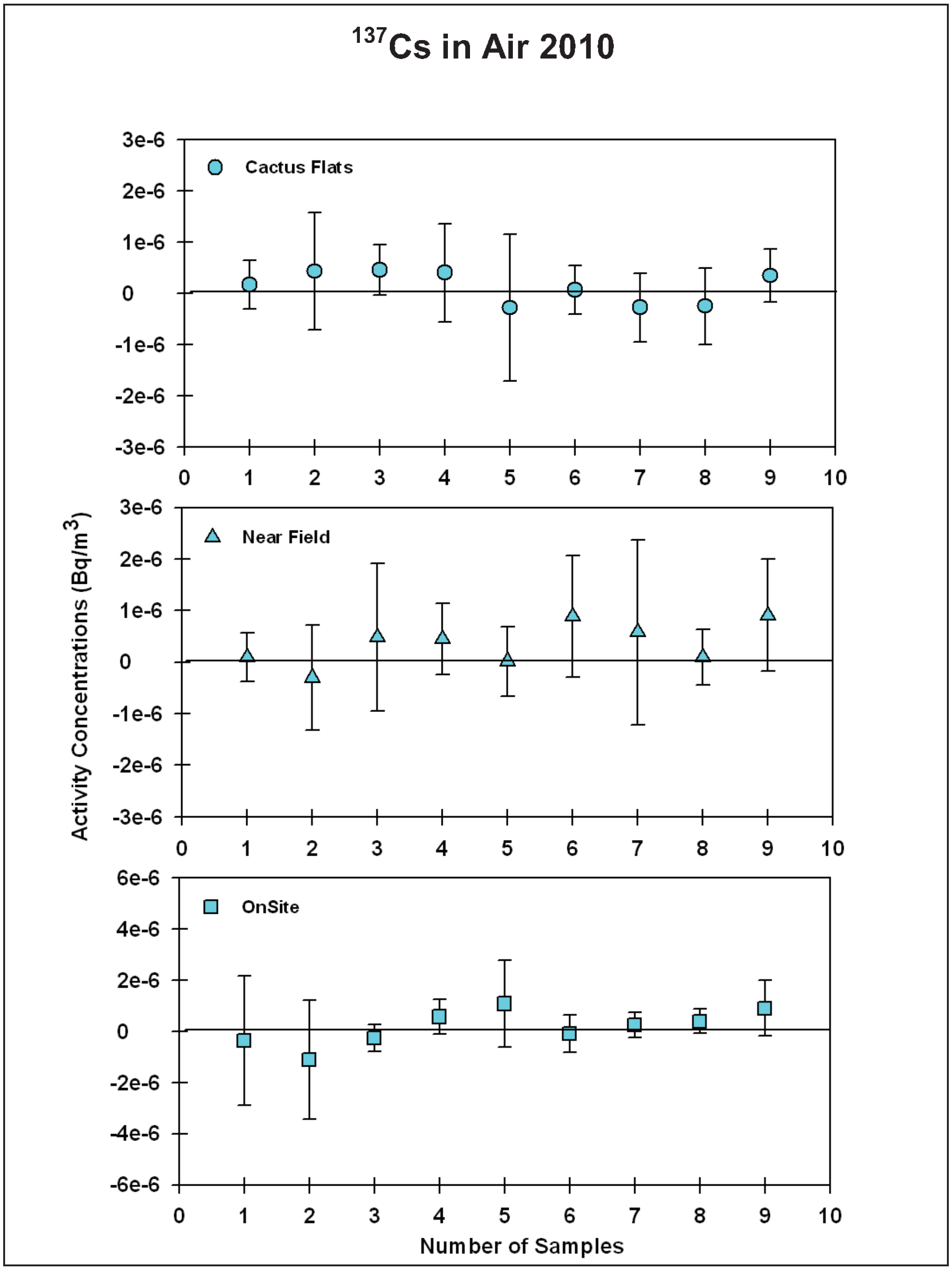

Figure 5.19: $^{137}$Cs Concentrations in Aerosol Filters Collected in 2010

## 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 | 5.33E-09 | 3.78E-09 | 1.44E-08 |
| | Average | 2.82E-09 | 1.88E-09 | 5.41E-09 |
| $^{238}$Pu | Minimum | -1.44E-09 | 4.00E-10 | 1.86E-09 |
| | Maximum | 3.74E-09 | 2.54E-09 | 1.08E-08 |
| | Average | 3.44E-10 | 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 | -1.09E-07 | 2.00E-07 | 6.64E-07 |
| | Maximum | 7.33E-07 | 5.44E-07 | 1.80E-06 |
| | Average | 2.34E-07 | 3.63E-07 | 1.20E-06 |
| $^{60}$Co | Minimum | -1.02E-06 | 1.93E-07 | 6.56E-07 |
| | Maximum | 1.77E-06 | 2.96E-06 | 9.90E-06 |
| | Average | 2.40E-08 | 5.98E-07 | 2.00E-06 |
| $^{40}$K | Minimum | 4.19E-06 | 1.39E-06 | 3.73E-06 |
| | Maximum | 3.65E-05 | 4.09E-06 | 1.32E-05 |
| | Average | 1.56E-05 | 2.79E-06 | 8.68E-06 |
| | 2008 | | | |
| $^{241}$Am | Minimum | 2.41E-09 | 7.48E-10 | 4.90E-10 |
| | Maximum | 8.11E-09 | 1.77E-09 | 3.47E-09 |
| | Average | 4.79E-09 | 1.29E-09 | 2.19E-09 |
| $^{238}$Pu | Minimum | -9.09E-09 | 9.80E-10 | 1.14E-09 |
| | Maximum | 2.52E-09 | 4.44E-09 | 2.37E-08 |
| | Average | -4.61E-10 | 1.88E-09 | 8.12E-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 | -2.93E-07 | 2.08E-07 | 6.89E-07 |
| | Maximum | 5.22E-07 | 1.35E-06 | 4.49E-06 |
| | Average | 1.51E-07 | 4.12E-07 | 1.37E-06 |
| $^{60}$Co | Minimum | -1.51E-06 | 2.05E-07 | 7.03E-07 |
| | Maximum | 2.54E-06 | 9.25E-07 | 3.17E-06 |
| | Average | 3.03E-08 | 3.51E-07 | 1.18E-06 |
| $^{40}$K | Minimum | -4.21E-06 | 1.95E-06 | 5.51E-06 |
| | Maximum | 5.95E-05 | 6.82E-06 | 1.99E-05 |
| | Average | 1.12E-05 | 2.84E-06 | 8.94E-06 |
| | 2009 | | | |
| $^{241}$Am | Minimum | 1.92E-09 | 7.36E-10 | 4.87E-10 |
| | Maximum | 1.15E-08 | 1.91E-09 | 5.29E-09 |
| | Average | 5.02E-09 | 1.20E-09 | 1.77E-09 |
| $^{238}$Pu | Minimum | -2.55E-09 | 1.25E-09 | 1.45E-09 |
| | Maximum | 3.94E-09 | 2.30E-09 | 1.09E-08 |
| | Average | 6.73E-10 | 1.55E-09 | 5.77E-09 |
| $^{239+240}$Pu | Minimum | 7.81E-09 | 2.34E-09 | 4.12E-09 |
| | Maximum | 1.95E-08 | 4.41E-09 | 1.16E-08 |
| | Average | 1.30E-08 | 3.21E-09 | 6.86E-09 |

| | | | | |
|---|---|---|---|---|
| $^{137}$Cs | Minimum | -4.66E-07 | 1.20E-07 | 4.01E-07 |
| | Maximum | 6.38E-08 | 5.04E-07 | 1.67E-06 |
| | Average | -2.17E-07 | 2.75E-07 | 9.18E-07 |
| $^{60}$Co | Minimum | -7.19E-07 | 9.52E-08 | 3.16E-07 |
| | Maximum | 3.10E-06 | 1.10E-06 | 3.73E-06 |
| | Average | 3.07E-07 | 3.56E-07 | 1.18E-06 |
| $^{40}$K | Minimum | 6.19E-07 | 1.26E-06 | 4.19E-06 |
| | Maximum | 3.12E-05 | 3.10E-06 | 9.80E-06 |
| | Average | 9.37E-06 | 2.33E-06 | 7.39E-06 |
| | **2010** | | | |
| $^{241}$Am | Minimum | -2.83E-12 | 4.75E-10 | 4.16E-10 |
| | Maximum | 5.58E-09 | 1.93E-09 | 6.13E-09 |
| | Average | 1.87E-09 | 1.07E-09 | 2.81E-09 |
| $^{238}$Pu | Minimum | -4.09E-09 | 7.34E-10 | 2.54E-09 |
| | Maximum | 2.42E-09 | 5.04E-09 | 2.27E-08 |
| | Average | 2.50E-10 | 2.01E-09 | 8.01E-09 |
| $^{239+240}$Pu | Minimum | 5.66E-10 | 7.81E-10 | 2.94E-09 |
| | Maximum | 1.20E-08 | 6.73E-09 | 2.12E-08 |
| | Average | 5.48E-09 | 2.57E-09 | 7.68E-09 |
| $^{234}$U | Minimum | 3.82E-07 | 1.24E-08 | 2.02E-09 |
| | Maximum | 1.46E-06 | 4.11E-08 | 1.36E-08 |
| | Average | 8.70E-07 | 2.71E-08 | 6.87E-09 |
| $^{235}$U | Minimum | 1.54E-08 | 1.95E-09 | 1.71E-09 |
| | Maximum | 5.39E-08 | 7.12E-09 | 9.07E-09 |
| | Average | 3.74E-08 | 4.97E-09 | 5.21E-09 |
| $^{238}$U | Minimum | 3.62E-07 | 1.19E-08 | 2.46E-09 |
| | Maximum | 1.27E-06 | 3.73E-08 | 9.64E-09 |
| | Average | 8.06E-07 | 2.57E-08 | 5.71E-09 |
| $^{137}$Cs | Minimum | -1.11E-06 | 2.38E-07 | 7.82E-07 |
| | Maximum | 1.08E-06 | 1.27E-06 | 4.24E-06 |
| | Average | 6.17E-08 | 5.91E-07 | 1.97E-06 |
| $^{60}$Co | Minimum | -3.32E-06 | 2.82E-07 | 9.26E-07 |
| | Maximum | 2.48E-06 | 1.28E-06 | 4.29E-06 |
| | Average | 1.62E-07 | 6.37E-07 | 2.13E-06 |
| $^{40}$K | Minimum | 1.06E-05 | 2.95E-06 | 9.47E-06 |
| | Maximum | 7.39E-05 | 1.22E-05 | 3.72E-05 |
| | Average | 2.63E-05 | 6.16E-06 | 1.95E-05 |

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

| Radionuclide | | Concentration | SD | MDC |
|---|---|---|---|---|
| | **2007** | | | |
| $^{241}$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 | -4.35E-09 | 4.31E-10 | 8.78E-10 |
| | Maximum | 2.07E-09 | 5.33E-09 | 2.61E-08 |
| | Average | 4.16E-10 | 1.94E-09 | 7.92E-09 |
| $^{239+240}$Pu | Minimum | -3.82E-09 | 9.78E-10 | 9.43E-10 |
| | Maximum | 1.12E-08 | 6.06E-09 | 2.80E-08 |
| | Average | 4.89E-09 | 2.59E-09 | 8.01E-09 |
| $^{137}$Cs | Minimum | -1.66E-07 | 2.00E-07 | 6.58E-07 |
| | Maximum | 5.46E-07 | 5.28E-07 | 1.74E-06 |
| | Average | 1.61E-07 | 3.67E-07 | 1.21E-06 |
| $^{60}$Co | Minimum | -6.34E-07 | 1.84E-07 | 6.10E-07 |
| | Maximum | 1.11E-06 | 5.71E-07 | 1.90E-06 |
| | Average | 1.52E-07 | 3.29E-07 | 1.10E-06 |
| $^{40}$K | Minimum | 2.82E-06 | 1.48E-06 | 3.83E-06 |
| | Maximum | 3.81E-05 | 4.06E-06 | 1.35E-05 |
| | Average | 1.85E-05 | 2.56E-06 | 7.71E-06 |
| | **2008** | | | |
| $^{241}$Am | Minimum | 1.08E-09 | 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 | -3.57E-09 | 1.06E-09 | 4.35E-09 |
| | Maximum | 2.65E-09 | 2.00E-09 | 1.14E-08 |
| | Average | 5.98E-11 | 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 | -3.88E-07 | 1.99E-07 | 6.60E-07 |
| | Maximum | 7.26E-07 | 1.32E-06 | 4.39E-06 |
| | Average | 6.44E-08 | 4.78E-07 | 1.58E-06 |
| $^{60}$Co | Minimum | -4.38E-07 | 2.12E-07 | 7.25E-07 |
| | Maximum | 1.12E-06 | 9.17E-07 | 3.03E-06 |
| | Average | 1.99E-07 | 3.89E-07 | 1.30E-06 |
| $^{40}$K | Minimum | 3.33E-07 | 1.73E-06 | 4.77E-06 |
| | Maximum | 5.83E-05 | 7.00E-06 | 2.07E-05 |
| | Average | 2.14E-05 | 2.92E-06 | 8.73E-06 |
| | **2009** | | | |
| $^{241}$Am | Minimum | 1.71E-09 | 6.83E-10 | 7.95E-10 |
| | Maximum | 7.48E-09 | 2.21E-09 | 5.30E-09 |
| | Average | 5.45E-09 | 1.32E-09 | 2.36E-09 |
| $^{238}$Pu | Minimum | -1.94E-09 | 1.17E-09 | 4.91E-09 |
| | Maximum | 1.86E-10 | 4.95E-09 | 2.04E-08 |
| | Average | -7.99E-10 | 2.46E-09 | 1.09E-08 |
| $^{239+240}$Pu | Minimum | 9.97E-09 | 2.39E-09 | 3.97E-09 |
| | Maximum | 2.18E-08 | 5.89E-09 | 1.03E-08 |
| | Average | 1.44E-08 | 3.82E-09 | 7.37E-09 |
| $^{137}$Cs | Minimum | -5.50E-07 | 1.22E-07 | 4.07E-07 |

| | | | | |
|---|---|---|---|---|
| | Maximum | 1.75E-07 | 3.91E-07 | 1.31E-06 |
| | Average | -1.83E-07 | 2.62E-07 | 8.74E-07 |
| $^{60}$Co | Minimum | -4.69E-07 | 9.26E-08 | 3.02E-07 |
| | Maximum | 5.94E-07 | 3.28E-07 | 1.11E-06 |
| | Average | 1.32E-07 | 1.97E-07 | 6.56E-07 |
| $^{40}$K | Minimum | 2.11E-06 | 1.35E-06 | 3.82E-06 |
| | Maximum | 2.45E-05 | 4.07E-06 | 1.33E-05 |
| | Average | 1.29E-05 | 2.30E-06 | 7.16E-06 |
| | **2010** | | | |
| $^{241}$Am | Minimum | -1.03E-12 | 5.34E-10 | 8.73E-10 |
| | Maximum | 4.43E-09 | 1.57E-09 | 3.49E-09 |
| | Average | 1.39E-09 | 8.79E-10 | 2.17E-09 |
| $^{238}$Pu | Minimum | -1.08E-09 | 7.94E-10 | 2.50E-09 |
| | Maximum | 1.23E-09 | 2.76E-09 | 1.28E-08 |
| | Average | 2.39E-10 | 1.35E-09 | 5.75E-09 |
| $^{239+240}$Pu | Minimum | 0.00E+00 | 1.28E-09 | 2.62E-09 |
| | Maximum | 7.31E-09 | 5.35E-09 | 1.81E-08 |
| | Average | 4.82E-09 | 2.39E-09 | 7.26E-09 |
| $^{234}$U | Minimum | 3.60E-07 | 1.13E-08 | 2.59E-09 |
| | Maximum | 1.32E-06 | 3.86E-08 | 9.63E-09 |
| | Average | 6.92E-07 | 2.21E-08 | 5.49E-09 |
| $^{235}$U | Minimum | 1.26E-08 | 2.02E-09 | 9.24E-10 |
| | Maximum | 8.44E-08 | 9.15E-09 | 1.15E-08 |
| | Average | 3.15E-08 | 4.34E-09 | 5.01E-09 |
| $^{238}$U | Minimum | 3.47E-07 | 1.10E-08 | 2.31E-09 |
| | Maximum | 1.19E-06 | 3.59E-08 | 9.61E-09 |
| | Average | 6.50E-07 | 2.12E-08 | 5.72E-09 |
| $^{137}$Cs | Minimum | -3.07E-07 | 2.34E-07 | 7.75E-07 |
| | Maximum | 9.05E-07 | 8.96E-07 | 2.97E-06 |
| | Average | 3.55E-07 | 4.93E-07 | 1.63E-06 |
| $^{60}$Co | Minimum | -1.82E-06 | 2.74E-07 | 9.03E-07 |
| | Maximum | 1.52E-06 | 9.99E-07 | 3.42E-06 |
| | Average | -1.11E-07 | 5.52E-07 | 1.85E-06 |
| $^{40}$K | Minimum | 5.35E-06 | 2.26E-06 | 6.59E-06 |
| | Maximum | 3.77E-05 | 8.94E-06 | 2.91E-05 |
| | Average | 1.99E-05 | 5.39E-06 | 1.73E-05 |

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

| Radionuclide | | Concentration | SD | MDC |
|---|---|---|---|---|
| | 2007 | | | |
| $^{241}$Am | Minimum | 2.28E-10 | 7.19E-10 | 1.42E-09 |
| | Maximum | 3.76E-09 | 3.01E-09 | 1.03E-08 |
| | Average | 2.45E-09 | 1.24E-09 | 3.56E-09 |
| $^{238}$Pu | Minimum | -2.31E-09 | 5.94E-10 | 1.95E-09 |
| | Maximum | 7.51E-09 | 5.46E-09 | 1.94E-08 |
| | Average | 1.09E-09 | 2.13E-09 | 7.58E-09 |
| $^{239+240}$Pu | Minimum | 3.91E-09 | 1.48E-09 | 2.61E-09 |
| | Maximum | 9.93E-09 | 9.04E-09 | 3.27E-08 |
| | Average | 7.11E-09 | 3.44E-09 | 1.05E-08 |
| $^{137}$Cs | Minimum | -2.00E-07 | 1.96E-07 | 6.50E-07 |
| | Maximum | 5.43E-07 | 6.08E-07 | 2.01E-06 |
| | Average | 1.50E-07 | 3.58E-07 | 1.18E-06 |
| $^{60}$Co | Minimum | -2.24E-06 | 1.77E-07 | 5.88E-07 |
| | Maximum | 8.94E-07 | 3.40E-06 | 1.14E-05 |
| | Average | -3.00E-07 | 6.29E-07 | 2.11E-06 |
| $^{40}$K | Minimum | -1.36E-07 | 1.41E-06 | 3.91E-06 |
| | Maximum | 2.18E-05 | 4.28E-06 | 1.42E-05 |
| | Average | 6.85E-06 | 2.95E-06 | 9.58E-06 |
| | 2008 | | | |
| $^{241}$Am | Minimum | 1.39E-09 | 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 | -2.47E-09 | 7.38E-10 | 6.56E-10 |
| | Maximum | 2.63E-09 | 4.28E-09 | 1.86E-08 |
| | Average | 1.06E-09 | 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 | -4.64E-07 | 2.05E-07 | 6.70E-07 |
| | Maximum | 6.79E-07 | 1.36E-06 | 4.52E-06 |
| | Average | 2.38E-07 | 4.42E-07 | 1.46E-06 |
| $^{60}$Co | Minimum | -5.16E-07 | 1.72E-07 | 5.72E-07 |
| | Maximum | 2.36E-06 | 9.54E-07 | 3.11E-06 |
| | Average | 2.89E-07 | 3.49E-07 | 1.16E-06 |
| $^{40}$K | Minimum | -4.92E-06 | 1.77E-06 | 4.87E-06 |
| | Maximum | 7.16E-05 | 6.74E-06 | 1.88E-05 |
| | Average | 1.85E-05 | 2.89E-06 | 8.76E-06 |
| | 2009 | | | |
| $^{241}$Am | Minimum | 3.17E-09 | 7.50E-10 | 1.27E-09 |
| | Maximum | 1.92E-08 | 2.39E-09 | 4.99E-09 |
| | Average | 7.43E-09 | 1.57E-09 | 2.40E-09 |
| $^{238}$Pu | Minimum | -1.71E-09 | 1.08E-09 | 4.31E-09 |
| | Maximum | 3.78E-09 | 3.58E-09 | 1.56E-08 |
| | Average | 7.79E-10 | 1.92E-09 | 7.52E-09 |
| $^{239+240}$Pu | Minimum | 3.20E-09 | 1.92E-09 | 3.33E-09 |
| | Maximum | 3.88E-08 | 5.08E-09 | 1.44E-08 |
| | Average | 1.69E-08 | 3.33E-09 | 6.74E-09 |
| $^{137}$Cs | Minimum | -1.83E-07 | 1.20E-07 | 4.00E-07 |

| | | | | |
|---|---|---|---|---|
| | Maximum | 2.95E-07 | 4.10E-07 | 1.36E-06 |
| | Average | 2.75E-08 | 2.59E-07 | 8.60E-07 |
| $^{60}$Co | Minimum | -5.01E-07 | 9.29E-08 | 3.00E-07 |
| | Maximum | 6.36E-07 | 3.50E-07 | 1.18E-06 |
| | Average | 1.88E-07 | 2.01E-07 | 6.66E-07 |
| $^{40}$K | Minimum | -1.50E-06 | 1.29E-06 | 4.32E-06 |
| | Maximum | 2.25E-05 | 4.23E-06 | 1.38E-05 |
| | Average | 1.03E-05 | 2.47E-06 | 7.85E-06 |
| | **2010** | | | |
| $^{241}$Am | Minimum | -3.46E-10 | 5.88E-10 | 1.54E-09 |
| | Maximum | 3.50E-09 | 1.56E-09 | 5.31E-09 |
| | Average | 1.72E-09 | 1.14E-09 | 3.30E-09 |
| $^{238}$Pu | Minimum | -2.68E-09 | 8.27E-10 | 3.43E-09 |
| | Maximum | 1.24E-09 | 1.97E-09 | 9.54E-09 |
| | Average | -8.79E-10 | 1.29E-09 | 6.08E-09 |
| $^{239+240}$Pu | Minimum | 3.79E-10 | 1.11E-09 | 3.78E-09 |
| | Maximum | 5.44E-09 | 3.41E-09 | 1.11E-08 |
| | Average | 2.89E-09 | 1.88E-09 | 6.11E-09 |
| $^{234}$U | Minimum | 2.67E-07 | 9.57E-09 | 2.37E-09 |
| | Maximum | 1.13E-06 | 3.40E-08 | 8.27E-09 |
| | Average | 6.13E-07 | 1.99E-08 | 5.21E-09 |
| $^{235}$U | Minimum | 7.85E-09 | 1.59E-09 | 2.36E-09 |
| | Maximum | 5.41E-08 | 6.50E-09 | 1.05E-08 |
| | Average | 2.73E-08 | 3.99E-09 | 5.59E-09 |
| $^{238}$U | Minimum | 2.52E-07 | 9.24E-09 | 2.36E-09 |
| | Maximum | 1.02E-06 | 3.15E-08 | 7.92E-09 |
| | Average | 5.69E-07 | 1.89E-08 | 5.21E-09 |
| $^{137}$Cs | Minimum | -2.83E-07 | 2.35E-07 | 7.80E-07 |
| | Maximum | 4.59E-07 | 7.16E-07 | 2.38E-06 |
| | Average | 1.18E-07 | 3.84E-07 | 1.27E-06 |
| $^{60}$Co | Minimum | -7.00E-07 | 2.74E-07 | 9.05E-07 |
| | Maximum | 1.07E-06 | 8.54E-07 | 2.83E-06 |
| | Average | 1.87E-07 | 4.43E-07 | 1.47E-06 |
| $^{40}$K | Minimum | -4.60E-07 | 2.39E-06 | 6.77E-06 |
| | Maximum | 3.32E-05 | 8.82E-06 | 2.91E-05 |
| | Average | 1.01E-05 | 4.46E-06 | 1.45E-05 |

## REFERENCES

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

Hardy, E. P., Krey, P. W., Volchok, H. L., 1973. Global inventory and distribution of fallout plutonium. Nature, 241, 444-445.

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

# CHAPTER 6

# Surface Soil Radionuclides

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## INTRODUCTION

Soils are of high interest to the WIPP-EM because aerosol releases of contaminants would eventually be deposited in surface soils, which then can serve as a source for continuing contaminant exposure and uptake via direct contact, food chain pathways, and re-suspension. From these perspectives, soils are an integrating medium of primary concern in predictive ecosystem and contaminant transport modeling that requires good information about the dispersion of analytes of concern across the landscape. The source of transuranic radionuclides in soils are mainly due to integrated global fallout from the testing of above-ground nuclear devices. The plutonium isotope $^{238}$Pu has been injected into the stratosphere by the burn-up of a failed radioactive thermal generator in 1964, release at the Gnome Site, and regional fallout from above-ground testing at the Nevada Test Site(NTS). Each of these sources have characteristic radionuclide signatures and/or abundances 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 2010 from a grid of 16 locations surrounding the WIPP site (the Near Field grid), Figure 6.1. Also reported are summary statistics for the 1998-2009 data for the Near Field grid (Table 6-1).

## METHODS

The 16 sampling locations constituting each grid are distributed over approximately 16,580 hectares. In both 1998 and 1999 at each of the 32 locations (grid nodes), soil was collected from three randomly selected sites within a 50-m radius of the selected reference point. In 2000, one sample was collected at each of the 32 grid nodes. In 2001, two samples were collected at each of the 32 grid nodes. One of each pair of the 2001 samples was analyzed and the other was archived. In 2005 one sample was collected at each of the 16 grid nodes, but these samples were collected in an annulus between 20 and 40 meters from the grid node in order to reduce the chance of re-sampling an area. As in 2005 and 2009, one sample was collected at each of the 16 grid nodes in 2010. 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 4L of soil samples were collected from within a 50x50 cm area, to a depth of approximately 2-cm for radionuclide analyses. Soil samples were excavated using a trowel and placed in plastic bags for transport and storage. Sampling equipment was cleaned between samples.

Initial preparation of the samples for radiological analyses consisted of passing the soil through a 2-mm sieve to remove rocks, roots and other materials. Samples were then dried at 105˚C for 12 hours and ground using a jar mill. Approximately 300-mL (500g) 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 a high purity HPGe detector for 48 hours. A set of soil matrix standards procured from Eckert and Ziegler Analytics (GA) was used to establish matrix-specific calibration and counting efficiencies. 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.

## DISSOLUTION OF THE SOLID SAMPLES

Soil samples were dried at 110°C and blended prior to sampling. For actinides analyses, 10g of sample were heated in a muffle furnace at 500°C for at least 6 hours or more to combust organic material. Each sample was then spiked with a radioactive trace and digested in a Teflon beaker with 30 ml of HCl, 10 ml of $HNO_3$ and 40 ml of HF. Sea sand was used as a matrix for Laboratory Control Standard (LCS) and reagent blank. The samples were heated at 250°C for at least 2 hours; longer heating does no harm. After digestion is complete, the samples were evaporated to dryness and 40 ml of $HClO_4$ was added and evaporated to complete dryness. This step was repeated once more with 30 ml of $HClO_4$. Then 20 ml of HF were added and evaporated to dryness. To each beaker 80 ml of 8M $HNO_3$, 1.5 g of $H_3BO_3$ and 0.5 ml of 30% $H_2O_2$ were added, covered with a watch glass and heated to boiling for 30 minutes. After cooling, samples were transferred to a 50 ml centrifuge tube and centrifuged at 3600 rpm for 10 minutes. The leachate was filtered through a 0.45 micron filter and transferred to a 250 ml beaker. 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 Nd, deposited onto filters, mounted and counted on the alpha spectrometer for five days.

## 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 radionuclides measured in 2010 soil samples are summarized in Table 6-1. Individual concentrations of these radionuclides collected from the Near Field grid are presented in Table 6-2. $^{241}$Am concentration slightly greater than MDC was detected in 16 samples whereas $^{238}$Pu was not detected in any soil samples in 2010. $^{239+240}$Pu was detected in every soil sample with one exception. All detected concentrations 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 (1.74 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 (0.0-743 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-kiloton $^{239}$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 0.21 Bq/g, which is consistent with the mean value of 0.17 Bq/g measured in 2010 soil samples collected from the same grid. The corresponding values for $^{238}$Pu and $^{241}$ Am were slightly higher in 2010 than in 1998. The activity concentrations of $^{238}$Pu, $^{239+240}$Pu and $^{241}$Am in 2010 soil samples from the Near Field grid are shown in Figures 6.2-6.4.

$^{40}$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 observed previously 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 location (Table 6-3). The average concentration of $^{137}$Cs, $^{60}$Co and $^{40}$K observed in 2010 soil samples are shown in Figures 6.5-6.7. The concentrations for $^{137}$Cs and $^{60}$Co fell within the range of values previously measured for the WIPP soil samples.

The average concentrations of $^{239+240}$Pu, $^{238}$Pu, $^{241}$Am, $^{137}$Cs, and $^{40}$K around the WIPP site across the year are shown in Figures 6.8-6.12 and combined average, minimum, and maximum concentrations (Bq/kg) of selected radionuclides for all soil sample collected from the Near Field grid are presented in Table 6-4.

## Table 6-1: Summary Statistics for Radionuclides in Soil Samples Collected in 2010

| Analyte | Unit | Near Field | | | |
|---|---|---|---|---|---|
| | | [a]N | [b]Mean | SD | Range |
| $^{241}$Am | Bq/ kg | 16 | 3.23E-01 | 1.04E-02 | 9.63E-03- 7.10E-02 |
| $^{137}$Cs | Bq/ kg | 18 | 2.12E+00 | 1.61E-01 | 5.49E-01 -3.59E+00 |
| $^{40}$K | Bq/ kg | 18 | 1.78E+02 | 4.48E+00 | 1.24E+02 -2.28E+02 |
| $^{60}$Co | Bq/ kg | 0 | 4.86E-03 | 1.18E-01 | -2.35E-01-2.09E-01 |
| $^{238}$Pu | Bq/ kg | 0 | 6.31E-03 | 5.83E-03 | -1.07E-03-2.77E-02 |
| $^{239+240}$Pu | Bq/ kg | 17 | 1.04E-01 | 1.48E-02 | 2.51E-02 -1.75E-01 |
| $^{238}$U | Bq/ kg | 18 | 7.13E+00 | 1.65E-01 | 5.10E+00 -2.06E+01 |
| $^{234}$U | Bq/ kg | 18 | 6.75E+00 | 1.57E-01 | 4.87E+00 -1.71E+01 |
| $^{235}$U | Bq/ kg | 18 | 4.25E-01 | 3.43E-02 | 2.40E-01 -2.48E+00 |

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

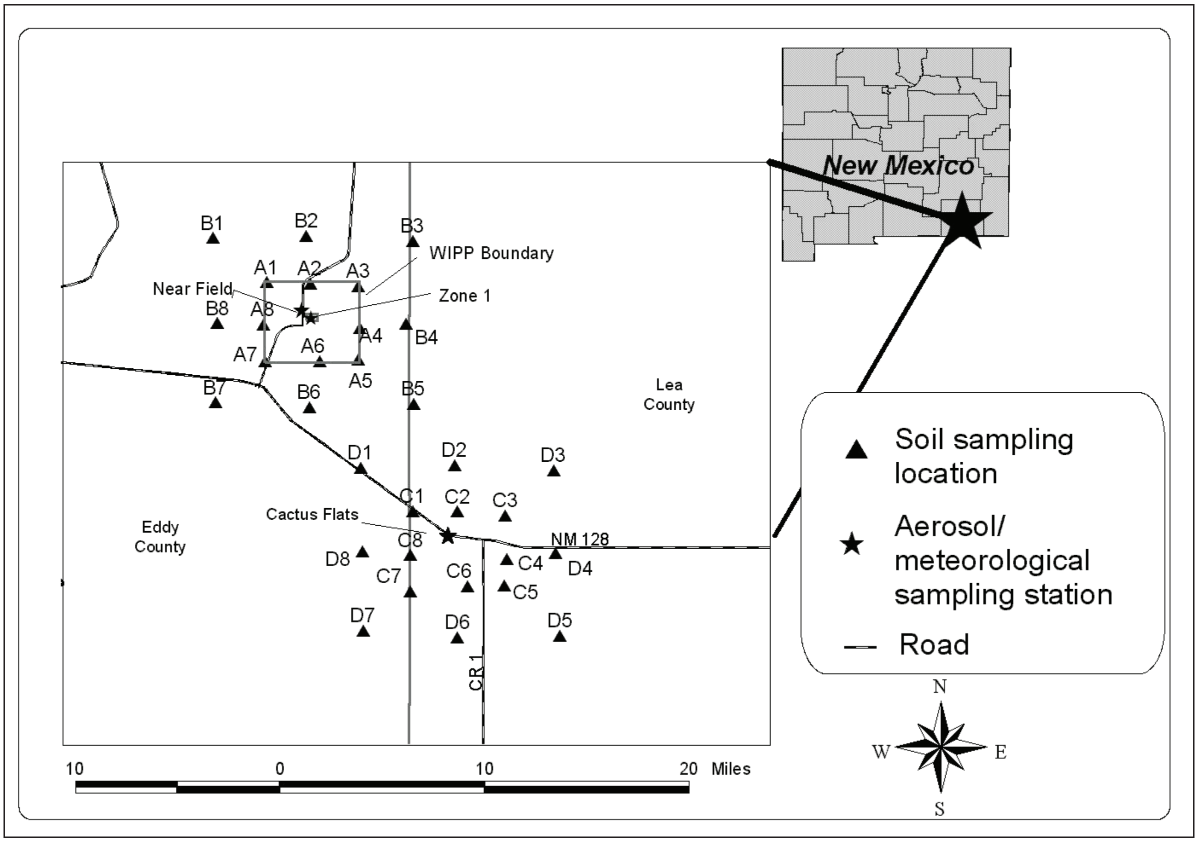


Figure 6.1: Soil Sampling Locations in the Vicinity of the WIPP Site

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

## Table 6-2: Americium, Plutonium, and Uranium Concentrations (Bq/kg) in the Soils Collected from Near Field in 2010

| | **Grid Node** | **Activity (Bq/kg)** | **SD (Bq/kg)** | **MDC (Bq/kg)** |
|---|---|---|---|---|
| **$^{238}$Pu** | A-1 | -2.93E-03 | 6.77E-03 | 3.24E-02 |
| | A-2 | -6.92E-03 | 1.02E-02 | 4.72E-02 |
| | A-3 | 6.56E-03 | 7.85E-03 | 2.95E-02 |
| | A-4 | 1.26E-02 | 6.65E-03 | 1.83E-02 |
| | A-5 | -1.47E-02 | 7.69E-03 | 6.41E-02 |
| | A-5 | 6.02E-03 | 6.59E-03 | 2.37E-02 |
| | A-6 | -2.51E-03 | 5.95E-03 | 2.85E-02 |
| | A-7 | 2.76E-03 | 4.67E-03 | 1.97E-02 |
| | A-8 | -6.16E-03 | 5.43E-03 | 2.69E-02 |
| | B-1 | 1.36E-03 | 3.04E-03 | 1.26E-02 |
| | B-2 | 9.46E-03 | 4.47E-03 | 1.25E-02 |
| | B-3 | 1.08E-02 | 8.22E-03 | 2.76E-02 |
| | B-4 | 1.30E-04 | 5.55E-03 | 2.42E-02 |
| | B-4 | 2.19E-02 | 5.91E-03 | 6.07E-03 |
| | B-5 | 6.57E-03 | 4.90E-03 | 1.61E-02 |
| | B-6 | 9.62E-03 | 5.16E-03 | 1.46E-02 |
| | B-7 | 9.74E-03 | 5.23E-03 | 1.48E-02 |
| | B-8 | 1.11E-02 | 5.79E-03 | 1.69E-02 |
| **$^{239+240}$Pu** | A-1 | 1.06E-01 | 2.10E-02 | 4.29E-02 |
| | A-2 | 1.31E-01 | 2.32E-02 | 3.35E-02 |
| | A-3 | 6.76E-02 | 1.61E-02 | 2.95E-02 |
| | A-4 | 2.78E-02 | 1.04E-02 | 2.68E-02 |
| | A-5 | 7.49E-02 | 1.34E-02 | 4.68E-02 |
| | A-5 | 1.45E-01 | 1.74E-02 | 1.46E-02 |
| | A-6 | 2.16E-02 | 1.07E-02 | 3.18E-02 |
| | A-7 | 1.10E-01 | 1.82E-02 | 2.49E-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 | 1.94E-01 | 2.13E-02 | 2.45E-02 |
| | B-4 | 1.15E-01 | 1.69E-02 | 2.09E-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 | 1.52E-01 | 1.72E-02 | 1.68E-02 |

## Table 6-2: Americium, Plutonium and Uranium Concentrations (Bq/kg) in the Soils Collected from Near Field in 2010

| | Grid Node | Activity (Bq/kg) | SD (Bq/kg) | MDC (Bq/kg) |
|---|---|---|---|---|
| $^{241}$Am | A-1 | 7.10E-02 | 1.17E-02 | 1.58E-02 |
| | A-2 | 1.63E-02 | 9.38E-03 | 2.30E-02 |
| | A-3 | 2.87E-02 | 6.61E-03 | 3.65E-03 |
| | A-4 | 6.27E-02 | 1.06E-02 | 1.31E-02 |
| | A-4 | 3.16E-02 | 7.87E-03 | 1.12E-02 |
| | A-5 | 1.70E-02 | 5.83E-03 | 1.19E-02 |
| | A-6 | 1.33E-02 | 5.51E-03 | 1.25E-02 |
| | A-7 | 5.53E-02 | 1.45E-02 | 2.69E-02 |
| | A-8 | 4.32E-02 | 1.20E-02 | 1.97E-02 |
| | B-1 | 6.65E-02 | 1.55E-02 | 2.68E-02 |
| | B-2 | 9.63E-03 | 4.18E-03 | 3.58E-03 |
| | B-3 | 4.31E-02 | 8.76E-03 | 1.53E-02 |
| | B-4 | 2.44E-02 | 7.94E-03 | 1.90E-02 |
| | B-5 | 3.08E-02 | 6.90E-03 | 9.75E-03 |
| | B-5 | 2.23E-02 | 6.84E-03 | 1.22E-02 |
| | B-6 | 6.07E-02 | 1.04E-02 | 1.10E-02 |
| | B-7 | 4.83E-02 | 8.85E-03 | 9.85E-03 |
| | B-8 | 3.88E-02 | 3.42E-02 | 9.21E-02 |
| $^{238}$Pu | A-1 | 7.37E-02 | 6.30E-02 | 2.19E-01 |
| | A-2 | 4.63E-02 | 4.08E-02 | 1.43E-01 |
| | A-3 | 7.00E-02 | 5.34E-02 | 1.80E-01 |
| | A-4 | 1.24E-02 | 6.06E-02 | 2.58E-01 |
| | A-4 | 9.23E-02 | 6.88E-02 | 2.26E-01 |
| | A-5 | -1.09E-02 | 5.46E-02 | 2.30E-01 |
| | A-6 | 5.68E-02 | 6.28E-02 | 2.28E-01 |
| | A-7 | 3.87E-02 | 6.51E-02 | 2.42E-01 |
| | A-8 | 3.92E-02 | 6.79E-02 | 2.57E-01 |
| | B-1 | 6.74E-02 | 4.77E-02 | 1.57E-01 |
| | B-2 | -9.40E-03 | 2.80E-02 | 1.34E-01 |
| | B-3 | 6.86E-02 | 4.75E-02 | 1.57E-01 |
| | B-4 | 6.63E-08 | 2.86E-02 | 1.33E-01 |
| | B-5 | 7.88E-02 | 4.16E-02 | 1.22E-01 |
| | B-5 | 8.67E-03 | 3.96E-02 | 1.61E-01 |
| | B-6 | 1.54E-01 | 8.13E-02 | 2.38E-01 |
| | B-7 | 2.76E-01 | 1.15E-01 | 3.23E-01 |
| | B-8 | 5.58E-02 | 6.96E-02 | 2.55E-01 |
| $^{239+240}$Pu | A-1 | 1.54E+00 | 1.91E-01 | 2.19E-01 |
| | A-2 | 7.09E-01 | 1.13E-01 | 1.66E-01 |
| | A-3 | 9.03E-01 | 1.18E-01 | 1.84E-01 |
| | A-4 | 1.14E+00 | 1.87E-01 | 3.25E-01 |
| | A-4 | 1.40E+00 | 1.84E-01 | 2.17E-01 |
| | A-5 | 2.69E-01 | 8.86E-02 | 2.35E-01 |
| | A-6 | 6.44E-01 | 1.23E-01 | 2.28E-01 |
| | A-7 | 7.31E-01 | 1.23E-01 | 2.26E-01 |
| | A-8 | 2.47E-01 | 9.88E-02 | 2.83E-01 |

| | | | | |
|---|---|---|---|---|
| | B-1 | 1.16E+00 | 1.54E-01 | 2.21E-01 |
| | B-2 | 2.78E-01 | 7.24E-02 | 1.68E-01 |
| | B-3 | 1.53E+00 | 1.48E-01 | 1.62E-01 |
| | B-4 | 9.71E-01 | 1.34E-01 | 1.94E-01 |
| | B-5 | 9.64E-01 | 1.18E-01 | 1.41E-01 |
| | B-5 | 1.01E+00 | 1.23E-01 | 1.39E-01 |
| | B-6 | 1.49E+00 | 2.11E-01 | 2.76E-01 |
| | B-7 | 1.74E+00 | 2.32E-01 | 3.34E-01 |
| | B-8 | 1.62E+00 | 1.95E-01 | 2.83E-01 |
| $^{234}$U | A-1 | 7.10E+00 | 1.34E-01 | 1.66E-02 |
| | A-2 | 4.87E+00 | 1.13E-01 | 1.60E-02 |
| | A-3 | 5.28E+00 | 1.22E-01 | 1.94E-02 |
| | A-4 | 6.01E+00 | 1.51E-01 | 2.66E-02 |
| | A-4 | 6.11E+00 | 1.32E-01 | 1.80E-02 |
| | A-5 | 5.00E+00 | 1.19E-01 | 2.08E-02 |
| | A-6 | 5.64E+00 | 1.39E-01 | 2.66E-02 |
| | A-7 | 5.60E+00 | 1.28E-01 | 1.69E-02 |
| | A-8 | 5.98E+00 | 1.34E-01 | 1.52E-02 |
| | B-1 | 6.70E+00 | 1.56E-01 | 1.91E-02 |
| | B-2 | 6.28E+00 | 1.87E-01 | 3.26E-02 |
| | B-3 | 6.78E+00 | 1.33E-01 | 1.69E-02 |
| | B-4 | 7.43E+00 | 1.76E-01 | 2.60E-02 |
| | B-5 | 5.83E+00 | 1.43E-01 | 2.75E-02 |
| | B-5 | 1.71E+01 | 4.14E-01 | 9.21E-02 |
| | B-6 | 6.58E+00 | 1.43E-01 | 1.99E-02 |
| | B-7 | 6.36E+00 | 1.25E-01 | 2.06E-02 |
| | B-8 | 6.83E+00 | 1.78E-01 | 2.23E-02 |
| $^{235}$U | A-1 | 4.18E-01 | 2.63E-02 | 1.45E-02 |
| | A-2 | 2.42E-01 | 2.08E-02 | 1.97E-02 |
| | A-3 | 2.66E-01 | 2.41E-02 | 2.41E-02 |
| | A-4 | 3.33E-01 | 2.74E-02 | 1.93E-02 |
| | A-4 | 2.98E-01 | 2.46E-02 | 2.24E-02 |
| | A-5 | 2.67E-01 | 2.28E-02 | 1.70E-02 |
| | A-6 | 2.80E-01 | 2.53E-02 | 1.99E-02 |
| | A-7 | 2.47E-01 | 2.17E-02 | 2.09E-02 |
| | A-8 | 2.90E-01 | 2.35E-02 | 2.09E-02 |
| | B-1 | 3.17E-01 | 2.46E-02 | 7.09E-03 |
| | B-2 | 2.73E-01 | 2.79E-02 | 2.75E-02 |
| | B-3 | 3.74E-01 | 2.63E-02 | 1.62E-02 |
| | B-4 | 3.62E-01 | 2.83E-02 | 1.89E-02 |
| | B-5 | 2.40E-01 | 2.39E-02 | 2.06E-02 |
| | B-5 | 2.48E+00 | 1.95E-01 | 3.95E-02 |
| | B-6 | 3.03E-01 | 2.57E-02 | 1.91E-02 |
| | B-7 | 3.44E-01 | 2.43E-02 | 1.92E-02 |
| | B-8 | 3.09E-01 | 2.47E-02 | 2.27E-02 |
| $^{238}$U | A-1 | 7.33E+00 | 1.37E-01 | 2.20E-02 |
| | A-2 | 5.10E+00 | 1.16E-01 | 1.23E-02 |
| | A-3 | 5.50E+00 | 1.25E-01 | 2.27E-02 |
| | A-4 | 6.04E+00 | 1.52E-01 | 3.03E-02 |
| | A-4 | 6.23E+00 | 1.34E-01 | 2.11E-02 |
| | A-5 | 5.18E+00 | 1.22E-01 | 2.28E-02 |
| | A-6 | 5.79E+00 | 1.42E-01 | 2.87E-02 |
| | A-7 | 5.48E+00 | 1.25E-01 | 1.68E-02 |

| | | | |
|---|---|---|---|
| A-8 | 6.25E+00 | 1.39E-01 | 1.98E-02 |
| B-1 | 6.80E+00 | 1.58E-01 | 1.51E-02 |
| B-2 | 6.44E+00 | 1.91E-01 | 2.69E-02 |
| B-3 | 7.32E+00 | 1.41E-01 | 1.98E-02 |
| B-4 | 7.84E+00 | 1.84E-01 | 2.97E-02 |
| B-5 | 6.06E+00 | 1.47E-01 | 2.97E-02 |
| B-5 | 2.06E+01 | 4.97E-01 | 1.32E-01 |
| B-6 | 6.58E+00 | 1.42E-01 | 2.33E-02 |
| B-7 | 6.79E+00 | 1.31E-01 | 2.33E-02 |
| B-8 | 7.05E+00 | 1.83E-01 | 2.44E-02 |

## Table 6-3: Selected Gamma Radionuclide Activity Concentrations (Bq/kg) in the Soils Collected from Near Field in 2010

| | Grid Nodes | Activity (Bq/kg) | SD (Bq/kg) | MDC (Bq/kg) |
|---|---|---|---|---|
| $^{137}$Cs | A-1 | 3.59E+00 | 1.84E-01 | 5.26E-01 |
| | A-2 | 1.77E+00 | 1.58E-01 | 4.85E-01 |
| | A-3 | 1.76E+00 | 1.52E-01 | 4.65E-01 |
| | A-4 | 2.31E+00 | 1.56E-01 | 4.64E-01 |
| | A-4 | 2.91E+00 | 1.63E-01 | 4.69E-01 |
| | A-5 | 7.51E-01 | 1.36E-01 | 4.35E-01 |
| | A-6 | 1.45E+00 | 1.52E-01 | 4.72E-01 |
| | A-7 | 1.42E+00 | 1.51E-01 | 4.71E-01 |
| | A-8 | 5.99E-01 | 1.55E-01 | 5.04E-01 |
| | B-1 | 1.88E+00 | 1.64E-01 | 5.06E-01 |
| | B-2 | 5.49E-01 | 1.42E-01 | 4.60E-01 |
| | B-3 | 2.91E+00 | 1.84E-01 | 5.43E-01 |
| | B-4 | 1.81E+00 | 1.62E-01 | 4.97E-01 |
| | B-5 | 2.42E+00 | 1.61E-01 | 4.77E-01 |
| | B-5 | 2.14E+00 | 1.51E-01 | 4.49E-01 |
| | B-6 | 3.19E+00 | 1.76E-01 | 5.05E-01 |
| | B-7 | 3.17E+00 | 1.69E-01 | 4.83E-01 |
| | B-8 | 3.58E+00 | 1.78E-01 | 5.02E-01 |
| $^{40}$K | A-1 | 2.28E+02 | 5.44E+00 | 6.26E+00 |
| | A-2 | 1.61E+02 | 4.18E+00 | 5.92E+00 |
| | A-3 | 1.58E+02 | 4.08E+00 | 5.76E+00 |
| | A-4 | 1.68E+02 | 4.25E+00 | 5.73E+00 |
| | A-4 | 1.78E+02 | 4.43E+00 | 5.73E+00 |
| | A-5 | 1.46E+02 | 3.85E+00 | 5.68E+00 |
| | A-6 | 1.88E+02 | 4.65E+00 | 5.88E+00 |
| | A-7 | 1.67E+02 | 4.22E+00 | 5.60E+00 |
| | A-8 | 2.01E+02 | 4.94E+00 | 6.17E+00 |
| | B-1 | 2.02E+02 | 4.96E+00 | 6.19E+00 |
| | B-2 | 1.49E+02 | 3.89E+00 | 5.72E+00 |
| | B-3 | 2.14E+02 | 5.28E+00 | 6.87E+00 |
| | B-4 | 2.10E+02 | 5.12E+00 | 6.31E+00 |
| | B-5 | 1.51E+02 | 3.92E+00 | 5.57E+00 |
| | B-5 | 1.24E+02 | 3.46E+00 | 5.62E+00 |
| | B-6 | 1.82E+02 | 4.60E+00 | 6.12E+00 |
| | B-7 | 1.76E+02 | 4.43E+00 | 5.89E+00 |
| | B-8 | 2.05E+02 | 4.94E+00 | 5.72E+00 |
| $^{60}$Co | A-1 | -5.66E-02 | 1.18E-01 | 4.78E-01 |

| | | | | |
|---|---|---|---|---|
| | A-2 | 7.64E-02 | 1.08E-01 | 4.21E-01 |
| | A-3 | -3.68E-02 | 9.48E-02 | 3.87E-01 |
| | A-4 | -1.20E-01 | 1.08E-01 | 4.43E-01 |
| | A-4 | 6.16E-02 | 1.04E-01 | 4.15E-01 |
| | A-5 | -4.37E-02 | 1.03E-01 | 4.19E-01 |
| | A-6 | 1.01E-01 | 1.07E-01 | 4.27E-01 |
| | A-7 | -2.21E-01 | 1.08E-01 | 4.48E-01 |
| | A-8 | -1.36E-01 | 1.18E-01 | 4.76E-01 |
| | B-1 | 1.98E-01 | 1.09E-01 | 4.23E-01 |
| | B-2 | 1.71E-01 | 9.95E-02 | 3.91E-01 |
| | B-3 | -3.27E-03 | 1.20E-01 | 4.86E-01 |
| | B-4 | -3.18E-02 | 1.17E-01 | 4.78E-01 |
| | B-5 | 1.27E-01 | 1.04E-01 | 4.10E-01 |
| | B-5 | -2.35E-01 | 1.06E-01 | 4.47E-01 |
| | B-6 | -1.35E-01 | 2.04E-01 | 6.81E-01 |
| | B-7 | 2.09E-01 | 1.91E-01 | 6.31E-01 |
| | B-8 | 1.63E-01 | 1.08E-01 | 4.39E-01 |

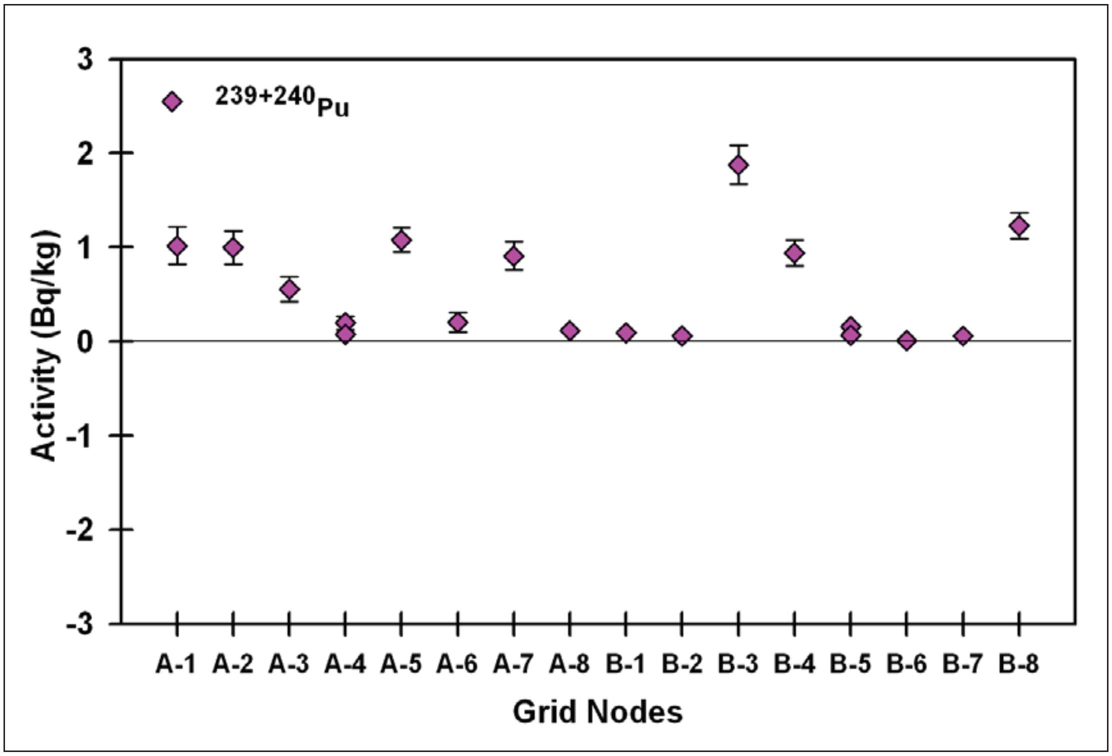


**Figure 6.2: Activity Concentrations of $^{239+240}$Pu in Soil Samples Collected from Near Field Grid in 2010**

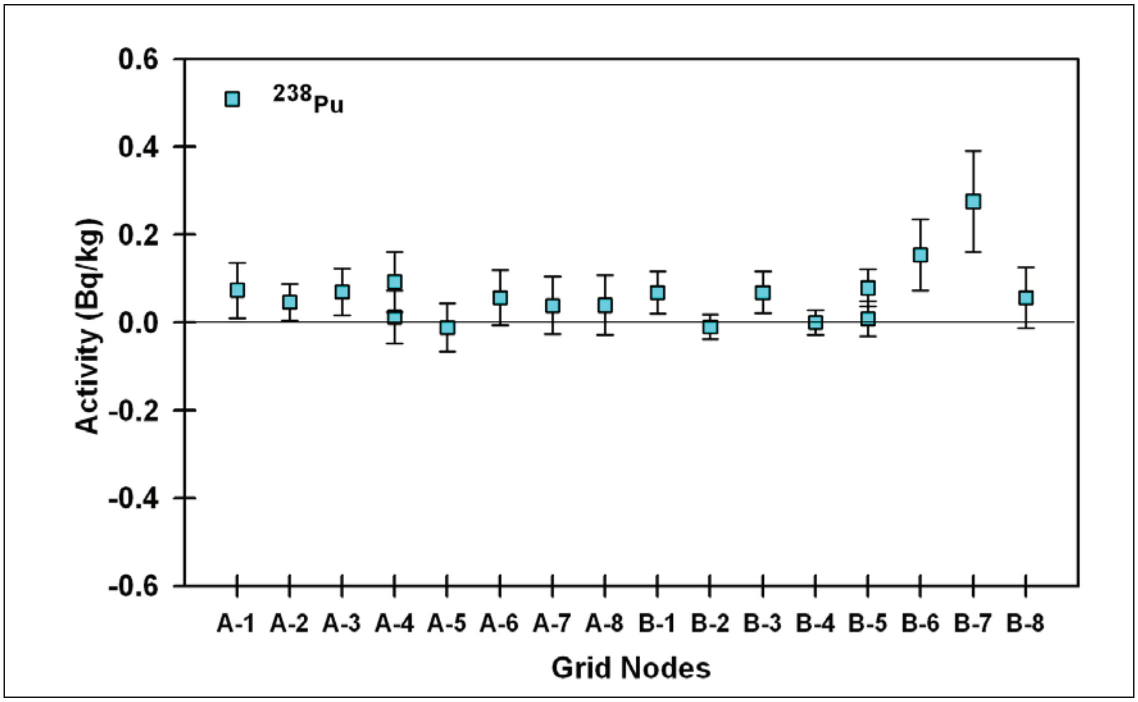


Figure 6.3: Activity Concentrations of $^{238}$Pu in Soil Samples Collected from Near Field Grid in 2010

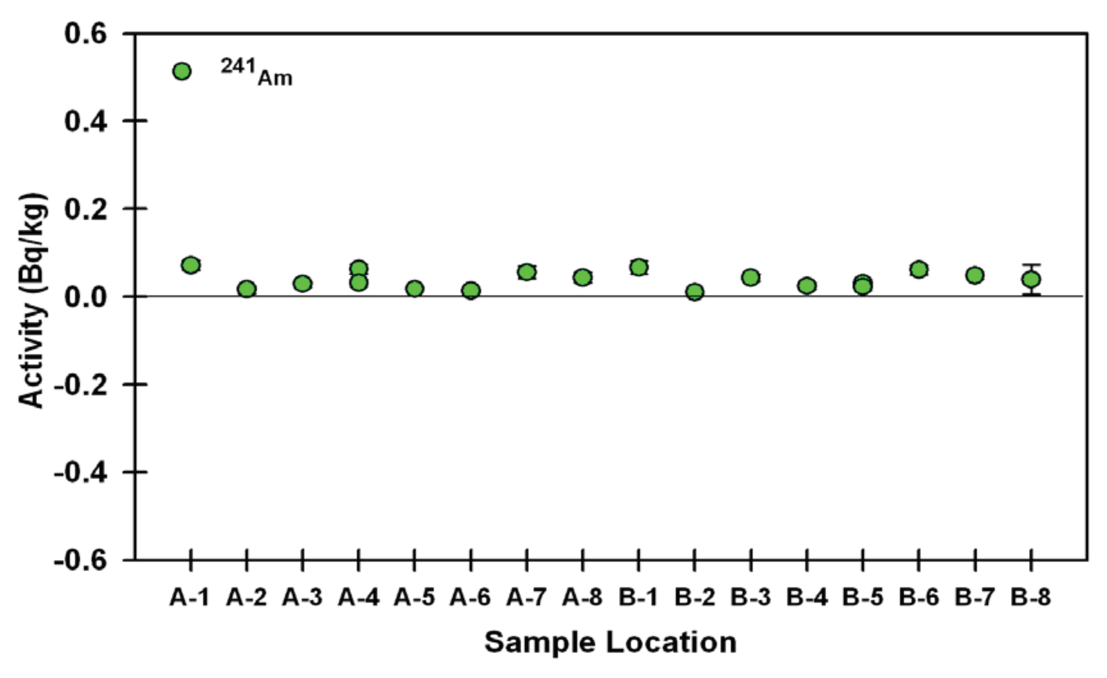


Figure 6.4: Activity Concentrations of $^{241}$Am in Soil Samples Collected from Near Field Grid in 2010

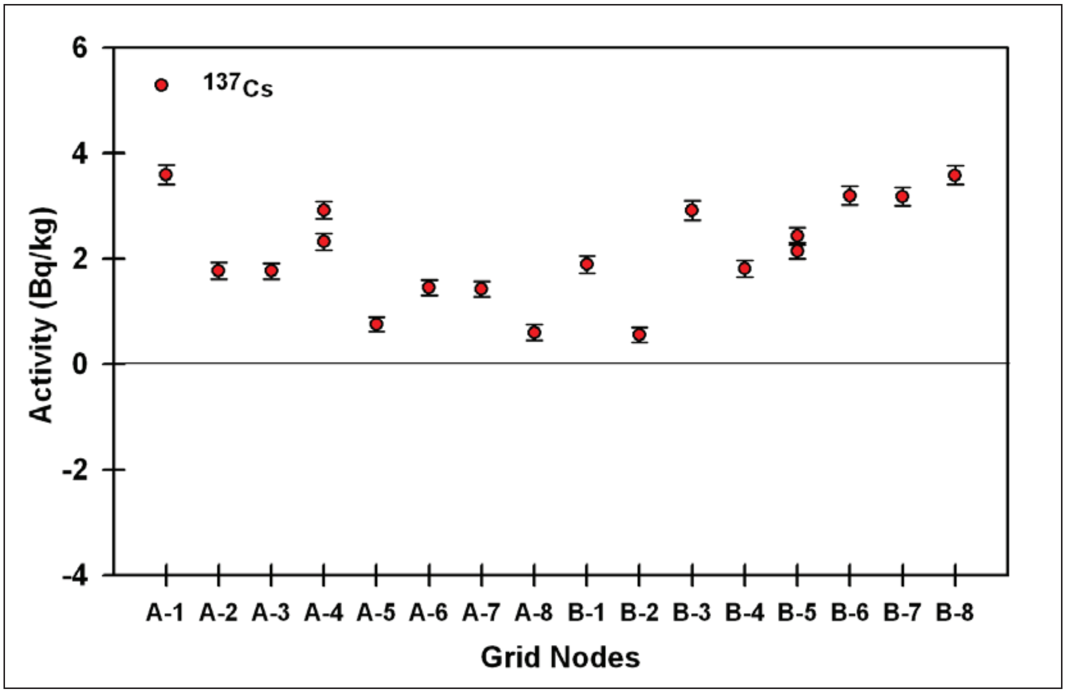


Figure 6.5: Activity Concentrations of $^{137}$Cs in Soil Samples Collected from Near Field Grid in 2010

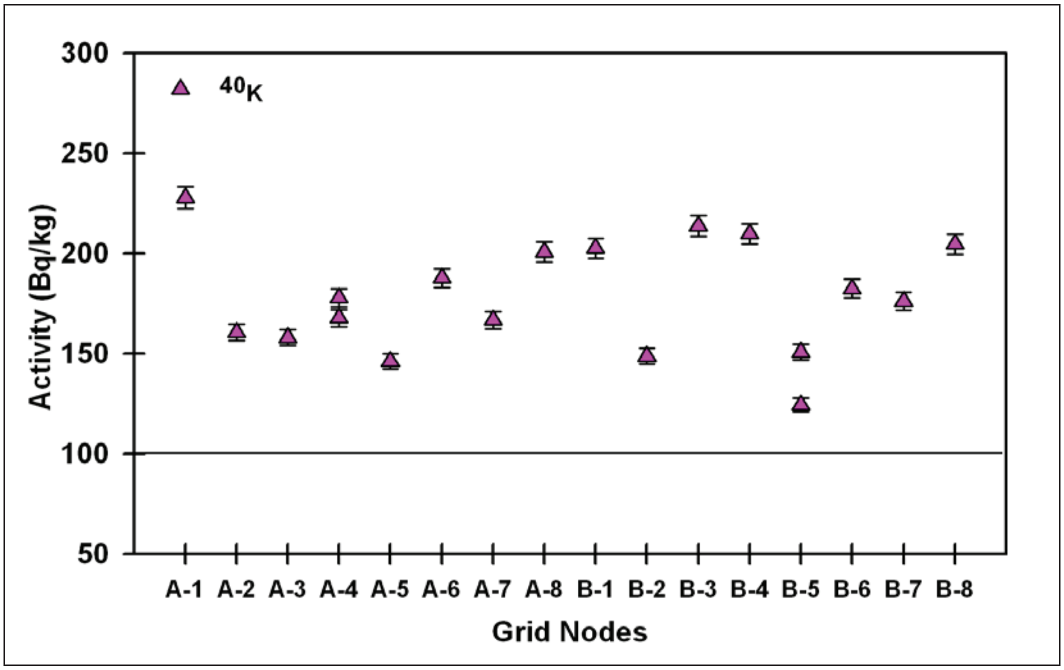


Figure 6.6: Activity Concentrations of $^{40}$K in Soil Samples Collected from Near Field Grid in 2010

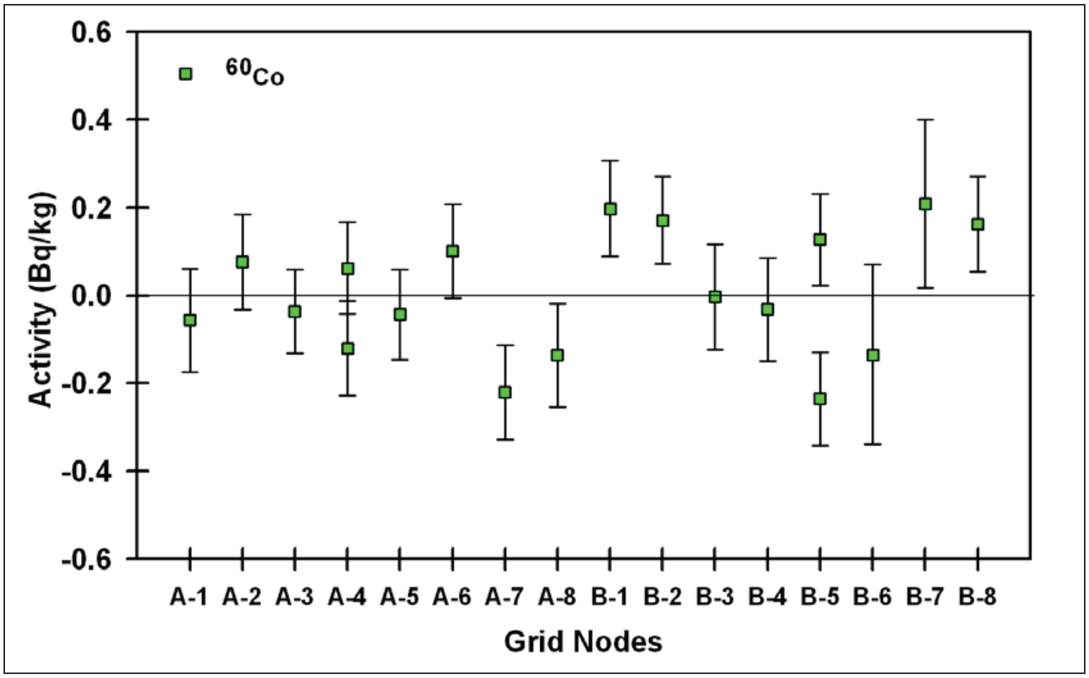


Figure 6.7: Activity Concentrations of $^{60}$Co in Soil Samples Collected from Near Field Grid in 2010

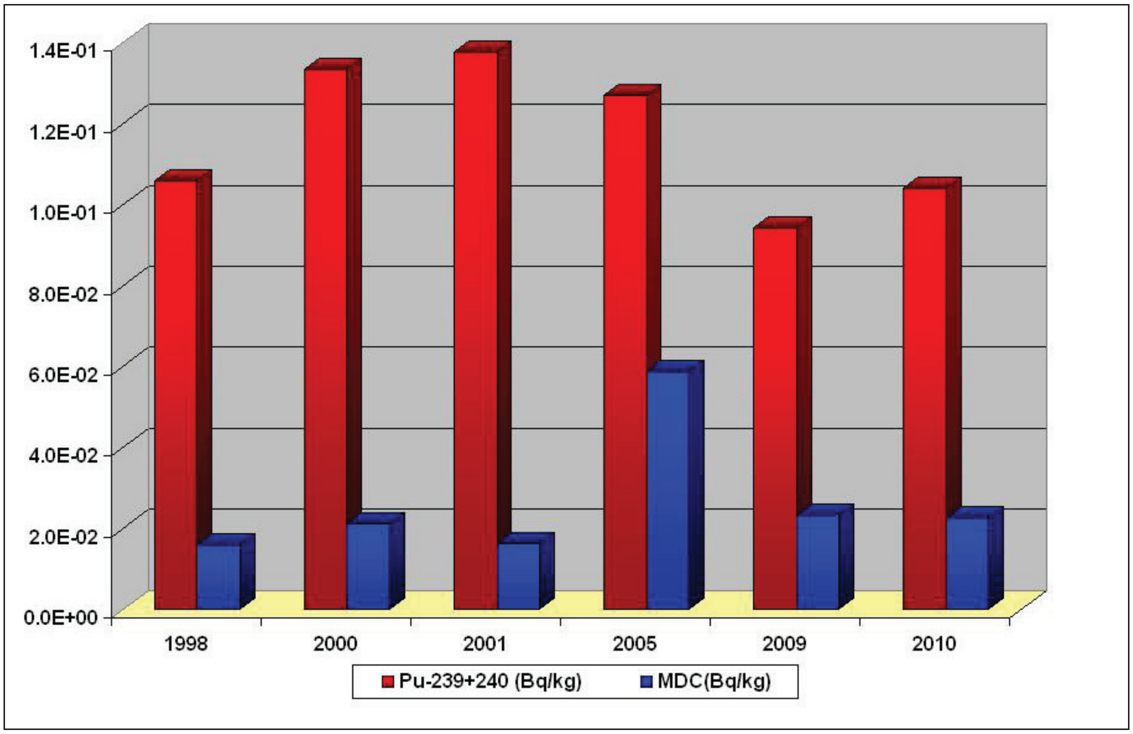


Figure 6.8: Average Activity Concentrations of $^{239+240}$Pu in WIPP Soil from 1998-2010

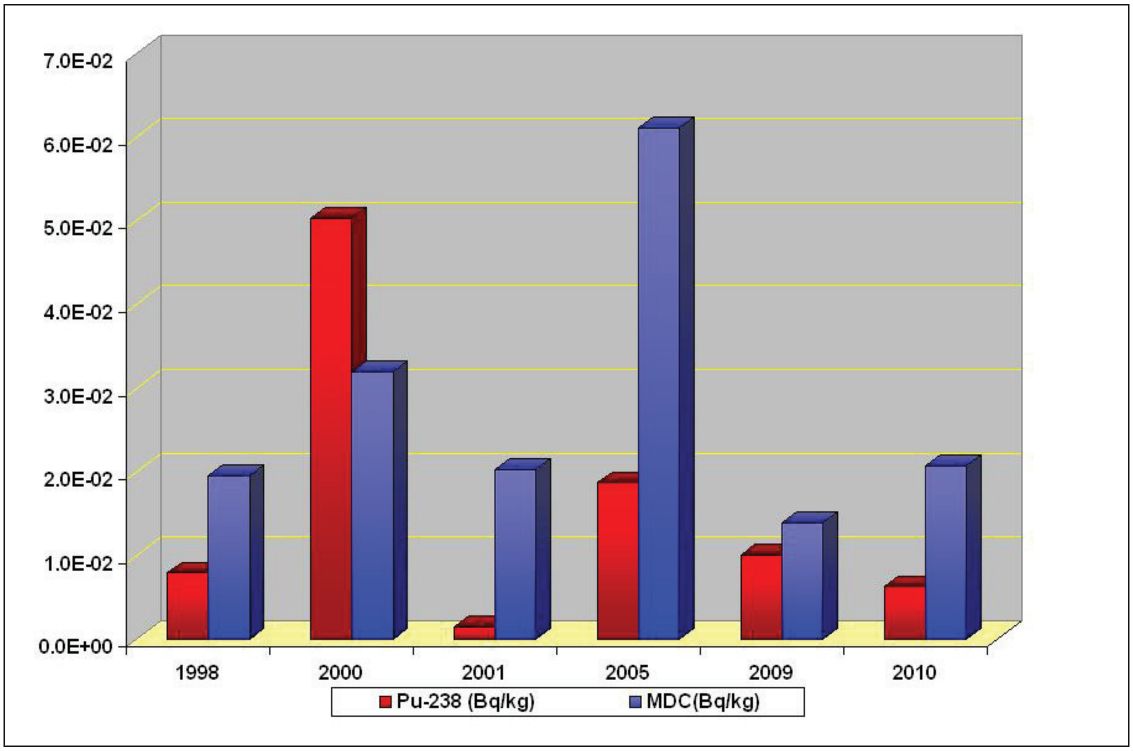


Figure 6.9: Average Activity Concentrations of $^{238}$Pu in WIPP Soil from 1998-2010

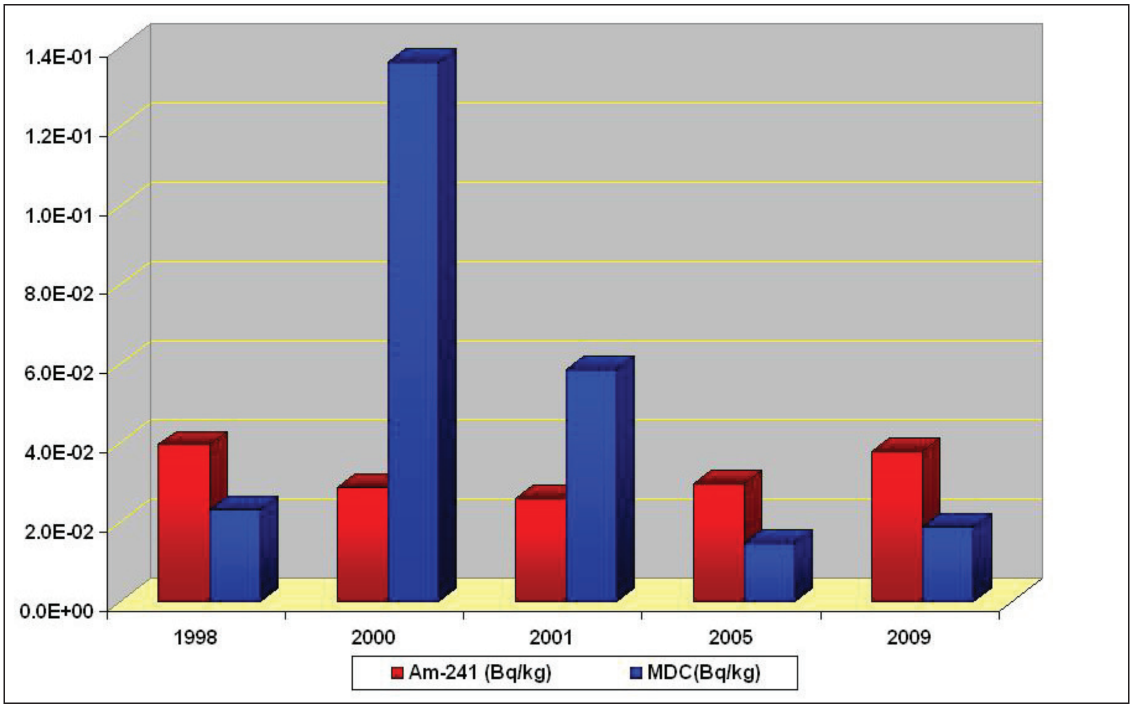


Figure 6.10: Average Activity Concentrations of $^{241}$Am in WIPP Soil from 1998-2010

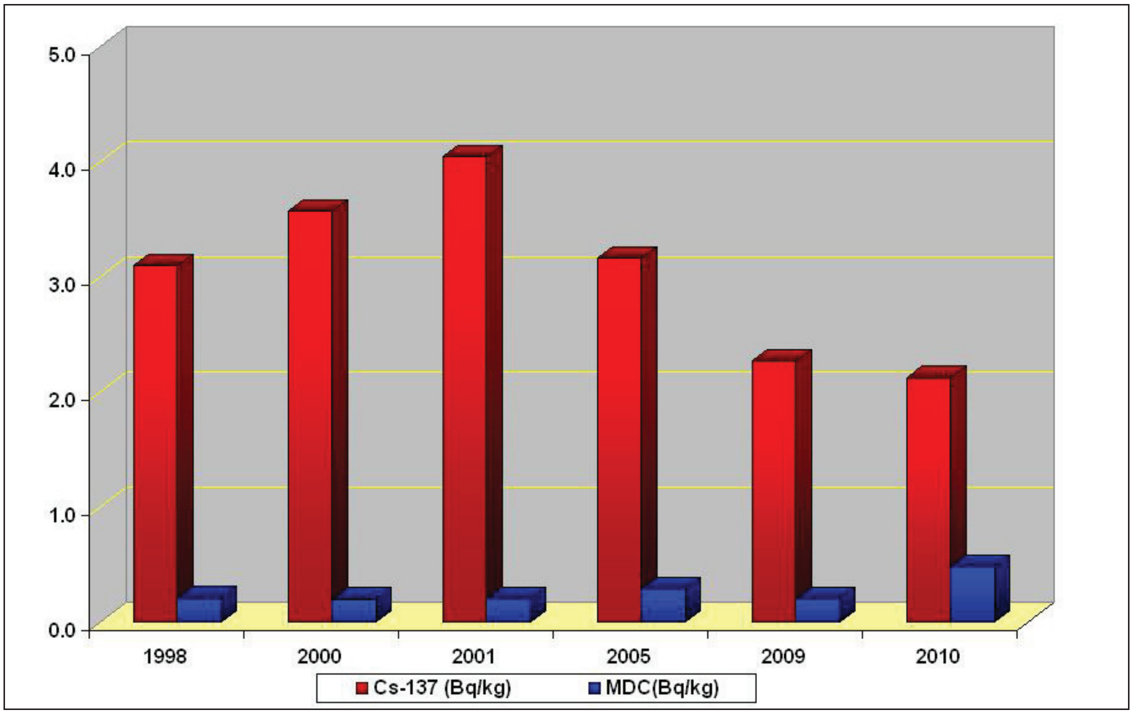


Figure 6.11: Average Activity Concentrations of $^{137}$Cs in WIPP Soil from 1998-2010

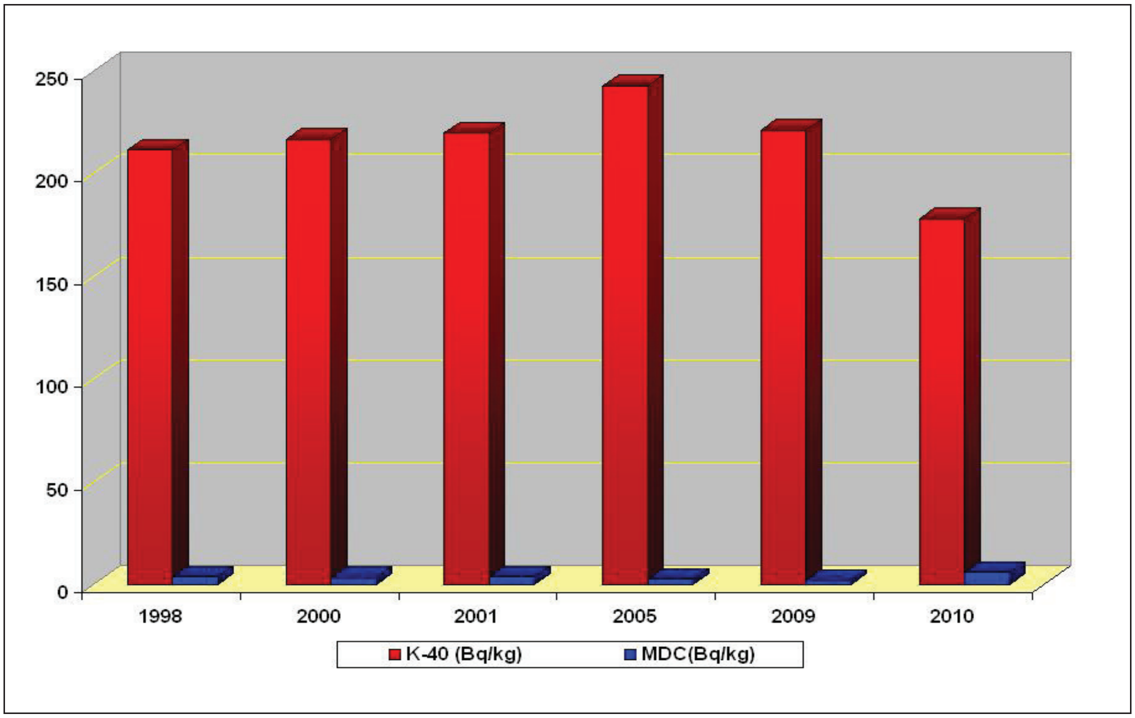


Figure 6.12: Average Activity Concentrations of $^{40}$K in WIPP Soil from 1998-2010

## Table 6-4: Maximum, Minimum and Mean Concentrations of Radionuclides in Soils from 1998-2010 in the Near Field 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 | 5.16E-02 | 1.05E-02 | 1.61E-02 | 1.43E-02 | 9.37E-02 |
| | $^{239+240}$Pu | 1.36E-01 | 1.77E-02 | 2.76E-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 | 4.02E+00 | 1.19E-01 | 2.13E-01 | 1.79E+00 | 6.88E+00 |
| | $^{40}$K | 2.53E+02 | 4.44E+00 | 3.31E+00 | 2.13E+02 | 2.83E+02 |
| | $^{234}$U | 9.50E+00 | 2.76E-01 | 5.39E-02 | 9.05E+00 | 1.04E+01 |
| | $^{235}$U | 5.12E-01 | 5.72E-02 | 5.20E-02 | 4.81E-01 | 5.75E-01 |
| | $^{238}$U | 9.83E+00 | 2.84E-01 | 5.65E-02 | 9.53E+00 | 1.03E+01 |
| A2 | $^{241}$Am | 3.30E-02 | 8.91E-03 | 1.90E-02 | 2.20E-02 | 4.28E-02 |
| | $^{239+240}$Pu | 1.02E-01 | 1.41E-02 | 1.88E-02 | 5.21E-02 | 1.41E-01 |
| | $^{238}$Pu | 1.05E-02 | 1.23E-02 | 4.38E-02 | 6.92E-03 | 4.63E-02 |
| | $^{137}$Cs | 2.28E+00 | 6.63E-02 | 1.88E-01 | 9.46E-01 | 4.00E+00 |
| | $^{40}$K | 1.98E+02 | 3.65E+00 | 3.21E+00 | 1.80E+02 | 2.27E+02 |
| | $^{234}$U | 6.89E+00 | 1.98E-01 | 4.10E-02 | 5.05E+00 | 8.22E+00 |
| | $^{235}$U | 3.49E-01 | 4.28E-02 | 4.44E-02 | 2.58E-01 | 4.49E-01 |
| | $^{238}$U | 7.25E+00 | 2.04E-01 | 4.58E-02 | 5.25E+00 | 9.19E+00 |
| A3 | $^{241}$Am | 3.85E-02 | 9.19E-03 | 1.73E-02 | 2.31E-02 | 5.30E-02 |
| | $^{239+240}$Pu | 1.17E-01 | 1.53E-02 | 2.02E-02 | 6.76E-02 | 1.92E-01 |
| | $^{238}$Pu | 1.28E-02 | 1.31E-02 | 4.48E-02 | -5.05E-04 | 7.00E-02 |
| | $^{137}$Cs | 3.17E+00 | 2.94E-01 | 2.13E-01 | 1.72E+00 | 4.39E+00 |
| | $^{40}$K | 1.81E+02 | 3.41E+00 | 3.00E+00 | 1.73E+02 | 1.91E+02 |
| | $^{234}$U | 6.28E+00 | 1.85E-01 | 4.31E-02 | 5.31E+00 | 7.27E+00 |
| | $^{235}$U | 3.01E-01 | 3.87E-02 | 4.41E-02 | 2.05E-01 | 3.80E-01 |
| | $^{238}$U | 6.29E+00 | 1.86E-01 | 4.23E-02 | 5.36E+00 | 7.01E+00 |
| A4 | $^{241}$Am | 3.74E-02 | 8.30E-03 | 1.52E-02 | 2.28E-02 | 5.04E-02 |
| | $^{239+240}$Pu | 6.63E-02 | 1.00E-02 | 1.82E-02 | 1.45E-02 | 9.84E-02 |
| | $^{238}$Pu | 1.65E-02 | 1.93E-02 | 7.09E-02 | -2.57E-03 | 9.23E-02 |
| | $^{137}$Cs | 2.35E+00 | 7.46E-02 | 1.93E-01 | 4.29E-01 | 3.98E+00 |
| | $^{40}$K | 2.00E+02 | 3.63E+00 | 3.05E+00 | 1.71E+02 | 2.30E+02 |
| | $^{234}$U | 7.42E+00 | 2.03E-01 | 3.43E-02 | 6.84E+00 | 7.82E+00 |
| | $^{235}$U | 3.80E-01 | 4.29E-02 | 4.17E-02 | 3.08E-01 | 4.24E-01 |
| | $^{238}$U | 7.44E+00 | 2.03E-01 | 4.01E-02 | 7.23E+00 | 7.85E+00 |
| A5 | $^{241}$Am | 3.56E-02 | 7.87E-03 | 1.30E-02 | 1.84E-02 | 5.89E-02 |
| | $^{239+240}$Pu | 1.02E-01 | 1.40E-02 | 2.10E-02 | 7.33E-02 | 1.45E-01 |
| | $^{238}$Pu | -1.38E-03 | 1.32E-02 | 5.55E-02 | -1.47E-02 | 6.02E-03 |
| | $^{137}$Cs | 2.47E+00 | 8.41E-02 | 2.15E-01 | 5.41E-01 | 3.73E+00 |
| | $^{40}$K | 1.91E+02 | 3.62E+00 | 3.01E+00 | 1.61E+02 | 2.30E+02 |
| | $^{234}$U | 6.16E+00 | 1.64E-01 | 4.36E-02 | 4.99E+00 | 7.94E+00 |
| | $^{235}$U | 3.71E-01 | 4.12E-02 | 3.85E-02 | 2.90E-01 | 4.67E-01 |
| | $^{238}$U | 6.60E+00 | 1.72E-01 | 4.42E-02 | 5.43E+00 | 8.28E+00 |

| Grid Node | Nuclide | Mean Activity (Bq/kg) | Mean Uncertainty (Bq/kg) | Mean MDC (Bq/kg) | Minimum Activity (Bq/kg) | Maximum Activity (Bq/kg) |
|---|---|---|---|---|---|---|
| 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 | 1.01E-02 | 1.45E-02 | 5.17E-02 | -3.04E-03 | 5.68E-02 |
| | $^{137}$Cs | 6.88E-01 | 1.30E-01 | 2.01E-01 | 2.97E-01 | 1.10E+00 |
| | $^{40}$K | 1.97E+02 | 3.70E+00 | 3.17E+00 | 1.85E+02 | 2.20E+02 |
| | $^{234}$U | 7.76E+00 | 2.41E-01 | 5.20E-02 | 5.69E+00 | 9.25E+00 |
| | $^{235}$U | 4.53E-01 | 5.64E-02 | 4.99E-02 | 2.94E-01 | 6.22E-01 |
| | $^{238}$U | 7.55E+00 | 2.38E-01 | 4.47E-02 | 5.71E+00 | 8.47E+00 |
| A7 | $^{241}$Am | 3.05E-02 | 7.20E-03 | 1.37E-02 | 2.20E-02 | 4.48E-02 |
| | $^{239+240}$Pu | 6.96E-02 | 1.13E-02 | 1.88E-02 | 1.86E-02 | 1.10E-01 |
| | $^{238}$Pu | 5.40E-03 | 1.43E-02 | 5.35E-02 | -1.28E-02 | 3.87E-02 |
| | $^{137}$Cs | 2.39E+00 | 9.56E-02 | 2.15E-01 | 6.11E-01 | 3.32E+00 |
| | $^{40}$K | 2.04E+02 | 3.75E+00 | 3.17E+00 | 1.79E+02 | 2.50E+02 |
| | $^{234}$U | 6.91E+00 | 2.06E-01 | 6.06E-02 | 5.36E+00 | 8.45E+00 |
| | $^{235}$U | 3.68E-01 | 4.90E-02 | 5.36E-02 | 2.18E-01 | 5.47E-01 |
| | $^{238}$U | 7.09E+00 | 2.09E-01 | 5.43E-02 | 5.62E+00 | 8.50E+00 |
| A8 | $^{241}$Am | 5.77E-02 | 1.08E-02 | 1.79E-02 | 4.12E-02 | 8.45E-02 |
| | $^{239+240}$Pu | 1.60E-02 | 6.91E-03 | 1.44E-02 | 1.55E-02 | 1.65E-02 |
| | $^{238}$Pu | 1.78E-01 | 1.76E-02 | 1.78E-02 | 7.18E-02 | 2.59E-01 |
| | $^{137}$Cs | 4.93E+00 | 1.22E-01 | 2.41E-01 | 2.80E+00 | 7.49E+00 |
| | $^{40}$K | 2.81E+02 | 4.94E+00 | 3.61E+00 | 2.27E+02 | 3.66E+02 |
| | $^{234}$U | 8.79E+00 | 2.86E-01 | 4.64E-02 | 6.89E+00 | 1.05E+01 |
| | $^{235}$U | 5.20E-01 | 5.78E-02 | 4.96E-02 | 3.56E-01 | 7.33E-01 |
| | $^{238}$U | 9.24E+00 | 2.99E-01 | 5.48E-02 | 7.39E+00 | 1.07E+01 |

# CHAPTER 7

## Nuclear Disaster in Fukushima, Japan

By
Punam Thakur

## INTRODUCTION

The earthquake and tsunami that hit northern Japan on March 11, 2011 created the worst nuclear crisis since the Chernobyl disaster. The three active reactors at the Fukushima Daiichi Nuclear Power Station 170 miles north of Tokyo overheated and partially melted down after the quake knocked out the plant's power and the tsunami disabled the backup generators meant to keep cooling systems working, Table 7-1 and Figure 7.1. The damage caused the failure of cooling and safety systems resulting in the atmospheric release of radiological materials from the reactor site. As the danger and radioactivity levels rose, tens of thousands of residents were evacuated or told to stay inside, Figures 7.2 and 7.3. Efforts began to focus on the spent fuel rods in Reactors No. 3 and 4, but the work was hindered by high levels of radioactivity.

On March 18, Japan's nuclear safety agency raised the assessment of its severity to 5 from 4 on a 7-level international scale retroactive to March 15. The accident at Three Mile Island was rated a 5, but far more radiation has already been released in the Fukushima plant. The I.A.E.A (International Atomic Energy Agency) has detected radiation levels 1,600 times above normal about 12 miles from the plant.

On March 23, the government announced that radioactive iodine had been detected in Tokyo’s water supply and warned that infants should not drink tap water there. The crisis has also raised fears about the spread of contamination for the environment and local food supply; traces of radioactive elements have been found in vegetables and raw milk from farms around the plant and radioactive water has been flowing into the ocean. On March 30, cesium 137, a long-lasting radioactive element, was found at levels that pose a long-term danger at one spot 25 miles from the crippled plant, raising questions about whether the evacuation zone should be expanded and whether the land might need to be abandoned.

On April 12, Japan raised its assessment of the accident at the crippled Fukushima Daiichi nuclear power plant from 5 to 7, the worst rating on an international scale, putting the disaster on par with the 1986 Chernobyl explosion, in an acknowledgement that the human and environmental consequences of the nuclear crisis could be dire and long-lasting. While the amount of radioactive materials released from Fukushima Daiichi so far has equaled about 10 percent of that released at Chernobyl, officials said that the radiation release from Fukushima could, in time, surpass levels seen in 1986.

## BACKGROUND

Japan is one of the world’s top consumers of nuclear energy. The country’s 17 nuclear plants-boasting 55 reactors-have provided about 30 percent of its electricity needs. With virtually no natural resources, Japan has considered nuclear power as an alternative to oil and other fossil fuels since the 1960s.

The reactors at Fukushima date from the 1960s and are of a design known as boiling water reactors (BWR). A controlled nuclear reaction produced by fuel rods containing pellets of uranium creates heat used to make steam that turns turbines to produce electricity. The flow of water also serves to cool the reactor.

Planning for earthquakes and tsunamis is highly developed in Japan, but the one-two punch of the 9.0 earthquake and the giant waves that followed it overwhelmed the reactors' safety systems. The earthquake knocked out power to the area, while the tsunami poured over the sea wall built around the plant and disabled diesel back-up generators.

When the tremor hit, the reactors at the Fukushima Daiichi plant shut down automatically, meaning that the nuclear chain reaction (which generated heat to turn water to steam for the turbines that make electricity) was halted. In such an emergency, the reactors are designed to insert special rods into the core that absorb neutrons and stop the chain reaction.

The reactors were very hot (they operate at about 550 degrees Fahrenheit) and it takes a while to remove that heat. In addition, even though the chain reaction is stopped, heat is still generated in the fuel by the natural decay of the radioactive elements present. This heat is the reason plant engineers needed to keep pumping water into the reactor core; if the fuel rods are exposed, even for a short time (as happened for at least two of the reactors), they become damaged and radioactivity is released. The engineers took what seemed at the time, a desperate step; they flooded the reactors with sea water laced with boric acid, a step that permanently disabled them.

In response to the Japanese nuclear incident, the CEMRC accelerated and increased sampling frequency and analysis to confirm that there were no harmful levels of radiation reaching the U.S. from Japan and to inform the public about any level of radiation detected. The report covers the first three months of air radiation monitoring following the Fukushima nuclear disaster and is intended to inform a wider public about the exact time and nature of the arrival of fission products to the Carlsbad area. On March 14-April 01, 2011 we detected the first arrival of the airborne fission products $^{131}$I, $^{132}$Te, $^{134}$Cs and $^{137}$Cs in Carlsbad, NM, USA by identifying their characteristic gamma rays using a germanium detector, Tables 7-2, 7-3, and Figure 7.4. From a public health standpoint, the isotopes of $^{131}$I and $^{137}$Cs are of most interest, because if high concentrations of $^{131}$I are inhaled or ingested, the radioactive iodine can concentrate in the thyroid and thereby increase the risk for cancer in that organ. Additionally, cesium is chemically similar to potassium and so will behave like potassium in the body; therefore, inhalation or ingestion of high concentrations of radioactive cesium can build up in multiple locations throughout the body, which can lead to an increased risk of various cancers. It is important to note that all of the radiation levels detected by CEMRC have been very low, well below any level of public health concern. We saw decreasing radiation levels during April and May. Since May, sample analyses have predominantly shown no detections of radionuclides associated with the Japanese nuclear incident. The activity of $^{131}$I measured was at least a factor of ~1500 below the limit given by the Environmental Protection Agency (EPA) of 3.7 Bq/m$^3$. Some comparative radiation doses and their effects are listed in the Radiation Charts, Figures 7.5 and 7.6. For comparison purposes, the concentrations of Cesium, Iodine, and Tellurium in the Seattle, WA area are shown in Figure 7.7.

The average dose received by the public from nuclear power is 0.0002 mSv/yr, which is of the order of 10,000 times smaller than the total yearly dose received by the public from background radiation. Naturally occurring background radiation is the main source of exposure for most people, and provides some perspective on radiation exposure from nuclear energy. The average dose received from background radiation is around 2.4 mSv/yr, which can vary depending on the geology and altitude where people live – ranging between 1 and 10 mSv/yr, but can be more than 50 mSv/yr. The highest known level of background radiation affecting a substantial population is in Kerala and Madras states in India where some 140,000 people receive doses which average over 15 millisievert per year from gamma radiation, in addition to a similar dose from radon. Comparable levels occur in Brazil and Sudan, with average exposures up to about 40 mSv/yr to many people. Several places are known in Iran, India and Europe where natural background radiation gives an annual dose of more than 50 mSv and up to 260 mSv (at Ramsar in Iran). Lifetime doses from natural radiation range up to several thousand millisievert. However, there is no evidence of increased cancers or other health problems arising from these high natural levels.

Radiation protection standards assume that any dose of radiation, no matter how small, involves a possible risk to human health. However, available scientific evidence does not indicate any cancer risk or immediate effects at doses below 100 mSv a year. At low levels of exposure, the body's natural repair mechanisms seem to be adequate to repair radiation damage to cells soon after it occurs.

**Table 7-1: Fukushima Daiichi Units**

| Unit Number | Type | First criticality | Electric power |
|---|---|---|---|
| 1 | BWR-3 | October 10, 1970 | 460 MW |
| 2 | BWR-4 | May 10, 1973 | 784 MW |
| 3 | BWR-4 | September 6, 1974 | 784 MW |
| 4 | BWR-4 | January 28, 1978 | 784 MW |
| 5 | BWR-4 | August 26, 1977 | 784 MW |
| 6 | BWR-5 | March 9, 1979 | 1,100 MW |

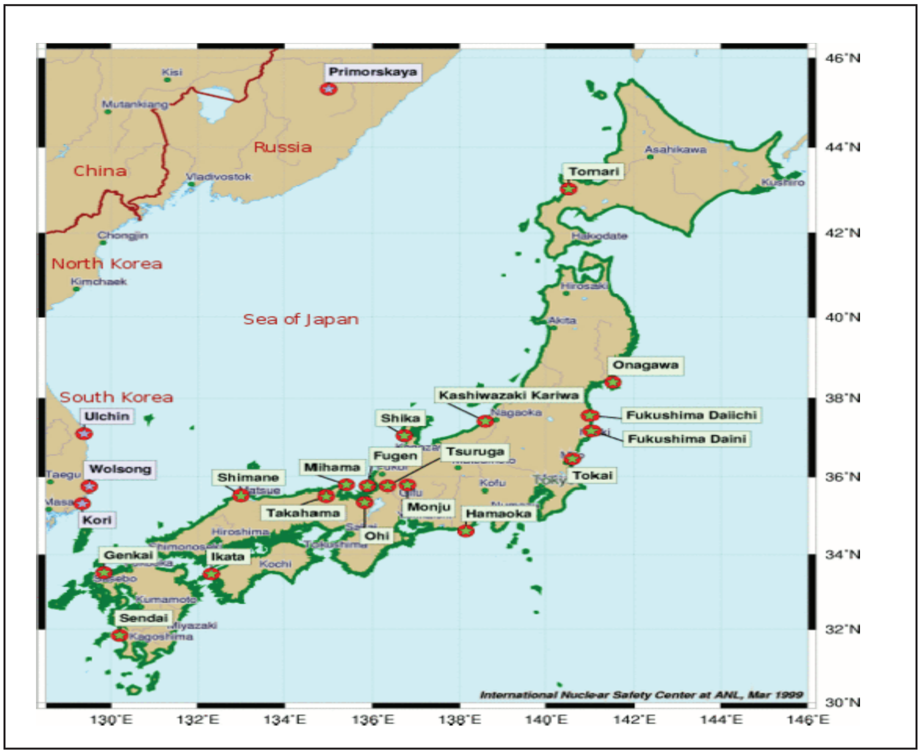


Figure 7.1: Location of Fukushima Daiichi

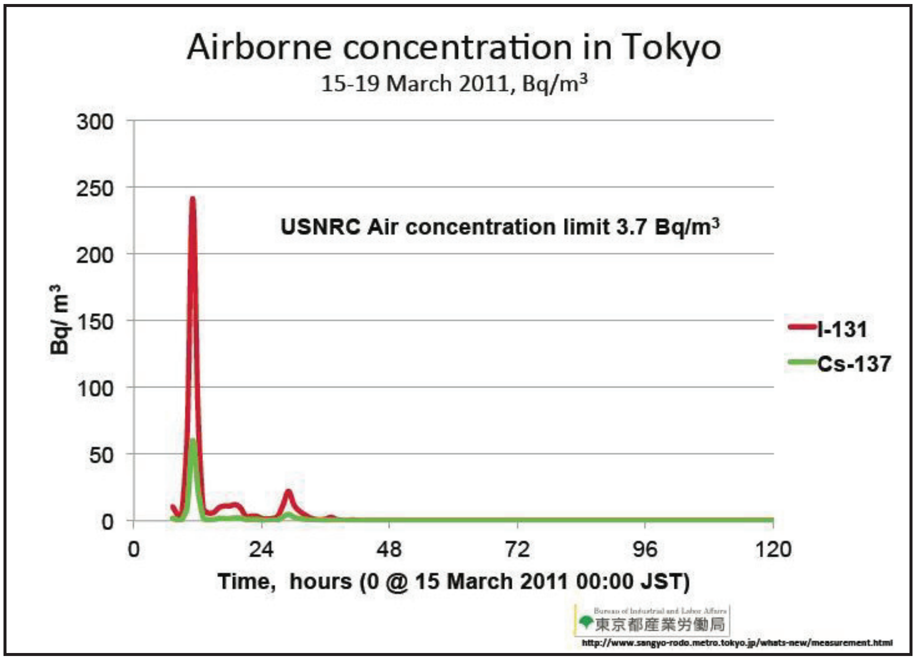
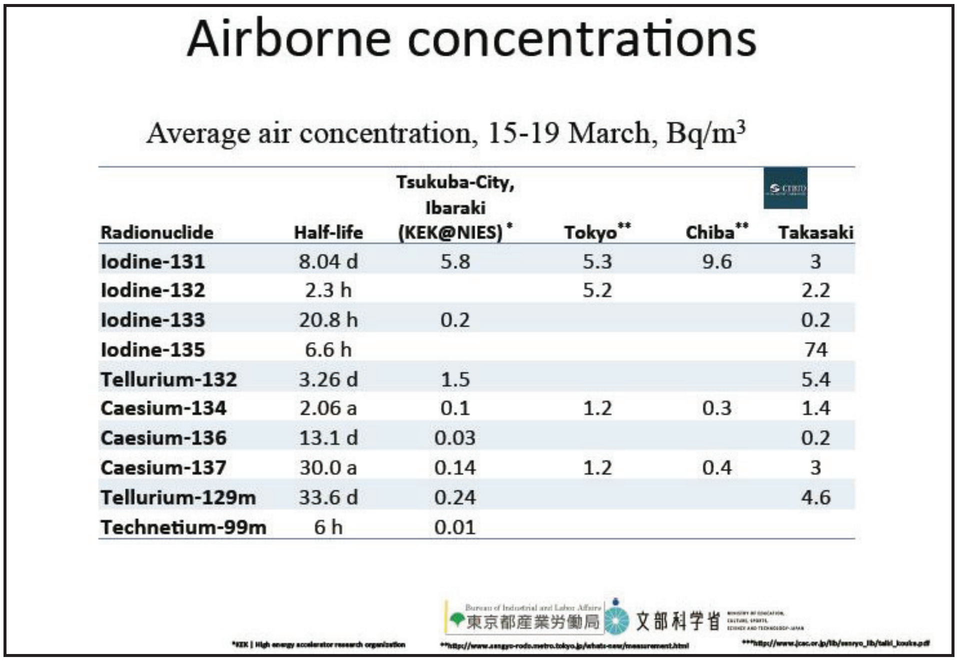


Figure 7.2: Concentration of Airborne Cesium and Iodine in Bq/m$^3$ Measured Between March 15-19, 2011



Airborne concentrations

Average air concentration, 15-19 March, Bq/m$^3$

| Radionuclide | Half-life | Tsukuba-City, Ibaraki (KEK@NIES)* | Tokyo** | Chiba** | Takasaki |
|---|---|---|---|---|---|
| **Iodine-131** | 8.04 d | 5.8 | 5.3 | 9.6 | 3 |
| **Iodine-132** | 2.3 h | | 5.2 | | 2.2 |
| **Iodine-133** | 20.8 h | 0.2 | | | 0.2 |
| **Iodine-135** | 6.6 h | | | | 74 |
| **Tellurium-132** | 3.26 d | 1.5 | | | 5.4 |
| **Caesium-134** | 2.06 a | 0.1 | 1.2 | 0.3 | 1.4 |
| **Caesium-136** | 13.1 d | 0.03 | | | 0.2 |
| **Caesium-137** | 30.0 a | 0.14 | 1.2 | 0.4 | 3 |
| **Tellurium-129m** | 33.6 d | 0.24 | | | 4.6 |
| **Technetium-99m** | 6 h | 0.01 | | | |

*KEK | High energy accelerator research organization

**http://www.sangyo-rodo.metro.tokyo.jp/whats-new/measurement.html

***http://www.jcac.or.jp/lib/senryo_lib/taiki_kouka.pdf

**Figure 7.3: Average Air Concentration Measured Between March 15-19, 2011 for Some Cities Near Fukushima, Japan**

**Table 7-2: Concentration of Airborne Fission Products Measured Near WIPP Site (Air Samples Employing a Glass Fiber Filter)**

| Station | Sampling Period | I-131 | Te-132 | Cs-134 | Cs-137 |
|---|---|---|---|---|---|
| Cactus Flats | 03/14-04/01/2011 | 2.23E-03 | 1.98E-04 | 2.76E-04 | 2.99E-04 |
| | 04/01-04/13/2011 | 2.29E-04 | ND | 6.54E-06 | 1.07E-05 |
| | 04/13-04/20/2011 | 2.04E-04 | ND | 1.29E-05 | 2.03E-05 |
| | 04/20-05/02/2011 | 2.39E-05 | ND | ND | ND |
| | 05/02-05/13/2011 | ND | ND | ND | ND |
| | 05/13-05/27/2011 | ND | ND | ND | ND |
| | | | | | |
| Near Field | 03/14-04/01/2011 | 3.85E-03 | 2.37E-04 | 3.79E-04 | 4.55E-04 |
| | 04/01-04/13/2011 | 2.24E-04 | ND | 7.00E-06 | 8.59E-06 |
| | 04/13-04/20/2011 | 1.96E-04 | ND | 1.80E-05 | 2.05E-05 |
| | 04/20-05/02/2011 | 2.74E-05 | ND | ND | ND |
| | 05/02-05/13/2011 | ND | ND | ND | ND |
| | 05/13-05/27/2011 | ND | ND | ND | ND |
| | | | | | |
| Onsite | 03/14-04/01/2011 | 2.31E-03 | 1.59E-04 | 2.87E-04 | 3.22E-04 |
| | 04/01-04/13/2011 | 1.97E-04 | ND | 5.24E-06 | 9.87E-06 |
| | 04/13-04/20/2011 | 1.70E-04 | ND | 1.26E-05 | 1.62E-05 |
| | 04/20-05/02/2011 | - | - | - | - |
| | 05/02-05/13/2011 | ND | ND | ND | ND |
| | 05/13-05/27/2011 | ND | ND | ND | ND |

ND= not detected

## Table 7-3: Concentration of Airborne Fission Products Measured in Several Communities Near WIPP Site (Air Samples Employing a Charcoal Filter)

| Station | Sampling Period | I-131 | Te-132 | Cs-134 | Cs-137 |
|---|---|---|---|---|---|
| Boulder City, NV | 3/17 - 3/21/2011 | 8.15E-03 | 7.04E-04 | 1.33E-03 | 1.74E-03 |
| Henderson, NV | 3/17 - 3/23/2011 | 8.52E-03 | 7.04E-04 | 1.33E-03 | 1.67E-03 |
| Las Vegas, NV | 3/17 - 3/23/2011 | 8.15E-03 | 8.15E-04 | 1.30E-03 | 1.63E-03 |
| Duckwater, NV | 3/16 - 3/27/2011 | 2.81E-03 | ND | 8.15E-04 | 1.04E-03 |
| Pahrump, NV | 3/16 - 3/27/2011 | 3.44E-03 | 7.04E-04 | 1.44E-03 | 1.44E-03 |
| Amargosa, NV | 3/16 - 3/28/2011 | 1.56E-03 | 4.44E-04 | 9.63E-04 | 1.22E-03 |
| Garden Valley, NV | 3/16 - 3/29/2011 | 2.41E-03 | 2.70E-04 | 1.00E-03 | 1.26E-03 |
| St. George, UT | 3/16 - 3/29/2011 | 3.30E-03 | 2.56E-04 | 8.52E-04 | 1.04E-03 |
| Overton, NV | 3/14 - 3/27/2011 | ND | ND | 9.63E-04 | 1.00E-03 |
| Mesquite, NV | 3/14 - 3/28/2011 | ND | ND | 1.00E-03 | 7.78E-04 |
| Cedar City, UT | 3/14 - 3/28/2011 | ND | ND | 8.89E-04 | 5.93E-04 |
| Milford, UT | 3/14 - 3/28/2011 | ND | ND | 8.15E-04 | 7.41E-04 |
| Delta, UT | 3/14-3/28/2011 | ND | ND | 8.15E-04 | 7.04E-04 |
| Pioche, NV | 3/14 - 3/28/2011 | ND | ND | 9.63E-04 | 8.89E-04 |
| Caliente, NV | 3/14 - 3/28/2011 | ND | ND | 1.11E-03 | 7.04E-04 |
| Alamo, NV | 3/14 - 3/28/2011 | ND | ND | 7.78E-04 | 8.52E-04 |
| Twin Springs, NV | 3/15 - 3/29/2011 | ND | ND | 6.67E-04 | 9.26E-04 |
| Nyala, NV | 3/15 - 3/30/2011 | ND | ND | 6.67E-04 | 7.41E-04 |
| Stone Cabin, NV | 3/16 - 3/30/2011 | ND | ND | 9.26E-04 | 1.11E-03 |
| Ely, NV | 3/18 - 3/28/2011 | ND | ND | 5.93E-04 | 8.52E-04 |
| Rachel, NV | 3/14 - 3/27/2011 | ND | ND | 1.30E-03 | 1.15E-03 |
| Tonopah, NV | 3/14 - 3/28/2011 | ND | ND | 1.30E-03 | 1.22E-03 |
| Goldfield, NV | 3/14 - 3/28/2011 | ND | ND | 8.89E-04 | 9.63E-04 |
| Sarcobatus, NV | 3/13 - 3/27/2011 | ND | ND | 1.07E-03 | 8.89E-04 |
| Beatty, NV | 3/14 - 3/27/2011 | ND | ND | 7.41E-04 | 7.04E-04 |
| Indian Springs, NV | 3/14 - 3/28/2011 | ND | ND | 1.11E-03 | 1.37E-03 |
| Tecopa, CA | 3/13 - 3/28/2011 | ND | ND | 1.15E-03 | 1.30E-03 |

Courtesy: Community Environmental Monitoring Program (CEMP);
http//cemp.dri.edu

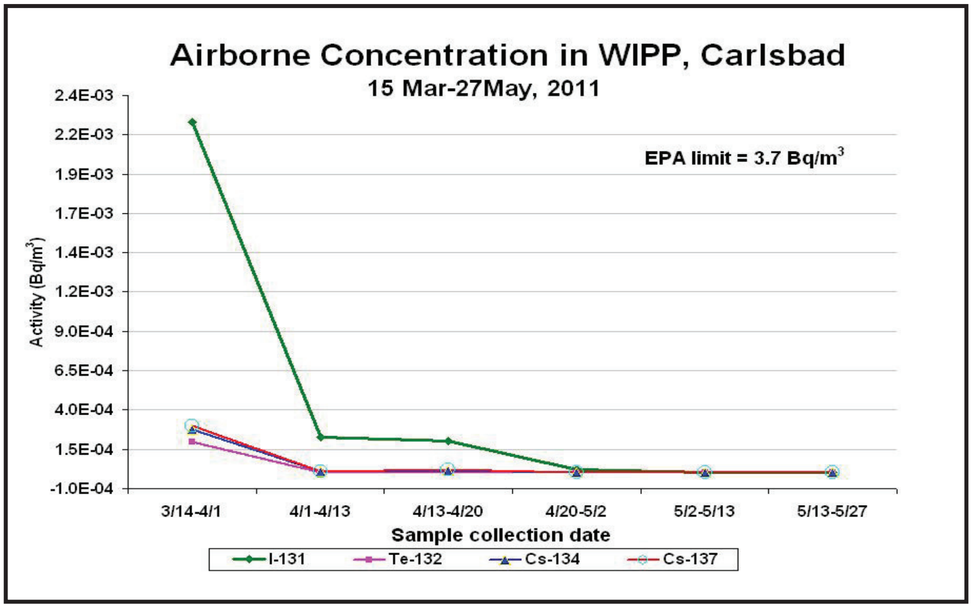
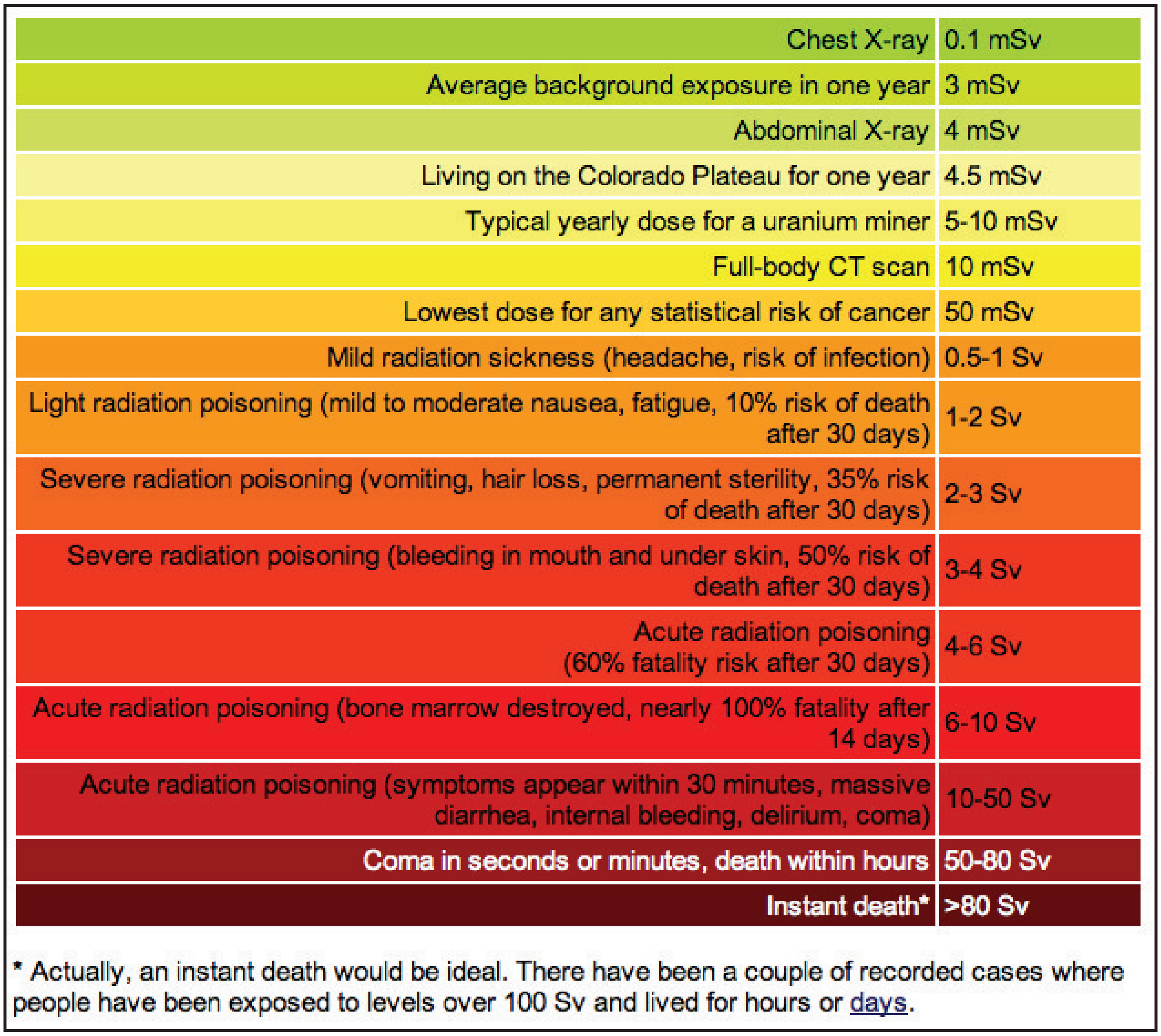


Figure 7.4: Concentration of Airborne Cesium and Iodine in Bq/m$^3$ Measured Between March 15, 2011 – May 27, 2011



| | |
|---|---|
| Chest X-ray | 0.1 mSv |
| Average background exposure in one year | 3 mSv |
| Abdominal X-ray | 4 mSv |
| Living on the Colorado Plateau for one year | 4.5 mSv |
| Typical yearly dose for a uranium miner | 5-10 mSv |
| Full-body CT scan | 10 mSv |
| Lowest dose for any statistical risk of cancer | 50 mSv |
| Mild radiation sickness (headache, risk of infection) | 0.5-1 Sv |
| Light radiation poisoning (mild to moderate nausea, fatigue, 10% risk of death after 30 days) | 1-2 Sv |
| Severe radiation poisoning (vomiting, hair loss, permanent sterility, 35% risk of death after 30 days) | 2-3 Sv |
| Severe radiation poisoning (bleeding in mouth and under skin, 50% risk of death after 30 days) | 3-4 Sv |
| Acute radiation poisoning (60% fatality risk after 30 days) | 4-6 Sv |
| Acute radiation poisoning (bone marrow destroyed, nearly 100% fatality after 14 days) | 6-10 Sv |
| Acute radiation poisoning (symptoms appear within 30 minutes, massive diarrhea, internal bleeding, delirium, coma) | 10-50 Sv |
| Coma in seconds or minutes, death within hours | 50-80 Sv |
| Instant death* | >80 Sv |

* Actually, an instant death would be ideal. There have been a couple of recorded cases where people have been exposed to levels over 100 Sv and lived for hours or days.

**Figure 7.5: Health Effects from Radiation are Shown in this Chart**
Courtesy: http//nextbigfuture.com/2011/03/radiation-chart.html

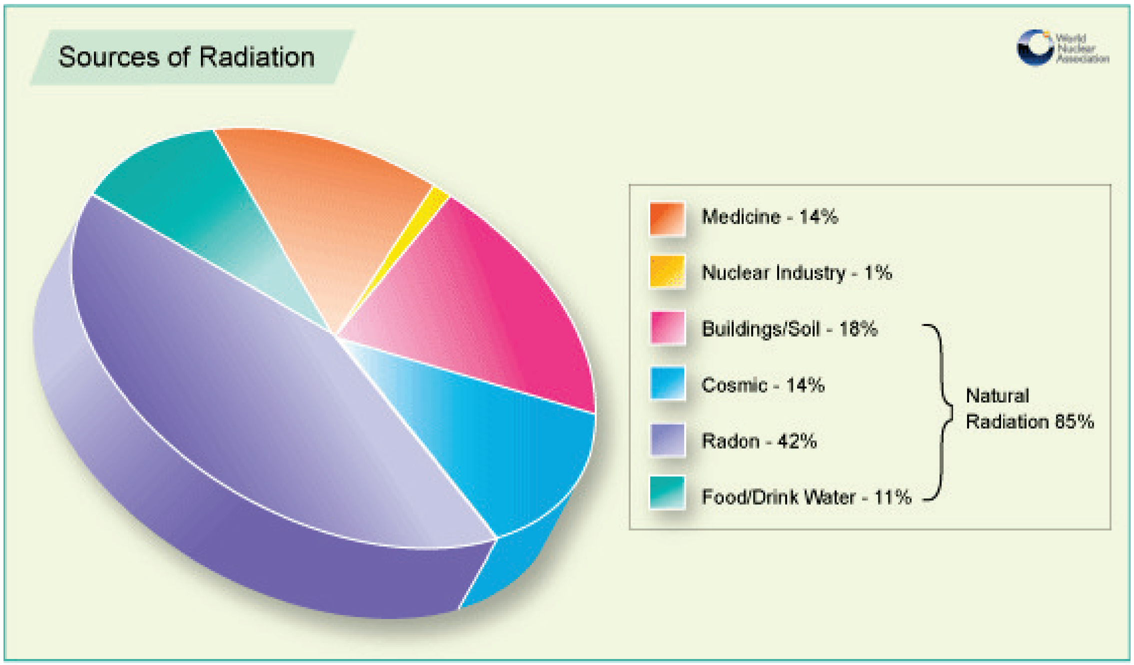


**Figure 7.6: Radiation Sources**
Courtesy: World Nuclear Association

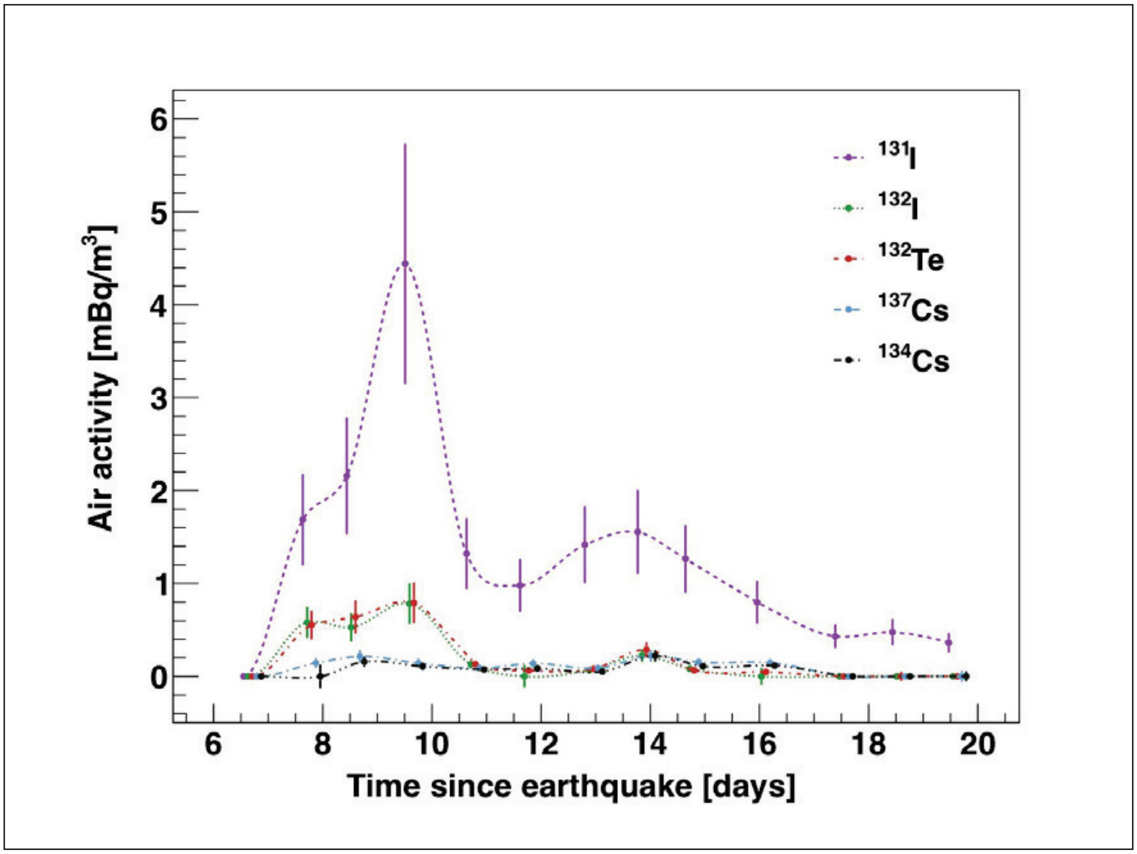


**Figure 7.7: Concentration of Airborne Cesium, Iodine, and Tellurium (mBq/m$^3$) Detected in Seattle, Washington Between March-April 2011**

# CHAPTER 8

# CEMRC RESEARCH PROGRAM

## INTRODUCTION

While the primary mission for CEMRC is environmental monitoring in the vicinity of the WIPP site, a concerted effort is underway to develop a research effort which supports the WIPP and utilizes the unique capabilities of CEMRC. The current research effort at CEMRC is a multi-year program funded by the Department of Energy's Carlsbad Field Office (DOE/CBFO). This effort entitled, Low Background Radiation Experiment (LBRE), is supervised by Dr. Geoffrey Smith, a professor of biology at New Mexico State University. Also, programs have been initiated by the lead scientists in radiochemistry (Dr. Punam Thakur), organic chemistry/environmental chemistry (Dr. Anuj Kumar), and internal dosimetry (Dr. Ila Pillalamarri). Brief descriptions for each proposed effort will be presented in the remainder of this chapter.

## LOW BACKGROUND RADIATION EXPERIMENT (Dr. G. Smith)

Three cell types were incubated underground at the U.S. WIPP, two bacteria (radiation resistant *Deinococcus radiodurans*, radiation sensitive *Shewanella oneidensis*), and the mammalian cell type, Chinese Hamster V79. The cells were incubated underground in the presence of a KCl radiation source (ca. 10 uR/hr) and in the absence of the KCl source (ca. 0.2 uR/hr). Cell growth and expression of stress genes were measured as a result of this plus/minus radiation treatment. Goals for the summer of 2011 work included: a) reducing the experimental noise in the data, b) testing mammalian cells underground and c) initiating a stress gene expression assay based on real-time PCR for the heat-shock proteins. This initial report is based on the bacterial and mammalian cell growth response, and, though we have successfully amplified RNA from underground treatments, gene expression results will be forthcoming.

One of the issues for the LBRE experiments is that the biological response to background levels of radiation vs. below background levels is likely to be a fairly subtle response which will be challenging to detect in the presence of experimental variation. Figure 8.1 demonstrates the effect of reducing experimental noise and allowing us to document a biological response to the radiation treatments. Five replicated experiments with the bacteria were carried out in the summer of 2011, and in the three which had little or no experimental noise (as measured by +/- 1 standard deviation from the mean), the *D. radiodurans* growth rate was higher in the plus-radiation treatment (e.g, Figure 8.1B). In the two other experiments where experimental noise was high, there was no difference in *D. radiodurans* growth rate (e.g, Figure 8.1A). A similar trend was observed with the radiation-sensitive *S. oneidensis*: the two experiments with reduced experimental noise showed higher growth rate in the plus radiation treatment (e.g, Figure 8.1D), and the three experiments which had elevated noise showed no difference (e.g, Figure 8.1C).

As part of the growth incubations described above, we incubated cells for 24 hours under one radiation treatment, and then transferred them into the opposite treatment in an effort to force responses from the cells. If the bacteria grow better in the presence of radiation, they will be inhibited when they are transferred from plus rad into minus rad (Plus→Minus), and they will be stimulated when they are transferred from minus rad into plus (Minus→Plus). This hypothesis is supported by the data shown in Figure 8.2. Though the experiment to experiment variation is high, each of the above-mentioned predictions was observed with both species of bacteria.

With considerable effort, we have modified standard cell culture techniques to, for the first time at WIPP, successfully grow and maintain mammalian cells underground at WIPP. The V-79 cell line of Chinese hamster cells was used based on the recommendation by Dr. Ludwig Feinendagen. The V79 cells were stored in liquid nitrogen at NMSU, transported on dry ice to WIPP, and revived in the aboveground lab at WIPP. Once the cell line was growing steadily, the cells were transported underground, where they were inoculated into two plates, one incubated in the background radiation treatment (10 uR/hr with KCl as source) and the other plates was incubated in the absence of external rad sources (ca. 0.2 uR/hr). Cells were grown without shaking at 37 deg. C, at 5% CO2 (CO2 levels were calibrated using a Fyrite instrument).

Cell growth was measured by increasing optical density of the cells attached to the multi-well dishes, and this has served well as an indicator for growth (data not shown – we are in the process of purchasing an instrumental cell counter). Within the first six days of growth, the cells in the absence of radiation grew more slowly than cells grown in the presence of radiation (Figure 8.3). Interestingly, after this initial lag, the minus-rad cells then exhibited very similar growth rates compared to the 40K-supplemented cells. This is a similar effect to that observed with the two bacterial species – that is, there was an initial inhibition of cell growth in the low rad treatment, but over time, the cells apparently acclimated to the diminished levels, and recovered to the growth rate of the background radiation control.

Synopsis. Consistent with previous results (Smith et al. 2011 Health Physics), we continue to document a small but potentially significant inhibition when cells are grown in the absence of background levels of radiation. Analysis of the expression of stress genes such as the heat shock proteins is on-going, and with appropriate method calibration, will hopefully confirm, and help us understand the physiological basis for, these results. In the upcoming year, these experiments will be replicated using the V79 mammalian cell line, and additional mammalian cell lines will be tested. Other stress-indicating genes need to be screened and applied to the molecular analyses. Lastly, we would like to test other natural sources of radiation to discover if radiation sources with other energy spectra give the same or enhanced effects.

## COMPLEXATION THERMODYNAMICS OF PLUTONIUM AND NEPTUNIUM WITH CARBONATE AS A FUNCTION OF TEMPERATURE AND IONIC STRENGTH (Dr. P. Thakur)

A three-year project is proposed that will investigate the complexation thermodynamics of plutonium and neptunium with carbonate (including hydrolysis) at elevated temperatures and ionic strengths. An integrated approach of high temperatures and ionic strengths is taken to

obtain fundamental understanding of actinide complexation in solution that is of importance in predicting the behavior of actinides in environmental transport.
Research is focused on two major thrusts:

1. Thermodynamic parameters of plutonium and neptunium complexes with carbonate (including hydrolysis) as a function of temperature that could have impact on the behavior of these actinides in disposing of spent nuclear fuel and assessing performance of the waste forms in the associated area and disposal environments.

2. Determine/qualify the key plutonium and neptunium species that could occur in a repository, in the presence of carbonate and as a function of temperature (up to 100°C) and ionic strength.

A pre-proposal has been submitted to the U.S. DOE Nuclear Energy University Program.

## ENVIRONMENTAL CHEMISTRY (Dr. A. Kumar)

The Organic and Environmental Chemistry groups, under the supervision of Dr. A. Kumar, propose research plans in analytical method development and impact of air emissions on the environment. Each research plan is described briefly as follows:

1. Effect of moisture and long-term stability study of VOCs in passivated canisters. Canisters were found to be a suitable approach for sampling and storage of several of the VOCs. However, for many compounds, canister stability data are extremely insufficient or widely differing. Therefore, stability testing of VOCs will provide the precise and accurate information on canister method.

2. An investigation study on VOC characterization and ozone formation potential (OFP) from agricultural sources/compost facility emissions will provide an understanding of these sources on environmental system. The study will focus on the emissions from feeding operations/waste of livestock, odors, and health risk assessment.

3. Development of portable monitoring systems for measurement of particulate matter and pollutants. Increased potash mining and radioactive waste disposal activities around Carlsbad lead to increased generation of particulate matter and pollutants, portable monitoring systems geared to these activities will be helpful in notifying workers and the general population of any hazardous contaminants in the air.

Proposed funding agencies for these efforts include the U.S. DOE, National Science Foundation (NSF), several state agencies, and private industry.

## INTERNAL DOSIMETRY (Dr. P. Ila)

The Internal Dosimetry group, under the supervision of Dr. P. Ila, will initiate efforts in three distinct areas, integrating interdisciplinary research, education, and training.

1. **Medical Geology/Geochemistry:** This effort is interdisciplinary and includes internal radiation dosimetry, epidemiology, allied health sciences, and nuclear analytics. Medical Geology/Geochemistry is the study of the interaction between abundances of elements and isotopes and the health of humans and plants.

2. **Precision measurement of heat producing elements** with low background gamma, deep underground. Development of high sensitive, accurate, precise new methodology and instrumentation for heat producing elemental analysis of K and trace and ultra-trace level U and Th in geologic materials.

3. **Development and presentation** of special research topics in radiation dosimetry as courses for informal science education (ISE), NSF Program, and public outreach.

Possible funding agencies for these efforts include the NSF and the U.S. DOE.

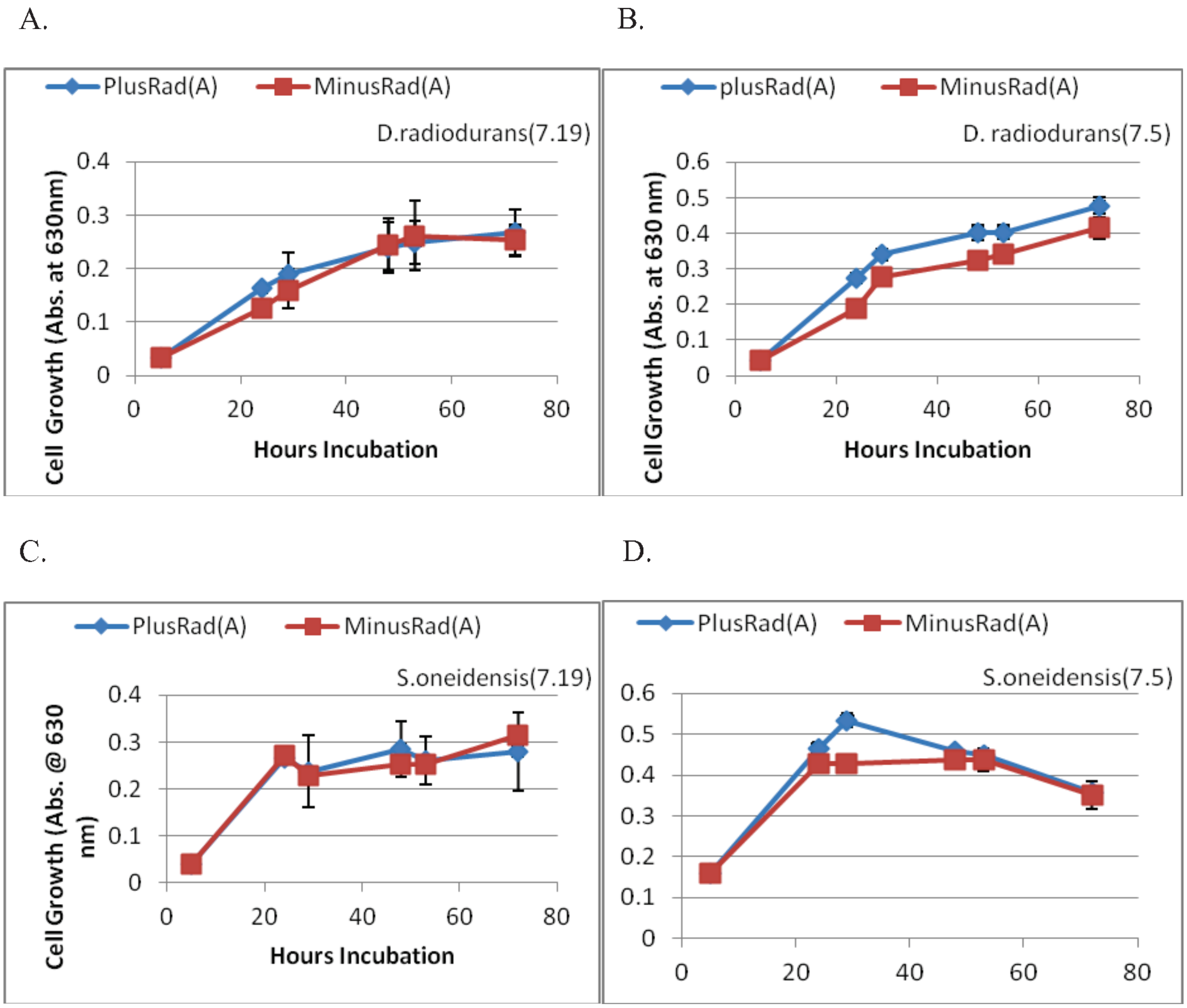


**Figure 8.1: Representative Bacterial Incubations**

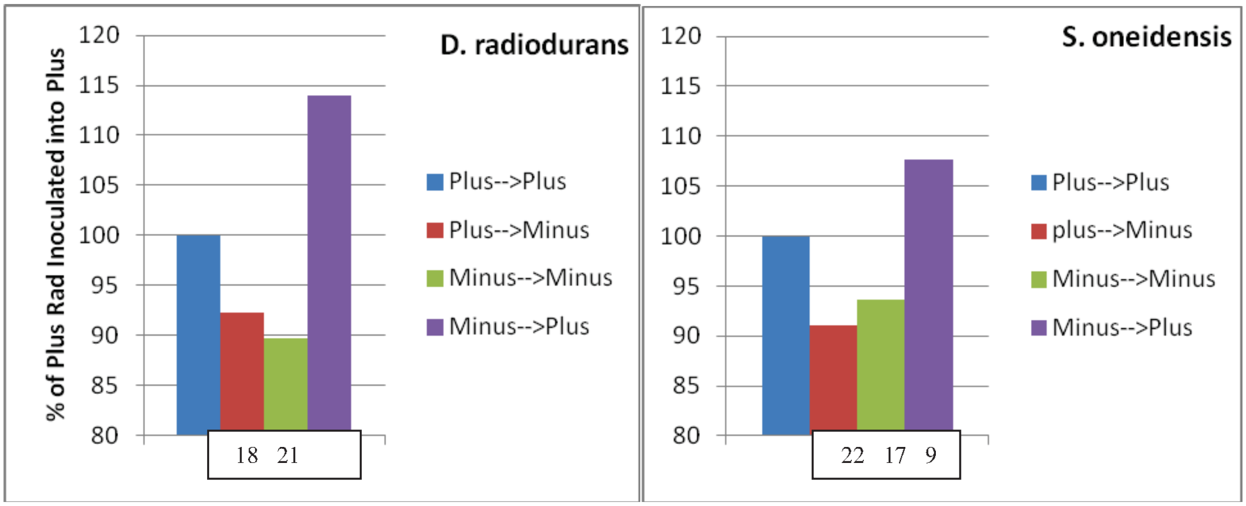


Figure 8.2: Bacteria Grown for 24 Hours in the Presence of Radiation

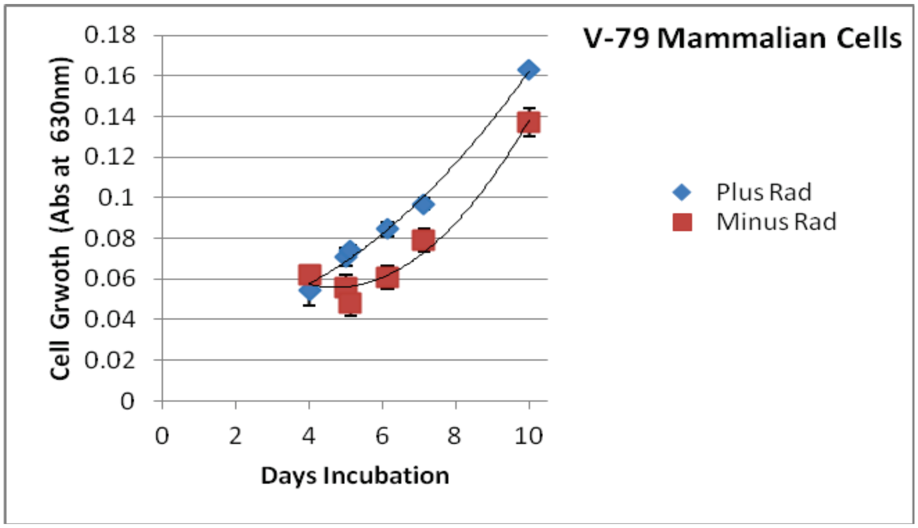


Figure 8.3: Mammalian Cell Growth

# 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. James Conca served as Director of the CEMRC until August 2010. In September 2010, Dr. George Mulholland became interim director of CEMRC and still holds the Director position as of December 2010.

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 |
|---|---|---|
| **P. Thakur**, G .P. Mulholland | Determination of Pu, Am, U and Cs in large soil samples in the vicinity of the USDOE Waste Isolation Pilot Plant | Journal of Radioanalytical & Nuclear Chemistry, vol. 288, p. 499-506, 2011. |
| **P. Thakur**, G .P. Mulholland | Monitoring of Gross Alpha, Gross Beta and Actinides Activities in Exhaust Air released from the Waste Isolation Pilot Plant. | Applied Radiation &Isotopes, Vol. 69, p.1307-1312, 2011 |
| **P. Thakur**, Y. Xiong, M. Borkowski, G. R. Choppin | Thermodynamic Modeling of Trivalent Am, Cm and Eu-Citrate Complexation in Concentrated $NaClO_4$ Media | Radiochim Acta (In press) |
| **P. Thakur**, S. Ballard, J. L. Conca | Sequential isotopic determination of plutonium, thorium, americium and uranium in the air filter and drinking water samples around the WIPP site. | Journal of Radioanalytical & Nuclear Chemistry, vol. 287, p. 311-321, 2011 |
| J. E. Stout, **R. Arimoto** | Threshold wind velocities for sand movement in the Mescalero Sands of southeastern New Mexico | Journal of Arid Environments, Vol 74, p. 1456-1460, 2010 |

# APPENDIX C: TOURS, PUBLIC PRESENTATIONS AND OTHER OUTREACH

| Group/Activity |
|---|
| CEMRC worked with local Carlsbad high school science teachers and students in 2010 to obtain science teaching grants |
| CEMRC participated in the annual Relay For Life |
| CEMRC participated in the annual Riverblitz |
| 2010 host of the monthly American Nuclear Society section meetings |
| **P. Thakur, J. L. Conca and G. R. Choppin**, Mixed-Ligand complexes of $Am^{3+}$, $Cm^{3+}$ and $Eu^{3+}$ with HEDTA and HEDTA+NTA- complexation thermodynamics and structural aspects, ACS National Meeting, Boston, Aug. 22-26, 2010 |
| **P. Thakur, T. B. Kirchner and J. L. Conca** , Plutonium in the WIPP Environment: Its Detection, Distribution and Behavior, Plutonium Future, Keystone, Colorado, Sept. 19-23, 2010 |
| **P. Thakur, J. L. Conca and G. R. Choppin**, EDTA and mixed-ligands complexes of trivalent Am, Cm, and Eu at high ionic Strength, International Workshop on Actinide and Brine Chemistry in a Salt –Based Repository, Carlsbad, Sept. 15-17, 2010 |
| **P. Thakur, J. L. Conca and G. R. Choppin**, Spectral Studies of Actinides Speciation in the Environment, PacificChem, Honolulu, Dec. 15-20, 2010 |
| **J. L. Conca** – Radiobioassay and Radiochemical Measurements Conference (RRMC), Nov. 3, 2010 |
| **J. L. Conca** – Gave presentation at NMSU STEM meeting, Las Cruces, NM, Mar. 5-6, 2010 |
| **J. L. Conca** – Gave presentation at NMSU Re-energizing America Conference, June 3-4, 2010 |
| **J. L. Conca** – Gave presentation at Low Background Radiation Effects Conference, May 1, 2010 |
| **J. L. Conca** – International Energy Agency Meeting at Colorado School of Mines, May 16-18, 2010 |
| **J. L. Conca** – Clean Energy Forum at UNLV in Las Vegas, NV, Sept. 7-9, 2010 |
| **J. L. Conca** – Gave briefing to Samsung South Korean delegation on global energy needs and the South Korean Nuclear Program, Sept. 9-10, 2010 |
| **J. L. Conca** – Gave presentation on energy plan to the NM Energy, Minerals, and Natural Resources Department, Sept. 30, 2010 – Oct. 8, 2010 |
| **J. L. Conca** – Gave presentations at the National Press Club and at the UC Washington Center, Nov. 2-4, 2010 |
| **J. L. Conca** – Gave presentation at the National Nuclear Infrastructure Council and at the Center for Climate and Energy Decision Making at Carnegie Mellon, Nov. 7-9, 2010 |
| **J. L. Conca** – Gave presentation at the Energy Councils 2010 Global Energy and Environmental Issues Conference, Dec. 9-10, 2010 |

# APPENDIX D: STUDENTS/VISITING SCIENTISTS SUPPORTED AT CEMRC 2010

| Student/Scientist | Support Period |
|---|---|
| Students (2) – Illinois Institute of Tech | Summer 2010 Radiation Physics 770 at ITT |
| Dr. Jeff Terry - Illinois Institute of Tech | Summer 2010 training |
| Dr. Geof Smith - NMSU Las Cruces | Visiting Professor 2010 |
| Christopher Kelly – NMSU Las Cruces | Undergraduate student |
| Donald Schoderbek - NMSU Las Cruces | Undergraduate student |
| Dan Olive - Illinois Institute of Tech | Post-doctoral Research Associate 2010 |

# 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 Environmental Chemistry Inorganic analysis (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. 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 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 as <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. Overall, the difference from the NIST values observed for the test nuclides are $\leq$ 10%.

## CEMRC Management Assessment Quality Assurance Report

### January 1, 2010 – December 31, 2010

This report serves as a periodic review of the Quality Assurance Program at the Carlsbad Environmental Monitoring & 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 for January 1, 2010 through December 31, 2010.

Currently, there are 69 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 2010, Washington TRU Solutions (WTS) audited the Volatile Organic Compound Monitoring Program (Organic Chemistry) and the In-Vivo Radiobioassay Program (Internal Dosimetry). The audits led to recertification of each program with three noteworthy practices, no findings, no conditions, and four observations. 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 four CEMRC programmatic areas in 2010. A summary of the internal audit findings is presented in Table 1, none of which significantly impacted CEMRC activities.[1] The surveillances will be used as a guideline to address areas that need improvement. Since aspects of the surveillances will be ongoing and checked periodically in the upcoming year, a summary of the surveillances has not been included in Table F-1.

Seventeen 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 110210FP66), which is to be closed when programming flaws on the new air samplers have been corrected by the manufacturer. 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.

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

**Table F-1: Internal Audit Summaries 2010 (# of Findings)**

| Aspect/Programmatic Area | AD | DC | EC | FP | ID | IM | OC | QA | RC |
|---|---|---|---|---|---|---|---|---|---|
| Personnel Qualification & Training | NF | 1 | NA | NF | NF | NA | NA | NA | NA |
| Quality Improvement | NF | NF | NA | NF | NF | NA | NA | NA | NA |
| Document Control | NF | 1 | NA | NF | NF | NA | NA | NA | NA |
| QA Records | NF | NF | NA | 1 | NF | NA | NA | NA | NA |
| Procurement | 1 | NF | NA | NF | NF | NA | NA | NA | NA |
| Work Processes | NF | NF | NA | 1 | 2 | NA | NA | NA | NA |
| Audits/Assessments | NF | NF | NA | NF | NF | NA | NA | NA | NA |
| Sample Control | NF | NF | NA | NF | NF | NA | NA | NA | NA |
| Scientific Investigations | NF | NF | NA | NF | NF | NA | NA | NA | NA |
| Scientific Notebooks | NF | NF | NA | NF | NF | NA | NA | NA | NA |
| Procedure Violation | NF | NF | NA | 3 | 2 | NA | NA | NA | NA |

### 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 2010 by the ORNL Intercomparison Studies In-vivo Program

### Oak Ridge National Laboratory

### Intercomparison Studies In-vivo Program Report
### 1st Quarter Calendar Year 2010

### Carlsbad Environmental Monitoring & Research Center
Set G

| ISOTOPE | SPIKE ACTIVITY As of 02/25/10 +/- 2 sigma (nCi) | REPORTED ACTIVITY As of 02/25/10 +/- 2 sigma (nCi) | % RELATIVE BIAS |
|---|---|---|---|
| Cs-137 | 200.3 +/- 10.0 | 203.25 +/- 10.16 | 1.5 |
| Co-60 | 280.4 +/- 14.0 | 283.19 +/- 14.16 | 1.0 |
| Co-57 | 90.89 +/- 4.54 | 91.74 +/- 4.59 | 0.9 |
| Y-88 | 114.9 +/- 5.7 | 114.24 +/- 5.71 | -0.6 |
| Ba-133 | 130.9 +/- 6.5 | 133.21 +/- 6.66 | 1.8 |

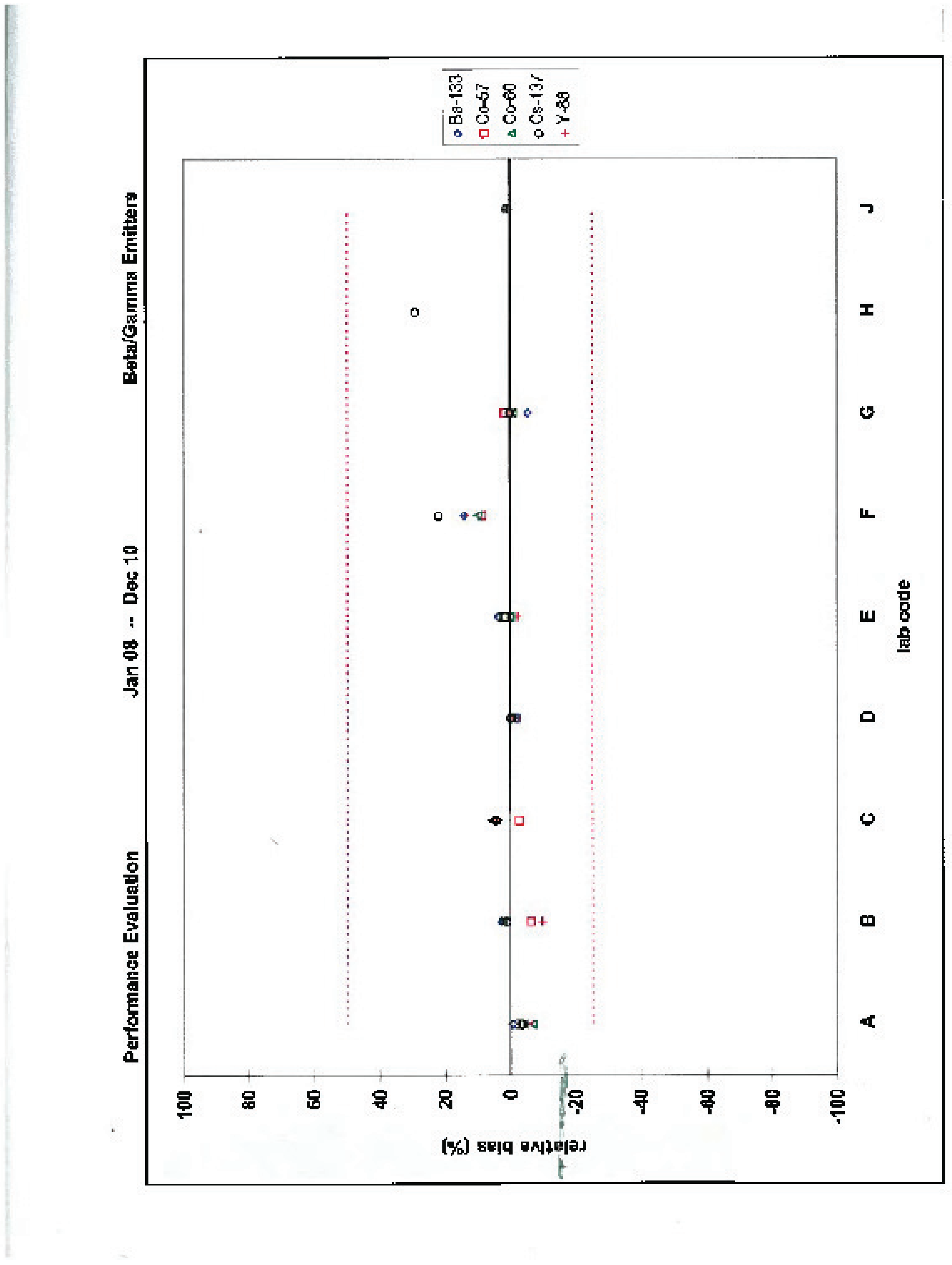
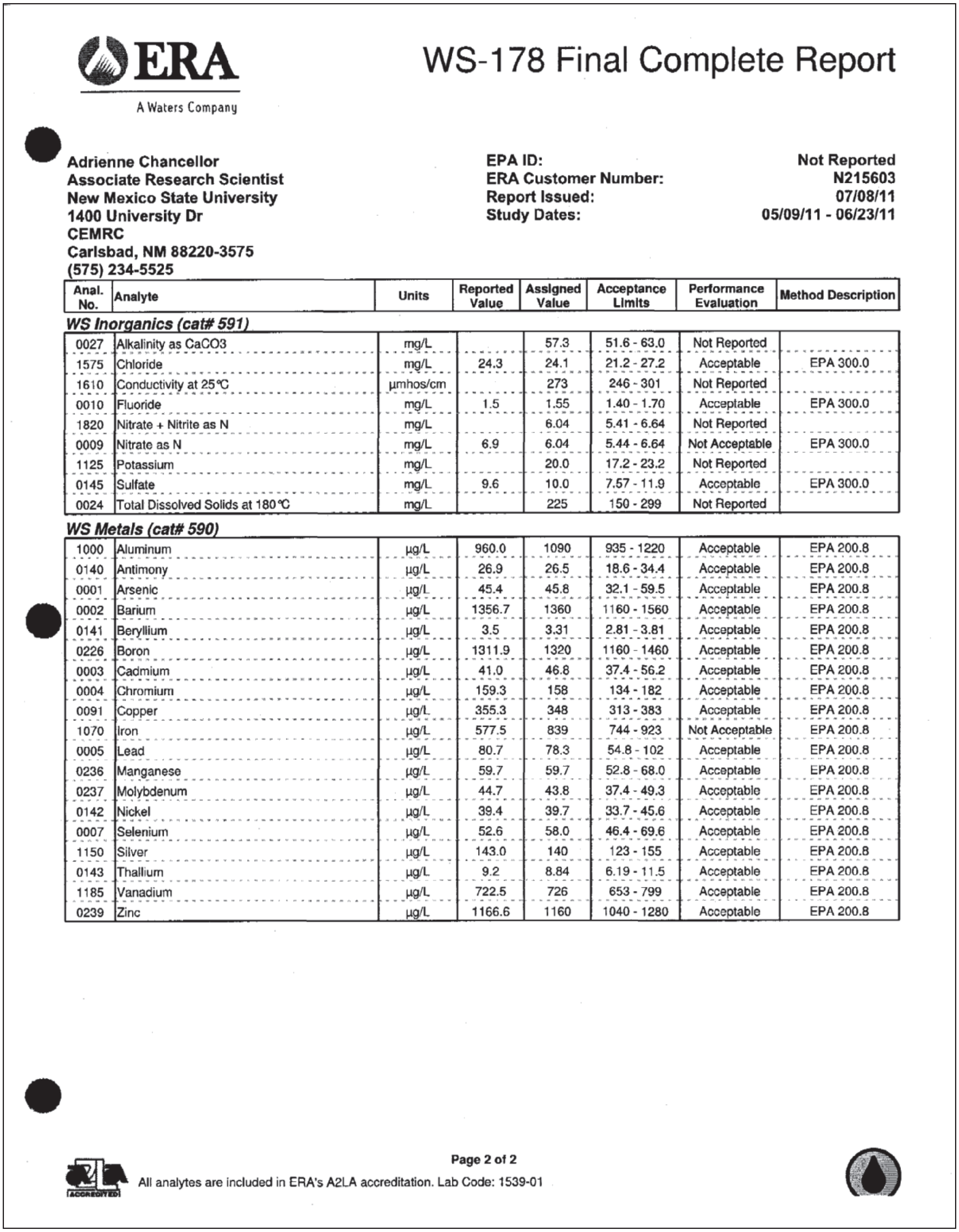


**Figure F.1: Comparison of Results for Ten Internal Dosimetry Laboratories in the U.S. During 2010 by the ORNL Intercomparison Studies In-vivo Program**

CEMRC is Lab J. 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 2010 Audits

| Agency | Date | Conclusion | Reason |
|---|---|---|---|
| Oak Ridge National Lab, Intercomparison Studies Program | Quarterly | Pass | External QC |
| WTS | 05/17/10 – 05/19/10 | No findings<br>4 observations<br>3 noteworthy practices<br>Pass | Annual |
| CEMRC Self Assessment | 05/13-14/10<br>05/25/10 | 2 findings<br>Pass | Quality System |



**ERA**
A Waters Company

## WS-178 Final Complete Report

**Adrienne Chancellor**
**Associate Research Scientist**
**New Mexico State University**
**1400 University Dr**
**CEMRC**
**Carlsbad, NM 88220-3575**
**(575) 234-5525**

| | |
|---|---|
| **EPA ID:** | **Not Reported** |
| **ERA Customer Number:** | **N215603** |
| **Report Issued:** | **07/08/11** |
| **Study Dates:** | **05/09/11 - 06/23/11** |

| Anal. No. | Analyte | Units | Reported Value | Assigned Value | Acceptance Limits | Performance Evaluation | Method Description |
|---|---|---|---|---|---|---|---|
| ***WS Inorganics (cat# 591)*** | | | | | | | |
| 0027 | Alkalinity as CaCO3 | mg/L | | 57.3 | 51.6 - 63.0 | Not Reported | |
| 1575 | Chloride | mg/L | 24.3 | 24.1 | 21.2 - 27.2 | Acceptable | EPA 300.0 |
| 1610 | Conductivity at 25°C | µmhos/cm | | 273 | 246 - 301 | Not Reported | |
| 0010 | Fluoride | mg/L | 1.5 | 1.55 | 1.40 - 1.70 | Acceptable | EPA 300.0 |
| 1820 | Nitrate + Nitrite as N | mg/L | | 6.04 | 5.41 - 6.64 | Not Reported | |
| 0009 | Nitrate as N | mg/L | 6.9 | 6.04 | 5.44 - 6.64 | Not Acceptable | EPA 300.0 |
| 1125 | Potassium | mg/L | | 20.0 | 17.2 - 23.2 | Not Reported | |
| 0145 | Sulfate | mg/L | 9.6 | 10.0 | 7.57 - 11.9 | Acceptable | EPA 300.0 |
| 0024 | Total Dissolved Solids at 180°C | mg/L | | 225 | 150 - 299 | Not Reported | |
| ***WS Metals (cat# 590)*** | | | | | | | |
| 1000 | Aluminum | µg/L | 960.0 | 1090 | 935 - 1220 | Acceptable | EPA 200.8 |
| 0140 | Antimony | µg/L | 26.9 | 26.5 | 18.6 - 34.4 | Acceptable | EPA 200.8 |
| 0001 | Arsenic | µg/L | 45.4 | 45.8 | 32.1 - 59.5 | Acceptable | EPA 200.8 |
| 0002 | Barium | µg/L | 1356.7 | 1360 | 1160 - 1560 | Acceptable | EPA 200.8 |
| 0141 | Beryllium | µg/L | 3.5 | 3.31 | 2.81 - 3.81 | Acceptable | EPA 200.8 |
| 0226 | Boron | µg/L | 1311.9 | 1320 | 1160 - 1460 | Acceptable | EPA 200.8 |
| 0003 | Cadmium | µg/L | 41.0 | 46.8 | 37.4 - 56.2 | Acceptable | EPA 200.8 |
| 0004 | Chromium | µg/L | 159.3 | 158 | 134 - 182 | Acceptable | EPA 200.8 |
| 0091 | Copper | µg/L | 355.3 | 348 | 313 - 383 | Acceptable | EPA 200.8 |
| 1070 | Iron | µg/L | 577.5 | 839 | 744 - 923 | Not Acceptable | EPA 200.8 |
| 0005 | Lead | µg/L | 80.7 | 78.3 | 54.8 - 102 | Acceptable | EPA 200.8 |
| 0236 | Manganese | µg/L | 59.7 | 59.7 | 52.8 - 68.0 | Acceptable | EPA 200.8 |
| 0237 | Molybdenum | µg/L | 44.7 | 43.8 | 37.4 - 49.3 | Acceptable | EPA 200.8 |
| 0142 | Nickel | µg/L | 39.4 | 39.7 | 33.7 - 45.6 | Acceptable | EPA 200.8 |
| 0007 | Selenium | µg/L | 52.6 | 58.0 | 46.4 - 69.6 | Acceptable | EPA 200.8 |
| 1150 | Silver | µg/L | 143.0 | 140 | 123 - 155 | Acceptable | EPA 200.8 |
| 0143 | Thallium | µg/L | 9.2 | 8.84 | 6.19 - 11.5 | Acceptable | EPA 200.8 |
| 1185 | Vanadium | µg/L | 722.5 | 726 | 653 - 799 | Acceptable | EPA 200.8 |
| 0239 | Zinc | µg/L | 1166.6 | 1160 | 1040 - 1280 | Acceptable | EPA 200.8 |

**Page 2 of 2**

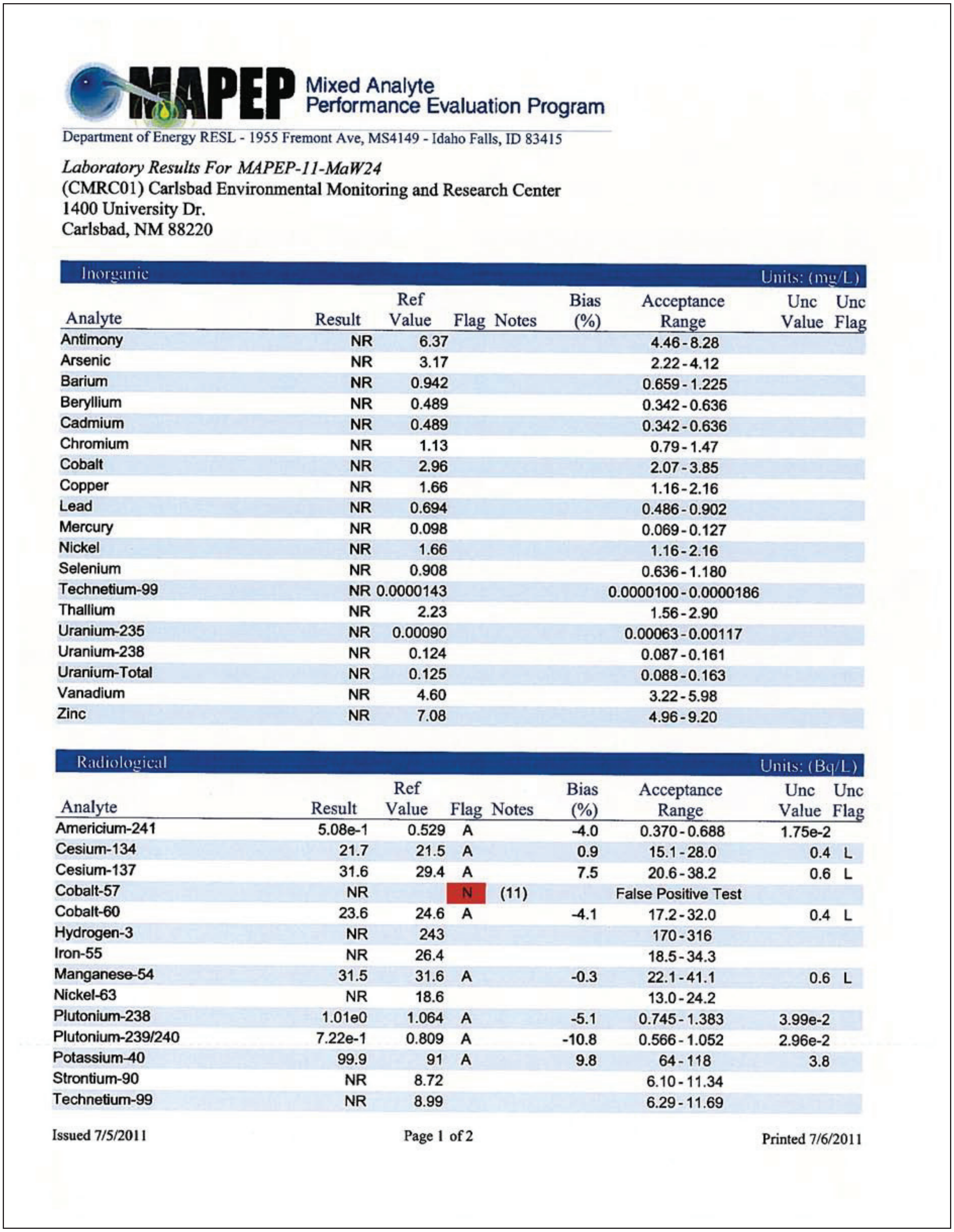
ACCREDITED

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

**Figure F.2: Blind Check 2010 Environmental Chemistry Inorganic Analyses**

## Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results

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



**MAPEP** Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

*Laboratory Results For MAPEP-11-MaW24*
(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Inorganic — Units: (mg/L)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Antimony | NR | 6.37 | | | | 4.46 - 8.28 | | |
| Arsenic | NR | 3.17 | | | | 2.22 - 4.12 | | |
| Barium | NR | 0.942 | | | | 0.659 - 1.225 | | |
| Beryllium | NR | 0.489 | | | | 0.342 - 0.636 | | |
| Cadmium | NR | 0.489 | | | | 0.342 - 0.636 | | |
| Chromium | NR | 1.13 | | | | 0.79 - 1.47 | | |
| Cobalt | NR | 2.96 | | | | 2.07 - 3.85 | | |
| Copper | NR | 1.66 | | | | 1.16 - 2.16 | | |
| Lead | NR | 0.694 | | | | 0.486 - 0.902 | | |
| Mercury | NR | 0.098 | | | | 0.069 - 0.127 | | |
| Nickel | NR | 1.66 | | | | 1.16 - 2.16 | | |
| Selenium | NR | 0.908 | | | | 0.636 - 1.180 | | |
| Technetium-99 | NR | 0.0000143 | | | | 0.0000100 - 0.0000186 | | |
| Thallium | NR | 2.23 | | | | 1.56 - 2.90 | | |
| Uranium-235 | NR | 0.00090 | | | | 0.00063 - 0.00117 | | |
| Uranium-238 | NR | 0.124 | | | | 0.087 - 0.161 | | |
| Uranium-Total | NR | 0.125 | | | | 0.088 - 0.163 | | |
| Vanadium | NR | 4.60 | | | | 3.22 - 5.98 | | |
| Zinc | NR | 7.08 | | | | 4.96 - 9.20 | | |

Radiological — Units: (Bq/L)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Americium-241 | 5.08e-1 | 0.529 | A | | -4.0 | 0.370 - 0.688 | 1.75e-2 | |
| Cesium-134 | 21.7 | 21.5 | A | | 0.9 | 15.1 - 28.0 | 0.4 | L |
| Cesium-137 | 31.6 | 29.4 | A | | 7.5 | 20.6 - 38.2 | 0.6 | L |
| Cobalt-57 | NR | | N | (11) | | False Positive Test | | |
| Cobalt-60 | 23.6 | 24.6 | A | | -4.1 | 17.2 - 32.0 | 0.4 | L |
| Hydrogen-3 | NR | 243 | | | | 170 - 316 | | |
| Iron-55 | NR | 26.4 | | | | 18.5 - 34.3 | | |
| Manganese-54 | 31.5 | 31.6 | A | | -0.3 | 22.1 - 41.1 | 0.6 | L |
| Nickel-63 | NR | 18.6 | | | | 13.0 - 24.2 | | |
| Plutonium-238 | 1.01e0 | 1.064 | A | | -5.1 | 0.745 - 1.383 | 3.99e-2 | |
| Plutonium-239/240 | 7.22e-1 | 0.809 | A | | -10.8 | 0.566 - 1.052 | 2.96e-2 | |
| Potassium-40 | 99.9 | 91 | A | | 9.8 | 64 - 118 | 3.8 | |
| Strontium-90 | NR | 8.72 | | | | 6.10 - 11.34 | | |
| Technetium-99 | NR | 8.99 | | | | 6.29 - 11.69 | | |

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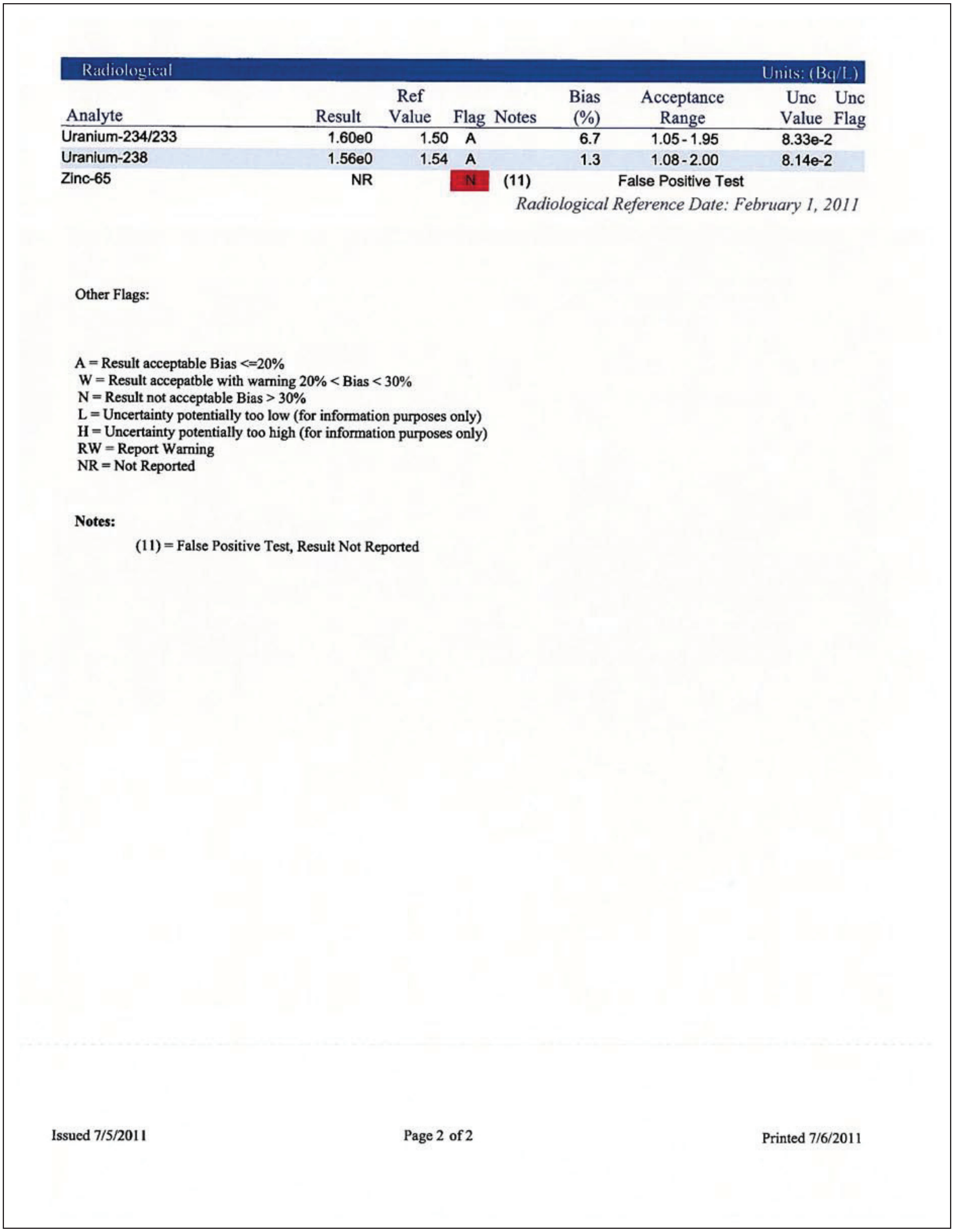
## Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results
(Continued)



**Radiological** Units: (Bq/L)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Uranium-234/233 | 1.60e0 | 1.50 | A | | 6.7 | 1.05 - 1.95 | 8.33e-2 | |
| Uranium-238 | 1.56e0 | 1.54 | A | | 1.3 | 1.08 - 2.00 | 8.14e-2 | |
| Zinc-65 | NR | | N | (11) | | False Positive Test | | |

*Radiological Reference Date: February 1, 2011*

Other Flags:

A = Result acceptable Bias <=20%
W = Result accepatble with warning 20% < Bias < 30%
N = Result not acceptable Bias > 30%
L = Uncertainty potentially too low (for information purposes only)
H = Uncertainty potentially too high (for information purposes only)
RW = Report Warning
NR = Not Reported

**Notes:**

(11) = False Positive Test, Result Not Reported

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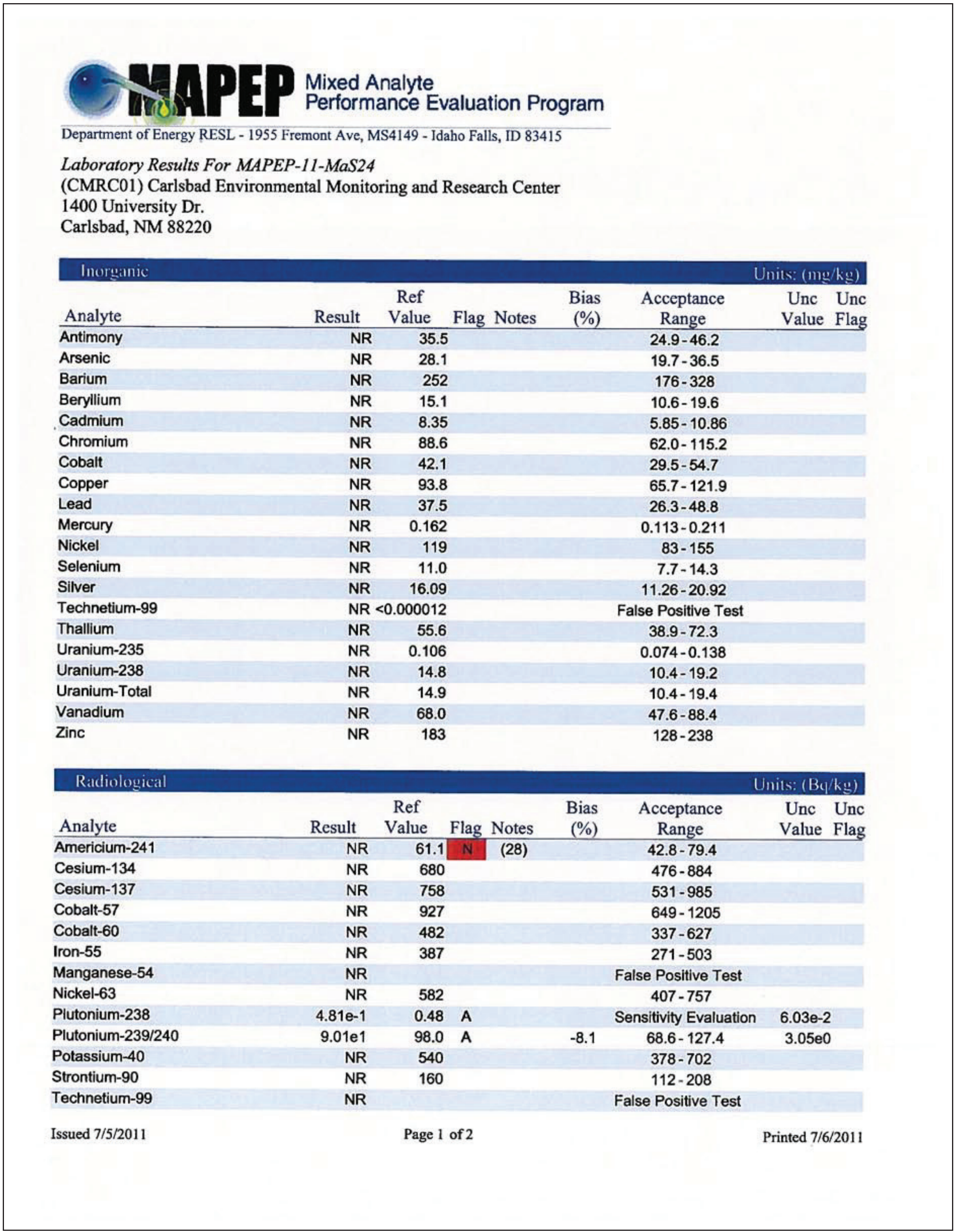
# Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results
(Continued)



**MAPEP** Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

*Laboratory Results For MAPEP-11-MaS24*
(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

**Inorganic** — Units: (mg/kg)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Antimony | NR | 35.5 | | | | 24.9 - 46.2 | | |
| Arsenic | NR | 28.1 | | | | 19.7 - 36.5 | | |
| Barium | NR | 252 | | | | 176 - 328 | | |
| Beryllium | NR | 15.1 | | | | 10.6 - 19.6 | | |
| Cadmium | NR | 8.35 | | | | 5.85 - 10.86 | | |
| Chromium | NR | 88.6 | | | | 62.0 - 115.2 | | |
| Cobalt | NR | 42.1 | | | | 29.5 - 54.7 | | |
| Copper | NR | 93.8 | | | | 65.7 - 121.9 | | |
| Lead | NR | 37.5 | | | | 26.3 - 48.8 | | |
| Mercury | NR | 0.162 | | | | 0.113 - 0.211 | | |
| Nickel | NR | 119 | | | | 83 - 155 | | |
| Selenium | NR | 11.0 | | | | 7.7 - 14.3 | | |
| Silver | NR | 16.09 | | | | 11.26 - 20.92 | | |
| Technetium-99 | NR | <0.000012 | | | | False Positive Test | | |
| Thallium | NR | 55.6 | | | | 38.9 - 72.3 | | |
| Uranium-235 | NR | 0.106 | | | | 0.074 - 0.138 | | |
| Uranium-238 | NR | 14.8 | | | | 10.4 - 19.2 | | |
| Uranium-Total | NR | 14.9 | | | | 10.4 - 19.4 | | |
| Vanadium | NR | 68.0 | | | | 47.6 - 88.4 | | |
| Zinc | NR | 183 | | | | 128 - 238 | | |

**Radiological** — Units: (Bq/kg)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Americium-241 | NR | 61.1 | N | (28) | | 42.8 - 79.4 | | |
| Cesium-134 | NR | 680 | | | | 476 - 884 | | |
| Cesium-137 | NR | 758 | | | | 531 - 985 | | |
| Cobalt-57 | NR | 927 | | | | 649 - 1205 | | |
| Cobalt-60 | NR | 482 | | | | 337 - 627 | | |
| Iron-55 | NR | 387 | | | | 271 - 503 | | |
| Manganese-54 | NR | | | | | False Positive Test | | |
| Nickel-63 | NR | 582 | | | | 407 - 757 | | |
| Plutonium-238 | 4.81e-1 | 0.48 | A | | | Sensitivity Evaluation | 6.03e-2 | |
| Plutonium-239/240 | 9.01e1 | 98.0 | A | | -8.1 | 68.6 - 127.4 | 3.05e0 | |
| Potassium-40 | NR | 540 | | | | 378 - 702 | | |
| Strontium-90 | NR | 160 | | | | 112 - 208 | | |
| Technetium-99 | NR | | | | | False Positive Test | | |

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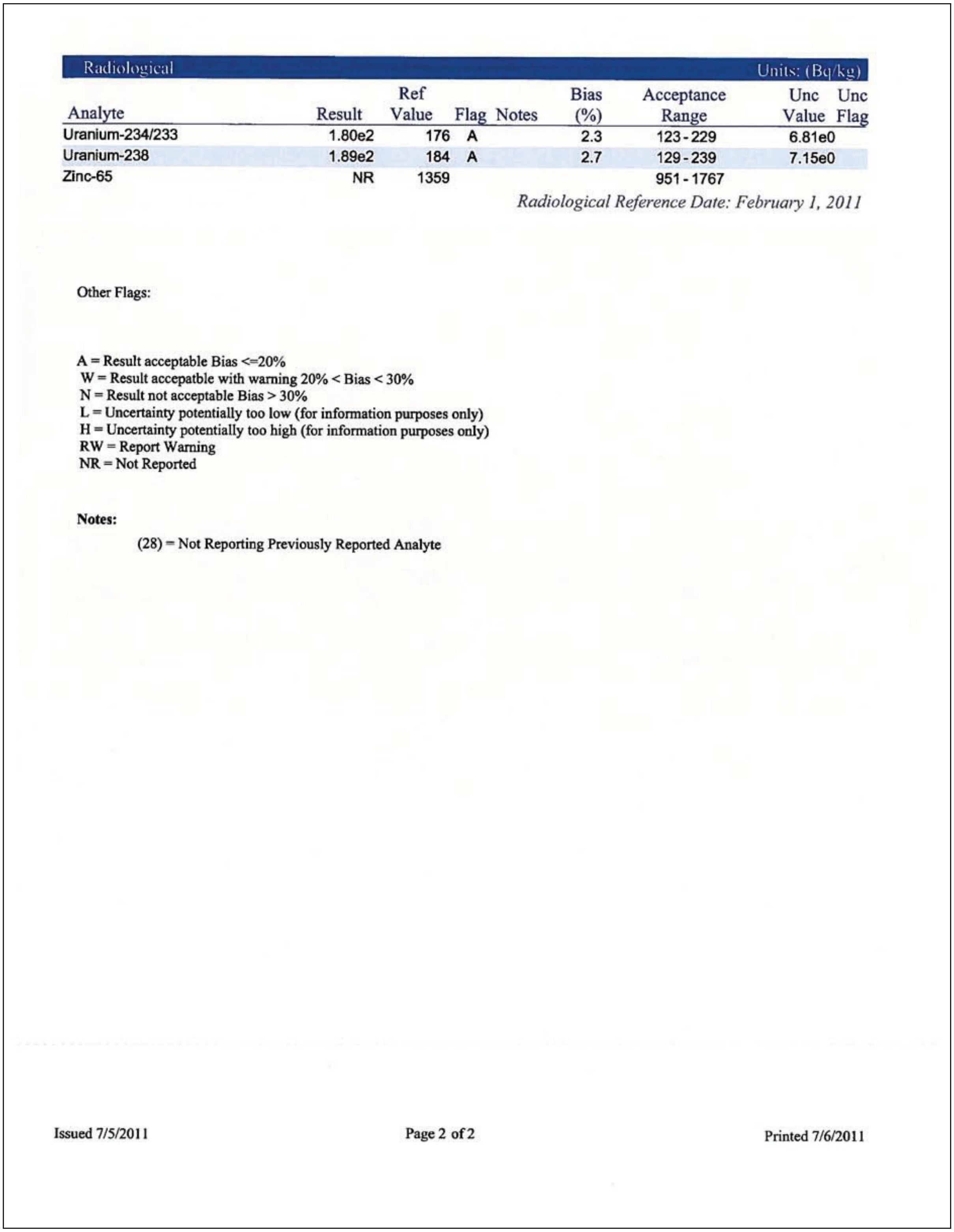
## Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results
(Continued)



Radiological | Units: (Bq/kg)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Uranium-234/233 | 1.80e2 | 176 | A | | 2.3 | 123 - 229 | 6.81e0 | |
| Uranium-238 | 1.89e2 | 184 | A | | 2.7 | 129 - 239 | 7.15e0 | |
| Zinc-65 | NR | 1359 | | | | 951 - 1767 | | |

*Radiological Reference Date: February 1, 2011*

Other Flags:

A = Result acceptable Bias <=20%
W = Result accepatble with warning 20% < Bias < 30%
N = Result not acceptable Bias > 30%
L = Uncertainty potentially too low (for information purposes only)
H = Uncertainty potentially too high (for information purposes only)
RW = Report Warning
NR = Not Reported

**Notes:**

(28) = Not Reporting Previously Reported Analyte

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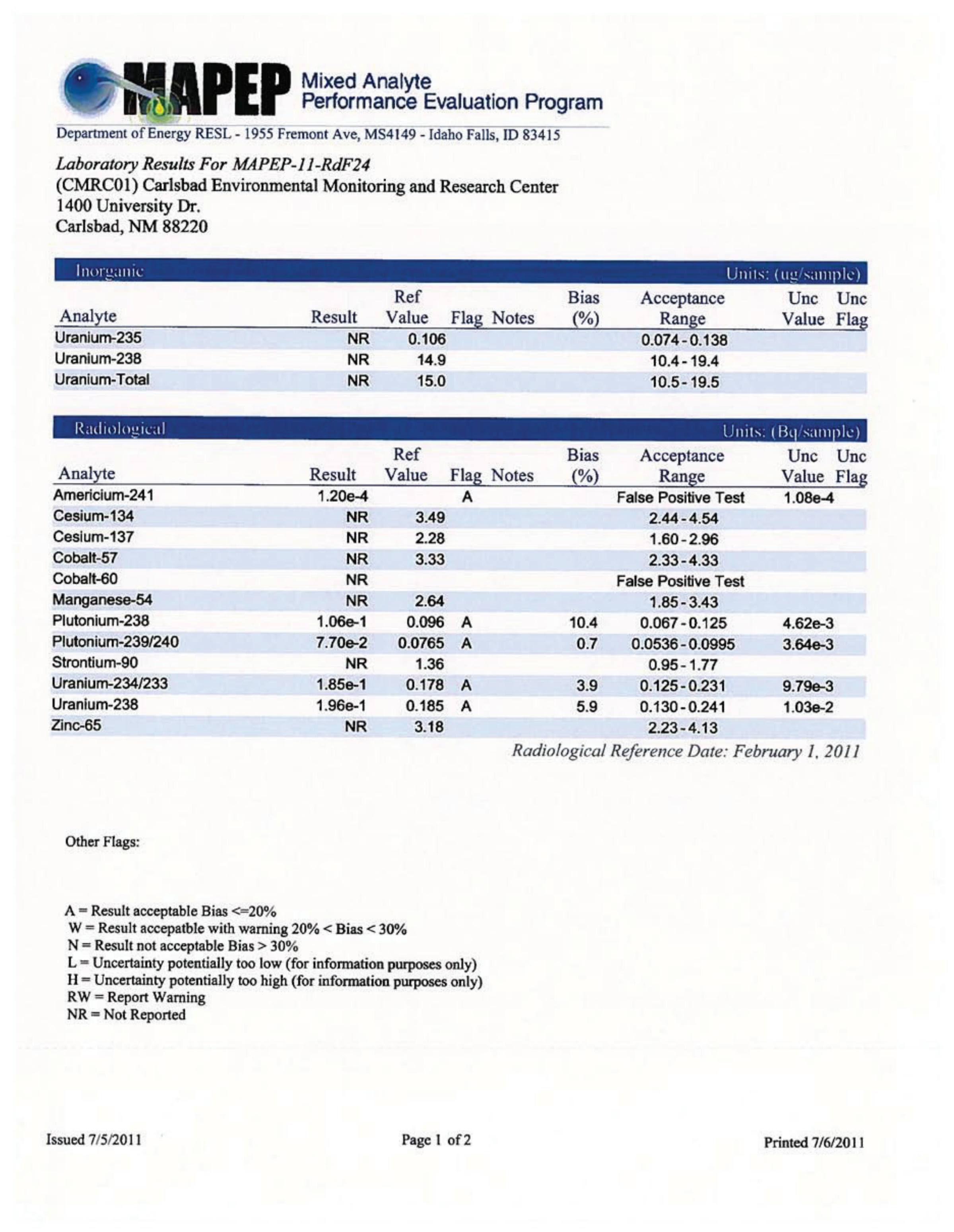
# Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results
(Continued)



**MAPEP** Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

*Laboratory Results For MAPEP-11-RdF24*
(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

**Inorganic** Units: (ug/sample)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Uranium-235 | NR | 0.106 | | | | 0.074 - 0.138 | | |
| Uranium-238 | NR | 14.9 | | | | 10.4 - 19.4 | | |
| Uranium-Total | NR | 15.0 | | | | 10.5 - 19.5 | | |

**Radiological** Units: (Bq/sample)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Americium-241 | 1.20e-4 | | A | | | False Positive Test | 1.08e-4 | |
| Cesium-134 | NR | 3.49 | | | | 2.44 - 4.54 | | |
| Cesium-137 | NR | 2.28 | | | | 1.60 - 2.96 | | |
| Cobalt-57 | NR | 3.33 | | | | 2.33 - 4.33 | | |
| Cobalt-60 | NR | | | | | False Positive Test | | |
| Manganese-54 | NR | 2.64 | | | | 1.85 - 3.43 | | |
| Plutonium-238 | 1.06e-1 | 0.096 | A | | 10.4 | 0.067 - 0.125 | 4.62e-3 | |
| Plutonium-239/240 | 7.70e-2 | 0.0765 | A | | 0.7 | 0.0536 - 0.0995 | 3.64e-3 | |
| Strontium-90 | NR | 1.36 | | | | 0.95 - 1.77 | | |
| Uranium-234/233 | 1.85e-1 | 0.178 | A | | 3.9 | 0.125 - 0.231 | 9.79e-3 | |
| Uranium-238 | 1.96e-1 | 0.185 | A | | 5.9 | 0.130 - 0.241 | 1.03e-2 | |
| Zinc-65 | NR | 3.18 | | | | 2.23 - 4.13 | | |

*Radiological Reference Date: February 1, 2011*

Other Flags:

A = Result acceptable Bias <=20%
W = Result accepatble with warning 20% < Bias < 30%
N = Result not acceptable Bias > 30%
L = Uncertainty potentially too low (for information purposes only)
H = Uncertainty potentially too high (for information purposes only)
RW = Report Warning
NR = Not Reported

Issued 7/5/2011 Page 1 of 2 Printed 7/6/2011

# Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results
(Continued)

Radiological Units: (Bq/sample)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|

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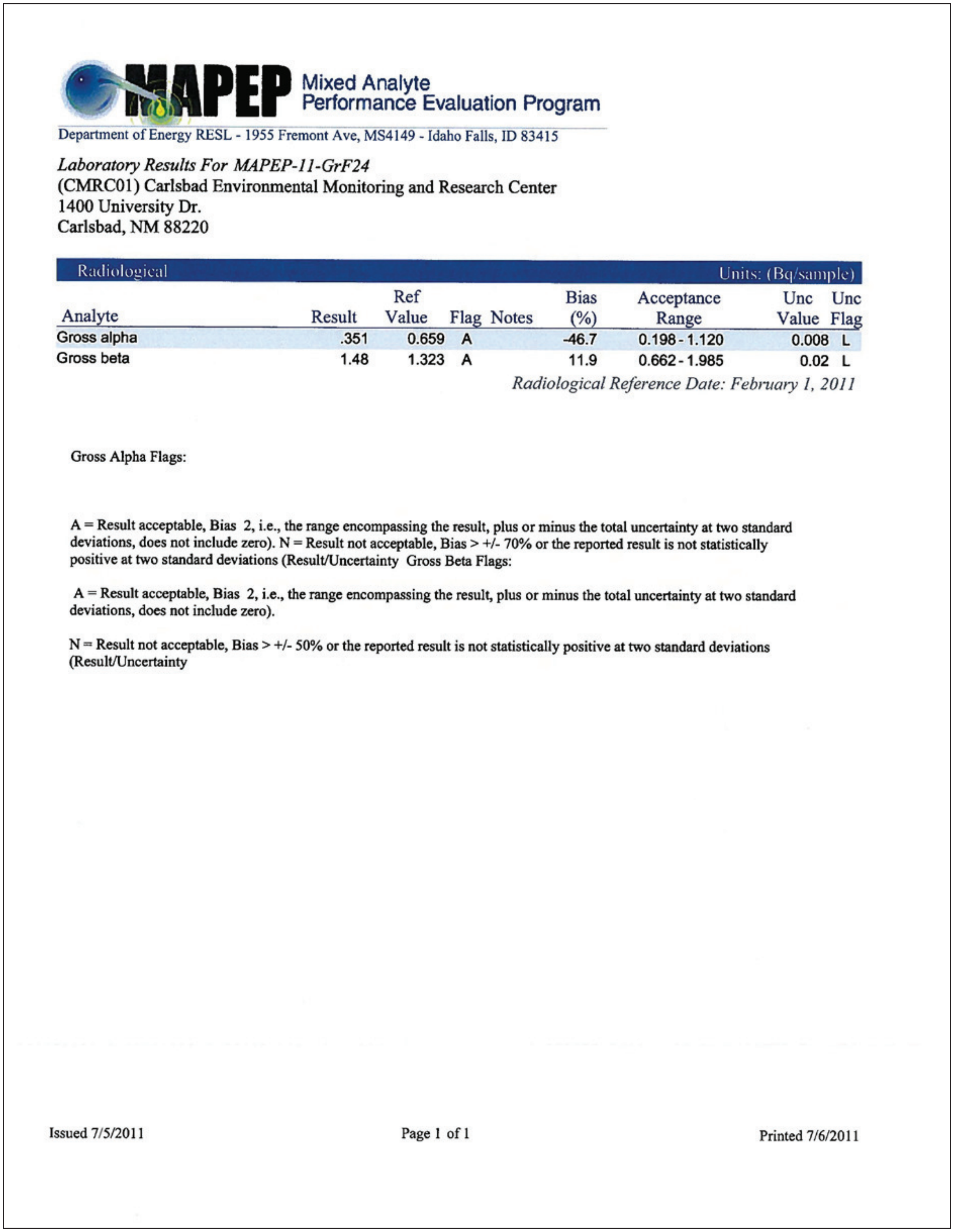
## Table F-4: Radiochemistry MAPEP 2010 Intercomparison Results
(Continued)



**MAPEP** Mixed Analyte Performance Evaluation Program

Department of Energy RESL - 1955 Fremont Ave, MS4149 - Idaho Falls, ID 83415

*Laboratory Results For MAPEP-11-GrF24*
(CMRC01) Carlsbad Environmental Monitoring and Research Center
1400 University Dr.
Carlsbad, NM 88220

Radiological — Units: (Bq/sample)

| Analyte | Result | Ref Value | Flag | Notes | Bias (%) | Acceptance Range | Unc Value | Unc Flag |
|---|---|---|---|---|---|---|---|---|
| Gross alpha | .351 | 0.659 | A | | -46.7 | 0.198 - 1.120 | 0.008 | L |
| Gross beta | 1.48 | 1.323 | A | | 11.9 | 0.662 - 1.985 | 0.02 | L |

*Radiological Reference Date: February 1, 2011*

Gross Alpha Flags:

A = Result acceptable, Bias  2, i.e., the range encompassing the result, plus or minus the total uncertainty at two standard deviations, does not include zero). N = Result not acceptable, Bias > +/- 70% or the reported result is not statistically positive at two standard deviations (Result/Uncertainty  Gross Beta Flags:

A = Result acceptable, Bias  2, i.e., the range encompassing the result, plus or minus the total uncertainty at two standard deviations, does not include zero).

N = Result not acceptable, Bias > +/- 50% or the reported result is not statistically positive at two standard deviations (Result/Uncertainty

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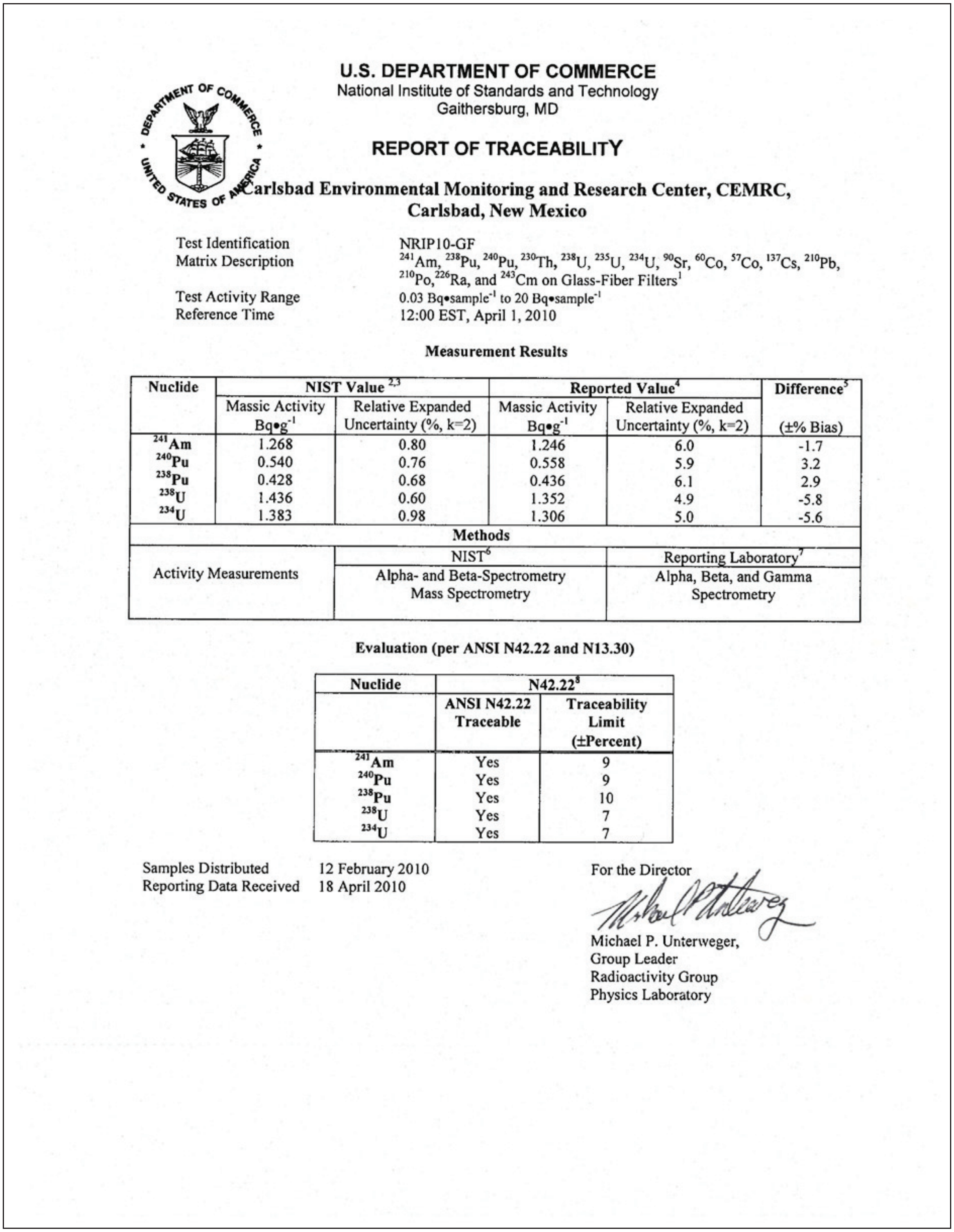
# Table F-5: Example of the Daily Performance Tests for ICP-MS

Sample Daily Performance Data of the Elan 6100 ICP-MS for March-April 2010

| | Acceptable Ranges | | 03/24/2010 | | | 03/31/2010 | | |
|---|---|---|---|---|---|---|---|---|
| | **Criteria for 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 | 0.0 - 5.0% | 2,850.9 | 1.5 | Acceptable | 2,537.2 | 0.9 | Acceptable |
| Mg | >18,000 | 0.0 - 5.0% | 42,735.8 | 1.0 | Acceptable | 40,523.8 | 0.7 | Acceptable |
| In | >120,000 | 0.0 - 5.0% | 454,957.4 | 2.1 | Acceptable | 472,391.1 | 1.5 | Acceptable |
| Pb | >60,000 | 0.0 - 5.0% | 240,117.4 | 1.6 | Acceptable | 233,506.2 | 1.4 | Acceptable |
| Ba | <900,000 | 0.0 - 5.0% | 418,702.3 | 1.7 | Acceptable | 416,334.7 | 1.3 | Acceptable |
| Ba++ | ≤ 10.0% | N/A | 1.3% | N/A | Acceptable | 1.3% | N/A | Acceptable |
| Ce | <900,000 | 0.0 - 5.0% | 536,525.4 | 1.7 | Acceptable | 522,261.6 | 1.2 | Acceptable |
| CeO | ≤ 5.0% | N/A | 2.4% | N/A | Acceptable | 2.8% | N/A | Acceptable |
| Bkgd | ≤ 25.0 | N/A | 10.0 | N/A | Acceptable | 9.0 | N/A | Acceptable |

| | Acceptable Ranges | | 04/01/2010 | | | 04/05/2010 | | |
|---|---|---|---|---|---|---|---|---|
| | **Criteria for 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 | 0.0 - 5.0% | 2,302.2 | 2.3 | Acceptable | 2997.1 | 2.7 | Acceptable |
| Mg | >18,000 | 0.0 - 5.0% | 35,327.8 | 2.1 | Acceptable | 46,083.2 | 2.4 | Acceptable |
| In | >120,000 | 0.0 - 5.0% | 436,946.3 | 1.5 | Acceptable | 458,642.0 | 2.7 | Acceptable |
| Pb | >60,000 | 0.0 - 5.0% | 233,427.5 | 1.2 | Acceptable | 230,168.2 | 1.3 | Acceptable |
| Ba | <900,000 | 0.0 - 5.0% | 400,647.6 | 0.8 | Acceptable | 405,796.0 | 1.8 | Acceptable |
| Ba++ | ≤ 10.0% | N/A | 1.3% | N/A | Acceptable | 1.3% | N/A | Acceptable |
| Ce | <900,000 | 0.0 - 5.0% | 510,643.1 | 1.3 | Acceptable | 510,683.5 | 2.2 | Acceptable |
| CeO | ≤ 5.0% | N/A | 2.4% | N/A | Acceptable | 2.5% | N/A | Acceptable |
| Bkgd | ≤ 25.0 | N/A | 8.8 | N/A | Acceptable | 9.4 | N/A | Acceptable |

## Table F-6: Participation in NIST Radiochemistry Intercomparison Program



**U.S. DEPARTMENT OF COMMERCE**
National Institute of Standards and Technology
Gaithersburg, MD

### REPORT OF TRACEABILITY

### Carlsbad Environmental Monitoring and Research Center, CEMRC, Carlsbad, New Mexico

| | |
|---|---|
| Test Identification | NRIP10-GF |
| Matrix Description | $^{241}$Am, $^{238}$Pu, $^{240}$Pu, $^{230}$Th, $^{238}$U, $^{235}$U, $^{234}$U, $^{90}$Sr, $^{60}$Co, $^{57}$Co, $^{137}$Cs, $^{210}$Pb, $^{210}$Po, $^{226}$Ra, and $^{243}$Cm on Glass-Fiber Filters[1] |
| Test Activity Range | 0.03 Bq•sample$^{-1}$ to 20 Bq•sample$^{-1}$ |
| Reference Time | 12:00 EST, April 1, 2010 |

**Measurement Results**

| Nuclide | NIST Value[2,3] | | Reported Value[4] | | Difference[5] |
|---|---|---|---|---|---|
| | Massic Activity Bq•g$^{-1}$ | Relative Expanded Uncertainty (%, k=2) | Massic Activity Bq•g$^{-1}$ | Relative Expanded Uncertainty (%, k=2) | (±% Bias) |
| $^{241}$Am | 1.268 | 0.80 | 1.246 | 6.0 | -1.7 |
| $^{240}$Pu | 0.540 | 0.76 | 0.558 | 5.9 | 3.2 |
| $^{238}$Pu | 0.428 | 0.68 | 0.436 | 6.1 | 2.9 |
| $^{238}$U | 1.436 | 0.60 | 1.352 | 4.9 | -5.8 |
| $^{234}$U | 1.383 | 0.98 | 1.306 | 5.0 | -5.6 |

**Methods**

| | NIST[6] | Reporting Laboratory[7] |
|---|---|---|
| Activity Measurements | Alpha- and Beta-Spectrometry<br>Mass Spectrometry | Alpha, Beta, and Gamma Spectrometry |

**Evaluation (per ANSI N42.22 and N13.30)**

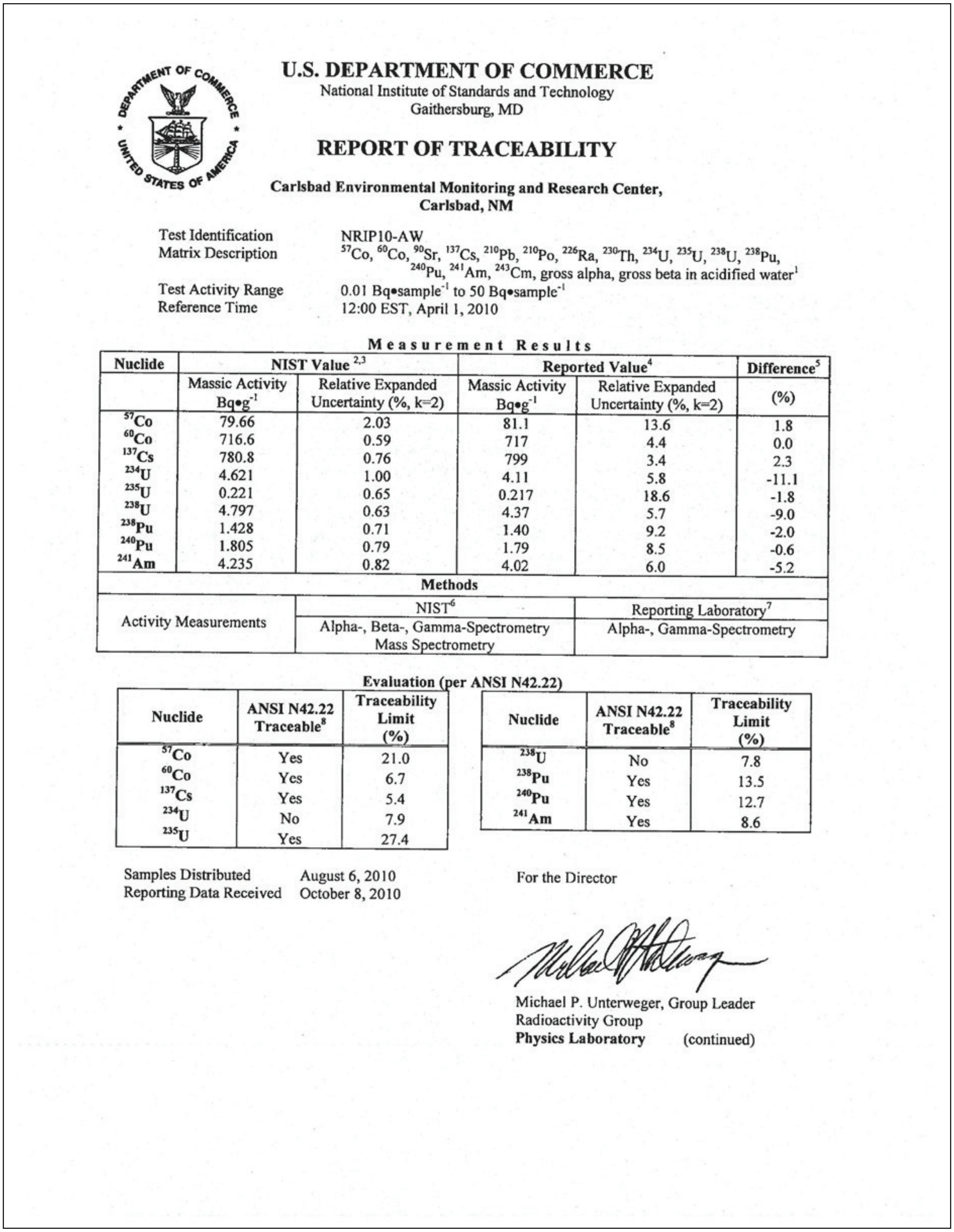
| Nuclide | N42.22[8] | |
|---|---|---|
| | ANSI N42.22 Traceable | Traceability Limit (±Percent) |
| $^{241}$Am | Yes | 9 |
| $^{240}$Pu | Yes | 9 |
| $^{238}$Pu | Yes | 10 |
| $^{238}$U | Yes | 7 |
| $^{234}$U | Yes | 7 |

Samples Distributed 12 February 2010
Reporting Data Received 18 April 2010

For the Director

Michael P. Unterweger,
Group Leader
Radioactivity Group
Physics Laboratory

## Table F-6: Participation in NIST Radiochemistry Intercomparison Program (Continued)



**U.S. DEPARTMENT OF COMMERCE**
National Institute of Standards and Technology
Gaithersburg, MD

### REPORT OF TRACEABILITY

**Carlsbad Environmental Monitoring and Research Center,**
**Carlsbad, NM**

| | |
|---|---|
| Test Identification | NRIP10-AW |
| Matrix Description | $^{57}$Co, $^{60}$Co, $^{90}$Sr, $^{137}$Cs, $^{210}$Pb, $^{210}$Po, $^{226}$Ra, $^{230}$Th, $^{234}$U, $^{235}$U, $^{238}$U, $^{238}$Pu, $^{240}$Pu, $^{241}$Am, $^{243}$Cm, gross alpha, gross beta in acidified water[1] |
| Test Activity Range | 0.01 Bq•sample$^{-1}$ to 50 Bq•sample$^{-1}$ |
| Reference Time | 12:00 EST, April 1, 2010 |

**Measurement Results**

| Nuclide | NIST Value[2,3] | | Reported Value[4] | | Difference[5] |
|---|---|---|---|---|---|
| | Massic Activity Bq•g$^{-1}$ | Relative Expanded Uncertainty (%, k=2) | Massic Activity Bq•g$^{-1}$ | Relative Expanded Uncertainty (%, k=2) | (%) |
| $^{57}$Co | 79.66 | 2.03 | 81.1 | 13.6 | 1.8 |
| $^{60}$Co | 716.6 | 0.59 | 717 | 4.4 | 0.0 |
| $^{137}$Cs | 780.8 | 0.76 | 799 | 3.4 | 2.3 |
| $^{234}$U | 4.621 | 1.00 | 4.11 | 5.8 | -11.1 |
| $^{235}$U | 0.221 | 0.65 | 0.217 | 18.6 | -1.8 |
| $^{238}$U | 4.797 | 0.63 | 4.37 | 5.7 | -9.0 |
| $^{238}$Pu | 1.428 | 0.71 | 1.40 | 9.2 | -2.0 |
| $^{240}$Pu | 1.805 | 0.79 | 1.79 | 8.5 | -0.6 |
| $^{241}$Am | 4.235 | 0.82 | 4.02 | 6.0 | -5.2 |

**Methods**

| | NIST[6] | Reporting Laboratory[7] |
|---|---|---|
| Activity Measurements | Alpha-, Beta-, Gamma-Spectrometry<br>Mass Spectrometry | Alpha-, Gamma-Spectrometry |

**Evaluation (per ANSI N42.22)**

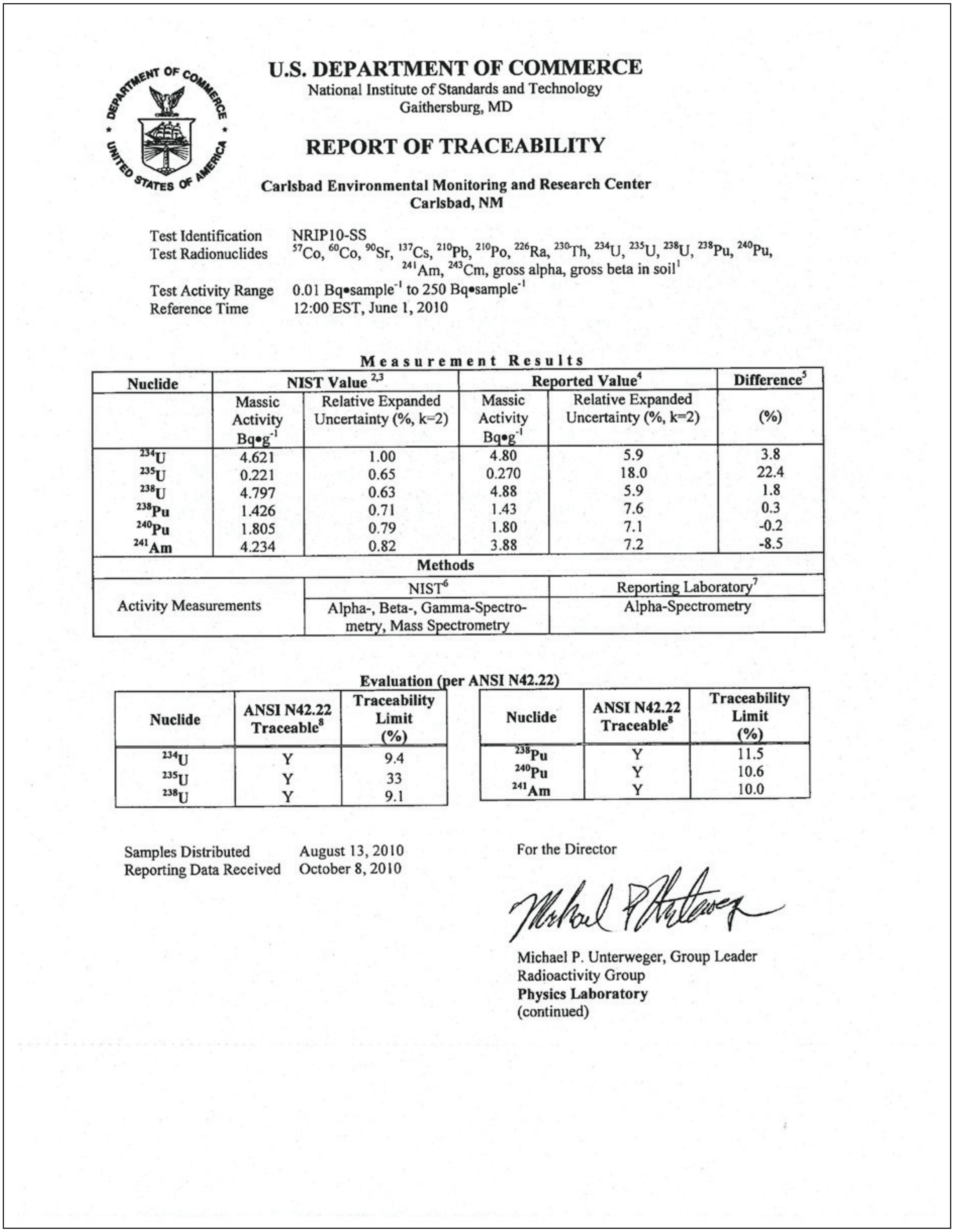
| Nuclide | ANSI N42.22 Traceable[8] | Traceability Limit (%) |
|---|---|---|
| $^{57}$Co | Yes | 21.0 |
| $^{60}$Co | Yes | 6.7 |
| $^{137}$Cs | Yes | 5.4 |
| $^{234}$U | No | 7.9 |
| $^{235}$U | Yes | 27.4 |
| $^{238}$U | No | 7.8 |
| $^{238}$Pu | Yes | 13.5 |
| $^{240}$Pu | Yes | 12.7 |
| $^{241}$Am | Yes | 8.6 |

| | |
|---|---|
| Samples Distributed | August 6, 2010 |
| Reporting Data Received | October 8, 2010 |

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
**Physics Laboratory** (continued)

## Table F-6: Participation in NIST Radiochemistry Intercomparison Program
(Continued)



**U.S. DEPARTMENT OF COMMERCE**
National Institute of Standards and Technology
Gaithersburg, MD

**REPORT OF TRACEABILITY**

**Carlsbad Environmental Monitoring and Research Center**
**Carlsbad, NM**

| | |
|---|---|
| Test Identification | NRIP10-SS |
| Test Radionuclides | $^{57}$Co, $^{60}$Co, $^{90}$Sr, $^{137}$Cs, $^{210}$Pb, $^{210}$Po, $^{226}$Ra, $^{230}$Th, $^{234}$U, $^{235}$U, $^{238}$U, $^{238}$Pu, $^{240}$Pu, $^{241}$Am, $^{243}$Cm, gross alpha, gross beta in soil[1] |
| Test Activity Range | 0.01 $Bq \bullet sample^{-1}$ to 250 $Bq \bullet sample^{-1}$ |
| Reference Time | 12:00 EST, June 1, 2010 |

**Measurement Results**

| **Nuclide** | **NIST Value[2,3]** | | **Reported Value[4]** | | **Difference[5]** |
|---|---|---|---|---|---|
| | Massic Activity $Bq \bullet g^{-1}$ | Relative Expanded Uncertainty (%, k=2) | Massic Activity $Bq \bullet g^{-1}$ | Relative Expanded Uncertainty (%, k=2) | (%) |
| **$^{234}$U** | 4.621 | 1.00 | 4.80 | 5.9 | 3.8 |
| **$^{235}$U** | 0.221 | 0.65 | 0.270 | 18.0 | 22.4 |
| **$^{238}$U** | 4.797 | 0.63 | 4.88 | 5.9 | 1.8 |
| **$^{238}$Pu** | 1.426 | 0.71 | 1.43 | 7.6 | 0.3 |
| **$^{240}$Pu** | 1.805 | 0.79 | 1.80 | 7.1 | -0.2 |
| **$^{241}$Am** | 4.234 | 0.82 | 3.88 | 7.2 | -8.5 |

**Methods**

| | NIST[6] | Reporting Laboratory[7] |
|---|---|---|
| Activity Measurements | Alpha-, Beta-, Gamma-Spectrometry, Mass Spectrometry | Alpha-Spectrometry |

**Evaluation (per ANSI N42.22)**

| **Nuclide** | **ANSI N42.22 Traceable[8]** | **Traceability Limit (%)** |
|---|---|---|
| **$^{234}$U** | Y | 9.4 |
| **$^{235}$U** | Y | 33 |
| **$^{238}$U** | Y | 9.1 |

| **Nuclide** | **ANSI N42.22 Traceable[8]** | **Traceability Limit (%)** |
|---|---|---|
| **$^{238}$Pu** | Y | 11.5 |
| **$^{240}$Pu** | Y | 10.6 |
| **$^{241}$Am** | Y | 10.0 |

| | |
|---|---|
| Samples Distributed | August 13, 2010 |
| Reporting Data Received | October 8, 2010 |

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
**Physics Laboratory**
(continued)

# 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:

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

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.

$T_{\text{blank}}$ = Blank count time

$T_{\text{bkg}}$ = 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 $1\sigma$ level. SD is found by using the following equation:

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

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 Tracers in FAS Samples

| Radionuclide | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| $^{243}$Am | 73.23 | 100.30 | 97.21 | 5.4 |
| $^{242}$Pu | 36.86 | 87.02 | 65.89 | 16.6 |
| $^{232}$U | 40.92 | 97.21 | 76.73 | 17.3 |

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

| Radionuclide | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| $^{243}$Am | 37.37 | 97.28 | 82.08 | 22.1 |
| $^{242}$Pu | 42.34 | 90.83 | 71.58 | 15.4 |
| $^{232}$U | 61.48 | 81.48 | 69.93 | 7.1 |

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

| Radionuclide | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| $^{243}$Am | 68.78 | 100.99 | 91.48 | 7.5 |
| $^{242}$Pu | 41.28 | 94.76 | 67.06 | 16.9 |
| $^{232}$U | 58.38 | 82.89 | 71.98 | 6.0 |

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

| Radionuclide | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| $^{243}$Am | 28.67 | 107.45 | 78.49 | 20.3 |
| $^{242}$Pu | 27.39 | 80.38 | 46.39 | 13.8 |
| $^{232}$U | 48.23 | 81.69 | 62.36 | 9.9 |

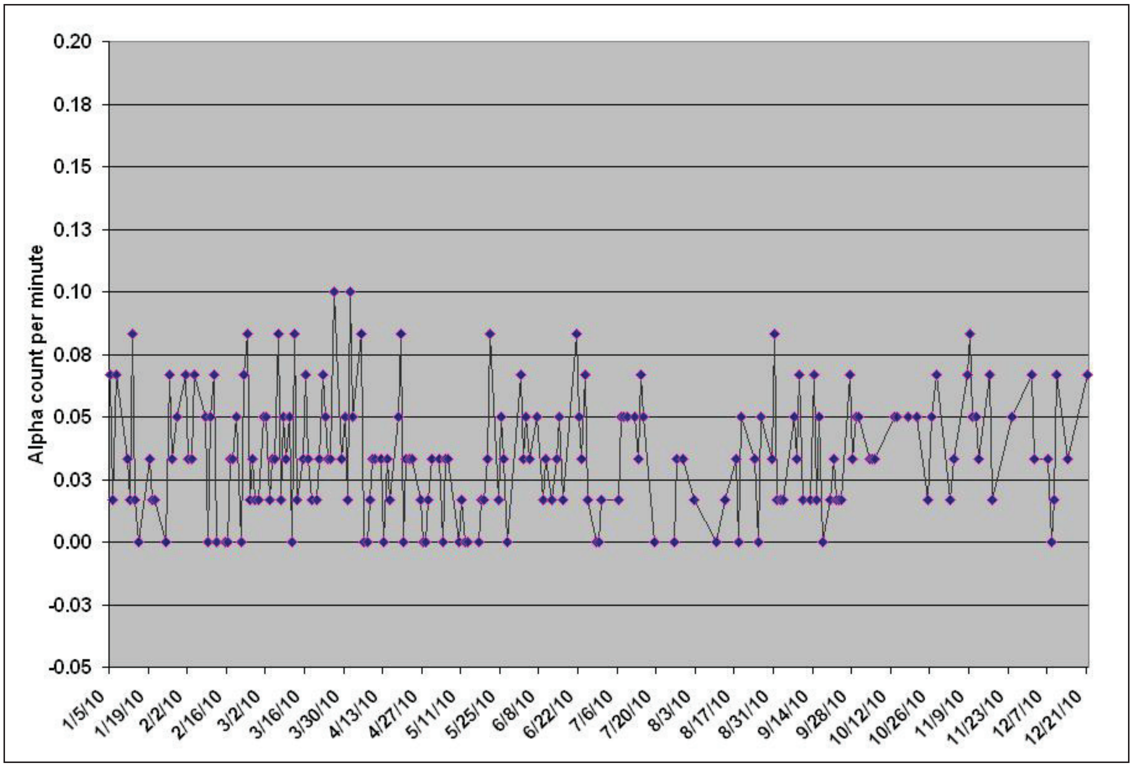


Figure G.1: Sixty Minutes Alpha Ambient Background Count for the PIC-MPC 9604 Gross Alpha and Beta Counter

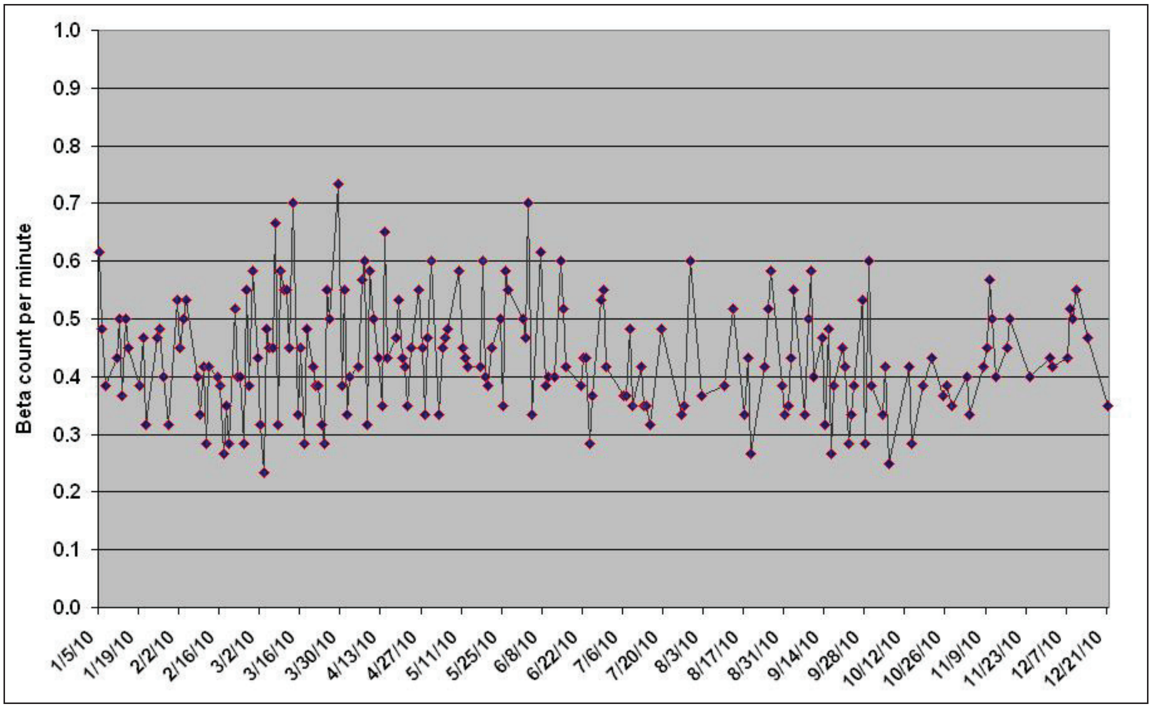


Figure G.2: Sixty Minutes Beta Ambient Background Count for PIC-MPC 9604 Gross Alpha and Beta Counter

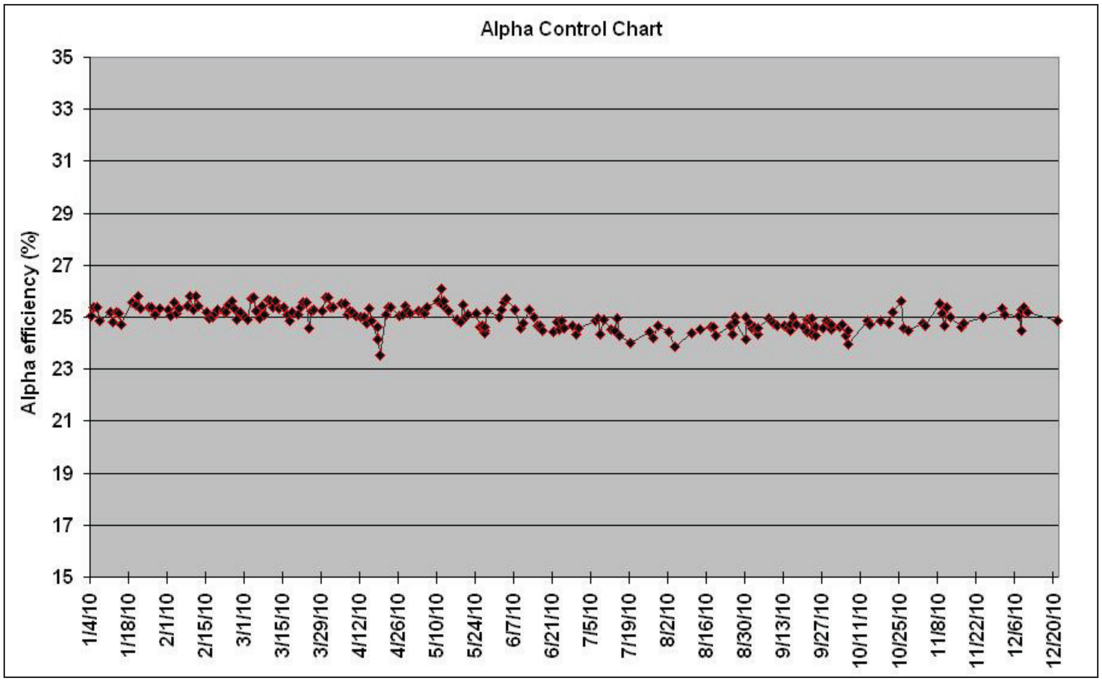


Figure G.3: Control Chart of Daily Alpha Efficiency of the PIC-MPC 9604 Gross Alpha and Beta Counter

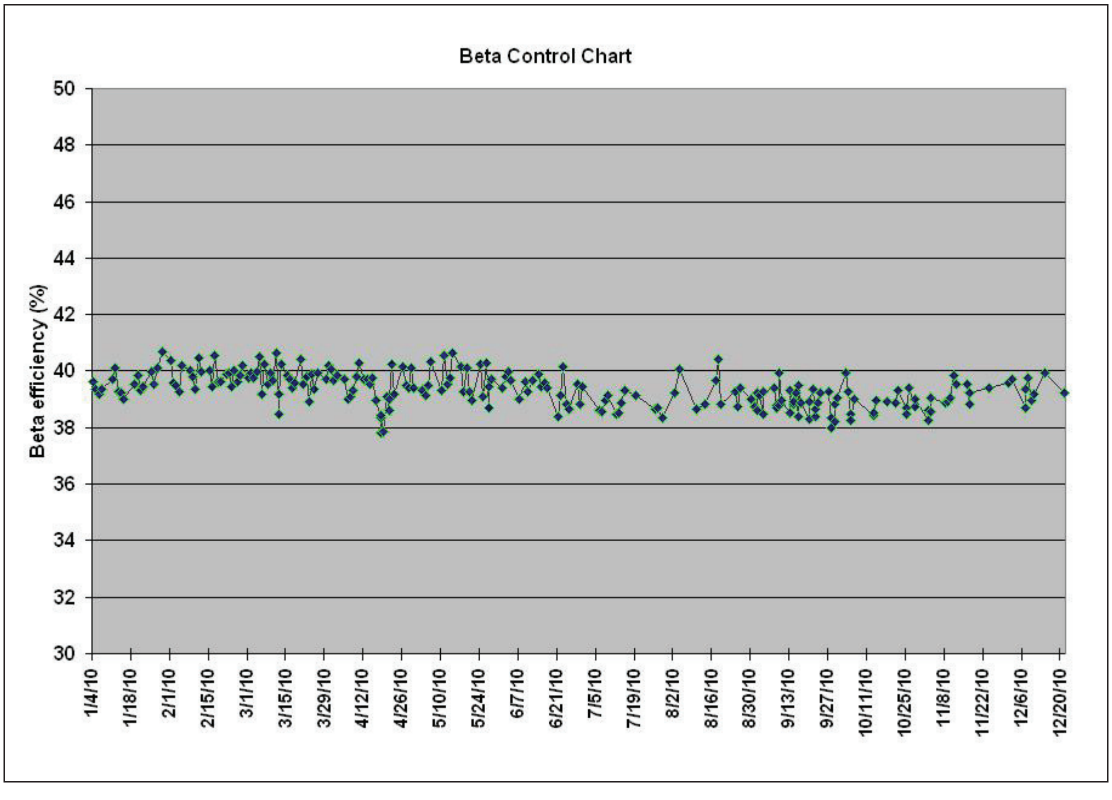


Figure G.4: Control Chart of Daily Beta Efficiency of the PIC-MPC 9604 Gross Alpha and Beta Counter

## 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, Texas.

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, Texas.

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, Wisconson.

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, Texas.

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, New Mexico 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, Nevada.

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, D.C.

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, D.C., 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, D.C., 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, D.C., 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, Colorado.

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.